Missouri Department of Natural Resources

UPPER AND LOWER BIG MARIES RIVER WATERSHEDS

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 symptoms in the Big Maries River are excessive nutrient and sediment loads, stream bank instability, diminished dissolved oxygen, and bloom of filamentous algae. To improve the water quality, the Agricultural Nonpoint Source-Special Land Area Treatment (AgNPS-SALT) program, approved in March 2004, sponsored a number of conservation practices through technical and financial assistance through the Maries County and Osage County Soil and Water Conservation Districts (SWCDs). The AgNPS-SALT program focused on agricultural and land management activities that influence sediment and nutrient loading through agricultural conservation practices.

The purpose of this study was to assess the change in nutrient and sediment loads in the Big Maries River due to 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 a reduction in sediments and nutrients resulted from implementing the conservation practices. The reductions varied by practice. The reductions in sediment and nutrients at the outlet, which included the nutrient and sediment loads from the entire watershed, were less than the reductions at the subbasin level, which accounted for nutrient and sediment runoff before reaching the stream. The differences in reduction rates at the outlet and the subbasins were influenced by the stream sediment and nutrient transport processes. Due to the spatial and temporal variability, the average amount of nutrients and sediment 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: grassland improvement, rotational grazing, woodland exclusion, and stream exclusion.

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.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Watershed Information

Geographically, the upper and the lower Big Maries River watersheds are adjacent to each other. The streams run from the south to the north (from the upper to the lower) and drain to the outlet located 2 to 3 miles north of Westphalia at the confluence with the Osage River.

The upper Big Maries River watershed is located south of Freeburg in Maries County and north of Dixon in Pulaski County (Figure 1). Highways 63 and 28 closely approximate the location of a winding ridgetop that divides the major watersheds in the county. The dominant topography consists of moderately sloping to steep uplands dissected by small stream flood plains. Flood plains along the Maries River and its tributaries were periodically covered with alluvial deposits. The lower Big Maries River watershed is located in Osage county, southwest of Linn (Figure 1). The majority of this watershed contains soils in the Ozark Highland Major Land Resource Area (MLRA) with slopes ranging from 2 to 35%.

The upper Big Maries River watershed contains 61,689 acres – the majority of the land is in pasture and woodland (Table 1). Of the 55% (33,568 acres) in pasture and hay, 60% (19,815 acres) is in poor condition due to overgrazing and steep slopes that cause excessive erosion, and need treatment. The remaining 45% is woodland. Due to excessive accessibility of cattle to the streams through the woodlands, 66% of the woodland is in poor condition and needs treatment.

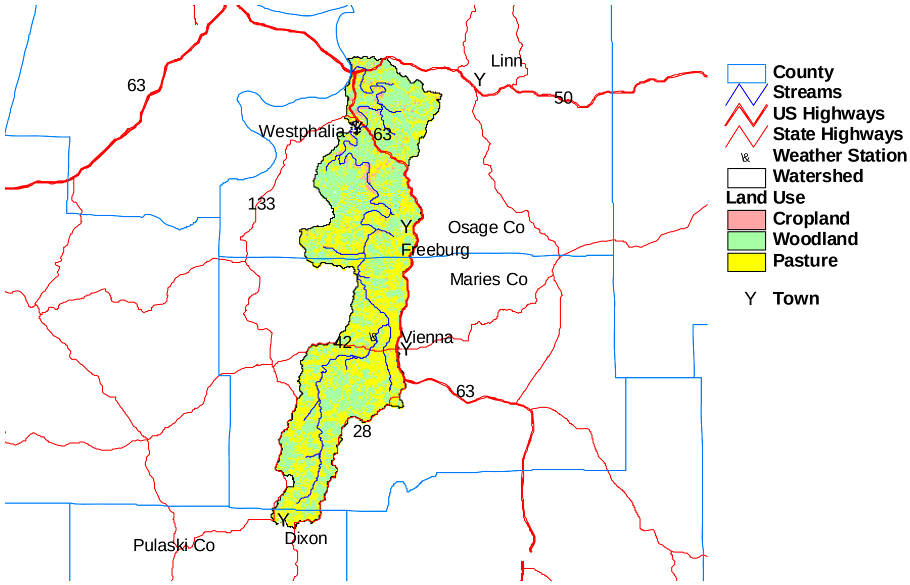

Figure 1. The Upper and Lower Big Maries River Watershed.

To improve acres that need treatment, the AgNPS-SALT project set the target acreages of land (17,225 acres) to be treated by conservation practices (Table 1). Under the AgNPS-SALT program, 315 streambank miles will be treated to reduce the sediment loads (Table 1).

Table 1. Land use of the upper Big Maries River watershed.

	Acres	% of Total Land Use	Acres Needing Treatment	Acres Treated
Cropland	118	0.19	74	37
Pasture/hayland	33, 568	54.41	19, 815	8, 900
CRP Land				
Urban	141	0.23		
Woodland	27, 628	44.79	18, 234	8, 288
Publicly Owned	234	0.38		
Total	61, 689	100.00	38, 123	17, 225
Stream (miles)	315		158	46

Source: AgNPS-SALT grant proposal for the upper Big Maries River watershed.

Of the 67,863 acres in the lower Big Maries River watershed, 39 % (26,496 acres) is pasture and hay land and 94% (25,000 acres) of all pasture and hay lands needs treatment. Fifty-six percent of this watershed is woodland and 71% of the total woodland needs treatment (Table 2).

Similar to the upper Big Maries River watershed, land in pasture needs treatment since it is in poor condition due to overgrazing (Table 2). Overgrazing causes the land to erode in excess of tolerable levels. In addition, unlimited access of cattle to rivers and streams through the woodland caused a decline in the stability of the stream banks and riparian corridors. Under the AgNPS-SALT project, conservation practices are to be implemented on 20,000 goal acres. In addition, stream banks are to be treated to reduce the sediment loads caused by bank instability.

Table 2. Land use of the lower Big Maries River watershed.

	Total Acreage	**% of Total Land Use**	**Acres Needing Treatment**	**Acres Treated AgNPS SALT**
Cropland	2, 664	3.93	1, 300	1, 000
Pasture/hayland	26, 496	39.04	25, 000	10, 000
CRP Land	110	0.16		
Urban	135	0.20		
Woodland	38, 354	56.52	27, 400	9, 000
Publicly Owned	104	0.15		
Total	67, 863	100.00	53, 700	20, 000
Stream Miles	279		139	67

Source: AgNPS-SALT grant proposal for the lower Big Maries River watershed.

