Missouri Department of Natural Resources

JENKINS BASIN WATERSHED

COMPUTER BASED EVALUATION OF THE AgNPS-SALT PROJECT

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The Food and Agricultural Policy Research Institute at the University of Missouri (FAPRI) is charged with providing objective, quantitative analysis to decision makers. Since 1984, this service has been provided to Congress and national trade associations, and has focused on commodity policy issues.

In 1995, the unit was asked to expand its focus and begin to bring the same level of effort to environmental issues, that of providing objective, analytical support. The unit spent considerable time examining the problems and determined the area most lacking analysis was at the local level; the farm, the watershed, and the local community.

Similar to the extensive peer-review effort the unit goes through on national commodity policy issues, the environmental analysis effort recognizes the strong need for local involvement. If the local people who must live with the analysis have doubts about the way the analysis was developed, then the effort is wasted. Consequently, the process FAPRI brings to the table also incorporates extensive local input with respect to data sources and model calibration.

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EXECUTIVE SUMMARY

Major water quality concerns in Jenkins Basin Watershed are related to the McNairy-Wilcox aquifers which are the primary source for public and private drinking supplies and for irrigation. To protect the water quality of the alluvial aquifer, the Agricultural Nonpoint Source-Special Land Area Treatment (AgNPS-SALT) project was approved in 2001 to support and cost-share agricultural conservation practices and to provide technical assistance through the Stoddard County Soil and Water Conservation District (SWCD).

The purpose of this study was to assess the changes in nutrient and sediment loads in the aquifer and in the ditches due to the implementation of the conservation practices proposed under the AgNPS-SALT program, using watershed scale computer modeling with the Soil and Water Assessment Tool (SWAT). The ability of the SWAT model as a tool to simulate the conservation practices associated with the AgNPS-SALT project was evaluated.

Results showed that implementing the conservation practices caused a reduction in sediments and nutrients. The reductions varied by practice, by crop, and by soil. Due to spatial and temporal variability, the average amount of nutrients, sediment, and chemical simulated by the model might not be observed on a year-to-year basis.

Conservation practices whose effects are influenced by human factors could not be simulated, i.e., information and education, because the outcome is difficult to quantify. The model was able to simulate the practices that are implemented on the ground: irrigation management and nutrient management.

The SWAT model can be used as an effective tool to quantify the amount of nutrient and sediment loads that varied due to agricultural management practices and physical characteristics, such as soil properties, topography, and hydrology. The information on pollutant load reductions from implementing conservation practices can be useful for the agencies in prioritizing the practices to achieve the optimal environmental impacts under the constrained resources.

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Watershed Information

The Jenkins Basin watershed is a 172 km^2 watershed (42,522 acres) located in Stoddard, Cape Girardeau, and Bollinger Counties in south east Missouri. It is approximately 17 miles long. Missouri Highway 25 and 91 provide access to the watershed. The natural springs and seeps located on Crowley's Ridge produce small streams and creeks which feed into the ditches that drain the lowland area.

