Changes in the Spatial Allocation of Cropland in the Ft. Cobb Watershed as a Result of Environmental Restrictions.

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Abstract:

Pollution runoff estimates from SWAT are used in a mathematical programming model to optimally model site-specific crop and conservation practices for pollution abatement in the Ft. Cobb watershed in Southwestern Oklahoma. Results indicate the tradeoffs between producer income, sediment and nutrient runoff and the spatial allocation of crops in the watershed.

Keywords: Water Pollution, SWAT, Conservation Reserve Program, Spatial Land Use

JEL Codes: Q250 - Renewable Resources and Conservation: Water, Q180 - Agricultural Policy; Food Policy

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Persistent concerns about agriculture's continued contribution to the reduced water quality in rural watersheds, even after several decades of federal and state programs to improve water quality, have led to a search for more effective strategies to achieve desired water quality goals. Past programs such as the Conservation Reserve Program have relied on voluntary efforts on the part of farmers to enroll eligible highly-erodible lands into the program. Advances in spatial modeling have allowed for greater modeling capabilities at the watershed and landscape level that model site-specific information about the relationships between agricultural practice and soil, slope, and rainfall, among others. This paper uses pollution runoff estimates from the Soil and Water Assessment Tool (SWAT) in a mathematical programming model to optimally model site-specific crop and conservation practices for pollution abatement at the watershed level in the Ft. Cobb Basin in Southwestern Oklahoma. By varying the percentage of desired decreases in sediment, nitrogen, and phosphorus levels in the watershed optimally, we demonstrate the lost producer income from changing crop practices or acceptance of conservation payments, the changing spatial allocation of crops on a watershed, and the tradeoffs between targeting different nutrients, including nitrogen, sediment, and phosphorus.

Several studies have dealt with optimal pollution abatement at the watershed level. Ribaudo (1989) examines the cost effectiveness of targeting programs for water quality benefits for the CRP and the resulting geographic pattern. Westra and Olson (2001) used mathematical programming to determine the most efficient way to reduce phosphorus loading in the Minnesota River by 40 percent. They found that targeting specific areas, rather than uniformly requiring reductions resulted in less income loss to producers. Ancev (2003) used the inputs and outputs from the SWAT model for the Eucha-Spavinaw reservoir in northeastern Oklahoma to construct

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a watershed linear program model to optimally model phosphorus abatement from chicken litter application. Khanna et al (2003) evaluate the cost-effectiveness of the Conservation Reserve Enhancement land retirement program in the Illinois River using the Agricultural Non-Point Source Pollution (AGNPS) hydrologic model and mathematical programming to optimally target sites for runoff reduction. Their model improves on past models since it assumes they target runoff by modeling flows through sets of parcels.

The 309 square mile Ft. Cobb watershed in southwest Oklahoma was selected as a representative watershed in the Southern Plains. The Fort Cobb Watershed contains 156 square miles of cropland, 128 square miles of pasture, 18 square miles of forest, and 7 square miles of water. The Fort Cobb Lake located at the southeast end of the watershed is listed as threatened due to excess nutrients entering the lake. The lake's water clarity has been listed as impaired by sediment inflows from agricultural production.

Thus, this study focuses on minimizing the producer's lost revenue or opportunity cost from changing land use on the 156 square miles of cropland to obtain water quality objectives. Other land uses such as forestry, approximately 153 square miles are constrained to their current use. For cropland switching between crops the conversion cost is assumed to be small. However, the cost of switching between major land use types such as pasture, forest, cropland or water switching is prohibitive, so these changes are not considered.

To determine the optimal spatial allocation of crops and cropping practices in the watershed, the impacts of the policy changes must be examined at both the farm and the watershed level. At the farm level, the optimal solutions for a reducing runoff from the current cropping pattern may lead to a reduction in farm income for some farmers as they shift to less intensive cropland use. Other producers, in areas with less of an impact on the environment may experience an increase in farm income as they shift to more intensive cropland use. As in other watersheds, the highest value crop often produces the greatest runoff levels.

The Soil and Water Analysis Tool (SWAT) is used to determine the level of sediment, nitrogen and phosphorus load on the watershed resulting from each combination of crop and cropping practice for each land unit in the watershed. A Linear Programming model is employed to measure the trade-off between farm income and levels of the three pollutants. A base model is set to mimic the current spatial allocation of crops and cropping practices. Various levels of constraints on pollutants are compared to the base to indicate the changes required to achieve the maximum level of income given the set of constraints. The LP solution yields the optimal spatial allocation by selecting the land units that provide the maximum attainable level of farm income subject to the global sediment and nutrient constraints.

