# Economic Analysis of Tillage and Nutrient Best Management Practices in the Ouachita River Basin, Louisiana

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**Abstract**

The Ouachita River Basin (ORB) in northeastern Louisiana accounts for almost 50 percent of the state's agricultural production. In the Cabin-Teele Sub-watershed, within the ORB, the alkaline soils are naturally low in organic matter and deficient in nitrogen so that producers occasionally over apply nitrogen fertilizer. Moreover, because the soils are poorly drained there are drainage ditches throughout the fields and along field borders. The abundance of ditches enhances the outflow of nutrients and sediments into adjacent waterbodies. This study evaluated and compared the net economic benefits of tillage and nutrient management practices at addressing specific sediment and nutrient criteria reductions; nitrogen, phosphorus and sediment reductions individually, and concurrently (reducing all three simultaneously) in Cabin-Teele Sub-watershed. Simulated results showed that reduced tillage, nitrogen management (nitrogen fertilizer application), and conservation tillage were cost-effective in helping reduce nutrient and sediment losses in Cabin-Teele sub-watershed despite the prevalence of poorly drained soils.

## Introduction

The Ouachita River Basin (ORB) covers an area of about 16,000 square miles and extends from Arkansas to northeastern Louisiana. Louisiana's portion of the Ouachita River Basin (LORB) is bordered to the east by the Mississippi River, and west, by the Red River Basin (figure 1). The basin's alluvial plains are compassed about by lakes, wetlands and bayous. The Ouachita River originating from the Ouachita Mountains in Arkansas flows through the ORB. Land use to the west of the river is dominated by forests and pastureland. To the east, row crop agriculture dominated by soybean, corn and cotton. Row-crops cultivated in the LORB accounts for almost 50 percent of the Louisiana's agricultural production (LSU AgCenter, 2007).

The latitude of row crop agriculture in northeastern Louisiana however brings the accompanying problem of agricultural nutrient runoff and sediment loads into surrounding water bodies (figure 2). Louisiana Department of Environmental Quality (LDEQ) notes that the majority of the waters within the LORB are impaired or threatened; particularly from nutrients and sediments. In the Cabin-Teele Sub-watershed, within the LORB, soils are naturally abundant in phosphorus; therefore farmers do not apply phosphorus fertilizer. However, the alkaline soils in this region are naturally low in organic matter and nitrogen. Producers therefore occasionally over apply nitrogen fertilizer to sure up crop investments. Moreover, because the soils are poorly drained there are drainage ditches throughout the fields and along field borders. The abundance of ditches enhances the outflow of nutrients and sediments into adjacent water bodies.

Given the importance of this highly productive region to the state, best management practices (BMPs) are encouraged to help address resource concerns in the watersheds. However, BMPs such as riparian buffers are virtually ineffective in trapping nutrients and sediment outflow from fields because the open-field ditches circumvent these conservation structures. For riparian buffers to be effective there is a need for them to be planted around every bordering open-field ditch. This is financially tasking for farmers without state or government assistance.

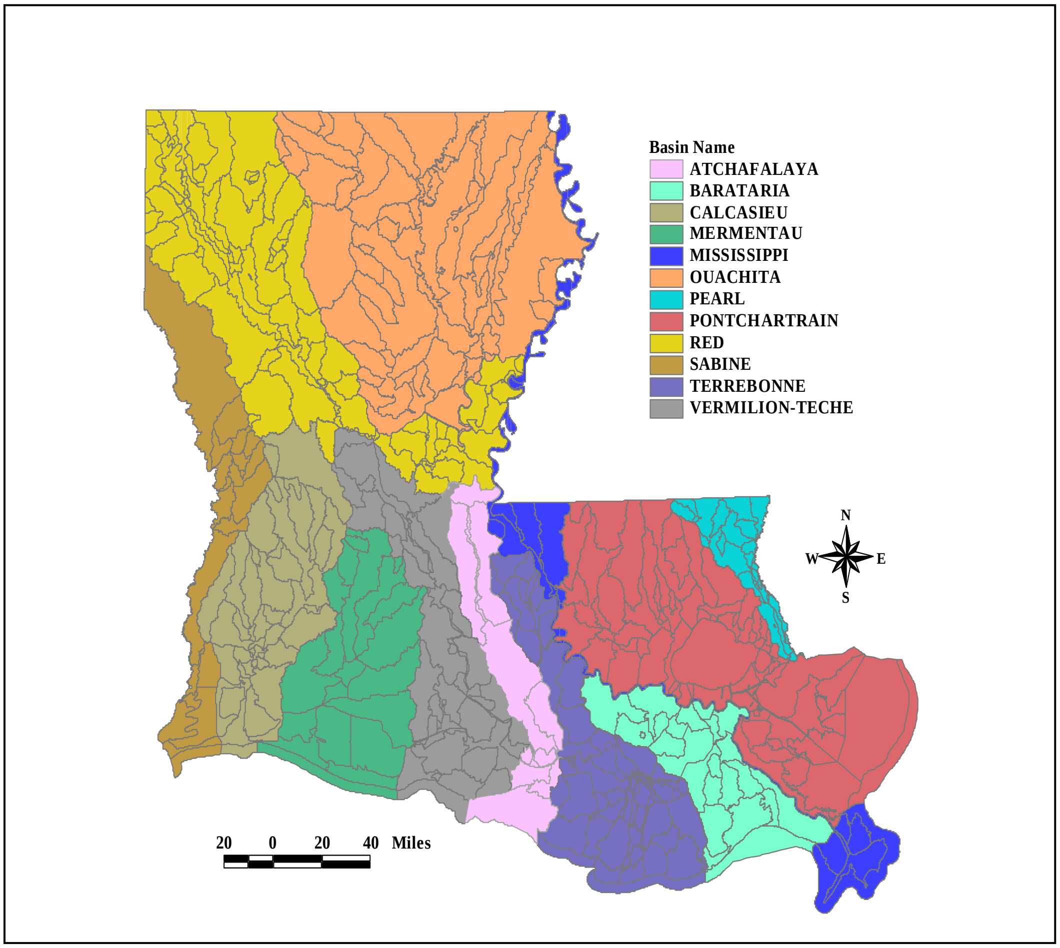


**Figure 1: Louisiana River Basins**

It is in this vein that the Lower Ouachita River Basin Conservation Reserve Enhancement Program for example was instituted in part to help reduce agricultural nutrient runoffs and sediment loads. This long-term program, establishes riparian buffers, bottomland hardwood and wetlands on 50,000 acres of cropland and marginal pastureland to help reduce sediment loads into streams by 30 percent (USDA, 2005). The program also seeks to reduce nitrogen and phosphorus runoffs by 2,100 tons and 975 tons annually respectively to help improve the wildlife and fish habitats as well as the hypoxic conditions in the Gulf of Mexico.