Analytical Tool

Due to their geographic connection, the upper and the lower watersheds were considered as one watershed and simulated together. However, SWAT allowed the results of each watershed to be interpreted separately, through the designation of smaller subbasins that comprise the larger watersheds.

The baseline scenario was developed by recognizing the initial conditions of the watershed. The model input requirements were electronic land cover and soil maps, data elevation map (DEM), soil database, climate data collected from nearby weather stations, and information about the management of the land. The SWAT version 2000 (SWAT2000) was used in this study. SWAT2000 is available in Geographic Information Systems (GIS) and non-GIS interfaces. The ArcView® program is used in the GIS interface. The SWAT2000 with ArcView® interface (AVS2000) was used to delineate the watershed and divide it into subbasins.

The digital maps of land cover and DEM were obtained from the Missouri Spatial Data Information Service (http://msdisweb.missouri.edu), while soil information (STATSGO) was obtained from the National Resource and Conservation Service (NRCS; http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo). Daily precipitation and temperature data from 1960-2004 were obtained from the Vienna weather station (Figure 1) and provided by Dr. Pat Guinan at the Missouri Climate Center at the University of Missouri Department of Soil, Environmental, and Atmospheric Sciences. Monthly rainfall and temperature were derived from a 44-year long series of daily values. Available daily flow data from 1948-1970 for water balance calibration were obtained from the USGS flow gauge at Westphalia (Figure 1). The model was calibrated using daily flow information. Details of model calibration appear in Appendix A.

The information on typical agricultural land management for the baseline scenario was gathered from meetings with the watershed steering committees. The committees consisted of landowners in the upper and lower watersheds who participated in the

AgNPS-SALT program and members of the boards of the SWCD of Osage and Maries Counties.

Approximations

To build a model with close approximation to reality, digital maps that contained land topography, streams, land use, and soils were incorporated. The heterogeneity of such information enabled the determination of 25 subbasins (Figure 2) - the upper watershed includes subbasins 16 to 24, while the lower watershed includes subbasins 1 to 15 and 25. The management practices developed for the simulation along with the historical and current land use were applied to both watersheds.

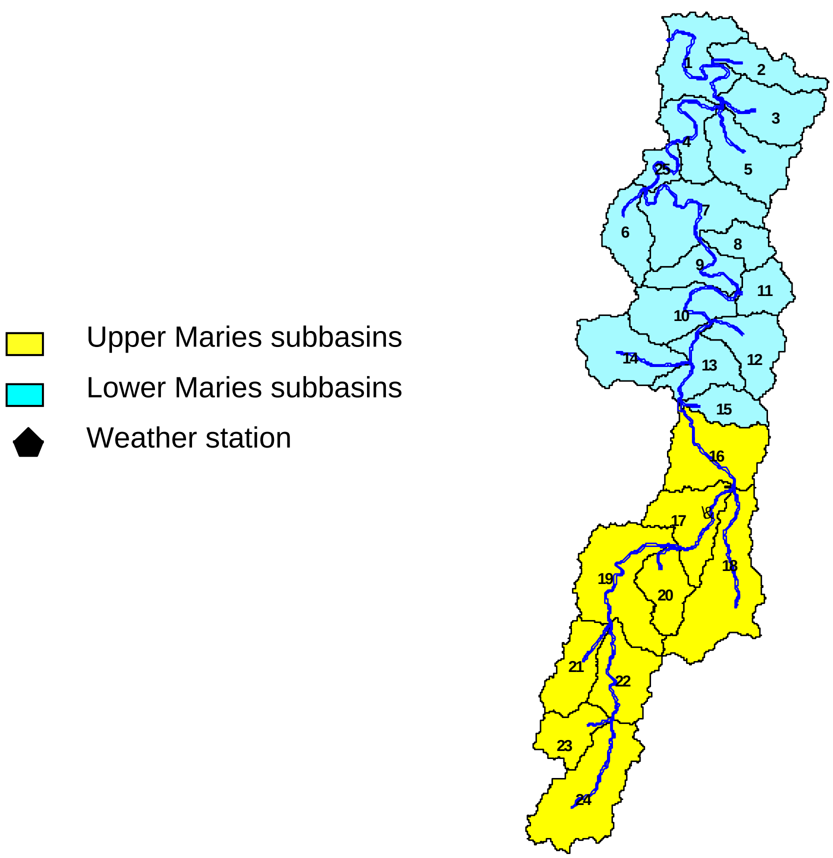

Figure 2. Subbasins of the Big Maries River Watershed

The digital land use map used in this study was based upon 1992 satellite images and produced proportions of land use that were similar to the land use distribution in the AgNPS-SALT proposal (Table 3).

Table 3. Percentage of land use distribution.

Land use	**AgNPS-SALT** (%)	**1992 satellite image** (%)
Cropland	2	2
Pasture/hayland	46	47
Woodland	51	51
Other	1	<1
Total	100	100

Limitations of the SWAT model

The alternative conservation practices under the AgNPS-SALT program included grassland improvement, grazing management, stream exclusion, streambank stabilization, woodland exclusion, and gully erosion control. Due to limitations of the AVS2000 model, some proposed practices were not addressed. The SWAT model cannot estimate how education and training efforts affect the behavior of the producers and land managers. Therefore, an evaluation of the impact of meetings, education, training, and farm visits was not included in the study. Waste utilization, nutrient management, and waste hauling/disposal practices also were not included in the study due to insufficient information on the quantity and hauling distance of wastes applied on nearby crop fields. Because of the small proportion of acreages relative to pasture and woodland, cropland conservation was not included. Practices that affect groundwater quality (spring development and well decommission) were not addressed because the SWAT model does not currently track the quality of the groundwater.

Scenarios

Scenarios presented in this study included the baseline and alternative scenarios. The baseline represented the current conditions of agricultural practices. Pasture land was divided according to the soil cover. Pastures needing treatment were classified as in poor condition; the rest were assumed to be in fair condition.