Reducing the sediment and nutrient runoff from the agricultural lands in the watershed will improve water quality. The improved water quality will thus result from changes in land use. The difference between the base level of income and the income received to achieve the water quality benefits may be viewed as the minimum incentive required to achieve the desired level of sediment and nutrient runoff reduction.

Data:

Combined price, yield, and runoff data was fed into a linear programming model to select the spatial allocation of the watershed that maximized producers profits subject to limits on the amount of total sediment, nitrogen and phosphorus runoff. The use of geo-referenced data in the SWAT watershed runoff model enables an examination of the data relating to individual land units in the watershed to determine the optimal allocation of cropland in the watershed to maximize producers profits while decreasing the environmental damages. The SWAT model generates the twenty-year average crop yields and sediment, nitrogen, and phosphorus runoff for each land unit and crop practice. The combination of SWAT GIS information with a linear programming model provides a way to compare how cropping patterns affect profits and the environment over a longer and more realistic time frame.

To develop the opportunity cost of switching from one crop activity to another requires the development of enterprise budgets for each of the dominant crops in the watershed. The Machsel program, Oklahoma State University's enterprise budget software, developed by Kletke and Sestak was used to calculate the annual depreciation, insurance, interest, taxes, fuel, lubrication, labor and repair costs per acre for the average peanut, sorghum, no till wheat, conventional till wheat, and CRP acre in the watershed.

The SWAT model was used to generate the expected crop yield and associated sediment, nitrogen, and phosphorus runoff for each crop in each land unit in the watershed.[3] SWAT was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large watersheds with many different soil types and over long periods of time. Land units or Hydrologic Response units (HRUs) , homogenous areas of land cover, soil type, and slope within a Sub basin, are first established by SWAT. In this study, there were 154 user defined sub-basins.. Crop growth is simulated using weather data, nutrient availability from recommended soil test phosphorus and fertilization practices for the area, and soils data. By combining this data in a GIS system, SWAT estimates the crop yield, sediment,

[3] SWAT is a distributed parameter basin scale model developed by the USDA Agricultural Research Service at the Grassland, Soil, and Water Research Laboratory in Temple, Texas. SWAT is included in the Environmental Protection Agency's latest release of Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) (Storm, White, and Stoodley) . The objective of the model is to "predict the effect of management decisions on water, sediment, nutrient, and pesticide yields with reasonable accuracy on large, ungauged river basins" (Grassland, Soil, and Water Research Laboratory [GSWRL]).

nitrogen, and phosphorus yield. The yield and runoff estimates for each crop are provided based on the same climate and production techniques so each of these cropping practices are directly comparable. A linear programming model was developed using the General Algebraic Modeling System (GAMS) that used the information generated by SWAT and the Enterprise Budgets for each HRU to maximize producer profits under different policy and pollution constraints.

Enterprise Budget Data

The timing, number, and type of machinery operations required for each type of crop production gathered from these sources is shown in table 1[4].

Table 1 Specified Monthly Field Operations for Peanut(P), Sorghum(S), CRP(G), Conventional till Wheat(W), and No-Till Wheat(N). (Superscript indicates number of times per month.)

Month ->	1	2	3	4	5	6	7	8	9	10	11	12
Machinery												
Offset Disc				P				W				
Chisel			$G^{.5}$									
Springtooth					S							
M.B. Plow			P			W						
Tandem Disk				S	P				W			
Planter					P,S							
Drill				G					W			
No-Till Drill									N			
Cultivator					P^{2}	P^{3},S	P					
Sprayer				G,W,N	P,S	P,N	P	N				
Dry Fert. Spdr.				P,S				W,N	W,N			
Baler										$P^{.75}$		

This Machinery data was used in Machsel to calculate the fixed and variable costs of the specified machinery operations. For Machsel calculation each farm was assumed to have 350 cropped acres and to have one 130 PTO horsepower and one 105 PTO horsepower tractor

