OBSERVING THE IMPACTS ON THE SPATIAL ALLOCATION OF CROP ACRES IN THE FORT COBB WATERSHED CAUSED BY MAXIMIZING PROFIT SUBJECT TO RUNOFF CONSTRAINTS.

By

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CHAPTER I

INTRODUCTION

IMPORTANCE

Under section 303(d) of the 1972 Clean Water Act(1972 CWA), states, territories and authorized tribes are required to develop water quality standards and lists of impaired waters that do not meet established water quality standards. The 1972 CWA applies even after point sources of pollution have installed the minimum required levels of pollution control technology. Over 40 percent of the United States' assessed waters still do not meet the 1972 CWA water quality standards. This amounts to over 20,000 individual river segments, lakes, and estuaries. The impaired waters include approximately 300,000 miles of rivers and shorelines and approximately 5 million acres of lakes -- polluted mostly by excess sediment, excess nutrients, and harmful microorganisms. An Overwhelming majority of the population - 218 million - lives within 10 miles of these impaired waters. (U.S. Environmental Protection Agency).

The Fort Cobb Reservoir and six stream segments in its basin were listed on the 1998 303(d) list as being impaired by nutrients, pesticides, siltation, suspended solids, and unknown toxicity. (Storm, White, and Stoodley)

LOCATION

The Oklahoma Water Resources Board's (OWRB) list of nutrient limited waters includes twelve lakes around the state. Included in this list is Fort Cobb Lake in Caddo County in Southwest Oklahoma. Quarterly samples taken from November 2001 to August 2002 indicated that the lake had excessive levels of algal productivity and nutrient rich conditions. These findings were consistent with historical data collection efforts and supported the listing of the lake as a Nutrient Limited Watershed. If a water body with a designated beneficial use is adversely affected by excess nutrients it is designated a Nutrient Limited Watershed. Having acquired this designation, the Fort Cobb Lake is considered threatened due to excessive nutrients until appropriate tests can confirm if the lake can support its beneficial use. Based on the turbidity of the water, the lake ranges from poor on the upper end to average in the middle and good on the lower end by the dam but received a poor rating throughout the lake based on its trophic state in 2002 (OWRB).

The watershed that the Fort Cobb Lake resides in is primarily composed of agricultural lands. The basin area being studied is approximately 309 square miles containing 156 (50.5 percent of total area) square miles of cropland, 128 (41.4 percent) square miles of pasture, 18 (5.8 percent) square miles of forest, and 7 (2.3 percent) square miles of water. Because the lake is threatened by high nutrient loadings, the Fort Cobb watershed provides an opportune location to compare the tradeoffs between farm income, environmental benefits, and economic costs of meeting sediment and nutrient abatement goals for clean water with and without commodity payments.

REGULATING AGENCY

The United States Department of Agriculture (USDA) is interwoven in almost all areas of American agriculture. The 17 agencies that comprise the USDA are aggregated under seven subsectrearies as follows:

- Farm and Foreign Agricultural Services
- Food Safety
- Natural Resources and Environment
- Rural Development
- Food, Nutrition, and Consumer Services
- Marketing and Regulatory
- Research, Education, and Economics

These 17 agencies distribute government assistance in the form of payments, marketing loans, conservation plans and programs, health inspection, international marketing, information, technical assistance, etc.

As the nation's largest user of land and water resources, agriculture has the potential to significantly affect the natural environment (Feather, Hellerston, and Hansen). Because of its extensive involvement in production agriculture, the USDA is vital to implementing and regulating conservation programs dealing with water quality in agricultural and rural areas. The USDA has many programs under its discretion to use in conservation and mitigating damages from erosion and nutrient runoff on agricultural lands. Some of these programs include:

1. Conservation Reserve Program (CRP)
2. Conservation Reserve Enhancement Program
3. Emergency Conservation Program
4. Environmental Quality Incentives Program
5. Environmental and Cultural Resource Compliance
6. Highly Erodible Land Conservation
7. Wetlands Reserve Program
8. Wildlife Habitat Incentives Program
9. Farmland Protection Program

10. Conservation Technical Assistance

Congress first established the Conservation Reserve Program (CRP) in the Farm Security Act of 1985. A voluntary program, CRP offers annual rental payments for 10 to 15 years and cover establishment cost-share assistance to eligible producers that establish long-term resource-conserving covers on eligible land to reduce soil erosion, improve water quality, and enhance wildlife habitat. (Agapoff, et al.)

When the Conservation Reserve Program was established some of the stated objectives were to improve water quality, reduce erosion, and act as a price support mechanism. The focus of the CRP has shifted to environmental benefits in recent years and the program has become one of the most significant mechanisms for mitigating the adverse environmental consequences of agriculture. Based on the importance of the USDA in agriculture and the significance of CRP in environmental improvement, policy recommendations from this research will suggest alternative methods to meet the USDA's environmental policy goals at lower cost.

CRP ENROLLMENT

Non-point pollution of water bodies by agricultural practices has been an ongoing issue for decades. Addressing the water quality problem has been problematic because no effective method utilizing readily available data exists for analyzing sediment and nutrient loadings of streams, lakes, and rivers.

The Environmental Benefits Index (EBI) is currently used to rank offers from landholders for CRP enrollment. The USDA/Farm Service Agency (FSA) collects data for each of the EBI factors based on the relative environmental benefits for the land offered. Each unique offer represents a specific farm unit or field and is assigned a point score based on the associated environmental factors and competes with all other offers. Bids are accepted competitively base upon available funds, i.e. a budget constraint.

For CRP sign-up 26, May 5th through June 13th , 2003, FSA used the following EBI factors to assess the environmental benefits for the land offered: (USDA 2003)

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

Debate concerning the criteria used for the selection of acreage to be enrolled in CRP has occurred since the program began. Corresponding changes to the criteria used to target the selection of acres for the program have occurred throughout the life of the CRP. In a study completed in 1988, it was concluded that government program implementation was becoming increasingly complex as the number of actors involved in and objectives for farm programs grew. Evidence was found that the implementation of the 1986 CRP was sub optimal because the net government cost of the program may have been reduced while the levels of erosion reduction and supply control could be improved (Reichelderfer and Boggess).

With over 1,600 square miles of Oklahoma’s arable land enrolled in the CRP, and receiving rental payments of 33 million dollars, the management of the program has a large impact on the state’s environment and economy. CRP is no less important in the

Fort Cobb watershed. Part of the Fort Cobb watershed is found in Caddo county which is located in Southwest Oklahoma. Caddo county had 7,541 acres enrolled in the CRP program as of July 2003. During the 26th sign-up in May and June of 2003, a total of 664 acres were accepted while 600 enrolled acres expired for a net increase of 64 acres during the sign-up. In summary Caddo County has 7,605 acres enrolled in CRP with an average rental rate of $40/acre (Agapoff, et al.).

Actual CRP enrollment in the watershed is not known due to the difference between county boundaries for CRP acreage reports and watershed boundaries. The statistics given in the next two tables show the CRP enrollment in the counties that contain the watershed. Table 1 includes information from the 26th sign-up for the state of Oklahoma, and the counties containing the Fort Cobb watershed, Caddo, Custer and Washita. Table 2 contains information on new and re-enrolling CRP acres, rental payments, and EBI scores.

Table 1. 26th CRP sign-up information for the State of Oklahoma and Caddo, Custer, and Washita Counties.[1]

County	**Offers Received**	**Offers Accepted**	**Acres Offered**	**Acres Accepted**	**Acreage as of July, 2003**	**Acreage Expiring Sept. 2003**	**Enrollment of Oct. 2003**	**Total Rental Payments Oct. 2003 ($1000)**
State Total	886	500	79,309	43,945	1,022,756	27,561	1,036,441	33,194
CADDO	9	9	664	664	7,541	600	7,605	266
CUSTER	17	11	1,198	728	5,455	880	5,303	189
WASHITA	9	9	1,267	1,267	4,636	376	5,527	158

Table 2 26th CRP sign-up Oklahoma new and re-enrolling acres, rental payments, and EBI.[1]

County	**Accepted Expiring Sept 2003 (Acres)**	**New Lands 2004 Contracts**	**Total New Lands (Acres)**	**Average Rental Payment ($/Acre)**	**Total Rental Payment ($/Year)**	**EBI without Cost Considered**	**EBI with Cost Considered**
State Total	8,016	33,235	35,929	37	1,644,327	196	298
CADDO	258	407	407	40	26,522	203	307
CUSTER	552	176	176	33	24,143	206	319
WASHITA	376	891	891	38	48,046	244	343

1.Due to information constraints, actual enrollment in the watershed is not known and provided statistics are by county.

OBJECTIVE

The intent of this research is to estimate the change in cropping patterns and farm revenue from the implementation of alternative environmental goals and conservation policy regulations in the Fort Cobb watershed.

The first goal is to develop a data set describing the economic and environmental characteristics of land use patterns in the watershed. A second step is to us linear programming to compare the tradeoffs in spatial allocation, net revenue, sediment, nitrogen, and phosphorus runoff of cropland in the Fort Cobb Watershed under different sediment and/or nutrient abatement goals for clean water with and without commodity payments.

Enterprise budgets for the crop production activities in the Fort Cobb watershed are used to determine the costs of production per acre for peanuts, conventional tillage wheat, no till wheat, grain sorghum, and native grass CRP. Using the Soil and Water Assessment Tool (SWAT), the crop, sediment, nitrogen, and phosphorus yields per acre are found.

The last step is to develop a linear programming model to utilize the output from SWAT. By combining the commodity prices and costs from enterprise budgets with the crop yield and runoff information from SWAT, a Linear Programming (LP) model may be used to determine the optimal economic and spatial allocation of cropland that maximizes farm revenue subject to meeting a set of potential environmental improving runoff restrictions.

Part I. Profit Maximizing Solutions with Various Runoff Levels and CRP Policy: Scenarios.

The LP model will be used to analyze each of the scenarios listed below. Under current CRP policy producers do not receive their commodity income support payments from a land parcel if they enroll that parcel in CRP. An alternative set of scenarios that maintain the commodity income support payments for owners of lands enrolled in CRP will be analyzed. By comparing these two policies under different nutrient and maximization scenarios, we will determine which of the two policies is more efficient at reducing sediment and nutrient runoff from agricultural lands and the effect of commodity payments. Essentially, what happens under the second policy is that the rental payment is increased for land parcels according to the established base crop on that parcel.

Scenarios for each CRP policy.

1. Reduce sediment, nitrogen, and phosphorus runoff each by ten percent.
2. Reduce sediment, nitrogen, and phosphorus runoff each by twenty percent.
3. Reduce sediment yield by twenty percent and nitrogen and phosphorus runoff by ten percent. These levels are chosen because they are the recommended sediment and nutrient reduction goals of the Illinois Conservation Reserve Enhancement Program (USDA 1998). The Fort Cobb Basin suffers from similar problems, which implies these levels are policy relevant.
4. Reduce sediment yield by ten percent alone
5. Reduce sediment runoff by twenty percent alone.
6. Reduce nitrogen runoff by ten percent alone.

7. Reduce nitrogen runoff by twenty percent alone.
8. Reduce phosphorus runoff by ten percent alone.
9. Reduce phosphorus runoff by twenty percent alone

These abatement goals will provide a comparison of the spatial cropping patterns and farm revenues for varying levels of abatement. Other situations that might be interesting to compare would be different combinations of the three. By looking at these various goals and levels of each, it is possible to determine any threshold levels that might be present where the landscape changes dramatically. One other important feature of examining the scenarios by varying the abatement goals is to identify the relationships between the sediment and nutrient runoff. It is possible that by only targeting the sediment runoff, the nutrient runoff is constrained to an acceptable level.

Under each of the two policy environments and within each scenario we want to determine:

1. Net Revenue and Marginal Abatement Cost for sediment, nitrogen, and phosphorus with each policy and scenario in the watershed
2. Acreage of each crop in the watershed and each sub basin and how the land use changed from the base scenario.
3. Phosphorus
    a. Loading of each sub basin and the total for the watershed
    b. Dollar per ton difference from the base.
4. Nitrogen
    a. Loading of each sub basin and the total for the watershed.
    b. Dollar per ton difference from the base.
5. Sediment
    a. Loading of each sub basin and the total for the watershed.
    b. Dollar per ton difference from the base.
6. Sensitivity of results by changing the abatement percentages, costs, and Revenues in each scenario.

Part II. Gross Polluter vs. Profit Maximizing Abatement.

In this section we will generate the expected costs to achieve runoff abatement goals with policy where only the greatest polluting acres are targeted for enrollment into CRP. This gross polluter policy targets the worst eroding lands for enrollment into CRP until a runoff abatement goal is met with an unconstrained budget. By comparing this policy to a Profit Maximizing policy at ten to forty percent runoff abatement levels, we will determine the most cost effective runoff abatement policy between the two.

THESIS ORGANIZATION

The research will be presented in several sections including, a literature review, conceptual framework, methods, results, and conclusions. The literature review provides the background information for policy, prior studies, and the software that is used for analysis. The conceptual framework further defines the objectives and constraints for each scenario that will be used. In the methods chapter the specific information and assumptions related to the development of enterprise budgets for cropping activities of the Fort Cobb watershed, the GIS analysis, the SWAT model and the linear programming model are described in detail. In the results chapter the specific final costs and returns from the budgeting process are discussed along with the discussion of the opportunity costs and marginal estimates from the linear programming output. The conclusions chapter gives final analysis of the results for the scenarios studied and the associated policy implications. The references and appendix sections give detailed information about the sources of data and information used in the thesis. The appendix provides a location for the general equations used by Machsel to calculate the machinery costs

(Section I),machinery operations (Section II), the detailed crop budgets (Section III), and the GAMS linear programming model (Section IV).

CHAPTER II

LITERATURE REVIEW

POLICY INSTRUMENTS

Govindasamy and Huffman compared the marginal cost of sediment abatement across different soil types. They found that a tradable coupon system was more cost effective than a ton per acre abatement program. A tradable coupon system will also bring more land under soil conservation programs than a fixed abatement program.

Theoretically the most cost effective environmental policy instruments equate marginal cost of abatement across the pollution sources like the one studied by Govindasamy and Huffman. This system allows firms with a lower marginal cost of abatement to sell their pollution credits to a firm with a higher cost of abatement. This system has had limited use in non-point pollution control, and in the programs that exist, trades were not performed. These programs did not see the planned results. Subsidy policies like land retirement programs have had success and have been implemented by different government agencies (Yang, Kanna, and Onal). A land retirement program will be the policy of choice in this study based on the findings of Yang.

FARM POLICY

Planting Flexibility

Large government owned commodity stocks and high level of government expenditures on commodity price support programs led to the introduction of very strong supply control and demand enhancement measures for storable agricultural commodities in the Farm Security Act of 1985 (FSA85). The first of these programs was the 0-50/85/92. Prior to FSA85 crop base was determined by a five year moving average of acres planted and considered planted to the base commodity. If a producer had 100 acres of corn base and planted 50 acres of land to experimental crop only 90 acres of corn base would exist in the following crop year ((100+100+100+100+50)/5). The 50/92 program in the FSA85 allowed producers to plant up to 50 percent of their crop base acreage to another crop and still receive the deficiency payment on 92 percent of their base acreage, and the area planted to the non-base crop would be considered planted to the base crop. Because of problems with farmers switching to higher value crops and keeping their base payment, the program was changed in 1986 to only allow for one or more crops from a list of specific crops to be eligible for planting on the base acreage. In 1987 the 50/92 provision was expanded for food and feed grains to 0/92, allowing all of part of the acreage to be devoted to the use of the new crop. In 1993 the 0/92 provision became the 0/85 reducing the acres eligible to receive the deficiency payment from 92 percent to 85 percent of those base acres participating in the 0/85 program. The 0-50/85/92 programs offered increased planting flexibility in a policy period when planting flexibility was severely limited as a means of managing supply (Dicks).

Recognizing the importance for agricultural production efficiency of allowing producers to decide what crop to produce when and where, Congress initiated a 0-25 program in 1990. With this program farmers were able to plant up to 25 percent of their base acreages to another eligible crop and not lose any of their crop base history. This 25 percent was divided into 15 percent normal flex and 10 percent optional flex when the Budget Reconciliation Act of 1990 called for 15 percent of crop base acreage to be ineligible for commodity program benefits (Dicks).

The Federal Agricultural Improvement and Reform Act of 1996 (FAIR96) fundamentally changed the way agricultural income support programs work. Under FAIR96 a one time seven year Production Flexibility Contract (PFC) was offered to producers to replace the target price/deficiency payment program. The PFC payments were not connected to current farm level production or market prices. In order to be eligible for payments from 1996-2002, farmers entering into production flexibility contracts were required to maintain compliance with conservation, wetland, and planting flexibility provisions, as well as keeping the land in agricultural uses. Payments on these contracts were based on enrolled acreage and were not related to current plantings. This program gave producers almost complete planting flexibility (Dicks and Young and Westcott).

This system of decoupled payments was expanded in the 2002 farm bill as direct and counter cyclical payments. Under this system base acreages and yields are either mandated from historic 1981-1985 levels or updated from 1998-2001 plantings and yields by farm. Farms are eligible for a direct payment calculated from the direct payment rate for the covered commodity times the base acreage and program yield, regardless of the commodity price. Counter cyclical payment rates are calculated from the difference between the "target" price and the greater of the marketing year average price or the loan rate less the direct payment rate. This counter cyclical payment rate is multiplied by the base acreage and program yield to calculate the total payment to the producer for the covered commodity (ERS 2003).

These systems of decoupled payments follow the conclusions of Westcott concerning planting flexibility made in 1991. In Westcott,a single period net returns framework was used to analyze planting flexibility options. It was determined that with planting flexibility, acreage allocations are more efficient because planting choices are made directly from price signals in the market.

Peanut Program

Changes in the peanut program in the 2002 Farm Bill have had a large impact on Southern agriculture, affecting peanut producers, landowners, and peanut quota holders (Smith and Bullen). This policy change had a large impact by decreasing the market price for peanuts and the income peanut producers receive. Knowledge of peanut policy history is needed to establish the significance of the change in the peanut program. To accommodate these changes, assumptions will be formed in the enterprise budgets to deal with peanut price and producer income.

The Agricultural Adjustment Act of 1938 gave authority to the administration to place quotas on imports of peanuts if those imports interfered with domestic price support programs. The first annual import quota was set at 1.7 million pounds in 1953. The quota and continued protection from imports held most of the programs in place that had been legislated under the 1949 Act, including acreage allotments, price supports based on parity, and non-recourse loans. The first major change to the program was in the Food and Agricultural Act of 1977. This Act began a two-price poundage quota program. Under this program farmers were required to have an allotment in order to grow more than one acre of peanuts. The national acreage allotment was set at 1.6 million acres at this time. Farm production quotas were established based on the acreage allotment and the farm yield. The minimum price support of $420 per ton was set for quota peanuts. Additional peanuts would be sold at the world market price and could only be sold for crush or export not for seed or food use (Dicks).

In 1981 the acreage allotments were removed and the quota loan minimum was raised to $550 per ton with the price of additionals (non-quota peanuts) set at the crush value. The Farm Security Act of 1985 raised the quota support price to $630 while the price for additionals was held just below $150. A minimum of 1.1 million tons was set on the quota at this time, but could be adjusted upward based on national needs. The program was continued in the Food, Agriculture, Conservation, and Trade Act of 1990 and once again the quota was raised to $678 with a minimum of 1.35 million tons. Although the net federal outlays for the peanut program have been small (averaging $10-25 million over the last 10 years), many members of congress were outspoken during the 1995 farm bill debate. There were attempts to eliminate the program in the Federal Agricultural Improvement and Reform Act of 1996, but these attempts were not successful. The support prices and the minimum national quota level were reduced, however. The allotment peanut price was set at $610 per ton and the price for additional tons was set at $132 per ton with a minimum national allotment of 1.1 million tons (Dicks).

In the Food Security and Rural Investment Act of 2002, the traditional peanut program was replaced with a marketing loan type program similar to the one established for other commodities. Under this new program, the quota system was removed and all peanuts produced are eligible for a marketing loan base of $355 per ton. Producers are also eligible for a direct payment of $36 per ton times their base tonnage. In addition, they are also offered a counter-cyclical payment calculated from a target price of $495 per ton minus the sum of the greater of the marketing year average price or the loan rate plus the direct payment amount of $36 per ton times the base tons. A farmer’s base tons are his/her historic 1998-2001 peanut production (ERS 2003).

LAND COVER DATA IMAGING

The current land cover theme for the Fort Cobb Basin was established from a project completed by Applied Analysis Inc. (AAI) for Dr. Dan Storm. The purpose of AAI’s project was to develop a digital land cover data layer using June 10, 2001, thirty-meter resolution Landsat Thematic Mapper (TM) imagery for the Fort Cobb Basin. Satellite imagery has been used since the 1970’s as an accurate and cost effective tool for deriving vegetation and land cover information. Digital processing techniques involving the statistical analysis of image data representing various portions of the electromagnetic spectrum allows for definition of areas that reflect solar radiation in a similar manner. These areas may then be related to land cover or vegetation types by corroborating them with actual ground cover, a system called ground truthing (Stoodley).

For this project, a traditional classification method was used where pixels are selected that represent patterns or land cover features that can be recognized or identified with help from other sources, such as ground data, aerial sources (photography and/or orthophoto quads), or maps. By identifying patterns, the software is trained to identify pixels with similar characteristics; AAI relied on local sources to assist in collection of geo-referenced ground truth data to ensure the accuracy of the final product. This type of land cover data can be used to conduct watershed assessments, resource inventories, and to detect changes in the ecosystems (Stoodley).

Riparian zone classification offers a qualitative targeting method to spatially locate high-risk land cover types within the study area. These highest risk land cover types would include bare soil/barren, planted/cultivated 1, and planted/cultivated 2. Barren includes fields with no vegetative biomass. Planted/cultivated 1 includes fields with a low vegetative biomass state. These fields contained some vegetative spectral response with a significant soil component. Wheat, peanuts, cotton, and other row crops are included in this classification. Planted/cultivated 2 includes fields with no vegetative spectral response. These are fields that have been recently tilled or have such a low vegetative biomass state as to not be spectrally or visually apparent. Combining Landsat land cover data with estimates of non-point source loadings attributed to sub-watersheds through SWAT modeling provides the watershed project coordinator with a mechanism to proactively identify landowners that are likely contributing to the overall degradation of water quality within the Fort Cobb Basin (Stoodley).

A summary by Nelson and Geoghegan provides an important reference for anyone interested in spatial analysis of land uses. Their summary provides details of their data collection methods from satellite images, photos, ground source methods and also lists agencies and companies that can provide information on Geographical Information Systems (GIS).

LANDSCAPE ECOLOGY

In a study conducted by Neal Niemuth, Geographical Information Systems (GIS) was used along with remote sensing technology to assess habitat models based on empirical relationships between grouse populations and landscape characteristics. He found that the use of a landscape scale to identify greater prairie chicken habitat was appropriate for biological and management reasons. Another major impact of the study was that it determined not only if it was possible to find new areas for translocation, but that GIS-based models can be used to evaluate characteristics of landscapes presently occupied by prairie chickens so that management prescriptions can be made to enhance movement among populations or targeting of areas for CRP or CREP grasslands.

A major step in landscape ecological research is to determine the area that is to be studied and to establish the locations and size of the places where detailed observations will be done. Examples are given including an ant hill with the scale of ten meters; eagles with the scale of 100 kilometers; or collembolans living in the litter of a forest needing 10 centimeters. The point of this discussion was that landscape ecology remains relevant for detecting the spatial characters of the area observed and for modeling its functions. There is no set scale for any study, but the size should be discussed. (Godron and Li)

In his comparison of studies relating to landscapes and riverscapes, Fausch made two observations. First, researchers have often answered questions on the wrong scale. He found that most research answered questions that are relevant over small spatial and short temporal scales, but those may have only been weakly linked to the problems at larger spatial and longer temporal scales that managers must address. Second, he found that landscape ecology provides a way for integrating ecological processes and spatial complexity into a system that can be studied. “The general theory in landscape ecology holds that heterogeneous spatial patterns matter.” (Fausch, et al.)

LAND USE AND WATER QUALITY

In this study the first assumption is that if the land use is changed then there will be an impact on water quality in the area. In fact, hydrologists and aquatic ecologists have long known that the surface across which water travels to a stream or lake has a major effect on water quality. Accordingly the relative amounts of particular land use and land cover (LULC) types in a watershed will affect water quality as well. This significant relationship between LULC and water quality has been documented in previous research (Griffith).

SOIL NUTRIENTS

Managing soil phosphorus to prevent surface water pollution is emerging as one of the significant challenges facing agriculture today (Sims and Sharpley). All plants and animals require nitrogen, phosphorus, and potassium for growth. Farmers regularly apply fertilizers containing these nutrients to fields to increase crop yield. Phosphorus is also typically the nutrient limiting algae growth in most lakes and streams. As the level of nutrients entering a stream or lake increases, the level of growth of aquatic plants and other organisms increases as well. Although these nutrients are necessary, excessive levels over-stimulate algae and plant growth in lakes and streams which reduces water quality. This progressive deterioration of water quality from an increase in the nutrient level is called eutrophication (Lory).

Plants require a relatively large amount of phosphorus so this essential element is usually added to soils in fertilizers. Phosphorus is used in energy transport in living organisms. Although phosphorus is essential for plant growth, mismanagement of soil phosphorus is a threat to water quality. If the concentration of phosphorus in fresh water increases, the level of algae growth also increases. High levels of algae growth reduce water clarity and can lead to decreases in available dissolved oxygen as the algae decays. (Bussman, et al.)

Phosphorus (P) is a somewhat unique pollutant because it is an essential element, has low solubility, and is not toxic itself: however, it may have detrimental effects on water quality at quite low concentrations. There is considerable concern about P being lost from soils and transported to nearby streams and lakes. Several chemical properties of soil P have important implications for the potential loss of P to surface water. (Bussman, et al.)

Chemical Properties of Soil Phosphorus

- Phosphorus in soils is almost entirely associated with soil particles. When soil particles are carried to a river or lake, phosphorus will be contained in this sediment. When the sediment reaches a body of water, it may act as a sink or a source of phosphorus in solution. In either case, it is a potential source of phosphorus that may eventually be released.
- Most soils have a large capacity to retain P. Even large additions of P will be mostly retained by soils provided there is adequate contact with the soil.
- Increasing the amounts of phosphate in soils results in increased levels of phosphate in soil solutions. This will generally result in small but potentially important increases in the amounts of phosphate in water that passes over or through soils.

- Phosphate in soils is associated more with fine particles than coarse particles. When soil erosion occurs, more fine particles are removed than coarse particles, causing sediment leaving a soil through erosion to be enriched in P. (Bussman, et al)

PRIOR RESEARCH ON SPATIAL ALLOCATION

Yang, Khanna, and Onal (2001) developed an integrated watershed management framework to study cost effective land retirement in multiple watersheds to achieve off-site sediment reduction goals. Their study focused on land parcels contained within 12 agricultural watersheds within 900 feet of a waterway. Their research examined two alternative standards; a “uniform standard” in which all watersheds had to reduce sediment by the same amount and a “non-uniform standard” in which sediment was abated across watersheds at an equal marginal cost. These two standards were analyzed looking at two alternative rental instruments. These rental instruments were a marginal cost of sediment abatement ($/ton) and an average rental payment per acre mechanism ($/acre). Results of the study were that the non-uniform methods equalizing marginal abatement costs across watersheds is more cost effective than the uniform standard. The study concluded that the $/ton instrument outperforms the $/acre instrument in either the uniform or non-uniform standard. In summary the most efficient scenario is the non-uniform standard with the $/ton instrument. The least efficient scenario is the uniform standard with the $/acre instrument costing 2.5 times more than the most efficient scenario. (Yang, Khanna, and Onal)

A common feature of these studies is the emphasis on the incentives required to induce landowner’s participation into conservation programs based on a fixed acreage reduction goal rather than on designing a policy tool based on environmental benefits of land parcels. Yang, Khanna and Onal summarized studies that have been done to estimate the minimum incentives necessary to induce farmers' participation in conservation programs. Seita and Osborn (1989) discussed the minimum variable incentive payment rates needed to induce conservation compliance based on cost per unit of erosion reduction criteria. The minimum incentive rates were defined as the farmer's costs of switching from the base scenario to conservation practices. Parks et al. (1995, 1996) developed a farmer behavior model to predict farmer's participation into the Wetland Reserve Program with farmers and land attributes as explanatory variables. With the predicted value as the minimum incentive to induce farmer's participation, they estimated the public funds required to achieve a million-acre target. Smith (1995) discussed how mechanism design theory could be used to design contracts to induce landowner's participation into the CRP under asymmetric information between government and landowners. Mechanism design theory is a type of game theory, but where game theory takes rules as a given mechanism design theory asks about the consequences of different types of rules (Levine). Based on county level cash rental value of farmland, his model simulated the required incentive payment to induce landowner's participation into the CRP and estimated the least cost for achieving the goal of a 34-million acre CRP. (Yang, Khanna, and Onal)

PRIOR MODELS

Khanna et al. used an integrated framework of spatial and biophysical characteristics of a watershed in hydrologic and economic models to identify cropland for enrollment in the Illinois Conservation Reserve Enhancement Program (CREP). Specifically, they developed an analytical framework to determine a cost effective land retirement scheme to reduce offsite sediment loadings. Linear programming (LP) was used to form a computationally convenient empirical model. Rather than defining every land parcel as a decision-making unit, this LP model considers every three-parcel chain bordering a waterway as a decision-making unit. One of eight land management plans can be selected for each chain (CCC, CCG, CGC, CGG, GCG, GGC, GGG, and GCC where C indicates cropping and G indicates permanent grass cover). These alternative plans are denoted in the equations by p=1…8, where 1=CCC. Khanna et al.'s objective was to minimize the cost of abatement defined as the difference in quasi-rents with crop production and those with management plan p.

$$Minimize \sum_{j=1}^{J} \sum_{p=1}^{8} (r_{1j} - r_{pj}) Z_{pj} \quad \text{Subject to} \tag{1}$$

$$S^{\circ} - \sum_{j=1}^{J} \sum_{p=1}^{8} e_{pj} Z_{pj} \geq \overline{A} \tag{2}$$

$$\sum_{p=1}^{8} Z_{pj} = 1 \text{ for all } j=1,\ldots J \tag{3}$$

$$Z_{pj} \geq 0 \text{ for all } p, j. \tag{4}$$

Where: e_{pj} is the total sediment generated by channel *j* loaded to the water body under plan *p*. Z_{pj} is the weight variable associated with the enrollment plan p for channel *i*. S° is the total sediment loading in the watershed when all land parcels are in crop production. $\overline{A}$ is the desired sediment abatement level. $r_{1j} - r_{pj}$ represents the costs of abatement are defined as the difference in quasi-rents with crop production and those with management plan p.

The empirical results show that the retirement of only 10.9 percent of the eligible cropland within a 900 foot buffer is sufficient to meet a twenty percent sediment abatement goal during a typical storm event in that region. This goal was achieved by retiring sloping, less productive cropland with erodible soils adjacent to streams. (Khanna et al.)

In a study by Yang et al. to determine a cost effective method of land retirement across watersheds to reach a uniform twenty percent sediment abatement standard the following model was developed.

(5) $$Minimize\sum_{n=1}^{N}\overline{\pi_n}-\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{i=1}^{I_j}\sum_{k=0}^{1}\pi_{nijk}x_{nijk} \text{ Subject to}$$

(6) $$\sum_{k=0}^{1}x_{nijk}=\alpha,\forall n,i,j$$

(7) $$\sum_{n=1}^{N}\overline{S_n}-\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{i=1}^{I_j}\left(1-\sum_{m=0}^{i-1}d\right)\sum_{k=0}^{1}s_{nijk}x_{nijk}\geq\overline{TA}$$

A detailed description of this system of equations is provided in Yang, et al’s paper, but the following summarizes the objective of the equation; minimize the difference of the sum of the average profits per watershed minus the sum of the profit on individual land parcels under the optimal cropping pattern with respect to watershed, sediment transfer coefficient, land unit, and crop type subject to a minimum sediment abatement level.

The results of Yang et al.’s study indicate that non-uniform sediment standard, which equalizes the marginal cost of sediment abatement across watersheds, outperforms the uniform standard. (“Uniform standard” indicates that each watershed must meet the sediment goal individually.) From this study the dollar per ton of abatement outperforms the dollar per acre-retired mechanism. The least preferred policy option, the uniform sediment abatement standard with a $/acre instrument, is 2.5 times as costly as the most preferred policy option, the non-uniform sediment standard with a $/ton payment instrument.

SOFTWARE

Three computer software programs along with two spreadsheets were used to analyze the tradeoffs between revenue, environmental benefits, and economic costs of changes in the spatial allocation of cropland with and without commodity payments. This software used includes the Excel based programs, Machsel and OSU Enterprise budgets; the linear programming system, General Algebraic Modeling System (GAMS); and the Soil and Water Assessment Tool (SWAT). The following gives a brief history and explanation of these programs.

Machsel

Machsel is a spreadsheet designed to assist decision makers in choosing farm machinery complements. Originally written in Lotus 1-2-3 in 1991, over the years the program has been updated for current machinery prices and is now an Excel based program. By entering different tractor sizes based on power take off (PTO) horsepower and machinery, it is possible to determine the feasibility (hours per month available and used per tractor) and costs of the various farm production practices. The program does not select the optimum mix of inputs for production; it simply gives a way to compare machinery compliment sizes with seven major machinery cost components. These cost components include variable costs of fuel, lubrication, and repair as well as the fixed costs of annual average depreciation, interest, taxes and insurance. The basic formulas used by Machsel for calculating the cost estimates are included in Appendix Section I. One major assumption of Machsel is that costs are only included if a machine is used. If a machine is owned but not in use the producer is incurring fixed costs for the machine, but these fixed costs during nonuse are not included in the estimates provided by Machsel (Kletke and Sestak).

Enterprise Budget

Oklahoma State University’s Enterprise Budget Software is another Excel based program designed to aid the farm manager in making his production decisions by providing a user-friendly system to enter and format the cost and returns of production. One feature that enhances the software is that it contains estimates of production cost and returns as well as the management practices typical of the area. These estimates can be overwritten but give the manager something to compare his numbers to. Another feature is the built in calculators and historical data that are available. Past years prices and yields are given for the producers’ area of the state. Fertilizer calculations are automatically run to recommend the fertilizer amounts needed to meet the production goals set by the producer. (Doye, et al.)

The current program used for this study is the 2.0 series, which was last updated in April of 2003. At this time the pesticide and fertilizer options were updated to the current recommended amounts and prices. Also updated at this time were the custom rates for machinery operations. (Sahs)

SWAT

Soil and Water Assessment Tool (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). 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. 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]).

SWAT model components include: weather, surface runoff, return flow, percolation, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer. SWAT model operation is computed using daily, time step-long term simulations for basins of several thousand square miles that are subdivided to account for differences in soils, land use, crops, topography, weather, etc. The basin is subdivided into subbasins that can be simulated in spatially displayed outputs. To add ease of use the model has GRASS GIS links to automate inputs, is interfaced in windows, and also accepts output form Erosion-Productivity Impact Calculator (EPIC). SWAT analysis is improved by the soil profile being divided up into ten layers and nutrient and pesticide input and output. Water movement is modeled using reach routing command language to route and add flows, a groundwater flow model, and transfer from channels and reservoirs (GSWRL).

The SWAT model has many characteristics to make it more useful for site-specific modeling of runoff. First, the model is physically based rather than being based on regressions to describe the relationships between input and output data. SWAT requires specific information for weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. Using this input data, SWAT is able to model the physical processes associated with water and sediment movement, crop growth, nutrient cycling, etc. A major benefit of this system is that stream monitoring data is not necessary for the model to be run. In fact, the model can be run using readily available data from government sources. Two other benefits of the model are that it is computationally efficient in that it does not take a large amount of time to run and that it is capable of performing analysis over long time periods to determine the results of pollutants that build up gradually. The downside is that SWAT cannot model the effects of a single storm event (GSWRL).

History and Development of SWAT

SWAT incorporates features of several Agriculture Research Service models and is a direct outgrowth of the Simulator for Water Resources in Rural Basins (SWRRB) model. Other models that contributed to the development of SWAT include Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS), Groundwater Loading Effects on Agricultural Management Systems (GLEAMS), and Erosion-Productivity Impact Calculator (EPIC). The following is a history provided on the development of SWAT.

The SWRRB model began as a modification to the daily rainfall hydrology model from CREAMS. CREAMS is a field level model developed to predict runoff, erosion, and chemical transport from agricultural management systems (Knisel). Nine major changes made to the CREAMS hydrology model include: a) an expansion to allow simultaneous computations on several sub basins; b) a groundwater component was added; c) a reservoir storage component was added; d) a weather simulation model incorporating data for rainfall, solar radiation, and temperature was added; e) improvements were made to the model predicting peak runoff rates; f) EPIC crop growth model was added; g) a simple flood routing component was added; h) sediment transport components were added; and calculations of transmission losses were incorporated. (GSWRL)

"EPIC is a continuous simulation model that can be used to determine the effect of management strategies on agricultural production and soil and water resources. The drainage area considered by EPIC is generally a field-sized area, up to 100 ha (weather, soils, and management systems are assumed to be homogeneous). The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient cycling, pesticide fate, plant growth, soil temperature, tillage, economics, and plant environment control." (Willams)

Water quality assessment was the primary focus of the SWRRB model in the late 1980's and the development of this period reflected this focus. During this time the pesticide fate component of GLEAMS was added as well as newly developed sediment yield equations. GLEAMS is a mathematical model developed for field size areas to evaluate the effects of agricultural management systems on the movement of agricultural chemicals within and through the plant root zone (Leonard, Knisel, and Still).