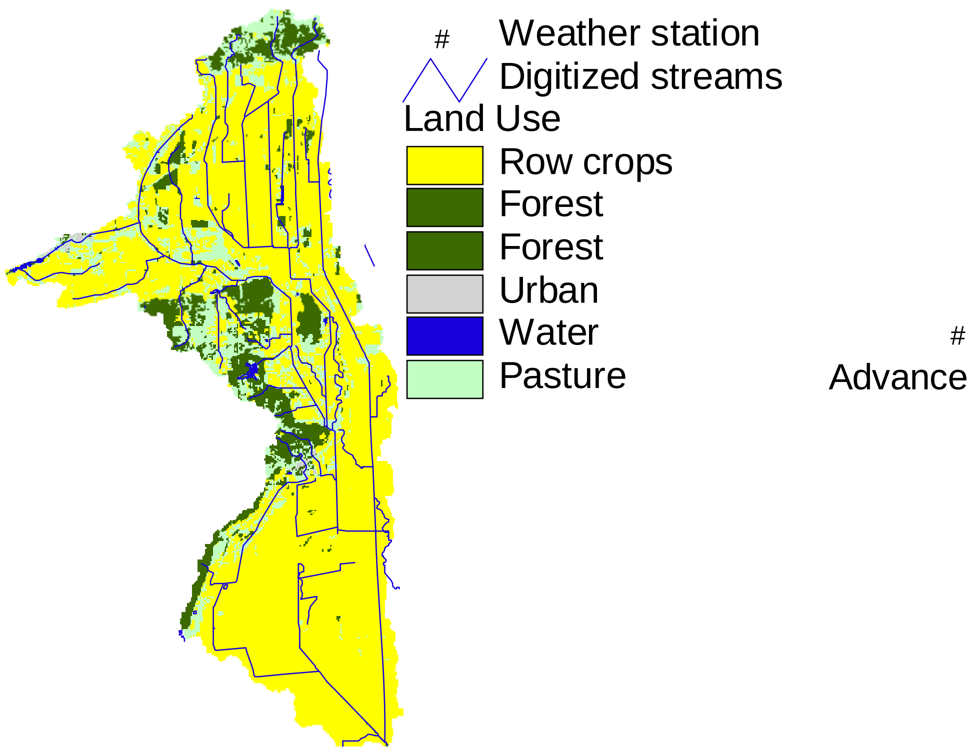

Figure 1. Jenkins Basin land use map (1992 satellite image).

The watershed is primarily agricultural with 73% of cropland, 16% of grassland and10% of forest. It includes some confinement operations. To improve acres that need treatment, the AgNPS-SALT project set the target acreage of land. Table 1 reproduces the land use distribution provided in the AgNPS-SALT proposal.

Table 1: Land use data, AgNPS-SALT project proposal.

Land use	Percent of watershed area (%)	Acres
Crop land	73	33,674
Pasture	16	7,096
Forest	10	5,041
Other	<1	372
Total	100	46,183

The water quality problems in the Jenkins Basin watershed were excessive chemical and nutrient loadings to the aquifer. More specific problems were identified as:

- The leaching of nitrogen,
- The leaching of pesticides,
- The transport of agricultural amendment into surface waters,
- The inadequate protection of stream riparian zones,
- Sheet and rill erosion on some cropland.

The AgNPS-SALT program focuses on agricultural and land management practices to protect and to improve the water quality of the alluvium aquifer. The goal acreages of each practice and their perceived importance are presented in Table 2. Several of these practices were implemented on the same field. The proposal did not report how many acres in the watershed were in need of treatment when the project started.

Table 2. Jenkins Basin AgNPS-SALT project goals.

Type of activity	Project Goals	Importance
Irrigation management	12,000 ac	25%
Nutrient management	11,000 ac	10%
Pest management	11,000 ac	10%
Filter strips	50 ac	5%
Wildlife habitat management	114 ac	5%
Ponds	34 each	5%
Well decommissioning	30 each	10%

Analytical Tool

Baseline Scenario

The baseline scenario was developed to represent the typical land use, physical characteristics (topography, soil, and climate), and agricultural practices of the watershed. The baseline scenario was used as a base case to compare with other scenarios where alternative managements or land uses were introduced. The comparison was based on sediment and nutrient loadings and yields.

The baseline scenario was developed by recognizing the initial conditions of the watershed. The model input requirements are electronic land cover and soil maps, digital elevation model (DEM), soil characteristics, climate data, and information about the land management. The ArcView® interface AVSWATX was used to delineate the watershed, overlay land use and soil maps, enter the required inputs, and run the model.

In this study, the electronic maps of land cover and DEM were obtained from Missouri Spatial Data Information Service (http://msdisweb.missouri.edu), while soils (STATSGO and SSURGO) were obtained from the National Resource and Conservation Service. Information on climate which include daily precipitation and temperature data from 1971-2003 were obtained for the Advance weather station (Figure 1). This data was provided by Dr. Patrick Guinan at the Missouri Climate Center at the University of Missouri Department of Soil, Environmental, and atmospheric Sciences. Monthly characteristics of rainfall and temperature were derived from this 33-year long series of daily values. Information on the current agricultural land management was gathered from meetings with the Jenkins Basin Watershed steering committee. Additional information was obtained from Kurt Lebeau and Stan Mick from the Natural Resources Conservation Service (NRCS).

General input parameters were set to values that have shown to produce reasonable results in Missouri. The model was run using the Penman-Monteith evapo-transpiration method; the channel flow routing method was selected to be the Muskingum method; channel degradation was turned off (the channel dimensions remain the same through the simulation); and the stream water quality was turned off. Since there was no flow or water quality data to calibrate the model, it was validated using county historical crop yields. The model results were compared to the estimated percolation and leaching given in the proposal.

Approximations

To build a model with close approximation to reality, data and information need to represent the watershed, be readily available, and be in a form that can be directly used in the AVSWATX ArcView® interface. To develop the model, digital maps that contain land topography, streams, land use and soils were used. The heterogeneity of such data along with information on management practices enabled the model to sub-divide the watershed into 28 subbasins. (Figure 2).