4 For this study crop production data was gathered from industry professionals and reference data. Information relating on all areas of crop production was gathered from pre planting tillage through crop harvest. Peanut planting data was gathered from David Nowlin, Caddo County Agricultural Extension Agent; Sorghum data from Mark Gregory, Southwest Oklahoma Agricultural Specialist; CRP planting data was obtained from Oklahoma Conservation Practice Job Sheet for Range Planting; Wheat data was obtained from Dr. Thomas Peeper, Professor in the Plant and Soil Science Department specializing in small grain weed control.

available. Also held constant was the interest rate/opportunity cost of the average capital invested of 6.5 percent. The tax rate for machinery was assumed to be one percent of the purchase price per year. The cost of insurance was assumed to be six tenths of one percent per year of the average capital investment. Depreciation was calculated from the purchase price minus the salvage value then divided by the number of years the machine will be owned. Fuel cost was calculated assuming a one dollar per gallon price using a technical coefficient (Fuel Cost Multiplier) according to the PTO horsepower of the tractor used. Lubrication cost was calculated as fifteen percent of the fuel cost. The software as using technical repair cost coefficients established by machinery research calculated repair cost.

Machinery costs were combined with other price and cost data in the budgets to calculate the average cost per acre for peanut, sorghum, no till wheat, conventional till wheat, and CRP production in Caddo county Oklahoma. Wheat and sorghum prices were calculated from a five-year average of the Oklahoma marketing year average price, which was obtained from Oklahoma Agricultural Statistics Service. Sorghum price was calculated as $1.85 per bushel from the marketing year average price received for Oklahoma published in the November 1999-2003 issues of Agricultural Prices (USDA Nov. 1999-2003). Wheat price was calculated as $2.67 per bushel from marketing year average prices for Oklahoma and were taken from August 1999-2003 issues of Agricultural Prices. (USDA Aug. 1999-2003). The peanut program changed significantly with the enactment of the Food Security and Rural Investment Act of 2002(FSRIA). Prior to enactment of FSRIA, peanuts were produced under a quota system to support farm incomes. Under the new law, peanut producers' incomes are supported with the same type program as other major grain commodities. In 2002, after FSRIA took effect, the Oklahoma Marketing year average price was 17 cents per pound and this priced was used (USDA Aug

2003) The average CRP rental rate of $40 per acre in Caddo County was used based on data from the 26th CRP signup. (Agapoff, et al.)

The five-year average price for wheat, sorghum and peanuts were all below their loan deficiency payment (LDP) price. Wheat qualified for an eight-cent per bushel LDP so that the actual price received by producers was $2.75 per bushel. Sorghum had a ten-cent LDP for an actual producer price of $1.95 per bushel. Peanuts also had a small LDP payment that set the receive price of peanuts at $355 dollars per ton. The average CRP rental rate of $40 dollars per acre was maintained.

Pesticide type and application rates received from Nowlin, Gregory, and Peepers were checked with the 2003 OSU Extension Agents' Handbook of Insect, Plant Disease, and Weed control. These application rates were combined with price information from the Enterprise Budgets (this was obtained from April 2003 Agricultural Prices and Estes Incorporated in Oklahoma City. (Sahs) Fertilizer application rates were taken as given and compared to the calculations given in the software from recommended levels for the crop yield. Price data for fertilizer was obtained from April, 2003 Agricultural Prices for the southwest area published by the USDA.

The average revenue, variable and fixed costs, and returns for crop production in the Fort Cobb Watershed are shown in table 1. The maximum, mean, minimum, and standard deviation of per acre returns for crop production in the Fort Cobb watershed are shown in Table 2.

Table 2. Average Revenue, Variable and Fixed Costs, and Average Returns for Crop Production in Caddo County.

Crop	Peanuts	C Wheat	N T Wheat	Sorghum	CRP
Average Revenue	$553.19	$142.63	$145.64	$62.95	$43.01
Variable Cost	$437.19	$70.94	$93.14	$95.19	$7.22
Fixed Cost	$71.06	$22.75	$25.89	$33.94	$3.18
Total Cost	$508.25	$93.69	$119.03	$129.13	$10.40

Average Return	$44.94	$48.94	$26.61	-$66.18	$32.61

Table 3. Per Acre Returns for Crop Production in the Fort Cobb Watershed

Crop	Peanuts	C Wheat	N T Wheat	Sorghum	CRP
Maximum	$62.59	$43.59	$32.15	-$4.26	$32.61
Mean	$44.94	$23.60	$16.51	-$30.74	$32.61
Minimum	$5.16	-$31.64	-$37.91	-$55.36	$32.61
Standard Deviation	$11.21	$10.97	$10.70	$14.90	$0.00

SWAT Data.