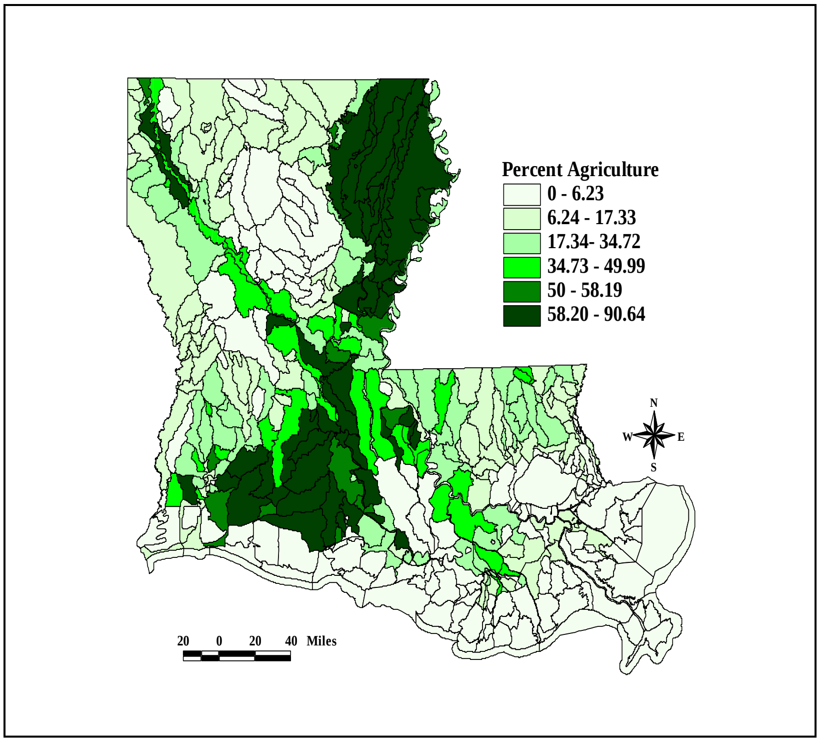


**Figure 2: Percent of Land Use in Louisiana Basin Sub-Segments**

However, what happens to farmers not qualified under Conservation Reservation Enhancement Program and other conservation program guidelines, or are outside the region of focus but within LORB? Conservation programs are also usually voluntary programs and landowners have a prerogative to choose whether they would like to participate or otherwise. How do we incorporate all row crop agricultural producers to help lessen nutrient runoffs and sediment yield into water bodies in LORB? This is the thrust of this study.

Foremost, since farmers in the region still utilize conventional tillage, conservation tillage practices and possible nutrient fertilizer reductions are potential means for mitigating adverse environmental impacts from agriculture. There are environmental benefits in pursuing BMPs. Economically however, is it cost effective to ask farmers to employ nutrient fertilizer application rate reductions even though soils are naturally deficient in nitrogen? Is it economically and environmentally justifiable to ask farmers to adopt these stipulated BMPs even with their peculiar problem of poorly drained soils? These critical, salient questions now facing producers and policy makers helped framed this study. The research integrates GIS, biophysical modeling and risk mathematical programming in analyzing this issue.

**Literature Review**

The effects of agricultural activities on the environment have well been documented (Randhir and Lee, 1997; Ribaudo et al., 2001). The watershed level has garnered a lot of interest due to focus of US Environmental Protection Agency on this unit for the purposes of decision making and policy. A brief review of contemporary research employing simulation models provides a reference point to this study.

Carpentier et al., (1998) used a linear programming model to assess the value of spatial information for reducing farmland nonpoint source pollution under a uniform and targeted regulatory performance standard, in the Lower Susquehanna watershed. Results showed that targeted standards reduced nitrogen runoffs more, compared to uniform standard. Schwabe (2001) finds that installation of vegetative filter strips lowers costs by about 23 percent compared to imposing an equal nitrogen percentage reduction for every county in North Carolina. However, the latter attained the 30 percent reduction strategy proposed by the North Carolina Department of Water Quality for the river basin while latter fell short by about 300,000 lbs.

Intarapapong et al., (2005) also compared the effects of continuous cropping and crop rotation on tillage practices in Mississippi. Impacts on expected income, nutrient and sediment runoff were also assessed. Results showed crop rotation practices had higher optimal profits compared to continuous cropping. Sediment and nitrate effluent restrictions both decreased net returns to farmers. Petrolia and others (2005) analyzed the potential of employing agricultural drainage in reducing nitrogen loads in the Cottonwood River Watershed, southwestern

Minnesota by 20 or 30 percent. They found that abating nitrogen loads using tile drainage when adopting a combined policy of nutrient management and retirement of non-drained land was cost effective. Removing tile drains from drained land was not cost-effective, even if the fields were totally retired for pasture or used for crop production.

Most of these studies mainly looked at nutrient and sediment restrictions on an individual basis, and analyzed impacts on net returns and the environment. None looked at simultaneous reduction of nutrients and sediments and ascertained the most binding restriction. This research goes a step further by evaluating and comparing the cost effectiveness of tillage and nutrient management practices at addressing nitrogen, phosphorus and sediment reductions individually and concurrently (reducing all three simultaneously).

**Cabin-Teele Sub-watershed: The Study Area**

The study was conducted in the Cabin-Teele sub-watershed, located in Madison Parish, Louisiana. This sub-watershed has impaired waters due to excess amounts of nitrates, phosphorus and sediments deposition (Appelboom and Fouss, 2006). Agriculturally, the watershed has more than 700 farms, with sizes ranging from one to over 1000 acres. Eleven soil maps and four different soil series are found in Cabin-Teele (Appelboom and Fouss, 2005). The soil series are Bruin, Commerce, Sharkey and Tunica. These soils are generally low in nitrogen and organic matter content, with pH ranging from highly acidic to mildly alkaline. Moreover, the similar soils, slopes and crops found in the area lend to relatively easy replication of best management practices.

**AnnAGNPS Data Sources**

Model inputs essential for AnnAGNPS simulations include: field, schedule and operations management data, fertilizer application data, crop data, non-crop land use data and soil data. This information was acquired from the extensive work done by Appelboom and Fouss (2006) in Cabin-Teele sub-watershed. Daily weather data, critical in the modeling process, were obtained from Dr. Kevin Robbins of the Southern Regional Climate Center, Louisiana State University. In the modeling, seven years of weather data (1998-2004) were used for the simulation. The average annual rainfall for simulation period was 1,226.15mm. The actual simulation used cropping data from 2002 only because these were the most detailed available.

**AnnAGNPS Methodology**

Annualized Agricultural Nonpoint Source (AnnAGNPS) model was used to estimate sediment, nutrient and phosphorus runoffs from crop production practices, including changes to nitrogen fertilizer application rates, tillage, and producer management practices. AnnAGNPS is a watershed scale model which simulates the effects of production practices and the resulting nutrients, pesticides and sediments runoff quantities and their movement through the watershed. Sediment and nutrient runoff calculations are conducted using the Revised Universal Soil Loss Equation (RUSLE) and runoff curve numbers respectively. Before simulating production activities, the watershed is divided into homogeneous soil types, land use and land management areas. The model output allows one to estimate the environmental impact of current practices with and without nutrient and tillage BMPs.

A vital element in biophysical simulations is model calibration, which is important for validation and applicability (Taylor et al., 1992). Though the model was not calibrated to this watershed (due to insufficient stream data), the model output fell within the range of observations from the watershed. Weather conditions over the simulation period were similar to the long-term averages for that area.