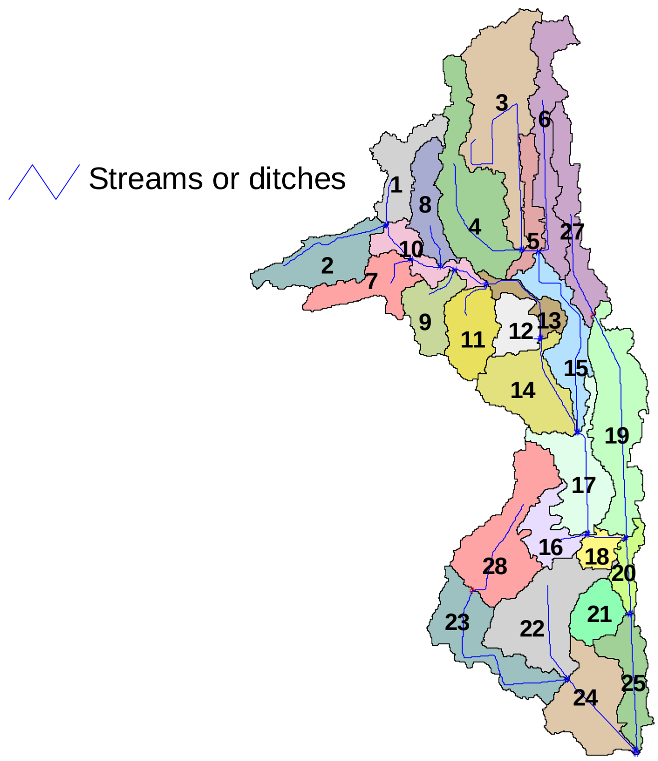

Figure 2. Delineation of the Jenkins Basin watershed.

The digital land use map used in this study was based upon 1992 satellite images. The proportions of the agricultural land uses obtained from the digital land use map and AgNPS-SALT proposal are stated in Table 3. The size of the watershed and the total acreages of agricultural land uses are different to some extent. However, the proportions of each type of land use to the total acreage are very closed (Table 3).

Land uses and soils which make up for very small percentages were eliminated according to the procedure implemented in the AVSWATX interface (Di Luzio, 2001). In this study, the thresholds for land use and soils were set to 5% and 25%, respectively. Three types of land uses (grassland, cropland, and forest) and five soil series (Sharkey silty clay loam, Commerce silt loam, Memphis silt loam, Foley silt loam, and Bosket fine sandy loam) were used (Figure 3). The Commerce silty clay loam was eliminated during the simulation procedure since it represented a very small percentage in each subbasin.

Table 3: Differences in land use distribution and watershed size.

	AgNPS-SALT Proposal		1992 satellite image	
Land use	Percent of watershed area (%)	Acres	Percent of watershed area (%)	Acres
Crop land	73	33,674	73	31,454
Pasture	15	7,096	16	6,800
Forest	11	5,041	10	4,177
Other	<1	372	<1	89
Total	100	46,183	100	42,522