A large amount of data is required for climate, soils, land use, and slope for each geographic location. GIS data used in the SWAT model included USGS digital elevation models, NRCS Soils, land use information, stream data, Tabular weather data, crop types in current use, and center pivot irrigations (See Table 4). The 30 m-land use data layer from Applied Analysis Inc. is a digital land cover data layer using Jun 10, 2001, 30 m resolution Landsat Thematic Mapper imagery for the Fort Cobb Basin. (Stoodley).

Table 4. Data Sources for SWAT Model Input.

Data Name	Data Class	Data Type	Data Source
10 m DEM	GIS	Elevation	U.S. Geological Survey
MIADS	GIS	Soils	Oklahoma Natural Resource Conservation Commission
Landsat imagery	Image	Multi-spectral	Satellite Imaging
Ground Truth	Tabular		Oklahoma Conservation Commission Personnel
STATSGO database	Tabular	Soils	Soil and Water Assessment Tool
NEXRAD precipitation	Tabular	Weather	Arkansas-Red Basin Forecast Center
NOAA Cooperative Observer Network	Tabular	Weather	National Oceanic and Atmospheric Administration
Soil Test Phosphorus	Tabular	Soil test Phosphorus	Oklahoma State University Soil, Water & forage Analytical Laboratory
Management operations	Tabular	Management	Cooperative Extension Publications
Stream gage	Tabular	Stream flow	US Geological Survey

Source: Storm

Also used were tabular weather data from the National Oceanic and Atmospheric Administration Cooperative Observation Network and USGS stream gage data showing the volume of water moving down a stream taken by measuring the area and velocity of the water.(USGS)   Land cover data from AAI were combined with crop type breakdown from the 1999-2001 Oklahoma Agricultural Statistics Service (OASS) Data. Center pivot irrigation locations were tagged from aerial photography. Using this information on land cover, the land was separated into categories for types of cropland, water, forests, grassland, roads, and urban. Because land cover specific data was not available for soil test phosphorus and fertilization practices, this data was derived from averages and recommended levels for the area. The phosphorus levels came from OSU county level averages for 1995-1999. The fertilization and management practices are based on OSU recommended levels and knowledge of local OSU extension and Conservation District personnel (Storm, White, and Stoodley).

Model

The linear programming model is used determine the optimal spatial allocation of each crop within the watershed. By analyzing the data at the HRU level we are able to determine the total number of acres of each crop and the location of these acres within the watershed.

The following model was used to maximize producer profits subject to constraints on the total runoff of sediment, nitrogen, and phosphorus.

I $$Maximize\sum_{i=1}^{5}\sum_{j=1}^{848}\left(\left(\left(P_i * Y_{ij}\right)+F_i+G_{ji}\right)-C_i\right)X_{ij}$$

Subject to:

i) $$\sum_{i=1}^{I}\sum_{j=1}^{J} Ph_{ji} * X_{ij} \leq Plimit$$

ii) $$\sum_{i=1}^{I}\sum_{j=1}^{J} NIT_{ji} * X_{ij} \leq Nlimit$$

iii) $$\sum_{i=1}^{I}\sum_{j=1}^{J} SED_{ji} * X_{ij} \leq Slimit$$

iv) $$\sum_{i=1}^{I} X_{ij} = Acres_j$$

v) $$X_{ij} \geq 0$$

Where P_i is the price of crop *i*, Y_{ij} is the per acre yield of crop *i* on HRU *j* from the SWAT model, and F_i is the dollar value per acre of the forage produced by crop *i*. G_{ji} represents the Direct and Counter Cyclical government payment per acre forfeited by the producer if that HRU is enrolled into CRP. The total cost per acre calculated in the budgeting process to produce crop *i* is C_i. The runoff of phosphorus, nitrogen, and sediment per acre from HRU *j* with crop production I from the SWAT model analysis is represented by Ph_{ji}, NIT_{ji}, and SED_{ji} respectively. $Plimit$, $Nlimit$, and $Slimit$ represent the total amount of phosphorus, nitrogen, and sediment runoff allowed in the watershed for the abatement goal being studied. For this analysis look at a spatial redistribution at current runoff levels, a ten percent runoff abatement level and a twenty percent runoff abatement level. Phosphorus and Nitrogen runoff is calculated in pounds per acre while sediment is calculated in tons per acre. $Acres_j$ is a vector of the number of crop acres in HRU j X_{ij} is the variable in the system of equations representing the number of acres of crop i in HRU j.

