PROFIT MAXIMIZING SELECTION OF MANAGEMENT PRACTICES FOR WILLOW CREEK TO MEET SEDIMENT AND PHOSPHOROUS ABATEMENT TARGETS

By

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Abstract: Fort Cobb Reservoir is located in Caddo County in the southwest region of Oklahoma. The lake has been experiencing high levels of sedimentation and phosphorous loading, primarily from agricultural land, which has resulted in a degradation of reservoir services for municipal and recreational use. The main way sediment and phosphorous originating from field surfaces has been abated is through voluntary enrollment in cost sharing programs. The objective of this study was to use the Environmental Policy Integrated Climate (EPIC) modeling tool to simulate erosion levels and phosphorous losses in the Willow Creek sub watershed with alternative management practices on wheat and cotton fields, including conversion to native grassland. A linear programming model was used to maximize net farm revenue while meeting abatement targets. A binary programming model was used to maximize net farm revenue while meeting targets while limiting each farm to a single improved management practice. Land owners with more than 40 acres and cotton or wheat production were included in the model. Slopes between 0 and 2 percent for cotton and 0 and 5 percent for wheat across the 19 most common soil types in the sub watershed were considered. Solutions for 40, 60, and 80 percent abatement of phosphorus and sediment together and sediment alone were determined. Net revenues for the watershed at each abatement level are included. The economic feasibility of using a binary programming model which requires a single management practice for each farm is demonstrated. No till is shown to have the lowest economic cost while providing all necessary abatements at lower targets. Grassland was determined to have the highest economic cost while also providing the highest abatement levels. Soil types with slopes, hectarage, erosion, and phosphorous loss with disk chisel, no till, contour, contour and no till, and conversion to native grassland are show.

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CHAPTER I

INTRODUCTION AND OBJECTIVES

Introduction

Soil erosion is a problem for both producers and society. Erosion is a major source of sedimentation and nutrients in watersheds and, agricultural production is the largest source (USEPA 1992). The United States government built reservoirs fifty to sixty years ago with expected lifespans of 150 to 200 years, but are expected to have their usable lifespans reduced significantly. Up to 100 years of planned use will be eliminated in severe cases (Hargrove et al. 2010). The loss of reservoir services such as recreation, municipal water, and flood control stand to negatively impact residents of the Fort Cobb watershed in Oklahoma. The Fort Cobb reservoir is considered to be a sensitive water supply for public and private uses, and it is designated as a nutrient limited watershed (OCC 2009). The Fort Cobb reservoir is fed primarily from four creeks that drain sub-watersheds: Five Mile Creek, Cobb Creek, Willow Creek, and Lake Creek. Willow Creek, along with the other three creeks and the reservoir itself were included on the Oklahoma 1998 303(d) list due to unacceptable levels of siltation, suspended solids, and nutrients (ODEQ 2006).

Sporadic efforts to reduce erosion in the watershed began in the 1930s. In 2001 there was an attempt to implement Best Management Practices (BMPs) to meet water quality targets.The Oklahoma Conservation Commission (OCC) partnered with the Environmental Protection Agency (EPA), the Office of the Secretary of the Environment (OSE), local conservation districts, and the Oklahoma Department of Agriculture, Food, and Forestry (ODAFF) to implement a cost share program focused on the implementation of grade stabilization and conversion of highly erodible cropland to pasture. Then, in 2005 the Oklahoma Department of Environmental Quality (ODEQ) issued a Total Maximum Daily Load (TMDL) for Fort Cobb Reservoir. This recommendation added a focus on no till practices (OCC 2009). The land cover in the watershed is 50% cropland, 41% grassland, 6% forest, and 2% other uses. An estimated 33% of all sediment originates on only 5% of the land. A SWAT study of the watershed concluded that conversion of peanuts to switchgrass, conservation reserve program (CRP), and no till wheat could improve water quality in the reservoir with the lowest cost share payment rates (Busteed et al. 2009).

Presently, agriculture in the Fort Cobb Watershed is in need of additional BMPs that are able to reduce reservoir sedimentation. Terracing of steeply sloped land is generally considered to be an excellent practice for reducing run off and sedimentation. However, the Fort Cobb watershed has had terraces implemented on approximately 80 to 90 percent of agricultural land where they are viable within the last 50 years. The sediment loss estimates for the entire Fort Cobb watershed in 2007 was 108 metric tons per km^2 per year. (Garbrecht and Starks 2009).

Farm operators underutilize erosion control because they fail to consider the external costs associated with erosion when making decisions. Damages to things like municipal water supply capacity and recreation value are not felt on the farm. Public policy lacks the mechanism to obligate land management practices that would curb the levels of erosion on farmland, therefore voluntary adoption of BMPs is the norm. The cost of implementing best management practices varies as does their ability to control sediment loss. Due to these factors, the most common way to encourage farm managers to implement BMPs is through cost sharing.

The purpose of this research is to determine a least-cost efficient combination of management practices to reduce erosion and phosphorous loss at the field edge.

Objectives

This research attempts to find a least cost efficient allocation of agricultural BMPs in the Willow Creek sub watershed of the Fort Cobb watershed. Specifically,

1. Determine a global profit maximizing allocation of additional BMPs that also meet sediment and phosphorous abatement targets
2. Determine the feasibility of a binary programming farm based targeting model with a homogenous BMP across a farm
3. Identify characteristics of farms with low and high marginal costs of abatement to inform conservation decision makers.

CHAPTER II

LITERATURE REVIEW

Models for Estimating Soil Erosion

There are numerous models for simulating erosion and nutrient loss over time. Most use a method of physical simulation. These models use equations based on physical relationships to describe streamflow, sediment, and nutrient loss (Merrit, Letcher, and Jakeman 2003). Examples of these models include the Environmental Policy Integrated Climate Model (EPIC), Agricultural Policy/Environmental eXtender (APEX), Soil and Water Assessment Tool (SWAT), Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS), Groundwater Loading Effects of Agricultural Management Systems (GLEAMS), Universal Soil Loss Equation (USLE), and Revised Universal Soil Loss Equation (RUSLE). All of these modeling systems require the use of computer software except for the USLE which was developed before the widespread availability of computers.

The Universal Soil Loss equation is an equation with six input parameters that is used to estimate the soil erosion that will occur on a field and to determine the effect of management:

plans as related to conservation goals. The relevant factors used for the equation were based on empirical research across the United States (Wischmeir and Smith 1978).

The equation is as follows:

$$A = R \times K \times L \times S \times C \times P$$

Where:

A is the predicted soil erosion in tons per acre

R is the parameter from a developed rainfall factor

K is the soil erodibility factor for a fallow field

L is the slope length factor in relation to a 72.6 foot slope

S is the slope gradient factor in relation to a 9 percent slope

C is the management factor that modifies the RKLS factor due to crop cover

P is the erosion control practice factor to account for terracing, contouring, with slope tillage.

The Revised Universal Soil Loss Equation (RUSLE) is a modification of the original USLE equation which takes advantage of the development of computers to run more complex calculations. This model includes more accurate data for the R parameter in the USLE for the western United States, and can account for rain falling into puddles and areas of ponding, which reduces the erosive force of a raindrop. The K factor has been modified to incorporate the varying soil erodibility over time due to water content and temperature. The L and S factors have been modified to more accurately account for this differences in rill and sheet erosion. The C factor was changed from a single number to a continuous variable that accounts for previous management practices, crop canopy, surface roughness, and soil moisture, and root mass. The K, C, and P factors are also modified by climatic data, and the P factor can now account for contouring, grassland, and terracing (USDA 1997). The advantage of the change in this model is the ability to use a computer to complete the calculations on much more complex empirically based equations and give a more accurate description of erosion, which is a physically complex process.

In 1977 the Soil and Water Conservation Act (RCA) created the need for a mathematical model that could be used to determine the long term effects of soil erosion on crop yields. In 1981, a modeling team was assembled within the Agricultural Research Service (ARS) and they began constructing the model that would become the Environmental Policy Integrated Climate Model (EPIC). EPIC operates on nine basic components: hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, economics, and plant environmental control. These components are combined specifically to address the relationship between erosion and yield (Williams, Jones, and Dyke 1984).

While EPIC operates at the field level, there was a need for a tool to simulate small watersheds. The Livestock and the Environment: A National Pilot Program's attempt to model issues relating to livestock production and manure necessitated a modeling system that could address more complex farms and small watershed scenarios. The APEX model was developed based on the EPIC model with the capability to simultaneously cover multiple fields. It functions on a daily time step using twelve components: climate, hydrology, crop growth, pesticide fate, nutrients, erosion, carbon, tillage, soil temperature, plant environmental control, economics, and subarea routing (Gassman et al. 2009).

The SWAT model was developed to address the need for a model that could handle simulations similar to EPIC and APEX, but at a larger geographical scale. The model operates on a daily time step to model sub-basins and is capable of long term simulations. One of the limitations encountered with a model is its inability to cover such a large geographical area is that the size of the fields within sub basins are assumed to be homogenous. Parameters can vary across small distances. Another limitation is that the crop model in SWAT is a more simplified version of the EPIC crop growth model (Arnold et al. 1998).

The 1972 Section 208 of PL-500 amendment to the clean water act necessitated a tool to select management practices to address nonpoint source pollution. The Science and Education Administration- Agricultural Research developed a physical based model to operate on the field level scale in CREAMS. There are three main components: hydrology, erosion, and pesticides. The model was able to simulate runoff, sediment, nutrient, and pesticide movement within a field. The model is capable of simulating runoff, erosion, nutrient, and pesticide fate (USDA 1980).

The GLEAMS model is an extension of the CREAMS model. This model was created to simulate the effects of agricultural pesticides on groundwater. By modifying the hydrology, nutrient, and pesticide components of the CREAMS model to account for the movements of water and pesticides through the root zone, GLEAMS addresses the ground water quality concerns related to agriculture (Leonard, Knisel, and Still 1987).

EPIC Model

The EPIC model is based on a system of empirical equations that simulate the physical processes of a single field of homogenous slope, soil type, and crop rotation on a daily time step basis. Input data includes weather, crop, tillage, and soil parameters. The data output from the simulations includes pesticide losses, fertilizer losses, crop yields, and sediment losses. The nine types of simulations handled in an EPIC model are: hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, economics, and the effect plants exert on the other simulations (Williams, Jones, and Dyke 1984).

There are 15 input files needed for the simulation: site file, weather file, wind file, crop file, tillage file, pesticide file, fertilizer file, soil file, operations file, machinery file, parameter file, print file, and an optional multiple run file used for setting up multiple simulations in a single run.

These files generally do not need to be manipulated by the user, except for the multiple run file, the soil files, the weather file, the operations file, and the site file. The EPIC control file contains the parameters that are to be held constant for the entire simulation. The RUN file contains a list of which site, weather, wind, soil, and operations schedules should be used from the input files for a specific simulation. The print file can be used to control the types of output files to be returned, whether they be daily, monthly, or annual. (EPIC Development Team 2015)

There are several choices to be made for simulation equations on erosion studies when using the EPIC model. The available water erosion models include the Universal Soil Loss Equation (USLE), the Modified USLE (MUSLE and RUSLE), and three different versions of the MUSLE: MUST, MUSS and MUSI. The MUSS is the recommended equation for studying erosion in small watersheds (EPIC Development Team 2015).

There is the option to use simulated weather data based on monthly averages from a weather station, or there is the option to include daily historical weather data. A complete historical daily weather file will include solar radiation, maximum temperature, minimum temperature, precipitation totals, relative humidity, and wind speed. The historical daily weather file must be the same length as the planned simulation if this option is chosen (EPIC Development Team 2015).

The soil files must be created by the user and added to the soil database in EPIC. A detailed list of physical qualities of the soil must be entered some of which include soil thickness, sand content, silt content, bulk density, and phosphorus sorption ratio (EPIC Development Team 2015).

The operations schedule is built by the user to simulate management of the crop rotation. The included database of machinery is extensive, and most operations can be simulated with the included data. The operation file consists of the year, month, and day of the operation to be performed. There is a code for the tillage operation that references the included data base. A choice of tractors is available if the economic simulation capabilities are needed. The crop must be identified for all operations. If the operation includes a chemical application, then the code referencing the included fertilizer and pesticides must be specified. Heat units from germination to maturity can be entered for more accurate crop growth simulation (EPIC Development Team 2015).

EPIC Applications

The first major application of EPIC was the 1985 RCA evaluation of the impacts of soil erosion on productivity and fertilizer requirements. They determined that one hundred twenty seven million acres of farmland would have sheet and rill erosion above soil tolerance levels. The estimate was a productivity loss of 2.3 percent over the next one hundred years across the country and a loss of $22 billion (Putnam, Williams, and Sawyer 1988).

The ability to account for rising carbon dioxide levels due to climate change was added to the model. Prior to this research, there was a simulation model for a single plant available, but nothing that could account for these changes at the farm level. Adjustments for changes in radiation use efficiency, evapotranspiration, and leaf conductance were made to account for rising carbon dioxide levels in the atmosphere (Stockle et al. 1992). A study was conducted by the researchers after making adjustments to the model to study the effects of rising carbon dioxide levels on corn, soybean, and wheat cropping systems in the United States. They determined that with constant precipitation levels rising carbon dioxide levels would increase crop yields (Stockle et al. 1992). The addition of the ability to account for climate change was the reason the name was changed from Erosion Impact Productivity Calculator to Environmental Policy Integrated Climate model.

EPIC can be used to model the effect of different management practices and crop rotations on soil erosion and nutrient loss. Four management practices for soybean and corn rotations in

Illinois were modeled and found that no till could reduce total soil erosion and nitrogen and phosphorous losses in the soil, but that no till resulted in more soluble nitrogen and phosphorous loss (Phillips et al. 1993). A study to verify the EPIC model for sediment and nutrient loss on pastures in Arkansas fertilized with poultry litter and inorganic fertilizers, found correlations between .66 and .92 between observed and predicted values (Edwards et al. 1994). A five year study of three conventional tillage and three no till watersheds to compare EPIC simulation results without calibration for erosion and nutrient loss with observed values was conducted in central Texas. They found the predicted runoff, sediment loss, and nitrogen loss to be significantly correlated for annual data (King, Richardson, Williams 1996).

The most recent abilities added to EPIC allowed the simulation of carbon cycling. They compared the changes in soil organic carbon for winter wheat in Alberta Canada and with Conservation Reserve Program (CRP) plots in Texas, Kansas, and Nebraska. Changes in soil organic carbon levels on CRP and spring wheat were found to be simulated well by EPIC when compared with 60 years of observed data. The new carbon algorithms were used by the United States Department of Agriculture to model carbon sequestration and its potential to offset rising CO_2 levels (Izaurralede et al. 2001).

Management Practices

One management practice used for the control of soil erosion and nutrient loss is no till. Worldwide the adoption of no till practices has been growing, and the United State has the most farmland acreage of any country worldwide under no till management. The benefits of no till farming include reducing runoff, lower sediment and nutrient loss, improved recharging of groundwater, cleaner water supplies, and more resilience to climate change (Derpsch et al. 2010). Results of using no till to control nutrient loss are mixed and depend on the crop and nutrient in question. A study of cotton tillage systems in Georgia found that the effect of no till cotton on nitrogen losses was not significant, and that a small increase in phosphorous losses did occur (Endale et al. 2001). Research on soil and nutrient loss in cotton with conservation tillage in Alabama found similar results for nutrient loss, but found that conservation tillage significantly reduced runoff and sediment loss (Soileau et al. 2016). Research in Texas and Oklahoma watersheds on the effects of no till found that winter wheat had lower levels of soil erosion under no till, and stressed the need to apply phosphorous with a subsoil method for phosphorous loss benefits to be realized (Sharpley et al. 1992).