A model was needed in the late 1980’s to estimate the downstream impact of water management within Indian reservation lands in Arizona and New Mexico. Limitations in the size and number of sub basins and the methods employed to model the water and sediment transported out of the sub basins in which both routed directly to the watershed outlet led to the development of another model. The Routing Outputs to Outlet (ROTO) model took output from multiple SWRRB runs and routed the flows through channels and reservoirs. This model overcame the SWRRB sub basin limitation by “linking” multiple SWRRB runs together. The input and output of multiple independent SWRRB runs was cumbersome and required considerable computer storage. In order to remove the difficulty of running the SWRRB model multiple times and then entering the output into ROTO, these two models were combined to create one new model, SWAT. This allows simulations of very extensive areas but retains all of the features that made SWRRB a valuable simulation model (GSWRL).

Since the early 1990’s when SWAT was developed it has undergone continued review and expansion of capabilities. Each release has provided more features enabling greater analytical opportunities. In addition to the expanded capabilities, SWAT has also undergone extensive validation. Some of the features added include: a) multiple hydrologic response units incorporated; b) auto-fertilization and auto-irrigation added as management options; c) canopy storage of water added; d) a carbon dioxide component added to crop growth model for climatic change studies; e) potential evapotranspiration equation added; f) lateral flow of water in the soil added; g) in-stream water quality equations and pesticide routing. Based on the usefulness of this tool, its users include NRCS, EPA, Environmental Consulting Firms, and universities. (GSWRL)

Model Uses

The SWAT Model has been used in studies measuring everything from the effects of climatic change on stream flows to predicting the effects of snowmelt. Many studies have also been conducted that compared actual data to SWAT output to determine if the model had the capability of accurately predicting flow levels. A few of the studies are described below and a list of titles of research that has been performed using SWAT is also given.

Jha (2004) used the SWAT model to analyze the impacts of potential future climate change on the hydrology of the Upper Mississippi River Basin. Estimates were created that linked average annual flow to changes in atmospheric carbon dioxide and temperature. The study found that the hydrology is very sensitive to these potential climate changes and that the changes could cause increased periods of drought or flooding. (Jha, et al 2004)

Amhad, Gassman, Kanwar measured drain flows from a research site near Nashua, Iowa which was compared to estimates of the subsurface drainage component of the SWAT model in order to test the reliability of the estimates given. Results of the study indicate that the model has the capability of satisfactorily predicting the subsurface flows satisfactorily for different soil, slope, and weather conditions.

Jha, et al. conducted research to determine the optimal procedures and methods in using the model. A study at Iowa State University compared the results of varying sub basin size, scale and number within the SWAT model in order to determine the appropriate level of division to simulate sediment yield. It was determined that sub basin size around three percent of the watershed adequately predicted sediment yield.

SWAT has been used for analysis of many other topics related to hydrology, sediment and nutrient runoff, and crop yields. Some of the titles of these research studies taken from the list of peer-reviewed papers on the SWAT website include: (GSWRL)

- Prediction of Stream Channel Erosion Potential. (Allen, Arnold, Jakubowski)
- Assessment of Bedrock Channel Erosion in Urban Watersheds. (Allen, Arnold, and Skipworth)
- Automated Methods for Estimating Base Flow and Groundwater Recharge from Stream Flow Records. (Arnold, and Allen 1999)
- A Comprehensive Surface-Ground Water Flow Model. (Arnold, and Allen 1993)
- Nonpoint Source (NPS) Pollution Modeling Using Models Integrated with Geographic Information Systems (GIS). (Engel, Srinivasan, Arnold, Rewerts, and Brown)
- Effects of Land Use Changes on the Water Balance of a Rural Watershed in a Peripheral Region. (Fohrer, Eckhardt, Haverkamp, and Frede)
- Modeling Runoff Response to Land Cover and Rainfall Spatial Variability in Semi-Arid Watersheds. (Hernandez, etal.)
- Predicting Sediment and Phosphorus Loads in the Rock River Basin Using SWAT. (Kirsh, Kirsh, and Arnold)
- Development of a Comprehensive Watershed Model Applied to Study Stream Yield Under Drought Conditions. (Perkins, and Sophocleous)
- Economic Evaluation of Riparian Buffers in an Agricultural Watershed. (Qiu, and Prato)
- Possible Impacts of Global Warming on the Hydrology of the Ogallala Aquifer Region. (Rosenberg, et al.)
- Application of a Watershed Model to Evaluate Management Effects on Point and Non-point Source Pollution. (Santhi, et al.)

GAMS

The General Algebraic Modeling System (GAMS) is a high level modeling system for mathematical programming models. GAMS is made for the construction of large easily maintainable models that can be changed quickly by the user for new situations. GAMS is specifically designed for use with linear, non-linear, and mixed integer optimization problems and is available for use on personal computers, workstations, mainframes and supercomputers.

GAMS has several unique features; first is the ease with which the program can be run. GAMS allows the user to focus on modeling and not on the computing language. A second feature is that data is entered in familiar lists and tables. GAMS allows the user to enter the data in a table format and then enter the equations and unless specified by the user, this equation can be used for every computation. This keeps the user from entering the same basic equation multiple times. An additional feature is that the program is very flexible and powerful. Models are portable from machine to machine and multiple variations of a model may be run at once. Because GAMS allows text to be entered, the output of the program can be easily identified even when multiple variations of the model are run at once. (GAMS)

CHAPTER III

CONCEPTUAL FRAMEWORK

Water quality is impacted by many factors including some that are outside of human control, such as the timing and amount of rainfall. Others such as land use, crops planted, and conservation efforts can be changed to minimize the adverse affects of agriculture on the environment.

Concern about the negative effects of agricultural activities on water quality has shifted the focus of land retirement programs from reducing on site erosion to mitigating the damages to water bodies caused by sediment, nutrient, and chemical laden runoff from fields and enhancing aquatic and wildlife habitat (Yang, Khanna, and Onal). The purpose of studying the Fort Cobb watershed is to compare the tradeoffs between revenue, environmental benefits, and economic costs of meeting reduced sediment and nutrient abatement goals for clean water with and without commodity payments.

By entering actual climate, sediment runoff, and land use into the SWAT model, these variables can be simulated to study the effects of changing the land use on sediment and nutrient runoff. Because the tillage practices, amount of plant nutrients, and harvest methods vary with the crop produced; the sediment and nutrient runoff also varies with the crop produced. By changing the simulated cropping mix to one with lower sediment and nutrient runoff, the water quality of the reservoir can be improved.

This research will test multiple runoff abatement scenarios in two policy environments. The first scenario will be to choose the land use that will meet the sediment and nutrient (nitrogen and phosphorus) runoff base levels to establish a profit maximizing solution with the current price, cost, and yield data for comparison with the other scenarios. This base scenario will produce a profit-maximizing solution with constraints on the number of acres of each crop, and total sediment, nitrogen, and phosphorus runoff. These constraints on acres and runoff force the model to mimic as closely as possible the current spatial allocation of the watershed. A second set of scenarios will be to vary the restrictions on sediment, nitrogen, and phosphorus runoff abatement required. A sediment, nitrogen, and phosphorus reduction goal of ten percent each from the base scenario and then a sediment, nitrogen, and phosphorus runoff reduction goal of twenty percent each from the base scenario will be used in this analyis. These levels were chosen as potential policy goals based on watershed improvement goals set by the Illinois CREP. The Illinois CREP goals of 20 percent sediment, 10 percent nitrogen, and 10 percent phosphorus abatement will be run to determine if a policy such as this would be feasible in the Fort Cobb Watershed. These sediment and nutrient abatement levels are established to reduce sediment, nitrogen, and phosphorus inflow into the water supply. By targeting 85,000 acres of riparian buffers and 15,000 acres or property immediately adjacent to the buffers classified as Highly Erodible Lands for enrollment into CRP, the Illinois CREP program attempts to protect water quality in the Illinois River and some of its tributaries. By improving the water quality in the area, the program aims to increase populations of waterfowl, shorebirds, and state and federally listed species by fifteen percent. Additionally, program designers also set a goal of increasing native fish and mussel stocks by ten percent in the lower reaches of the Illinois River. (USDA 1998) Since the Fort Cobb reservoir's water quality is threatened by the same activities as the Illinois River, the Illinois CREP goals may be relevant in the Fort Cobb area to improve water quality.

Additional scenarios are variations of the first set to identify the affect on runoff levels of sediment, nitrogen, and phosphorus when only one of the three is targeted for abatement at ten or twenty percent while the other runoff levels are unconstrained. Each of these scenarios will be tested under a policy environment with and without commodity payments. The current CRP regulations require that a producer forfeit his or her commodity payments from a parcel of land if that parcel is not used in an agricultural activity. CRP is not considered an agricultural activity so when a producer enrolls his land into CRP, he loses his Direct and Counter cyclical Payment (DCP) on that land. This policy makes the CRP program economically infeasible to a producer with a crop base payment based on peanuts. The average DCP per acre for peanut base in the area is about 170 dollars and the average CRP rental payment in Caddo County is approximately 40 dollars an acre. If a peanut producer enrolls in CRP, he automatically loses 130 dollars of income per acre. By letting producers keep the DCP when land is enrolled into CRP, the rental price of an acre of CRP increases depending on the program crop base on that acre. Letting the producers keep the DCP when enrolling land removes the economic disincentives associated with the commodity programs that keep some acres of land from being offered for enrollment in the CRP. By running the model with the changed CRP/DCP payment policy, this research will determine which of the two policies is most efficient at reducing runoff in the watershed.

Producers are assumed to have an objective of maximizing profits and to use an efficient mix of inputs in production. Thus, changes in current cropping practices may be assumed to lower the actual profits of the producer. To calculate the opportunity cost associated with changing the land use, the forgone quasi-rent from crop production will be calculated. This is defined as total revenues minus total costs. To estimate these quasi rents for each crop area agricultural specialists and county agricultural agents were used to determine the revenue and costs on a "generic farm" in the region or county.

In the studies discussed earlier in the literature review by Khanna et al. and Yang et al., the objective was to minimize the forgone quasi-rent. In their models, each one minimized the difference between a calculated total area profit for current cropping patterns of the area and a cropping mix selected by their model to maximize profits subject to the imposed constraints. By comparing the quasi-rents from the old land allocation returns with the new allocation returns, the economic cost of their abatement programs were found.

This study will focus on the allocation of cropland, total profit, sediment runoff, nitrogen runoff, and phosphorus runoff. Since we are interested in determining the total runoff, cropland, and profit resulting from the changes in land allocation, minimizing the difference between base and scenario profits results in the same spatial allocation of cropland as maximizing the scenario profit, but does not provide the information that we seek. By not calculating the base case profit each time the model is run, our model is the dual of Kanna and Yang's models minimizing the difference between current and scenario profit to a model where profit is maximized in the current scenario. Our model will be run to establish each of the base values for runoff, cropland, and profit. The scenarios with their various restrictions will then be run to determine their runoff, cropland, and profit values to compare to the fixed values for the base outside the linear programming model. By performing the calculation in this way, we will be able to determine not only the changes in runoff, cropland, and profit but also the totals. The model that we use maximizes profits of the watershed subject to constraints on sediment and nutrient runoff. Mathematically stated the model is as follows:

EQUATIONS

$$Maximize\sum_{i=1}^{I}\sum_{j=1}^{J}\left(\left(\left(P_i * Y_{ij}\right)+F_i\right)-C_i\right)X_{ij} \text{ Subject to:} \tag{8}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}Ph_{ji} * X_{ij} \leq Plimit \tag{9}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}NIT_{ji} * X_{ij} \leq Nlimit \tag{10}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}SED_{ji} * X_{ij} \leq Slimit \tag{11}$$

$$\sum_{i=1}^{I}X_{ij} = Acres_j \tag{12}$$

$$X_{ij} \geq 0 \tag{13}$$

Where:

P_i	Price of Crop *i*
Y_{ij}	Yield of Crop *i* on HRU *j*
F_i	Forage and Hay Value for Crop *i* (peanuts and wheat)
C_i	Total Cost to produce Crop *i*
Ph_{ji}	Phosphorus runoff from HRU *j* under Crop *i*
NIT_{ji}	Nitrogen runoff from HRU *j* under Crop *i*
SED_{ji}	Sediment runoff from HRU *j* under Crop *i*
$Acres_j$	Acres in HRU *j*
X_{ij}	The Variable: the number of acres of Crop *i* in HRU *j*.
$Plimit$	Total Phosphorus Runoff allowed in Watershed
$Nlimit$	Total Nitrogen Runoff allowed in Watershed
$Slimit$	Total Sediment Runoff allowed in Watershed

CHAPTER IV

METHODS

By using information from a study currently underway at Oklahoma State University on the Fort Cobb watershed (Storm, White, and Stoodley), the effects of various agricultural and conservation practices on sediment runoff can be examined. Using data compiled by Nisrani[1] on crop, sediment, nitrogen, and phosphorus yield from various cropping practices, I will be studying the economic questions associated with altering cropping patterns.

SWAT

A large amount of data are required for climate, soils, land use, and slope for each geographic location, because the Soil and Water Assessment Tool (SWAT) is a distributed model. To minimize the effort of manipulating this large amount of data, an Arc View GIS interface was used to generate model inputs from commonly available GIS data. This GIS interface summarizes the data and converts it to a form that is usable by the SWAT model. GIS data used includes:

- 10 m USGS DEM
- 200 m NRCS Soils Dataset
- 30m land use data layer from Applied Analysis Inc
- EPA Reach3 streams
- Tabular weather data

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[1] Nisrani, Mengistu Geza is a graduate research associate in the Department o f Bio-Systems and Agricultural Engineering at Oklahoma State University.

- Crop type breakdown
- Center pivot irrigation locations

The 10 m USGS Digital Elevation Map (DEM) is an array of regularly spaced elevation values referenced horizontally either to a Universal Transverse Mercator(UTM) projection or to a geographic coordinate system. Using the UTM or a coordinate system determines how the error of projecting the curved surface of the spherical world onto a flat map is displayed. On the UTM the polar regions of the map will contain most of the error. On an equidistant map the error is more or less distorted on every equal area of the map (USGS). The 200 m NRCS Soils Dataset is a three-layer composite of data derived from county soil surveys, gridded using 200-meter grid increments (White). The 30 meter 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 (Stoodly). EPA Reach3 streams is a system of national hydrologic databases that uniquely identify and interconnect stream segments that comprise the country's surface water drainage system (USGS). 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 were not available for fertilization practices, these practices were derived from 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)

Table 3. 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

SWAT partitioned the Fort Cobb watershed into 154 sub-basins, with 1,819 unique land areas known as Hydrologic Response Units (HRUs), using the specified data according to land use and soil type. Each of the HRUs are homogeneous areas of land use and soil type. Using this breakdown of the watershed, SWAT calculates the catchment (reservoirs, ponds, etc.) parameters and simulates the hydrologic cycle in the watershed. The four main components of the hydrologic cycle are precipitation, surface movement of water, subsurface movement of water, and evaporation into the atmosphere. The sediment and nutrient movement in the watershed is governed by the simulated hydrological cycle (Ancev).

The model was calibrated for hydrology, total phosphorus, and total nitrogen runoff. The hydrologic calibration was performed using stream gage data from a site on Cobb Creek near Eakley from Jan 1990-Oct 2001. The nutrient loadings were calibrated using water quality data throughout the basin. (Storm, White, and Stoodley)

From the generated multi level map, SWAT analysis can be run to find the amount of sediment, nitrogen, phosphorus runoff, and crop yield from the land use areas based on the land use and cropping practices used. Tables 4, 5,6, and 7 provide examples of the data (a small subset of HRU's) provided by SWAT that will be used in the analysis.

Table 4. Snapshot of Crop Yield from each HRU Under each Cropping System

HRU	SUB	Peanut Lb./Acre	C Wheat Bu./Acre	N T Wheat Bu./Acre	Sorghum Bu./Acre	Sorghum Bu./Acre	CRP
4	1	2743.320	32.915	35.520	26.022	24.164	1.0
5	1	2544.939	19.339	22.105	28.128	26.118	1.0
6	1	2743.320	32.740	33.522	26.893	24.972	1.0
11	2	2743.320	32.726	33.873	26.923	25.000	1.0
12	2	2743.320	32.915	35.520	26.022	24.164	1.0
20	3	2737.652	38.623	42.402	32.024	29.737	1.0
21	3	2737.652	36.464	37.260	24.777	23.008	1.0
22	3	2737.652	38.003	37.625	22.176	20.592	1.0
27	4	2737.652	38.650	42.389	32.075	29.784	1.0
28	4	2737.652	36.464	37.260	24.787	23.017	1.0
31	4	2737.652	35.034	38.178	26.184	24.314	1.0

Table 5. Snapshot of Sediment Yield in Tons per Acre for each HRU Under each Cropping System

HRU	SUB	Peanut Ton/Acre	C Wheat Ton/Acre	N T Wheat Ton/Acre	Sorghum Ton/Acre	CRP Ton/Acre
4	1	6.414	2.205	0.616	4.476	0.016
5	1	14.301	10.562	6.565	11.166	0.068
6	1	5.354	1.652	0.597	3.396	0.017
11	2	5.591	1.719	0.614	3.564	0.018
12	2	6.580	2.249	0.628	4.603	0.016
20	3	9.616	3.741	1.466	7.424	0.025
21	3	6.706	1.830	0.706	3.926	0.017
22	3	7.116	2.161	0.986	4.590	0.022
27	4	2.880	1.144	0.448	2.227	0.008
28	4	2.279	0.626	0.245	1.334	0.006
31	4	3.600	1.055	0.339	2.520	0.010

Table 6. Snapshot of Nitrogen Yield in Kg per Acre for each HRU Under each Cropping Practice

HRU	SUB	Peanut Lb./Acre	C Wheat Lb./Acre	N T Wheat Lb./Acre	Sorghum Lb./Acre	CRP Lb./Acre
4	1	19.812	7.962	3.079	14.570	0.561
5	1	19.029	17.490	10.221	18.485	6.238
6	1	17.066	6.338	2.976	11.532	0.604
11	2	17.527	6.524	3.048	11.890	0.632
12	2	20.108	8.077	3.127	14.808	0.576
20	3	27.258	12.854	5.983	22.784	1.192
21	3	19.298	6.328	3.197	12.757	0.423
22	3	21.032	8.164	4.288	14.833	0.861
27	4	12.880	5.706	2.575	10.721	0.816
28	4	9.782	3.000	1.479	6.299	0.242

Table 7. Snapshot of Phosphorus Yield in Kg per Acre in Each HRU Under Each Cropping Practice

HRU	SUB	Peanut Lb./Acre	C wheat Lb./Acre	N T Wheat Lb./Acre	Sorghum Lb./Acre	CRP Lb./Acre
4	1	6.225	1.716	1.166	3.339	0.460
5	1	8.690	5.172	5.329	5.380	1.450
6	1	5.709	1.400	1.181	2.753	0.537
11	2	5.863	1.440	1.204	2.837	0.546
12	2	6.315	1.739	1.179	3.393	0.461
20	3	8.593	2.778	2.231	5.184	0.715
21	3	6.825	1.498	1.315	3.156	0.415
22	3	7.488	1.818	1.714	3.724	0.724
27	4	3.954	1.229	0.990	2.380	0.547
28	4	3.380	0.710	0.630	1.530	0.314
31	4	4.989	1.162	0.818	2.665	0.521

This study will focus on changes in cropland use and the associated changes to sediment, nitrogen, and phosphorus runoff. The data generated by SWAT for crop, sediment, nitrogen, and phosphorus yield will be combined with price and cost data in a linear programming model. This is done to find the optimum mix and location of crops to maximize returns per acre based on crop produced subject to the constraints on sediment, nitrogen, and phosphorus runoff.

CROPPING DATA

To determine the cost of changing the land use/cropping pattern the change in profit for each crop will be found using Enterprise Budget Software and Machsel. Data for the different cultural practices used in the production of each crop was gathered from many different sources. The information for the peanut budget came from David Nowlin, Agricultural Extension Agent in Caddo County. Sorghum information was received from Mark Gregory, Southwest Oklahoma Agricultural Specialist. Information for establishing CRP acreages came from the NRCS Oklahoma Conservation Practice Job Sheet for Range Planting. And wheat data came from Dr. Thomas Peeper, Professor in the Plant and Soil Science Department, specialist in small grain weed control.

MACHSEL

The first step in calculating the budgets for each of the cropping systems was to determine the machinery costs. The budget software has a section to calculate machinery costs but was not used because it is not accurate enough for our purposes. The default, owned equipment cost estimates entered when the program starts are loosely based on the number of acres farmed and the horsepower of the largest tractor used. The problem arises because if the machinery operations change, the fixed costs cannot change with them. The only way to change the machinery operations used and the associated costs within the budget program is to calculate the machinery costs based on custom machinery rates. One option for changing per acre machinery fixed costs is to change the number of acres farmed and divide the costs over more or fewer acres. Another option is to change the PTO horsepower tractor range selected when the software opens. None of these options are accurate enough for our purposes. The budget software does allow the user to use their machinery costs directly.

To calculate cost estimates for the machine operations specified, the cropping information gathered was entered into the Machsel program to estimate the variable and fixed costs of the machines used. To allow for comparison, all of the cropping systems factors that could be were held constant. These factors include the tractor sizes of one 130 PTO horsepower and one 105 PTO horsepower and which implements that each pulled. (If the planter was used it was always pulled by the 105 horsepower tractor, for example).

The acreages for each crop were also held constant at 350 acres of cropland. The 350 acres of cropland is an approximation of the cropland available on each farm in the watershed. Also held constant for each crop was the cost of fuel, labor, equipment, tax rates, insurance rates, and repair coefficients.

The Machsel program calculates the variable machinery costs of fuel, lubrication, repairs, and labor and the fixed costs of interest, taxes, insurance, and depreciation. These estimates are based on technical coefficients established by research on machinery operation costs. Based on the horsepower of the tractors selected by the user, crop acres farmed, new or used equipment compliment, and the field operations performed, the variable and fixed costs are calculated. For this study, a budget for 350 acres of each crop was simulated individually. Each simulation had one 130 PTO horsepower and one 105 PTO horsepower tractor and the same equipment complement. A used machinery complement was always assumed. Tables in Appendix Section II contain specific information about the field operations performed.

The basic equations used in these calculations are included in the appendix. Interest was calculated using a 6.5 percent rate; the average price of a machine is multiplied by 6.5 percent to calculate an opportunity cost of the capital invested. The annual tax rate is figured as one percent of the purchase price of the machine and the insurance cost is assumed to be six-tenths of a percent of the average machinery cost. One feature of this software that must be noted is that only equipment used has fixed costs calculated for it. In other words the program assumes that if a machine is not used it is not owned.

ENTERPRISE BUDGET

The per acre machinery costs for annual depreciation, interest, insurance, tax, repairs, fuel and lube from Machsel were entered into the OSU Enterprise Budget Software in the machinery cost section. This software provides an orderly method to calculate the variable costs of production. Information about types and rates of seed, fertilizers, and pesticides used in crop production were entered into the budgets in the various dialog boxes according to the user guide that accompanies each budget generator. The brand and application rates of pesticides (herbicide, insecticide, and fungicide) received from the professional's surveyed, and any application rate data was crosschecked with the 2003 OSU Extension Agents' Handbook of Insect, Plant Disease, and Weed Control. The prices for the pesticides used were obtained from the prices available in the software and were cross checked using price information from www.agscoinc.com. Chemical prices available in the software were obtained from the April 2003 Agricultural Prices publication and from 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 goals assumed. Price data for fertilizer came from April 2003 Agricultural Prices for the southwest area published by USDA.

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 Agricultural Prices. Sorghum prices came from the marketing year average price received for Oklahoma published in the November 1999-2003 issues of Agricultural Prices (USDA Nov. 1999-2003). Wheat prices were 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. Under the new law, peanut producers’ incomes are supported with the same type program as the major grain other commodities. This system of decoupled direct and counter cyclical payments is designed to allow producers to make production decisions without considering government programs. To compare peanut prices before and after the program change, the five-year average price for Oklahoma Marketing years 1997-2001 was calculated at 29 cents per pound (USDA Nov 1998-2002). In 2002, after FSRIA took effect, the Oklahoma Marketing year average price was 17 cents per pound (USDA Aug 2003). Because the program has changed, prior year prices may not be used to accurately predict the future. Therefore, only the 2002 peanut price was used in the analysis. 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.).

By using the above information in the Enterprise Budget Software, a general budget for each crop was established. For discussion an estimated yield per acre from the SWAT model was used to show an approximate return for each crop. For the analysis the yield from each sub basin is used to calculate total revenue. The estimated profit per year before government payments was calculated at $44.94 per acre for peanuts, $48.94 per acre for conventional tillage wheat, $26.61 for no till wheat, -$66.18 per acre for sorghum, and $32.61 per acre for CRP with conventional till establishment. The revenues, and variable and fixed costs for each crop are included in the following table and each crop are detailed in the Appendix Section III. It must be noted that these returns are at best an average and are shown here only for discussion. The linear programming model calculates the returns per acre for each HRU as part of the solution.

Table 8. 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 9. 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

Direct and Counter Cyclical Payment Calculation

Direct payments per acre are calculated as follows;

$$\text{Direct Payment} = DPR * \text{Base Yield} * .85 \tag{14}$$

Counter cyclical payments are not as straightforward, because the greater of the posted loan rate and the marketing year average price for the commodity is used in the calculation of the counter cyclical payment:

$$CCP = (TP-(LR \text{ or } MYA)-DP) * \text{Base Yield} * .85 \tag{15}$$

Where:	DP	Direct Payment
	DPR	Direct Payment Rate
	CCP	Counter Cyclical Payment
	TP	Target Price
	LR	Loan Rate
	MYA	Marketing Year Average Price
	DP	Direct Payment

Data for the calculations of wheat, sorghum, and peanut direct and counter cyclical payments came from the FSRIA 2002 and USDA agencies. Direct, counter cyclical, and loan deficiency payment rates were established by the FSRIA of 2002 and can be accessed on the USDA's farm bill website (USDA 2004). These payment rates were combined with the marketing year average price data collected from NASS publications for the crop prices used in the budgets with average base yield data for Oklahoma collected from FSA. Actual data collected and used from these sources are shown in tables 10 and 11. The average total Direct and Counter Cyclical Payment (DCP) per acre of wheat is $31.95, per acre of sorghum is $21.55, and per acre of peanuts is $165.90.

Table 10. Direct payment calculation for wheat, sorghum, and peanuts.

Crop	Direct Rate	Base Yield	Percent of Base	Direct Payment
Wheat	$0.52/bu.	31.9/bu.	85%	$14.10
Sorghum	$0.35/bu.	40.9/bu.	85%	$12.17
Peanut	$36/ton	1.394/ton	85%	$42.67

Table 11. Counter Cyclical Rate Calculation for wheat, sorghum, and peanuts.

		Greater of LR and MYA					
	Target Price	Loan Rate	MYA price	Direct Payment	Base Yield		Counter Cyclical Payment
Wheat	$3.92/bu.	$2.75/bu.	$2.67/bu.	$0.52/bu.	32.3	85%	$17.85
Sorghum	$2.57/bu.	$1.95/bu.	$1.85/bu.	$0.35/bu.	40.9	85%	$9.39
Peanut	$495/ton	$355/ton	$340/ton	$36/ton	1.3941	85%	$123.24

GAMS

Part I. Profit maximizing solutions with various runoff levels and CRP policy.

To test the scenarios established above in the conceptual framework for different sediment, nitrogen, and phosphorus abatement levels with and without commodity payments, a linear programming model was established in GAMS. The equations solved by this model include two different profit equations depending on which policy environment is being tested. To model current CRP policy where the DCP is lost when the land is enrolled into CRP the following equation was used.

$$(16) \qquad Maximize \sum_{i=1}^{5} \sum_{j=1}^{848} \left(\left(\left(P_i * Y_{ij} \right) + F_i - G_{ji} \right) - C_i \right) X_{ij}$$

For scenarios with an alternative CRP policy where the DCP to producers is continued when the land is enrolled into CRP equation 17 was used.

$$(17) \qquad Maximize \sum_{i=1}^{5} \sum_{j=1}^{848} \left(\left(\left(P_i * Y_{ij} \right) + F_i \right) - C_i \right) X_{ij}$$

These equations were solved subject to the following constraints:

(18) $$\sum_{i=1}^{5}\sum_{j=1}^{848} Ph_{ji} * X_{ij} \le Plimit$$

(19) $$\sum_{i=1}^{5}\sum_{j=1}^{848} NIT_{ji} * X_{ij} \le Nlimit$$

(20) $$\sum_{i=1}^{5}\sum_{j=1}^{848} SED_{ji} * X_{ij} \le Slimit$$

(21) $$\sum_{i=1}^{5} X_{ij} = Acres_{j}$$

(22) $$X_{ij} \ge 0$$

Where:

P_i	Price of Crop I
Y_{ij}	Yield of Crop I on HRU J
F_i	Forage Value for Crop I
G_{ji}	Direct and Counter Cyclical Payment Forfeited if HRU J is enrolled in CRP
C_i	Total Cost to produce Crop I
Ph_{ji}	Phosphorus runoff from HRU J under Crop I
NIT_{ji}	Nitrogen runoff from HRU J under Crop I
SED_{ji}	Sediment runoff from HRU J under Crop I
R_i	Total Acres of Crop I in the Watershed
$Acres_j$	Acres in HRU J
X_{ij}	The Variable: the number of acres of Crop I in HRU J.

The difference in the equations 16 and 17 is the removal of $-G_{ji}$ in equation 17. G_{ji} represents a vector of actual DCPs per acre for each HRU determined from that parcel's crop base. In equation 16 the "cost" of enrolling in CRP to the producer is increased by the loss of the DCP for that land parcel. In this analysis the only time that the DCP is included in the calculations is when it is forfeited under current CRP regulations, since this is the only time that producers should include the DCP in their decision of what to produce.

In equation 16, if a producer has a land parcel with peanuts as the base and he plants wheat on the land crop under the current policy he would still receive his DCP calculated from peanut base so G_{ji} is not a factor. But, if that producer enrolled that parcel into CRP the DCP would be forfeited. In equation 17, the alternative policy where DCP is not forfeited when a land parcel is enrolled in CRP G_{ji} is never a factor so it is not included in the equation. CRP revenue is calculated in both equations using a price of $43.01 and a quantity of 1.

An example of the GAMS Linear Programming model used to test the scenarios is included in Appendix Section IV to show how the data was entered and used. The equations and constraints given above were used by selecting the appropriate objective function for the policy environment being tested and by changing the sediment, nitrogen, and phosphorus limits in the constraints.

Assumptions required to establish the model include;

a. Management was constant--the cultivation, chemical, and fertilizer was assumed constant across HRUs for the same crops.

b. All land was allocated. Each HRU was assigned some cover type so that no HRU could be removed from calculation.

c. HRUs that were in pasture, water, or forest in the base were assumed to be either physically or economically unable to be converted to crop use so they remained in their base use.

d. Yield data from SWAT was assumed to represent actual production from each HRU in each particular land use.

e. Crop prices and input costs for each crop type are constant for each HRU.

f. Per acre direct and counter cyclical payments are constant for wheat, peanuts, and sorghum on each HRU.

g. Runoff data for CRP was calculated using information primarily gathered to represent a well-maintained Bermuda pasture land use. It is assumed that the actual runoff levels from CRP would be at least as good as those shown by this SWAT output for improved pasture.

h. The total runoff levels for sediment, nitrogen, and phosphorus from the base were assumed to be the starting levels for abatement in each of the scenarios.

An alphanumeric system was developed to increase understanding of what policy environment and runoff abatement levels were being tested in each scenario. If the direct and counter cyclical payment (DCP) is lost when land is enrolled into CRP the description begins with the letter “L”. If the DCP is kept by the producer when land is enrolled into CRP then the description begins with the letter “K”. To indicate the level of runoff abatement for sediment, nitrogen, and phosphorus a series of three numbers follow the “L” or “K” as sediment abatement / nitrogen abatement / phosphorus abatement. A few examples of how this system works would be K/20/10/10. This description indicates that the producer keeps the DCP if cropland is enrolled into CRP and there is 20 percent sediment abatement, 10 percent nitrogen abatement, and 10 percent phosphorus abatement. L/20/0/0 indicates that the DCP is lost to the producer if the land is enrolled into CRP and there is 20 percent sediment abatement and nitrogen and phosphorus runoff levels are only constrained by the physical relationship to sediment runoff.

Part II. Gross Polluter vs. Profit Maximizing Abatement.

Information taken from SWAT for crop, sediment, nitrogen, and phosphorus yield per acre will be combined in a spreadsheet with commodity prices and production costs from the Enterprise Budgets. For the gross polluter analysis all of the assumptions developed for the SWAT model and the Enterprise Budgets were used. In addition, the only land use that a parcel of land could convert to is CRP.

In EXCEL the producers' profit equation was established to calculate the sum of the individual profits from each HRU according to the crop selected for that HRU by the linear programming model. In this equation if a parcel of land was enrolled in CRP the producer does not receive the DCP for that parcel. From the results of the linear programming solutions in each scenario, when the phosphorus runoff was controlled, the sediment and nitrogen runoff was also controlled. With this information the HRUs will be sorted in EXCEL according to their phosphorus runoff per acre. By adding a column depicting CRP enrollment and an "IF" statement in the profit equation, the HRUs will be systematically converted to CRP beginning with the HRU with the highest rate of phosphorus runoff per acre until the runoff abatement goal is met.

Solutions to the profit maximizing scenarios were derived from the linear programming model used in the other sections of this study. This model maximizes producer profits subject to constraints on runoff and the percent of acres that can be enrolled into CRP.

To compare between the two policies, the cost per pound of phosphorus abated and the net change in the society cost will be computed. To estimate the net change to society, the change in producer profits was added to the change in government expense (GE). The change in producer profit (PP) was calculated by:

(23) $PP_b - PP_a = \Delta PP$

The change in government expense was calculated by:

(24) $GE_b - GE_a = \Delta GE$

Where:

(25) GE=Total DCP + Total CRP Rental Cost

b Scenario with zero abatement.
a Scenario with current abatement amount (10, 20, 30, 40 percent)

Each of these calculations was performed for both policies at all phosphorus abatement levels for a comparison of the net change to society and in the cost per pound abated.

CHAPTER V

RESULTS

The results section will be broken down into sections for discussion. The first section will contain information relating to the total profit, crop acreages, and runoff levels from Table 1 with the descriptions of the model runs in Table 2. The second part of the results will contain information about how the total crop acreages and runoff levels change as the level of sediment, nitrogen, and phosphorus abatement increases. Part three of the results will show to the extent possible how the spatial allocation of the landscape changes in each of the model runs by using ArcView GIS maps. Part four will contain the comparison of a policy targeting the gross polluting land parcels only and a profit maximizing policy to achieve corresponding abatement goals.

PART I. MODEL RUN RESULTS.

Table 12. Profit, Total Crop Acres, Runoff, Abatement Level, and Percent of Erosion Compared to Base Levels for Each Model Run. (Model runs are described in Table 13.)

Scenario	Base	Profit Max	L/10/10/10	L/20/20/20	L/20/10/10	K/10/10/10	K/20/20/20	K/20/10/10	L/10/0/0	L/20/0/0
Profit including DCP	$7,035,706	$7,807,361	$7,630,914	$7,439,376	$7,630,914	$8,387,771	$8,209,580	$8,387,771	$8,192,981	$8,011,169
DCP/Acre of CRP [1]		-$31.14	-$31.17	-$31.20	-$31.17	-$43.59	-$43.28	-$43.59	-$31.10	-$31.16
Government Expense	$5,026,696	$5,181,754	$5,205,007	$5,227,728	$5,205,007	$6,097,516	$6,097,516	$6,097,516	$5,198,983	$5,212,430
Acres										
Con Wheat	79800	58648	61060	62961	61060	52601	57061	52601	17422	18605
Peanut	14204	21548	16774	12120	16774	20274	14414	20274	40552	35908
Sorghum	5583									
NT Wheat	0	6332	6696	7488	6696	1815	3216	1815	27147	29403
CRP	0	13059	15057	17019	15057	24897	24897	24897	14466	15671
Marginal Cost										
CRP						24.93	27.31	24.93		
Runoff										
Sediment (tons)	204,880	171,773	155,329	138,178	155,329	145,445	131,566	145,445	184,389	163,901
Nitrogen (lbs)	652,830	583,990	532,307	481,463	532,307	511,476	465,322	511,476	678,399	617,695
Phosphorus (lbs)	180,370	180,370	162,333	144,296	162,333	162,333	144,296	162,333	242,765	221,538
Marginal Cost										
Sediment									8.71	9.12
Nitrogen										
Phosphorus		9.58	10.11	11.02	10.11	9.46	10.40	9.46		
Restriction										
Sediment		0%	10%	20%	20%	10%	20%	20%	10%	20%
Nitrogen		0%	10%	20%	10%	10%	20%	10%		
Phosphorus		0%	10%	20%	10%	10%	20%	10%		
Sediment % of Base	100.0%	83.8%	75.8%	67.4%	75.8%	71.0%	64.2%	71.0%	90.0%	80.0%
Nitrogen % of Base	100.0%	89.5%	81.5%	73.8%	81.5%	78.3%	71.3%	78.3%	103.9%	94.6%
Phosphorus % of base	100.0%	100.0%	90.0%	80.0%	90.0%	90.0%	80.0%	90.0%	134.6%	122.8%

Table 12 Continued Profit, Total Crop Acres, Runoff, Abatement Level, and Percent of Erosion Compared to Base Levels for Each Model Run. (Model runs are described in Table 13.)