Results and Discussion

A linear programming (LP) solution to represent the current crop allocation, runoff levels and profit in the watershed is used as the base scenario for comparison throughout this study. This allocation of land that is used for the spatial analysis is the result from a profit maximizing LP scenario where crop acres are constrained to 79,800 acres of conventional till wheat, 14204 acres of peanuts, and 5583 acres of sorghum. Total producer profit including the direct and counter cyclical payment allocation is constrained to $7,035,706, and runoff is constrained to 204,880 tons of sediment, 652,830 pounds of nitrogen runoff, and 180,370 pounds of phosphorus runoff. This model scenario will be referred to as the “base scenario”.

Analysis includes additional scenarios where the base scenario is modified to test the results of changing the total amount of runoff allowed in the watershed. To aid in the understanding a numeric system is developed so that these scenarios can be discussed and referenced more easily. In each of the references to the runoff abatement levels, the abatement levels will be listed in the order of sediment, nitrogen, and phosphorus (SNP). As an example; twenty percent sediment, ten percent nitrogen, and ten percent phosphorus abatement would be represented in this system as 20/10/10.

Table 5. Profit, Total Crop Acres, Runoff, Abatement Level, and Percent of Erosion Compared to Base Levels for Each Scenario.

(Model runs are described in Table 13.)

Scenario	Base	Profit Max	L/10/10/10	L/20/20/20
Profit including DCP	$7,035,706	$7,807,361	$7,630,914	$7,439,376
Government Expense	$5,026,696	$5,181,754	$5,205,007	$5,227,728
Acres				
Con Wheat	79800	58648	61060	62961
Peanut	14204	21548	16774	12120
Sorghum	5583			
NT Wheat	0	6332	6696	7488
CRP	0	13059	15057	17019
Runoff				
Sediment (tons)	204,880	171,773	155,329	138,178
Nitrogen (lbs)	652,830	583,990	532,307	481,463
Phosphorus (lbs)	180,370	180,370	162,333	144,296
Restriction				
Sediment		0%	10%	20%
Nitrogen		0%	10%	20%
Phosphorus		0%	10%	20%
Actual Runoff				
Sediment % of Base	100.0%	83.8%	75.8%	67.4%
Nitrogen % of Base	100.0%	89.5%	81.5%	73.8%
Phosphorus % of base	100.0%	100.0%	90.0%	80.0%

This study focuses on scenarios 0/0/0, 10/10/10, and 20/20/20. In these scenarios the constraints of interest are the SNP constraints. The other constraint that is placed on the model is a policy constraint on CRP that limits CRP acreage to 25% of the cropland in the area. Crop acres not constrained to meet individual acreage goals just that each acre of cropland in the watershed is put to some use.

In scenario 0/0/0 constraints are placed on SNP runoff levels to be less than or equal to their respective base levels. This determines the greatest producer profit that can be expected based on the crop budgets and yield data used in this study. In this scenario crop acres are allowed to vary to maximize profit.

Comparing the base and 0/0/0 scenarios indicates that the watershed is not currently spatially allocated to maximize farm incomes or minimize sediment and nutrient runoff. The total farm income estimated from the base scenario is $7,035,706 and is roughly $800 thousand dollars less than the 0/0/0 scenario solution selected by the model when only the number of acres allowed to enroll in CRP was constrained (but not binding) and the runoff levels were constrained to be less than or equal to the base amounts. In the 0/0/0 scenario the number of acres of conventional tillage wheat decreased by 21,152 acres, peanut production increased by 7,344 acres, sorghum production decreased to zero acres, no till wheat increased by 6,332 acres and CRP increased by 13,059 acres from the current levels. In scenario 0/0/0 the number of crop acres was unconstrained with sediment, nitrogen, and phosphorus runoff levels restricted to less than or equal to the base levels. Interestingly, we find from this scenario that even though the profit increased by 11 percent, the sediment runoff decreased by 16.2 percent, nitrogen runoff decreased by 11.5 percent, and phosphorus runoff remained at the base level. Thus, rearranging the spatial allocation of crops and cropping activities to maximize profit and at least maintain current level of runoff both increases total farm income and reduces the runoff of sediment and nitrogen.