**Yield Data and Methodology**

Yield data associated with various nitrogen fertilizer application rates were unavailable for Cabin-Teele watershed. Crop yield data from research station experiments were obtained for LSU AgCenter Research Experiment Station reports (cotton, corn, soybean and rice) and Mississippi State University Research and Extension Center reports (grain sorghum) (Table 1). To determine the amount of nitrogen fertilizer applied on corn, cotton, rice, and grain sorghum in Cabin-Teele watershed, agricultural producers were personally interviewed by Appelboom and Fouss (2006).

**Table 1: Experimental Crop Yield Data.**

| Nitrogen lb/acre | Conventional Till | Conservation Till |
|---|---|---|
| | Cotton (lbs/A) | |
| 135 | 913 | 1,082 |
| 90 | 888 | 1,109 |
| 45 | 716 | 982 |
| 0 | 399 | 700 |
| | Corn (bu/A) | |
| 200 | 174 | 178 |
| 150 | 158 | 162 |
| 100 | 126 | 130 |
| 50 | 79 | 83 |
| | Rice (cwt/A) | |
| 180 | 65 | 73 |
| 150 | 67 | 69 |
| 120 | 67 | 70 |
| 90 | 66 | 65 |
| | Grain Sorghum (bu/A) | |
| 200 | 75 | 78 |
| 120 | 81 | 80 |
| 80 | 76 | 83 |
| 40 | 71 | 79 |

Because data from research experimental stations did not correspond to producer crop nitrogen application rates, we fit a quadratic equation between nitrogen application rates and corn, cotton, rice and grain sorghum yields. This form helped derive values that corresponded to farming practices in the watershed (assuming diminishing marginal product in yields at higher increments of fertilizer application). We also assumed that effects of weather and soil conditions on crop yield are minimal and following the example of Giraldez and Fox (1995), the fitted equation (using ordinary least squares) for each crop (corn, cotton, rice, and grain sorghum) was estimated as follows:

$$cyd_i = a_0 + nit_i + nit_i^2 \tag{1}$$

In equation (3.0), *i*, refers to different rates of nitrogen fertilizer application. The variables *cyd* and *nit* refer to crop yield and amount of nitrogen fertilizer applied, respectively. In the equation, $a_0$ refers to the intercept. Values obtained from equation (1) corresponded well with crop yield values obtained from agronomists.

Because data were unavailable for expected yields associated with reduced tillage, I assumed that reduced tillage values were within the continuum of conventional and conservation tillage yields. Average yield values of the sum of conventional and conservation tillage yields were assumed to represent reduced tillage. A tillage index was created based on relative productivity of the other tillage practices to conventional tillage; that is, simply dividing the other tillage yield values by conventional tillage. Table (2) summarizes this information. We estimated the USDA-NASS Madison Parish area weighted crop yield values by dividing crop production units by harvested crop acres. Crop yields by tillage are estimated by multiplying the tillage index by corresponding average weighted yields for Madison Parish (2002-2007). These estimated values were within the range of yield observed in Louisiana.

**Table 2: Estimated Crop Yield Data and Tillage Index.**

| Nitrogen | Estimated Tillage Data | | | Tillage Index | | |
|---|---|---|---|---|---|---|
| lb/acre | Conventional | Reduced | Conservation | Conventional | Reduced | Conservation |
| | | | Cotton (lbs/A) | | | |
| 100 | 906 | 1,011 | 1,116 | 1.00 | 1.12 | 1.23 |
| 90 | 888 | 998 | 1,109 | 0.98 | 1.10 | 1.22 |
| 80 | 862 | 978 | 1,094 | 0.95 | 1.08 | 1.21 |
| 70 | 830 | 951 | 1,072 | 0.92 | 1.05 | 1.18 |
| | | | Corn (bu/A) | | | |
| 200 | 174 | 176 | 178 | 1.00 | 1.01 | 1.02 |
| 180 | 169 | 171 | 173 | 0.97 | 0.98 | 1.00 |
| 160 | 162 | 164 | 166 | 0.93 | 0.94 | 0.96 |
| 140 | 153 | 155 | 157 | 0.88 | 0.89 | 0.90 |
| | | | Rice (cwt/A) | | | |
| 150 | 67 | 69 | 71 | 1.00 | 1.02 | 1.05 |
| 135 | 67 | 68 | 70 | 1.00 | 1.02 | 1.03 |
| 120 | 67 | 68 | 68 | 0.99 | 1.00 | 1.01 |
| 105 | 66 | 67 | 67 | 0.98 | 0.99 | 0.99 |
| | | | Grain Sorghum (bu/A) | | | |
| 100 | 79 | 81 | 83 | 1.00 | 1.02 | 1.05 |
| 90 | 78 | 80 | 82 | 0.99 | 1.02 | 1.04 |
| 80 | 77 | 79 | 81 | 0.98 | 1.01 | 1.03 |
| 70 | 76 | 78 | 80 | 0.96 | 0.99 | 1.02 |

In deriving crop yield values by soil type, the following methods were employed. The soil series map of Madison Parish (Soil Survey Map of Madison Parish) gives estimated dryland average yield per acre for farmers under the following assumptions: "rainfall is effectively used and conserved; surface drainage systems are installed; crop residue is managed to maintain soil tillage; minimum but timely tillage is used; insect, disease and weed control measures are consistently used; fertilizer is applied according to soil test and crop needs; and suitable crop varieties are used at recommended seeding rates" (USDA-NRCS, 1982).

A soil yield index was created to determine crop yields by tillage and soil type. On research plots, corn, rice, cotton, and soybeans were planted on Sharkey clay soil, and grain sorghum on Bruin Silt loam soil. In the case of rice and grain sorghum, soil type differed from the ones found in Madison Parish. Soil types were matched with that of Madison Parish by considering permeability of the soil and soil fertility. Values for the soil index as well as crop yields by tillage and soil type were also estimated (for more information on estimation procedures, look at Matekole, 2009).

**Input Data and Methodology**

Crop machinery and input requirements for tillage practices were gathered from farm management research and extension reports (Paxton, 2008). Data for physical inputs (for example, machinery complements) were gathered through personal interviews of agricultural producers in Cabin-Teele watershed. Historic prices (2002-07) were gathered from USDA-NASS (USDA-NASS, 2008). Historical payment rates, crop acres, and crop yields for direct payments and counter-cyclical payments were obtained from USDA-FSA (USDA-FSA, 2009). Information on annual per acre rental payments for conservation programs (WRP and CRP) were obtained from USDA-FSA (USDA-FSA, 2009). Extent of tillage practices or crop residue management for Madison parish were obtained from Conservation Technology Information Center (CTIC website: http://www.conservationinformation.org/?action=members_crm). Production costs and returns estimates for each cropping system, for conventional, reduced and conservation tillage practices were customized to farming practices in the sub-watershed. Input and equipment costs for the simulation period 2007/2008 were used in preparing the budgets. Input costs reflected for the most recent rise through 2008.