Contour farming, where the field operations are performed at a right angle to the slope of the land is another management practice which can reduce soil and nutrient loss. Wheat which is tilled on the contour has less erosion than wheat tilled on the slope. This effect is most pronounced when a conventional tillage system is used (Dickey et al. 1983). Research on the effects of contouring on row crops found that runoff and along with it, erosion and nutrient loss were significantly reduced for contoured tillage compared to slope tillage. Similarly, the effect of contouring is greater when a conventional tillage system is contoured than a no till system (McIsaac, Hirschi, and Mitchell 1989).

Conversion to grassland is a conservation practice that can greatly reduce runoff, soil erosion, and nutrient loss. The Loess Plateau in China has one of the highest rates of soil erosion in the world. Land that was once grassland and forest was converted to cropland. In 2000, the Grain-to-Green program was implemented to begin converting cropland back into grassland and forest. Results of the program include a reduction in yearly soil loss by 957 tons per square kilometer (Fu et al. 2011). A study of land use changes found that the conversion of native grassland to nonnative grasses which required fertilization is responsible for an eight fold increase in the phosphorous loading of reservoirs and their subsequent eutrophic state. A conversion of land back to a less nutrient intensive management practice can be used to offset the increased nutrient losses in other areas of more intense agricultural production (Ierodiaconou et al. 2003).

Math Programming and Best Management Practices

Math programming models have also been used to simplify the distribution of management practices when large watersheds are considered. A watershed with 27 sub watersheds spreading across Kansas and Nebraska was evaluated simulating the effect of management practices with SWAT. A solution for randomly implemented management practices similar to voluntary enrollment, a globally cost effective solution of practices in the entire watershed, and a targeted solution where sub watersheds were entirely converted to a single practice was found. They found average costs of abatement of $2.26 for the globally cost-effective solution, $5.99 for the sub watershed targeting model, and $32.79 for the randomly implemented practices (Smith et al. 2014). This study shows the importance of targeting management practices. Targeting using a math programming model was used to address phosphorous pollution in a Minnesota watershed. A positive math programming model was used to compare the effect on farm income when phosphorous abatement targets were set at a watershed level versus when they were set at the field level. This study addressed the physical differences in farmland and the varying contributions to water pollution. Eliminating agricultural production nearest to the rivers and streams and leaving the production far from the stream edge allows for the highest net farm income for the watershed (Easter, Olson, and Westra 2002).

Sediment abatement for the Illinois River Basin in western Illinois was addressed with a math programming model using an aggregate abatement target for 12 watersheds and it was compared it to a model with uniform targets across watersheds to be accomplished by retiring land from agricultural production. The abatement target was set at 20% for the aggregate of all 12 watersheds, and they determined abatement levels for each watershed that would meet the aggregate total at the least cost with some abating more and some less than 20%. They found that by equalizing the marginal cost of abatement across watersheds, there was a potential cost share savings of $280,000 when compared to setting abatement levels at the watershed level (Khanna et al. 2003).

Math programming models have been used to optimize the distribution of farm management practices through watersheds while meeting targets for pollution control. Sediment and nitrogen are two pollutants with a complementary production relationship. A study of irrigated onion and potatoes in Oregon utilized a multiple objective programming model to determine a least cost application of management practices to simultaneously abate nitrate leaching and sediment erosion. They found that a solution that reduced erosion alone by 49% increased nitrate leaching by 27%, but when both pollutants were evaluated together the same expenditure level could reduce erosion by 42% and nitrate leaching by 12% (Conner et al. 1995). This method is helpful when the practices to be considered may increase one pollutant while decreasing another. Another multiple objective programming model used EPIC simulated data to maximize farm income while minimizing nitrogen pollution and soil erosion on farms in Tunisia. This study found that up to a certain level, farmers could improve profit levels, nitrogen pollution, and soil erosion simultaneously. At higher pollution abatement levels, a reduction in income will be required to reduce sediment and nitrogen loss (Flichman, Mimouni, and Zekri 2000). This study brings to light the complexity of distributing management practices when organization to share machinery does not exist. A complex distribution of management practices will not always be used in reality. One example is no till farming. A farmer must decide to purchase either a no till planter or a conventional planter. It is unlikely that a farmer would purchase and utilize two different types of planters for the same crop, even if he would be at an advantage to control erosion using no till practices on one portion of his farm while using conventional tillage on the rest of the farm. Another example is tillage operations. A farmer would be unlikely to purchase a moldboard plow or disk and chisel implements, and only use them on the un-sloped land in agricultural production, and then practice no till farming on the hillsides of the same field. If there does not exist an organization between farmers to pool these resources they are likely to make a onetime decision either in favor or against a specific management practice and then maintain that practice across their entire production of a crop.

CHAPTER III

METHODOLOGY

The Willow Creek sub-watershed is one of four sub-watersheds that make up the Fort Cobb reservoir watershed. The land in the sub-watershed is primarily used for agricultural production. The sub watershed covers are region of 8,494 hectares. The watershed is covered by 31% winter wheat production. Winter wheat is the primary crop produced in the Willow Creek sub-watershed. There is a total of 2,630 hectares of winter wheat spread across 26 soil types. Slopes with over 20 hectares of winter wheat production range from 0% to 5%. The crop with the second highest hectarage of production is cotton. Covering 5% of the watershed, there are 372 total hectares of cotton production spread across 21 soil types in the Willow Creek sub-watershed with slopes of 0% to 2% having production over 20 hectares. Pasture and grassland covers 37% with 3,143 hectares spanning 27 soil types, and with areas over 20 hectares from 0% to 7% slopes. The other 27% of the watershed is a combination of less common crops, residences, roads, and other uses. To determine the sediment and phosphorous loss levels for the baseline and with management practices in place, an Environmental Policy Integrated Climate (EPIC) model is used to simulate fifty years of winter wheat and cotton agricultural production with and without management practices. ArcGIS was used to intersect maps of land slope, soil type, and land use.

Each unique combination of slope, soil, and winter wheat or cotton was then simulated from using daily weather from 1965 to 2014 in the EPIC software. The first five years of results were discarded to allow the simulation to come to an equilibrium. The average sediment and phosphorous loss per hectare from 1970 to 2014 were then taken for each simulation.

Net revenues for each of five management practices was determined from yield data from the EPIC simulations and the Oklahoma State Enterprise Budget Software. The level of phosphorous and sediment abatement was determined to be the improvements in pollutant losses from the baseline conventional tillage to the improved management practice. The results from the background data, the EPIC simulation, and the net incomes by crop and soil type are summarized in the results section.

The first objective of a profit maximizing distribution of BMP's in the watershed was accomplished using a linear programming model to select hectarage within each soil to be managed by a either conventional disk chisel tillage, no till, contouring, contour with no till, or conversion to native grassland. This model maximized net revenue for the entire watershed while prescribing management practices that reduced watershed level phosphorous and sediment loss by 40%, 60%, and 80% when compared to watershed level phosphorous and sediment losses from a conventional disk chisel tillage system alone.

A binary integer programing model was also used to accomplish the second objective by finding a solution which prescribed homogenous management practices across farms. The purpose of this model is to avoid a solution that requires more than one set of equipment for tillage, planting, and other farm operations to be used on the same farm as a farmer is unlikely to purchase multiple implements to accomplish the same types of field operation. This model also maximized net revenue for the entire watershed. Watershed level constraints for the minimum total abatement of sediment and phosphorus to be achieved in the watershed were included in the model.

The third objective was accomplished by examining the characteristics of farms with both high and low marginal costs of abatement for phosphorous and sediment. Characteristics of these farms are discussed and could be used to inform decision making on future BMP implementation in the watershed.

EPIC Simulations

The EPIC model uses a daily time step to simulate the effect of management practices on the fate of soil, nutrients, pesticides, and water. The model is physically based, and it uses hundreds of parameters to simulate a field with the same management practices and soil slope. The unique data used for this study are the slope, management practice, soil, and weather. The EPIC model was used to simulate the sediment and phosphorous loss for each of the management practices in the math programming models. Yield data from the EPIC simulation were used in the Oklahoma State Enterprise Budget software to determine net revenues for the farms under each of the examined management practices. Abatement levels from each of the improved management practices used in both the binary and linear programming models were calculated as the improvement in phosphorous and sediment losses in relation to a disk chisel tillage.

Management Practices

A conventional disk chisel tillage continuous winter wheat and continuous cotton management system was used to determine a baseline level of sediment and phosphorous loss. Improved management practices were simulated to provide a difference in phosphorous, sediment, and crop yield. An .ops file was assembled for field operations and chemical applications. To determine management practice abatement levels, a no till .ops file was assembled with field operations and chemical applications for wheat (Decker et al., 2009) and cotton (Varner, Epplin, and Strickland, 2011). To incorporate the practice of contour farming, the conservation practice factor was adjusted in the EPICCONT.dat file. Tables of operations schedules follow in tables 3.1, 3.2, 3.3,

Table 3.1: Conventional Winter Wheat Operation Schedule

Month	Field Operation (day)	Chemical Application Amounts
June	Harvest(5th) Chisel (30th)	
August	Disk (15th) Anhydrous Application (16th)	 90 kg/ha
September	Disk (5th)	
October	Disk (1st) Apply 18-46-0 (2nd) Drill Seed (10th)	 57 kg/ha

Table 3.2: No Till Winter Wheat Operation Schedule

Month	Field Operation (day)	Chemical Application Amounts
June	Harvest (5th) Apply glyphosate(post-harvest)	 59 fl oz/ha
July		
August	Apply glyphosate (9th) Anhydrous Application (16th)	59 fl oz/ha 90 kg/ha
September	Apply glyphosate (25th)	59 fl oz/ha
October	Apply 18-46-0 (2nd) No Till Drill Seed (10th)	57 kg/ha

Table 3.3: Conventional Cotton Operation Schedule

Month	Field Operation (day)	Chemical Application Amounts
March	Chisel (15th) Disk (16th)	
May	Apply Anhydrous (10th) Chisel (11th) Apply trifluralin (11th) Row Cultivator (15th) Plant (16th)	136 kg/ha 1.75 l/ha
June	Apply Glyphosate Apply s-metolachlor	1.6 l/ha 1.17 l/ha
November	Apply Defoliant thidiazuron-diuron (1st) Harvest (4th)	.82 l/ha
December	Rotary Mow (15th)	

Table 3.4: No Till Cotton Operation Schedule

Month	Field Operation (day)	Chemical Application Amounts
May	Apply Anhydrous (10th) Plant No Till (16th) Apply Glyphosate (18th)	136 kg/ha 1.6 l/ha
June	Apply Glyphosate(25th)	1.6 l/ha
November	Apply Defoliant thidiazuron-diuron (1st) Harvest (4th)	.82 l/ha
December	Rotary Mow (15th)	

and 3.4. Buffalo grass was used to simulate conversion to grassland because it was included in the crop data base for EPIC and it is native to the watershed (Blair and Hubbell, 1938).

Slope

Land Slopes were gathered from a 10 meter digital elevation map (USDA 2014). Slope in percent grade was used. Only areas with slopes between zero and two percent were used to simulate cotton production while areas with slopes between zero and five percent were used to simulate wheat production. More steeply sloped land was not simulated because very little production of wheat and cotton occurred above these slopes.

Soil

Data on soil types were taken from the Natural Resource Conservation Service (NRCS) National Cooperative Soil Survey SSURGO soil database (USDA 2015). A map of the distribution of soils through the watershed was created in ArcGIS. The nineteen soils with over 40 hectares in the watershed were used. An EXCEL spreadsheet with input parameters for the EPIC program soil files was provided by Evlyn Steligch of the Blackland Research and Extension Center (personal communication, November 01, 2014). These data were used to create the .sol files. A table of soils used for the simulations is shown in table 3.5.

Weather

Weather data for the simulation required daily measurements of solar radiation, wind speed, temperature, precipitation, and relative humidity. When available, these weather data were gathered from the Mesonet station at Fort Cobb. To deal with the problem of missing data, surrounding weather stations with available data were used. These stations were Colony, Cordell, Sedan, Carnegie, Anadarko, Apache, Chickasaw Experiment Station, Amber, Geary, Lookeba, El Reno, Sherman, Hobart, and Oklahoma City. An OLS regression for each parameter was

Table 3.5: Epic Soils for Simulation

Soil	Description	Cotton (Ha) Slope (%)	Wheat (Ha) Slope (%)
Pond Creek (PkB)	Silt Loam	1.73 0-2%	131.27 0-3%
IronMound-Dill (LuE)	Fine Sandy Loam	N/A[a]	1.25 1-5%
Gracemont and Ezell (GM)	Loam and Fine Sandy Loam	.02 2%	.95 0-5%
Eufaula (EuB)	Loamy Fine Sand	N/A[a]	15.24 0-5%
Darnell-Noble(DnD)	Fine Sandy Loam	N/A[a]	6.00 0-5%
Binger and Grant (CrD3)	Fine Sandy Loam	N/A[a]	8.22 0-4%
Binger (CoD)	Fine Sandy Loam	N/A[a]	20.49 0-5%
Binger (CoB)	Fine Sandy Loam	.57 0-2%	11.82 0-4%
Binger (CoC)	Fine Sandy Loam	6.94 0-2%	128.98 0-4%
Binger (CoD2)	Fine Sandy Loam	2.19 0-2%	65.05 0-5%
Dougherty and Konawa (DoB)	Fine Sandy Loam and Loamy Fine Sand	29.77 0-2%	240.93 0-4%
Dougherty and Konawa (DuD)	Fine Sandy Loam and Loamy Fine Sand	13.13 0-2%	147.08 0-5%
Eufaula (EfD)	Fine Sand	7.39 0-2%	67.07 0-5%
Konawa (KoC2)	Loamy Fine Sand	7.05 0-2%	33.93 0-5%
IronMound-Dill (LuD)	Complex	1.12 0-2%	54.83 0-5%
Noble (NoB)	Fine Sandy Loam	1.16 0-2%	46.82 0-4%
Noble (NoD)	Fine Sandy Loam	.76 0-2%	61.16 0-5%
Pond Creek (PcA)	Fine Sandy Loam	72.65 0-1%	162.51 0-4%
Pond Creek (PcB)	Fine Sandy Loam	53.81 0-2%	748.20 0-4%

[a] N/A means no cotton on this soil type

estimated with the surrounding weather stations as the independent variables. The resulting parameters were used to predict the necessary weather data values at Fort Cobb. To deal with missing daily data from the surrounding weather stations, additional regressions were estimated excluding the missing independent variable observations. Regressions were then ranked by the R^2 value. Finally predictions were made for missing Fort Cobb weather data using the regression with the highest R^2 value for which complete data were available.

Linear Programing Model

A linear programming model was used to select a net revenue maximizing combination of management practices for the entire watershed that would meet a specified abatement target. This model was used to accomplish the first objective and the information gained from it can give an idea of the effect that implementing BMPs in the watershed will have on net farm income for the watershed. The objective function in this model is the net revenue of one hectare of a practice on a given farm multiplied by the number of hectares of a practice on a given farm which are implemented when constraints on minimum level of phosphorous and sediment abatements are met. Targets of 40%, 60%, and 80% abatement compared to the levels of sediment and phosphorous with conventional disk chisel tillage system were used. Farm revenues were determined for each of the five management types by using the yield data from the EPIC simulations, and budgets created using the Oklahoma State Enterprise budget software. Cost and yield differences from the different machinery, field operations, harvest costs, and chemical applications resulted in differing levels of per hectare income across farms and management practices. Net revenue in this model is in dollars per hectare for each of the possible practices.