The objective of scenario 10/10/10 was to maximize profit subject to a constraint on CRP acres, and reduce sediment, nitrogen, and phosphorus runoff by 10 percent from the base level. Scenario 10/10/10 has a total farm income of $7.6 million and is directly comparable to scenarios 0/0/0 and 20/20/20. Comparing the 10/10/10 and 0/0/0 scenario, profit decreased by $176,447 with a 9.6 percent decrease in sediment runoff, 8.9 percent decrease in nitrogen runoff, and a 10 percent decrease in phosphorus runoff.

Compared to the base scenario, the 0/0/0 scenario reduced SNP runoff by 24.2 percent, 18.5 percent, and 10 percent respectively from the base but still led to an increase of roughly $600 thousand. To reach the goals placed on runoff levels, land shifted from peanut production into conventional and no till wheat production and CRP acreage.

The 20/20/20 scenario reduces runoff levels to at least 80 percent of the base level. Compared to the 0/0/0 scenario, the 20/20/20 scenario decreased total farm income by $367,985, and by $191,538 from 10/10/10 scenario. Phosphorus abatement at 20 percent was again the limiting constraint in scenario 20/20/20 scenario. Sediment runoff decreased by 32.6 percent, nitrogen decreased by 26.2 percent, and phosphorus decreased by 20 percent from the base scenario. SNP decreased by 19.6 percent, 17.6 percent, and 20 percent respectively from scenario 0/0/0. To reach these higher abatement goals more land shifted from peanut production to conventional and no till wheat production and CRP.

Spatial analysis

To show the spatial allocation of cropland and the associated changes between the scenarios, the optimal cropping patters were mapped in ArcView GIS. The segments of the maps shown represent the individual sub basins defined by the Soil and Water Assessment Tool (SWAT). SWAT does not provide the necessary data to map the individual Hydrologic Response Units (HRUs). The crop yield and runoff data from the SWAT runs at the HRU level were used in the linear programming model for analysis and then aggregated to the sub basin level for mapping, because SWAT provides the GIS shape file showing the HRU shapes and locations that comprise the watershed.

The maps in this section show, at the sub basin level, the changes that cannot be seen in Table 5 (Maps available by request). By studying the maps, it was possible to determine not only what the changes were in the number of acres of each crop produced, but also where in the watershed the changes occur. The first discussion in this section include the change in crop acres from the base scenario to the 0/0/0 scenario, then to the 10/10/10 scenario, scenario 0/0/0 to 20/20/20 scenario and the base scenario to scenario 20/20/20. The second discussion in this section give how the sediment, nitrogen, and phosphorus runoff per acre shifted from the base scenario to scenario 0/0/0 to scenario 10/10/10, to the scenario 20/20/20.

Spatial Allocation of Cropland

Crop acreages in each sub basin changed dramatically from the base scenario to scenario 0/0/0. Conventional till wheat decreased in the northern half of the watershed away from the major waterways and the lake with some increases in acreage in the southern end of the watershed. No till wheat increased on some of the land areas with greater slopes in the northwest portion of the watershed in sub basins that had been in conventional till wheat production.

Peanut acres changed throughout the watershed, but the pattern shows that acres decreased in the southern portion and increased in the northern portion of the watershed. CRP acres increased on the higher sloping sub basins along the edges of the watershed that were in conventional till wheat in the base scenario.

The changes in the spatial allocation of land from scenario 0/0/0 to scenario 10/10/10 include a large decrease in peanut acres that were replaced primarily by conventional till wheat. CRP acres increased in the northern greater sloping sub basins and no till wheat experienced small changes from the profit maximizing solution increasing on sub basins where conventional wheat and peanuts decreased.

As the level of runoff abatement increases from scenario 10/10/10 to scenario 20/20/20, more conventional till wheat is produced in the southern region of the watershed closer to the reservoir. Peanut production is reduced throughout the watershed in the sub basin nearer to the major waterways and the reservoir. No till wheat replaced peanuts on greater sloping sub basins in the northern part of the watershed. CRP increased on the sub basins with greater slope along the perimeter of the watershed.