Several alternative scenarios were defined: one for each best management practice (BMP) implemented on the target acreage of the AgNPS-SALT project, and one for each BMP implemented on all acres needing treatment. These scenarios evaluate the effectiveness at the watershed level of each BMP. A final scenario combined all the BMPs proposed in the project in the amounts proposed. This final scenario enables evaluation of the impact of the AgNPS-SALT project as a whole. The nutrient and sediment loads from the baseline scenario were simulated and compared to the loads from the alternative scenarios.

In each scenario, the BMP was simulated on land or stream banks in poor condition which was part or all of the acres needing treatment. The numbers of acres needing treatment were obtained from the AgNPS-SALT proposals prepared by the Maries and Osage SWCDs. The combined BMP scenario addressed the nutrient and sediment reductions when all the conservation practices were implemented on the target acreages simultaneously.

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. Cropland was not included in the model because it represents only a very small fraction of the Lower Big Maries watershed. The sediment, nitrogen and phosphorus loadings generated in the baseline scenario were compared with the loadings obtained with the alternative BMP scenarios.

In addition to topographic, soil, and land use information previously described, current representative agricultural management practices are key elements to determine the environmental outcomes. Under the baseline scenario, typical grazing management for the region was applied for both the upper and the lower watersheds. Cattle were rotated between two pastures and one hay field harvested in June and later grazed. They grazed 30 days in each area. During the winter, from December 16 until the beginning of April, the cattle were moved to a wooded winter area. Both summer pastures and the hay field were fertilized at the beginning of March.

Some information was not available. For instance, access to the stream by cattle implies that livestock spend some time in the streams and deposit some manure directly into the water. Excluding cattle from streams therefore not only contributes to a more stable and less erodible bank, it also decreases the nutrient load directly deposited in the stream. However, the number of animals having access to the streams was not known. Since this is critical information to estimate the amount of manure directly deposited into the streams, we did not address that aspect. In addition, due to insufficient information about their number, size, and drainage area, ponds were not included in the baseline.

BMPs on Target Acres Scenario

The ultimate goal of the AgNPS-SALT project is to reduce nonpoint source pollution associated with agricultural practices. Through the project, a number of conservation practices are being introduced in the upper and lower watersheds.

The target acres of the AgNPS-SALT project did not include all acres needing treatment. To assess the environmental improvement due to the project, the "BMP on target acres" scenario was developed. This scenario 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 and sediment runoff.

BMPs on All Acres Needing Treatment Scenario

The BMPs introduced under the AgNPS-SALT project covered part of all acres needing treatment. For instance, 1,115 target acres were identified on which implement the grassland improvement practice in the upper watershed, while the pasture and hay land needing treatment were 25,000 acres. Only 5% of pastureland needing improvement was treated by implementing grassland management. This study further assessed the environmental impacts if the grassland management were applied to all the acres needing treatment. Similar procedures were applied to other conservation practices on both watersheds.

Combined BMPs Scenario

Under the combined BMPs scenario, the nutrient and sediment reduction of all the conservation practices proposed by the AgNPS-SALT program were assessed simultaneously. The sediment and nutrient loadings generated by this scenario were developed and compared to the loadings from the baseline scenario.

Results

The study focused on the outputs from the subbasins and at the outlets of the upper and lower Big Maries watersheds. The nutrient and sediment loadings transported by the stream result from what is contributed to the stream by the land around it and from the stream capacity, given its size and slope. Subbasin contributions are averaged over all the subbasins in the watershed. We call them yields and express them on a per unit area basis. Stream loadings are reported at the outlet of the upper (outlet of subbasin 16) and lower (outlet of subbasin 1) watersheds.

Baseline Scenario

Subbasin contributions

The average annual sediment yield and nutrient runoff per acre are stated in Table 4. The simulation was run for a period of 30 years. Due to spatial and temporal variabilities, these results are unlikely to be observed on a year-to-year basis throughout the watershed. The time variability is caused by the climatic changes from year to year, while the spatial variability is caused by differences in slope, soils, and land use from subbasin to subbasin.

Table 4. Variability of the subbasin contributions in the baseline scenario.

	Amount	**Spatial Variability***	**Temporal Variability****
Sediment Yield (tons/ac/yr)	5.26	1.9 (36%)	2.5 (48%)
Total Nitrogen (lbs/ac/yr)	17.16	4.8 (28%)	5.2 (30%)
Total Phosphorus (lbs/ac/yr)	6.37	1.8 (28%)	2.5 (39%)

*Spatial variability is the standard deviation among all subbasins.
**Temporal variability is the standard deviation among the 30 years of simulation.

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 2.5 t/a/yr indicates a 70% chance to observe an annual yield of 5.26 ± 2.5 tons/acre/year. The spatial variability is calculated as the standard deviation of the average annual values obtained for each of the 25 subbasins.

Stream loads

The outlets of the upper and the lower watersheds are located at the boundaries of subbasins 16 and 1, respectively. Sediment and nutrient loads transported by streams in the upper watershed (Table 5) go through the channel outlet located at subbasin 16. The nutrient and sediment loads at the outlet of subbasin 1 are total loads transported from the entire watershed. For example, out of 574,849 tons/year of sediment carried out of the watershed, 263,670 and 311,179 tons/year were contributed by the upper and the lower watersheds, respectively (Table 5).

Table 5. Environmental impacts of the baseline scenario at the outlet.

	Sediment (tons/year)	**Nitrogen** (lbs/year)	**Phosphorus** (lbs/year)
Upper Maries (Subbasin 16)	263,670	672,623	311,378
Lower + Upper Maries (Subbasin 1)	574,849	1,591,721	760,807

BMPs on Target Acres and Combined BMPs

Subbasin contributions

The reductions of the sediment yields from grassland improvement and grazing management practices in the upper and the lower watersheds were 8.7% and 10.9%, respectively. For woodland exclusion, the reduction was less than 1% due to few acres of woodland being treated. Stream exclusion and stream bank stabilization affect the stream directly, not what is contributed to the stream by the land around it. The effects of these two practices are only detectable when examining stream loads. No change in sediment and nutrient yields was shown from gully erosion control because there were few target drainage acres from ponds (400) compared with the total acres (45,000) of pasture and hay land needing treatment. In addition, there was a lack of information about the number, the nature, and the location of these critical areas. In general, there is a lack of knowledge regarding how to identify critical areas in a watershed and assess their impact. This is a major thrust of the U.S. Department of Agriculture Conservation Effects Assessment Program (CEAP) and research in that area is being undertaken at present.