Negative net revenue has been projected for the cotton crop in northeastern Louisiana. In this study, cotton enterprise budgets included ginning revenue and cost. Including ginning in the budget is justified on the grounds that cotton farmers obtain additional revenue from ginning which is not included in the traditional enterprise cotton budgets. Mitchell et al., (2007) found that seed per lint ratio in Texas has been declining since the 1970's. The lint to seed ratio for the 2000's has been 1.57 (Mitchell et al.). For Louisiana, I assumed lint to seed ratio of 1.33 based on information (personal interviews) obtained from ginners for new cotton varieties in Louisiana. Crop prices and nitrogen fertilizer prices were averaged over 6 years (2002-2007) and reflect nominal prices.

**Economic Modeling with Environmental Constraints**

The model employed in the analysis incorporates crop yield, input prices, government crop price subsidies, tillage practices, nitrogen fertilizer management, soil types, and cropland effluents of nitrogen (attached and dissolved), phosphorus (attached and dissolved) and sediments (clay, silt, and sand) in maximizing net revenues for producers in the watershed. Only continuous cropping was considered in the analysis.

Maximizing expected net revenues is the primary factor driving crop production in this study area. Net watershed income is maximized in the following equations by subtracting total cost from total revenues across various combinations of crop and soil types, tillage practices, and nitrogen fertilizer application rates. A linear programming model is used for the estimation. The objective function, equation (3.1), is maximized subject to these constraints:

$$Max\ \ NB = \left( \sum_{i,k,b,t} \left[ (p_i) y_{i,k,b,t} \right] - VC_{i,t} - FC_{i,t} \right) x_{i,k,b,t} + \sum_i \begin{bmatrix} (cp_i)(pgyldcp_i) \\ (0.85)(baseacp_i) \end{bmatrix} + \sum_i \begin{bmatrix} (dp_i)(pgylddp_i) \\ (0.85)(baseadp_i) \end{bmatrix} + \left[ (RP_{wrp})(x_{wrp}) + (RP_{crp})(x_{crp}) \right] \quad (2)$$

$$\sum_{i,k,b,t} x_{i,k,b,t} \le \overline{A} \quad (3)$$

$$\sum_{i,k} x_{i,k,b,t} \le \overline{\overline{A}}_{i,k} \quad (4)$$

$$x_{i,k,b,t} \geq 0 \quad \forall i,k,b,t \tag{5}$$

In the above equations, $i$ represent crop type (corn; cotton; rice; sorghum; and soybean). $k$ shows soil type (nine). $t$ represents tillage practices (conventional; reduced; and conservation). $b$ refers to fertilizer nitrogen application rates (hundred, ninety, eighty and seventy percent levels). Hundred represents current nitrogen fertilizer application in the sub-watershed. Ninety, eighty and seventy show a 10 percent, 20 percent and 30 percent reduction from current nitrogen fertilizer application rates respectively. $x$ refers to cropping acres. $p_i$ is a vector of averaged Louisiana crop prices received over the years 2002-07. $y$ represents crop yields. $VC$ shows variable input costs per acre. $FC$ is fixed cost per acre. $\overline{\overline{A}}$ refers to soil-crop acre combinations. $\overline{A}$ represents total acres in the sub-watershed for crop production.

Moreover, $cp_i$ and $dp_i$ refer to vectors of averaged counter-cyclical payment rates and averaged direct payment rates for the crop $i$ received over the years 2002-2007 respectively. $pgyldcp_i$ represents historical counter-cyclical payment yield for the commodity. $pgylddp_i$ refers to historical direct payments yield for the commodity. $baseacp_i$ is counter-cyclical historical payment crop acres. $baseadp_i$ shows direct payments historical payment crop acres. $RP_{wrp}$ shows WRP annual rental payments per acre. $RP_{crp}$ is CRP annual rental payments per acre. $x_{wrp}$ shows total acres under WRP in the watershed. $x_{crp}$ is total acres under CRP in the watershed.

The first term in equation (2) is affected by producer planting decisions. Net revenues are a function of crop prices, crop yield, variable input costs and fixed costs. The second and third terms (in equation 2) refer to counter-cyclical payments and direct payments received by agricultural producers respectively. Payment rates are not affected by planting decisions. These payment programs are based on historical base acres and payment yields. Counter-cyclical payment rates ($cp_i$) are affected by national average market prices ($cp_i$ = target price for the commodity – [$dp_i$ + higher of (national average market year price for the commodity or the national loan rate for the commodity)]. The fourth term in equation (2) show annual revenue obtained by producers from enrolling in WRP and CRP.

The equation (3) constrains the simulated total acres to total watershed crop acres. Equation (4) constrains simulated acres by soil and crop type to current soil-crop acre combinations in the watershed (nine equations). It ensures that less productive soils are not wholly ignored in the mathematical simulation process. Equation (5) is a non-negativity constraint. The model was initially estimated with conventional tillage and current fertilizer applications.

The environmental impact of agricultural production is analyzed through the following equations:

$$\sum_{i,k,b,t} n_{i,k,b,t} x_{i,k,b,t} \le \overline{N}(1-\alpha) \qquad (6)$$

$$\sum_{i,k,b,t} s_{i,k,b,t} x_{i,k,b,t} \le \overline{S}(1-\alpha) \qquad (7)$$

$$\sum_{i,k,b,t} ph_{i,k,b,t} x_{i,k,b,t} \le \overline{ph}(1-\alpha) \qquad (8)$$

In these equations, n refers to nitrate-nitrogen loads at the outlet per acre. ph represents phosphorus loads at the outlet per acre. S is sediment yield at the outlet per acre. $\overline{S}$ shows total sediment load at the outlet. $\overline{N}$ refers to total nitrogen runoff at the outlet. $\overline{ph}$ represents total phosphorus runoff at the outlet. si,k,b,t shows tons per acre sediment runoffs. $n_{i,k,b,t}$ is pounds per acre nitrogen runoffs. $ph_{i,k,b,t}$ shows pounds per acre phosphorus runoffs. The environmental equations show the limits on overall quantity of sediments, nitrogen and phosphorus loss by crops, tillage, soils and nitrogen fertilizer application in the watershed. In equations (6) to (8), $\alpha$

(which equals 0.10, 0.20 and 0.30) indicates 10 percent, 20 percent and 30 percent reduction from baseline loadings.

The study then evaluates and compares social economic benefits of achieving a set of tillage and nutrient management practices in addressing specific sediment and nutrient criteria reductions; nitrogen, phosphorus and sediment reductions individually and concurrently (reducing all three simultaneously). The baseline results are compared to the above scenarios (10%, 20%, and 30% reductions from baseline loadings) to evaluate environmental and economic benefits in the Cabin-Teele Sub-watershed in northeast Louisiana. The equations are solved using the General Algebraic Modeling Systems (GAMS).

**Biophysical Scenario Results**

Before policy scenarios were analyzed, we calculated the integrated model to assess crop production acreage, by soil type, within the watershed for 2002 (Table 3). Examining acreage across crops, one observes that corn is the dominant crop cultivated within this watershed, followed closely by cotton, soybeans, grain sorghum and rice.