It was necessary to determine an abatement level for each practice on a homogenous combination of slope, soil, and crop. The objective in this study is to find the most cost effective set of management practices, both conventional and improved, that could be used to reduce sediment and phosphorous levels when compared to disk chisel management practices. As mentioned above, terraces have been installed on 80 to 90 percent of land which would be possible to terrace. Disk chisel tillage as opposed to moldboard plow tillage was used for the conventional or baseline tillage to account for some of the changes in historical management practices that have occurred in the watershed. The equation to determine that abatement level on each homogenous slope, soil, and crop combination follows:

$$A_{s\,p} = B_s - P_{s\,p}$$

Where:

$A_{s\,p}$ is the abatement provided by practice p on slope soil crop s

B_s is the pollutant loss on slope soil crop s with conventional disk chisel tillage

$P_{s\,p}$ is the pollutant loss on slope soil crop s with practice p

An example of a conventional linear programming model and one which uses abatement levels to meet sediment targets is given in tables 3.6 and 3.7. The potential management practices are represented as activities. These are conventional tillage (CV), no till (NT), contour and no till (CTNT), contour (CT), and conversion to native grassland (G). In the conventional model phosphorous and sediment are constrained at 20% of the conventional tillage levels. In the abatement model, the abatement or reductions row multiplied by the number of hectares in the activity row must be greater than 80%. This results in levels of phosphorous and sediment that are the same 20% as in the conventional linear programming model. Note that the solutions in the two models are the same. The abatement model approaches from a maximum sediment and phosphorous loss and requires minimum reductions to be provided by the chosen practices. The conventional model approaches from a scenario of no sediment and phosphorous loss towards a maximum sediment and phosphorous loss. Both models maximize the same objective function which is based on the net revenues of each management practice, and are independently determined by the heterogeneous combination of slopes and soils making up a farm.

The linear programming model by soil types took the form of:

Maximize:

$$\sum_{i=1}^{I}(R_{i\,p} - C_{i\,p}) \times H_{i\,p}$$

Subject to:

$$\sum_{i=1}^{I} E_{i\,p} \times H_{i\,p} \geq S$$

$$\sum_{i=1}^{I} P_{i} \times H_{i} \geq F$$

$$\sum_{i=1}^{I} H_{i\,p} = A_{i}$$

Where:

$H_{i\,p}$ is the hectares of a management practice p on farm i

$E_{i\,p}$ is the erosion abatement per hectare provided by a management practice p on a farm i

$P_{i\,p}$ is the phosphorous abatement per hectare provided by a management practice p on a farm i

A_i is the total hectares on a farm i available for a management practice

S is the targeted sediment abatement level in metric tons.

F is the targeted phosphorous abatement level in kilograms

$R_{i\,p}$ is the total revenue per hectare of management practice p on farm i

$C_{i\,p}$ is the total cost of production per hectare of management practice p on farm i

Table 3.6 Example of Conventional Linear Programming Model

				Farm 1					Farm 2				
				CV[e]	NT[f]	CT[g]	CTNT[h]	G[i]	CV	NT	CT	CTNT	G
Decision Variables[a]	→	→	0	0	0	0	0	10	2.3	0	0	0	17.7
Objective[b]	→	→	$ 207.69	20	15	17	12	5	30	21	24	18	5
Hectares 1[c]	10[c]	=	10	1	1	1	1	1					
Hectares 2[c]	20[c]	=	20						1	1	1	1	1
Phosphorous Level (kg)[d]	80[d]	≥	80	10	7	8	6	1	15	12	14	10	2
Erosion Level[d] (MT)	24[d]	≥	19.69	3	1.7	1.9	1.4	0.4	4.5	3	2.5	2.1	0.3

[a] Decision Variables are the hectares of practice to be implemented on each farm
[b] Objective is the net revenue per hectare and the objective function when multiplied by the decision variables
[c] Hectares 1 and 2 are the number of hectares on each farm and all hectares must be assigned a practice
[d] Phosphorous and Erosion Levels are the per hectare losses for phosphorous and erosion. These when multiplied by the hectares to be implemented must be less than or equal to the constraint set which is a percentage of the original 400 kg and 120 MT losses when a conventional tillage is used
[e] CV is conventional tillage
[f] NT is no till
[g] CT is contour
[h] CTNT is contour and no till
[i] G is conversion to native grassland

Table 3.7 Example of Abatement Linear Programming Model

				Farm 1					Farm 2				
				CV[e]	NT[f]	CT[g]	CTNT[h]	G[i]	CV	NT	CT	CTNT	G
Decision Variables[a]	→	→	0	0	0	0	0	10	2.3	0	0	0	17.7
Objective[b]	→	→	$ 207.69	20	15	17	12	5	30	21	24	18	5
Hectares 1[c]	10[c]	=	10	1	1	1	1	1					
Hectares 2[c]	20[c]	=	20						1	1	1	1	1
Phosphorous Level (kg)[d]	320[d]	≤	320	0	3	2	4	9	0	3	1	5	13
Erosion Level[d] (MT)	96[d]	≤	100.3	0	1.3	1.1	1.6	2.6	0	1.5	2	2.4	4.2

[a] Decision Variables are the hectares of practice to be implemented on each farm
[b] Objective is the net revenue per hectare and the objective function when multiplied by the decision variables
[c] Hectares 1 and 2 are the number of hectares on each farm and all hectares must be assigned a practice
[d] Phosphorous and Erosion Levels are the per hectare abatements for phosphorous and erosion. These when multiplied by the hectares to be implemented must be greater than or equal to the constraint set which is a percentage of the original 400 kg and 120 MT losses when a conventional tillage is used
[e] CV is conventional tillage
[f] NT is no till
[g] CT is contour
[h] CTNT is contour and no till
[i] G is conversion to native grassland

Optimal Adoption of Farm Level Conservation Practices

The third objective involves developing a model that can be used to determine the most profitable tillage for each individual farm in the watershed such that abatement targets could be met. GIS shape files for individual farm boundaries have become available. These shape files allow tabulation of areas by individual soil types and land slopes. The soil types and land slopes can then be used to estimate crop yields and erosion rates for those crops with specific tillage systems. Net returns and erosion abatement for an individual farm can be calculated by summation across the areas of soil types and land slopes within the farm. This process beginning with the selection of individual farms is described in the next section.

Farm Selection

Data on farm ownership were gathered from the PVPlus GIS software, and owners with over 40 acres owned in the watershed were included (County Records 2016). A limitation of this study was the inability to distinguish between tenant operated and owner operated farms. Information grouping farms by operator would be useful, but is not publically available. Those farms which included some wheat or cotton production were used in the linear and binary programming models. There were 104 total farms with some wheat production, and 45 of those farms also included some cotton production. There were no farms with cotton production that did not also include some wheat production. The results of the EPIC simulations are presented in part two of the results section.

Erosion and phosphorous abatement levels will vary within a farm and across fields which have a heterogeneous distribution of soils and slopes for the same crop. Due to the complexity and unique distributions of soils, slopes, and crops on each farm and field, a calculation of a simpler abatement total for each farm was necessary to model the entire watershed simultaneously. Abatement for a farm were determined to be the hectare weighted sum of the differences between the conventional and improved management practice of all slope soil crop combinations of the farm.

$$I_{i\,p} = \sum_{s=1} P_{s\,p} \times H_{i\,s}$$

Where:

$I_{i\,p}$ is the weighted average abatement provided by practice p on farm i

$P_{s\,p}$ is the pollutant abatement level per hectare of practice p on s slope soil combination

$H_{i\,s}$ is the hectares of slope soil combination s on farm i

Integer Programming Model

A binary integer programming model was used to select either contouring, contoured no till, no till conversion to grassland, or conventional tillage for both cotton and wheat on each farm. This model accomplishes the second objective by allowing only one management practice per farm. The purpose of modeling in this manner is so that the solution does not require farmers to utilize multiple types of equipment for planting, chemical application, and tilling. If a practice is prescribed it would cover the entire hectarage of the crop production on a farm. Sediment and phosphorous abatement targets were set as the same 40%, 60%, and 80% watershed level reductions when compared to the conventional disk chisel tillage system. Net revenues were determined for each farm using the Oklahoma State University Enterprise Budget Software. The net revenues in this farm were the difference between the total revenue for the farm and the total costs for the farm. This differs from the linear programing model which had a net revenue defined in dollars per hectare. Yields used were the weighted total yield of each slope soil combination for the farm.

Abatements for a farm were determined to be the total difference in sediment and phosphorous loss between the conventional disk chisel tillage and the improved management practice for an entire farm. This is different from the linear programming model which included a per hectare abatement level for each farm. Abatement levels in this farm are the aggregate of all of the abatements provided across each slope, soil, and crop for a given farm.

Examples of the setups of a conventional binary programming model and an abatement binary programming model follow in tables 3.8 and 3.9. The potential management practices are represented as the same activities as in the linear programming models. These are conventional tillage (CV), no till (NT), contour and no till (CTNT), contour (CT), and conversion to native grassland (G). The difference in this model is that the choice of management practice will apply to all of the hectares on a farm.

In the conventional binary model phosphorous and sediment are constrained at 20% of the conventional tillage levels. In the abatement model, the abatement or reductions row multiplied by the farm decision in the binary activity row must be greater than 80% of the conventional tillage level. This results in levels of phosphorous and sediment that are the same 20% as in the conventional linear programming model.

Table 3.8 Example of Conventional Binary Programming Model

				Farm 1					Farm 2				
				CV[e]	NT[f]	CT[g]	CTNT[h]	G[i]	CV	NT	CT	CTNT	G
Decision Variables[a]	→	→	0	0	0	0	0	1	0	0	0	0	1
Objective[b]	→	→	$ 150	200	150	170	120	50	600	420	480	360	100
Farm 1[c]	1[c]	=	1	1	1	1	1	1					
Farm 2[c]	1[c]	=	1						1	1	1	1	1
Phosphorous Level (kg)[d]	80[d]	≥	50	100	70	80	60	10	300	240	280	200	40
Erosion Level (MT)[d]	24[d]	≥	10	30	17	19	14	4	90	60	50	42	6

[a] Decision Variables are the hectares of practice to be implemented on each farm
[b] Objective is the net revenue and the objective function
[c] Farm 1 and farm 2 are constraints allowing only one practice per farm
[d] Phosphorous and Erosion Levels are the farm losses for phosphorous and erosion. These when multiplied by the practice to be implemented must be greater than or equal to the constraint set which is a percentage of the original 400 kg and 120 MT losses when a conventional tillage is used
[e] CV is conventional tillage
[f] NT is no till
[g] CT is contour
[h] CTNT is contour and no till
[i] G is conversion to native grassland

This results in levels of phosphorous and sediment that are the same 20% as in the conventional linear programming model. Note that the solutions in the two models are the same. Both models maximize the same objective function which is based on the net revenues of each management practice when implemented for the entire farm. Also, note that although the same two farms are simulated using the binary and linear approaches. The objective function value is lower for the

Table 3.9 Example of Abatement Binary Programming Model

				Farm 1					Farm 2				
				CV[e]	NT[f]	CT[g]	CTNT[h]	G[i]	CV	NT	CT	CTNT	G
Decision Variables[a]	→	→	0	0	0	0	0	1	0	0	0	0	1
Objective[b]	→	→	$ 150	200	150	170	120	50	600	420	480	360	100
Farm 1[c]	1	=	1	1	1	1	1	1					
Farm 2[c]	1	=	1						1	1	1	1	1
Phosphorous Level (kg)[d]	320	≤	350	0	30	20	40	90	0	60	20	100	260
Erosion Level (MT)[d]	96	≤	110	0	13	11	16	26	0	30	40	48	84

[a] Decision Variables are the hectares of practice to be implemented on each farm
[b] Objective is the net revenue and the objective function
[c] Farm 1 and farm 2 are constraints allowing only one practice per farm
[d] Phosphorous and Erosion Levels are the farm abatements for phosphorous and erosion. These when multiplied by the practice to be implemented must be greater than or equal to the constraint set which is a percentage of the original 400 kg and 120 MT losses when a conventional tillage is used
[e] CV is conventional tillage
[f] NT is no till
[g] CT is contour
[h] CTNT is contour and no till
[i] G is conversion to native grassland

binary model. This is because the optimal spread of practices in the linear model reduces sediment and phosphorous at a lower marginal cost, but requires multiple tillage practices on the same farm. The binary model took the form:

Maximize:

$$\sum_{i=1} (R_{ij} - C_{ij}) \times O_{i\,j}$$

Subject to:

$$\sum_{i=1} E_{i\,j} \geq S$$

$$\sum_{i=1} P_{i\,j} \geq F$$

$$\sum_{j} O_{i\,j} = 1$$

Where:

R_j is the total revenue of farm j

C_i is the total cost of production of farm j

$O_{i\,j}$ is a binary variable for farm j and management practice i

$E_{i\,j}$ is the total sediment abatement on farm j with management practice i

$P_{i\,j}$ is the total phosphorous abatement on farm j with management practice i

S is the sediment abatement target

F is the phosphorous abatement target

CHAPTER IV

RESULTS

Practice Abatement Levels

Sediment and phosphorous abatement levels were determined for conventional tillage, no till, contouring, contoured no till, and conversion to grassland. There were a total of 104 wheat farms and 45 cotton farms with a total of 2,151 hectares in production. Cotton was observed on 198 hectares and winter wheat was observed on 1,952 hectares. Table 4.1 shows the average abatement for each practice. The abatement levels are the quantity of pollutant that does not leave the farm when compared to a conventional disk chisel tillage practice. These totals are from EPIC simulations across both crops using fifty years of historical daily weather data, 10m digital elevation data for slope, and land use data from satellite imagery. Slopes and the number of hectares of soil are given in table 3.5. Contouring had comparable but slightly lower levels of sediment abatement than no till on fourteen soils. The two soils where contouring outperformed no till, LuE and DnD, were generally of a steeper slope and were 100% in wheat production. The EuB, EfD, and PcA soils were within 10 kg/ha per year of sediment loss. Contour with no till was strictly better than either practice alone. Conversion to grassland had strictly higher abatement levels than any other practice. The most erosive soil types were the DnD and LuE soils both of these soil groups belong to hydrological soil group D, the group with the highest potential for

Table 4.1 Average Abatement Levels by Practice and Soil

Soil Type	Sediment Abatement (MT/h)[a]				Without abatement	Phosphorous Abatement(KG/h)[a]				Without abatement
	CT[c]	CTNT	NT	G	CV[b]	CT[c]	CTNT	NT	G	CV[b]
PkB	0.72	1.10	0.75	1.44	**1.45**	0.17	0.25	0.15	0.39	**0.39**
LuE	5.55	8.16	5.03	10.83	**10.88**	0.92	1.16	0.48	1.83	**1.9**
Gm	4.23	6.43	4.42	8.31	**8.34**	0.67	1.08	0.81	1.34	**1.4**
EuB	0.21	0.32	0.21	0.43	**0.43**	0.03	0.04	0.01	0.06	**0.1**
DnD	7.13	10.20	6.20	13.67	**13.74**	0.96	1.17	0.45	1.90	**2**
CrD3	2.50	3.78	2.51	4.97	**4.99**	0.19	0.26	0.13	0.40	**0.5**
CoD	3.68	5.62	3.89	7.23	**7.25**	0.53	0.86	0.65	1.07	**1.1**
CoB	1.42	2.26	1.56	2.89	**2.9**	0.22	0.36	0.27	0.49	**0.5**
CoC	1.73	2.72	1.87	3.51	**3.53**	0.27	0.44	0.32	0.58	**0.6**
CoD2	2.17	3.39	2.36	4.36	**4.38**	0.32	0.53	0.40	0.68	**0.7**
DoB	0.48	0.91	0.59	1.05	**1.06**	0.07	0.12	0.09	0.16	**0.2**
DuD	0.88	1.50	0.98	1.80	**1.81**	0.12	0.16	0.07	0.26	**0.3**
EfD	0.26	0.59	0.26	0.54	**0.54**	0.04	0.04	0.01	0.08	**0.1**
KoC2	1.20	2.04	1.52	2.52	**2.53**	0.12	0.19	0.13	0.29	**0.3**
LuD	3.54	5.33	3.61	6.93	**6.95**	0.63	0.92	0.58	1.28	**1.3**
NoB	0.96	1.53	1.13	1.93	**1.94**	0.14	0.23	0.17	0.30	**0.4**
NoD	1.75	2.76	2.05	3.45	**3.46**	0.30	0.46	0.31	0.62	**0.7**
PcA	0.26	0.44	0.26	0.66	**0.66**	0.09	0.12	0.05	0.28	**0.3**
PcB	0.66	1.11	0.84	1.39	**1.4**	0.13	0.23	0.16	0.32	**0.4**

[a] Abatement levels are the reductions given by implementing one hectare of a practice when compared to one hectare of a disk chisel tillage system.
[b] Conventional Tillage (CV) is the average per hectare loss for a disk chisel system
[c] Contour (CT), contour no till (CTNT), no till (NT), conversion to native grassland (G) are the average per hectare reductions when one hectare of conventional tillage is converted.

runoff. The EuB, EfD, and PcA soils were the least erosive on average with less than one metric ton of soil loss per hectare per year.