Scenario	K/10/0/0	K/20/0/0	L/0/10/0	L/0/20/0	K/0/10/0	K/0/20/0	L/0/0/10	L/0/0/20	K/0/0/10	K0/0/20
Profit	$8,937,132	$8,776,387	$8,045,451	$7,832,402	$8,829,114	$8,623,364	$7,630,914	$7,439,376	$8,387,771	$8,209,580
DCP/Acre of CRP [1]	-$42.39	-$41.54	-$31.17	-$31.06	-$41.85	-$40.79	-$31.17	-$31.20	-$43.59	-$43.28
Total Gov. expense	$6,097,516	$6,097,516	$5,261,127	$5,300,314	$6,097,516	$6,097,516	$5,205,007	$5,227,728	$6,097,516	$6,097,516
Acres										
Con Wheat	12686	14495	14290	13289	12340	13424	61060	62961	52601	57061
Peanut	43994	39326	42281	37594	44511	38295	16774	12120	20274	14414
Sorghum										
NT Wheat	18011	20869	23223	25805	17839	22971	6696	7488	1815	3216
CRP	24897	24897	19793	22899	24897	24897	15057	17019	24897	24897
Marginal Cost										
CRP	22.03	26.26			29.31	31.15			24.93	27.31
Runoff										
Sediment (tons)	184,389	163,901	198,711	176,290	200,862	176,519	155,329	138,178	145,445	131,566
Nitrogen (lbs)	665,322	610,090	587,547	522,264	587,547	522,264	532,307	481,463	511,476	465,322
Phosphorus (lbs)	245,644	224,905	237,824	215,933	241,109	216,209	162,333	144,296	162,333	144,296
Marginal Cost										
Sediment	7.34	8.48								
Nitrogen			3.20	3.38	3.03	3.35				
Phosphorus							10.11	11.02	9.46	10.40
Restriction										
Sediment	10%	20%								
Nitrogen			10%	20%	10%	20%				
Phosphorus							10%	20%	10%	20%
Sediment % of Base	90.0%	80.0%	97.0%	86.0%	98.0%	86.2%	75.8%	67.4%	71.0%	64.2%
Nitrogen % of Base	101.9%	93.5%	90.0%	80.0%	90.0%	80.0%	81.5%	73.8%	78.3%	71.3%
Phosphorus % of Base	136.2%	124.7%	131.9%	119.7%	133.7%	119.9%	90.0%	80.0%	90.0%	80.0%

[1] Average DCP payment that is lost or would be lost per acre when the land is enrolled in CRP, With the current CRP policy this is subtracted from the profit per acre when considering whether or not to enroll into CRP. In the alternative policy it is not subtracted.

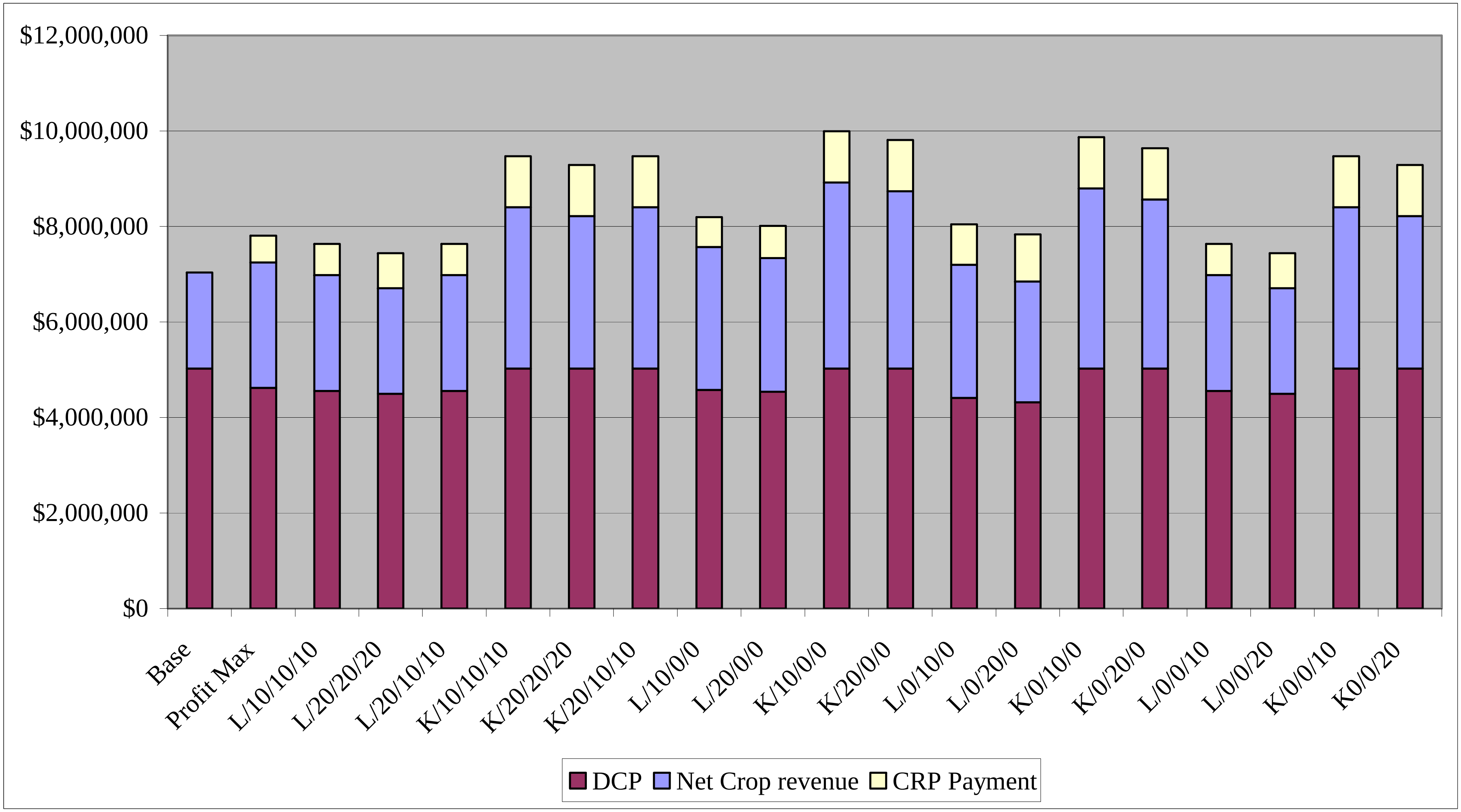


Figure 1. Total Producer Profits from DCP, Net Crop Revenue, and CRP Rental Payment for each scenario.

Table 13. Objectives and Constraints of Model Runs used for Analysis.

Base	Model check-profit, crop acres, and runoff levels all equal to base scenario with no CRP acres.
L/0/0/0	Profit maximized with constraints on CRP acres and runoff less than or equal to base levels.
2	Profit maximized with an acreage constraint on CRP and **with the DCP lost** if the land is enrolled in CRP.
L/10/10/10	Sediment, nitrogen, and phosphorus runoff each restricted by 10 percent from the base
L/20/20/20	Sediment, nitrogen, and phosphorus runoff each restricted by 20 percent from the base.
L/20/10/10	Sediment runoff restricted by 20 percent, nitrogen and phosphorus each restricted by 10 percent from the base.
3	Profit maximized with an acreage constraint on CRP and **without the DCP lost** if the land is enrolled into CRP. (For A, B, and C)
K/10/10/10	Sediment, nitrogen, and phosphorus runoff each restricted by 10 percent from the base.
K/20/20/20	Sediment, nitrogen, and phosphorus runoff each restricted by 20 percent from the base.
K/20/10/10	Sediment runoff restricted by 20 percent, nitrogen and phosphorus each restricted by 10 percent from the base.
4	Profit maximized with an acreage restriction on CRP, **with DCP lost** if land is enrolled in CRP under different runoff abatement restrictions on sediment nitrogen and phosphorus individually.
L/10/0/0	10 percent reduction in sediment with nitrogen and phosphorus unconstrained.
L/20/0/0	20 percent reduction in sediment with nitrogen and phosphorus unconstrained.
L/0/10/0	10 percent reduction in nitrogen with sediment and phosphorus unconstrained.
L/0/20/0	20 percent reduction in nitrogen with sediment and phosphorus unconstrained.
L/0/0/10	10 percent reduction in phosphorus with sediment and nitrogen unconstrained.
L/0/0/20	20 percent reduction in phosphorus with sediment and nitrogen unconstrained.
5	Profit maximized with and acreage restriction on CRP **without DCP lost** if land is enrolled in CRP under different runoff abatement restrictions on sediment nitrogen and phosphorus individually.
K/10/0/0	10 percent reduction in sediment with nitrogen and phosphorus unconstrained.
K/20/0/0	20 percent reduction in sediment with nitrogen and phosphorus unconstrained.
K/0/10/0	10 percent reduction in nitrogen with sediment and phosphorus unconstrained.
K/0/20/0	20 percent reduction in nitrogen with sediment and phosphorus unconstrained.
K/0/0/10	10 percent reduction in phosphorus with sediment and nitrogen unconstrained.
K/0/0/20	20 percent reduction in phosphorus with sediment and nitrogen unconstrained.

Discussion of Table 12. Total acres, cost, and runoff for runoff abatement under two CRP policies.

A linear programming model, with the objective of maximizing producer profits subject to constraints on CRP acres and sediment, nitrogen, and phosphorus (SNP) was run according to the restrictions on runoff levels for each scenario. The results of these scenarios are shown in Table 12. These scenarios show how the totals of each of the variables of interest change as the runoff abatement levels reduce by ten percent and twenty percent from the base. Also shown is how the total runoff and crop acres change across the two policies. In this section the totals presented only include the profit, acres, and runoff from the cropland in the watershed. Forest, water, and grassland have been removed because these areas are assumed to be either not physically or economically feasible to convert to cropland. The profits represented in Table 12 are the profits that should be expected in the watershed with direct and counter cyclical payments allocated according to the policy environment being tested. The profits in the scenarios beginning with the letter "L" have been reduced by the amount that would be deducted from the DCP if the land were enrolled in CRP. Figure 1 shows how the total producer profits from cropland in the watershed change throughout the different scenarios.

First, a test was conducted to determine how accurately the profit-maximizing model using the crop budgets could reproduce the spatial allocation of actual current cropping patterns in the watershed. The Base scenario is equal to the "spread sheet" answer for total crop acres, profit, and runoff levels. In this scenario the profit-maximizing model was solved for 79,800 acres of wheat, 14,204 acres of peanuts, and 5,583 acres of sorghum with producer profits before government payments of

$2,009,010. Sediment runoff equal to 204,880 tons, nitrogen runoff equal to 661,110 pounds, and phosphorus runoff equal to 180,370 pounds were also constrained.

Of the 1,819 HRUs in the watershed approximately 75 percent of the total land use selected by the model was the same as the current land use in the watershed. This percentage is inflated by the way that the restrictions are placed on the model. Grassland, forest, and water account for roughly half of the watershed both in number of HRUs and in the number of acres. To convert from one land use to another has a cost attached to that land use conversion. For cropland switching between crops this cost is assumed to be insignificant. The cost for land switching from grassland, forest, or water to cropland would be quite high. The assumption was also made that if a HRUs’ land use was grassland, forest, or water it would remain in grassland, forest, or water. Based on the assumption of high conversion costs, it is assumed that if a land parcel has not been in crop production it will not be converted to crop production. If the spatial allocation of cropland in the watershed in the current land use is compared to the spatial allocation of the cropland in the watershed from the linear programming solution approximately fifty percent of the HRUs have the same actual land use as the hypothetically optimal programming solution. If the profit-maximizing model had all of the factors that producers use when making their planting decision included, these solutions would have selected the exact same acreages. Although the model has been constructed to mimic as closely as possible the expected crop and runoff yields from each HRU and the revenues and costs for the average producer in the watershed it cannot account for all uncertainty. Primarily, the planting habits or the risk characteristics of the producers.

By comparing the base scenario with scenario L/0/0/0 we find that according to the estimated price, cost, runoff, and production information used to construct the model, the watershed is not spatially allocated in a way that maximizes revenue to the farmers or minimizes the environmental damages from runoff. The profit estimated from the spreadsheet solution of the current cropland use in the watershed using the same price, cost, runoff, and yield information used in the model is $7,035,706 with government payments. This is roughly $800 thousand dollars less than L/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 scenario L/0/0/0 the number of acres of conventional tillage wheat decreased by 21,152 acres, while peanuts increased by 7,344 acres, sorghum decreased to zero acres, no till wheat increased by 6,332 acres and CRP increased by 13,059 acres from the current levels. In the scenario L/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, with phosphorus remaining at the base level as the limiting constraint.

The scenarios L/10/10/10, L/20/20/20, L/20/10/10, K/10/10/10, K/20/20/20, and K20/10/10 each have restrictions on all three runoff variables, sediment, nitrogen, phosphorus. The scenarios with descriptions beginning with the letter “L” are the results from analysis when the direct and counter cyclical payments are lost when that piece of cropland is enrolled into CRP. The payments that were used in the model runs were

$165.90/acre for peanut base crop, $31.95/acre for wheat base crop, and $21.55/acre for sorghum base crop. Farmers are only able to receive these payments, which are calculated from past production and yield, only if their land remains in an agricultural use. The difference in scenarios beginning with “L” and “K” is that the runs beginning with “K” do not have this payment loss considered in the profit equation.

The objective of scenario L/10/10/10 was to maximize profit subject to a constraint on CRP acres, and limit sediment, nitrogen, and phosphorus runoff by 10 percent from the base level. Scenario L/10/10/10 has a profit of 7.6 million dollars and is directly comparable to scenarios, L/0/0/0, L/20/20/20, and K/10/10/10. First, between L/10/10/10 and L/0/0/0, profit decreased by $176,447 with a 9.6 percent decrease in sediment(S) runoff, 8.9 percent decrease in nitrogen(N) runoff, and a 10 percent decrease in phosphorus(P) runoff from L/0/0/0. SNP runoff decreased by 24.2 percent, 18.5 percent, and 10 percent respectively from the base. Phosphorus was the limiting constraint. To reach the goals placed on runoff levels, land shifted from peanut production into conventional and no till wheat production and CRP acreage. In the L/20/20/20 scenario runoff levels were each restricted to 80 percent of the base level for analysis, profit decreased by $367,985 from L/0/0/0, and by $191,538 from L/10/10/10. Phosphorus abatement at 20 percent was again the limiting constraint in scenario L/20/20/20 in this basin. Sediment runoff decreased by 32.6 percent, nitrogen decreased by 26.2 percent, and phosphorus decreased by 20 percent from the base. SNP decreased by 19.6 percent, 17.6 percent, and 20 percent respectively from the profit maximizing solution. To reach these higher abatement goals more land shifted from peanut production to conventional and no till wheat production and CRP.

The results from scenario K/10/10/10 are not entirely consistent with what was expected. In model scenarios where the DCP is lost when land is enrolled into CRP, there was a very high cost associated with switching ground that was in peanut production into CRP ($165.90/acre). In the scenarios beginning with the letter "K" the cost has been removed and a reduction in peanut acres is expected because land that was in peanut production would not have a large "penalty" assessed for enrolling in CRP. However, this was not the case according to the total acres allocated to each crop. Scenario K/10/10/10 had a large decrease in the number of acres planted in conventional and no till wheat, but had a small decrease in the number of acres planted in peanuts. The CRP did have an increase of 11,838 acres, which according to the totals came primarily from land that was in wheat production. The policy change decreased SNP runoff levels by 6.4 percent, 3.9 percent, and 0 percent respectively from scenario L/10/10/10. SNP runoff decreased by 29.0 percent, 21.7 percent, and10 percent respectively from the base and 15.3 percent, 12.4 percent and 10 percent from scenario L/0/0/0. Phosphorus was the limiting constraint. Profit increased by $1,352,065 from the base, $580,410 from scenario L/0/0/0 and $756,858 from L/10/10/10.

Comparison between K/10/10/10 and K/20/20/20 shows that profit decreased by $177,921, and crop production shifted from peanuts into conventional and no till wheat. SNP runoff levels each decreased by 9.5 percent, 9.0 percent, and 11.1 percent from K/10/10/10, respectively.

Results for scenarios L/10/0/0 through K/0/0/10 in Table 12 are very similar to the results of the scenarios in the previous paragraphs, so they will not be discussed in as great of detail here. There are a few very important observations that should be noted.

First, total phosphorus runoff cannot be controlled by only targeting sediment or nitrogen runoff. In the all of the scenarios with individual sediment or nitrogen abatement when either sediment runoff or nitrogen runoff is constrained the other runoff level is also reduced or maintained close to the base level. Phosphorus does not follow this pattern; in the runs where only sediment or nitrogen is controlled, phosphorus increases by about twenty percent or more above the base level. Second, when phosphorus runoff is controlled, the sediment and nitrogen runoff levels are also controlled. If phosphorus runoff is controlled, sediment and nitrogen will be reduced by at least the amount of phosphorus reduction. Third, the solutions for phosphorus individually are identical to the solutions when SNP runoffs were restricted together. Since phosphorus was the binding constraint from the combined runs this is not surprising.

Comparison of the average DCP payment lost under the current policy or the amount of the equivalent calculation with the policy that is not lost is shown in Table 12 as the average DCP lost per acre of CRP. This average is around 31 dollars indicating that the acres enrolled in CRP with this policy are primarily from land that was in wheat and sorghum production. When the policy is changed so that the DCP is not reduced when the land is enrolled, the average increases to over 43 dollars indicating that more peanut land is being enrolled into CRP.

The total government expense is also included in Table 12. This total is calculated as the DCP payment amount for the watershed minus the DCP lost under the current policy plus the total CRP rental payment. Across all of the restrictions, the policy where the farmers keep all of the DCP regardless of enrollment in CRP always results in a higher government expense. The difference between comparable runs is a maximum of

$898,533 more and a minimum of $797,202 more. This increase in government expense can simply be viewed as a transfer of funds between the government and the producers. One factor that needs to be determined is how much of the added government expense benefits the producers.

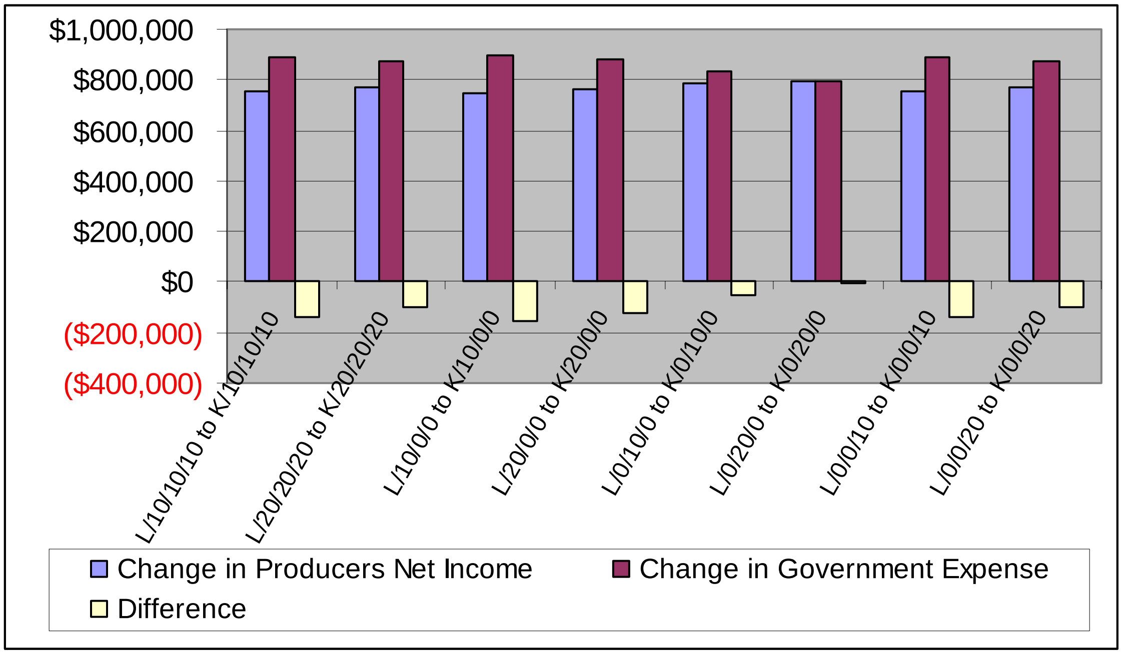


Figure 2. Welfare gain or losses because of the change from current CRP policy to proposed policy where DCP is not forfeited.

Figure 2 shows the change in producer profit, the change in government expense, and the amount of the difference between the increase in producer profits from the change in policy and the increase in government expense with the same change in policy. For example for the change from L/10/10/10 to K/10/10/10 producers net income or profit increased by $756,857, Government expense increased by $892,509 resulting in a difference of -$135,652. Each of the comparisons are performed on scenarios that had identical restrictions. The only change was the DCP payment policy. Examination of the results indicates that before the value of damage costs is included there may be a loss to society, because the increase in producer profits is not as large as the increase in government outlay.

Figures of increasing abatement levels.

This section contains a discussion of the figures that illustrate how total acres of each crop, total cost to producers, and percentage of base runoff change as the level of abatement increases. The linear programming model described in the procedures was solved to maximize producer profits subject to constraints on the amount of runoff in the watershed. Constraints on the model include total acres selected must equal the total cropland in the watershed; CRP acres are limited to 25 percent of the cropland; and the amounts of SNP runoff.

The variation in each of the following charts is found in the level of abatement of sediment, nitrogen, or phosphorus either individually or a combination of the three. Each of the charts corresponding to the abatement of one kind of runoff will be discussed together. All of the charts containing percent of base runoff will contain a line showing how the runoff level under the abatement constraint changes as well as lines showing how the other unconstrained runoffs react.

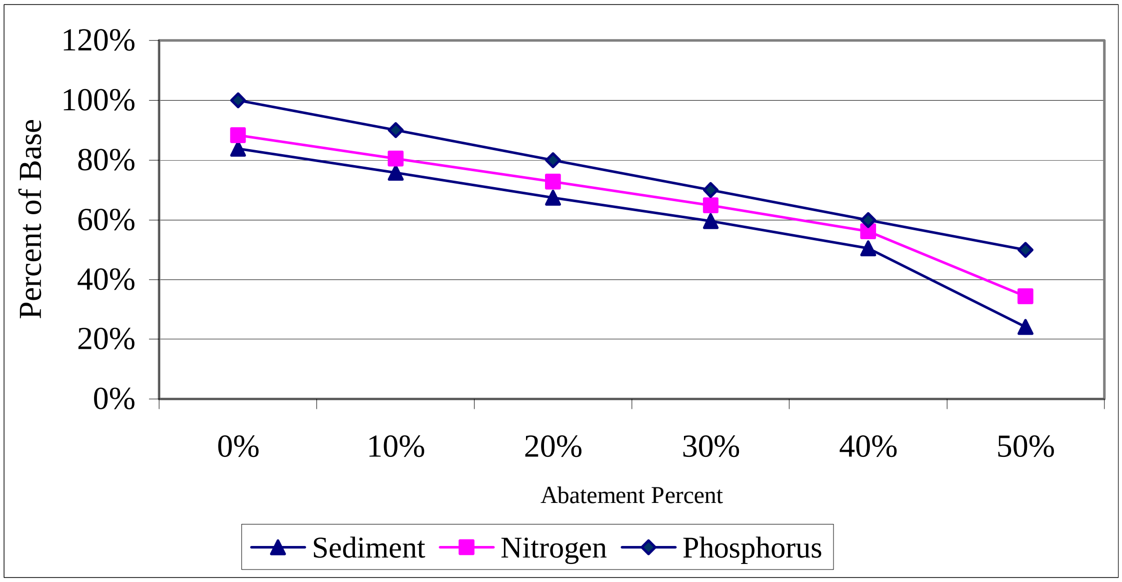


Figure 3. Percent of Base Runoff if DCP is Lost if Land is enrolled in CRP with Constraints on All Three Runoff Variables.

Figure 3 shows how the relationship of SNP runoff change when all three are constrained to increasing abatement levels with the producers DCP lost for a land parcel if that parcel is enrolled into CRP. In the model runs depicted in this Figure, SNP runoff levels are each constrained to greater than or equal to 0, 10, 20, 30, 40, and 50 percent abatement. Analysis of the figure shows that at each abatement level, phosphorus runoff is the limiting constraint so that sediment and nitrogen runoff abated is greater than the target level for each point.

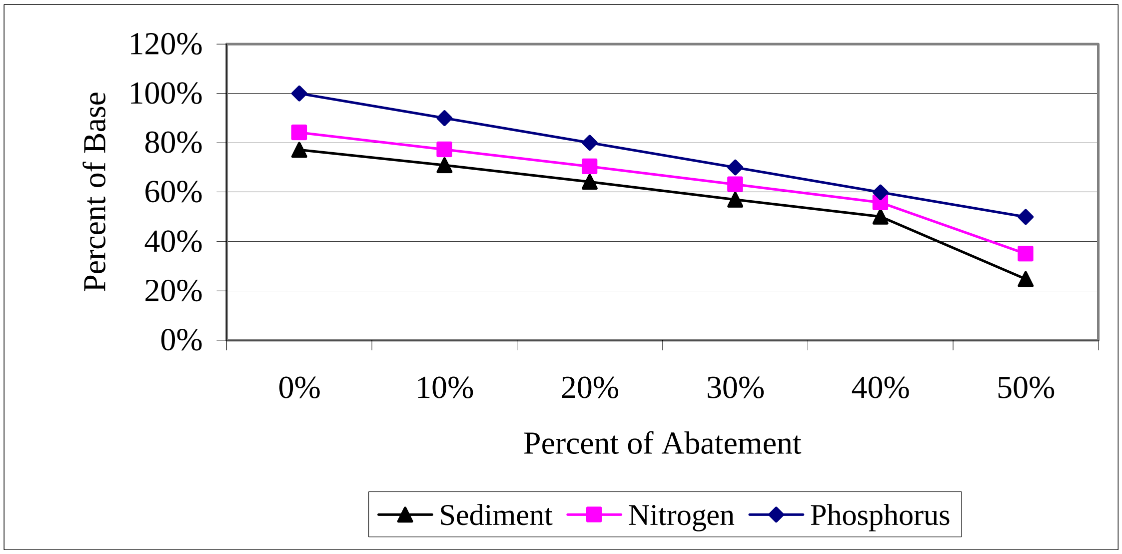


Figure 4. Percent of Base Runoff without DCP lost if Land is enrolled in CRP with Constraints on All Three Runoff Variables.

Figure 4 shows how the SNP runoff interacts as runoff abatement level increases. This chart shows how the SNP runoff percents change as the abatement percent increases to 50 percent when the producers direct and counter cyclical payment is received by producers even if their land is enrolled in CRP. Phosphorus is the limiting runoff variable in the model solutions shown in figure 4. Analysis of this figure indicates that if only phosphorus runoff was limited then sediment and nitrogen runoff levels will also be reduced to at least the same level.

Sediment abatement with DCP lost if land is enrolled into CRP.

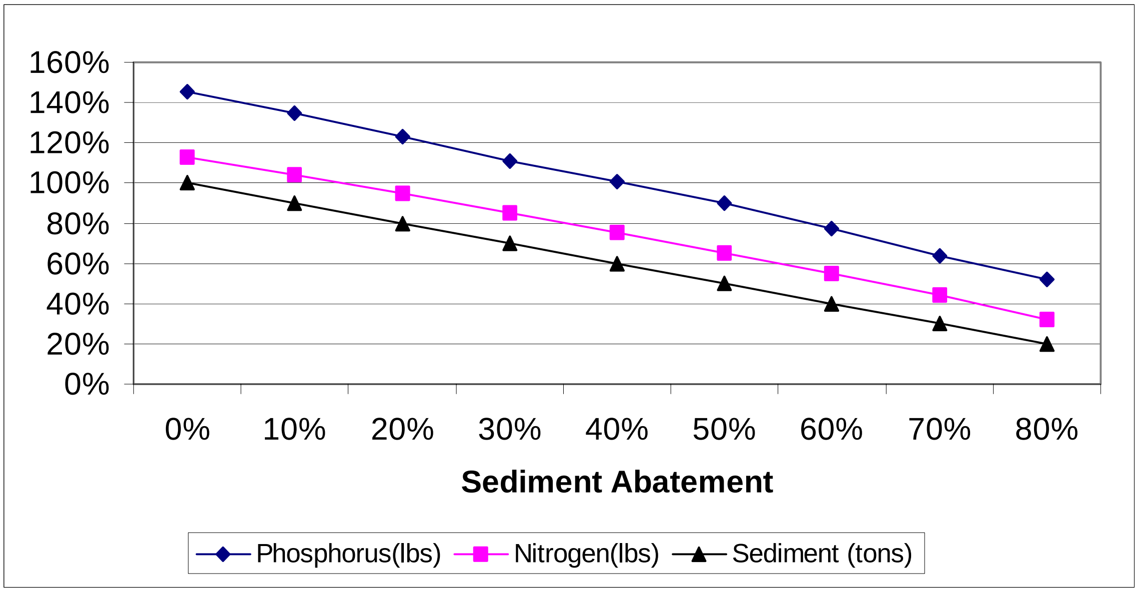


Figure 5. Percentage Change from Base Runoff when Profit is Maximized Subject to Sediment Abatement if the DCP is Not Received when Land is Enrolled into CRP.

Figure 5 shows the percent of base runoff for sediment nitrogen and phosphorus runoff when sediment runoff is constrained to meet increasing abatement goals. Nitrogen and phosphorus runoff decreases as the abatement level of sediment increases, but when only sediment is constrained, nitrogen and phosphorus increased to 113 percent and 146 percent of their base levels, respectively. Approximately a fifteen percent sediment abatement goal is needed for nitrogen runoff to equal the base, and about forty percent sediment abatement is needed for phosphorus runoff to equal the base. Analysis of this figure indicates that if phosphorus and nitrogen runoff levels cannot increase above the base, then policy only limiting sediment would not be feasible.

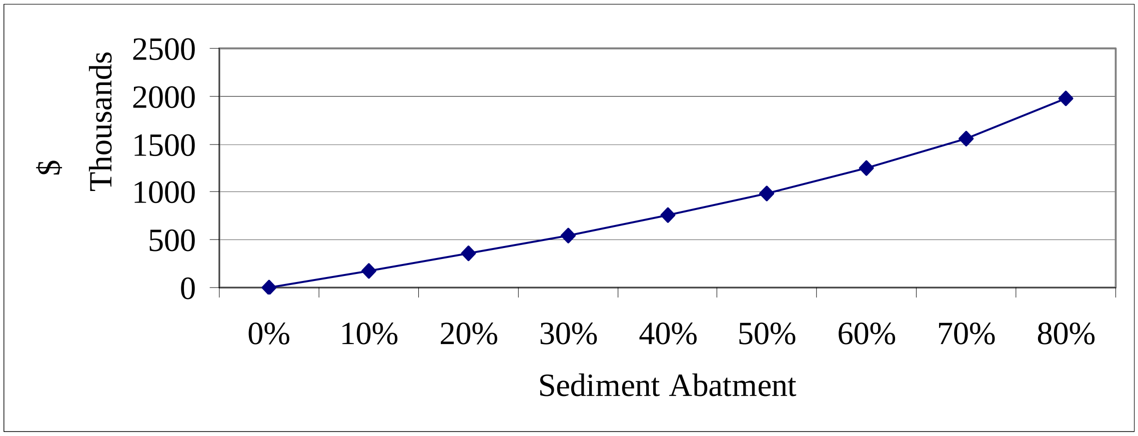


Figure 6. Cost of Sediment Abatement with DCP lost by Producers if Land is enrolled in CRP.

Figure 6 shows how the total producers' profit decreases as the level of sediment abatement increases. Cost was calculated as the difference of total profit with zero sediment abatement and the total profit at the current level of sediment abatement along the X-axis. According to this calculation, a 50 percent reduction in sediment runoff from cropland in the watershed would decrease producers' total profit by $988,334. This is calculated as $9.65 per ton of sediment abated.

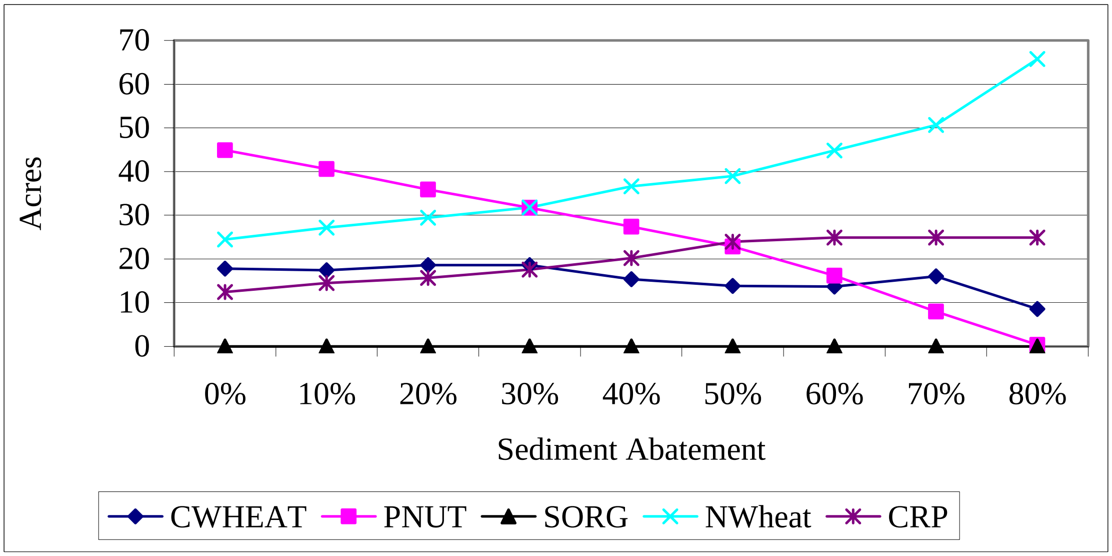


Figure 7. Crop Acres with DCP Not Received by Producers if Land is Enrolled in CRP.

Figure 7 depicts how the acres of conventional tillage and no till wheat, peanut, sorghum, and CRP change as the level of sediment abatement increases. With zero and 50 percent sediment abatement, there were 17,193 (13,853) acres of conventional tillage wheat, 44,919 (22,836) acres of peanuts, 0 (0) acres of sorghum, 24,454 (38,983) acres of no till wheat and 12,421 (23,915) acres of CRP (crop acres with fifty percent sediment abatement given in parentheses). By studying this figure, it can be seen that as the level of sediment abatement increases, the major change in acres planted to the various crops is the decrease in peanut and conventional tillage wheat acres and the increase in no till wheat and CRP acreages.

Sediment abated without DCP lost if land is enrolled in CRP

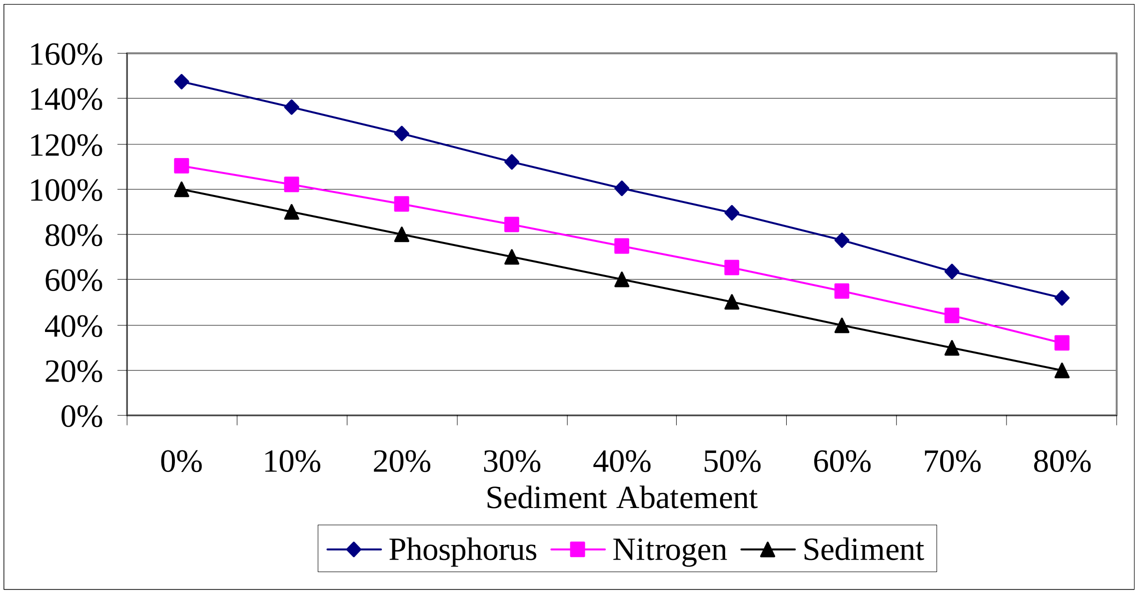


Figure 8. Percentage Change from Base Runoff when Profit is Maximized Subject to Sediment Abatement.

Figure 8 shows how the sediment, nitrogen, and phosphorus runoff levels change as a percent of the base levels as the amount of sediment abatement increases. Nitrogen and phosphorus runoff are 110 percent and 147 percent of their respective base levels at zero sediment abatement. As the amount of sediment abatement increases, the levels of nitrogen and phosphorus decline, but it takes a ten percent and a forty percent reduction in sediment runoff respectively for nitrogen and phosphorus to be decreased to their base levels. Analysis of this figure indicates that even when government payments are kept when land is enrolled in CRP, a policy that only limits sediment runoff would not effectively control nitrogen and phosphorus runoff below the base runoff levels.