**Table 3: Acres Planted to Crops in Cabin-Teele Watershed, by Soil Types for Biophysical Results.**

| Soil Types | Corn | Cotton | Rice | Sorghum | Soybean | Totals |
|---|---|---|---|---|---|---|
| BA | 215 | 108 | | | 132 | 454 |
| CM | 1,701 | 2,525 | | | 229 | 4,456 |
| CN | 1,714 | 763 | | 68 | 85 | 2,629 |
| CO | 39 | 270 | | | | 309 |
| SB | 672 | 253 | | 146 | 583 | 1,653 |
| SC | 3,576 | 2,652 | 276 | 1,687 | 5,850 | 14,040 |
| SD | 29 | | | | | 29 |
| ST | 1,921 | 1,372 | | | 843 | 4,136 |
| TU | 238 | 341 | | | 129 | 708 |
| **Totals** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |

**Table 4: Nitrogen, Phosphorus and Sediment Loading at Cabin-Teele Watershed by Crop for Biophysical Results.**

| | Corn | Cotton | Rice | Sorghum | Soybean | Totals |
|---|---|---|---|---|---|---|
| Nitrogen (lbs) | 239,351 | 33,838 | 4,209 | 26,171 | 341 | 303,910 |
| Phosphorus (lbs) | 602 | 424 | 16 | 113 | 455 | 1,609 |
| Sediments (tons) | 849 | 864 | 13 | 160 | 681 | 2,567 |

Table (4) presents environmental impacts of the biophysical simulation results. One can see that corn, which represents 36 percent of total planted acres, accounted for almost 79 percent of the nitrate-nitrogen effluent load at the outlet (assuming conventional tillage is the sole tillage practice). Cotton, with 29 percent of planted acreage accounted for 11 percent of nitrogen effluent runoffs. With grain sorghum responsible for 7 percent of total planted acreage, 9 percent of nitrogen effluent. Rice had nitrogen effluent proportional to acreage planted. Similar results were found for sediment and phosphorus loadings at the watershed level.

**Economic Baseline Results**

Nitrogen fertilizer application rates could differ from current levels depending on weather conditions, crop rotation, risk aversion, and soil test results for example. To model such a possibility, the baseline scenario allowed the integrated model to choose between tillage practices and nitrogen fertilizer application rates to maximize net revenues in the watershed. The baseline scenario was termed economic baseline. Nutrients and sediment reductions at the outlet were assessed against this economic baseline. Annual revenue of $400,018 was obtained from WRP and CRP payments for this watershed. Additionally, estimations showed that producers received direct payments amounts of $621,357, and counter-cyclical payments of $702,365 in the watershed.

Table (5) shows acreage allocations between tillage practices and nitrogen fertilizer applications for the economic baseline. The table also gives net revenues corresponding to planted crops. Simulated results show that nitrogen fertilizer application rates were reduced for the least profitable crops- grain sorghum and rice. In this watershed, rice might be considered the less profitable crop due to the minimal acreage allocated to its production.

**Table 5: Acres Planted, by Crop, in Cabin-Teele Watershed for the Economic Baseline.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | **Corn** | **Cotton** | **Rice** | **Sorghum** | **Soybean** | **Totals** |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | 1,413 | | | | 1,413 |
| 90% Nitrogen Application Rate | | | | 68 | | 68 |
| 80% Nitrogen Application Rate | | | 276 | | | 276 |
| 70% Nitrogen Application Rate | | | | | | |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 10,104 | | | | 7,850 | 17,954 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | 1,833 | | 1,833 |
| 70% Nitrogen Application Rate | | | | | | |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | 6,871 | | | | 6,871 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Totals of Panted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,276,486** | **15,969** | **18,996** | **14,963** | **858,807** | **2,185,222** |

**Table 6: Environmental Impacts in Cabin-Teele Sub-Watershed.**

| Scenarios | Nitrogen | Phosphorus | Sediment |
|---|---|---|---|
| | (lbs) | (lbs) | (tons) |
| Biophysical Scenario | 303,910 | 1,609 | 2,567 |
| Biophysical Economic Scenario | 155,922 | 748 | 1,077 |
| Economic Baseline | 153,287 | 748 | 1,077 |

Simulated model results in all cropping systems indicated negative net revenue for cotton on most of the soil types. This conforms to the negative net revenue estimated for cotton in my crop budget enterprise analyses. Plausible reasons not incorporated in the analysis why producers might continue producing cotton even with negative revenues are: contract specifications with crop procurers, and off-farm income derived as shareholders of cotton ginneries. Finally, current high yielding seed varieties increase net revenues, ceteris paribus. Table (5) shows conservation tillage was used for most of cotton acreage planted. For cotton cultivated using conservation tillage, profits were not earned. Net revenue per acre under reduced tillage systems were the most profitable tillage system. This was followed by conventional tillage, then conservation tillage.

Table (6) shows the environmental impacts of management practices in Cabin-Teele for the biophysical scenario, biophysical-economic scenario and economic baseline. Note that the latter two were smaller compared to the biophysical baseline due to the relaxing of the constraint on tillage allocation by crop. Nitrogen loads were considerably less for biophysical-economic scenario and economic baseline compared to the biophysical scenario. Sediment and phosphorus loads were respectively 53 percent and 58 percent lower than the biophysical scenario, for the biophysical-economic scenario and economic baseline

**Nitrogen Effluent Load Restriction Results**

Appelboom and Fouss (2006) observed an impairment of streams from excess amounts of nitrate deposition at Cabin-Teele watershed outlet. Assuming the state implemented a TMDL environmental policy to reduce nitrogen loads at the outlet in this watershed, we analyzed nitrate-nitrogen reductions of 10 percent, 20 percent and 30 percent to achieve the TMDL, relative to the economic baseline. Tables (7) to (9) show acreage reallocations or reductions given scenarios of 10 percent, 20 percent and 30 percent nitrate-nitrogen effluent load restrictions.

**Table 7: Acres Planted, by Crop, in Cabin-Teele Watershed with a 10% Nitrate-Nitrogen Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | **Corn** | **Cotton** | **Rice** | **Sorghum** | **Soybean** | **Totals** |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | 1,405 | | | | 1,405 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | 276 | | | 276 |
| 70% Nitrogen Application Rate | | | | | | |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 6,208 | | | | 7,850 | 14,058 |
| 90% Nitrogen Application Rate | 3,867 | | | | | 3,867 |
| 80% Nitrogen Application Rate | | | | 68 | | 68 |
| 70% Nitrogen Application Rate | | | | 146 | | 146 |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | 3,473 | | | | 3,473 |
| 90% Nitrogen Application Rate | 29 | 3,406 | | | | 3,435 |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | 1,687 | | 1,687 |
| **Totals of Planted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,265,498** | **15,897** | **18,996** | **4,095** | **858,807** | **2,163,294** |

Simulated results showed that increasing nitrogen effluent load restriction in Cabin-Teele watershed from 10 percent to 30 percent increased reductions in fertilizer application rates on planted acres. Nitrogen fertilizer application rates were reduced for these crops- corn, cotton, and grain sorghum. Planted corn acres saw the highest reduction in fertilizer application rates in this watershed. The result was reasonable because planted corn contributes about 79 percent of