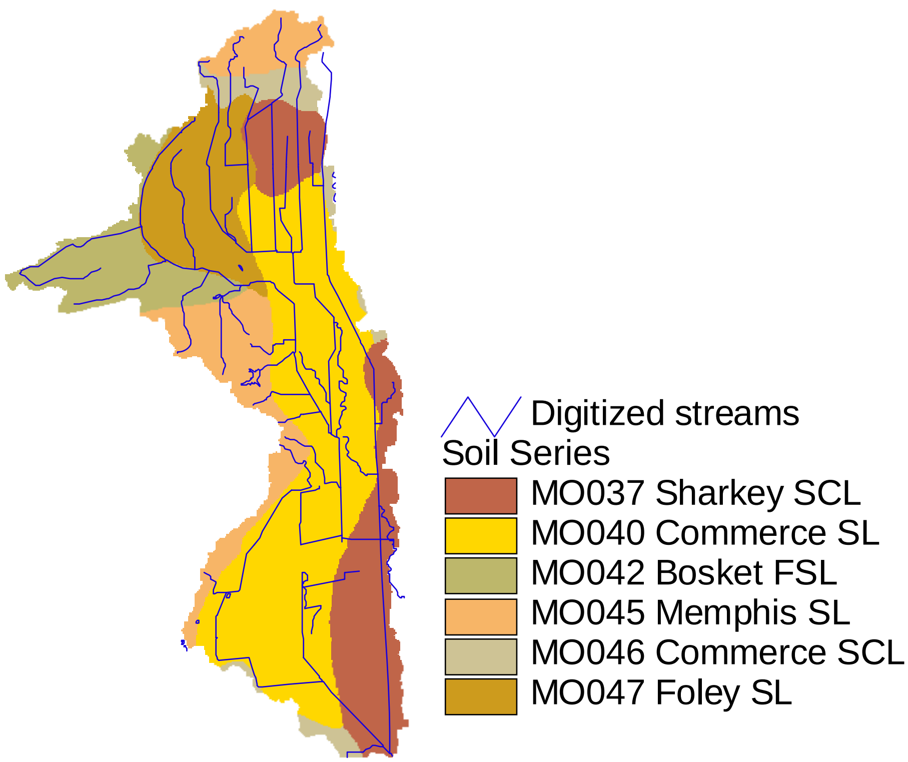

Figure 3. Soils of the Jenkins Basin watershed.

The information on cropland management including the rotation of crops, the timing and amount of fertilizer applications, and the tillage management was required. Multiple rotations are used in the watershed and each type is found throughout the watershed. To make the model manageable, four rotations were selected: a corn-soybeans rotation, a corn-winter wheat-double cropped soybeans rotation, a continuous rice rotation, and a soybeans-wheat rotation. Detailed descriptions of these managements are given in Appendix A.

To simulate the rotation and tillage management on each field would give us a model that closely follows the reality. However, simulating all the combinations of rotations, nutrient managements, irrigation management, and tillage managements in each subbasin would result in a large number of individual simulation units and be unmanageable. To limit the number of individual units in each subbasin to a minimum that would allow the assessment of the AgNPS-SALT project, the following factors were considered.

- One row crop rotation was assigned to each subbasin to balance the acreages of corn, soybeans, and wheat in the whole watershed.
- One of three irrigation managements was applied for each subbasin: dry, furrow-irrigated, and pivot irrigated. In the model, the factor that differentiates furrow from pivot irrigation is the amount of water used. Alternative irrigation management practices (surge valves, pivot renozzeling) were evaluated by assuming that they would result in less water being applied.
- One type of tillage was applied for each crop.
- One baseline nutrient management system was used. Alternative nutrient management plans were introduced afterward to be assessed.
- Grassland was considered to be in fair condition.

- Grassland was considered to be hayed but not grazed. The impact of cattle grazing was not assessed.

- No filter strips, riparian buffers, or ponds were assumed in the baseline condition.

Limitations of the SWAT model

The alternative conservation practices under the AgNPS-SALT program included nutrient and irrigation management, pesticide management, well decommissioning, filter strips, wildlife habitat in the upland, and grades stabilization structures (ponds). This assessment focuses on the irrigation and nutrient management on cropland and grassland, which are the main practices proposed and cost-shared in the AgNPS-SALT project. Pesticide was not considered because SWAT does not simulate pesticide leaching through the soil profile.

Model validation

Crop yields

In the absence of flow and water quality data to calibrate the model, we utilized county average crop yields and estimates of water and nitrate leaching to verify that the model produces reasonable results. County crop yields were obtained from the National Agricultural Statistical Survey. Table 4 shows that the simulated corn, soybean, and rice average yields for a 30 year period fall in or above the range of historical yields obtained from 1976 to 2005. It is expected that simulated yields are higher than historical yields because SWAT only simulates stress related to water, temperature, nitrogen, and phosphorus. Other stress factors such as pests or soil aeration are not included in the simulated processes. Rice acreage and rice yields have steadily in the area since 1970 which reflects the greater experience of producers with this new crop. The model reflects the yields most recently obtained.

Table 4. Model simulated and Stoddard County historical crop yields

	Dry-land average simulated yields	Irrigated average simulated yields	Historical yields 1976-2005
Corn (bu/ac)	141	151	69 - 159
Soybeans (bu/ac)	47	48	17 - 40
Rice (kg/ha)	NA	7,240	4,800- 6,780

Nitrogen leaching

The project proposal estimated infiltration amounts and nitrogen leaching for various crops and soil types. These estimations are based on general guidelines given by the US Environmental Protection Agency (EPA). They assume that 5 pounds of available nitrate will move downward with every inch of water moving below the crop’s root zone. These estimates can be taken as an indication of the trends in nitrogen leaching that we should obtain from the model. Table 5 summarizes the estimates given in the proposal. Table 6 summarizes those obtained from the model.

Table 5. Nitrate leaching AgNPS-SALT proposal estimates for corn, soybeans, and rice.