When the conservation practices were implemented simultaneously under the combined BMPs scenario, the reduction in the average annual sediment yields was 22% (Table 6). The expected changes were similar in the upper and lower watersheds. They are due in large part to grassland improvement and grazing management.

The nitrate reductions from grazing management and grassland improvement were among the highest in both the upper and the lower watersheds. Woodland exclusion showed change of less than 1% nitrate reductions. The combined BMPs indicated a total reduction in sediment or nutrients of approximately 20% (Table 6).

Phosphorus reductions from the grassland improvement and the grazing management practices were 4% and 12%, respectively. Total phosphorus reduction was 19% when all the conservation practices were conducted simultaneously (Table 6).

Table 6. Expected impacts of the AgNPS SALT project at the subbasin level, percentage change in pollutant yields from the baseline.

	Sediment (% change)	**Nitrogen** (% change)	**Phosphorus** (% change)
Grassland Improvement			
Total (Upper + Lower)	-9	-5	-4
Upper	-11	-6	-5
Lower	-7	-5	-4
Grazing Management			
Total (Upper + Lower)	-11	-11	-12
Upper	-12	-16	-15
Lower	-10	-10	-10
Woodland Exclusion			
Total (Upper + Lower)	-0.01	-0.03	0.00
Upper	-0.01	-0.04	0.00
Lower	-0.01	-0.03	0.00
Combined BMPs			
Total (Upper + Lower)	-22	-20	-19
Upper	-22	-20	-19
Lower	-22	-21	-19

Stream loads

The reductions in sediment stream load at the outlet of the whole watershed due to grassland improvement and grazing management were 3% and 4%, respectively. Sediment load reduction from the stream exclusion practice was 4%, while woodland exclusion yielded a reduction of less than 1%. There were no changes in the sediment and nutrient loads from stream bank stabilization because only a fraction of the stream miles that need treatment will be stabilized. The combined BMPs scenario resulted in a 9% sediment load reduction for the entire watershed (Table 7).

Table 7. Expected impacts of the AgNPS-SALT project at the outlet, percentage change in stream loads from the baseline.

	Sediment (% change)	**Nitrogen** (% change)	**Phosphorus** (% change)
Grassland improvement			
Upper (Subbasin 16)	-7	-6	-5
Upper + Lower (Subbasin 1)	-3	-7	-3
Grazing management			
Upper (Subbasin 16)	-7	-9	-11
Upper + Lower (Subbasin 1)	-4	-9	-6
Stream exclusion			
Upper (Subbasin 16)	-4	NA	NA
Upper + Lower (Subbasin 1)	-4	NA	NA
Woodland exclusion			
Upper (Subbasin 16)	-0.3	-0.03	-0.01
Upper + Lower (Subbasin 1)	-0.2	-0.08	-0.02
Combined BMPs			
Upper (Subbasin 16)	-14	-10	-13
Upper + Lower (Subbasin 1)	-9	-10	-7

Stream loading of nitrogen at the outlet of the entire watershed were reduced by 7% and 9% for grassland improvement and grazing management, respectively. As indicated previously, this study does not address the nutrient reduction that would result from less manure being deposited directly in the water due to stream exclusion. The nitrogen load from woodland exclusion was reduced by less than 1%. The combined BMPs are expected to produce a 10% reduction of the nitrogen stream loads (Table 7).

The total phosphorus stream loads at the outlet of the entire watershed would be reduced by 3% for grassland improvement and 6% from grazing management. Streambank stabilization and gully erosion control produced no change in phosphorus loads. The phosphorous load reduction from woodland exclusion was less than 1%. The combined BMPs scenario represented a 7% decrease in the phosphorus stream load (Table 7).

BMPs on all acres needing treatment

Subbasin contributions

In the entire watershed, 44,815 acres of pasture and hay land needed to be improved. Only 3,195 acres were proposed for treatment by applying grassland improvement. If the grassland improvement practice were applied to the entire watershed, sediment, nitrogen, and phosphorus yields contributed to the streams would be reduced by 80%, 64% and 69%, respectively. If the grazing management practice were applied to all of the pasture land needing treatment, the sediment, nitrogen, and phosphorus reductions would be 65%, 58%, and 60%, respectively. Woodland exclusion also would result in a small reduction in pollutants (Table 8).

Table 8. Expected impacts of BMPs implemented on all acreage needing treatment at the subbasin level, percent change from the baseline.

	Sediment Yields (% change)	**Nitrogen** (% change)	**Phosphorus** (% change)
Grassland improvement			
Total (Upper + Lower)	-80	-64	-69
Upper	-80	-55	-57
Lower	-80	-68	-75
Grazing management			
Total (Upper + Lower)	-65	-58	-60
Upper	-66	-59	-59
Lower	-65	-58	-61
Woodland exclusion			
Total (Upper + Lower)	-0.2	-0.8	-0.2
Upper	-0.2	-0.8	-0.2
Lower	-0.2	-0.7	-0.2

Stream loads

The sediment stream loads at the outlet of the entire watershed were reduced by 34% due to grassland improvement and 28% due to grazing management (Table 9). Woodland exclusion showed the least reduction compared with the other conservation practices. Stream exclusion is expected to produce a 21% sediment load reduction.

Table 9. Expected impacts of BMPs on all acreage needing treatment at the outlet, percentage change from the baseline.

	Sediment (% change)	**Nitrogen** (% change)	**Phosphorus** (% change)
Grassland improvement			
Upper (Subbasin 16)	-55	-48	-57
Upper + Lower (Subbasin 1)	-34	-51	-66
Grazing management			
Upper (Subbasin 16)	-47	-53	-60
Upper + Lower (Subbasin 1)	-28	-50	-61
Stream exclusion			
Upper (Subbasin 16)	-13	NA	NA
Upper + Lower (Subbasin 1)	-21	NA	NA
Woodland exclusion			
Upper (Subbasin 16)	-6	-2	-1
Upper + Lower (Subbasin 1)	-9	-2	-1

Grassland improvement reduced the total nitrogen load at the outlet of the entire watershed by 51% compared to grazing management at 50%. The nitrogen stream loads declined by 2% due to woodland exclusion (Table 9).

Total phosphorus load reductions due to grassland improvement and grazing management were 66% and 61%, respectively, while the reductions due to woodland exclusion were less than 1%. Stream exclusion and stream bank stabilization produced no change in the phosphorus loads (Table 9).