**Table 8: Acres Planted, by Crop, in Cabin-Teele Watershed with a 20% Nitrate-Nitrogen Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | **Corn** | **Cotton** | **Rice** | **Sorghum** | **Soybean** | **Totals** |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | 1,397 | | | | 1,397 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | 276 | | | 276 |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 4,341 | | | | 7,850 | 12,191 |
| 90% Nitrogen Application Rate | 3,813 | | | | | 3,813 |
| 80% Nitrogen Application Rate | 1,298 | | | | | 1,298 |
| 70% Nitrogen Application Rate | | | | 213 | | 213 |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | | | | | |
| 90% Nitrogen Application Rate | | 6,887 | | | | 6,887 |
| 80% Nitrogen Application Rate | 652 | | | | | 652 |
| 70% Nitrogen Application Rate | | | | 1,687 | | 1,687 |
| **Totals of Planted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,219,667** | **15,824** | **18,375** | **4,064** | **858,807** | **2,116,737** |

nitrate-nitrogen loading in this watershed (if conventional tillage is the only tillage system). Adoption of conservation tillage increased with the imposition of nitrate-nitrogen effluent load restrictions (compared to the economic baseline where only planted cotton used this tillage system). Planted corn and grain sorghum used conservation tillage on the imposition of nitrate-nitrogen load reductions in the watershed. From Table (7), imposing a 10% nitrogen load restriction at the watershed level caused a reallocation of 29 acres of planted corn to conservation tillage (compared to the baseline). Table (9) shows that planted corn acres increased to 1,881 acres for a 30% nitrogen load reduction in the watershed (using conservation tillage).

Tables (7) and (9) show that, while watershed reductions in net revenue were about one percent (compared to the economic baseline), on the imposition of a 10 percent nitrogen load reduction, it decreased by about 3 percent for a 20 percent reduction. Imposition of a 30 percent nitrogen load reduction resulted in watershed net revenues decreasing by about 6 percent.

**Table 9: Acres Planted by Crops in Cabin-Teele Watershed with a 30% Nitrate-Nitrogen Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | Corn | Cotton | Rice | Sorghum | Soybean | Totals |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | 1,397 | | | | 1,397 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | 276 | | | 276 |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 4,341 | | | | 7,850 | 12,191 |
| 90% Nitrogen Application Rate | 3,813 | | | | | 3,813 |
| 80% Nitrogen Application Rate | 69 | | | | | 69 |
| 70% Nitrogen Application Rate | | | | 213 | | 213 |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | | | | | |
| 90% Nitrogen Application Rate | | 6,887 | | | | 6,887 |
| 80% Nitrogen Application Rate | 1,881 | | | | | 1,881 |
| 70% Nitrogen Application Rate | | | | 1,687 | | 1,687 |
| **Totals of Planted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,163,588** | **15,824** | **18,375** | **4,064** | **858,807** | **2,060,658** |

Shadow prices for nitrate-nitrogen, phosphorus and sediment restriction are an estimate of forgone marginal net revenue per unit of nitrate-nitrogen, phosphorus and sediment runoff reduction respectively in this watershed. Table (10) presents the shadow prices for nitrate-nitrogen effluent reductions at the watershed level. Table (10) indicates that the shadow price for a 10 percent reduction in nitrogen load runoffs at the outlet was $1.69 per pound. This implies that marginal net revenue forgone by producers for a unit pound reduction in nitrate-nitrogen effluent at the 10 percent level will be $1.69 per pound. For 20 percent and 30 percent reduction in nitrogen load runoffs at the outlet, the shadow price was $3.66 per pound. Nitrogen-nitrates effluent reductions of 10 percent, 20 percent and 30 percent reductions results in declines in phosphorus by 5 percent, 6 percent and 13 percent respectively. For sediments, the corresponding reductions were 6 percent, 8 percent and 12 percent respectively

**Table 10: Environmental Impacts in Cabin-Teele Sub-Watershed for Nitrate-Nitrogen Reduction Imposed at the Watershed Level.**

| Scenarios | Nitrogen | Phosphorus | Sediment | Shadow Price |
|---|---|---|---|---|
| | (lbs) | (lbs) | (tons) | ($/lbs) |
| 10% Nitrate-Nitrogen Reduction | 137,958 | 709 | 1,010 | 1.69 |
| 20% Nitrate-Nitrogen Reduction | 122,630 | 690 | 990 | 3.66 |
| 30% Nitrate-Nitrogen Reduction | 107,301 | 652 | 950 | 3.66 |

**Phosphorus Effluent Load Restriction Results**

Phosphorus effluent load reduction in this watershed was also of policy interest because phosphorus runoff into neighboring streams accelerates eutrophication which promotes algae growth. Algae bloom reduces dissolved oxygen in waters essential for the survival of aquatic organisms. Phosphorus presents a unique quandary since agricultural producers do not apply phosphorus on crops in this watershed. Table (11) shows that the initial 10 percent phosphorus load restriction reduces planted acres using conventional tillage. Most producers used reduced and conservation tillage systems for planting crops. Tables (12) and (13) indicated that for 20 percent and 30 percent phosphorus load reduction, producers adopted reduced tillage and conservation tillage practices in this watershed.  Table (13) shows that planted acres using conservation tillage was greater than reduced tillage for the 30 percent phosphorus load reduction in Cabin-Teele watershed.

Overall simulated net revenues decreased by less than one percent for the 10 percent phosphorus effluent reduction (Table 11). In addition, simulated watershed net revenue was reduced by 2 percent and 8 percent for 20 percent and 30 percent phosphorus effluent reductions respectively (Table 12 and 13).

**Table 11: Acres Planted, by Crop, in Cabin-Teele Watershed with a 10% Phosphorus Effluent Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | Corn | Cotton | Rice | Sorghum | Soybean | Totals |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | 108 | | | | 108 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | 276 | | | 276 |
| 70% Nitrogen Application Rate | | | | | | |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 10,104 | 1,306 | | | 7,850 | 19,260 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | 68 | | 68 |
| 70% Nitrogen Application Rate | | | | 820 | | 820 |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | 6,871 | | | | 6,871 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | 1,013 | | 1,013 |
| **Totals of Planted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,205,521** | **3,567** | **6,994** | **1,178** | **858,807** | **2,076,067** |

Table (14) shows that the shadow price for 10 percent phosphorus effluent reduction was $287 per pound. The shadow price for the 20 percent phosphorus load restriction at the watershed level was $1,717 per pound. For the 30 percent phosphorus load restriction, shadow

**Table 12: Acres Planted, by Crop, in Cabin-Teele Watershed with a 20% Phosphorus Effluent Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | **Corn** | **Cotton** | **Rice** | **Sorghum** | **Soybean** | **Totals** |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | | | | | |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 8,736 | 108 | | | 7,850 | 16,694 |
| 90% Nitrogen Application Rate | | | 276 | | | 276 |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 1,368 | 8,177 | | | | 9,544 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | 68 | | 68 |
| 70% Nitrogen Application Rate | | | | 1,833 | | 1,833 |
| **Totals of Planted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,205,521** | **3,567** | **6,994** | **1,178** | **858,807** | **2,076,067** |

price was $2,627 per pound. Tables (12) to (13) showed that adopting conservation and reduced tillage practices was the only option available to agricultural producers to achieve TMDL requirements for phosphorus in this watershed. Phosphorus effluent load restrictions also influenced nitrogen and sediment loads at the outlet. Phosphorus effluent reductions by 10 percent, 20 percent and 30 percent decreased nitrogen runoff by 4 percent, 22 percent and 37 percent, and sediment, by 14 percent, 24 percent and 33 percent respectively.