Crop	Irrigation amount (inches)		Nitrate-N leaving the root zone (lbs/a)					
	Furrow or flood	Pivot	Sandy soil		Loamy soil		Silt or clay soil	
			Furrow	Pivot	Furrow	Pivot	Furrow	Pivot
Corn	33.9	20.9	76	37	51	26	10	7
Soybeans	22.5	13.8	0	0	0	0	0	0
Rice	36	NA	NA	NA	36	NA	7	NA

Table 6. SWAT estimated nitrate leaching for corn, soybeans, and rice, (pounds per acre).

Crop	Bosket fine sandy loam (sandy soil)	Foley silt loam (loamy soil)	Commerce silt loam (loamy soil)	Sharkey silty clay loam (clay soil)
Corn	54	20	18	15
Soybeans	27	17	14	15
Rice	NA	NA	NA	121

A strict comparison is not feasible or desirable because the methods used are different. In the model, the nitrate leaching is dependent on the percolation amounts that are directly proportional to the soil specific hydraulic conductivities. The EPA estimates are based on typical soil types. Overall, the SWAT estimates are in the same range than those estimated using the EPA guidelines.

Scenarios

The AgNPS-SALT project has provided incentive payments to encourage the adoption of Best Management Practices (BMPs) and the application of Resource Management Systems (Table 2). The project did not list how many acres were in need of treatment; we have assumed that all acres need treatment.

Several alternative scenarios were defined. These scenarios evaluate the effectiveness of the BMPs at the watershed level. The final scenario combined the proposed BMPs, irrigation and nutrient management, in the amounts proposed to evaluate the total impact of the AgNPS-SALT project. In each scenario, the model was run over a 30-year long period to estimate annual sediment and nutrient loadings to the stream, through the soil profile, and out of the watershed. The nutrient and sediment loads from the baseline scenario were compared to the loads from the alternative scenarios. Since the areas where the practices have been or will be implemented were not identified, the BMPs were simulated arbitrarily in certain subbasins.

Baseline Scenario

The baseline scenario was developed to represent the typical land use, physical characteristics (topography and climate), and agricultural management practices in the watershed. Urban land was not included in the model because it represents a very small fraction of the watershed. The sediment, nutrient, and chemical loadings generated in the baseline scenario were compared with the loadings obtained from the alternative BMP scenarios. Assumptions on tillage systems were derived from information obtained during our meeting with the watershed steering committee.

Alternative Scenario

The ultimate goal of the AgNPS-SALT project is to reduce nutrient and pesticide transport through leaching and surface movement. Through the project, a number of conservation practices are introduced in the watershed. To assess the environmental improvement due to the project, the alternative scenarios were developed (Table 7).

These scenarios carried the same physical characteristics and climate information as the baseline scenario. Replacement of the conventional practices by conservation practices caused some changes in the environmental parameters used in SWAT, and, consequently, impacted the nutrient, sediment, and chemical runoff. Appendix B reviews how each management practice was simulated in the model.

Table 7. Alternative scenarios tested for the Jenkins Basin Watershed.

Scenario number	BMP	Sub-basins	Goal (acres)
1	Irrigation management	All	11,334
2	Nutrient management on irrigated land	All	11,334
3	Nutrient management on grassland	1 to 6	8,482

Results

The study focused on the outputs from the subbasins and at the outlets of the Jenkins Basin watershed. The nutrient and sediment loadings transported by the stream result from what is contributed to the stream through surface runoff, infiltration, and groundwater flow. The sediment and nutrient loadings also depend on the ditch capacity that is limited by its size and slope. Subbasin contributions are averaged over all the subbasins in the watershed. We call them yields and express them per unit area on an annual basis. Stream loadings are reported at the outlet of the watershed (outlet of subbasin 26); they represent the total amount of sediment or nutrient per year.

Baseline Scenario

Subbasin contributions

The average annual sediment yield and nutrient and atrazine runoff per acre are stated in Table 8. The simulation was run for a period of 30 years. Due to temporal variability, these results are unlikely to be observed on a year-to-year basis. The time variability is caused by the climatic changes from year to year.

Table 8. Variability of the subbasin contributions in the baseline scenario.