Conclusions

Grazing management and grassland improvement were among the most effective practices to reduce sediment and nutrient runoff from agricultural land. Grazing management showed the highest reduction rates in subbasin contributions and stream loads. The sediment and nutrient reduction rates from both practices are higher at the subbasin level than at the outlet. When each application was extended to the entire acreage needing treatment, the reductions obtained with grassland improvement practice resulted in the higher reduction rates for sediment and nutrient contributions to the streams; they are more similar when considering sediment and nutrient stream loads.

Stream exclusion showed a reduction in sediment loads at the watershed outlet. The nutrient reductions from the stream exclusion practice were not captured because information on the deposits of cow manure directly into the water was not collected.

The conservation practice of woodland exclusion showed the smallest percentage of sediment and nutrient reductions when applied to the target scenario, which accounted for 2% of the total woodland acres needing treatment. When extended to the total acres of woodland needing treatment, the reductions in sediment and nutrient loadings at the watershed outlet increased. Assumptions had to be made to estimate the impact of this practice: the length of fencing for woodland protection had to be translated into acres of protected land. While the length of fencing drives the cost, the number of protected acres drives the environmental impact.

The model was not able to address the sediment and nutrient reductions from gully erosion control because of the small acreage treated. Grade stabilization structures (ponds) were simulated in selected subbasins. However, the critical erosion conditions that are supposed to exist to justify the construction of a pond were not defined. This would have required either more information or an additional GIS-based process to identify these critical areas. In addition, SWAT AVS2000 lacks the ability to simulate such specific areas. For further study, another simulation program can be used at a smaller scale to capture the environmental contribution from critical areas. The results can be used as inputs to SWAT simulations.

When all of the conservation practices were implemented simultaneously on the target acres under the combined BMPs scenario, the sediment and nutrient reductions were significant. 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 and nutrient loads when the conservation practices were implemented. Each practice must be carefully evaluated and prioritized according to its cost and effectiveness to obtain the ultimate environmental outcome.

Appendix A. Model Calibration

Flow, sediment, and water quality parameters are estimated with the SWAT model. When data are available, it is always best to compare the simulated values obtained during a given numbers of years to measured data during that time and adjust the model parameters so they match – model calibration. Simulated values and measured data are then compared for a different period of time not used for the model calibration - model validation. Ideally, one would have flow, sediment, and water quality data over several years to calibrate and validate the model. In reality, the data are rarely available and the model is calibrated, validated, or simply verified with what data are available.

Flow data in the Maries River watershed are available at the US Geological Survey flow gauge at Wesphalia from 1948 to 1970. Climate data are available from 1962 to 2004 at the Vienna weather station. The common years between these two sets were from 1962-1970 but 1966 and 1967 climate data were missing and these two years were taken out for the calibration process. As a result, the years 1962-1965 were used for model calibration; the years 1968-1970 were used for model validation.

The base flow separation program described in Arnold et al. (1995) and Arnold and Allen (1999) was run using the complete set of available flow data. This analysis indicated that the base flow represented between 16% and 39% of the total flow. The recession factor (alpha) used by the SWAT model to control return flow was estimated to be 0.0224. This value was used for the model.

Several calibration indicators were used to quantify how well the model reproduced the measured flows. The relative deviations in annual surface and groundwater flow indicate the overall over- or under-prediction of the model. For flow, these should be within 10%. The Nash-Sutcliffe coefficient is based on monthly flow values and indicates whether and how much the model simulates the flow better than the average annual value of the measured data. An acceptable value should be greater than 0.5 while a good value should be greater than 0.7. Table A1 presents the values of these indicators before and after calibration of the model for the Maries River watershed. To improve results during calibration, the following parameters were adjusted: curve number (CN), soil available water capacity (AWC), evaporation compensation factor (ESCO), minimum value for groundwater flow to occur (GWQMN), and re-evaporation coefficient (REVAP). Additional calibration efforts would be necessary to improve the fitness of the model.

Table A1. Calibration criteria for the Maries River watershed

	Total flow deviation	**Base flow deviation**	**Nash-Sutcliffe coefficient**
Initial run: calibration	16%	NA	0.39
Final run: calibration	1.45 %	2.43%	0.54
Final run: validation	25%	20%	0.46

The values of the calibration criteria are acceptable but not as accurate as desired. They also decrease during the validation period. One problem may be due to the use of the 1992 land use map to calibrate a model over the 1960 decade. There is anecdotal evidence that more land was used at that time as cropland and pasture. However, there are no other climate and flow data available and the 1992 land use map is the earliest that was available to us. The analysis was performed with this model.

Appendix B. BMP Simulation

Baseline Scenario

Under the baseline scenario, conventional agricultural practices were used. Cattle were rotated across two summer pastures and one hay field every month. Cows were left in the woodland for protection during the winter. No ponds were included in this scenario due to insufficient information. The baseline and alternative values of the SWAT parameters that were modified to simulate the alternative scenarios are stated in Table B1. The SWAT model requires use of the international system of units.

Table B1. Baseline values of the SWAT parameters selected to simulate the alternative practices proposed in the SALT project.

BMP	Goal	SWAT Parameter		
		Variable (input file)	Initial values	
			Upper Maries	Lower Maries
Grassland improvement	Reduce overland flow	CN (.mgt)	B 73 C 83	B 73 C 83
	Reduce soil erosion	USLE_C (crop.dat)	0.080	0.097
Grazing management	Intensive grazing	Number of pastures (.mgt)	4	4
		Grazing duration (days) (.mgt)	30	30
		BIO_MIN (kg/ha) (.mgt)	200	200
		WMANURE (kg/ha) (.mgt)	14.6	14.6
		BMEAT (kg/ha) (.mgt)	25.8	25.8
		BMTRMP (kg/ha) (.mgt)	25.8	25.8
	Reduce overland flow	CN on pasture (.mgt)	B 73 C 83	B 73 C 83
	Reduce soil erosion	USLE_C (crop.dat)	0.08	0.097

BMP	Goal	SWAT Parameter		
		Variable (input file)	Initial values	
			Upper Maries	Lower Maries
Stream exclusion	Increase channel cover	CH_COV (.rch)	0.30	0.30
	Reduce channel erodibility	CH_EROD (.rch)	0.25	0.25
Woodland exclusion	Reduce erosion	Woodland grazing (.mgt)	Yes	Yes
	Reduce overland flow	CN on woods (.mgt)	B 66 C 77	B 66 C 77
Stream bank stabilization	Increase channel cover	CH_COV (.rch)	0.30	0.30
	Reduce channel erodibility	CH_EROD (.rch)	0.25	0.25
Gully erosion control	Reduce erosion	Pond (.pnd)	No ponds	No ponds

The minimum plant biomass (BIO_MIN) is the minimum biomass below which grazing will not be allowed on that pasture. This parameter was varied according to the condition of the pasture. Pastures in good condition were assumed to have at least 3 inches of grass to allow grazing (700 kg/ha on a dry basis), pastures in poor condition were assumed to have one inch (200 kg/ha on a dry basis). Only pastures in poor condition were assumed to eligible for cost-share. A reduction of the minimum plant biomass (BIO_MIN) to a very low level resulted in an increase in erosion.