**Sediment Effluent Load Restriction Results**

Table (15) shows total crop acreage for a 10 percent reduction in sediment load from economic baseline. Results indicated that planted acreage using conventional tillage practice decreased compared to the economic baseline. Tables (16) show the implications for a 20 percent sediment effluent reduction. Producers in the watershed adopted conventional tillage for only

**Table 13: Acres Planted, by Crop, in Cabin-Teele Watershed with a 30% Phosphorus Effluent Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | Corn | Cotton | Rice | Sorghum | Soybean | Totals |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | | | | | |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 7,204 | | | | 7,007 | 14,211 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 2,900 | 8,284 | 276 | | 843 | 12,303 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | 68 | | 68 |
| 70% Nitrogen Application Rate | | | | 1,833 | | 1,833 |
| **Totals of Planted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,099,921** | **3,325** | **650** | **1,178** | **803,349** | **1,908,422** |

**Table 14: Environmental Impacts in Cabin-Teele Sub-Watershed for Phosphorus Reduction Imposed at the Watershed Level.**

| Scenarios | Nitrogen | Phosphorus | Sediment | Shadow Price |
|---|---|---|---|---|
| | (lbs) | (lbs) | (tons) | ($/lbs) |
| 10% Phosphorus Reduction | 146,901 | 673 | 930 | 287.36 |
| 20% Phosphorus Reduction | 120,244 | 599 | 819 | 1,716.55 |
| 30% Phosphorus Reduction | 95,982 | 524 | 726 | 2,627.06 |

rice production. Reduced tillage and conservation tillage were used to produce corn, cotton, grain sorghum and soybean. Table (17) indicates that a 30-percent restriction on sediment loads results in producers adopting only conservation and reduced tillage practices in this watershed.

There was virtually no impact on watershed net revenues from the 10 percent sediment load TMDL restriction (Table 15). Table (16) indicated that simulated net revenue decreased by about two percent for a 20 percent sediment effluent reduction. For the 30 percent sediment load TMDL restriction, watershed net revenue decreased by 10 percent (compared to the economic baseline).

**Table 15. Acres Planted, by Crop, in Cabin-Teele Watershed with a 10% Sediment Effluent Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | **Corn** | **Cotton** | **Rice** | **Sorghum** | **Soybean** | **Totals** |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 29 | 376 | | | | 405 |
| 90% Nitrogen Application Rate | | | | 68 | | |
| 80% Nitrogen Application Rate | | | 276 | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 10,075 | 1,038 | | | 7850.015 | 18,962 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | 1,833 | | 1,833 |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | 6,871 | | | | 6,871 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Totals of Planted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,276,004** | **10,386** | **32,235** | **1,725** | **858,807** | **2,179,157** |

**Table 16: Acres Planted, by Crop, in Cabin-Teele Watershed with a 20% Sediment Effluent Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | **Corn** | **Cotton** | **Rice** | **Sorghum** | **Soybean** | **Totals** |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | | | | | |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | 276 | | | 276 |
| 70% Nitrogen Application Rate | | | | | | |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 10,075 | | | | 7,731 | 17,806 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 29 | 8,284 | | | 119 | 8,432 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | 68 | | 68 |
| 70% Nitrogen Application Rate | | | | 1,833 | | 1,833 |
| **Totals of Planted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,275,949** | **3,325** | **18,996** | **1,178** | **848,442** | **2,147,891** |

Shadow prices were $60 per ton, $1,536 per ton and $1,891 per ton for 10 percent, 20 percent and 30 percent sediment yield effluent reductions (Table 18). Importantly, nitrogen runoff was also reduced by 1 percent, 7 percent, and 27 percent, and phosphorus by 6 percent, 14 percent, and 26 percent due to sediment TMDL in the watershed.

**Simultaneous Nutrient and Sediment Effluent Load Restriction Results**

An interesting scenario in addressing nutrient and sediment criteria reductions entail reducing nitrogen, phosphorus and sediment concurrently to evaluate the most binding constraint(s) on environmental and economic activities. Table (19) shows that a 10 percent simultaneous load reduction increased the adoption of reduced and conservation tillage. Specifically, about ninety five percent of planted acres in the watershed used reduced and conservation tillage systems. Planted crop acres adopting conventional tillage also increased compared to the economic baseline.

**Table 17: Acres Planted, by Crop, in Cabin-Teele Watershed with a 30% Sediment Effluent Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | Corn | Cotton | Rice | Sorghum | Soybean | Totals |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | | | | | |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 8,154 | | | | 6,845 | 14,999 |
| 90% Nitrogen Application Rate | | | 276 | | | 276 |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 1,950 | 8,284 | | | 1,005 | 11,239 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | 68 | | 68 |
| 70% Nitrogen Application Rate | | | | 1,833 | | 1,833 |
| **Totals of Planted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Totals** | **1,174,895** | **3,325** | **6,994** | **1,178** | **787,569** | **1,973,961** |

**Table 18: Environmental Impacts in Cabin-Teele Sub-Watershed for Sediment Reduction Imposed at the Watershed Level.**

| Scenarios | Nitrogen | Phosphorus | Sediment | Shadow Price |
|---|---|---|---|---|
| | (lbs) | (lbs) | (tons) | ($/ton) |
| 10% Sediment Reduction | 151,536 | 706 | 969 | 60.34 |
| 20% Sediment Reduction | 142,967 | 645 | 862 | 1,536.11 |
| 30% Sediment Reduction | 111,154 | 553 | 754 | 1,891.19 |

**Table 19: Acres Planted, by Crop, in Cabin-Teele Watershed with a 10% Simultaneous Nitrogen, Phosphorus and Sediment Effluent Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | Corn | Cotton | Rice | Sorghum | Soybean | Totals |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | 509 | | | | 509 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | 276 | | | 276 |
| 70% Nitrogen Application Rate | | | | | | |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 6,866 | 889 | | | 7,850 | 15,605 |
| 90% Nitrogen Application Rate | 3,209 | | | | | 3,209 |
| 80% Nitrogen Application Rate | | | | 68 | | 68 |
| 70% Nitrogen Application Rate | | | | 146 | | 146 |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | 323 | | | | 323 |
| 90% Nitrogen Application Rate | 29 | 6,564 | | | | 6,593 |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | 1,687 | | |
| **Totals** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,267,564** | **11,047** | **18,996** | **4,095** | **858,807** | **2,160,510** |

Table (20) presents the 20 percent simultaneous reduction in nutrient and sediments in the watershed. Results indicated that agricultural producers adopted only reduced and conservation tillage for planting crops. Similar results were obtained for the 30 percent simultaneous TMDL reduction in the watershed (Table 21). Ten percent simultaneous load reduction caused net revenue to decrease by about one percent. Twenty and 30 percent simultaneous effluent restrictions decreased watershed net revenue by about 5 percent and 13 percent respectively.