The EuB and EfD soil types both belong to hydrological soil group A, the type with the lowest potential for runoff. The PcA soil type belongs to hydrological soil group C, a potentially high runoff group, but this soil is only present on land sloped 1% or less which contributes to lower pollutant losses.

Phosphorous abatement with contouring was slightly better than no till alone across nine soils, while no till provided higher abatement on ten soils. Soils that had a higher phosphorous abatement using contouring generally had higher percentages of wheat production and were more steeply sloped. Soils that had lower slopes and more cotton production generally had higher abatement with no till. As expected, combined contour with no till had strictly higher phosphorous abatement levels than either practice alone. Conversion to grassland had the highest phosphorous abatement, almost completely eliminating phosphorous loss.

Yields and Profits by Soil Type

Table 4.2 EPIC Crop Yields by Soil Type

Soil	Wheat Yield MT/Ha					Cotton Yield MT/Ha				
	CT[c]	NT	CTNT	CV	Slope[a] %	CT[c]	NT	CTNT	CV	Slope[a] %
PkB	2.163	2.135	2.131	2.166	0.23	0.737	0.706	0.706	0.737	0.53
LuE	1.390	1.388	1.391	1.385	3.26	N/A[b]	N/A[b]	N/A[b]	N/A[b]	N/A[b]
Gm	2.024	2.014	2.011	2.027	2.37	0.717	0.646	0.646	0.717	2.00
EuB	1.879	1.867	1.866	1.879	0.72	N/A[b]	N/A[b]	N/A[b]	N/A[b]	N/A[b]
DnD	1.276	1.283	1.288	1.263	3.30	N/A[b]	N/A[b]	N/A[b]	N/A[b]	N/A[b]
CrD3	1.840	1.850	1.854	1.832	2.01	N/A[b]	N/A[b]	N/A[b]	N/A[b]	N/A[b]
CoD	1.844	1.836	1.838	1.839	2.67	N/A[b]	N/A[b]	N/A[b]	N/A[b]	N/A[b]
CoB	1.860	1.851	1.853	1.855	0.99	0.634	0.640	0.640	0.634	0.96
CoC	1.842	1.835	1.837	1.838	1.31	0.630	0.636	0.636	0.630	0.97
CoD2	1.860	1.851	1.853	1.855	1.67	0.634	0.640	0.640	0.634	1.26
DoB	2.218	2.209	2.209	2.218	0.32	0.709	0.706	0.706	0.709	0.50
DuD	2.034	2.018	2.017	2.035	1.67	0.668	0.663	0.663	0.668	0.87
EfD	1.781	1.777	1.780	1.781	1.48	0.599	0.597	0.597	0.599	1.08
KoC2	2.049	2.053	2.053	2.037	1.13	0.674	0.679	0.680	0.673	0.91
LuD	1.695	1.691	1.692	1.690	2.50	0.598	0.603	0.603	0.597	1.12
NoB	2.350	2.321	2.316	2.355	0.62	0.774	0.716	0.716	0.774	0.79
NoD	2.347	2.316	2.312	2.350	1.48	0.769	0.723	0.723	0.769	0.95
PcA	2.179	2.152	2.152	2.178	0.08	0.734	0.715	0.715	0.734	0.02
PcB	2.414	2.390	2.387	2.417	0.19	0.773	0.758	0.758	0.773	0.22

[a] Slopes are given as an average percent slope across the entire watershed
[b] N/A means no cotton was produced on this soil type
[c] CT is contoured NT is no till CTNT is contour with no till CV is Conventional Disk chisel tillage

Yields varied across management practice and soil type through the EPIC simulations. The yields in table 4.2 are the average from the last 45 years of the EPIC simulation. The wheat management practice with the highest yields was the disk chisel practice, although yields differed more by soil type than by management practice. The soils with the steepest slopes in wheat production, LuE and DnD, had an average yield over 45 years which were 64% and 58% respectively of the least sloped PcA soil wheat yields using conventional disk chisel tillage. Yields ranged from a low of 1.263 metric tons per hectare on conventional tillage DnD soil to 2.417 metric tons per hectare on conventional tillage PcB soil. When examining cotton production, soils with higher levels of erosion tended to have slightly higher yields using the no till and contour with no till managements. Soils with relatively lower amounts of erosion saw higher yields with the conventional disk chisel tillage system. The soil type had a greater magnitude of effect of yields. Cotton yields ranged from 597 kilograms per hectare to 774 kilograms per hectare on the EfD and NoB soils respectively. Levels of erosion had less effect over the 45 years of crop growth simulated on cotton than on wheat.

The net revenues across soil types shown are shown in table 4.3. The net revenue for cotton on the same soil type as the wheat generally had higher net revenue. Cotton also tended to occupy less steeply sloped land for a given soil type. On wheat production the conventional tillage had the highest net revenue on nine soil types. No till had a higher net revenue on 10 soil types. No till had an advantage on more highly erosive soil types, and conventional tillage was the most profitable on less erosive and less steeply sloped soil types. Wheat had drastically lower net revenues on LuE and DnD soil types. These soils had the lowest yields causing the low revenue. On cotton production, no till had a higher net revenue on 12 soil types, and conventional tillage had a higher net revenue on 2 soil types. Neither of the least profitable wheat soils were observed to have any cotton production. The lowest net revenue cotton soils had average slopes around 1% and higher.

Table 4.3 Crop Net Revenues by Soil Type

Soil	Net Revenue Wheat $/h					Net Revenue Cotton $/h				
	CT[c]	NT	CTNT	CV	Slope[a] %	CT[c]	NT	CTNT	CV	Slope[a] %
PkB	$328.49	$329.06	$324.00	$335.74	0.23	$478.97	$568.18	$527.06	$524.21	0.53
LuE	$94.01	$103.17	$99.91	$99.29	3.26	N/A[b]	N/A[b]	N/A[b]	N/A[b]	N/A
Gm	$286.28	$292.63	$287.67	$293.92	2.37	$444.60	$465.20	$424.03	$489.96	2.00
EuB	$242.24	$247.95	$243.95	$248.87	0.72	N/A[b]	N/A[b]	N/A[b]	N/A[b]	N/A[b]
DnD	$59.62	$71.18	$68.76	$62.48	3.30	N/A[b]	N/A[b]	N/A[b]	N/A[b]	N/A[b]
CrD3	$230.44	$242.78	$240.14	$234.78	2.01	N/A[b]	N/A[b]	N/A[b]	N/A[b]	N/A[b]
CoD	$231.57	$238.72	$235.32	$236.92	2.67	N/A[b]	N/A[b]	N/A[b]	N/A[b]	N/A[b]
CoB	$236.47	$243.31	$239.90	$241.83	0.99	$302.20	$454.73	$414.30	$346.82	0.96
CoC	$231.19	$238.38	$234.99	$236.53	1.31	$294.23	$447.70	$407.16	$338.89	0.97
CoD2	$236.47	$243.31	$239.90	$241.83	1.67	$302.20	$454.73	$414.30	$346.82	1.26
DoB	$345.19	$351.63	$347.60	$351.69	0.32	$431.04	$568.47	$527.52	$476.20	0.50
DuD	$289.39	$293.73	$289.59	$296.06	1.67	$360.17	$494.50	$453.51	$405.27	0.87
EfD	$212.58	$220.84	$217.79	$219.23	1.48	$240.75	$381.20	$340.26	$285.89	1.08
KoC2	$293.74	$304.23	$300.46	$296.95	1.13	$370.01	$522.37	$482.63	$413.32	0.91
LuD	$186.63	$194.70	$191.16	$191.88	2.50	$238.72	$390.48	$349.71	$283.57	1.12
NoB	$385.05	$385.47	$380.02	$392.92	0.62	$542.41	$585.47	$544.17	$587.98	0.79
NoD	$384.04	$383.87	$378.77	$391.48	1.48	$533.01	$597.63	$556.34	$578.34	0.95
PcA	$333.14	$334.39	$330.58	$339.39	0.08	$473.34	$584.36	$543.42	$518.38	0.02
PcB	$404.57	$406.27	$401.56	$411.91	0.19	$540.63	$657.83	$616.78	$585.73	0.22

[a] Slopes are given as an average percent across the entire watershed
[b] N/A means no cotton was produced on this soil type
[c] CT is contoured NT is no till CTNT is contour with no till CV is Conventional Disk chisel tillage

Profit Maximizing Allocation of BMPs Meeting Abatement Targets

A profit maximizing combination of management practices for three sediment and phosphorous abatement targets of 40%, 60% and 80% was found using a linear programming model. There were 1,952 hectares of winter wheat and 198 hectares of cotton production available for a practice. There were 104 total farms with winter wheat production, with 45 of those farms also producing cotton. Every farm in the watershed that produced cotton also had some wheat production. The baseline level of erosion simulated using conventional tillage methods was 3,988 metric tons per year with an average soil loss of 2 metric tons per hectare yearly. The baseline level of phosphorous loss for conventional tillage was 776 kilograms per year with an average loss of .4 kilograms per hectare yearly.

At a 40% sediment and phosphorous abatement level, the total profit maximizing management practices are listed in table 4.4. The total profits if all farms used a conventional disk chisel tillage method would be $797,104 for the watershed. The results indicate that a 40 percent reduction in sediment and phosphorous levels could be met using a combination of contouring and no till on 267 hectares, and no till on 1,019 hectares. A 40% abatement level reduces field point erosion and sediment loss by 1,598 metric tons per year from the Willow Creek watershed. Phosphorous loss is reduced by 310 kilograms per year. Sediment abatement in this model is not a

Table 4.4 Profit Maximizing 40% Abatement Practices

Practice	Phosphorous Model[b]		Sediment Model[c]	
	Wheat **$**[d] (ha)[a]	Cotton **$**[d] (ha)[a]	Wheat **$**[d] (ha)[a]	Cotton **$**[d] (ha)[a]
Contouring: **Profit**	**$0**	**$0**	**$0**	**$0**
Hectares	0	0	0	0
Contour & No-Till	**$82,752**	**$0**	**$14,192**	**$0**
	267	0	51	0
No-Till	**$ 348,597**	**$116,113**	**$ 337,356**	**$116,113**
	1019	198	1018	198
Conversion to Grassland	**$0**	**$0**	**$0**	**$0**
	0	0	0	0
Conventional	**$260,954**	**$0**	**$342,567**	**$0**
	666	0	883	0
Total Net Revenue	**$692,303**	**$116,113**	**$694,115**	**$116,113**
Total Hectares	1952	198	1952	198
Watershed Net Revenue[e]	**$808,416**		**$810,228**	

[a] The hectarages listed are the aggregate for a given practice throughout the watershed
[b] The Phosphorous model refers to the model with both pollutants ,but where phosphorous was the only constraining pollutant
[c] The Sediment model refers to the model run when the requirement for phosphorus abatement was removed
[d] Bold dollar values are the total net revenue in the watershed for a given practice
[e] Watershed Net Revenue is the revenue of cotton and wheat combined across all management practices

constraining factor. Phosphorous abatement is a constraining factor at the 40% abatement level. The net revenue for the watershed in the 40% phosphorous constrained model is $ 808,416. The total cost to the watershed in foregone revenue is $4,426. The marginal cost for the last kilogram of phosphorous reduction is $33. The average cost per kilogram for phosphorous reduction is $14.27. The 40% phosphorus abatement constrained model also abates 1980 metric tons of sediment. The unconstrained profit maximizing solution only abates 232 metric tons of sediment and 32 kilograms of phosphorous per year. Total returns for all farms in the watershed are $812,842 with no abatement constraints. No till is able to increase net revenue on cotton farms while also providing abatement because no till has higher net revenues than conventional tillage. Research on no till versus tilled for cotton in South West Oklahoma found higher net revenues with no till, and theorized that risk preferences and the magnitude of revenue differences may contribute to the reluctance to switch to no till management practices (Varner, Epplin, and Strickland 2011).

To find a distribution constrained by sediment at the 40% abatement level, phosphorous abatement levels can be ignored. In this scenario, field point sediment loss is 1,598 metric tons, and 242 kilograms of phosphorous are also abated. The solution for sediment abatement alone has a net revenue of $810,228 for an average cost per metric ton of sediment reduction of $1.62. The marginal cost for the last ton of sediment abated is $3.88. The sediment only constrained model also abates 243 kilograms of phosphorous. The net revenue in the sediment only model is $1,912 higher than the model which also constrains phosphorous. The model only abating sediment does not differ from the model that includes phosphorous on the cotton hectarage. The solution for the wheat hectarage has more hectares in the baseline disk chisel tillage practice, and less using the contour with no till practice than does the model which is constrained by phosphorous. The solution on the cotton hectarage was consistent between the phosphorous constrained model and the model only constraining sediment.

At a 60% sediment and phosphorous abatement level, the total profit maximizing management practices are listed in table 4.5. A 60% abatement level would reduce field surface sediment loss by 2,393 metric tons per year. Phosphorous loss would be reduced by 466 kilograms per year. The model solution results in a sediment reduction of 2,764 metric tons per year, and a phosphorous reduction of 466 kilograms per year. Sediment abatement in this model is not a constraining factor. Phosphorous abatement is a constraining factor, and the marginal cost for the last kilogram of phosphorous reduction is $54.48 in lost revenue to farm operators. Total returns for all farms in the watershed are $801,647. The total cost of abating at a 60% level is $11,195 at an average cost of $24.02 per kilograms of phosphorous reduction.