	Amount	Min-Max	Temporal Variability*	70% Range
Sediment Yield (tons/ac/yr)	4	1.6 – 6.8	1.5 (38%)	2.5 – 5.5
Total Nitrogen (lbs/ac/yr)	13.6	5.9 – 23.8	8.5 (63%)	5.1 - 22.1
Total Phosphorus (lbs/ac/yr)	4.6	1.9 – 8.0	1.7 (37%)	2.9 – 6.3
Leached nitrogen (lbs/ac/yr)	16.4	6.7 – 27.5	5.7 (35%)	10.7 – 22.1

*Temporal variability is the standard deviation among the 30 years of simulation. The number in parenthesis represents the coefficient of variation (standard deviation divided by average annual value)

The temporal variability is calculated as the standard deviation of the annual values obtained for each of the 30 simulated years. It corresponds to a 70% confidence interval. For sediment, for example, a temporal variability of 1.5 t/a/yr indicates a 70% chance to observe an annual yield of 4.0 ± 1.5 tons/acre/year.

Stream loads

The outlet of the watershed is located at the outlet of subbasin 26. The nutrient, sediment, and chemical loads at the outlet of that subbasin are loads transported from the entire watershed (Table 9).

Table 9. Environmental impacts of the baseline scenario at the outlet.

	Sediment (tons/year)	**Nitrogen** (lbs/year)	**Phosphorus** (lbs/year)
Jenkins Basin Watershed (Subbasin 26)	7,160	619,890	196,832

Alternative scenarios

Subbasin contributions

The expected reductions in sediment, nitrogen, and phosphorus from irrigation and nutrient management are indicated in Table 10. Leached nitrogen reductions from irrigation management are not as large as expected from the AgNPS-SALT project proposal, in part because the reduction in percolation is very small for clay and loamy soils. Irrigation management was distributed across the watershed among the different soil types.

Table 10. Expected impacts of the AgNPS-SALT project at the subbasin level, percentage change in pollutant yields from the baseline.

	Sediment (% change)	**Surface Nitrogen** (% change)	**Leached Nitrogen** (% change)	**Phosphorus** (% change)
1: Irrigation management	-6%	-5%	-0.3%	-3%
2: Irrigation and nutrient management	-7%	-6%	-3%	-15%
3: Combined BMPs: 2 + nutrient management on some grassland	-6%	-6%	-3%	-15%

Table 11 shows the field level reductions predicted by the model in water movement and nitrates for the different soil types. These results show that the total water yields were reduced in amounts that were similar to the reduction of the applied water. However, it did not cause a comparable reduction in percolation because in this case the controlling factor was the hydraulic conductivity of the soil, not the applied water. The decrease of leaching nitrate is even smaller.

Table 11. Expected impacts of irrigation management on water and nitrogen movement for different soils planted with corn.

Soil series Texture Irrigation soil type	Bosket FSL pivot (sandy soil)	Foley SL pivot (loamy soil)	Foley SL furrow (loamy soil)	Commerce SL pivot (loamy soil)	Commerce SL furrow (loamy soil)	Sharkey SCL pivot (clay soil)	Sharkey SCL furrow (clay soil)
percolation	-7%	-6%	-7%	-6%	-7%	-5%	-6%
NO_3 leaching	-2%	-2%	-3%	-3%	-3%	-2%	-4%
Water yield	-16%	-18%	-35%	-16%	-34%	-16%	-34%
Surface NO3	-6%	-5%	-9%	-5%	-11%	-5%	-9%

Phosphorus reductions were significant on cropland when nutrient management was combined with irrigation management. The phosphorus loadings were estimated to be reduced by 15% at the watershed level when 11,334 acres of cropland were subject to this type of management (Table 10). At the field level, simulated reductions were estimated to achieve as much as 40% (not shown).

The third scenario consisted of the second scenario plus nutrient management on 8,482 acres of grassland. Results at the field level indicated a decrease of soluble nutrient on treated grassland associated with the decrease of applied nitrogen and phosphorus. However it caused an increase in erosion and associated organic nutrient loadings that traveled with sediment. Even if, overall, the total nutrient loadings from treated grassland were decreased compared to the baseline, the effect was not strong enough to be detected at the watershed level. The additional decreases in nutrient loadings in the subbasins where some grassland was treated were 1%-2% for nitrogen and phosphorus each.

Stream loads

The reductions in sediment achieved at the subbasin level were accentuated at the outlet of the watershed through additional deposition in the streams because of decreased flow. The combined BMPs scenario resulted in an 11% sediment load reduction for the watershed (Table 12), which was explained by the decrease of irrigation water.

The decrease of flow also explains an additional decrease in organic nitrogen and phosphorus adsorbed to sediment particles. Stream loading of nitrogen and phosphorus at the outlet of the entire watershed were reduced by 6% through irrigation management. These reductions were increased when nutrient management was implemented on part of the cropland. The combined BMPs were expected to produce an 8% reduction of the nitrogen stream loads and a 17% reduction of the phosphorus loads (Table 13). At the subbasin level, the nutrient management on the grassland was not detected at the outlet of the watershed.