The model was set up to reflect the change in the environmental parameters due to changes in management practices. The dry weight of biomass trampled daily (BMTRMP) and dry weight of biomass consumed daily (BMEAT) reflected the amount of the biomass removal or destruction.

More frequent grazing rotations promoted an improvement in grass growth and resulted in an improved ground cover and a decrease in erosion. This effect was simulated by a lower value of the USLE cover factor (USLE_C). Its value ranged from 0.001 to 0.5. The lower value indicated less erosion because of increased residue and soil cover. Since we did not have sediment data to calibrate sediment transport from the watershed, the values of USLE_C used to represent the pasture condition were selected from the literature. The initial values for good, fair, and poor conditions were 0.003, 0.05, and 0.1, respectively.

Other SWAT parameters were the channel cover factor (CH_COV), the channel erodibility factor (CH_EROD), and the runoff curve number (CN).

CH_COV quantifies the amount of vegetation that protects the stream banks. Vegetation reduces the stream velocity, its erosive power and, therefore, the channel degradation. A value of 0.00 indicates a channel completely protected from degradation while the value of 1.0 indicates no vegetative cover. The values for good and poor conditions used in this study were 0.1 and 0.5, respectively.

CH_EROD is set to a value between 0.0 and 1.0. A value of 0.0 indicates a non-erosive channel while a value of 1.0 indicates no resistance to erosion. The initial values used in this study were 0.1 and 0.4 for good and poor conditions, respectively.

CN is the runoff curve number; it is a function of soil permeability, land use, land cover, and hydrologic condition.

SWAT AVS2000 could not explicitly create different land units in each subbasin according to their condition. The input values of parameters that represent the condition of the pasture (CN, USLE_C) were the area weighted averages of the values that correspond to good, fair, and poor conditions. Similarly, AVS2000 allowed only one channel reach per subbasin. A weighted average of the stream bank cover factor was calculated as a function of stream mileage in good condition and in need of treatment. Considering the initial values of the parameters and the condition of the stream miles, the overall CH_COV and CH_EROD for the upper and lower watersheds were 0.30 and 0.25, respectively. The overall USLE_C for pasture was 0.08 and 0.097 for the upper and lower watersheds, respectively. The overall CN for hydrologic soil groups B and C for the pasture land in the upper and the lower watersheds were 73 and 83, respectively. Details of the calculations appear in Appendix C.

Alternative Practices

The alternative conservation practices under the AgNPS-SALT project addressed in this study included grassland improvement, grazing management, stream exclusion, streambank stabilization, woodland exclusion, and gully erosion control.

Grassland Improvement

Grassland improvement included the practices of permanent vegetation establishment (DSL-1), permanent vegetation improvement (DSL-2), permanent vegetation cover enhancement (DSP-2), and permanent vegetation cover-critical areas (DSL-11). The acreages of pasture in the upper and the lower watersheds were 33,568 acres and 26,496 acres, respectively, with 19,815 acres and 25,000 acres, respectively, needing treatment. According to the AgNPS SALT proposals, the acreages of grassland improvement practice proposed in the upper and the lower watersheds totaled 2,080 and 1,115 acres, respectively. The parameters used to simulate the changes in land management were the curve number (CN) to simulate less runoff due to increased water demand by the grass cover and the ground cover factor (USLE_C) to characterize the increased ground cover and the associated decrease in soil erosion.

As explained previously, the parameter values are calculated as area weighted averages of the values that correspond to good, fair, and poor pasture condition. Table B2 details the acreage of pasture in each condition for the baseline, once the SALT project is completed, and in the hypothetical case where all the land needing treatment would be treated. The overall parameter values of CN and USLE_C are given. Details of the calculations appear in Appendix C.

Table B2**.** SWAT parameters for grassland improvement.

	Upper Maries	Lower Maries
Current condition		
Pasture in good condition (acres)	0	0
Pasture in fair condition (acres)	13,753	1,496
Pasture in poor condition (acres)	19,815	25,000
Overall CN soil class B	73	73
Overall CN soil class C	83	83
Overall USLE_C	0.08	0.097
After AgNPS SALT project		
Pasture in good condition (acres)	2,080	1,115
Pasture in fair condition (acres)	13,753	1,496
Pasture in poor condition (acres)	17,735	23,885
Overall CN soil class B	72	73
Overall CN soil class C	82	82
Overall USLE_C	0.074	0.093
All acres needing treatment		
Pasture in good condition (acres)	19,815	25,000
Pasture in fair condition (acres)	13,753	1,496
Pasture in poor condition (acres)	0	0
Overall CN soil class B	62	57
Overall CN soil class C	76	71
Overall USLE_C	0.02	0.006

Grazing Management

Grazing management included grazing system (DSP-3), grazing system w/pond (DSP-33), and grazing system with well. Under the grazing management scenario, shorter more frequent grazing periods at higher grazing intensities were used on the area that required treatment to fertilize the soil and promote grass growth. The impacts were improved grass cover and reduced runoff. The target acreages for the upper and the lower watersheds were 4,200 and 3,000 acres, respectively. Based on percentage ground cover, condition was assumed to improve from poor to good.

The prescribed grazing system was simulated by switching to more intensive grazing management - the number of pastures used was doubled, the duration of grazing on each of them was only two weeks, and the grazing intensity was double the baseline level. This resulted in higher values of WMANURE and BMEAT. However, since the grass is of better quality and cattle are there for a shorter period of time, the grazing efficiency is better and there are less trampling losses.