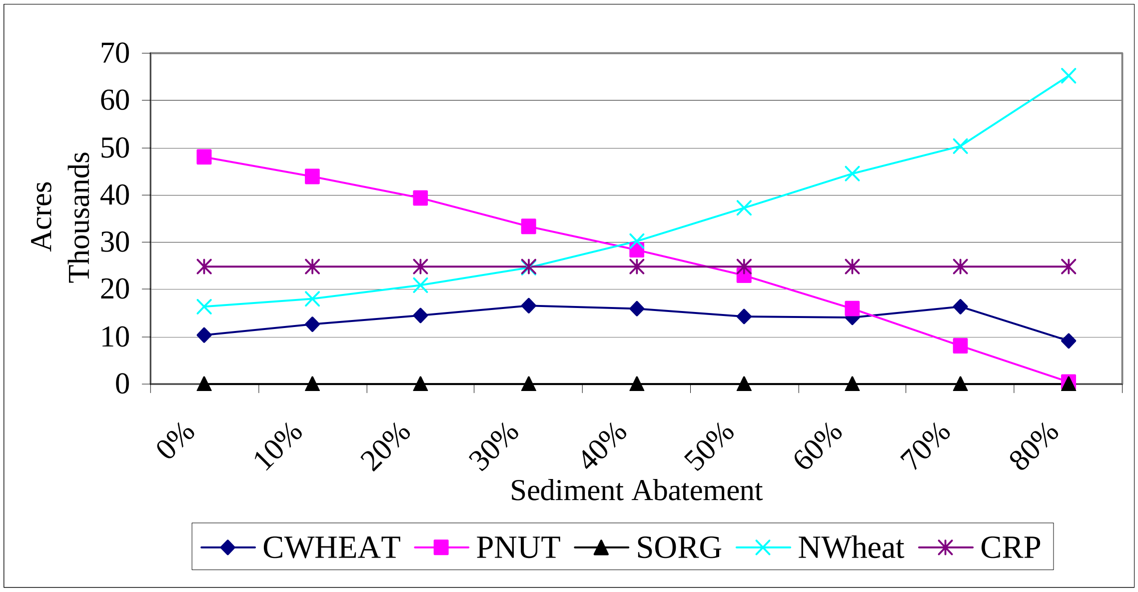


Figure 9. Crop Acres When DCP is received by Producers If Land is enrolled in CRP.

The total crop acreages of conventional and no till wheat, peanuts, sorghum and CRP are shown in Figure 9 when direct and counter cyclical payments are kept if cropland is converted into CRP. This figure shows that as the level of sediment abatement increases in the watershed that the number of acres of peanuts declines rapidly from 47,984 acres, while the number of acres planted into no till wheat production increases. CRP acreage remains constant across all abatement levels at the maximum allowed enrollment amount of 24,897 acres, which is 25 percent of the cropland in the watershed. Conventional till wheat fluctuates between 10,283 and 16,515 acres, and sorghum remained at zero acres regardless of the sediment abatement.

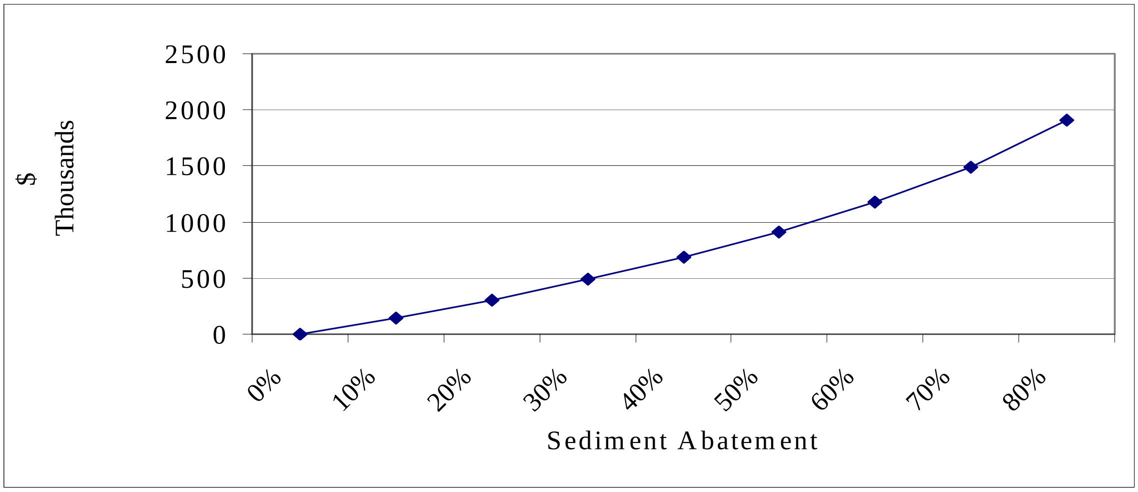


Figure 10. Cost of Sediment Abatement with DCP Received by Producers if Land is enrolled in CRP.

This figure shows how the total profit lost to producers increases as the level of sediment abatement increases. Cost is calculated as the difference in producer’s total profit with sediment runoff equal to the base level and total producers profit with the current sediment abatement level shown on the X-axis. The cost of reducing sediment runoff by fifty percent is $913,977 or $8.92 per ton.

Nitrogen Abatement with DCP lost if cropland is enrolled into CRP.

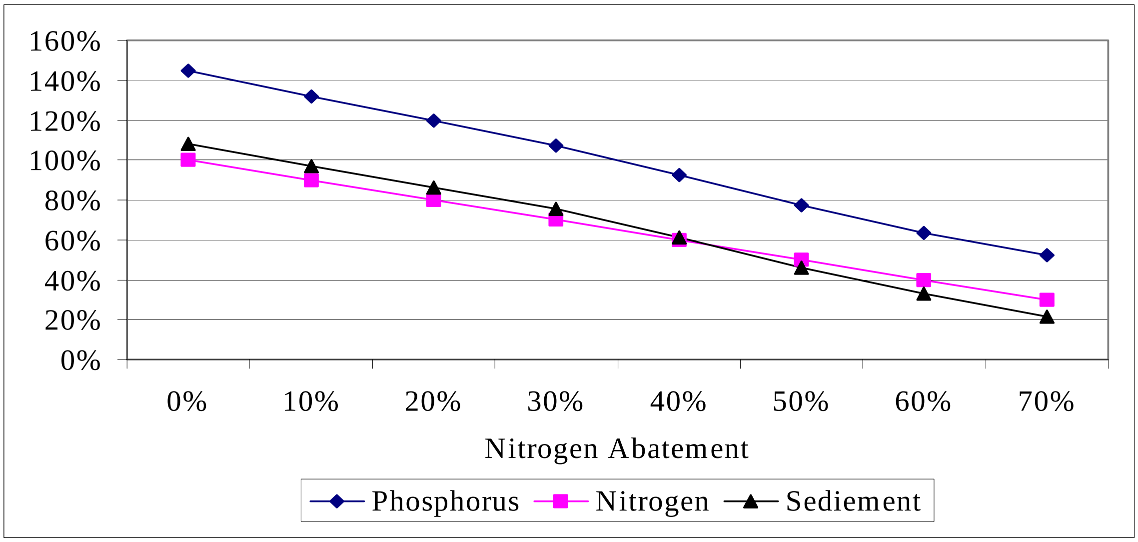


Figure 11. Percentage Change from Base Runoff When Profit is Maximized Subject to Nitrogen Abatement.

Figure 11 shows the percentage change in the relationship between sediment, nitrogen, and phosphorus runoff when nitrogen runoff is abated and producers forfeit their DCP payment if they enroll their land in CRP. This indicates that if only nitrogen abatement is targeted, then phosphorus and sediment runoff would not be decreased below base levels until nitrogen abatement reached 35 percent and 10 percent respectively. Sediment runoff is 108 percent of the base and phosphorus runoff is at 145 percent of its base level when nitrogen runoff is constrained to its base level.

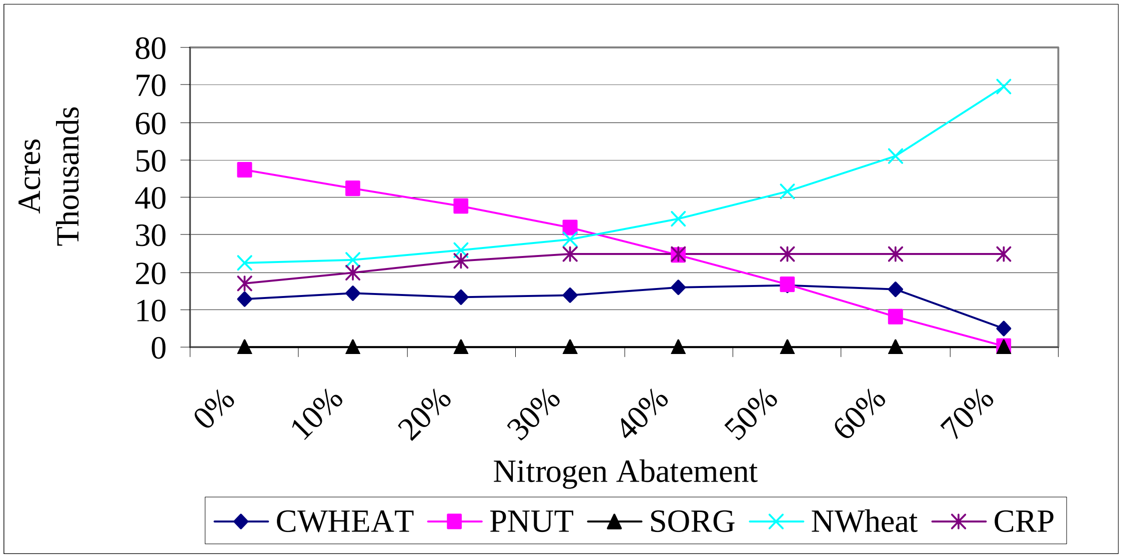


Figure 12. Crop Acres with Nitrogen Abatement without DCP Received by Producers if the Land is Enrolled in CRP.

Figure 11 shows how the total acres allocated to each crop change as the level of nitrogen abatement increases. The two crops with the largest change in total acres are peanuts, which decreased from 47,412 acres to 16,652 acres and no till wheat, which increased from 22,528 acres to 41,651 acres from zero to fifty percent nitrogen abatement. CRP also increased from 16,926 acres to 24,897, acres and conventional till wheat increased from 12,720 to 16,387 acres, while sorghum remained at zero acres.

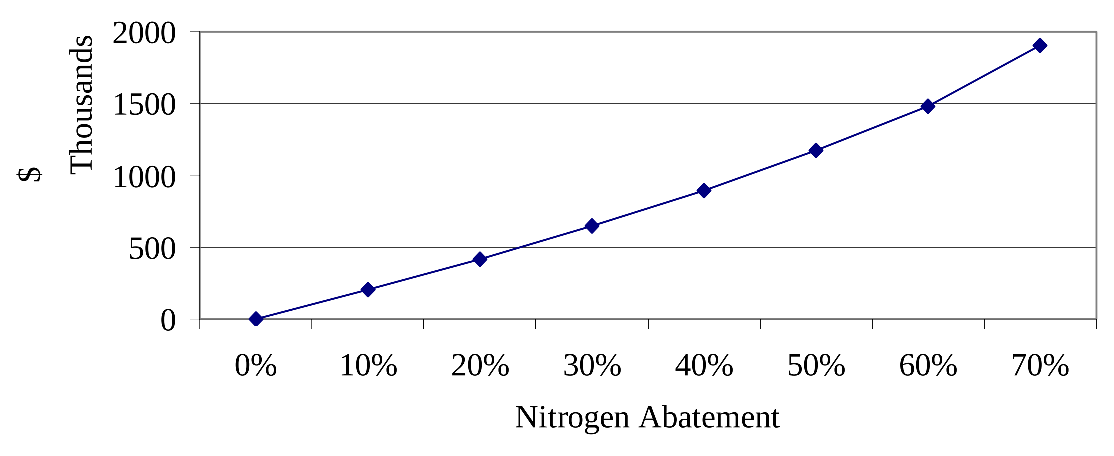


Figure 13. Cost of Nitrogen Abatement without DCP Received by Producers if Land is enrolled in CRP.

Figure 13 shows that the total profits lost to producer's increases as the level of nitrogen abatement increases. As the level of nitrogen abatement increases, the cost to producers increases as well. At a fifty percent level of nitrogen abatement, the total profit lost to producers is $1,177,411 or $3.61 per pound of nitrogen abated.

***Nitrogen Abatement if DCP is received by producers if cropland is enrolled into CRP. ***

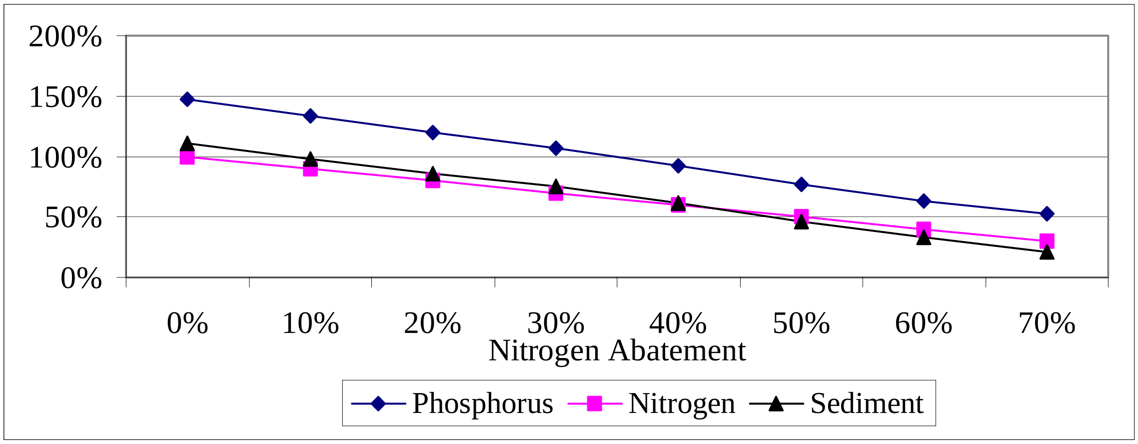


Figure 14. Percentage Change from Base Runoff When Profit is maximized subject to Nitrogen Abatement.

Figure 14 shows how the level of sediment, nitrogen, and phosphorus runoff changes as a percent of their base levels when nitrogen alone is targeted for abatement. The results shown in this figure are based on policy where producers keep their DCP if they enroll land into CRP. With zero nitrogen abatement, sediment is at 111 percent of its base level and phosphorus is at 147 percent of its base level. Nitrogen runoff must be abated to 10 percent before sediment runoff is reduced to its base level, and nitrogen runoff must be reduced to 35 percent of its base level before phosphorus runoff is reduced below its base level. This figure shows that if sediment and nitrogen runoff cannot increase, then a policy only targeting nitrogen would not be effective to reduce the environmental damages from cropland in an area.

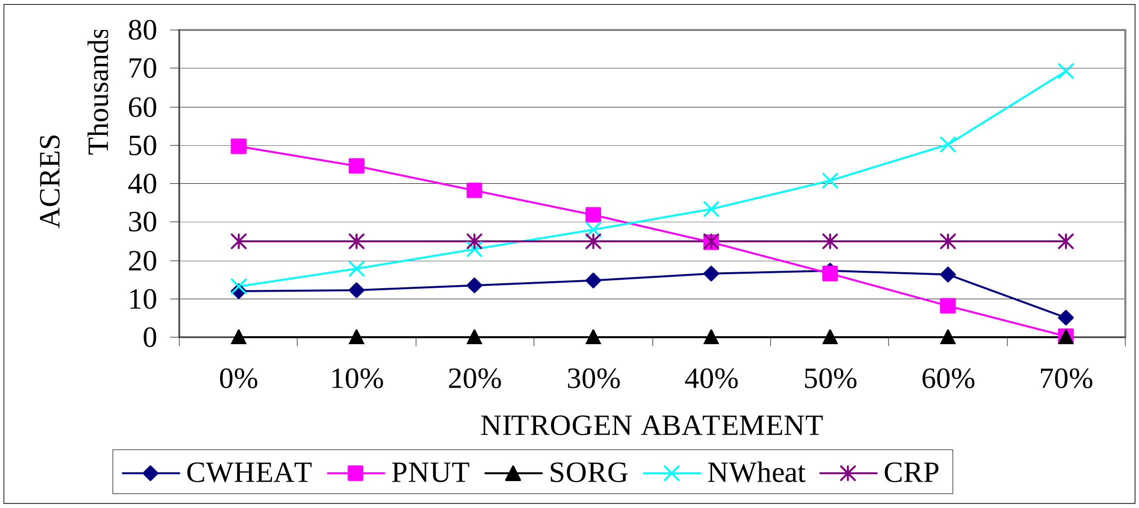


Figure 15. Crop Acres when Producers receive DCP if Land is enrolled in CRP.

Figure 15 shows how the total crop acres of each crop in the watershed change as the level of nitrogen abatement increases. Once again the two crops that have the largest increase and decrease respectively are no till wheat and peanuts. There are 13,177 acres of no till wheat with zero nitrogen abatement which increases to 40,787 acres as the level of nitrogen abatement increases to 50 percent. Peanut acres decreased from 49,630 to 16,666, sorghum acres remained at zero from zero to fifty percent abatement. Conventional till wheat acres increased from 12,720 to 16,387 over the same range. CRP acres remained constant at 24,897 acres, which is the maximum amount allowed by current CRP policy over any abatement range.

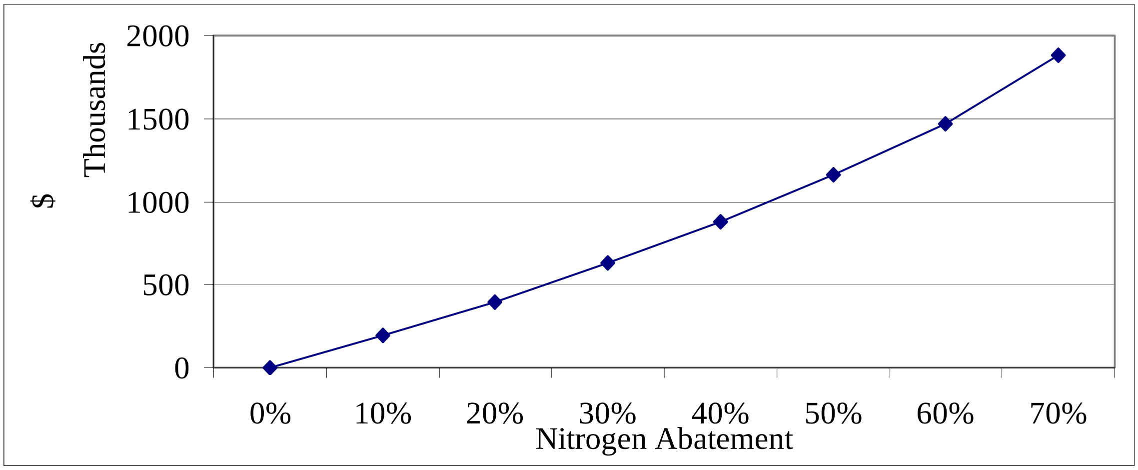


Figure 16. Cost of Nitrogen Abatement With DCP Received by Producers if Land is Enrolled in CRP.

Figure 16 shows the cost to producers in the amount of profit given up as the level of nitrogen abatement increases when they are able to keep their DCP for a parcel of land if that parcel is enrolled into CRP. Producers' profits are decreased by $1,161,047 or $3.56 per pound of nitrogen abated at the 50 percent level of nitrogen abatement.

Phosphorus Abatement when Producers do not receive DCP if cropland is enrolled into CRP

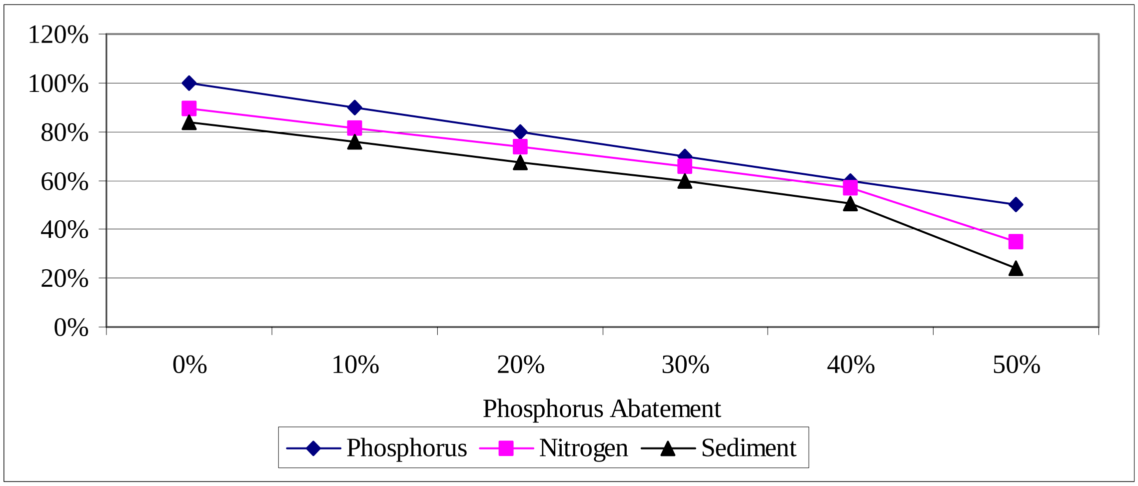


Figure 17. Percentage Change from Base Runoff when Profit is Maximized Subject to Phosphorus Abatement.

Figure 17 shows the relationship of sediment, nitrogen, and phosphorus runoff as a percent of their base levels when phosphorus is targeted for abatement. When phosphorus is targeted, it gives a very different result from when sediment or nitrogen only are targeted. In this case the sediment and nitrogen runoff levels are always below their base levels. If the phosphorus runoff is targeted, sediment and nitrogen runoff levels are also decreased.

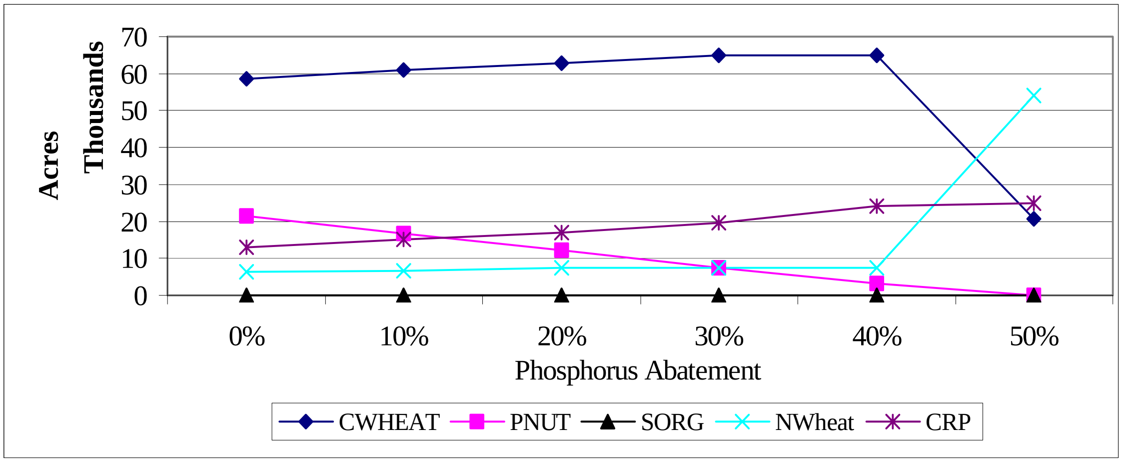


Figure 18. Crop Acres without DCP Received by Producers if Land is enrolled in CRP.

Figure 18 shows how the total crop acres in the watershed change as the level of phosphorus abatement increases. Peanut acres decrease from 21,548 acres to 0 acres, and sorghum acres remained at zero as phosphorus abatement increases from zero to fifty percent. CRP acres increased from 13,060 acres to 24,897 acres over the same range. Conventional and no till wheat both increased over the range of phosphorus abatement from zero to forty percent. However, from forty to fifty percent abatement conventional and no till wheat experienced a large shift. Conventional wheat increased from 58,648 acres at zero abatement to 64,836 acres at forty percent phosphorus abatement but decreased to 20,657 acres at fifty percent abatement. No till wheat experienced the opposite reaction to this increase in phosphorus abatement. No till wheat increased from

6,331 acres with zero abatement and increased to 7,544 acres at forty percent abatement and jumped to 54,033 acres at fifty percent phosphorus abatement.

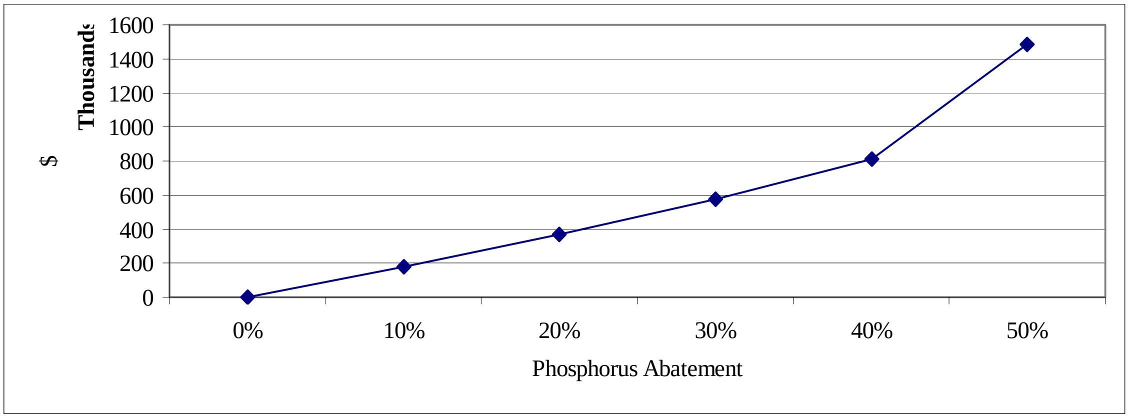


Figure 19. Cost of Phosphorus Abatement without DCP Received by Producers if Land is Enrolled in CRP.

Figure 19 shows how the cost to producers increases as the level of phosphorus abatement increases from zero to fifty percent. The cost is increasing at approximately the same rate from zero to forty percent but experiences a shift in this rate of increase from forty to fifty percent abatement. This shift coincides with the dramatic shift in conventional and no till wheat acreages from the previous figure. At forty percent phosphorus abatement, the total cost to producers calculated as a decrease in total profits is $811,414 ($1,484,545) or $11.25 ($16.46) per pound at forty percent phosphorus abatement. (Fifty percent phosphorus abatement shown in parenthesis).

Phosphorus Abatement with DCP received by producers if cropland is enrolled into CRP

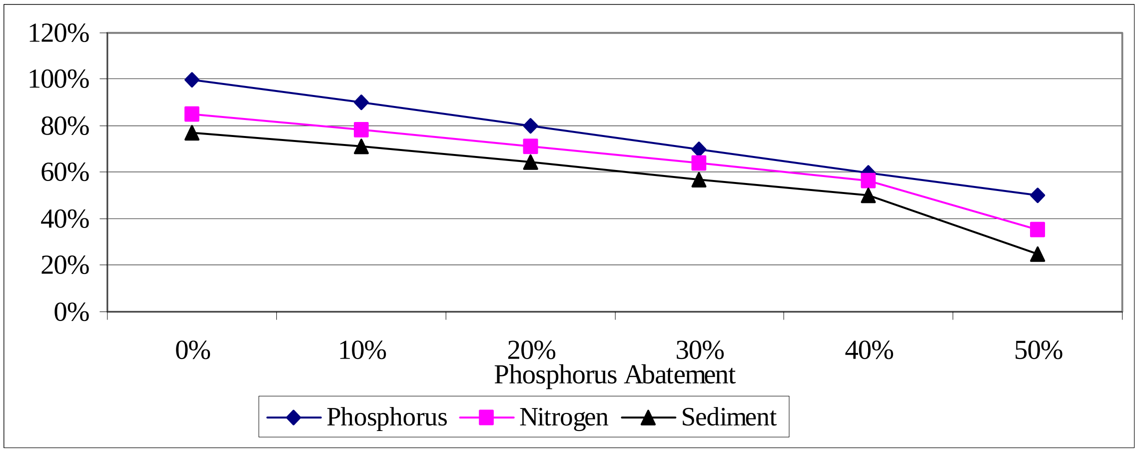


Figure 20. Percentage Change from Base When Profit is Maximized Subject to Phosphorus Abatement.

Figure 20 shows the percent of base runoff levels for sediment, nitrogen, and phosphorus as the level of phosphorus abatement increases. In this figure the numbers represented are for CRP policy where the producer receives the DCP payment when land is enrolled into CRP. When the phosphorus runoff is constrained, then the levels of sediment and nitrogen runoff are controlled below their base levels by their physical relationship to phosphorus runoff. This indicates that to control sediment, nitrogen, and phosphorus runoff below their base levels, then a policy only needs to target phosphorus runoff.

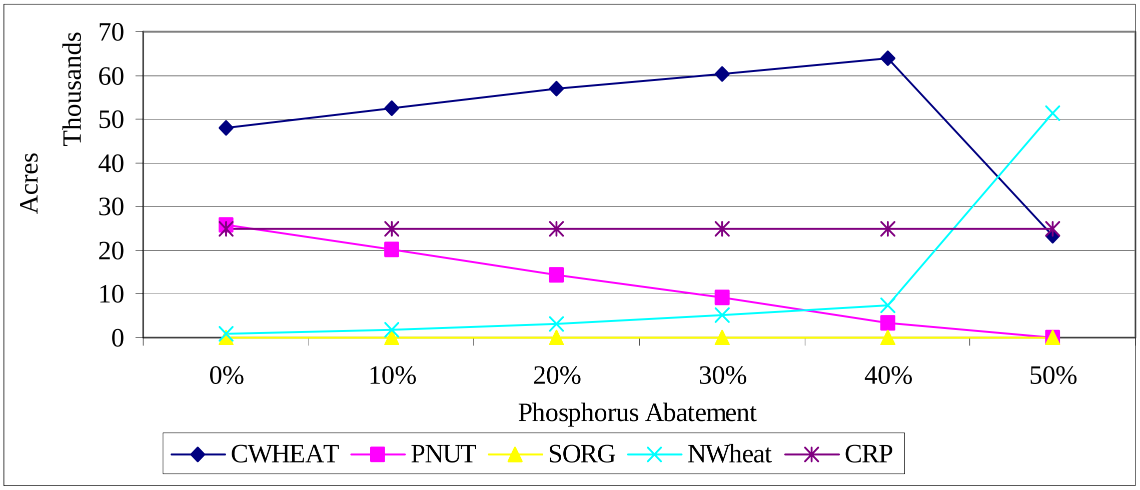


Figure 21. Crop Acres With DCP Received by Producers if Land is Enrolled in CRP.

Figure 21 shows how the total acres of conventional and no till wheat, peanuts, sorghum, and CRP change as the level of phosphorus abatement increase when the producer is able to keep the DCP for a land parcel if that parcel is enrolled into CRP. Peanut acres decrease from 25,857 to 0 and sorghum acres remain at zero over the range from zero to fifty percent phosphorus abatement. Conventional till wheat increases from 47,913 acres at zero abatement to 63,928 acres at forty percent and then decreases rapidly to 23,381 acres at fifty percent phosphorus abatement. No till wheat also increases from 920 acres with zero abatement to 7,328 acres at forty percent abatement before increasing rapidly to 51,310 acres at fifty percent phosphorus abatement. CRP acres remain constant at their maximum allowed acres of 24,897. From this chart the threshold level for phosphorus abatement before a large change in crop acres is between forty and fifty percent phosphorus abatement.

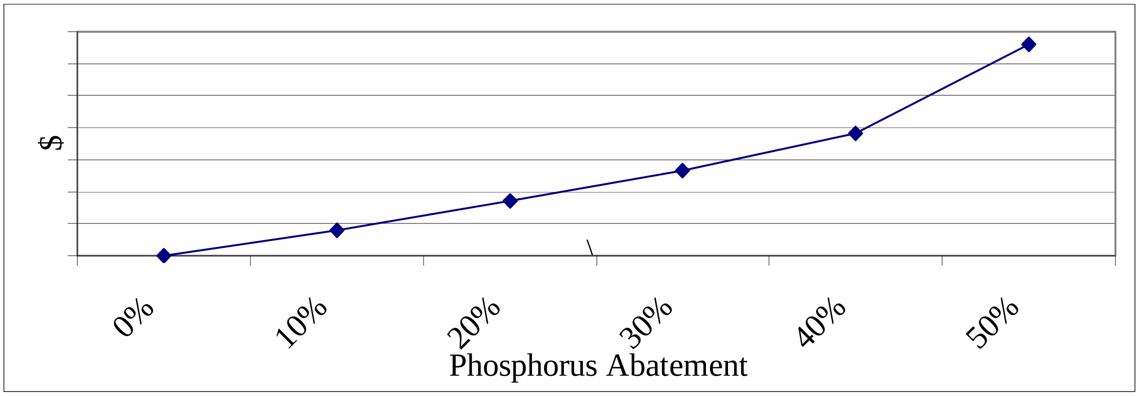


Figure 22. Cost of Phosphorus Abatement With DCP Received by Producers if land is Enrolled in CRP.

Figure 22 shows how the total cost to producers increase as the level of phosphorus abatement increases from zero to fifty percent. The cost increases at approximately the same rate from zero to forty percent before increasing between forty and fifty percent. This increase in the cost rate coincides with the large shift in total acres of conventional and no till wheat shown in the previous chart. This chart can be interpreted to show the cost to producers for forty percent phosphorus abatement as $762,068 (1,322,068) or $10.56 ($14.66) per pound of phosphorus abated. (Fifty percent phosphorus abatement shown in parenthesis.)

Comparison of costs of abatement for sediment, nitrogen, and phosphorus.

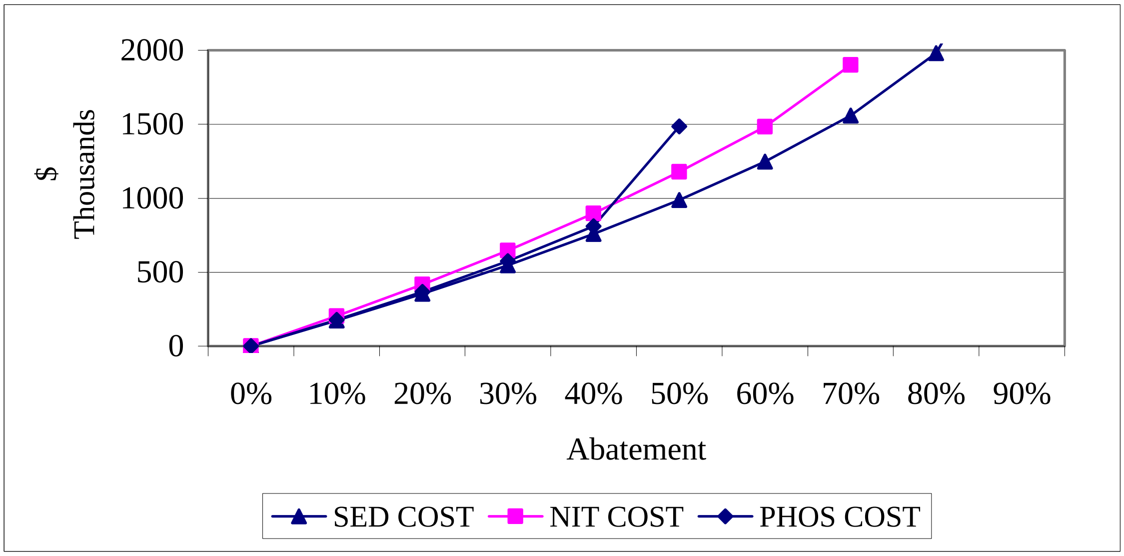


Figure 23. Cost of Individual Sediment, Nitrogen, and Phosphorus Abatement with DCP not received by Producers if Land is enrolled in CRP.

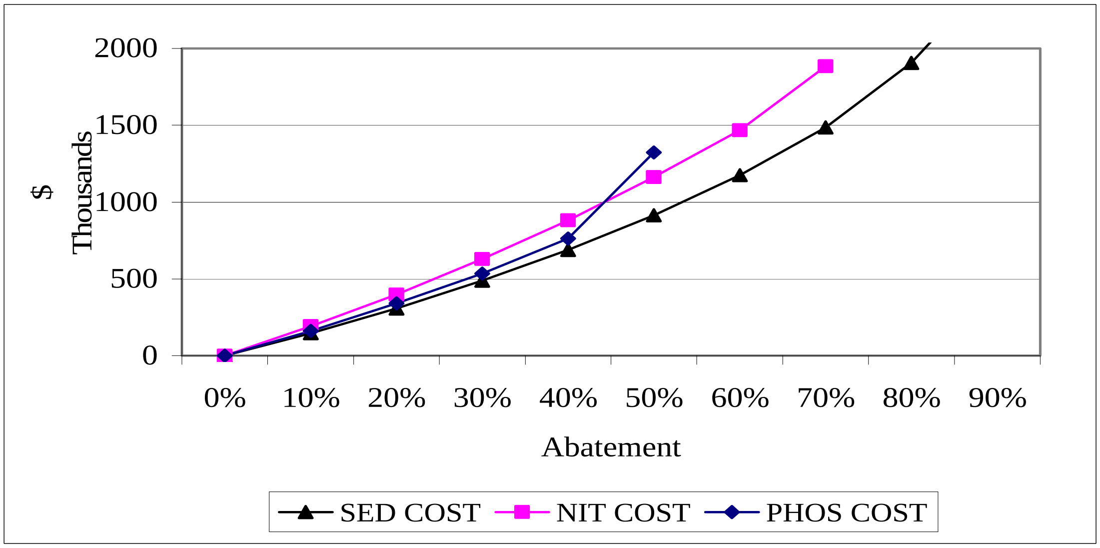


Figure 24. Cost of Sediment, Nitrogen, and Phosphorus Abatement Individually with DCP Received by Producers if Land is enrolled in CRP.