Table 4.5 Profit Maximizing 60% Abatement Practices

Practice	Phosphorous Model[b]		Sediment Model[c]	
	Wheat $[d] (ha)[a]	Cotton $[d] (ha)[a]	Wheat $[d] (ha)[a]	Cotton $[d] (ha)[a]
Contouring: **Profit**	**$0**	**$0**	**$0**	**$0**
Hectares	0	0	0	0
Contour & No-Till	**$419,583**	**$0**	**$154,748**	**$0**
	1192	0	1163	0
No-Till	**$228,801**	**$116,133**	**$411,569**	**$116,133**
	660	198	479	198
Conversion to Grassland	**$0**	**$0**	**$0**	**$0**
	0	0	0	0
Conventional	**$37,130**	**$0**	**$123,067**	**$0**
	100	0	310	0
Total Net Revenue	**$685,514**	**$116,133**	**$689,384**	**$116,113**
Total Hectares	1952	198	1952	198
Watershed Net Revenue[e]	**$801,647**		**$805,497**	

[a] The hectarages listed are the aggregate for a given practice throughout the watershed
[b] The Phosphorous model refers to the model with both pollutants ,but where phosphorous was the only constraining pollutant
[c] The Sediment model refers to the model run when the requirement for phosphorus abatement was removed
[d] Bold dollar values are the total net revenue in the watershed for a given practice
[e] Watershed Net Revenue is the revenue of cotton and wheat combined across all management practices

A scenario with only sediment constrained at the 60% abatement level shows the differences between the scenarios with respect to the phosphorous and sediment constraints. It is easier to and less costly to reduce sediment by 60 percent than it is to reduce phosphorus by 60 percent. There is less hectarage converted to contour and no till and no hectarage converted to grassland on the wheat production. There are more hectares left in the baseline disk chisel tillage, and less conversion to no till is required. The cotton production is all left in the no till production method. Total returns for all farms in the watershed are $805,497. The total cost of abating only sediment at the 60% level is $7,345. At an average cost of $3.07 per metric ton of sediment for the watershed. The marginal cost of the last metric ton of sediment abated was $7.60. The model only constraining sediment at the 60% level abates 384 kilograms of phosphorous.

At an 80% sediment and phosphorous abatement level, the total profit maximizing management practices are listed in table 4.6. An 80% abatement level reduces field surface sediment loss by

3,190 metric tons per year and phosphorous loss by 621 kilograms per year. Sediment abatement in this model is not a constraining factor. Phosphorous abatement is a constraining factor, and the marginal cost for one kilogram of phosphorous reduction is $1,616 in lost revenue to farm operators. Total returns for all farms in the watershed is $683,770. The total cost of abating at the 80% level is $129,072 for an average cost of $207.85 per kilogram of phosphorous to the watershed. Sediment is reduced by 3,318 metric ton per year in this model.

Table 4.6 Profit Maximizing 80% Abatement Practices

Practice	Phosphorous Model[b]		Sediment Model[c]	
	Wheat **$**[d] (ha)[a]	Cotton **$**[d] (ha)[a]	Wheat **$**[d] (ha)[a]	Cotton **$**[d] (ha)[a]
Contouring: **Profit**	**$0**	**$0**	**$0**	**$0**
Hectares	0	0	0	0
Contour & No-Till	**$663,478**	**$16,745**	**$674,319**	**$107,986**
	1885	34	1922	198
No-Till	**$0**	**$0**	**$0**	**$0**
	0	0	0	0
Conversion to Grassland	**$1,026**	**$2,521**	**$456**	**$0**
	67	164	30	0
Conventional	**$0**	**$0**	**$0**	**$0**
	0	0	0	0
Total Net Revenue	**$664,504**	**$19,266**	**$674,775**	**$107,986**
Total Hectares	1952	198	1952	198
Watershed Net Revenue[e]	**$683,770**		**$782,761**	

[a] The hectarages listed are the aggregate for a given practice throughout the watershed
[b] The Phosphorous model refers to the model with both pollutants ,but where phosphorous was the only constraining pollutant
[c] The Sediment model refers to the model run when the requirement for phosphorus abatement was removed
[d] Bold dollar values are the total net revenue in the watershed for a given practice
[e] Watershed Net Revenue is the revenue of cotton and wheat combined across all management practices

A scenario in which only sediment is constrained at the 80% level while ignoring phosphorous loss is also different from the scenario in which both pollutants are constrained. The sediment constrained model has more hectares converted to contour with no till on the wheat hectarage and less conversion to grassland. There is a stark difference in the results on cotton production with more use of contour with no till, and no use of conversion to grassland. Total returns for farms in the watershed are $782,761. The total cost of abating only sediment at the 80% level is $30,082 with an average cost of $13.98 per hectare to the watershed. The marginal cost of the last metric ton of sediment abated is $236.21. The 80% abatement sediment only model reduces phosphorous loss by 546 kilograms.

The average and marginal costs of abatement strictly increases from $0 after a watershed phosphorous abatement level of 232 kilograms and the sediment abatement level is 32 metric tons. The farms with the highest marginal cost on land were all cotton farms in the 40% and 60% abatement models. These were the farms with the highest overall net revenues. They were not required to move to a lower net revenue production method, and the abatement was attained on farms with lower net revenues. Farms with the lowest marginal cost on land were wheat farms. There was a common few soil types which were present on farms with a low marginal cost for the land constraint. Shown in table 4.3, the DnD and LuE soil types had low net revenues per hectare contributing to the low marginal cost for another hectare of land on farms predominantly of this soil type. The DnD and LuE soil types were also highly erosive and had high phosphorous losses in the EPIC simulations. These farms increase the net revenue function because when one hectare is added, the erosion and phosphorous targets remain the same, and this land is converted by the model to a practice which provides high abatement. This high abatement frees up other farms to utilize profitable management practices. Farms with the highest marginal cost on land in the models with 40% and 60% abatement levels were all cotton farms. These farms were the most profitable farms in the watershed, they were placed into the management practice with the highest revenues, and the abatement targets were met by making conversion improved practices on other farms.

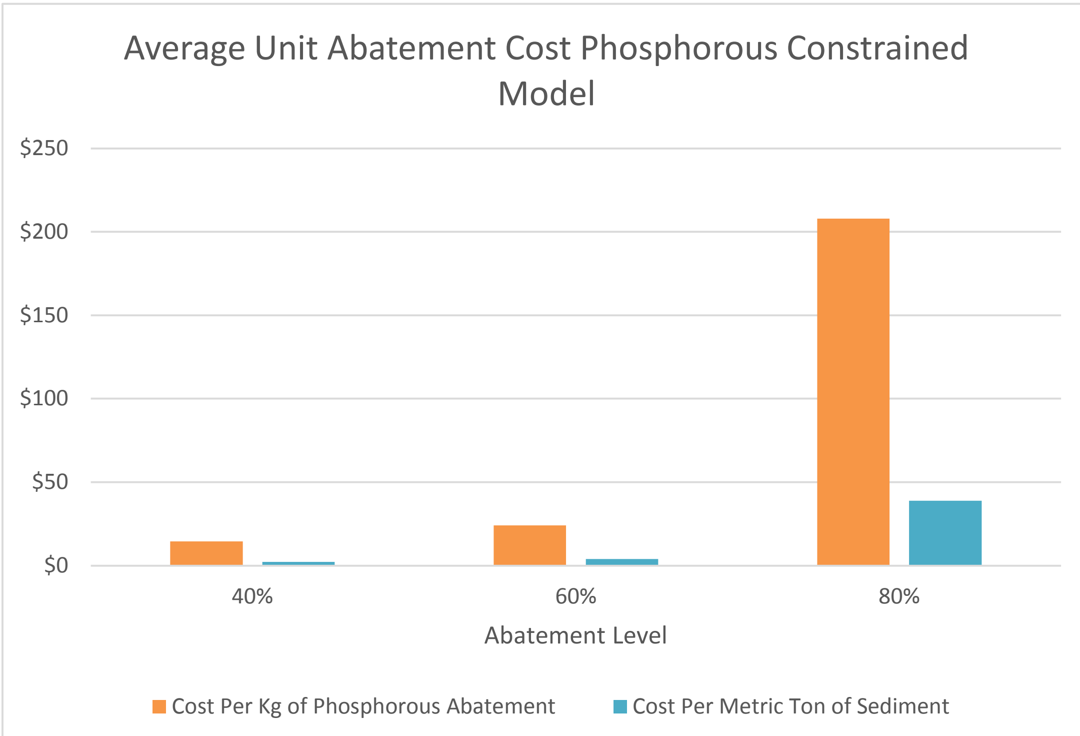
When the constraints on phosphorous and sediment are set at 80% the five highest marginal costs on land are split between two cotton farms and three wheat farms. A cotton farm with one hundred percent PcB had a high abatement by converting to grassland because the farm was entirely in the highest sloped cotton category of 2%. One extra hectare of grassland replacing cotton at a 2% slope would provide high abatements. When the total watershed target remains the same this high abatement can reduce the need for abatement on other farms and free those farms up for more profitable management practices. The other cotton farm in the top five highest marginal cost group had 100% of the highly erosive LuD soil type at a slope of 2% creating similar results. The wheat farm with the highest marginal cost for land was 96% of the highly erosive DnD soil type. 78% of this was a 2% slope or greater. The other wheat farms with high marginal costs on land consisted of 61% LuD with 60% of that being sloped 2% or greater and a farm where all of the soil was sloped 2% or greater.

The higher returns for no till dryland cotton due to lower costs of production result in the unconstrained solution being completely no till cotton (Segarra, Keeling, and Abernathy 1991) (Varner, Epplin, and Strickland 2011). Abatement targets are met in 40% model by converting baseline disk chisel wheat into a no till wheat system. Some of the no till is also contoured. Contouring is not used alone. The cotton farms in the 40% abatement model all use no till. There is no requirement for conversions to grassland. As the abatement target rises to 60%, there is more use of contouring with no till. Wheat hectarage is removed from the disk chisel tillage system, and placed into no till or contour with no till. Cotton remains in the no till tillage system as abatement levels are met on the wheat hectarage. The higher costs for harvest and field operations for contour give lower returns, but the returns are higher than grassland so contouring is used on the no till wheat farms. There is still no use of conversion to grassland at the 60% abatement level. At the highest abatement level of 80%, almost all of the cotton is converted to grassland some of the cotton is left in contour with no till. This is because of the generally higher levels of phosphorous and sediment loss found on the cotton hectarage, and the limited ability for no till cotton to reduce phosphorous loss (Hajek et al. 1994) or to cause more phosphorous loss (Cabrera et al. 2001), and at the 80% abatement level targets are no longer met by converting practices on wheat hectarage alone. Some wheat is converted to grassland at this abatement target, but the majority is prescribed a contour with no till practice.

Average Abatement Cost

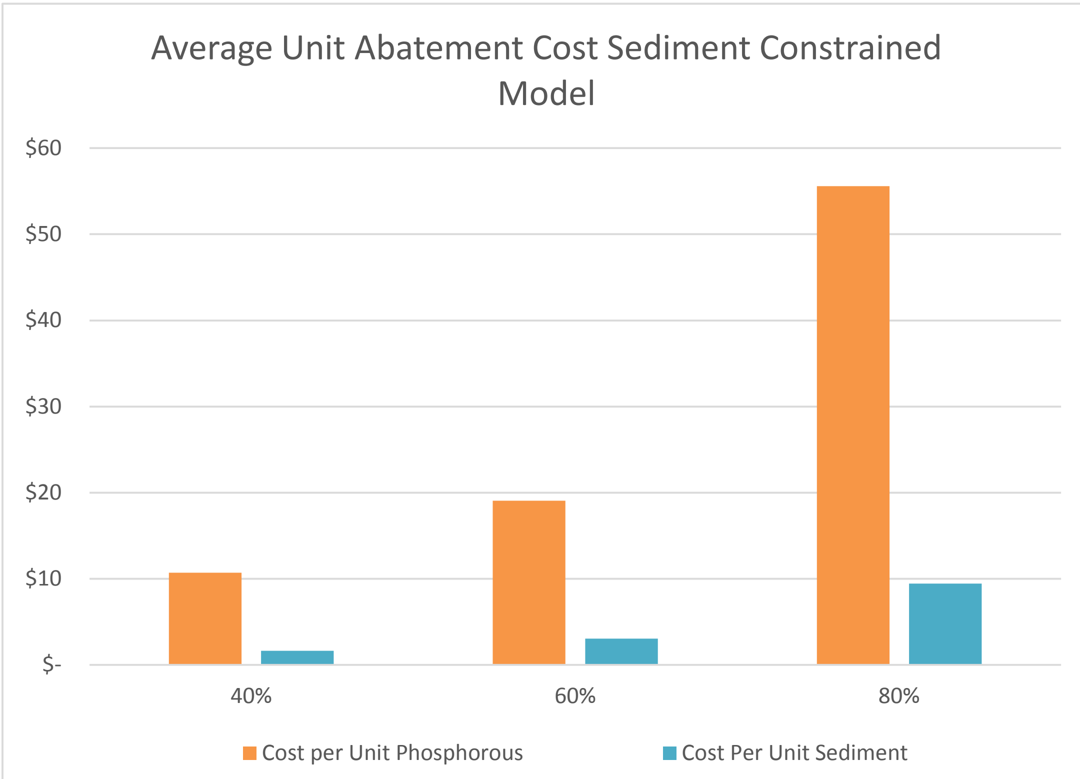
As expected, the average unit abatement cost for both sediment and phosphorous increases as the abatement requirements become more restrictive. The 40% abatement model is able to keep 666 hectares of wheat in the most profitable disk chisel tillage system. The no till system is applied to 1,019 hectares of wheat. The remaining 267 hectares of wheat require no till with contouring. All

Figure 1



cotton in the 40% abatement scenario is placed in no till production. When the abatement target rises to 60%, the use of contouring is required on wheat farms which lowers farm net revenue through higher costs for harvest and field operations. An area of 566 hectares of wheat were moved out of the highest profit disk chisel tillage system. There is a rapid rise in cost when the 80% abatement target is used. This result occurs because this is the abatement target in which farmland must be taken out of production and converted to grassland which has much lower per hectare net revenues. There are 67 hectares of wheat and 164 hectares of cotton converted to grassland at the 80 % abatement level. The remaining 1,885 hectares of wheat and 34 hectares of cotton are placed in contour with no till. The high per unit abatement cost in this scenario can be attributed to the lower returns for grassland and the higher production costs for contoured no till wheat production. A graph of the average unit abatement costs for phosphorous and sediment in both the phosphorous constrained and sediment constrained models follows in figures 1 and 2.

Figure 2



<u>Farm Based Binary Programming Model</u>

A profit maximizing combination of management practices for the same three sediment and phosphorous abatement targets of 40%, 60% and 80% was found using a binary programming model. This was used to force each farm into a single practice. The same 1952 hectares of winter wheat and 198 hectares of cotton production were available for a practice. There were 104 total farms with winter wheat production, with 45 of those farms also producing cotton. The baseline level of erosion simulated using conventional tillage methods was 3,988 metric tons per year, and the baseline level of phosphorous loss for conventional tillage was 776 kilograms per year. Table 4.7 contains a count of farms by practice type for phosphorous abatement.