Table 12. Expected impacts of the AgNPS-SALT project at the outlet, percentage change in stream loads from the baseline.

Scenario number and description	**Sediment** (% change)	**Nitrogen** (% change)	**Phosphorus** (% change)
1: Irrigation management	-11%	-6%	-6%
2: Irrigation and nutrient management	-11%	-8%	-17%
3: Combined BMPs: 2 + nutrient management on grassland	-11%	-8%	-17%

Conclusions

This analysis estimated the individual and combined impact of the practices proposed in the AgNPS-SALT project in the Jenkins Basin watershed using the acreage amounts proposed in the project proposal. The model could not be calibrated due to a lack of flow and water quality data. Best estimates and default values were used as input parameters. The results should be reviewed when data become available to verify and calibrate the model.

Four model simulations were performed to determine the impact of irrigation and nutrient management practices on cropland and on grass land. The four simulations included the baseline irrigation management, the irrigation and nutrient management on cropland, and the irrigation and nutrient management on cropland and part of grassland grass land. The comparisons were based on long-term (30 years) averages. The expected reductions may not be observed on a year-to-year basis due to weather variability. Therefore, short term water quality measurements might not show any improvement. However, the results indicated reductions in sediment, nutrient, and chemical loads when the conservation practices were implemented.

Irrigation management did not result in significant reductions in infiltrations and nitrogen leaching except on sandy soils. On clay soils, infiltration was limited by the slow permeability in the soil profile and decreasing the amount of irrigation resulted in less runoff. On the other hand, the reduction in flow contributed to a decrease of erosion and sediment yields and the associated nutrients transported by sediment. It also contributed to additional sediment deposits in the streams and ditches.

Nutrient management combined with irrigation management resulted in larger decreases of nutrients because of the reduction in flow and erosion on one hand, and the decrease of nutrient inputs on the other hand.

Pasture nutrient management did contribute to reductions in nitrogen and phosphorus loadings even though the erosion increased. Since there is a small amount of grassland in this watershed, the impact of this BMP was not detected at the watershed outlet.

Appendix A: BMP Simulation

Irrigation Management

The purpose of irrigation management is to improve the water delivery system and thus reduce the water application rates. The only parameter by which SWAT can differentiate the different irrigation methods is the amount of water applied. There is currently no method in SWAT to simulate the heterogeneity of water amounts received in different areas of a field. The whole field is assumed to receive the same amount. The amounts received under baseline and irrigation management conditions for corn and soybeans in this analysis are specified in Table A1. They are all extracted from the AgNPS-SALT project proposal. The number of irrigation events were assumed to remain the same but the depths of water applied per event were reduced. Rice was simulated with the auto-irrigation option that applied enough water to fill the soil up to field capacity as soon as the plant experienced 10% of water stress. Over 30 years of simulation, the model applied an average of 23 inches of water on rice, going from 17 to 27 inches.

Table A1. Water amounts per irrigation event for corn and soybeans under baseline and irrigation management conditions in the Jenkins Basin Watershed.

Crop	Start	End	# of irrigation events per season	Furrow baseline [mm (in)]	Furrow alternate [mm (in)]	Pivot baseline [mm (in)]	Pivot alternate [mm (in)]
Corn	June 21	Aug. 30	8	107 (4.2)	64 (2.5)	66 (2.6)	48 (1.9)
Soybeans	July 4	Sep. 12	8	70 (2.8)	43 (1.7)	44 (1.7)	32 (1.3)

Nutrient Management

The purpose of nutrient management is to optimize nutrient application rates while ensuring crops' nutrient requirements for their full potential growth and minimizing nutrient loadings to the streams. Nutrient management includes the determination of nutrient needs as a function of the soil chemical composition, the crop growth rate, and the expected yield. On grassland, it is determined as a function of the soil chemical composition and the hay harvest. Nutrient management plans can include a split application of nutrients but this was not included in the analysis.

The phosphorus and nitrogen application dates and rates for the different crops under baseline conditions and under a nutrient management plan are shown in Tables A2 to A5. The proposal indicated a 10% reduction of nitrogen rate, which was used in the analysis. The phosphorus application rates were calculated by considering the average annual amount P removed by crops and adding a given percentage to account for losses and increased yield. The average amount of P removed by crops was estimated with the SWAT model from the baseline results. To account for losses, we added 10% of phosphorus. Phosphorus is applied in spring before corn is planted. An extra 10% of P is added for potential yield increase. On grassland, nitrogen is reduced by 10% and the September application of phosphorus is eliminated.