Tables (22), (23) and (24) present the shadow prices for the simultaneous policy scenarios. It indicated that the most binding constraint in all scenarios was phosphorus. A 10 percent

**Table 20: Acres Planted, by Crop, in Cabin-Teele Watershed with a 20% Simultaneous Nitrogen, Phosphorus and Sediment Effluent Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | **Corn** | **Cotton** | **Rice** | **Sorghum** | **Soybean** | **Totals** |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | | | | | |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 8,736 | 108 | | | 7,850 | 16,694 |
| 90% Nitrogen Application Rate | | | 276 | | | 276 |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | | | | | |
| 90% Nitrogen Application Rate | 1,368 | 8,177 | | | | 9,544 |
| 80% Nitrogen Application Rate | | | | 68 | | 68 |
| 70% Nitrogen Application Rate | | | | 1,833 | | 1,833 |
| **Totals of Planted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,205,521** | **3,567** | **6,994** | **1,178** | **858,807** | **2,076,067** |

simultaneous load reduction showed that nitrogen and phosphorus were binding in achieving the TMDL. The respective shadow costs for nitrogen and phosphorus were $1.69 per pound and $78.85 per pound (Table 22). For a 20 percent effluent load reduction, the binding constraint was phosphorus. Table (23) shows a shadow price of $1,717 per pound for the 20 percent effluent reduction. Similarly, for the 30 percent simultaneous reduction, the only binding constraint was phosphorus with a shadow price of $2,627 per pound (Table 24).

**Conclusion**

This study evaluated and compared the net economic benefits of tillage and nutrient management practices at addressing specific sediment and nutrient criteria reductions; nitrogen,

**Table 21: Acres Planted, by Crop, in Cabin-Teele Watershed with a 30% Simultaneous Nitrogen, Phosphorus and Sediment Effluent Reduction Imposed at Watershed Level.**

| Tillage Practices | Planted Acres | | | | | |
|---|---|---|---|---|---|---|
| | **Corn** | **Cotton** | **Rice** | **Sorghum** | **Soybean** | **Totals** |
| **Conventional Tillage** | | | | | | |
| 100% Nitrogen Application Rate | | | | | | |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Reduced Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 7,204 | | | | 7,007 | 14,211 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | | | |
| 70% Nitrogen Application Rate | | | | | | |
| **Conservation Tillage** | | | | | | |
| 100% Nitrogen Application Rate | 2,900 | 8,284 | 276 | | 843 | 12,303 |
| 90% Nitrogen Application Rate | | | | | | |
| 80% Nitrogen Application Rate | | | | 68 | | 68 |
| 70% Nitrogen Application Rate | | | | 1,833 | | 1,833 |
| **Totals of Planted Acres** | **10,104** | **8,284** | **276** | **1,900** | **7,850** | **28,414** |
| **Net Revenue ($)** | **1,099,921** | **3,325** | **650** | **1,178** | **803,349** | **1,908,422** |

**Table 22: Environmental Impacts in Cabin-Teele Sub-Watershed for a 10% Simultaneous Nitrogen, Phosphorus and Sediment Effluent Reduction Imposed at the Watershed Level.**

| Scenarios | Nitrogen | Phosphorus | Sediment | Shadow Price |
|---|---|---|---|---|
| | (lbs) | (lbs) | (tons) | |
| 10% Nitrate-Nitrogen Reduction | 137,958 | | | 1.69 |
| 10% Phosphorus Reduction | | 673 | | 78.85 |
| 10% Sediment Reduction | | | 930 | - |

phosphorus and sediment reductions individually, and concurrently (reducing all three simultaneously) in Cabin-Teele Sub-watershed. Waters within the watershed are impaired;

particularly from nutrients and sediments. Moreover, because the soils are poorly drained there are drainage ditches throughout the fields and along field borders. The abundance of ditches enhances the outflow of nutrients and sediments into adjacent waterbodies.

**Table 23: Environmental Impacts in Cabin-Teele Sub-Watershed for a 20% Simultaneous Nitrogen, Phosphorus and Sediment Effluent Reduction Imposed at the Watershed Level.**

| Scenarios | Nitrogen | Phosphorus | Sediment | Shadow Price |
|---|---|---|---|---|
| | (lbs) | (lbs) | (tons) | |
| 20% Nitrate-Nitrogen Reduction | 120,244 | | | - |
| 20% Phosphorus Reduction | | 599 | | 1,717 |
| 20% Sediment Reduction | | | 819 | - |

**Table 24: Environmental Impacts in Cabin-Teele Sub-Watershed for a 30% Simultaneous Nitrogen, Phosphorus and Sediment Effluent Reduction Imposed at the Watershed Level.**

| Scenarios | Nitrogen | Phosphorus | Sediment | Shadow Price |
|---|---|---|---|---|
| | (lbs) | (lbs) | (tons) | |
| 30% Nitrate-Nitrogen Reduction | 95,982 | | | - |
| 30% Phosphorus Reduction | | 524 | | 2,627 |
| 30% Sediment Reduction | | | 726 | - |

Results indicated that reduced tillage, conservation tillage and nutrient management (nitrogen fertilizer) were cost-effective in helping reduce nutrient and sediment losses in Cabin-Teele sub-watershed despite the prevalence of poorly drained soils. However, as expected, farmers reduced acreage and nitrogen fertilizer application rates as more restrictive nutrient loading criteria were implemented. Conservation tillage was adopted as effluent restrictions at the mouth of the watershed increased.

In the scenario with all nutrient and sediment being reduced simultaneously, the constraining element varied, though the most binding was phosphorus. For example, at the 10 percent reduction from the economic baseline scenario, nitrogen and phosphorus were binding. At the 20 percent and 30 percent reduction scenarios, only phosphorus was binding. In all scenarios with phosphorus reduction being the binding constraint, the shadow price per pound of phosphorus reduced was substantial – ranging from $78 per pound to $2,627 per pound. Simultaneous policy scenarios also showed a preference for reduced tillage and conservation tillage compared to conventional tillage. Findings suggest that producers might increase the use of conservation tillage with the imposition of simultaneous effluent restrictions in Cabin-Teele watershed.

Results on nitrate-nitrogen, phosphorus and sediment reduction in the watershed show the tradeoffs between cropland acreage, net revenue and environmental goals for improving water quality. It showed that producers could use conservation tillage to help decrease fertilizer application rates in the watershed (and potentially remain profitable). Findings suggest that without the flexibility of farmers to decide on tillage management and the amount of nitrogen fertilizer they will apply to crops, reductions in net revenue would have been greater.

.This research showed that tillage management and nutrient management (for nitrogen) provide options for producers to address resource concerns in watersheds. These findings also provide policymakers evidence that there are readily available and economically feasible alternative management practices for reducing agricultural pollutants. Our research provides policymakers and producers with the necessary information to address some of the negative externalities associated agricultural production while providing an important resource to society.

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