Figure 23 is a combination of Figures 6, 13, and 19. Figure 24 is a combination of Figures 10, 16, and 22. Each of the lines in the charts show the total producer cost for sediment, nitrogen, and phosphorus abatement at the percentage along the X axis of the chart. This data for each line came from independent model runs for that runoff variable and policy environment. These figures are presented to show how the costs of abatement of sediment, nitrogen, and phosphorus compare to each other. When examining these figures, it must be remembered that sediment abatement only, did not control nitrogen and phosphorus; and that nitrogen abatement only, did not control sediment and phosphorus, to below their base levels until the abatement levels reached ten percent for sediment and nitrogen and forty percent for phosphorus. After seeing that phosphorus abatement only controlled sediment and nitrogen runoff below the base levels, it is interesting to see that the cost of phosphorus abatement is not always above the cost of sediment and nitrogen abatement at each respective level of abatement.

Spatial Allocation of Cropping Patterns and Runoff under Water Quality Constraints

To show the spatial allocation of cropland and the associated changes between the scenarios tested, Arc View Graphical Interface System (GIS) was used to create maps from the GAMS linear programming output. 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 from analysis of Table 12. By studying the maps, it is possible to determine not only what the changes in the number of acres of each crop produced, but also where in the watershed the changes occur. The first maps in this section include the change in crop acres from the base scenario to the profit-maximizing scenario, the profit maximizing to the L/10/10/10 scenario, profit maximizing to L/20/20/20 scenario and the base to L/20/20/20 scenario. The second set of maps show the sediment, nitrogen, and phosphorus runoff per acre in the base, profit maximizing, L/10/10/10, and L/20/20/20 scenarios.

Spatial Allocation of Cropland

Crop acreages in each sub basin changed dramatically from the current land use (base) to the profit maximizing solution. 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. These changes between conventional and no till wheat are of little significance. Because of the data collection methods used, it was not possible to determine which sub basins had which tillage practice, only that they were planted to wheat; therefore they were all assumed to be conventional till in the base. Peanut acres changed throughout the watershed, but the pattern shows that acres decreased in the southern portions and increased in the northern portions 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 majority of the changes in the spatial allocation of land from the profit maximizing solution and L/10/10/10 are that peanut acreages decreased and 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 L/10/10/10 to L/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 as land allocation of the watershed is changed to maximize profit subject to meeting runoff constraints that 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.

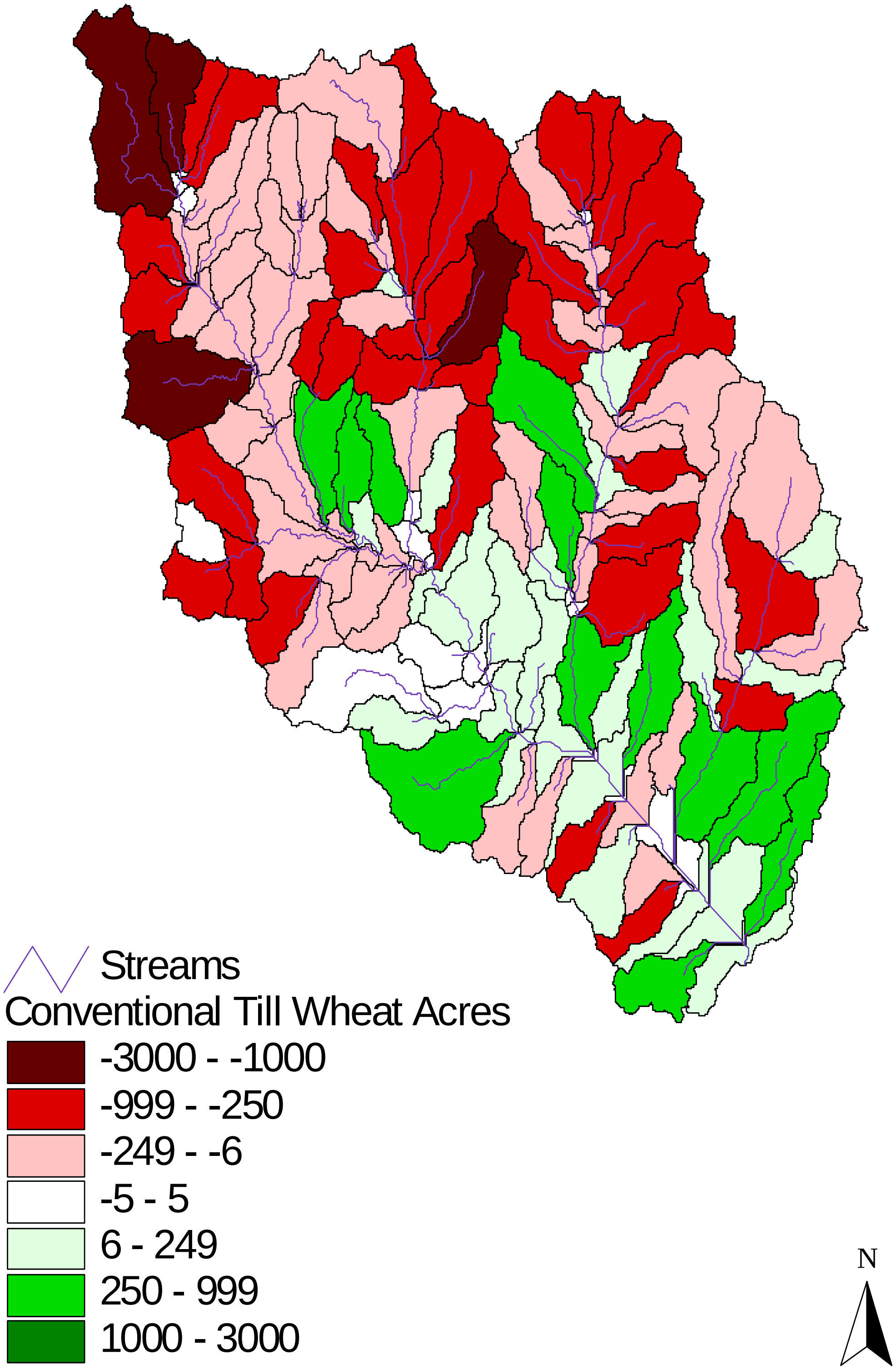
Allocation of Runoff

Maps 17, 18, 19, and 20 show the sediment runoff per acre for each subbasin under the base, profit maximizing, L/10/10/10, and the L/20/20/20 scenarios respectively. The change from the base and to the profit-maximizing scenario provides the largest shift in sediment runoff. Under the base scenario, sediment runoff is spread throughout the watershed. Under the profit-maximizing scenario, the sediment runoff in the watershed is reduced, the total sediment runoff in the watershed was less in the profit-maximizing scenario than in the base scenario, and runoff is more concentrated in the northern end of the watershed. As the level of abatement increases to 20 percent in L/20/20/20, the sediment runoff continues to decrease in the southern half of the watershed.

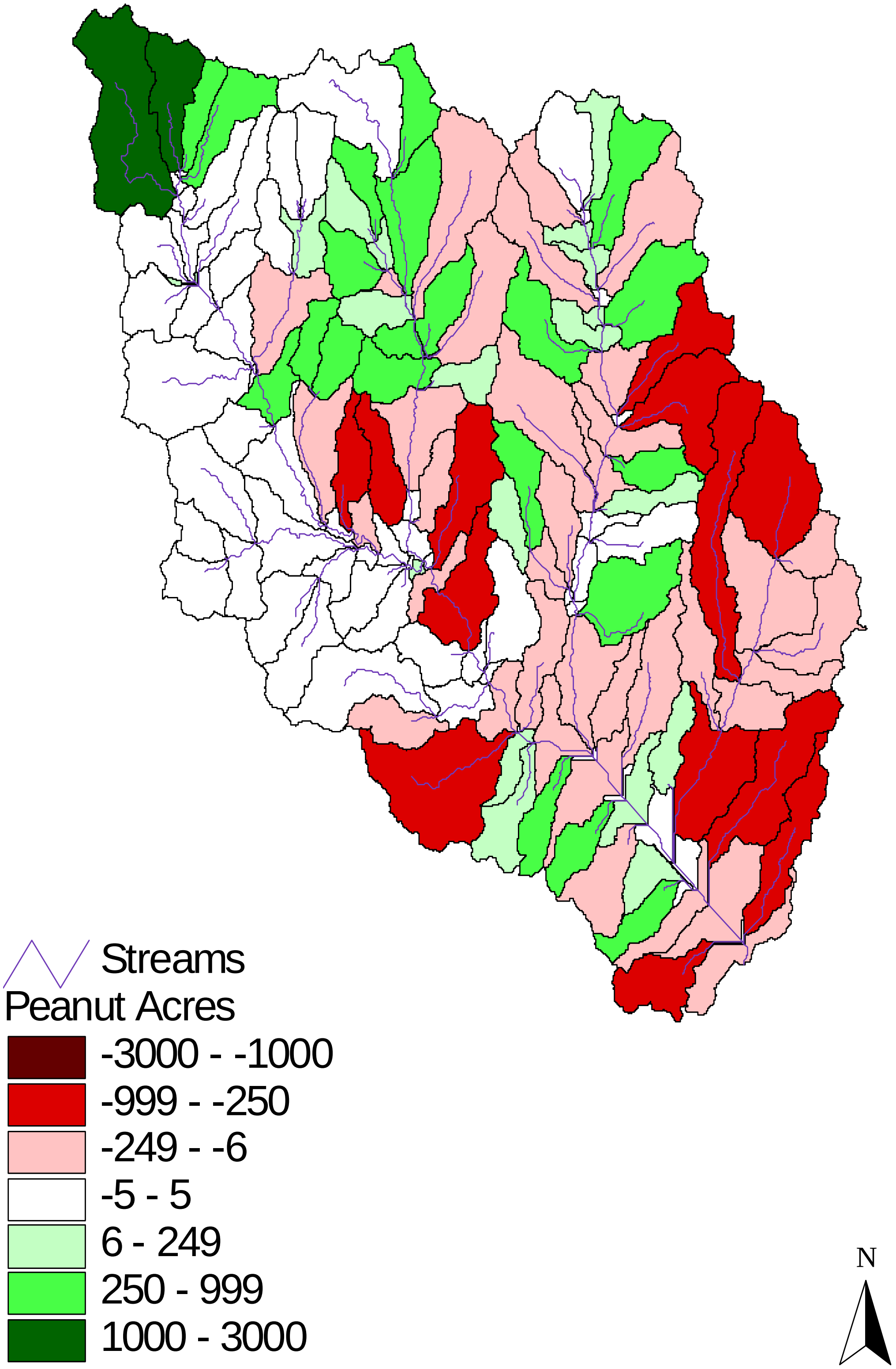
Nitrogen runoff per acre in each sub basin under the base, profit maximizing, L/10/10/10, and L/20/20/20 is shown in maps 21, 22, 23, and 24, respectively. The total nitrogen runoff decreases from the base to the profit-maximizing scenario and becomes more concentrated in the northern portions of the watershed. The runoff continues to decrease in the southern half of the watershed as the level of abatement increases to twenty percent in scenario L/20/20/20.

Phosphorus runoff per acre on the sub basin level is shown in map 25 for the base scenario, map 26 for the profit maximizing scenario, map 27 for scenario L/10/10/10, and map 28 for scenario L/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 profit maximizing scenarios. 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.

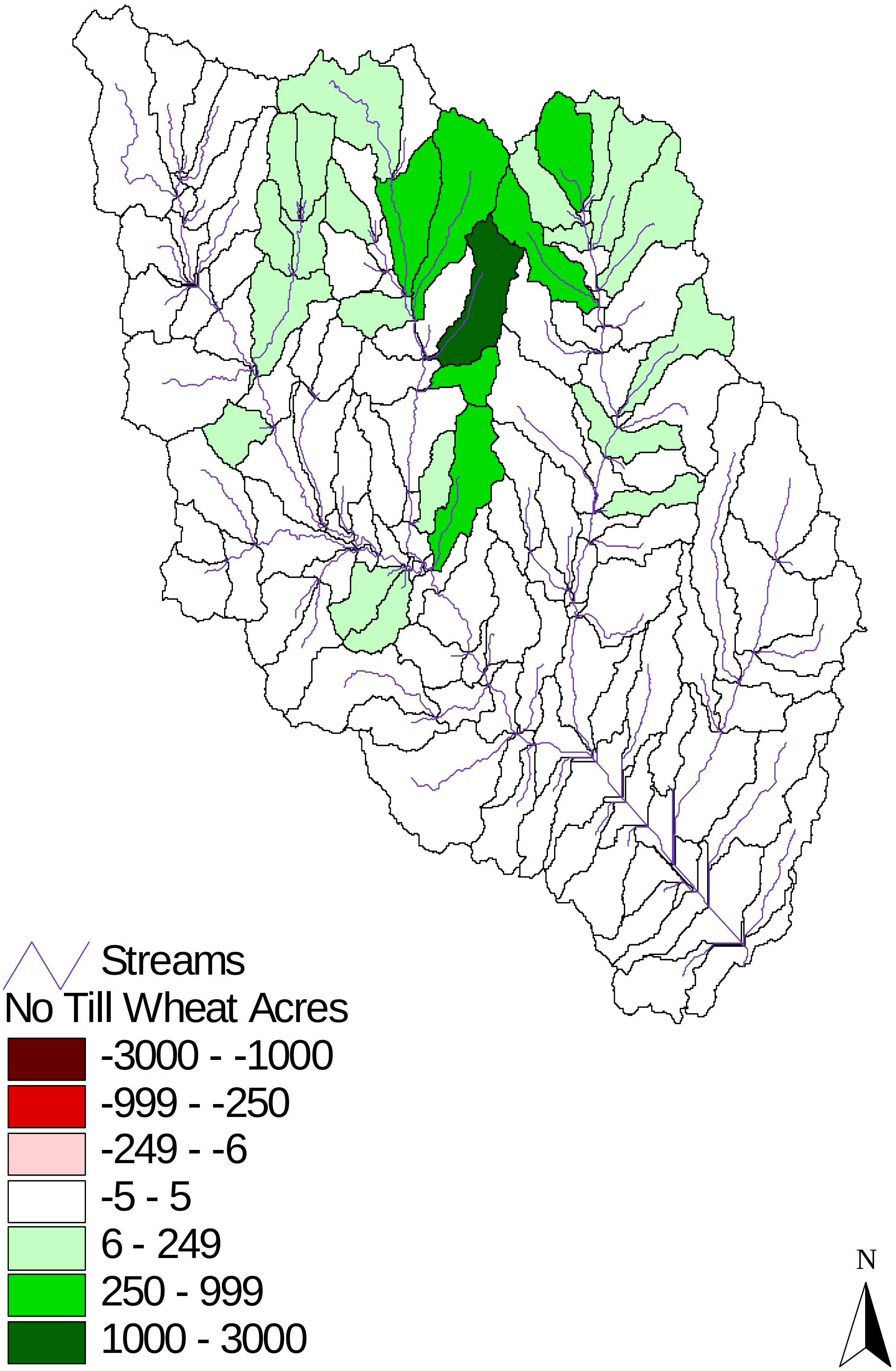
Map 1. Change in Conventional Till Wheat Acres from the Base Scenario to the Profit Maximizing Scenario.



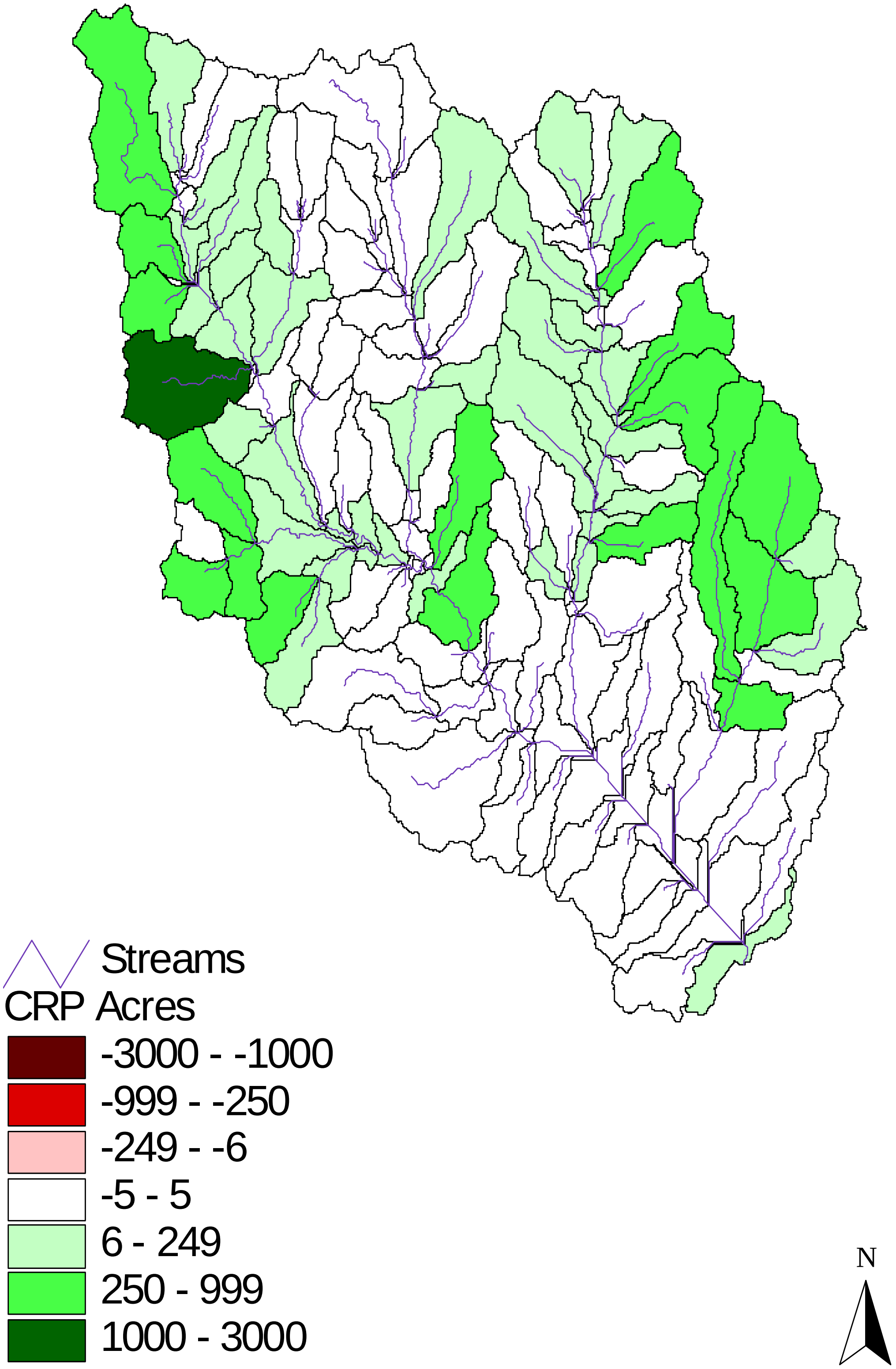
Map 2. Change in Peanut Acres from the Base Scenario to the Profit Maximizing Scenario.



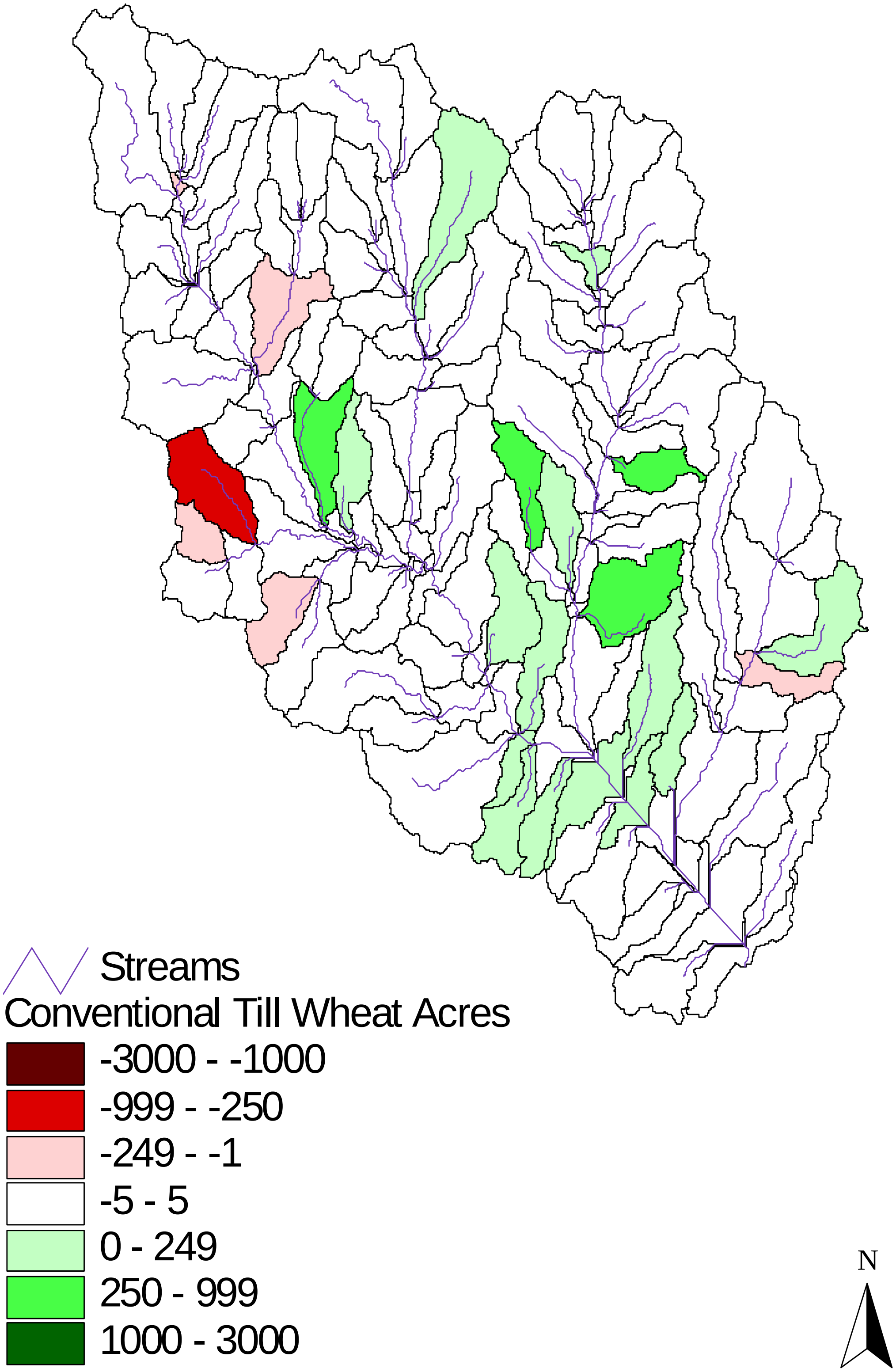
Map 3. Change in No Till Wheat Acres from the Base Scenario to the Profit Maximizing Scenario.



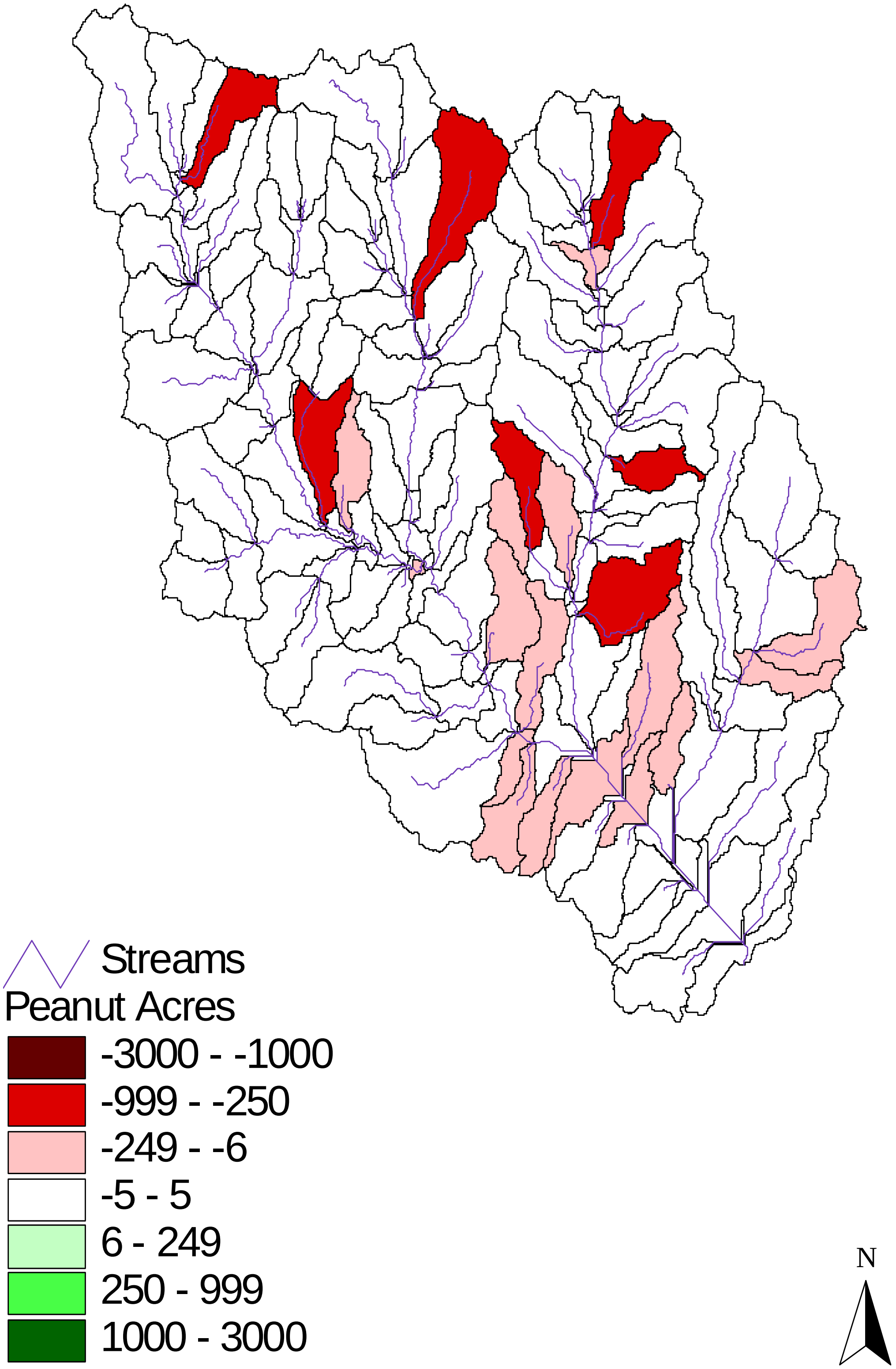
Map 4. Change in CRP Acres from the Base Scenario to the Profit Maximizing Scenario.



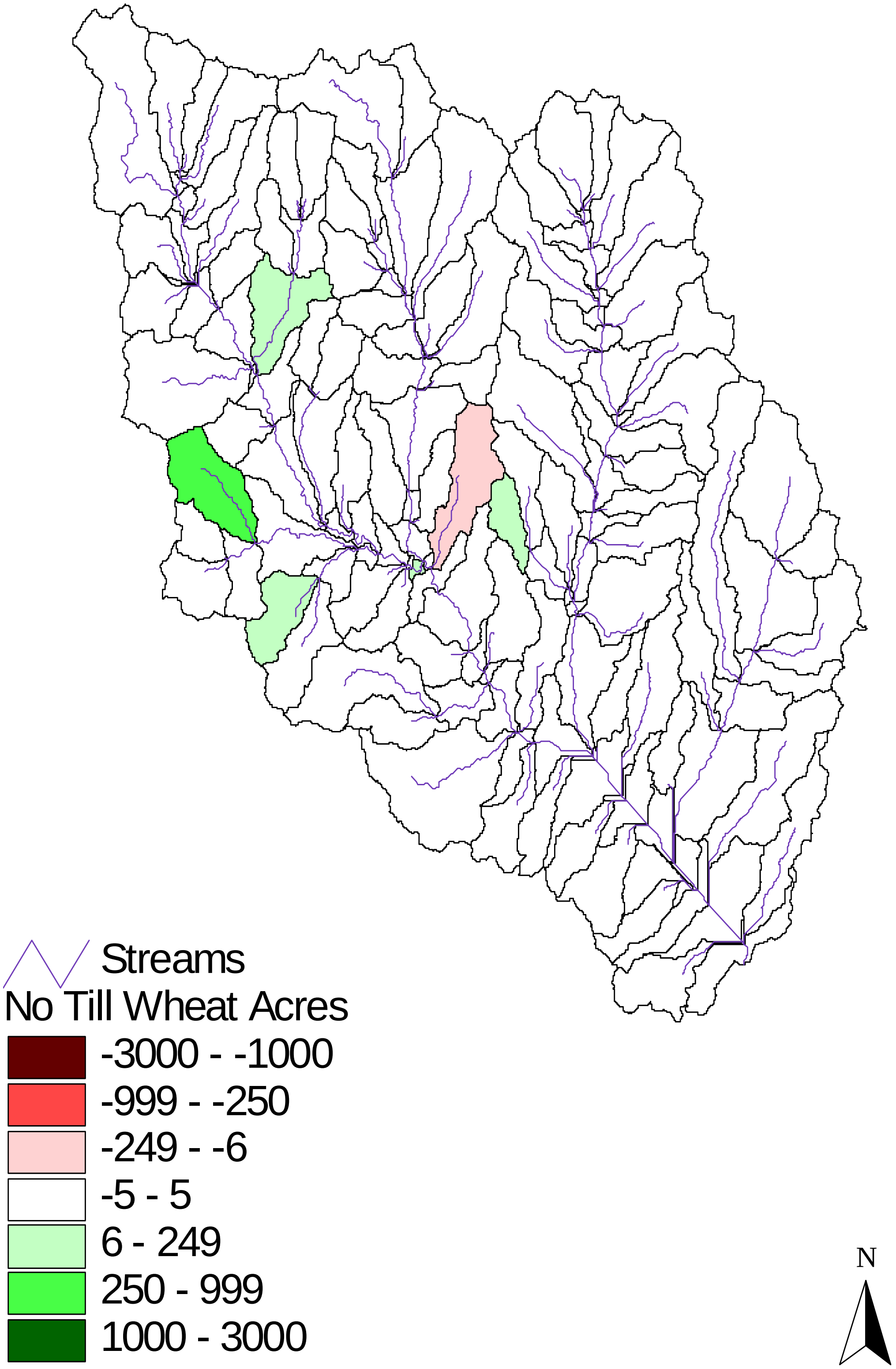
Map 5. Change in Conventional Till Wheat acres from the Profit Maximizing Scenario to L/10/10/10.



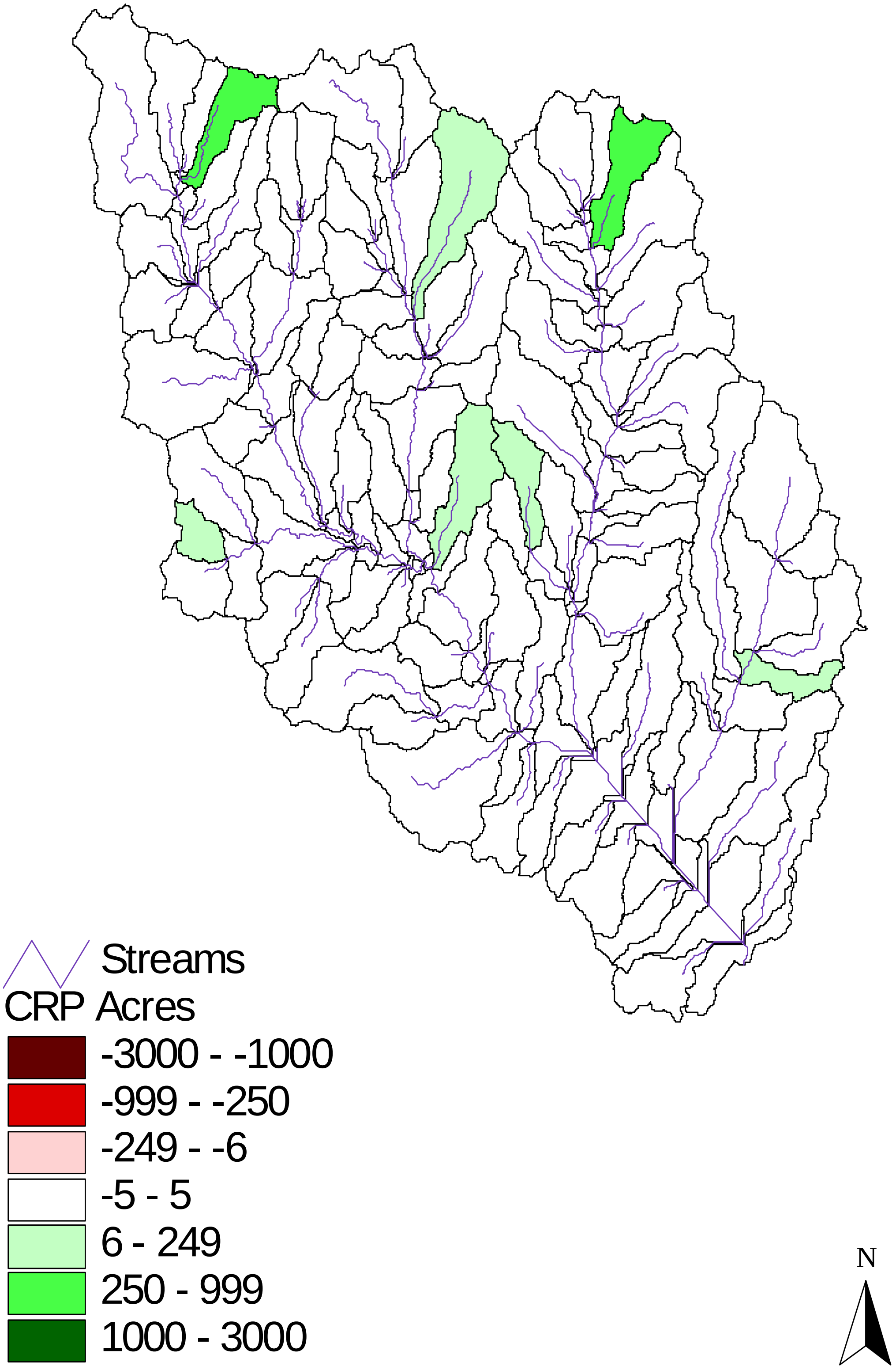
Map 6. Change in Peanut Acres from Profit Maximizing Scenario to L/10/10/10.



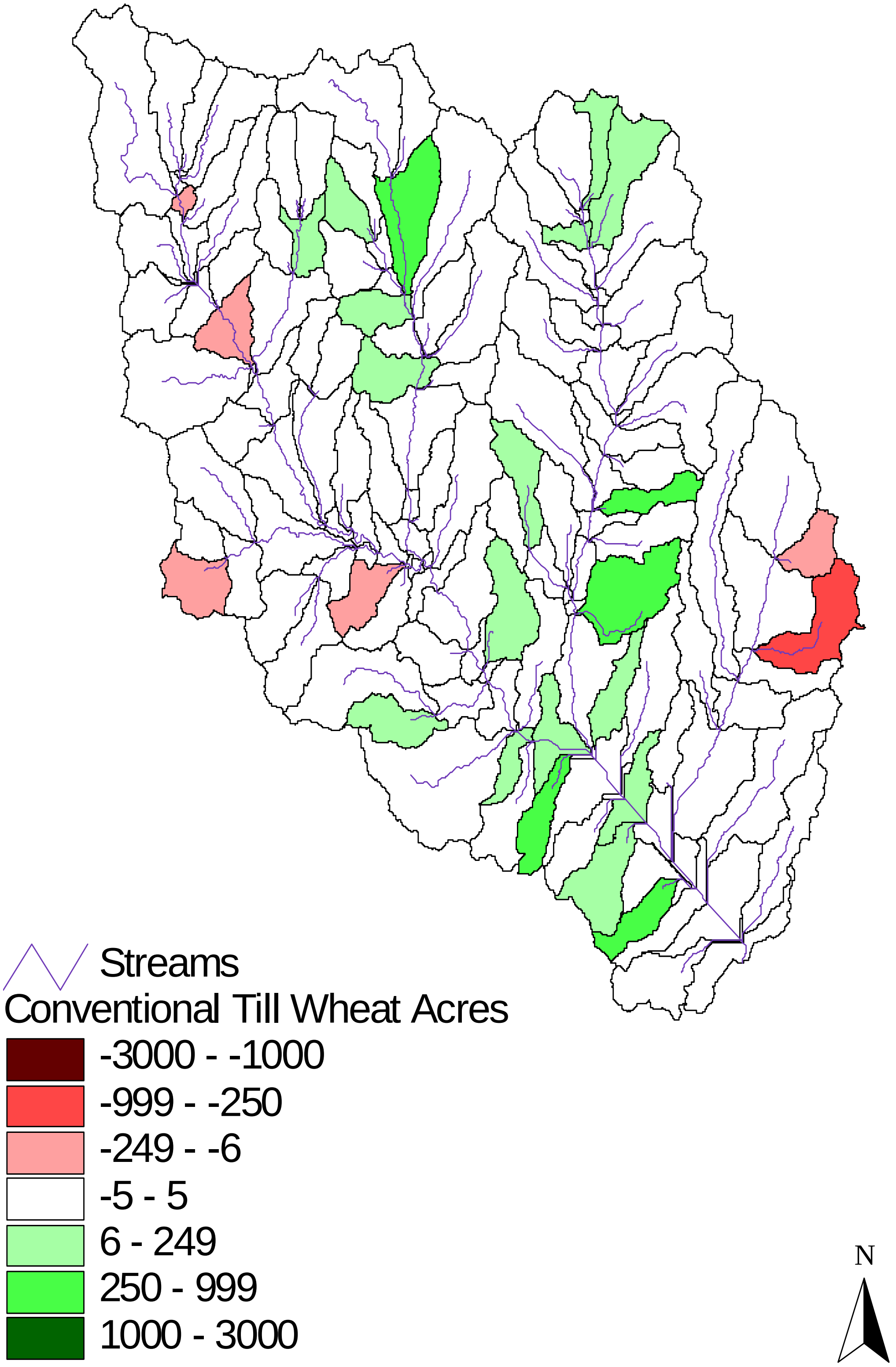
Map 7. Change in No Till Wheat Acres from Profit Maximizing Scenario to L/10/10/10.