Because the prescribed grazing scenario is very different from the baseline grazing scenario, it was necessary to assign that scenario to specific HRUs. A distribution of the grazing management scenario across all the HRUs was not possible. We selected HRUs that had the most common soil in the watershed and whose combined area was similar to the target acreages. These areas are pastures on soil MO062 in subbasins 2, 4, 6, 8, 20-22, and 24. A baseline grazing management was assigned to all other grassland areas.

Table B3 details the acreage of pasture in good, fair, and poor conditions in the baseline, once the SALT project is completed, and in the hypothetical case that all acres needing treatment would be treated. In summary, the following parameters were modified for the prescribed grazing HRUs.

- The curve numbers and the USLE cover factor were set to values that characterize good pasture conditions.
- BIO_MIN was set at 700 kg/ha.
- The duration of grazing was halved and the grazing density doubled.
- WMANURE, BMEAT, and BTRMP were set to 29, 51 and 22 kg/ha, respectively, according the grazing density and grazing efficiency.

Table B3. SWAT parameters for grazing management.

	Upper Maries	Lower Maries	Subbasins	Soil Type
Current condition				
Pasture in good condition (acres)	0	0		
Pasture in fair condition (acres)	13,753	1,496		
Pasture in poor condition (acres)	19,815	25,000		
Overall CN soil class B	73	73	All	All
Overall CN soil class C	83	83	All	All
Overall USLE_C	0.08	0.097	All	All
After AgNPS SALT project				
Pasture in good condition (prescribed grazing acres)	4,200	3,000	2,4,6,8,20,21,22,24	MO062
Pasture in fair condition (acres)	13,753	1,496		
Pasture in poor condition (acres)	15,615	22,000		
Overall CN soil class B	73	73		
Overall CN soil class C	83	83		
CN soil class C-prescribed grazing	74	71	2,4,6,8,20,21,22,24	MO062
Overall USLE_C	0.08	0.097		
USLE_C for prescribed grazing	0.003	0.003	2,4,6,8,20,21,22,24	MO062
All acres needing treatment				
Pasture in good condition (prescribed grazing acres)	19,815	25,000		
Pasture in fair condition (acres)	13,753	1,496		
Pasture in poor condition (acres)	0	0		
USLE_C for prescribed grazing	0.003	0.003	All	MO062
USLE_C for fair conditions	0.05	0.05	All	Other than MO062
CN on prescribed grazing	74	71	All	MO062
CN soil class B on fair condition	67	64	All	Other than MO062
CN soil class C on fair condition	79	76	All	Other than MO062

Stream Exclusion

The stream exclusion practice included riparian forest buffer (N391), use exclusion (N472), and alternative watering system (C050). The target acreages were 250 and 400 acres for the upper and the lower watersheds, respectively. The targeted acreages were converted into the length based on a 100-foot buffer width; the calculated total length of the buffers was 54 miles for the upper (21 miles) and the lower (33 miles) watersheds.

When the cattle have access to streams, they can cause stream bank degradation and deposit manure directly into the water. The sediment reduction due to stream exclusion was simulated by decreasing the bank erodibility (CH_EROD) and increasing its vegetation cover (CH_COV). To address the nutrient reductions, the information on deposits of cow manure directly into the water was required. However, such information was not available. Nutrient reduction due to stream exclusion, therefore, was not simulated.

CH_COV and CH_EROD. To estimate the overall CH_COV and CH_EROD, the 54 target stream miles in AgNPS-SALT were taken into account. The initial values of good and poor conditions of CH_COV used in this study were 0.1 and 0.5, respectively. For CH_EROD, the initial values used for good and poor conditions were 0.1 and 0.5, respectively. Details of the calculations appear in Appendix C. Table B4 summarizes the stream miles in each condition and the resulting bank cover and bank erodibility factors.

Table B4. SWAT parameters for stream exclusion

	Upper Maries	Lower Maries
Current condition		
Stream miles in good condition	157	140
Stream miles in poor condition	158	139
Overall CH_COV	0.30	0.30
Overall CH_EROD	0.25	0.25
After AgNPS SALT project		
Stream miles in good condition	178	173
Stream miles in poor condition	137	106
Overall CH_COV	0.27	0.25
Overall CH_EROD	0.23	0.21
All acres needing treatment		
Stream miles in good condition	315	279
Stream miles in poor condition	0	0
Overall CH_COV	0.10	0.10
Overall CH_EROD	0.10	0.10

Woodland Exclusion

To protect the woodland acres that are susceptible to erosion, cattle which are usually left in the forest during the winter would be permanently removed from the woodland. The target length of fence to keep the cattle out of the woodlands in the upper and lower watersheds were 28,000 feet, and 12,000 feet, respectively. These amounts of fencing could protect the woodland of 700 acres (2.8 km^2), and 300 acres (1.2 km^2), respectively (Sandy Hutchison, personal communication; Table B5).

Since the woodland fencing could not be distributed throughout the watershed, we selected the wooded HRUs in the lower and the upper watersheds whose combined acres were similar to the goal for this practice and it was assumed that all the treated woodland would be located in that HRU. The HRU of woodland of soil MO062 from subbasin 23 (2.7 km^2 or 667 acres) and subbasin 25 (1.9 km^2 or 469 acres) were chosen as the representative areas for the upper and the lower Maries watersheds, respectively (Table B5).

CN: The CN values of non-grazing woodland were set to good condition at 55 and 70 for soil classes B and C, respectively. When cows were left in the woodland and grazing was allowed, the CNs of soil classes B and C were set to the poor condition at 66 and 77, respectively.

Table B5. SWAT parameters for woodland exclusion.

	Upper Maries	Lower Maries	Subbasins	Soil Type
Current condition				
Woodland in good condition (acres)	0	0		
Woodland in fair condition (acres)	9,394	10,954	10, 12-15, 24	All
Woodland in poor condition (acres)	18,234	27,400	1-9, 11, 16-23, 25	All
After AgNPS SALT project				
Target in AgNPS SALT (feet)	28,000	12,000		
- Estimation in acres	700	300		
Fenced woodland in good condition (acres)	700	300	23, 25	MO062
Woodland in fair condition (acres)	9,394	10,954	10, 12-15, 24	All
Woodland in poor condition (acres)	17,534	27,100	1-9, 11, 16-22, 23, 25	All but not MO062 in 23 and 25
All acres needing treatment				
Fenced woodland in good condition (acres)	18,234	27,400	1-9, 11, 16-22, 23, 25	All
Woodland in fair condition (acres)	9,394	10,954	10, 12-15, 24	All
Woodland in poor condition (acres)	0	0		

Stream Bank Stabilization

The purpose of stream bank stabilization is to protect the stream banks from accelerated erosion, provide adequate stream bank vegetation, and improve water quality in the watershed.