The results of the binary programming model are similar to the linear programming model for the 40 percent abatement level. The binary programming model prescribes 52 of the wheat farms into no till with 28 farms remaining in the conventional disk chisel tillage and 24 farms using contour with no till. The cotton farms at this abatement level are similar to the linear programming model with 3 farms in contouring and 42 farms in no till. There is a small decrease in net revenue of $70 with a net revenue of $808,328 using the binary model. The total cost for using the binary model at this abatement level is $4,512. The average cost for one kilogram of phosphorous abatement is $14.55. Phosphorous is abated at 310 kilograms per year and sediment is abated at 1,980 metric tons per years in this model.

The 60 percent abatement level binary programming model reflects the solution in the linear programming model. There are 54 farms converted to contour with no till and 39 converted to no till. There are less farms with the conventional disk chisel tillage practice than in the 40% binary model. This model abates 466 kilograms of phosphorous and 2,759 metric tons of sediment. The net revenue in this model is $319 less than in the linear programming model at the same abatement level and is $11,514 lower than in the unconstrained linear model. The average cost for one kilogram of phosphorous abatement in this model is $24.71. This is a small decrease compared to the linear programming model showing that a binary model can provide a solution comparable to the linear programming model. Phosphorous abatement is the constraining pollutant, and is the same in both models, although the linear model abates five metric tons of sediment per year more.

The 80 percent abatement binary model has one farm with contouring, 28 more farms with contoured no till, and 15 more farms with conversion to grassland than does the 60 percent binary programming model. The net revenue in the binary model is $4,340 less than in the linear programming model and is $133,412 lower than in the unconstrained model. The average cost of phosphorous abatement in this model is $214.83. Sediment abatement in the binary model is 17 metric tons lower than in the linear programming model. Phosphorous abatement is the same in both models, and it is the constraining pollutant.

A scenario in which phosphorous loss was not constrained, and sediment was constrained at the 40%, 60%, and 80% watershed level abatement has a distribution of practices across farms shown in table 4.8. The results of the binary model only constraining sediment differ from the binary model where phosphorous is the constraining pollutant at the 40% abatement level. The phosphorous model requires more farms to implement contour with no till. There are also 8 more wheat farms with conventional disk chisel tillage in the sediment model. The cotton results are consistent across models. The model in which only sediment is constrained abates 1,598 metric tons of sediment and also abates 243 kilograms of phosphorous. The total cost in lost net revenue within the watershed is $2,621. The average cost to abate one metric ton of sediment in this model is $1.64. The results in the sediment binary model differ from the results in the phosphorous constrained model at the 60% abatement level. The wheat hectarage requires less farms to convert to contour with no till to control sediment alone. There are 8 more farms with conventional disk chisel in the sediment only model. More farms use no till without contouring in the model only constraining sediment. The solution on the cotton farms remains consistent between the phosphorous constrained model and the sediment only model.

Table 4.7 Number [a] of Farms by Practice Phosphorous Constrained Model

	Wheat			**Cotton**		
Abatement Level	40%[b]	60%	80%	40%	60%	80%
Contour	0	0	1	3	3	3
Contour No Till	24	54	82	0	0	10
No Till	52	39	1	42	42	0
Grassland	0	0	15	0	0	32
Conventional	28	11	5	0	0	0

[a] Counts are the number of farms which implemented a given practice across the entire farm
[b] Percentages are abatement levels relative to a conventional disk chisel tillage practice

The sediment only model abates 2,393 metric tons of sediment and 385 kilograms of phosphorous. The total cost in lost net revenue to the watershed at the 60 percent abatement level when only sediment is constrained is $7,432. The average cost of one metric ton of sediment abatement is $3.11.

Table 4.8 Number [a] of Farms by Practice Sediment Constrained Model

	Wheat			**Cotton**		
Abatement Level	40% [b]	60%	80%	40%	60%	80%
Contour	0	0	1	3	3	3
Contour No Till	11	33	89	0	0	38
No Till	57	52	1	42	42	2
Grassland	0	0	9	0	0	2
Conventional	36	19	4	0	0	0

[a] Counts are the number of farms which implemented a given practice across the entire farm
[b] Percentages are abatement levels relative to a conventional disk chisel tillage practice

A model where sediment is the constraining pollutant at the 80% abatement level differs from the model where phosphorous is the constraining pollutant at the 80% abatement level. There are 28 more farms with no till with contouring in the sediment only model. There are 30 less farms which required a conversion to grassland. No till is able to be used on 2 of the cotton farms in the sediment constrained model. On the wheat hectarage, there are 7 more farms with contour no till, 6 less farms converted to grassland, and 1 less farm in conventional disk chisel when sediment is the constraining pollutant. The sediment only model at an 80% constraint abates 3,190 metric tons of sediment and 546 kilograms of phosphorous per year. The total cost in lost net revenue to the watershed in this model is $31,468 with an average cost per metric ton of sediment abated of $9.86. The binary programming whole farm based model has solutions which are a close approximation of those found in the linear programming model. The extra costs associated with using a single tillage practice across a farm are low enough to justify using this model in watershed sediment and phosphorous control planning. The added benefit of more realistically modeling the choices producers are likely to face outweigh the slightly lower abatement levels.

Table 4.9 Net Revenue Binary Phosphorous Model						
	40%[c]		60%		80%	
	Wheat	Cotton	Wheat	Cotton	Wheat	Cotton
Contour	$0	$0	$0	$0	$487	$0
Contour No Till	$98,966	$0	$422,573	$0	$658,940	$12,171
No Till	$328,435	$116,133	$237,178	$116,133	$10	$0
Grassland	$0	$0	$0	$0	$1,026	$2,656
Conventional	$264,794	$0	$26,173	$0	$4,136	$0
Crop Revenue [a]	$692,195	$116,133	$685,605	$116,133	$664,599	$14,827
Total Revenue [b]	**$808,328**		**$801,328**		**$679,426**	
Cost Over LP [d]	**$88**		**$319**		**$4,344**	

[a] The crop revenue is the revenue on a single crop for the abatement level in the column above
[b] The Total revenue is the sum of the crop revenue across all crops and practices for the abatement level in the column above
[c] Percentages are abatement levels relative to a conventional disk chisel tillage practice

Table 4.10 Net Revenue Binary Sediment Model						
	40%[c]		60%		80%	
	Wheat	Cotton	Wheat	Cotton	Wheat	Cotton
Contour	$0	$0	$0	$0	$487	$0
Contour No Till	$15,528	$0	$158,686	$0	$673,851	$105,856
No Till	$340,463	$116,133	$423,179	$116,133	$10	$309
Grassland	$0	$0	$0	$0	$436	$60
Conventional	$338,087	$0	$107,412	$0	$365	$0
Crop Revenue [a]	$694,148	$116,133	$675,149	$116,133	$116,133	$106,225
Total Revenue [b]	**$810,221**		**$805,410**		**$781,374**	
Cost Over LP [d]	**$7**		**$87**		**$1,387**	

[a] The crop revenue is the revenue on a single crop for the abatement level in the column above
[b] The Total revenue is the sum of the crop revenue across all crops and practices for the abatement level in the column above
[c] Percentages are abatement levels relative to a conventional disk chisel tillage practice

CHAPTER V

CONCLUSION

EPIC provides a farmland simulation model that sufficiently approximates values for sediment loss, phosphorous loss, and crop yield. This allows the researcher to obtain data for watershed studies which is not readily observable. Reasonable differences are shown in the resulting sediment and phosphorous loss outputs for each of the management practices simulated. These show that it is possible to make economic decisions for water quality projects at the watershed level.

The improved tillage choices of no till, contouring, no till with contour, and conversion to native grassland all provided improvements on sediment and phosphorous loss total. Grassland was shown to be the best able to abate both pollutants on cotton and wheat production, although it was the most costly in terms of net farm income. This is a reasonable result as native grassland did not have fertilizer applied and provided a high USLE C factor for the entire year round. A combination of no till and contouring was the next best practice across both cotton and wheat production in terms of sediment and phosphorous abatement. This combination of practices was the second most costly relative to net farm income. The next highest abating practice was no till.

No till resulted in the lowest cost to farmers in terms of net revenue. The practice with the lowest abatement rates for both crops was contouring. Contouring was the second least costly practice in terms of net revenue.

The binary programming model provided a reasonable approximation of the linear programming solution. This method of modeling provides a feasible single management practice solution to conservation planning decision makers. Costs increase as required abatement increases, but even at 80% abatement are not drastically higher than the linear model.

When watershed net revenue is maximized, the most common practice is disk chisel tillage. This practice had the highest net revenue which can be attributed to yields that were slightly higher over the 50 year simulation. No Till farming had the lowest costs. Although the cost was low, the revenue provided by conventional disk chisel tillage contour farming was higher than no till and so this relatively low cost abatement does not occur in the profit maximizing unconstrained solution. Contour no till was represented more frequently than contour alone when contour was applied to farms that would have been no till at lower abatement targets. A limitation of this study was the equipment was assumed to be replaced as needed. Encouraging farmer to adopt an improved tillage practice before they are required to purchase new tillage and planting equipment is likely to require cost share payments to make the decision profit neutral. A limitation of the study was that EPIC provides a field point estimate of pollutant losses so practices such as filter strips which catch erosion after leaving the field and before entering the reservoir were unable to be evaluated.

Watershed planners should make the effort to identify land owners who control highly erosive and less productive hectarages of land, and encourage the conversion of this land into grassland. No till should be encouraged throughout the watershed when producers are looking to make machinery purchases. Contouring could serve to reduce erosion best on steeply sloped land, and could be implemented before the farm operator is looking to purchase new machinery.

One factor that could make an improvement on this model in further research is gathering data on farm operators. Knowledge of rental arrangements could give a better estimate on how land should be grouped in the binary programming model. Another inclusion to be considered by future researchers is early tillage equipment replacement and the cost shares required to facilitate the adoption of improved practices before machinery would normally be replace. Finally a biophysical model which is capable of routing and modeling the deposition of pollutants beyond the field would provide an opportunity to examine a broader range of management practices.

REFERENCES

Abernathy, J. R., J. W. Keeling, E. Segarra. 1991. "Tillage and Cropping System Effects on Cotton Yield and Profitability on the Texas Southern High Plains." *Journal of Production Agriculture.* 4:566-571.

Arnold, J. G., R. Srinivasan, R. S. Mittiah, J. R. Williams, 1998. "Large Area Hydraulic Modeling and Assessment: Part I-Model Development." *Journal of the American Water Resources Association.* 34:73-89.

Blair, W. F., T. H. Hubbell. 1938. "The Biotic Districts of Oklahoma." *The American Midland Naturalist.* 20(2):425-454

Busteed, P. R., S. J. Phillips, S. H. Stoodley, D. E. Storm. 2009. "Evaluating Nonpoint Source Critical Source Area Contributions at the Watershed Scale." *Journal of Environmental Quality.* 38:1654-1663.

Cabrera, M. L., D. M. Endale, D. E. Radcliffe, J. L. Steiner. 2001. Paper presented at the 2001 Georgia Water Resources Conference, Athens GA, 26-27 March.

Connor, J. D., G. M. Perry, R. M. Adams. 1995. "Cost-Effective Abatement of Multiple Production Externalities." *Water Resources Research.* 31(7):1789-1796.

County Records, Inc. 2016. Current Inventory of GIS and Ownership for Caddo Co., OK. accessed 7/22/2016.

Decker, J. E., F. M. Epplin, D. L. Morley, T. F. Peeper. 2009. "Economics of Five Wheat Production Systems with No-Till and Conventional Tillage." *Agronomy Journal.* 101(2):364-372.

Derpsch, R., T. Friedrich, A. Kassam, L. Hongwen. 2010. "Current Status of Adoption of No-Till Farming in the World and Some of Its Main Benefits." *International Journal of Agricultural and Biological Engineering.* 3(1):1-13.

Dickey, E.C., C. R. Fenster, J. M. Laflen, R. H. Mickelson. 1983. "Effects of Tillage on Soil Erosion in a Wheat-Fallow Rotation." *Transactions of the ASAE.* 26(3):814-820.

Edwards, D. R., V. W. Benson, J. R. Williams, T. C. Daniel, J. Lemunyon, R. G. Gilbert. 1994. "Use of the EPIC Model to Predict Runoff Transport of Surface-Applied Inorganic Fertilizer and Poultry Manure Constituents." *Transactions of the ASAE*. 37(2):403-409.

Endale, D. M., M. L. Cabrera, D. E. Radcliffe, J.L. Steiner. 2001. "Nitrogen and Phosphorus Losses from No-Till Cotton Fertilized with Poultry Litter in the Southern Piedmont." Paper presented at the Georgia Water Resources Conference, Athens GA, 26-27 March.

Fu, B., Y. Liu, Y. Lu, C. He, Y. Zeng, B. Wu. 2011. "Assessing the Soil Erosion Control Service of Ecosystems Change in the Loess Plateau of China." *Ecological Complexity.* 8(2011):284-293.

Garbrecht, J. D., P.J. Starks. 2009. "Watershed sediment yield reduction through soil conservation in a West-Central Oklahoma watershed." *Ecohydrology*. 2:313-320.

Gassman, P. W., J. R. Williams, X. Wang, A. Saleh, E. Osei. 2009. "The Agricultural Policy Environmental Extender (APEX) Model: An Emerging Tool for Landscape and Watershed Environmental Analyses." Technical Report, CARD,. Iowa State University, Ames.

Hajek, B. F., J. M. Soileau, J.T. Touchton, K. H. Yoo. 1994. "Sediment, nitrogen, and phosphorus runoff with conventional- and conservation-tillage cotton in a small watershed". *Journal of Soil and Water Conservation*, 49(1): 82-89.

Hargrove, W.L., D. Johnson, D. Snethen, and J. Middendorf. 2010. "From Dust Bowl to Mud Bowl: Sedimentation, conservation measures, and the future of reservoirs." *Journal of Soil and Water Conservation.* 65(1):14-17.

Ierodiaconou, D., L. Laurenson, M. Leblanc, F. Stagnitti, G. Duff, S. Salzman, V. Versace. 2005. "The Consequences of Land Use Change on Nutrient Exports: A Regional Scale Assessment in South-West Victoria, Australia." *Journal of Environmental Management.* 74:305-316.

Izaurralde, R. C., J.R. Williams, W. B. Mcgill, N. J. Rosenberg. 2001. "Simulating Soil Carbon Dynamics, Erosion and Tillage with EPIC." Paper presented at the First national Conference on Carbon Sequestration, Washington DC, 14-18 May.

King, K.W., C.W. Richardson, and J.R. Williams. 1996. "Simulation of Sediment and Nitrate Loss on a Vertisol with Conservation Tillage Practices." *Transactions of the. ASAE* 39(6): 2139-45.

McIsaac, G. F., M. C. Hirschi, J. K. Mitchell. 1990. "Nitrogen and Phosphorus in Eroded Sediment from Corn and Soybean Tillage Systems." *Journal of Environmental Quality*. 20(3):663-670.

Merritt, W. S., R. A. Letcher, A. J. Jakeman. 2003. "A Review of Erosion and Sediment Transport Models." *Environmental Modelling & Software.* 18:761-799.

Mimouni, M., S. Zekri, G. Flichman. 2000. "Modelling the Trade-Offs Between Farm Income and the Reduction of Erosion and Nitrate Pollution." *Annals of Operations Research*. 94:91-103.