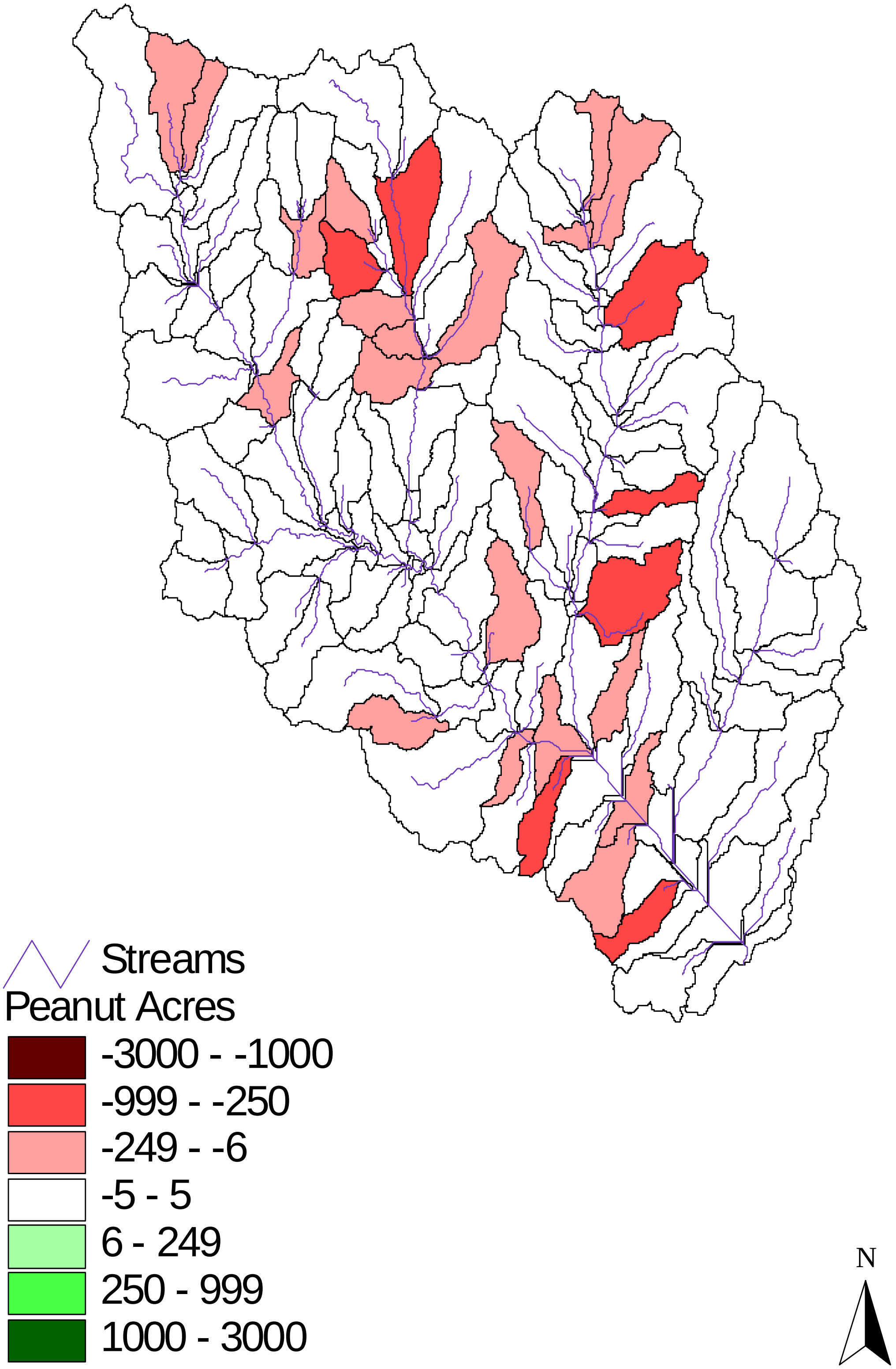
Map 8. Change in CRP Acres from Profit Maximizing Scenario to L/10/10/10.



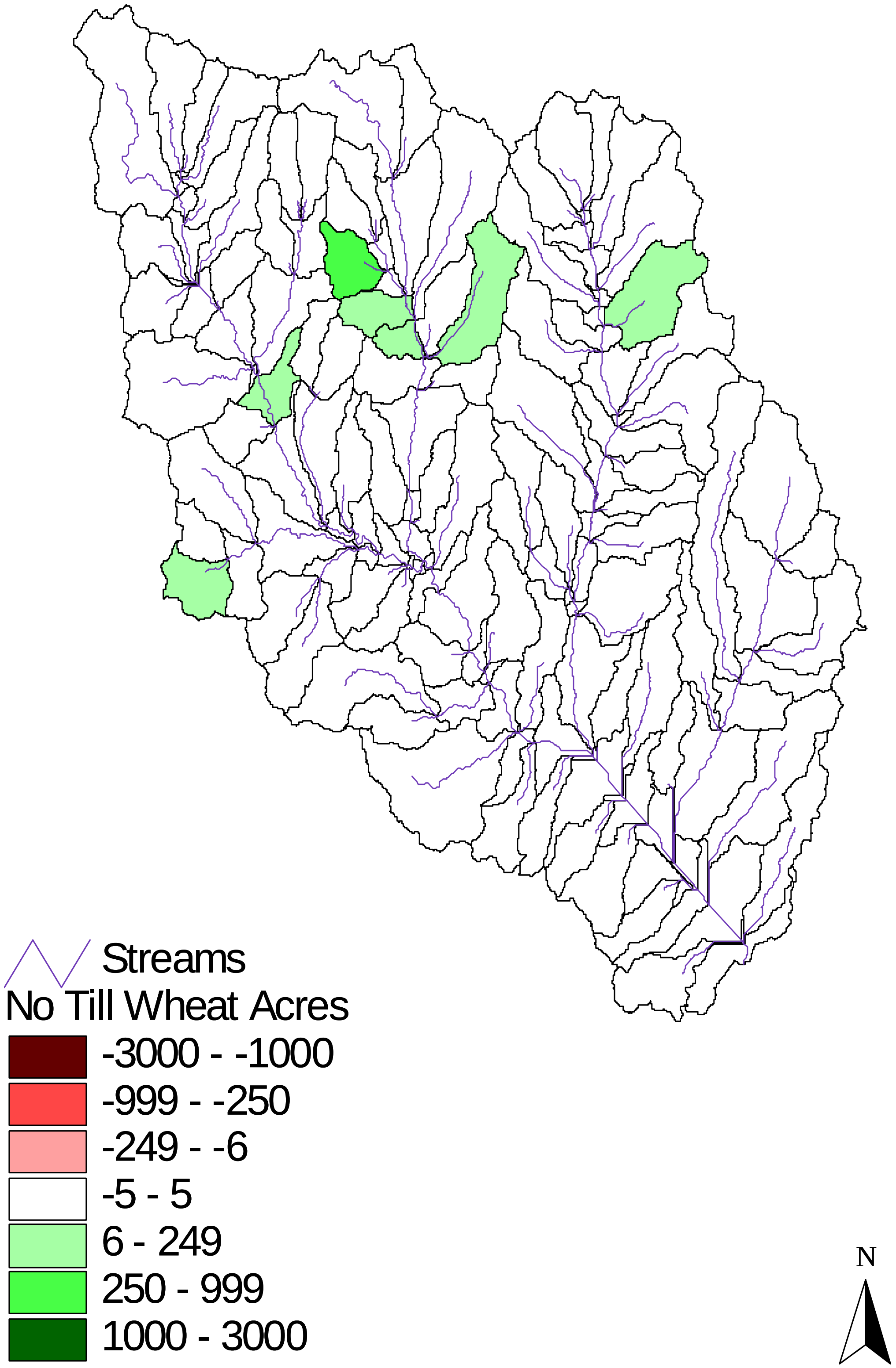
Map 9. Change in Conventional Till Wheat Acres from L/10/10/10 to L/20/20/20.



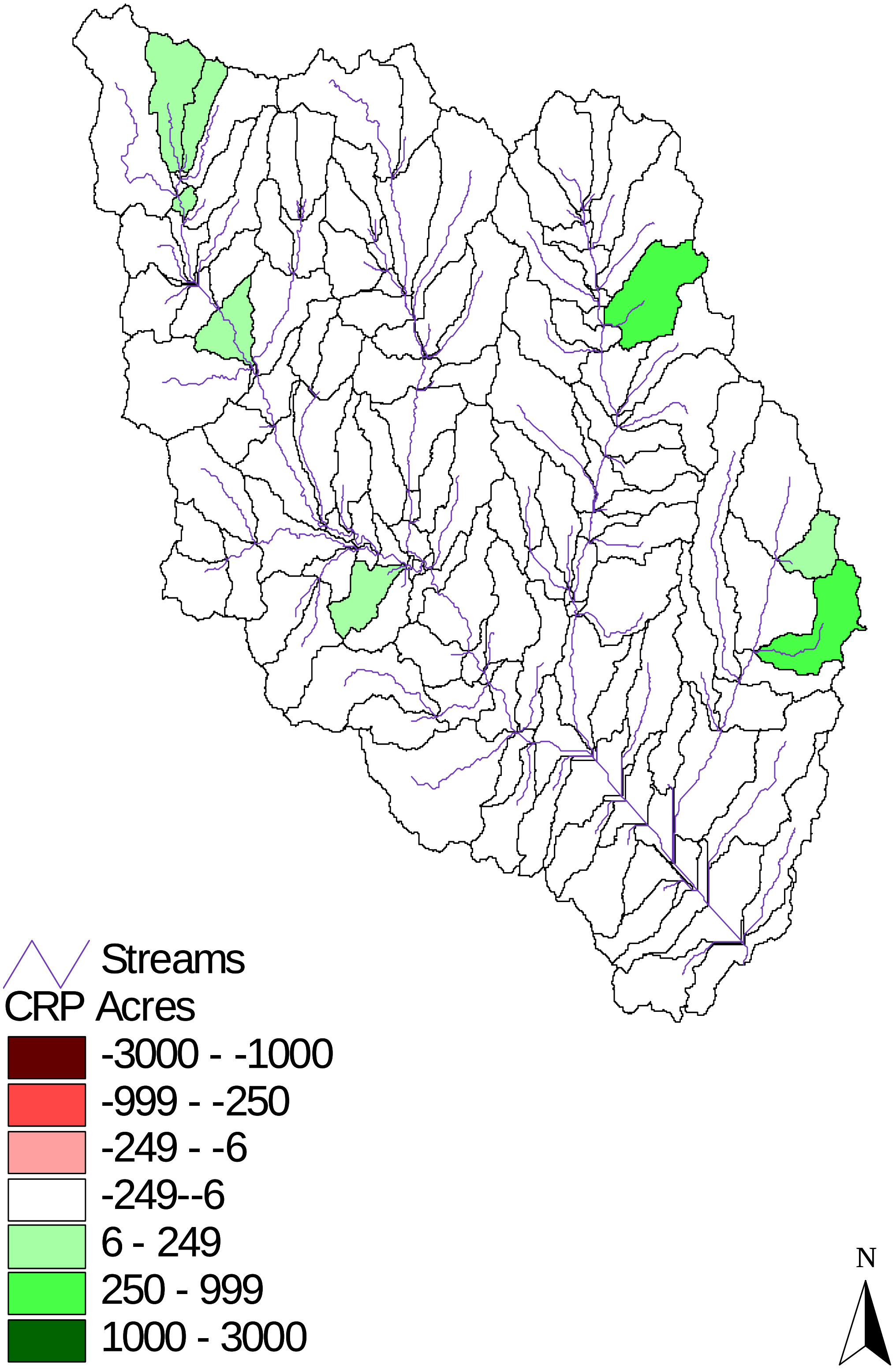
Map 10. Change in Peanut Acres from L/10/10/10 to L/20/20/20.



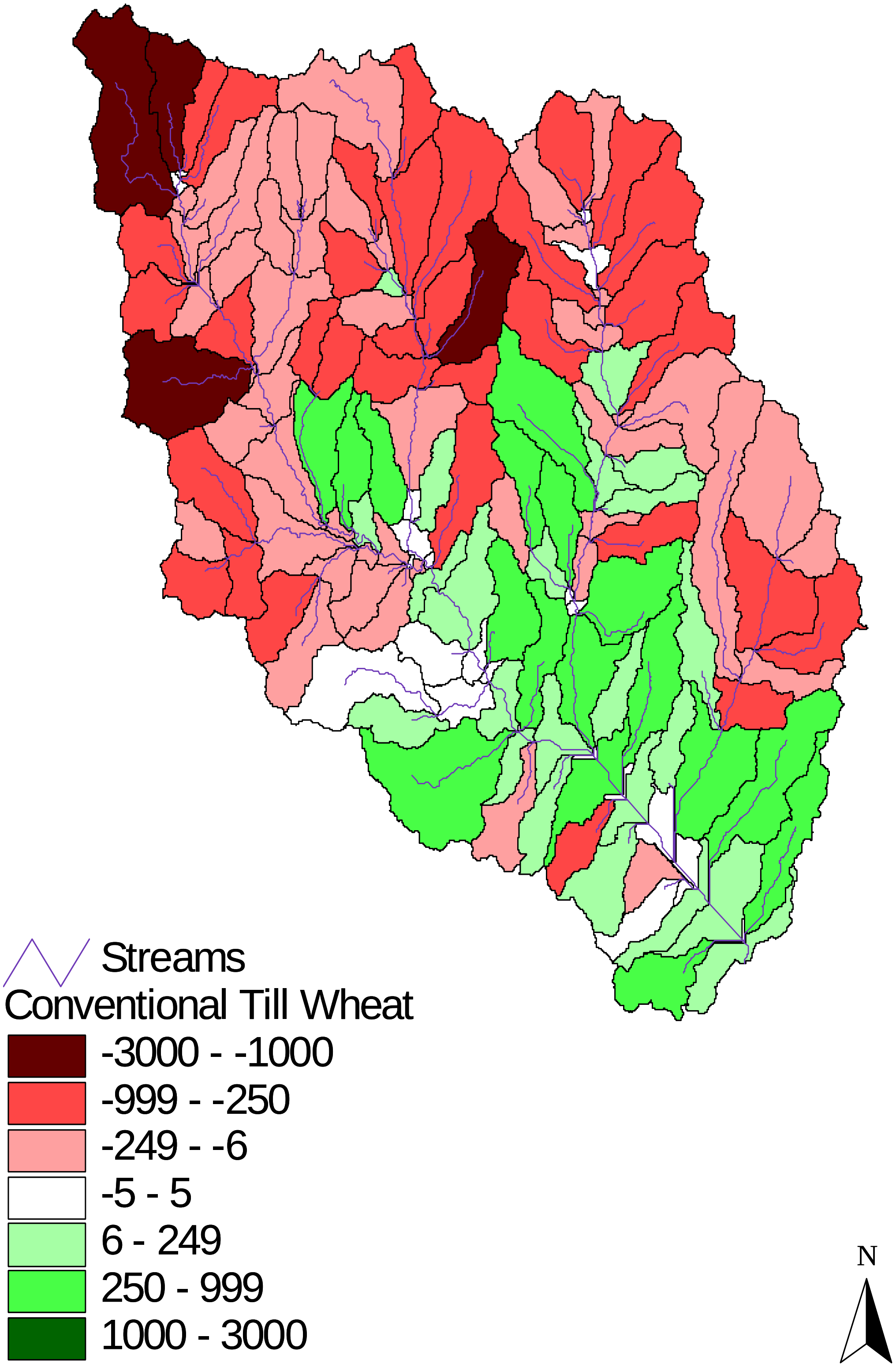
Map 11. Change in No Till Wheat Acres from L/10/10/10 to L/20/20/20.



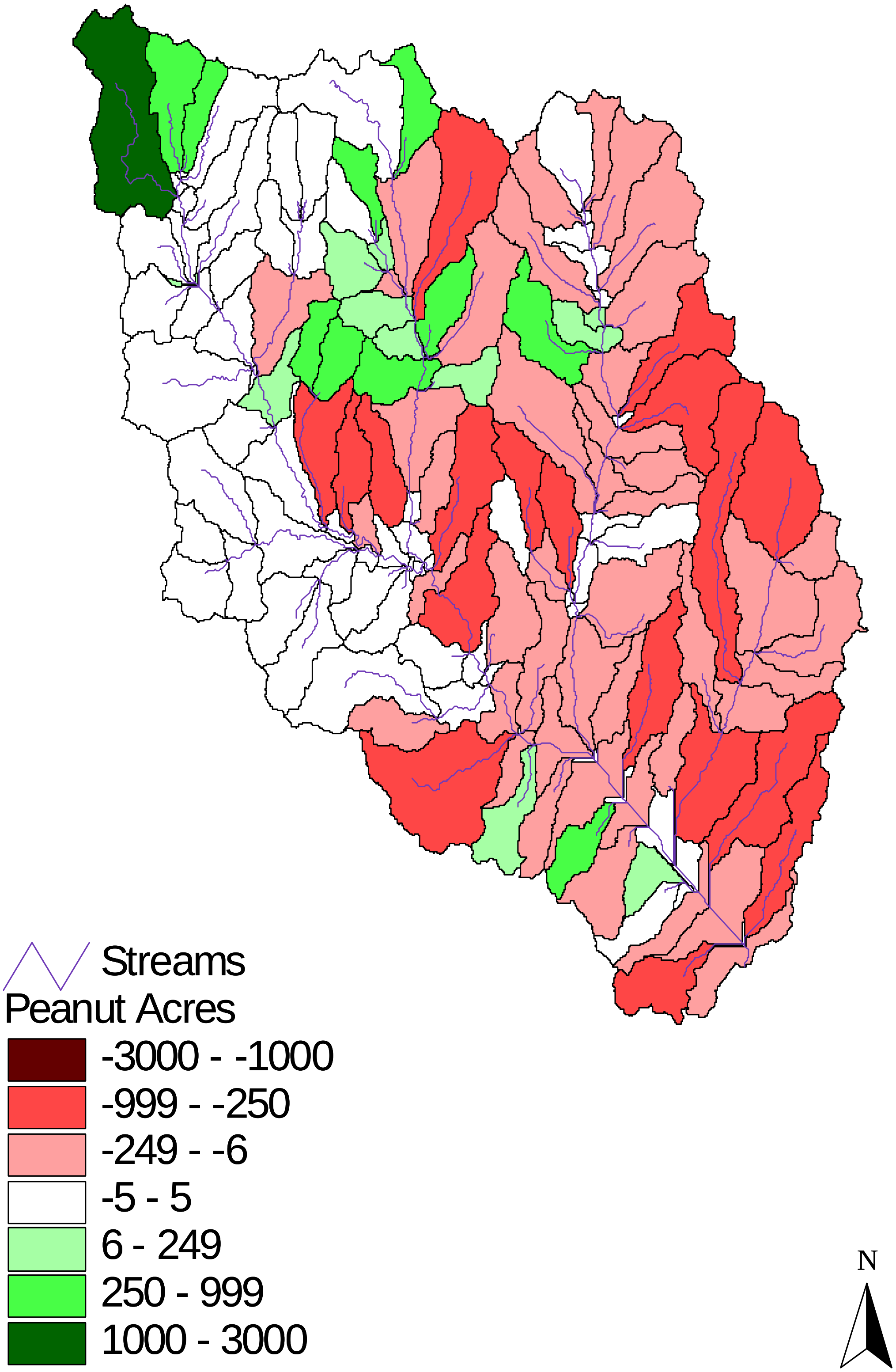
Map 12. Change in CRP Acres from L/10/10/10 to L/20/20/20.



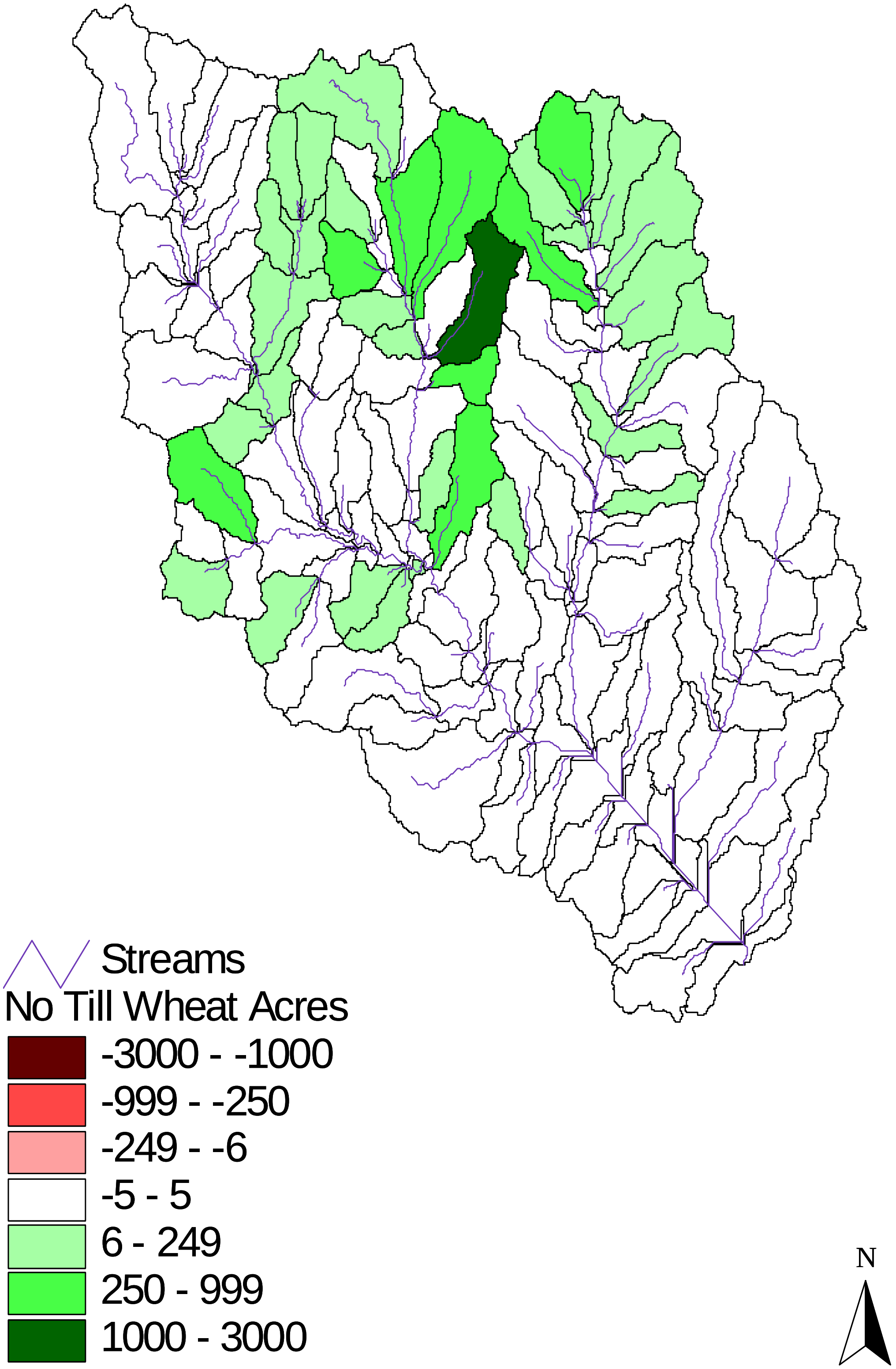
Map 13. Change in Convetional Till Wheat Acres from the Base Scenario to L/20/20/20.



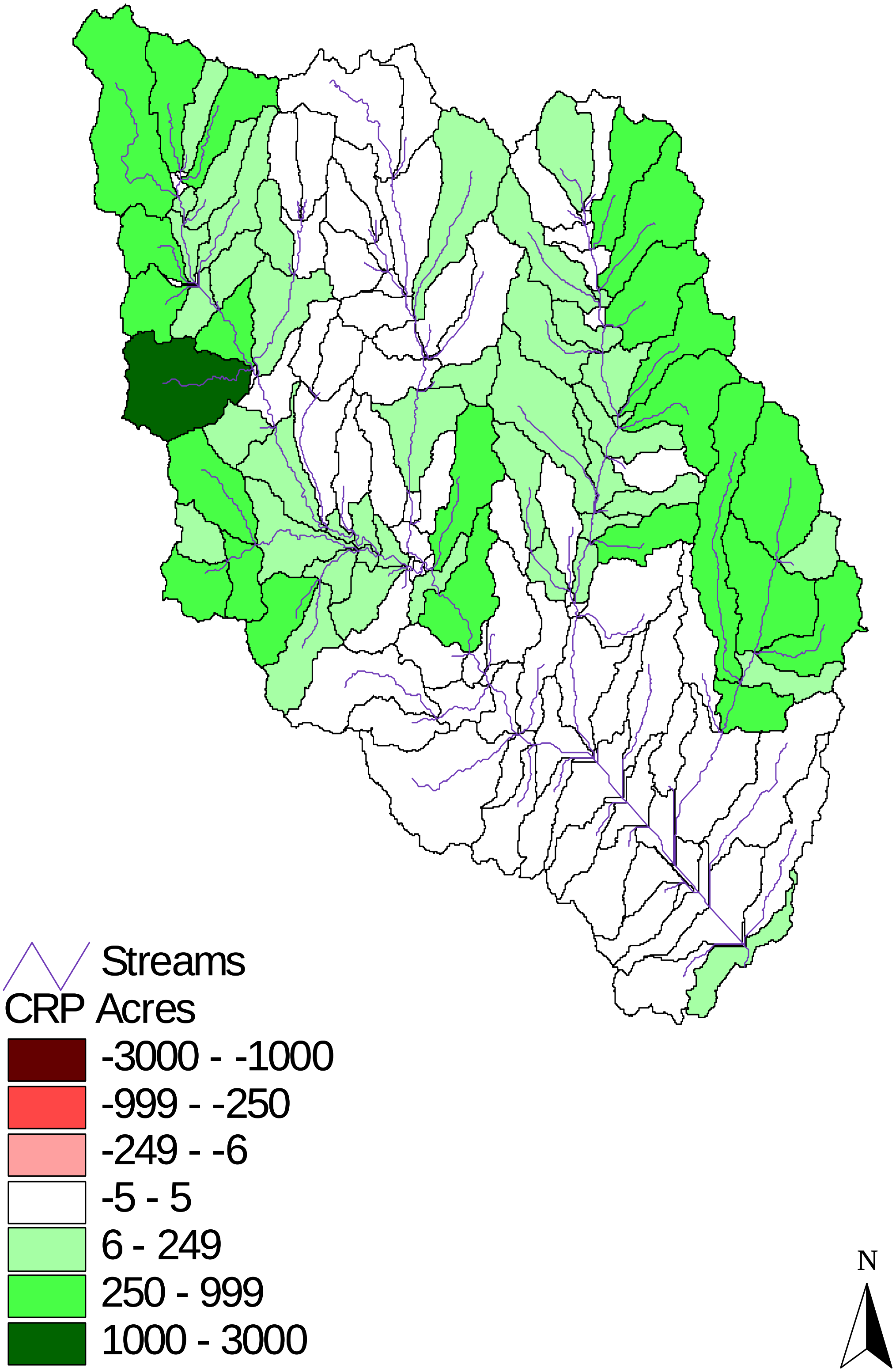
Map 14.   Change in Peanut Acres from the Base to L/20/20/20.



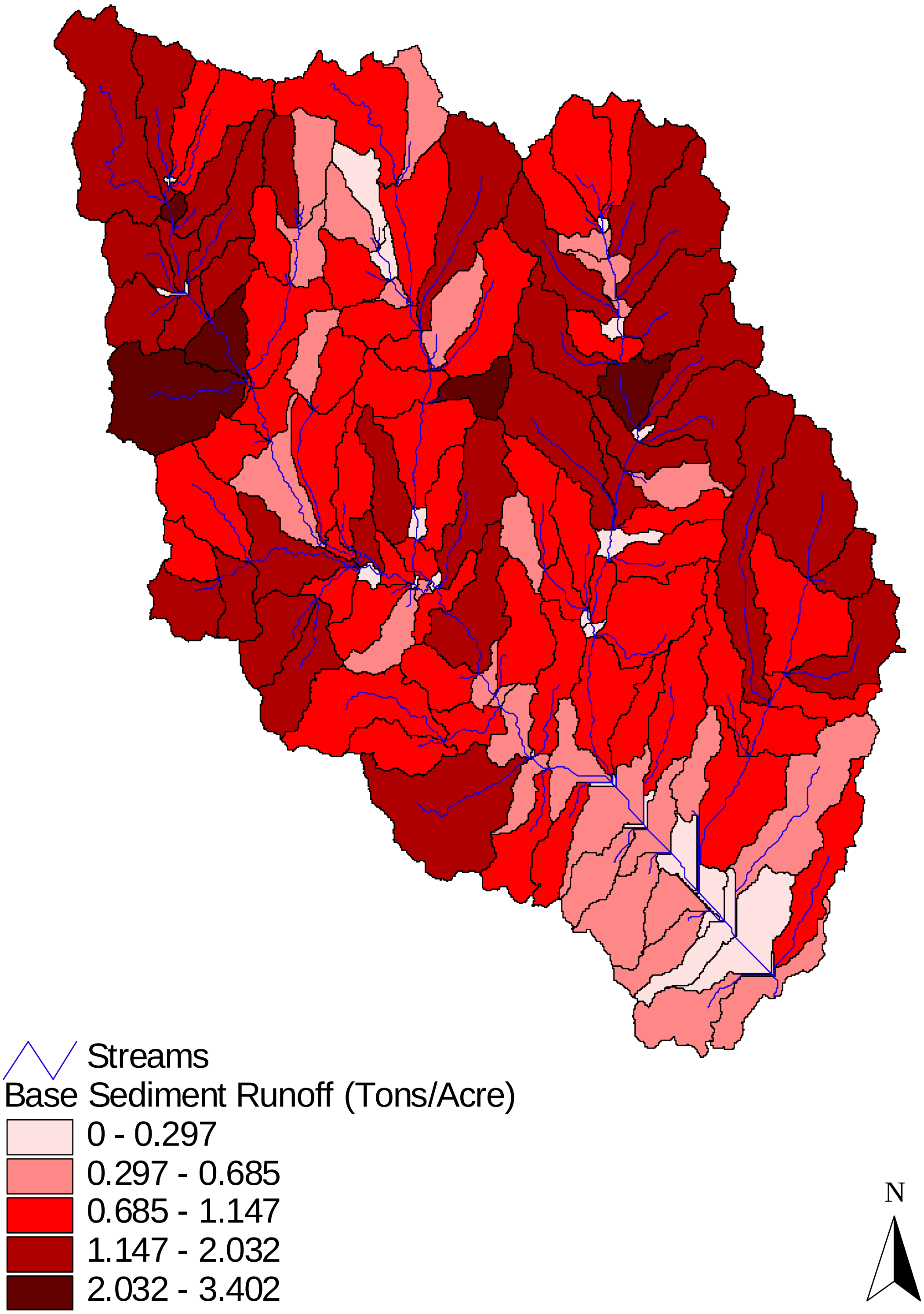
Map 15. Change in No Till Wheat Acres from the Base to L/20/20/20.



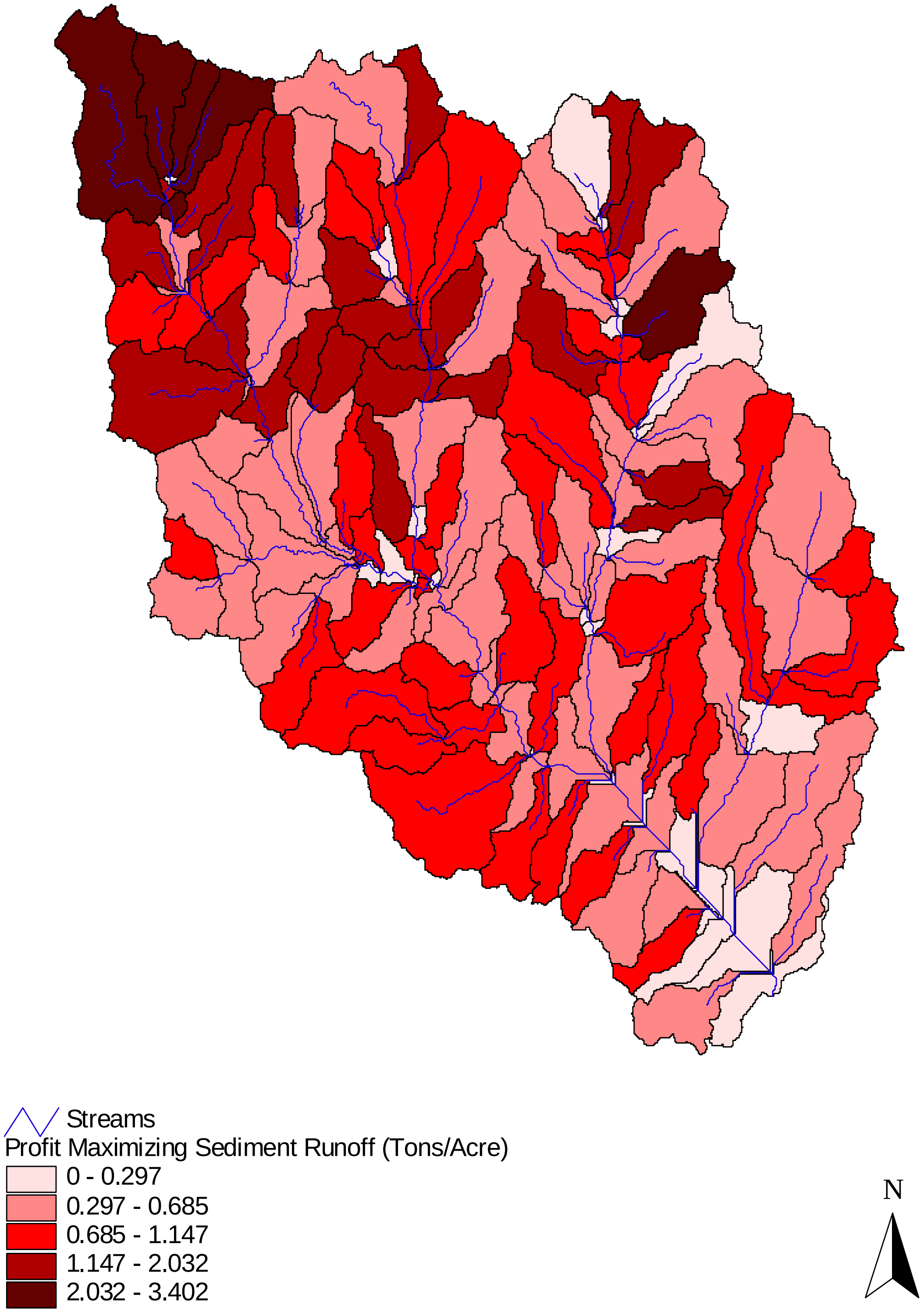
Map 16. Change in CRP Acres from the Base to L/20/20/20.



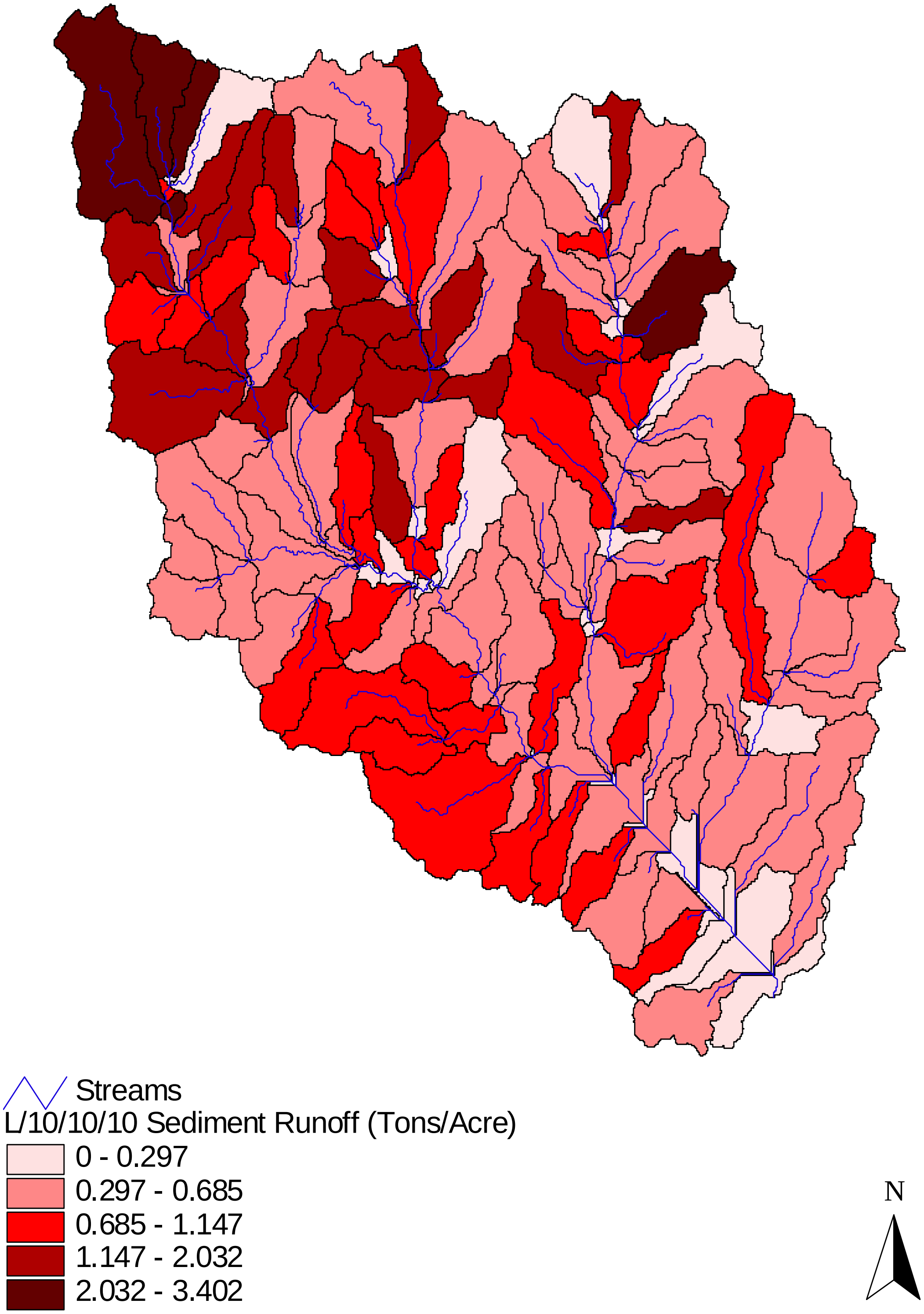
Map 17. Sediment Runoff under the Base Scenario, shown in Tons per Acre.