Analysis of the changes in spatial allocation in the watershed indicates that to maximize profit and meet runoff constraints peanut acres continually move away from the major waterways and the reservoir. CRP acres are established on the greater sloping sub basins around the perimeter of the watershed. This may reduce the amount of runoff from these sloping sub basins but does not allow these CRP acres to act as "buffer strips" for crop production along the waterways. As expected, based on the relative returns of conventional and no till wheat, land enters into conventional till wheat and is then converted to no till wheat as the level of runoff abatement increases.

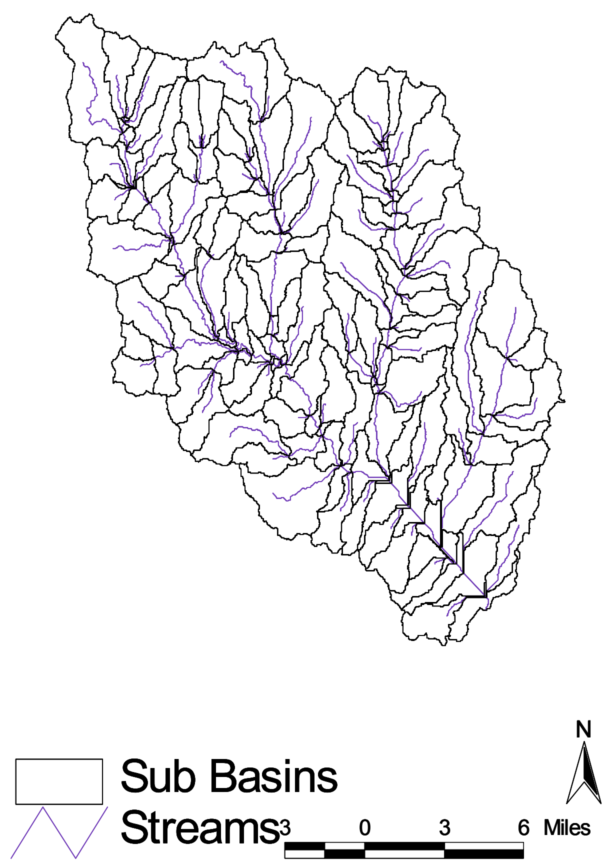
Spatial Allocation of Runoff

Sediment runoff per acre for each sub basin under the base, 0/0/0, 10/10/10, and 20/20/20 scenarios were mapped to show the changes in the spatial pattern of runoff per acre as the level of abatement increases. The change from the base to scenario 0/0/0 provides the largest shift in sediment runoff. Under the base scenario, sediment runoff is spread throughout the watershed. Under scenario 0/0/0 the sediment is more concentrated in the northern end of the watershed. As the level of abatement increases to 20 percent in 20/20/20 scenario, the sediment runoff continues to decrease in the southern half of the watershed.

Nitrogen runoff per acre in each sub basin under the base, 0/0/0, 10/10/10, and 20/20/20 was mapped to show the resulting spatial changes in nitrogen runoff as the level of runoff abatement increases. The total nitrogen runoff reduction becomes more concentrated in the northern portions of the watershed as the runoff constraints are tightened. The runoff continues to decrease in the southern half of the watershed as the level of abatement increases to twenty percent in scenario 20/20/20.

Phosphorus runoff per acre on the sub basin level was also mapped at for the base, 0/0/0, 10/10/10, and 20/20/20. As was found in the analysis of the total runoff in each scenario from section one of the results, as the phosphorus runoff did not decrease between the base and scenario 0/0/0. Instead, between these two scenarios, the phosphorus runoff only shifted from the southern end of the watershed to sub basins in the northern area. As the level of abatement increased phosphorus runoff decreased equally throughout the watershed.

Figure 1: Map of Fort Cobb Watershed showing the Sub Basin outlines used in the Spatial Allocation.



Conclusions

The spatial allocation of runoff from the sub basins exhibits the expected results. The runoff per acre in the base scenario was distributed equally throughout the watershed. As the level of runoff abatement increases, the runoff per acre is reduced on the sub basins in the southern end of the watershed, and the practices with high runoff are shifted to the northern portions of the watershed away from the major waterways and the reservoir.

Possibly, the most important finding of this study is that producer profits do not have to be reduced in order to reduce the damages to the environment. By comparing the results of the base scenario and the profit maximizing scenario, it is determined that the producer profit would be increased, while runoff is decreased in the watershed by optimizing the spatial allocation of the watershed.

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