Table A2. Management operations for the corn – soybeans rotation

Date	Operation	Dry	Irrigated	Irrigated with Nutrient management
March 10	Anhydrous ammonia	207 lbs/a	240 lbs/a	216 lbs/a
March 10	P fertilizer	75 lbs/a	75 lbs/a	32 lbs/a
March 12	Tillage	Disk chisel		
March 31		**Plant Corn**		
April 12	Atrazine	1.25 lbs/a	1.25 lbs/a	1.25 lbs/a
May 1	Atrazine	0.75 lbs/a	0.75 lbs/a	0.75 lbs/a
June 21				
September 15		**Harvest**		
November 6	Fall tillage	Disk	Disk	Disk
April 28	Spring tillage	Chisel/ cultivator	Chisel/ cultivator	Chisel/ cultivator
May 2		**Plant soybeans**		
July 4	Irrigation			
July 14	Irrigation			
July 24	Irrigation			
August 3	Irrigation			
August 13	Irrigation	**See Irrigation management**		
August 23	Irrigation			
September 2	Irrigation			
September 12	Irrigation			
October 1		**Harvest**		
October 25	Fall tillage	Disk	Disk	Disk

Table A3. Management operations for the soybeans – wheat rotation

Date	Operation	Dry	Irrigated	Irrigated with Nutrient management
April 28	Spring tillage	Chisel/ cultivator	Chisel/ cultivator	Chisel/ cultivator
May 2		**Plant soybeans**		
July 4	Irrigation	**See Irrigation management**		
July 14	Irrigation			
July 24	Irrigation			
August 3	Irrigation			
August 13	Irrigation			
August 23	Irrigation			
September 2	Irrigation			
September 12	Irrigation			
October 1		**Harvest**		
October 5	N fertilizer	50 lbs/a	50 lbs/a	45 lbs/a
October 5	P fertilizer	70 lbs/a	70 lbs/a	70 lbs/a
October 8		**Plant no-till wheat**		
March 5	N fertilizer	45 lbs/a	45 lbs/a	40 lbs/a
June 5		**Harvest**		
November 6	Fall tillage	Disk	Disk	Disk

Table A4. Management operations for the corn –wheat – double cropped soybeans rotation.

Date	Operation	Dry	Irrigated	Irrigated with Nutrient management
March 10	Anhydrous ammonia	207 lbs/a	240 lbs/a	216 lbs/a
March 10	P fertilizer	75 lbs/a	75 lbs/a	32 lbs/a
March 12	Tillage	Disk chisel		
March 31	**Plant Corn**			
April 12	Atrazine	1.25 lbs/a	1.25 lbs/a	1.25 lbs/a
May 1	Atrazine	0.75 lbs/a	0.75 lbs/a	0.75 lbs/a
July 4	Irrigation			
July 14	Irrigation			
July 24	Irrigation			
August 3	Irrigation			
August 13	Irrigation	**See Irrigation management**		
August 23	Irrigation			
September 2	Irrigation			
September 12	Irrigation			
September 15		**Harvest**		
October 5	N fertilizer	50 lbs/a	50 lbs/a	45 lbs/a
October 5	P fertilizer	70 lbs/a	70 lbs/a	70 lbs/a
October 8		**Plant no-till wheat**		
March 5	N fertilizer	45 lbs/a		
June 5		**Harvest**		
July 1		**Plant soybeans**		
October 1		**Harvest**		
November 1	Fall tillage	Disk	Disk	Disk

Table A5. Management operations for rice.

Date	Operation	Irrigated
March 20	Tillage	Bedder
April 6	Tillage	Bedder
April 20	Tillage	Hipper
May 3	**Plant Rice**	
May 10	Urea	315 lbs/a
May 10	Phosphorus	25 lbs/a
May 14	Start irrigation, based on plant need, stress level of 90%	
July 5	Urea	68 lbs/a
July 5	Urea	68 lbs/a
September 14	**Harvest grain**	
September 15	Kill	
October 5	Fall tillage	

Table A6. Management operations for grassland.

Date	Operation	Type	Baseline Rate	Nutrient management rate
March 1	Fertilization	17-17-17	300 lbs/a	270 lbs/a
May 15	Harvest			
September 1	Harvest			
September 5	Fertilization	17-17-17	90 lbs/a	
September 5	Fertilization	Nitrate-N		15 lbs/a
November 5	Harvest			