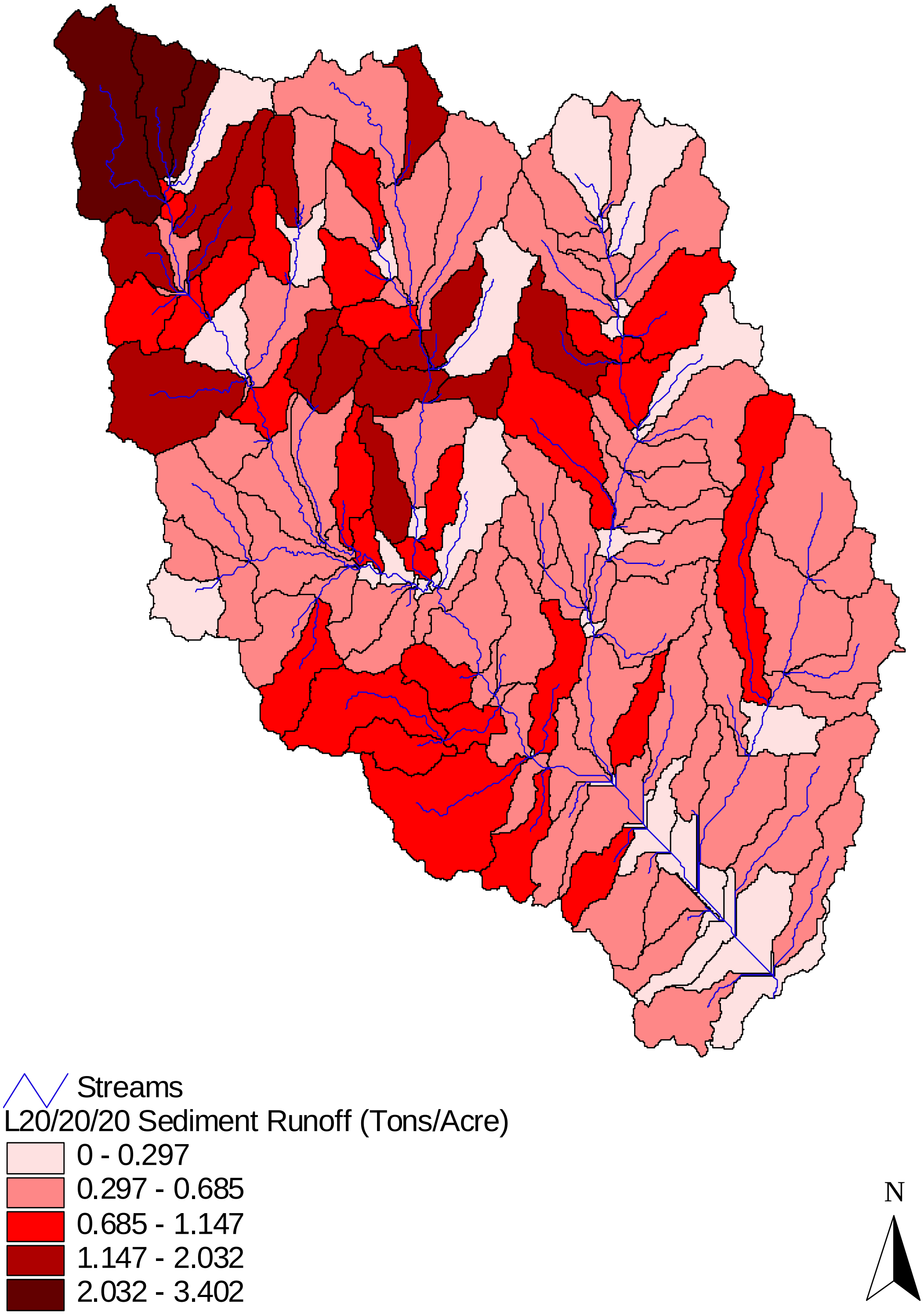
Map 18. Sediment Runoff under the Profit Maximizing Scenario, shown in Tons per Acre.



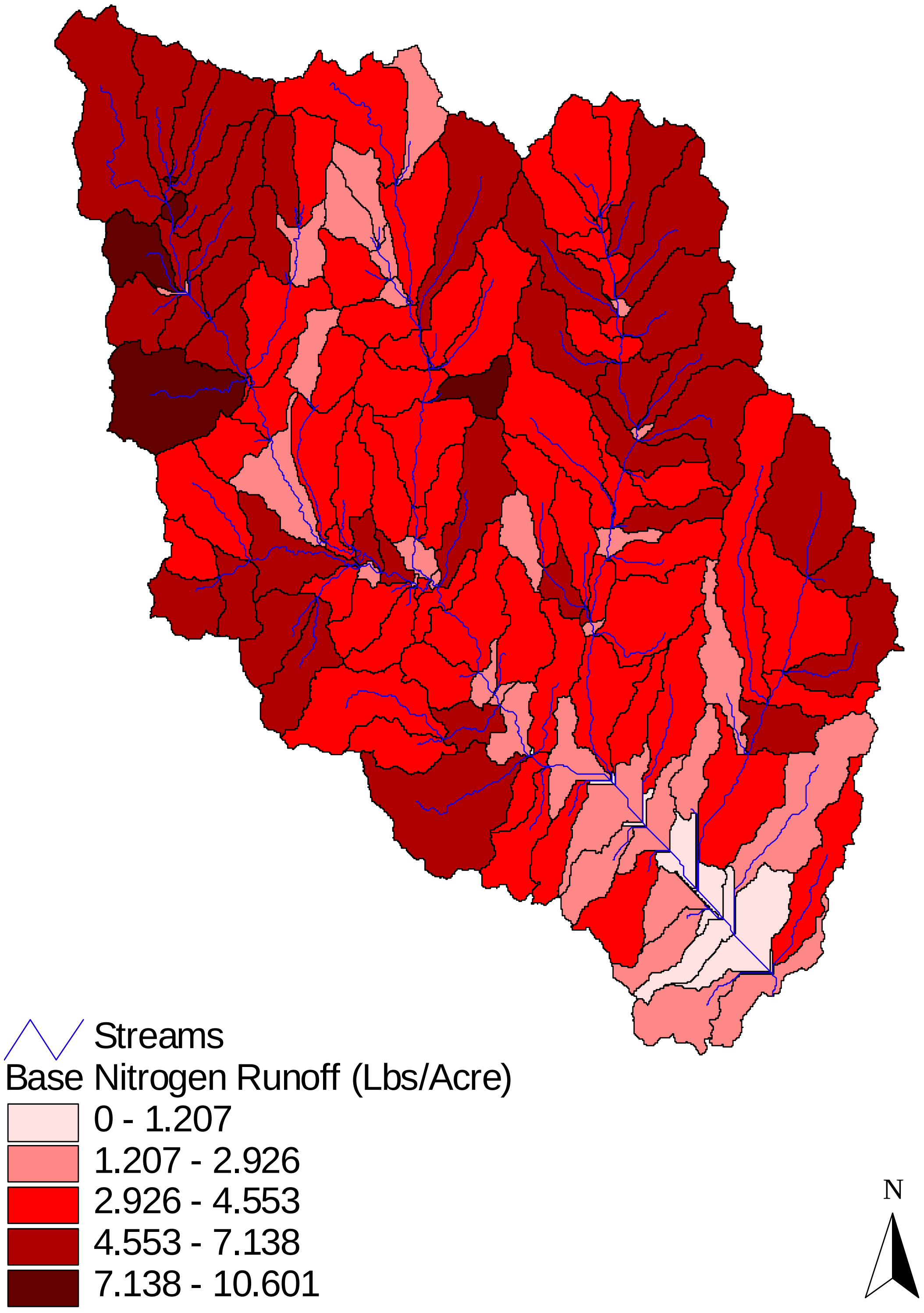
Map 19. Sediment Runoff under Scenario L/10/10/10, shown in Tons per Acre.



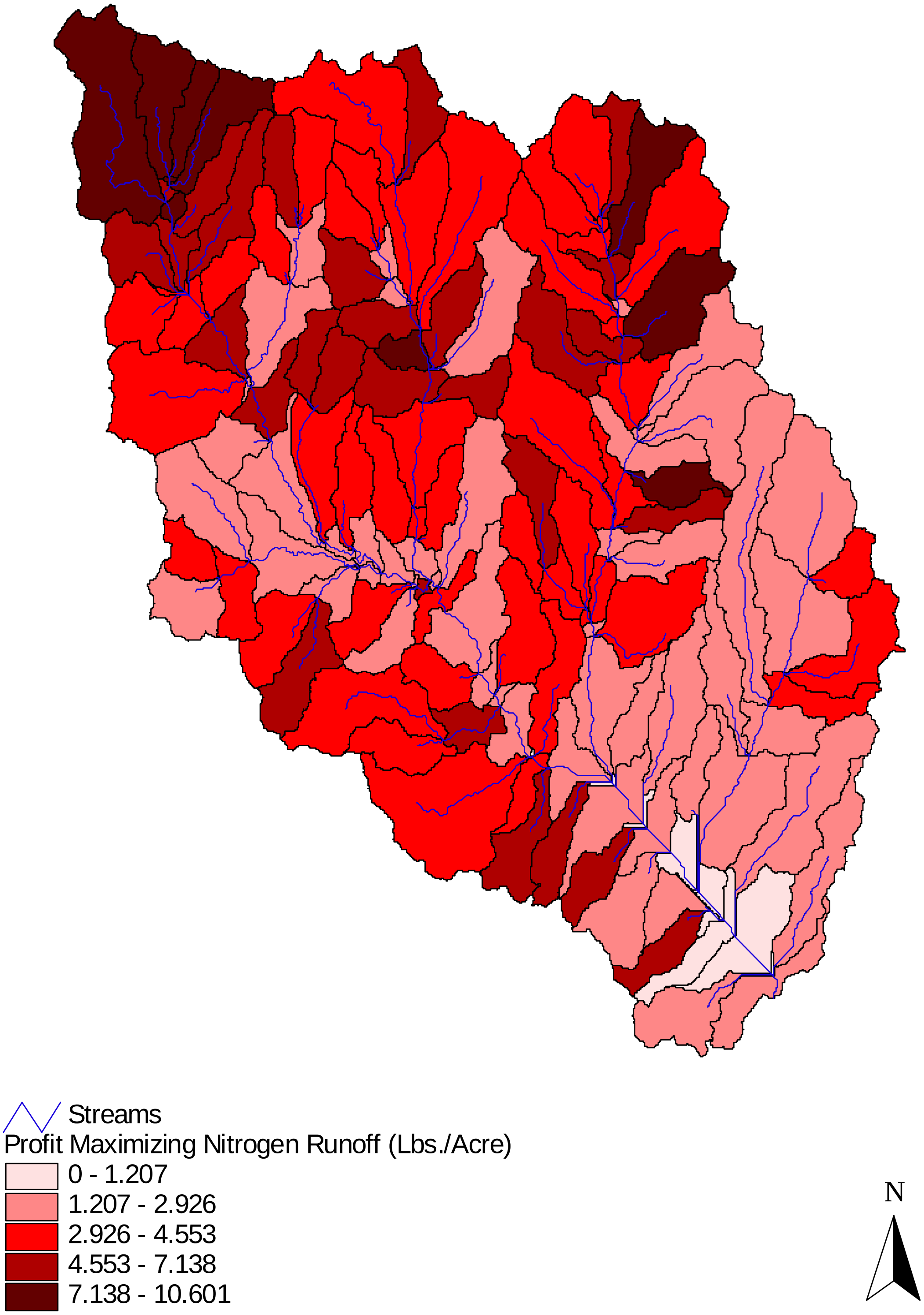
Map 20. Sediment Runoff under Scenario L/20/20/20, shown in Tons per Acre.



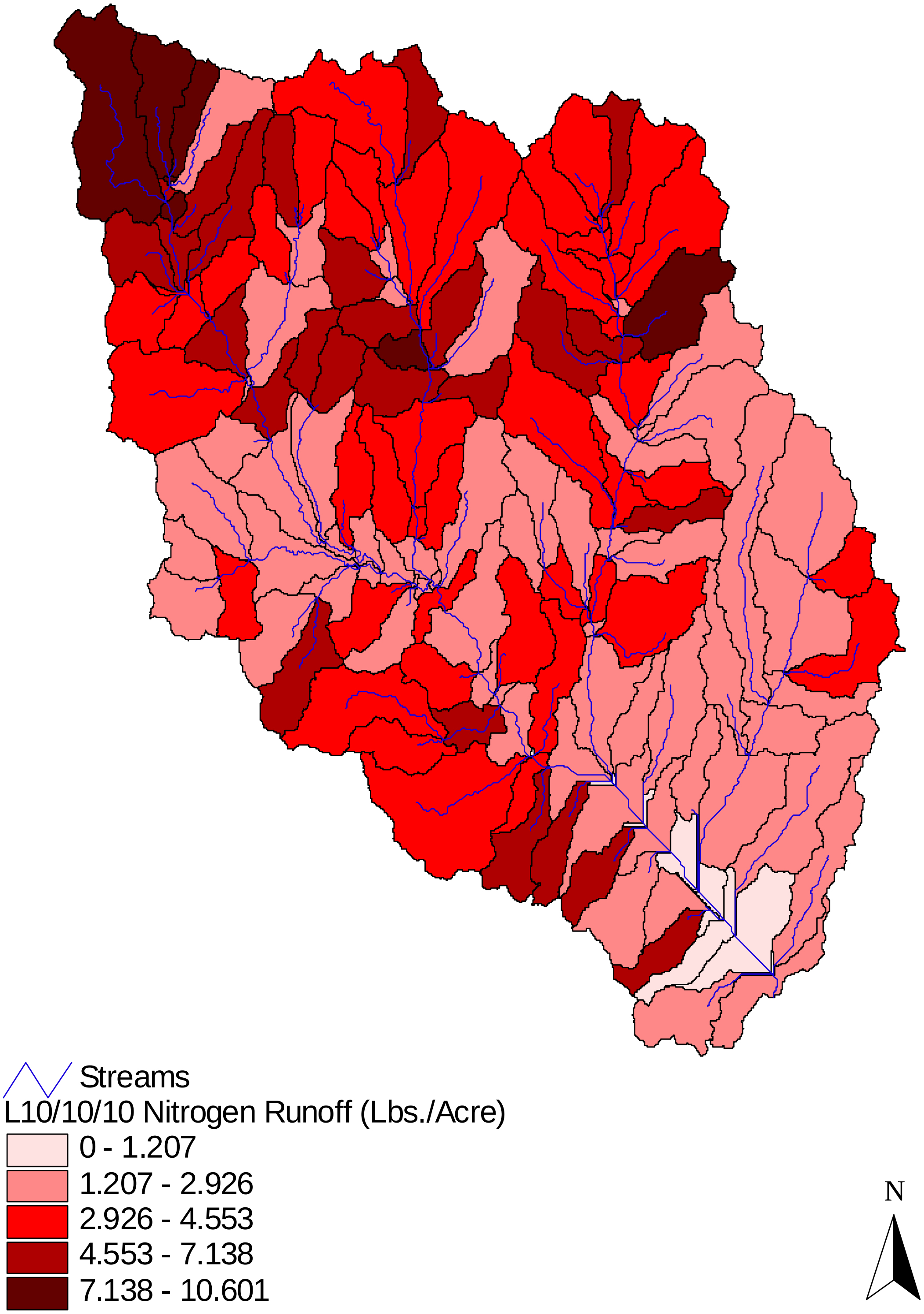
Map 21. Nitrogen Runoff under the Base Scenario Shown in Pounds per Acre.



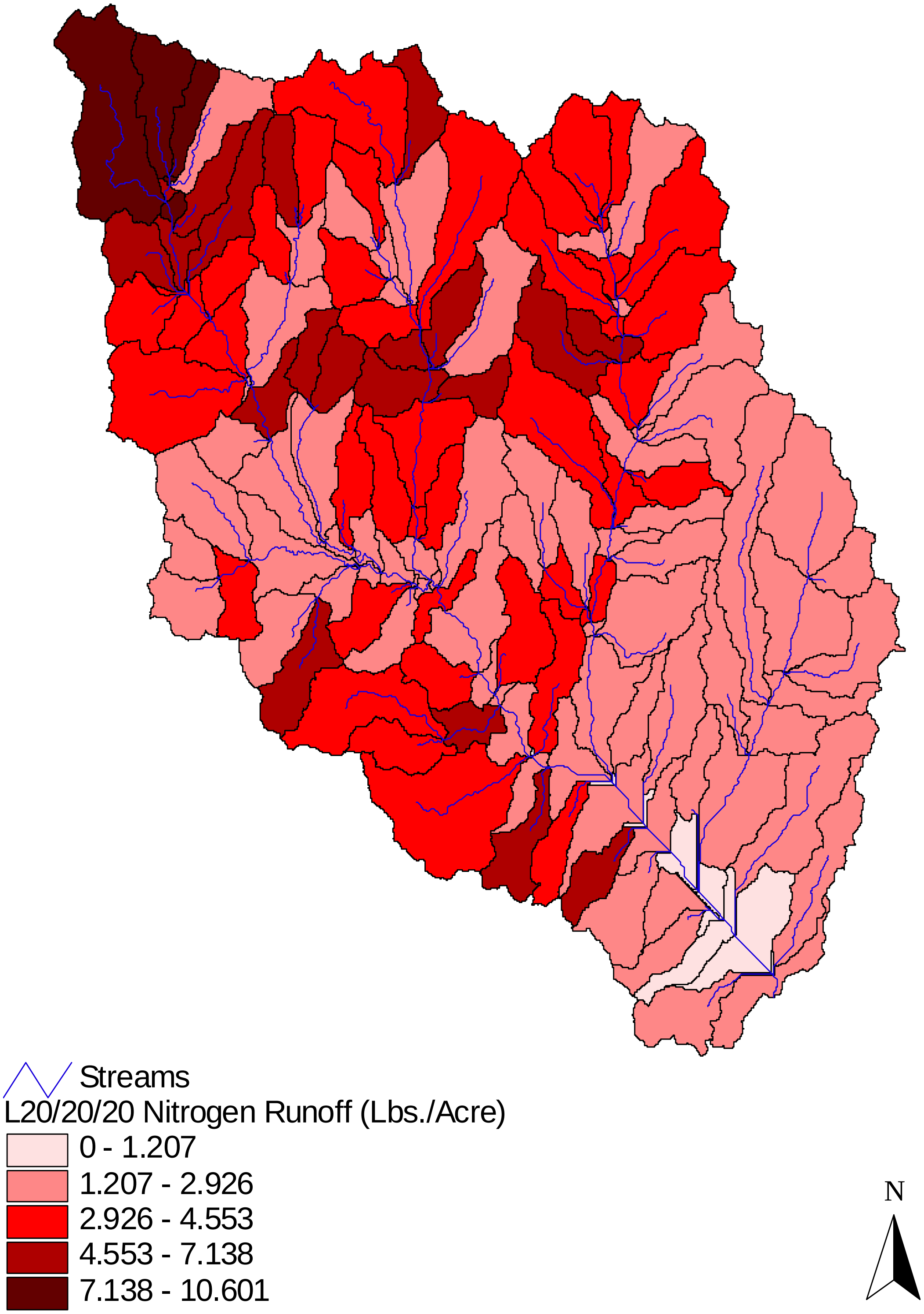
Map 22. Nitrogen Runoff under the Profit Maximizing Scenario Shown in Pounds per Acre.



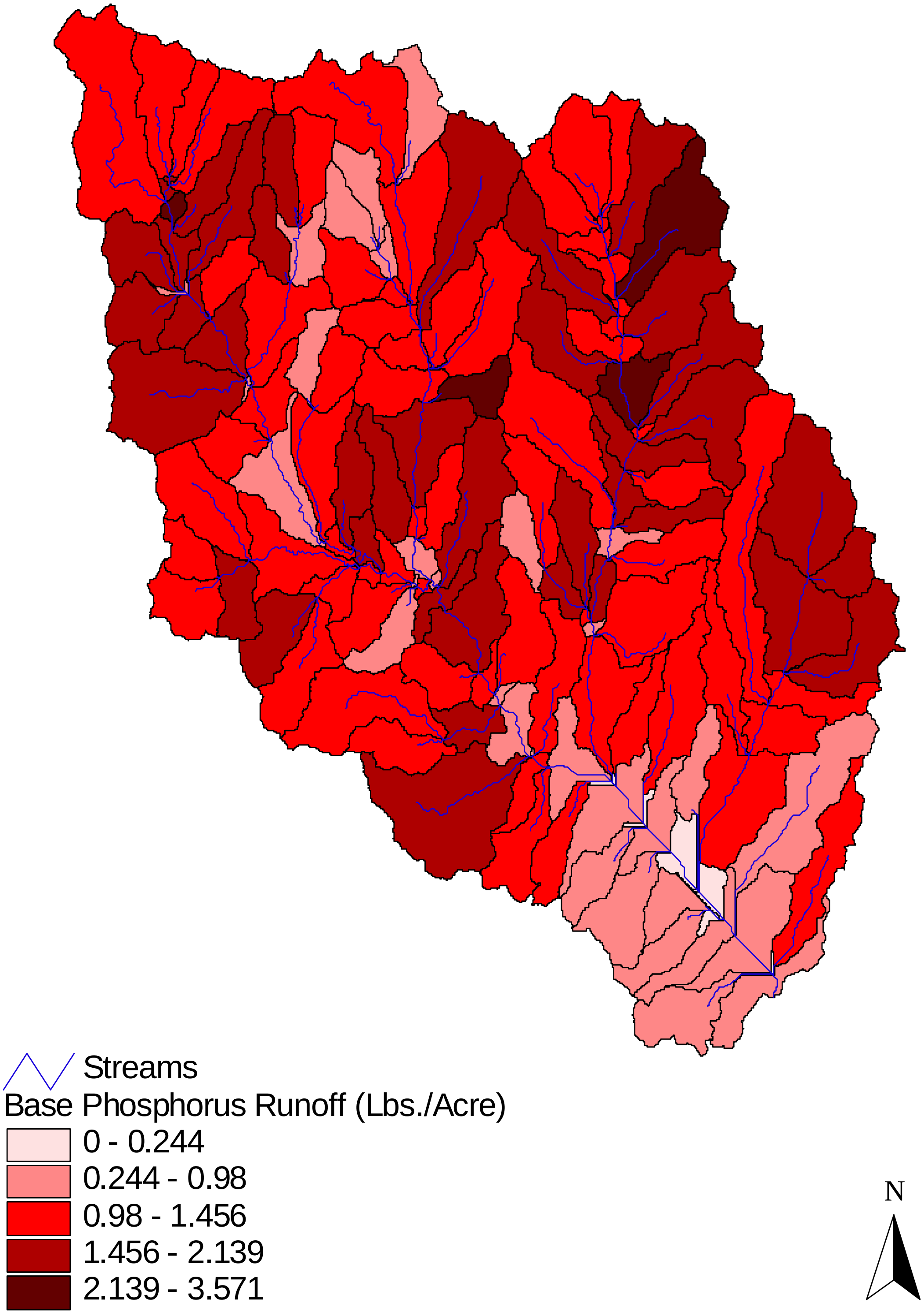
Map 23. Nitrogen Runoff under Scenario L/10/10/10 Shown in Pounds per Acre.



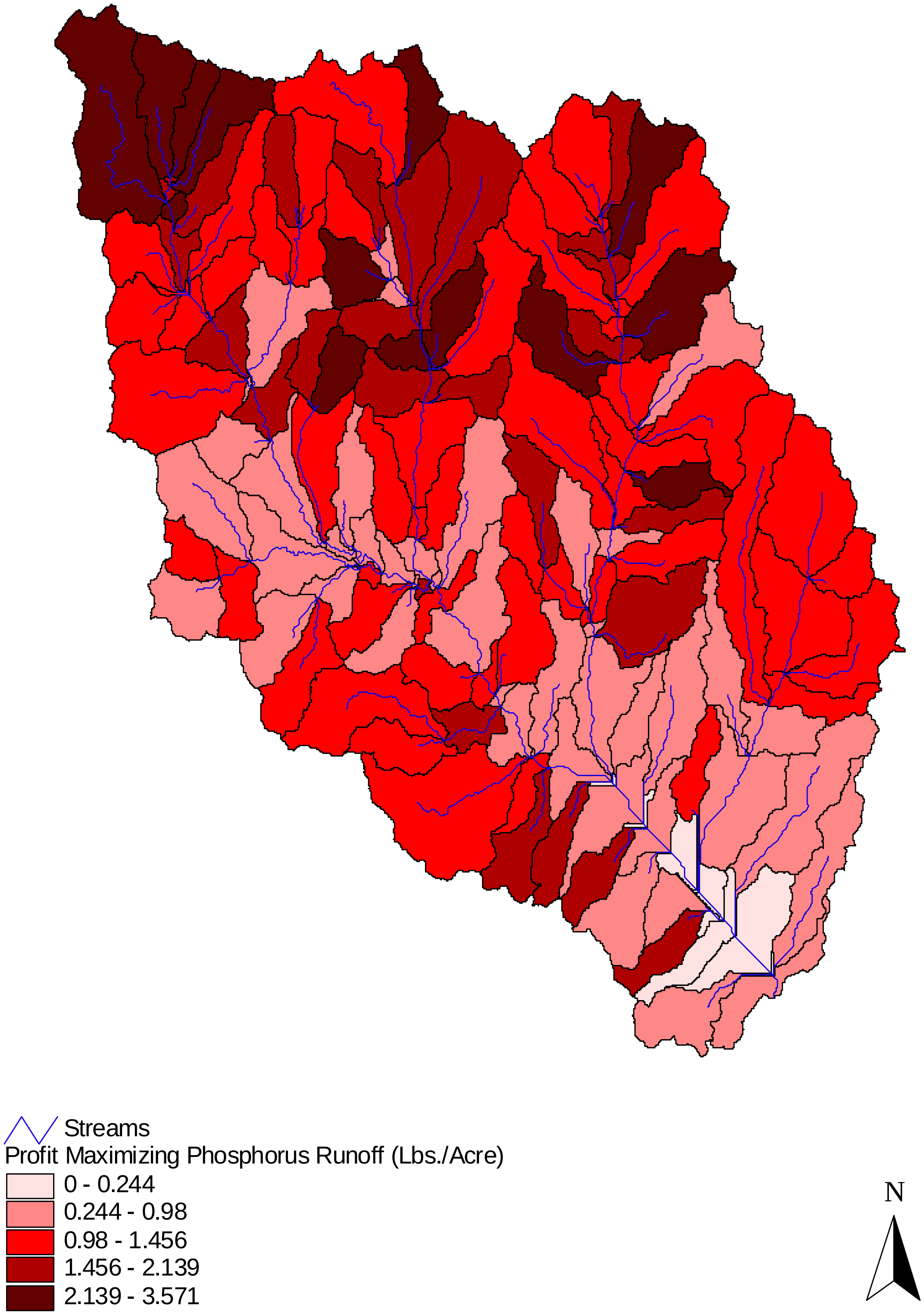
Map 24. Nitrogen Runoff under Scenario L/20/20/20 Shown in Pounds per Acre.



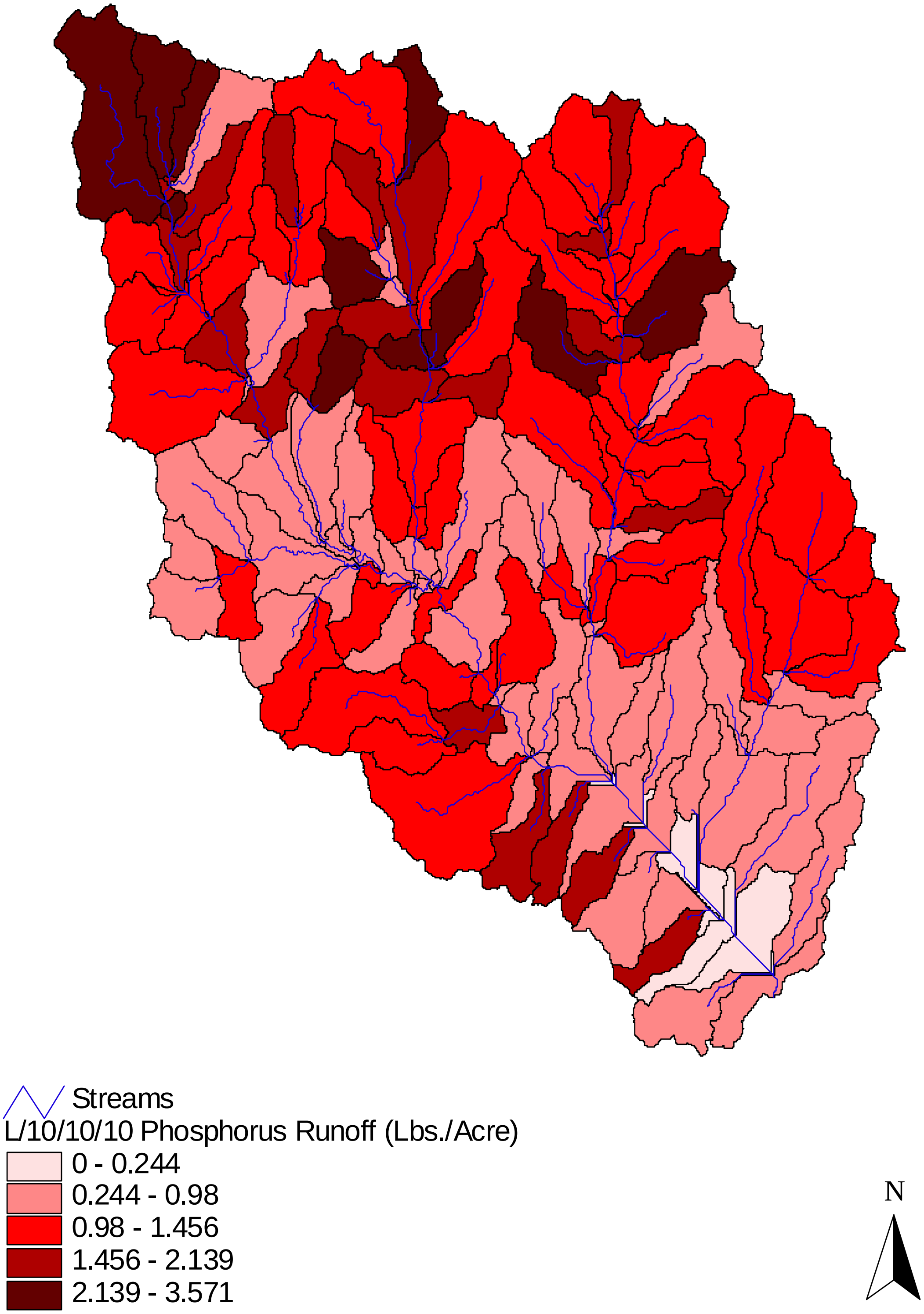
Map 25. Phosphorus Runoff under the Base Scenario Shown in Pounds per Acre.



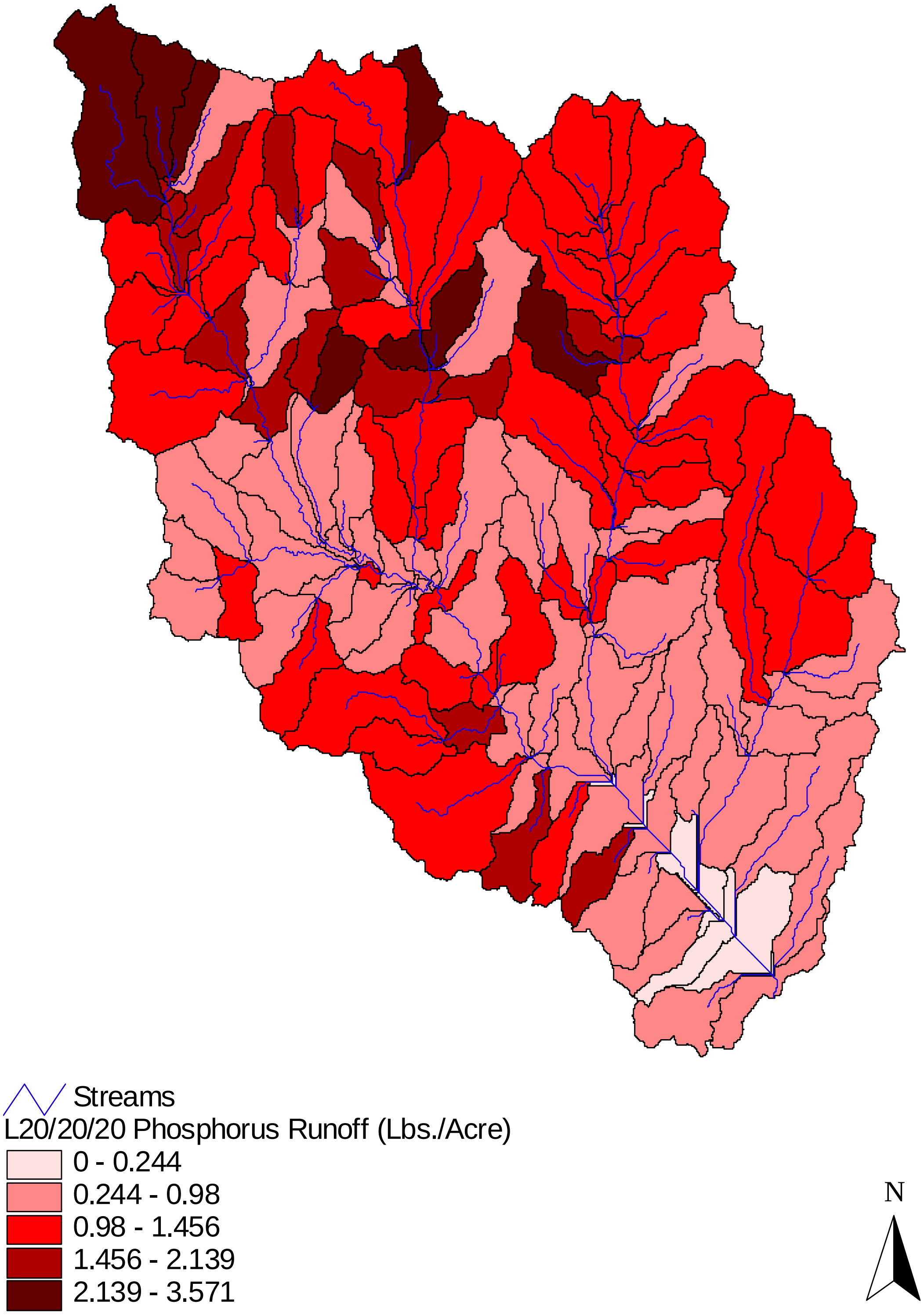
Map 26. Phosphorus Runoff under the Profit Maximizing Scenario Shown in Pounds per Acre.



Map 27. Phosphorus Runoff under Scenario L/10/10/10 Shown in Pounds per Acre.



Map 28. Phosphorus Runoff under Scenario L/20/20/20 Shown in Pounds per Acre.



PART II. GROSS POLLUTER VS. PROFIT MAXIMIZING ABATEMENT

In this section the comparison of a policy targeting only gross polluting land parcels for enrollment into CRP and a profit maximizing solution will be discussed. The program cost calculated as the sum of the change in producer profits and the change in government expense is shown in Figure 25. The results are presented as the change from the profit maximizing solution with no abatement. Each of the scenarios presented include a profit maximizing solution to meet a ten and twenty percent phosphorus abatement and the solutions targeting the highest polluting land parcels for ten and twenty percent phosphorus abatement. In studying the figure, the comparison should be between L/10/10/10 and 10 percent phosphorus or between L/20/20/20 and 20 percent phosphorus. At the ten percent level of abatement, the cost to society is increased by $58,230 after the switch from the profit maximizing solution to the gross polluter policy. This cost is $137,124 at the 20 percent level of phosphorus abatement. From this it is evident that the profit maximizing solution provides the same environmental benefits at a lower cost to producers and the government in terms of DCP and CRP rental payments.