Oklahoma Conservation Commission, Water Quality Division. 2009. Watershed Based Plan for the Fort Cobb Watershed, June Update. Oklahoma City, June.

Oklahoma Department of Environmental Quality. 2006. TMDL Development for Cobb Creek Watershed and Fort Cobb Lake, Final Report. Oklahoma City, June.

Phillips, D. L., P. D. Hardin, V. W. Benson, J. V. Baglio. 1993. "Nonpoint Source Pollution Impacts of Alternative Agricultural Management Practices in Illinois: A Simulation Study." *Journal of Soil and Water Conservation*. 48(5):449-457.

Putnam, J., J. Williams, D. Sawyer. 1988. "Using the Erosion-Productivity Impact Calculator (EPIC) to Estimate the Impact of Soil Erosion for the 1985 RCA Appraisal." *Journal of Soil and Water Conservation.* 43(4):321-326.

Sharpley, A. N., S. J. Smith, O. R. Jones, W. A. Berg, G. A. Coleman. 1992. "The Transport of Bioavailable Phosphorus in Agricultural Runoff." *Journal of Environmental Quality.* 21:30-35.

Smith, C. M., J. R. Williams, A. Nejadhashemi, S. A. Woznicki, J. C. Leatherman. 2014. "Cost-Effective Targeting for Reducing Soil Erosion in a Large Agricultural Watershed." *Journal of Agricultural and Applied Economics.* 46(4):509-526.

Soileau, J. M., J. T. Touchton, B. F. Hajek, K. H. Yoo. 1994. "Sediment, Nitrogen, and Phosphorus Runoff with Conventional- and Conservation-Tillage Cotton in a Small Watershed." *Journal of Soil and Water Conservation.* 49(1):82-89.

Stockle, C. O., J. R. Williams, N. J. Rosenberg, C. A. Jones. 1992. "A Method for Estimating the Direct and Climatic Effects of Rising Atmospheric Carbon Dioxide on Growth and Tield of Crops: Part I—Modification of the EPIC Model for Climate Change Analysis." *Agricultural Systems.* 38(3): 225-238.

U.S. Department of Agriculture, Natural Resource Conservation Service. 2015. *Web Soil Survey*. *http://websoilsurvey.nrcs.usda.gov/* accessed 3/01/2015.

U.S. Department of Agriculture, Natural Resource Conservation Service. 2014. *Geospatial Data Gateway*. *https://gdg.sc.egov.usda.gov/* accessed 11/15/2014.

U.S. Department of Agriculture. 1980. *CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems.* SEA-AR Conservation Research Report 26, Tucson Arizona, May.

U.S. Department of Agriculture. 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE).* USDA-ARS Agricultural Handbook 703, Washington DC, January.

U.S. Environmental Protection Agency, Department of Water. 1992. *Managing Nonpoint Source Pollution, Final Report to Congress on Section 319 of the Clean Water Act.* Washington DC, January.

Varner, B.T., F. M. Epplin, G. L. Strickland. 2011. "Economics of No-Till Versus Tilled Dryland Cotton Grain Sorghum, and Wheat." *Agronomy Journal*. 103(5):1329-1338.

Westra, J. V., K. W. Easter, E. D. Olson. 2002. "Targeting Nonpoint Source Pollution Control: Phosphorus in the Minnesota River Basin." *Journal of the American Water Resources Association.* 38(2):493-505.

Williams, J. R., C. A. Jones, P. T. Dyke. 1984. "A Modeling Approach to Determining the Relationship Between Erosion and Soil Productivity. *Transactions of the ASAE.* 27(1):129:144.

Williams, J. R., E. Wang, A. Meinardus, W. L. Harman, M. Siemers, J. D. Atwood. 2006. "EPIC USERS GUIDE v. 0509." BlackLand Research and Extension Center, USDA Agricultural Research Service, Temple, Texas 76502.

Wischmeier, W. H., D.D. Smith. "Predicting Rainfall Erosion Losses: A Guide to Conservation Planning", USDA Handbook 537, December, 1978.

Yang, W., M. Khanna, R. Farnsworth, H. Onal. 2003. "Integrating Economic, Environmental and GIS Modeling to Target Cost Effective Land Retirement in Multiple Watersheds." *Ecological Economics*. 46:249-267.

APPENDICES

Appendix 1: Soil File Setup

POND CREEK (34) (FSL)*

.09	*2.*							
4.	3.	60.	2.	.01	.01	.01	.04	.04
0.2	0.3	1.5	1.83					
1.43	1.43	1.47	1.77					
0.12	0.15	0.19	.17					
0.21	0.27	0.32	0.31					
66.	36.5	7	9					
20.	42.5	65	65					
0.	0	0	0					
6.2	6.6	7	7.3					
0.	0	0	0					
1.15	0.82	0	0					
0.	0	0	0					
0.	8.5	15	16.5					
0.	0	0	0					
0.	0	0	0					
0.	0	0	0					
0.	0	0	0					
0.	0	0	0					

28. 15.5 3 3

0. 0 0 0

10. 10 10 10

0. 0 0 0

0. 0 0 0

0. 0 0 0

0. 0 0 0

0. 0 0 0

0. 0 0 0

0. 0 0 0

Specific definitions for each number are provided in the epic manual. The italicized 2 in the first line denotes the hydrological soil group A, B, C, or D.

Appendix 2: Example of EPIC Control File

Definitions of the control parameters can be found in the epic manual. The first numbers in the file are the length of the simulation and the beginning year referencing the first year that weather data exists.

501965 1 1 22345 10 0 0 4 0 0 0 0 0 2 0 -1 0 0

0 0 0 0 0 0 0 0 0

2.00 330.00 0.0 .00 .0 5.00 .75 .00 2.00 1.00

.00 .00 .30 100.00 .00 0.00 800.00 00.00

0.9 0 200.0 1.00 .00 1.0 .00 .00 00.00 .00

.01 .00 3.00 1.58 .56 .56 .12

.00 .00 .00 .00 .00 .00

Appendix 3: Example EPIC Site File

OK Fort Cobb

.......x.......x.......x.......x.......x.......x.......x.......x.......x

DryCotton

35.33 -98.49   409.

100.0   53.00   x.xx   p.p

00   7   0 000 52   0   0

FC6514.dly

The slope in decimal percent form is entered in place of x.xx. The erosion control practice factor for the USLE is entered in the place of p.p. The weather file is specified in place of FC6514.dly.

Appendix 4: Example EPIC Model Yield Output

YLDG is the yield of the crop in metric tons. CPNM is the crop in this simulation, cotton in this case. A similar output in the .ACY (annual crop year) file for wheat is also used. Only years 1970 onward were used in the math programming models.

YR	RT#	CPNM	YLDG
1965	1	COTS	0.736
1966	2	COTS	1.066
1967	3	COTS	1.059
1968	4	COTS	0.952
1969	5	COTS	0.977
1970	6	COTS	0.432
1971	7	COTS	0.953
1972	8	COTS	0.464
1973	9	COTS	1.536
1974	10	COTS	0.823
1975	11	COTS	1.123
1976	12	COTS	0.577
1977	13	COTS	0.61
1978	14	COTS	0.367
1979	15	COTS	0.567
1980	16	COTS	0.283
1981	17	COTS	0.75
1982	18	COTS	0.511
1983	19	COTS	0.335
1984	20	COTS	0.431
1985	21	COTS	0.655
1986	22	COTS	0.94
1987	23	COTS	1.003
1988	24	COTS	0.449
1989	25	COTS	1.051
1990	26	COTS	0.559
1991	27	COTS	0.789
1992	28	COTS	1.029
1993	29	COTS	0.795
1994	30	COTS	0.537
1995	31	COTS	1.077

1996	32	COTS	1.055
1997	33	COTS	1.051
1998	34	COTS	0.321
1999	35	COTS	0.706
2000	36	COTS	0.544
2001	37	COTS	0.601
2002	38	COTS	0.635
2003	39	COTS	0.647
2004	40	COTS	0.899
2005	41	COTS	0.846
2006	42	COTS	0.541
2007	43	COTS	1.091
2008	44	COTS	0.789
2009	45	COTS	0.803
2010	46	COTS	0.982
2011	47	COTS	0.277
2012	48	COTS	0.588
2013	49	COTS	0.964
2014	50	COTS	0.634

Appendix 5: Example EPIC Sediment and Phosphorous Losses

These are selected data from the .ACM (Annual Crop Man) file the actual output contains more extensive data. MUSS is the sediment loss in metric tons per hectare. YP is the phosphorous loss in kilograms per hectare. The averages between 1970 and 2014 were the values used in the

YR	RT#	MUSS	YP
1965	1	1	0
1966	2	0.3	0
1967	3	0.4	0.1
1968	4	1.2	0.2
1969	5	1.3	0.1
1970	6	0.1	0
1971	7	0	0
1972	8	0.7	0.1
1973	9	2.2	0.3
1974	10	0.5	0.1
1975	11	2	0.3
1976	12	0	0
1977	13	0.9	0.3
1978	14	1.1	0.4
1979	15	0.6	0.2
1980	16	1.2	0.2
1981	17	0.3	0
1982	18	2.4	0.9
1983	19	0.9	0.4
1984	20	0.3	0.1

1985	21	2.7	1
1986	22	2.3	1.2
1987	23	1.7	0.6
1988	24	0.7	0.2
1989	25	3.7	1.6
1990	26	1.3	0.3
1991	27	3.2	1.5
1992	28	1.5	0.7
1993	29	2.3	0.5
1994	30	1.6	0.2
1995	31	5.4	2.3
1996	32	0	0
1997	33	1.2	0.5
1998	34	1	0.4
1999	35	2	0.6
2000	36	4.2	1.7
2001	37	0.9	0.4
2002	38	1.2	0.1
2003	39	0.9	0.2
2004	40	0.4	0.3
2005	41	0.3	0
2006	42	0	0
2007	43	5.5	2.3
2008	44	1.3	0.5
2009	45	1.3	0.4
2010	46	0.2	0
2011	47	1.7	0.5
2012	48	1.9	0.4
2013	49	1	0.2
2014	50	0.7	0.4

Appendix 6: GAMS LINEAR PROGRAMMING MODEL

Set A/ERAVG/;

Set B/PHOSAVG/

Set R /HectareConstraint_1wheat,HectareConstraint_3wheat,HectareConstraint_4wheat,HectareConstraint_5wheat,HectareConstraint_6wheat,HectareConstraint_8wheat,HectareConstraint_11wheat,HectareConstraint_12wheat,HectareConstraint_14wheat,HectareConstraint_15wheat,HectareConstraint_16wheat,HectareConstraint_17wheat,HectareConstraint_19wheat,HectareConstraint_21wheat,HectareConstraint_22wheat,HectareConstraint_23wheat,HectareConstraint_24wheat,HectareConstraint_27wheat,HectareConstraint_30wheat,HectareConstraint_31wheat,HectareConstraint_32wheat,HectareConstraint_33wheat,HectareConstraint_34wheat,HectareConstraint_35wheat,HectareConstraint_36wheat,HectareConstraint_38wheat,HectareConstraint_40wheat,HectareConstraint_41wheat,HectareConstraint_42wheat,HectareConstraint_44wheat,HectareConstraint_46wheat,H ectareConstraint_47wheat,HectareConstraint_50wheat,HectareConstraint_52wheat,HectareConstraint_53wheat,HectareConstraint_54wheat,HectareConstraint_56wheat,HectareConstraint_57wheat,HectareConstraint_58wheat,HectareConstraint_59wheat,HectareConstraint_61wheat,HectareConstraint_62wheat,HectareConstraint_63wheat,HectareConstraint_64wheat,HectareConstraint_65wheat,HectareConstraint_66wheat,HectareConstraint_68wheat,HectareConstraint_69wheat,HectareConstraint_70wheat,HectareConstraint_71wheat,HectareConstraint_72wheat,HectareConstraint_73wheat,HectareConstraint_74wheat,HectareConstraint_76wheat,HectareConstraint_77wheat,HectareConstraint_78wheat,HectareConstraint_80wheat,HectareConstraint_84wheat,HectareConstraint_85wheat,HectareConstraint_86wheat,HectareConstraint_88wheat,HectareConstraint_89wheat,HectareConstraint_90wheat,HectareConstraint_91wheat,HectareConstraint_92wheat,HectareConstraint_93wheat,HectareConstraint_94wheat,HectareConstraint_95wheat,HectareConstraint_96wheat,HectareConstraint_97wheat,HectareConstraint_99wheat,HectareConstraint_100wheat,HectareConstraint_102wheat,HectareConstraint_103wheat,HectareConstraint_104wheat,HectareConstraint_105wheat,HectareConstraint_106wheat,HectareConstraint_107wheat,HectareConstraint_109wheat,HectareConstraint_111wheat,HectareConstraint_113wheat,HectareConstraint_115wheat,HectareConstraint_116wheat,HectareConstraint_117wheat,HectareConstraint_118wheat,HectareConstraint_120wheat,HectareConstraint_121wheat,HectareConstraint_124wheat,HectareConstraint_125wheat,HectareConstraint_126wheat,HectareConstraint_127wheat,HectareConstraint_128wheat,HectareConstraint_129wheat,HectareConstraint_130wheat,HectareConstraint_132wheat,HectareConstraint_133wheat,HectareConstraint_135wheat,HectareConstraint_137wheat,HectareConstraint_138wheat,HectareConstraint_141wheat,HectareConstraint_142wheat,HectareConstraint_143wheat,HectareConstraint_145wheat,HectareConstraint_146wheat,HectareConstraint_12cotton , HectareConstraint_14cotton, HectareConstraint_17cotton , HectareConstraint_22cotton, HectareConstraint_23cotton , HectareConstraint_24cotton, HectareConstraint_32cotton , HectareConstraint_33cotton, HectareConstraint_34cotton , HectareConstraint_35cotton, HectareConstraint_41cotton , HectareConstraint_44cotton, HectareConstraint_46cotton , HectareConstraint_50cotton, HectareConstraint_53cotton , HectareConstraint_62cotton, HectareConstraint_63cotton , HectareConstraint_64cotton, HectareConstraint_68cotton , HectareConstraint_71cotton, HectareConstraint_72cotton , HectareConstraint_77cotton, HectareConstraint_85cotton , HectareConstraint_86cotton, HectareConstraint_88cotton , HectareConstraint_89cotton, HectareConstraint_91cotton , HectareConstraint_92cotton, HectareConstraint_93cotton , HectareConstraint_95cotton, HectareConstraint_103cotton , HectareConstraint_104cotton, HectareConstraint_107cotton , HectareConstraint_109cotton, HectareConstraint_116cotton , HectareConstraint_117cotton, HectareConstraint_118cotton , HectareConstraint_121cotton, HectareConstraint_129cotton , HectareConstraint_138cotton, HectareConstraint_141cotton , HectareConstraint_142cotton, HectareConstraint_143cotton , HectareConstraint_145cotton, HectareConstraint_146cotton / ;