CH_COV and CH_EROD: The target lengths for stream bank stabilization (C650) were 4,000 feet for the upper watershed and 6,000 feet for the lower watershed, for a combined length of 1.9 miles. The overall CH_COV and CH_EROD for this practice were 0.30 and 0.25, respectively, which was the same as the baseline. The small treated length (1.9 miles) compared to the 297 stream miles needing treatment explains why the overall values of CH_COV and CH_EROD were not different from the baseline (Table B6). Details of the calculations appear in Appendix C.

Table B6. SWAT parameters for stream bank stabilization.

	Upper Maries	Lower Maries
Current condition		
Stream miles in good condition	157	140
Stream miles in poor condition	158	139
Overall CH_COV	0.30	0.30
Overall CH_EROD	0.25	0.25
After AgNPS SALT project		
Stream miles in good condition	157.76	141.14
Stream miles in poor condition	157.24	137.86
Overall CH_COV	0.30	0.30
Overall CH_EROD	0.25	0.25
All acres needing treatment		
Stream miles in good condition	315	279
Stream miles in poor condition	0	0
Overall CH_COV	0.10	0.10
Overall CH_EROD	0.10	0.10

Gully Erosion Control

Twenty-five ponds are projected for construction in the upper watershed. Ponds are constructed to trap sediment from the gully erosion runoff to the stream. Ponds would be constructed in each subbasin of the upper watershed where this practice was implemented. While a pond is typically installed where there is gully erosion, in the SWAT AVS2000 ponds are placed in the subbasin, they are not associated with a specific land use. Gully erosion was considered as being problematic, but it was not specified in the baseline.

Each pond has an average surface area of 1 acre or less with a depth of 10 feet (Sandy Hutchison, personal communication). The total surface area of ponds in the upper watershed was 20 acres. Each acre of water surface drained from 10-30 acres, 20 acres on average. With 20 acres of water surface, the total area drained into these ponds was 400 acres. The 20 acres of total pond water surface were assigned to all subbasins located in the upper watershed proportionally to the area of each subbasin. The values of PND_FR (fraction of subbasin area that drains into ponds), PND_PSA (surface area of ponds when filled with the principal spillway), and PND_POVL (volume of water stored in ponds when filled to the principal spillway) were assigned, while the other coefficients of pond simulation were left as default values.

Combined BMPs Scenario

All of the BMPs mentioned above were included in the combined BMP scenario. The parameter specifications of this scenario were as follows.

1. The overall CH_COV and CH_EROD were 0.27 and 0.23, respectively, for the upper watershed; they were 0.25 and 0. 21, respectively, for the lower watershed.
2. The overall USLE_C factors for pasture were 0.074 and 0.093, respectively, for the upper and the lower watersheds.
3. The overall CN of soil B and C for the pasture and hay land under fair condition of the upper watershed were 72 and 82, respectively, and 73 and 82, respectively, for the lower watershed.
4. The CN for the HRUs that were assigned to prescribed grazing management (Table B3) were set in good condition of 74 and 71 for soil class B and C, respectively. The USLE_C was set to 0.003 (good ground cover).

5. Grazing was not allowed in some acres of woodland (Table B5).

6. Twenty-five ponds were added in the upper watershed.

Appendix C. Calculation of weighted average

Curve Number (CN)

- To estimate the CN, the information on hydrologic soil groups, total acres, acres needing treatment, and target treated acres were required. For the upper and the lower watersheds, most soils were in the hydrologic soil groups C and B. The overall CN can be calculated as:

$$OCN^{Base} = [(TA - NT)* CN_i^{Fair} + NT * CN_i^{Poor}]/ TA$$

$$OCN^{BMP} = [(TA - NT)* CN_i^{Fair} + (NT - AgT)* CN_i^{Poor} + AgT* CN_i^{Good}]/ TA$$

Where: CN_i^j = CN of hydrology soil group i, (i = A, B, C, or D) under soil condition, j (j = good, fair, poor);

TA = total acreage (i.e., total grassland in the watershed);

NT = acreage needing treatment (i.e., grassland needing treatment);

AgT = target acres treated under AgNPS SALT program;

OCN^{Base} = overall CN for the baseline scenario;

OCN^{BMP} = overall CN for the BMP scenario.

The CN of good, fair, and poor conditions were adjusted using the information in the SWAT manual. On pasture land, the CN values for soil class B under poor, fair, and good conditions are 83, 73, and 65, respectively. While the CN values for soil class C under poor, fair, and good conditions are 90, 83, and 78, respectively.

Ground Cover Factor (USLE_C)

- USLE_C baseline was estimated by taking into account the acres needing treatment. The values were 0.003, 0.05, and 0.10 for good, fair, and poor conditions, respectively. The overall USLE_C can be calculated as:

$$USLE\_C^{base} = [(TA-NT)*0.05 + NT*0.10]/TA$$

$$USLE\_C^{BMP} = [(TA-NT)*0.05 + (NT-AgT)*0.10 + AgT*0.003]/TA$$

Where: TA = total acreages (i.e. total grassland in the watershed);

NT = acreages needing treatment (i.e. grassland needing treatment); and

AgT = target acres treated under AgNPS SALT project;

Channel cover factor (CH_COV)

- The overall CH_COV was estimated according to the length of the treated stream. The initial values of 0.1 and 0.5 represented good and poor conditions, respectively.

$$CH\_COV^{base} = [SNT*0.5+(STL-SNT)*0.1]/STL$$

$$CH\_COV^{BMP} = [(SNT-SAgT)*0.5+(STL-SNT+SAgT)* 0.1]/STL$$

Where: STL = total stream length;

SNT = stream length needing treatment; and

SAgT = target stream length to get treatment under AgNPS-SALT.

Channel erodibility factor (CH_EROD)

- The overall CH_EROD was calculated using a similar approach as CH_COV. The initial values of CH_EROD for good and poor conditions were 0.1 and 0.4, respectively.