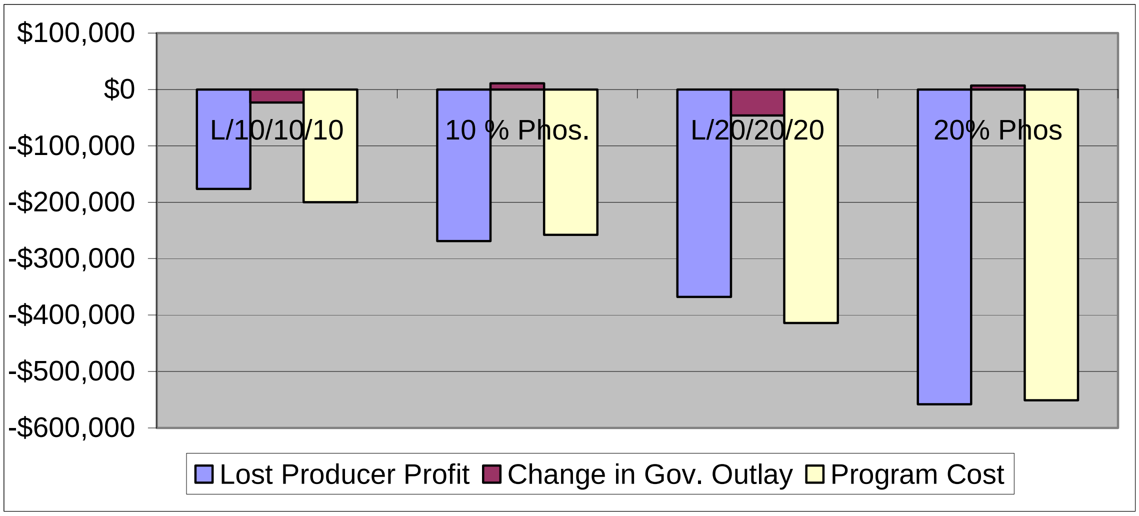


Figure 25. Change in Producer Profits, Government Outlay and the Net Change to Society from the Profit Maximizing Solution with Optimal and Naïve Abatement at the ten and twenty percent abatement levels.

Figure 26 shows how the cost per pound of phosphorus abated by each policy compare at abatement levels up to forty percent. At each abatement level the policy targeting gross polluters has a higher cost per pound abated.

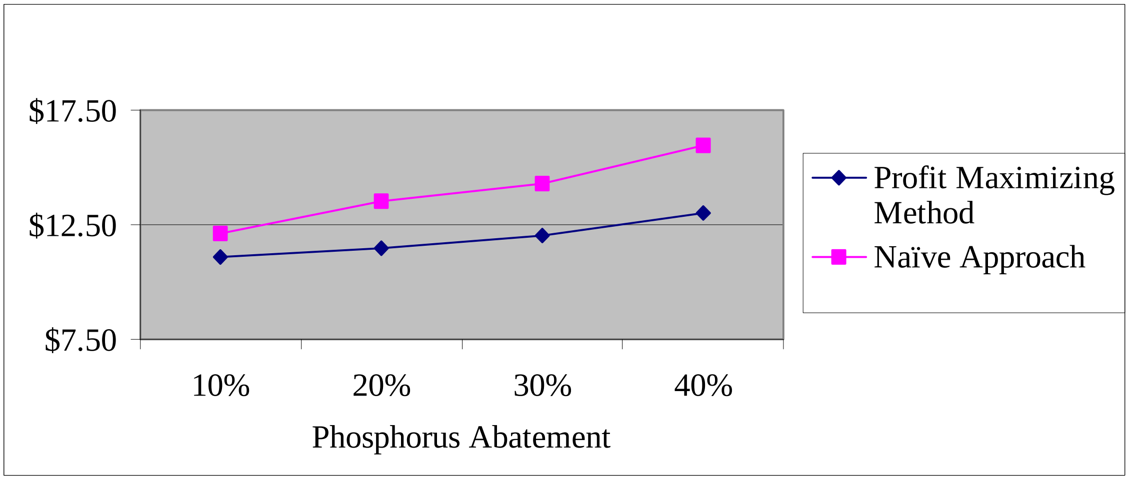


Figure 26. Comparison of Cost per Pound of Phosphorus Abatement with two Policy Approaches.

The results of this analysis indicate that CRP policy only targeting land parcels for enrollment would not have the least cost.

CHAPTER VI

CONCLUSIONS

SUMMARY

Surface water throughout the United States is threatened or impaired by runoff from point and non-point sources of pollution. Government agencies monitor surface water and provide listings of watersheds and water bodies that do not meet set standards of water quality even after the point sources of pollution have installed pollution control devices. The Fort Cobb Lake and watershed in southwest Oklahoma is one of these listed water bodies.

The Fort Cobb Lake is listed as threatened because of excess nutrients entering the lake as runoff from agricultural lands. Runoff from agricultural lands has been a topic of much debate and has had conservation programs established to mitigate the damages. Some of these programs are overseen by the United States Department of Agriculture. The premier program under the USDA’s discretion is the Conservation Reserve Program (CRP) established by the Farm Security Act of 1985. By using this program, the USDA mitigates the environmental damages caused by agricultural production.

The Fort Cobb watershed, because of its listing as a nutrient threatened watershed and agricultural production as its primary land use, provides an opportune location to examine the tradeoffs between producer revenue, sediment, nitrogen, and phosphorus runoff when the spatial allocation of the watershed is optimized to meet runoff abatement goals.

By using Graphical Information System (GIS) data for soil type, slope, climate, current cropping patterns, and crop management in the Soil and Water Assessment Tool (SWAT), the crop yield, sediment, nitrogen, and phosphorus runoff per acre were estimated for each acre in the watershed. Using Machsel and Oklahoma State University Enterprise Budget Software, the average production cost for each crop was determined based on cropping information provided by area Cooperative Extension Agricultural Agents and Industry Specialists. By entering this runoff and crop yield data for conventional till wheat, no till wheat, peanuts, sorghum, and CRP into a linear programming (LP) model, the optimal spatial allocation of the watershed could be determined. The objective of the LP model is to maximize producer's profits based on estimated crop yield and the average production cost for the watershed, subject to constraints on the amount of land enrolled into CRP, that every acre in the watershed is used, and limits on the sediment, nitrogen, and phosphorus runoff.

Using this LP model three CRP policies were compared to determine which one is the most efficient at reducing runoff in the watershed. The first CRP policy represents the program as it currently is, if producers enroll their land into CRP they do not receive the direct and counter cyclical payment (DCP) on that land. The second policy is a variation of the current policy where the producer receives the DCP regardless of CRP enrollment. This policy in effect raises the CRP rental payment depending on the program crop base established on that land parcel. The third CRP policy is one that targets land for enrollment into CRP based only on the runoff from that land. With this policy, land with the greatest runoff per acre is targeted first for enrollment into CRP.

The results section is broken down into two sections dealing with these CRP policies. The first section contains the tables, figures, maps, and discussion comparing the CRP policy where the DCP is either received or not received based on CRP enrollment. The second section contains the tables, figures, and discussion comparing CRP policy where land allocation is optimized and where only the gross polluters are targeted for enrollment into the CRP program.

CONCLUSIONS

To determine which CRP policy is most efficient at reducing runoff, LP model scenarios were used as outlined in the first section of the results. In these scenarios the CRP Policy and the sediment, nitrogen, and phosphorus runoff abatement level were varied. By analyzing the government expenditure and producer revenue between the CRP policies dealing with the DCP, it is determined that at each runoff abatement level the alternative CRP payment where the producer receives the DCP regardless of CRP enrollment increases the cost to society. The results of this analysis are shown in Figure 1. As expected at each abatement level, the government expenditure is increased for the alternative CRP policy. What needed to be determined was how much of this increased transfer or government expenditure was a benefit to producers. From this analysis for each abatement level, the alternative policy always resulted in a larger increase in the government expenditure than the increase in producer profits.

Based on the data from these scenarios, it was determined that in order to reduce sediment, nitrogen, and phosphorus runoff in the watershed that phosphorus must be targeted for abatement. In each scenario if phosphorus were abated, sediment and nitrogen were abated to at least the level of phosphorus abatement. If only sediment or nitrogen were abated the other runoff levels increased above their base levels.

The maps section of the results gives a visual representation of how the spatial allocation of land and how the runoff per acre in the watershed changed from the base, to the Profit Maximizing, to the L/10/10/10, through the L/20/20/20 scenarios. The spatial allocation of conventional till wheat moved from the upper end of the watershed down to the southern end around the reservoir and major streams as the level of runoff abatement increased. Peanut production decreased in the watershed, but the acres that did remain moved from the sub basins in the southern portion of the watershed to the northern areas away from the waterways and the reservoir. No till wheat and CRP acres increased on the more sloping sub basins in the middle and northern part of the watershed. The interesting fact here is the lack of CRP acres that are established on the southern end of the watershed nearer to the reservoir.

The spatial allocation of runoff from the sub basins does exhibit 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 remaining runoff is shifted to the northern portions of the watershed away from the major waterways and the reservoir.

In the second section of the results, the comparison of the current CRP policy and the alterative policy where only gross polluting HRUs are targeted for enrollment is discussed. From this analysis it is determined that only targeting gross polluters for CRP enrollment without regard to cost would result in greater CRP cost per ton of phosphorus abatement, and in most cases a loss to producers' profits resulting in a net loss to society. Comparison at each level of phosphorus abatement determined that the alternative policy always results in a greater cost per ton abated.

In conclusion the results of this study indicate that the current CRP policy is more efficient at reducing sediment, nitrogen, and phosphorus runoff than either of the other two alternative policies. This research has estimated the marginal cost of sediment, nitrogen, and phosphorus abatement. In order to choose the "optimal level" of runoff abatement further research needs to be conducted to estimate the marginal damage cost of runoff in the watershed.

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.

Limitation of SWAT

The biggest limitation of SWAT is in the way that HRUs are established and used by SWAT. SWAT establishes homogeneous HRUs based on their slope, soil type, and land use in each sub basin. Each HRU is not necessarily one continuous land unit or field. Because the HRUs are not established as continuous units or fields, mapping the individual HRUs and the land use changes associated with the various scenarios is not possible. The best mapping that is possible is to map the changes in land use in each sub basin. As technology advances to a point when HRUs can be established as field units, analysis of this type will be very powerful in making land use decisions.

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APPENDIX

SECTION I. MACHSEL

Fixed Costs

- Annual Average Depreciation= (Purchase Price-Salvage Value)/Years
- Annual Average Interest= ((Purchase Price-Salvage Value)/2)*Interest Rate
- Annual Tax= Purchase Price * Tax Rate
- Annual Insurance= ((Purchase Price-Salvage Value)/2)*Insurance Rate

Variable Costs

- Fuel Cost= PTO Horsepower * FCM * Price per Gallon * Hours Used.
  FCM=Fuel Cost Multiplier
  PTO=Power Take Off
- Lubrication Cost= Fuel Cost * .15
- Repair Cost= List Price * RC1 * RC2 * Percent Life^RC3
  Percent Life= ((Years Used * Hours per year) / Hours of Life) * 100
  RC1 is and engineering ratio of total lifetime accumulated repairs
  RC2 and RC3 are coefficients that define how repairs are allocated over the life of the machine.

SECTION II. FIELD OPERATIONS

Table 14 Specified Monthly Field Operations for Peanut Production

Month ->	1	2	3	4	5	6	7	8	9	10	11	12
Machinery												
Offset Disc				1								
M.B. Plow			1									
Tandem Disk					1							
Planter					1							
Cultivator					2	3	1					
Sprayer					1	1	1					
Dry Fert. Spdr.				1								
Baler										0.75		

Table 15. Specified Monthly Field Operations for Sorghum Production

Month->	1	2	3	4	5	6	7	8	9	10	11	12
Machinery												
Tandem Disk				1								
Springtooth					1							
Planter					1							
Cultivator						1						
Sprayer					1							
Dry Fert. Spdr.				1								

Table 16. Specified Monthly Field Operations for CRP Production

Month ->	1	2	3	4	5	6	7	8	9	10	11	12
Machinery												
Chisel			0.5									
Sprayer				1								
Drill				1								

Table 17. Specified Non-Harvest Monthly Field Operations for Conventional Tillage Wheat

Month->	1	2	3	4	5	6	7	8	9	10	11	12
Machinery												
Offset Disc								1				
M.B. Plow						1						
Tandem Disk									1			
Springtooth S. Harrow												
Drill									1			
Sprayer				1								
Dry Fert. Spdr.								1	1			

Table 18. Specified Monthly Field Operations for No-Till Wheat production.

Month->	1	2	3	4	5	6	7	8	9	10	11	12
Machinery												
No-Till Drill									1			
Sprayer				1		1		1				
Dry Fertilizer Spreader								1	1			

SECTION III. BUDGETS AND MACHINERY OPERATIONS

Table 19. Revenue, Variable Costs, Fixed Costs and Returns for Irrigated Peanuts.

Production	Units	Price	Quantity	$/acre
Peanuts	Pound	$0.17	3000	$510.00
LDP	Pound	$0.01	3000	$22.50
Direct Payment	Acre			$42.66
Counter Cyclical Payment	Acre			$123.24
Hay Crop	Ton	$100.00	0.75	$75.00
Total Receipts				$773.40
Operating Inputs				
Tamrun 96 Seed	lbs.	$0.82	75	$61.01
Fertilizer				
10/20/2010	lbs.	$0.10	100	$10.35
Disease Control				
Abound 2.1F	Fl. Oz.	$1.96	18	$35.28
Folicur 3.6F	Fl. Oz.	$2.87	7	$20.09
Bravo 720	Pint	$7.21	1.5	$10.82
Bravo 720	Pint	$7.21	1.5	$10.82
Insect Control				
Temik 15G	Gallon	$1.25	3.8	$4.69
Weed Control				
Prowl 3.3EC	Pint	$2.76	2	$5.52
Pursuit (pre)	Ounce	$11.15	4	$44.60
Crop Insurance				
Approved yield (lb.)	Yield Cover. Level	Prem. Rate for MPCI	Price ($/lb) Crop	
2833	65%	$0.03	0.18	$11.27
Annual Operating Capital	Dollar	6.75%	98.5	$6.65
Machinery Labor	Hrs.	$7.50	2.82	$21.15
Irrigation Labor	Hrs.	$7.50	1	$7.50
Custom Hire				
Aerial Fungicide App.	Times	$4.06	2	$8.12
Machinery Fuel	Gallon	$1.00	13.74	$13.74
Machinery Lube		$0.15	13.74	$2.06
Repair Cost	Acre	$59.28	1	$59.28
Irrigation	Acre/inch	$3.44	12.86	$44.24
Other Expense				
Drying	Ton	$60.00	0.75	$45.00
Hauling	Ton	$20.00	0.75	$15.00
Total Operating cost				$437.19
Fixed Costs				
Machinery/Irrigation				
Interest	Dollar	6.50%		$26.96
Taxes	Dollar	1.00%		$5.27
Insurance	Dollar	0.60%		$2.49
Depreciation	Dollar			$36.34
Total Fixed Costs				$71.06
Total Costs (Operating + Fixed)				$508.25
Returns Above All Specified Costs				$264.66

Table 20. Revenue, Variable Costs, Fixed Costs, and Returns for Grain Sorghum.

Production	Units	Price	Quantity	$/acre
Grain Sorghum	Bu.	$ 1.85	43.86	$ 81.29
LDP	Bu.	$ 0.10	43.86	$ 4.39
	Percent	Rate	Base Yld.	
Direct Payment	85%	$ 0.35	40.9	$ 12.17
Counter Cyclical Payment	85%	$ 0.27	40.9	$ 9.39
Total Receipts				$ 107.23
Operating Inputs				
Sorghum Seed	Plants/acre	40,000		$ 3.27
Fertilizer				
Diammonium Phosphate	Lbs.	$ 0.12	75	$ 8.85
Urea	Lbs.	$ 0.12	75	$ 9.30
Custom Harvest				
Per Acre Charge	Acre	$ 14.00	1	$ 14.00
Yield Charge over 45 Bu.				
	Bu.	$ 0.08	0	$ -
Hauling	Cwt.	$ 0.07	43.86	$ 3.19
Pesticide				
Dual Magnum	Pint	$ 12.38	0.50	$ 6.19
Peak	Oz.	$ 11.59	0.75	$ 8.69
Crop Insurance	Acre	$ 2.44	1	$ 2.44
Annual Operating Capital	Dollar	6.75%	19.56	$ 1.32
Machinery Labor	Hrs.	$ 7.50	0.62	$ 4.63
Machinery Fuel	Gallon	$ 1.00	$ 3.07	$ 3.07
Machinery Lube		$ 0.15	$ 3.07	$ 0.46
Repair Cost	Acre	$ 5.53	1	$ 5.53
Total Operating cost				$ 70.94
Fixed Costs				
Machinery/Irrigation				
Interest	Dollar	6.50%		$ 7.83
Taxes	Dollar	1.00%		$ 1.82
Insurance	Dollar	0.60%		$ 0.72
Depreciation	Dollar			$ 12.38
Total Fixed Costs				$ 22.75
Total Costs (Operating + Fixed)				$ 93.69
Returns Above All Specified Costs				$ 13.54

Table 21. Revenue, Variable Costs, Fixed Costs, and Returns for Conservation Reserve Acreage.

Production	Units	Price	Quant.	Success Rate	% of Total Acres	$/Acre
CRP Rental Payment	Acre	$ 40.00	1		100%	$ 40.00
Establishment Cost Share	Acre	$ 30.05	1		10%	$ 3.01
Total Receipts						$ 43.01
Operating Inputs						
Establishment Cost						
Seed						
Switchgrass	lbs.	$ 3.50	0.75	70%	10%	$ 0.38
Sideoats Grama	lbs.	$ 8.25	0.9	70%	10%	$ 1.06
Blue Grama	lbs.	$ 8.25	0.2	70%	10%	$ 0.24
Indiangrass	lbs.	$ 9.00	0.45	70%	10%	$ 0.58
Big Bluestem	lbs.	$ 11.50	0.6	70%	10%	$ 0.99
Little Bluestem	lbs.	$ 9.00	0.51	70%	10%	$ 0.66
Maximilian Sunflower	lbs.	$ 15.00	0.1	70%	10%	$ 0.21
Illinois Bundleflower	lbs.	$ 15.00	0.2	70%	10%	$ 0.43
Fertilizer						
Ammonium Nitrate	lbs.	$ 0.11	40	70%	10%	$ 0.64
Diammonium Phosphate	lbs.	$ 0.12	40	70%	10%	$ 0.67
Machinery Fuel	Gallon	$ 1.00	1.40	70%	10%	$ 0.20
Machinery Lube		$ 0.15	1.40	70%	10%	$ 0.03
Machinery Repair	Acre	$ 3.29	1	70%	10%	$ 0.47
Labor	Hour	$ 7.50	0.281	70%	10%	$ 0.30
Annual Operating Capital	Dollar	6.75%	3.85	70%	100%	$ 0.37
Total Operating cost						$ 7.22
Fixed Costs						
Establishment Machinery						
Interest	Dollar	6.50%	$ 7.70	70%	10%	$ 1.10
Taxes	Dollar	1.00%	$ 1.79	70%	10%	$ 0.26
Insurance	Dollar	0.60%	$ 0.71	70%	10%	$ 0.10
Depreciation	Dollar		$ 12.08	70%	10%	$ 1.73
Total Fixed Costs						$ 3.18
Total Costs (Operating + Fixed)						$ 10.40
Returns Above All Specified Costs						$ 32.60

Table 22. Revenue, Variable Costs, Fixed Costs, and Returns for Conventional tillage Wheat.

Production	Units	Price	Quantity	$/acre
Wheat	Bushel	$ 2.67	40.35	$ 107.73
LDP	Bu.	$ 0.08	40.35	$ 3.23
	Percent	Rate	Base Yld.	Payment
Direct Payment	85%	$ 0.52	31.9	$ 14.10
Counter Cyclical Payment	85%	$ 0.65	32.3	$ 17.85
Small Grain Pasture	Acre	$ 35.25	1	$ 35.25
Total Receipts		$ 178.16		$ 178.16
Operating Inputs				
Wheat Seed	Bu./acre	$ 2.75	2	$ 5.50
Fertilizer				
Urea	lbs.	$ 0.12	200	$ 24.80
Diammonium Phosphate	lbs.	$ 0.12	55	$ 6.49
Pesticide				
Dimethoate	Pint	$ 4.13	0.75	$ 3.09
Crop Insurance	acre	$ 2.10	1	$ 2.10
Custom Harvest				
Per Acre Charge	Acre	$ 13.00	1	$ 13.00
Charge over 20 Bu./A	Bushel	$ 0.13	20.35	$ 2.65
Hauling	Bushel	$ 0.13	40.35	$ 5.25
Machinery Fuel	Gallon	$ 1.00	$ 5.73	$ 5.73
Machinery Lube		$ 0.15	$ 5.73	$ 0.86
Machinery Repair	Acre	$ 12.60	1	$ 12.60
Labor	Hour	$ 7.50	1.05	$ 7.84
Annual Operating Capital	Dollar	6.75%	48.03	$ 3.24
Total Operating cost		$ 97.75		$ 93.14
Fixed Costs				
Machinery				
Interest	Dollar	6.50%		$ 8.78
Taxes	Dollar	1.00%		$ 2.06
Insurance	Dollar	0.60%		$ 0.81
Depreciation	Dollar			$ 14.24
Total Fixed Costs				$ 25.89
Total Costs (Operating + Fixed)				$ 119.03
Returns Above All Specified Costs				$ 59.12

Table 23. Revenue, Variable Costs, Fixed Costs, and Returns for No-Till Wheat

Production	Units	Price	Quantity	$/acre
Wheat	Bushel	$ 2.67	35	$ 93.45
LDP	Bu.	$ 0.08	35	$ 2.80
	Percent	Rate	Base Yld.	Payment
Direct Payment	85%	$ 0.52	31.9	$ 14.10
Counter Cyclical Payment	85%	$ 0.65	32.3	$ 17.85
Small Grain Pasture	Acre	$ 35.25	1	$ 35.25
Total Receipts				$ 163.45
Operating Inputs				
Wheat Seed	Bu./acre	$ 2.75	2	$ 5.50
Fertilizer				
Urea	lbs.	$ 0.12	200	$ 24.80
Diammonium Phosphate	lbs.	$ 0.12	55	$ 6.49
Pesticide				
Lorsban 4E-SG	Pint	$ 5.20	0.80	$ 4.16
Roundup ultra Max	oz	$ 7.50	1.00	$ 7.50
R.T. Master	Pint	$ 3.00	2.00	$ 6.00
Dimethoate	oz	$ 0.25	12.00	$ 3.00
Crop Insurance	acre	$ 2.10	1	$ 2.10
Custom Harvest				
Per Acre Charge	Acre	$ 13.00	1	$ 13.00
Charge over 20 Bu./A	Bushel	$ 0.13	15	$ 1.95
Hauling	Bushel	$ 0.13	35	$ 4.55
Machinery Fuel	Gallon	$ 1.00	$ 2.33	$ 2.33
Machinery Lube		$ 0.15	$ 2.33	$ 0.35
Machinery Repair	Acre	$ 3.60	1	$ 3.60
Labor	Hour	$ 7.50	0.90	$ 6.73
Annual Operating Capital	Dollar	6.75%	46.39	$ 3.13
Total Operating cost				$ 95.19
Fixed Costs				
Machinery				
Interest	Dollar	6.50%		$ 11.28
Taxes	Dollar	1.00%		$ 2.76
Insurance	Dollar	0.60%		$ 1.04
Depreciation	Dollar			$ 18.86
Total Fixed Costs				$ 33.94
Total Costs (Operating + Fixed)				$ 129.13
Returns Above All Specified Costs				$ 34.32

SECTION IV. GAMS PROGRAMMING MODEL

```
$TITLE FORT COBB WATERSHED RUN 1
$OFFUPPER OFFSYMXREF OFFSYMLIST OFFUELLIST OFFUELXREF
OPTION LIMROW=0, LIMCOL=0
OPTION SOLPRINT=OFF;


SETS
J  HRU
 /H0010004, H0010005, H0010006, H0020011, H0020012, H0030020, H0030021,
H0030022, H0040027, H0040028, H0040031, H0040032, H0060040, H0070044,
*…..
*DATA OMITTED
*…..,
, H1531798, H1531799, H1531800, H1531801, H1531802, H1541808, H1541809,
H1541813, H1541814, H1541815, H1541816, H1541817, H1541818, H1541819/


S SUB
/SB1, SB2, SB3, SB4, SB6, SB7, SB8, SB9, SB10, SB11, SB12, SB13, SB14, SB15,
SB16, SB17
*…..
*DATA OMITTED
*…..,
SB140, SB141, SB142, SB143, SB144, SB145, SB146, SB147, SB148, SB149, SB150,
SB151, SB152, SB153, SB154 /


JS(J,S)
/  (H0010004, H0010005, H0010006) . SB1, (H0020011, H0020012) . SB2, (H0030020,
H0030021, H0030022) . SB3, (H0040027, H0040028, H0040031, H0040032) . SB4,
*…..
*DATA OMITTED
*…..
H1531801, H1531802).SB153, (H1541808, H1541809, H1541813, H1541814,
H1541815, H1541816, H1541817, H1541818, H1541819).SB154/


CROPS
/CWHEAT, PNUT, SORG, NWHEAT, CRP/


PARAMETER F(I)  FORAGE AND HAY REVENUE PER ACRE.
/CWHEAT        35.25
```

```
PNUT              75
SORG               0
NWHEAT          35.25
CRP              0/;


PARAMETER C(I) COST TO PRODUCE CROP I PER ACRE
/CWHEAT        119.03
PNUT           508.25
SORG             93.69
NWHEAT          129.13
CRP              10.40/


PARAMETER R(I)
/CWHEAT     100000
PNUT        100000
SORG        100000
NWHEAT      100000
CRP           24897/;

PARAMETER P(I) PRICE OF CROP I
 /CWHEAT       2.75
  PNUT        .18
  SORG       1.95
  NWHEAT       2.75
  CRP       43.01/

TABLE B(J,I)

                  SORG      NWHEAT        PNUT
H0010004       319.136    1166.097     248.432
H0010005      1421.796    2397.136     696.273
H0010006      1440.240    5537.182    1221.033
H0020011       624.015    2380.179     522.735
*…..
*DATA OMITTED
*…..
H1541814        70.585     134.456      39.516
H1541815        15.917      68.076      15.509
H1541816       107.559     250.519      64.758
H1541817        28.408      99.506      21.730
H1541818        69.089     146.872      35.853
H1541819        23.872      99.227      22.195
```

```
TABLE G(J,I)  GOVERNMENT PAYMENT FORFETED IF LAND IS ENROLLED IN
CRP
                CRP
H0010004       -31.95
H0010005       -31.95
H0010006       -31.95
H0020011       -31.95
*…..
*DATA OMITTED
*…..
H1541814       -21.55
H1541815       -21.55
H1541816       -31.95
H1541817       -31.95
H1541818       -31.95
H1541819       -31.95


PARAMETER ACRES(J)  ACRES IN SUB BASIN J

/H0010004       144.7420
H0010005       134.6150
H0010006       871.9100
H0020011       363.0900
*…..
*DATA OMITTED
*…..
H1541814       8.8920
H1541815       6.4714
H1541816       46.9300
H1541817       20.9703
H1541818       30.1340
H1541819       16.2526/;


TABLE Y(J,I)   CROP YIELD FOR SUB BASIN J UNDER CROP I
                 PNUT     CWHEAT NWHEAT  SORG     CRP
H0010004     2743.320     32.915     35.520     26.022     1.0
H0010005     2544.939     19.339     22.105     28.128     1.0
H0010006      2743.320    32.740     33.522     26.893     1.0
H0020011     2743.320     32.726     33.873     26.923     1.0
*…..
*DATA OMITTED
*…..
H1541814     2600.810     37.854     38.300     43.057     1.0
H1541815      2616.194    38.731     41.161     35.820     1.0
```

```
H1541816     2617.814    43.009     44.872     41.731     1.0
H1541817      2618.623   42.497     41.781     44.534     1.0
H1541818     2625.101    44.642     45.493     32.794     1.0
H1541819      2616.194   38.731     41.161     35.820     1.0


TABLE PH(J,I)  PHOSPORUS YIELD IN SUBBASIN J UNDER CROP I
                PNUT  CWHEAT NWHEAT  SORG      CRP
H0010004        6.225      1.716      1.166      3.339      0.460
H0010005        8.690      5.172      5.329      5.380      1.450
H0010006        5.709      1.400      1.181      2.753      0.537
H0020011        5.863      1.440      1.204      2.837      0.546
*…..
*DATA OMITTED
*…..

H1541814        9.236      3.237      3.232      4.444      2.070
H1541815        4.521      1.268      1.081      2.396      0.851
H1541816        4.560      1.380      1.354      2.348      1.063
H1541817        4.199      1.036      1.041      1.906      0.848
H1541818        4.044      1.190      1.416      2.197      0.994
H1541819        4.855      1.366      1.169      2.575      0.865


TABLE N(J,I)   NITROGEN YIELD IN SUBBASIN J WITH CROP I

                 PNUT   CWHEAT  NWHEAT    SORG       CRP
H0010004        19.812       7.962       3.079       14.570       0.561
H0010005        19.029       17.490     10.221       18.485       6.238
H0010006        17.066       6.338       2.976       11.532       0.604
H0020011        17.527       6.524       3.048       11.890       0.632
*…..
*DATA OMITTED
*…..
H1541814        12.946       9.660       5.089       11.980       6.500
H1541815        11.450       5.182       2.391       9.295       1.813
H1541816         8.248       5.079       2.387       7.225       2.333
H1541817         6.508       4.343       2.903       7.037       4.457
H1541818         7.852       4.472       2.194       6.690       0.949
H1541819        12.254       5.562       2.581       9.930       1.834


TABLE SED(J,I) SEDIMENT YIELD IN SUBBASIN J WITH CROP I
               PNUT   CWHEAT NWHEAT   SORG      CRP
H0010004        6.414      2.205      0.616      4.476      0.016
H0010005        14.301    10.562     6.565      11.166     0.068
```

```
H0010006     5.354    1.652    0.597    3.396    0.017
H0020011     5.591    1.719    0.614    3.564    0.018
*…..
*DATA OMITTED
*…..
H1541814     11.828   5.753    2.361    7.938    0.052
H1541815     3.625    1.321    0.506    2.460    0.013
H1541816     5.472    2.292    0.721    3.676    0.019
H1541817     3.996    1.355    0.536    2.529    0.013
H1541818     5.115    2.293    0.958    3.739    0.018
H1541819     4.039    1.469    0.562    2.740    0.014


PARAMETER GRSMRGN (I,J);
GRSMRGN (I,J) = (((P(I)*Y(J,I))+F(I)+G(J,I))-C(I));
DISPLAY GRSMRGN;

SET L /RUN1 * RUN1/;
PARAMETER TARGET (L)
/
RUN1    204880
*RUN2    184389.12
*RUN3    163901.44
*RUN4    163901.44
*RUN5    184389.12
*RUN6    163901.44
*RUN7    1000000
*RUN8    1000000
*RUN9    1000000
*RUN10   1000000
/ ;
SCALAR CURRENT;
PARAMETER NITRO (L)
/
RUN1    652830.42
*RUN2    595003.23
*RUN3    476002.23
*RUN4    595003.23
*RUN5    1000000
*RUN6    1000000
*RUN7    595003.23
*RUN8    528891.76
*RUN9    1000000
*RUN10   1000000
/ ;
SCALAR NITROG;
```

```
PARAMETER PHOSP (L)
/
RUN1    180370
*RUN2    162332.91
*RUN3    144295.92
*RUN4    162332.91
*RUN5    1000000
*RUN6    1000000
*RUN7    1000000
*RUN8    1000000
*RUN9    162332.91
*RUN10   144295.92
/;
SCALAR PHOSPH;


VARIABLES
X(I,J)
Z;

POSITIVE VARIABLE X;
EQUATIONS
OBJ
ROWS(I)
PRUNOFF
NRUNOFF
SRUNOFF
LAND(J);
OBJ.. Z =E= SUM((I,J), GRSMRGN(I,J)*X(I,J));
LAND(J)..   SUM(I,X(I,J)) =E= ACRES(J);
ROWS(I)..   SUM(J,X(I,J)) =L= R(I);
PRUNOFF..   SUM((J,I),PH(J,I)*X(I,J)) =L= PHOSPH;
NRUNOFF..   SUM((J,I),N(J,I)*X(I,J)) =L= NITROG;
SRUNOFF..   SUM((J,I),SED(J,I)*X(I,J)) =L= CURRENT;


MODEL DAVID /ALL/;
PARAMETER REPORT (*,*);
LOOP ( L, CURRENT = TARGET(L); NITROG = NITRO(L); PHOSPH = PHOSP(L);
SOLVE DAVID USING LP MAXIMIZING Z;
REPORT ("SRUNOFF", L) = SRUNOFF.L;
REPORT ("NRUNOFF", L) = NRUNOFF.L;
REPORT ("PRUNOFF", L) = PRUNOFF.L;
REPORT ("Z", L) =  Z.L;
REPORT(I, L) = SUM(J,X.L(I,J));
REPORT ("PAYMENT", L) = SUM((J,I),X.L(I,J) * G(J,I));
```

```
);
DISPLAY REPORT;

PARAMETER   ASUB, ASUBII, PHOST, NITT, SEDT, PROFIT2, SBRUNOFF,
CROPS, BASE;
SBRUNOFF(S, "SEDIMENT") =  SUM((J,I)$JS(J,S), X.L(I,J) * SED(J,I));
SBRUNOFF(S, "NITROGEN") =  SUM((J,I)$JS(J,S), X.L(I,J) * N(J,I));
SBRUNOFF(S, "PHOSPHORUS") =  SUM((J,I)$JS(J,S), X.L(I,J)*PH(J,I));
PROFIT2 = SUM((I,J), GRSMRGN(I,J)*X.L(I,J));
PHOST = SUM((I,J), X.L(I,J)*PH(J,I));
NITT = SUM((I,J), X.L(I,J)*N(J,I));
SEDT = SUM((I,J), X.L(I,J)*SED(J,I));
ASUB(S,I) = SUM((J)$JS(J,S), X.L(I,J));
ASUBII(J,I) = X.L(I,J);
SBRUNOFF(S, "TOTAL ACRES") = SUM((I,J)$JS(J,S), X.L(I,J));
CROPS(I) =  SUM(J,X.L(I,J));
BASE(S,I) = SUM((J)$JS(J,S), B(J,I));
DISPLAY PROFIT2, SEDT, NITT, PHOST, CROPS, ASUB, SBRUNOFF, BASE,
ASUBII;
```

VITA

David Lee Adams

Candidate for the Degree of

Master of Science

Thesis: OBSERVING THE IMPACTS ON THE SPATIAL ALLOCATION OF CROP ACRES IN THE FORT COBB WATERSHED CAUSED BY MAXIMIZING PROFIT SUBJECT TO RUNOFF CONSTRAINTS.

Major Field: Agricultural Economics

Biographical

Personal Data: Born in McAlester, OK on Aug. 12, 1980, the son of John and Deanna Adams. Married Jamie Horsley of Kiowa, OK July 28, 2001.

Education: Graduated from Indianola High School, Indianola, OK in May of 1999; attended Eastern Oklahoma State College in Wilburton in 1998/99 and the summer of 2001; received Bachelor of Science from Oklahoma State University, Stillwater Oklahoma in May of 2002. Completed the requirements for the Master of Science degree with a major in Agricultural Economics at Oklahoma State University in December of 2004.

Experience: Raised on a family farm near Indianola, OK gaining first hand production agriculture experience; Part-time for Advantage Truck Accessories in McAlester, OK in Sales and Service; work as a graduate assistant for Oklahoma State University Department Agricultural Economics, Aug 2002-July 2004.

Professional Memberships: Oklahoma State University Agricultural Economics Graduate Student Association.

Name: David Lee Adams Date of Degree: December, 2004

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: OBSERVING THE IMPACTS ON THE SPATIAL ALLOCATION OF CROP ACRES IN THE FORT COBB WATERSHED CAUSED BY MAXIMIZING PROFIT SUBJECT TO RUNOFF CONSTRAINTS.

Pages in Study: 152 Candidate for the Degree of Master of Science

Major Field: Agricultural Economics

Scope and Method of Study: Costs and returns of production for peanuts, sorghum, conventional till wheat, no-till wheat, and Conservation reserve program acres were generated. Using GIS programs landscape characteristics for the Fort Cobb Basin were compiled and inputted into the Soil and Water Assessment Tool (SWAT). The SWAT model then predicted annual crop, sediment, nitrogen, and phosphorus yields for each sub basin in the watershed. This SWAT output combined with the returns and costs of productions where then used in a linear programming model to compare three alternative policy programs to reduce the sediment, nitrogen, and phosphorus loading of the watershed by cropland. These policy programs included changing the current CRP to allow producers to receive their Direct and Counter cyclical payment and the CRP rental payment. As sub scenarios to the policy changes sediment, nitrogen and phosphorus runoff levels abated at increasing levels. Also tested was a policy were only the highest polluting acres were targeted for retirement.

Findings and Conclusions: From linear programming it was determined that in order to reduce sediment, nitrogen and phosphorus runoff in the watershed targeting only phosphorus runoff would satisfactorily control sediment and nitrogen runoff. It was determined that a policy only targeting only the acres with the highest runoff for abatement would increase abatement costs above profit maximizing abatement targeting at any level. As the level of runoff abatement increases peanut acres 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 reduces 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. 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.

ADVISORS APPROVAL: ______________________________