Set C
/Contour_1wheat,Contour_3wheat,Contour_4wheat,Contour_5wheat,Contour_6wheat,Contour_8wheat,Contour_11wheat,Contour_12wheat,Contour_14wheat,Contour_15wheat,Contour_16wheat,Contour_17wheat,Contour_19wheat,Contour_21wheat,Contour_22wheat,Contour_23wheat,Contour_24wheat,Contour_27wheat,Contour_30wheat,Contour_31wheat,Contour_32wheat,Contour_33wheat,Contour_34wheat,Contour_35wheat,Contour_36wheat,Contour_38wheat,Contour_40w

heat,Contour_41wheat,Contour_42wheat,Contour_44wheat,Contour_46wheat,Contour_47wheat,
Contour_50wheat,Contour_52wheat,Contour_53wheat,Contour_54wheat,Contour_56wheat,Cont
our_57wheat,Contour_58wheat,Contour_59wheat,Contour_61wheat,Contour_62wheat,Contour_
63wheat,Contour_64wheat,Contour_65wheat,Contour_66wheat,Contour_68wheat,Contour_69w
heat,Contour_70wheat,Contour_71wheat,Contour_72wheat,Contour_73wheat,Contour_74wheat,
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5wheat,Contour_126wheat,Contour_127wheat,Contour_128wheat,Contour_129wheat,Contour_1
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_146wheat,ContourNOTill_1wheat,ContourNOTill_3wheat,ContourNOTill_4wheat,ContourNO
Till_5wheat,ContourNOTill_6wheat,ContourNOTill_8wheat,ContourNOTill_11wheat,ContourN
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397.42,ContourNOTill_69wheat 371.81,ContourNOTill_70wheat 342.7,ContourNOTill_71wheat
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302.36,ContourNOTill_85wheat 281.56,ContourNOTill_86wheat
283.42,ContourNOTill_88wheat 362.1,ContourNOTill_89wheat 346.5,ContourNOTill_90wheat
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376.97,ContourNOTill_97wheat 315.3,ContourNOTill_99wheat
233.28,ContourNOTill_100wheat 225.31,ContourNOTill_102wheat
375.04,ContourNOTill_103wheat 386.86,ContourNOTill_104wheat
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318.39,ContourNOTill_115wheat 77.55,ContourNOTill_116wheat
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385.71,ContourNOTill_124wheat 373.22,ContourNOTill_125wheat
356.77,ContourNOTill_126wheat 341.03,ContourNOTill_127wheat
237.73,ContourNOTill_128wheat 356.33,ContourNOTill_129wheat
416,ContourNOTill_130wheat 310.26,ContourNOTill_132wheat
254.75,ContourNOTill_133wheat 191.95,ContourNOTill_135wheat
402.94,ContourNOTill_137wheat 251.58,ContourNOTill_138wheat
294,ContourNOTill_141wheat 251.44,ContourNOTill_142wheat

313.29,ContourNOTill_143wheat 318.89,ContourNOTill_145wheat
237.57,ContourNOTill_146wheat 298.66,NoTill_1wheat 226.59,NoTill_3wheat
297.64,NoTill_4wheat 347.75,NoTill_5wheat 273.21,NoTill_6wheat 389.21,NoTill_8wheat
348.52,NoTill_11wheat 391.18,NoTill_12wheat 323.62,NoTill_14wheat 395.4,NoTill_15wheat
256.83,NoTill_16wheat 350.08,NoTill_17wheat 330.11,NoTill_19wheat 365,NoTill_21wheat
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255.05,NoTill_142wheat 316.87,NoTill_143wheat 322.28,NoTill_145wheat
241.14,NoTill_146wheat 302.3

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326.86,Baseline_63wheat 297.2,Baseline_64wheat 353.27,Baseline_65wheat
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287.75,Baseline_88wheat 369.83,Baseline_89wheat 354.29,Baseline_90wheat
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572.25,x_33cottonNo-Till 616.4,x_34cottonNo-Till 515.48,x_35cottonNo-Till
667.2,x_41cottonNo-Till 614.77,x_44cottonNo-Till 542.87,x_46cottonNo-Till
561.86,x_50cottonNo-Till 570.57,x_53cottonNo-Till 607.67,x_62cottonNo-Till
488.63,x_63cottonNo-Till 460.33,x_64cottonNo-Till 522.06,x_68cottonNo-Till
532.16,x_71cottonNo-Till 567.28,x_72cottonNo-Till 416.32,x_77cottonNo-Till
551.83,x_85cottonNo-Till 450.32,x_86cottonNo-Till 497.89,x_88cottonNo-Till
585.23,x_89cottonNo-Till 557.82,x_91cottonNo-Till 514.3,x_92cottonNo-Till
426.99,x_93cottonNo-Till 648.23,x_95cottonNo-Till 597.5,x_103cottonNo-Till
660.52,x_104cottonNo-Till 665.74,x_107cottonNo-Till 644.99,x_109cottonNo-Till
574.3,x_116cottonNo-Till 547.29,x_117cottonNo-Till 575.06,x_118cottonNo-Till
554.26,x_121cottonNo-Till 613.99,x_129cottonNo-Till 614.23,x_138cottonNo-Till
524.58,x_141cottonNo-Till 389.89,x_142cottonNo-Till 582.33,x_143cottonNo-Till
570.06,x_145cottonNo-Till 482.2,x_146cottonNo-Till 549.59,x_12cottonGrass
15.36,x_14cottonGrass 15.36,x_17cottonGrass 15.36,x_22cottonGrass 15.36,x_23cottonGrass
15.36,x_24cottonGrass 15.36,x_32cottonGrass 15.36,x_33cottonGrass 15.36,x_34cottonGrass
15.36,x_35cottonGrass 15.36,x_41cottonGrass 15.36,x_44cottonGrass 15.36,x_46cottonGrass
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15.36,x_107cottonGrass 15.36,x_109cottonGrass 15.36,x_116cottonGrass
15.36,x_117cottonGrass 15.36,x_118cottonGrass 15.36,x_121cottonGrass
15.36,x_129cottonGrass 15.36,x_138cottonGrass 15.36,x_141cottonGrass
15.36,x_142cottonGrass 15.36,x_143cottonGrass 15.36,x_145cottonGrass
15.36,x_146cottonGrass 15.36,x_12cottonBaseline 578.76,x_14cottonBaseline
535.23,x_17cottonBaseline 519.02,x_22cottonBaseline 460.35,x_23cottonBaseline
511.61,x_24cottonBaseline 456.1,x_32cottonBaseline 477.78,x_33cottonBaseline
546.79,x_34cottonBaseline 410.34,x_35cottonBaseline 593.65,x_41cottonBaseline
545.3,x_44cottonBaseline 450.64,x_46cottonBaseline 471.36,x_50cottonBaseline
514,x_53cottonBaseline 538.78,x_62cottonBaseline 390.45,x_63cottonBaseline
365.51,x_64cottonBaseline 424.38,x_68cottonBaseline 442.63,x_71cottonBaseline
474.68,x_72cottonBaseline 324.57,x_77cottonBaseline 460.61,x_85cottonBaseline
351.18,x_86cottonBaseline 407.13,x_88cottonBaseline 499.09,x_89cottonBaseline
472.81,x_91cottonBaseline 406.46,x_92cottonBaseline 396.55,x_93cottonBaseline
577.54,x_95cottonBaseline 578.35,x_103cottonBaseline 587.64,x_104cottonBaseline
591.81,x_107cottonBaseline 573.29,x_109cottonBaseline 492,x_116cottonBaseline
455.13,x_117cottonBaseline 479.63,x_118cottonBaseline 524.96,x_121cottonBaseline
543.94,x_129cottonBaseline 544.8,x_138cottonBaseline 423.09,x_141cottonBaseline
293.77,x_142cottonBaseline 509.6,x_143cottonBaseline 490.85,x_145cottonBaseline
383.14,x_146cottonBaseline 447.84/;

Variables Returns;
Positive Variables Hectares(C);

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Equations ReturnsRW,constraints(R), Eros, Phos;
ReturnsRW.. Returns=E=sum(c, Hectares(c)*OBJ(c));
constraints(r).. sum(c,ones(R,C)*Hectares(c))  =e=RHS(R);
Eros.. sum(c,abate("ERAVG",C)*Hectares(c))=G=0;
Phos..sum(c,phosphorous("PHOSAVG",C)*Hectares(c))=G=0;
model Landowners /all/;
option LP=Cplex;
Solve Landowners using LP maximize Returns;
```

Appendix 7 GAMS Binary Programming Model

```
Set A/ERAVG/;
Set B/PHOSAVG/;
Set
R/HectareConstraint_1wheat,HectareConstraint_3wheat,HectareConstraint_4wheat,HectareConst
raint_5wheat,HectareConstraint_6wheat,HectareConstraint_8wheat,HectareConstraint_11wheat,
HectareConstraint_12wheat,HectareConstraint_14wheat,HectareConstraint_15wheat,HectareCon
straint_16wheat,HectareConstraint_17wheat,HectareConstraint_19wheat,HectareConstraint_21w
heat,HectareConstraint_22wheat,HectareConstraint_23wheat,HectareConstraint_24wheat,Hectare
Constraint_27wheat,HectareConstraint_30wheat,HectareConstraint_31wheat,HectareConstraint_
32wheat,HectareConstraint_33wheat,HectareConstraint_34wheat,HectareConstraint_35wheat,He
ctareConstraint_36wheat,HectareConstraint_38wheat,HectareConstraint_40wheat,HectareConstr
aint_41wheat,HectareConstraint_42wheat,HectareConstraint_44wheat,HectareConstraint_46whe
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heat,HectareConstraint_116wheat,HectareConstraint_117wheat,HectareConstraint_118wheat,Hec
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28wheat,HectareConstraint_129wheat,HectareConstraint_130wheat,HectareConstraint_132wheat
,HectareConstraint_133wheat,HectareConstraint_135wheat,HectareConstraint_137wheat,Hectare
Constraint_138wheat,HectareConstraint_141wheat,HectareConstraint_142wheat,HectareConstrai
nt_143wheat,HectareConstraint_145wheat,HectareConstraint_146wheat,HectareConstraint_12cot
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HectareConstraint_32cotton 1, HectareConstraint_33cotton 1, HectareConstraint_34cotton 1, HectareConstraint_35cotton 1, HectareConstraint_41cotton 1, HectareConstraint_44cotton 1, HectareConstraint_46cotton 1, HectareConstraint_50cotton 1, HectareConstraint_53cotton 1, HectareConstraint_62cotton 1, HectareConstraint_63cotton 1, HectareConstraint_64cotton 1, HectareConstraint_68cotton 1, HectareConstraint_71cotton 1, HectareConstraint_72cotton 1, HectareConstraint_77cotton 1, HectareConstraint_85cotton 1, HectareConstraint_86cotton 1, HectareConstraint_88cotton 1, HectareConstraint_89cotton 1, HectareConstraint_91cotton 1, HectareConstraint_92cotton 1, HectareConstraint_93cotton 1, HectareConstraint_95cotton 1, HectareConstraint_103cotton 1, HectareConstraint_104cotton 1, HectareConstraint_107cotton 1, HectareConstraint_109cotton 1, HectareConstraint_116cotton 1, HectareConstraint_117cotton 1, HectareConstraint_118cotton 1, HectareConstraint_121cotton 1, HectareConstraint_129cotton 1, HectareConstraint_138cotton 1, HectareConstraint_141cotton 1, HectareConstraint_142cotton 1, HectareConstraint_143cotton 1, HectareConstraint_145cotton 1, HectareConstraint_146cotton 1/;

Parameter OBJ(C)/Contour_1wheat 394.614,Contour_3wheat 3785.892,Contour_4wheat 7845.252,Contour_5wheat 1426.896,Contour_6wheat 3135.672,Contour_8wheat 3929.922,Contour_11wheat 194.555,Contour_12wheat 6048.945,Contour_14wheat 9042.752,Contour_15wheat 324.779,Contour_16wheat 24891.74,Contour_17wheat 13629.232,Contour_19wheat 22663.814,Contour_21wheat 7896.636,Contour_22wheat 11472.945,Contour_23wheat 1180.584,Contour_24wheat 12130.104,Contour_27wheat 2500.8,Contour_30wheat 965.44,Contour_31wheat 755.766,Contour_32wheat 28831.328,Contour_33wheat 35.045,Contour_34wheat 1228.975,Contour_35wheat 23425.6,Contour_36wheat 7568.16,Contour_38wheat 13712.46,Contour_40wheat 1880.85,Contour_41wheat 2434.761,Contour_42wheat 82.371,Contour_44wheat 2969.379,Contour_46wheat 1036.02,Contour_47wheat 3143.778,Contour_50wheat 26078.52,Contour_52wheat 19711.406,Contour_53wheat 28836.615,Contour_54wheat 17552.6,Contour_56wheat 30339.82,Contour_57wheat 4746.371,Contour_58wheat 5324.752,Contour_59wheat 8430.19,Contour_61wheat 4261.57,Contour_62wheat 7456,Contour_63wheat 610.659,Contour_64wheat 13232.098,Contour_65wheat 15460.956,Contour_66wheat 12839.148,Contour_68wheat 12581.415,Contour_69wheat 0,Contour_70wheat 6704.698,Contour_71wheat 4615.353,Contour_72wheat 5986.44,Contour_73wheat 64.576,Contour_74wheat 939.224,Contour_76wheat 811.976,Contour_77wheat 14651.292,Contour_78wheat 10122.84,Contour_80wheat 50.784,Contour_84wheat 2285.852,Contour_85wheat 6596.895,Contour_86wheat 1543.3,Contour_88wheat 1523.802,Contour_89wheat 18922.945,Contour_90wheat 4262.699,Contour_91wheat 1432.176,Contour_92wheat 7291.452,Contour_93wheat 5027.558,Contour_94wheat 1708.031,Contour_95wheat 7961.074,Contour_96wheat 8853.858,Contour_97wheat 9078.45,Contour_99wheat 45.888,Contour_100wheat 377.519,Contour_102wheat 942.15,Contour_103wheat 3075.233,Contour_104wheat 13780.267,Contour_105wheat 6616.06,Contour_106wheat 1422.18,Contour_107wheat 12247.038,Contour_109wheat 3940.52,Contour_111wheat 9144.28,Contour_113wheat 2081.904,Contour_115wheat 27.248,Contour_116wheat 1964.235,Contour_117wheat 461.928,Contour_118wheat 976.347,Contour_120wheat 3356.98,Contour_121wheat

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7838.64,ContourNOTill_5wheat 1454.166,ContourNOTill_6wheat
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22573.002,ContourNOTill_21wheat 7866.828,ContourNOTill_22wheat
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2293.2,x_143cottonBaseline 981.7,x_145cottonBaseline 153.256,x_146cottonBaseline 268.704/;

Variables Returns;
Binary Variables Hectares(C);
Equations ReturnsRW,constraints(R), Eros, Phos;
ReturnsRW.. Returns=E=sum(c, Hectares(c)*OBJ(c));
constraints(r).. sum(c,ones(R,C)*Hectares(c))  =E=RHS(R);
Eros.. sum(c,abate("ERAVG",C)*Hectares(c))=G=2393;
Phos..sum(c,phosphorous("PHOSAVG",C)*Hectares(c))=G=466;
model Landowners /all/;
Option MIP=CPLEX;
Solve Landowners using MIP maximize Returns;
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VITA

Mason Lee Halcomb

Candidate for the Degree of

Master of Science

Thesis: PROFIT MAXIMIZING SELECTION OF MANAGEMENT PRACTICES FOR WILLOW CREEK TO MEET SEDIMENT AND PHOSPHOROUS ABATEMENT TARGETS

Major Field: Agricultural Economics

Biographical:

Education:

Completed the requirements for the Master of Science in Agricultural Economics at Oklahoma State University, Stillwater, Oklahoma in December, 2016.

Completed the requirements for the Bachelor of Science in Economics at Oklahoma State University, Stillwater, Oklahoma in May 2013.