MIAMI CREEK WATERSHED
WATER QUALITY ANALYSIS

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EXECUTIVE SUMMARY

Rural water supplies are at risk of contamination from agricultural chemicals and sediment, as well as from non-agricultural sources. The US Environmental Protection Agency (EPA) funded the Missouri Water Quality Initiative as a means of developing a watershed evaluation and planning process that reviews the main non-point sources of water quality degradation in a watershed. The Food and Agricultural Policy Research Institute at the University of Missouri (FAPRI), with significant input from the local community, has developed this analysis defining how current agricultural practices in the Miami Creek Watershed affect water quality. The intent is to provide local producers and planners the information for making decisions with respect to protecting their drinking water supply.

FAPRI, in conjunction with the USDA Natural Resources Conservation Service (NRCS) and other local sources of information, identified soils and production practices that are common to the watershed. These were used to assess the sources of sediments, atrazine, and nutrients. A watershed scale computer simulation model was built to identify the relative contributions of sediment, nutrients, and atrazine from the subbasins and land uses in the watershed.

The highest estimated erosion rates came from the subbasins that have the most cropland, and more specifically the most corn. Sediment yields from cropland averaged 2 to 9 t/a/yr. Grassland erosion rates were negligible. For the most part, these sediments were deposited in the flatter channels of the watershed and the resulting annual sediment yield for the entire watershed averaged 0.75 t/a. However, the annual variability of sediment yields was high as annual sediment values varied between 0.125 t/a and 2 t/a.

Estimated atrazine loss ranged from 2 to 40%, with an average loss of 10%. Atrazine concentrations were highest during the month of April when the pesticide is sprayed and spring precipitations occur. The model showed that daily concentrations of atrazine in Miami Creek reach values above 70 ppb each year one day in April. Estimated May concentrations also reach these high values, although not as often as in April.

The model showed that nitrogen losses come from cropland and pastures. Because estimated sediment losses from grassland are very small, pastures contributed nitrogen mostly in the dissolved nitrate form. Estimated nitrogen losses from cropland were in the form of nitrates and organic nitrogen associated with sediments. The model outputs indicated that the subbasins with the most cropland and/or pastures contribute the highest nitrogen yields. Cropland contributed to the phosphorus load mostly because of erosion. Very little runoff phosphorus came from grassland.

Four alternatives to the baseline production practices were investigated. Removing field cultivation does not appear to have any significant impact on runoff or erosion. Replacing disc operations by field cultivation does demonstrate reduced erosion and nutrient loads. Adopting no-till practices for soybeans, wheat, and corn does significantly reduce the erosion rates and, therefore, the nutrient loads. It should be strongly pointed out however, that the results show considerable variability across years due to different weather events. The field cultivation replacement for the disc operation, for example, while giving a noticeable reduction in erosion and nutrient loads, was well within the year-to-year weather induced fluctuations. In the end, the shift to no-till operations was the only alternatives that significantly lowered erosion rates.

The adoption of no-till practices for corn also meant using Roundup Ready™ corn and using Roundup instead of atrazine to control the weeds. The alternative therefore resulted in no atrazine being used in the watershed, and no atrazine being found in the streams. Estimated Roundup concentrations increase when no-till practices are implemented but remain low.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Introduction

The Miami Creek watershed above the confluence with Mound Branch is a 124 square mile watershed (80 000 acres) located in the northwest corner of Bates County in western central Missouri. A small portion of it lies in the southwest corner of Miami County in Kansas. It is approximately 17 miles long. U.S. Highway 71 and Missouri Highways 18 and 52 provide access to the watershed. Miami Creek and its tributaries flow in a southeasterly direction to the Marais des Cygnes River, Osage River and eventually into the Truman reservoir. The watershed is located in the Cherokee Prairie Area, Major Land Resource Area (MLRA) 112, detailed in Appendix A.

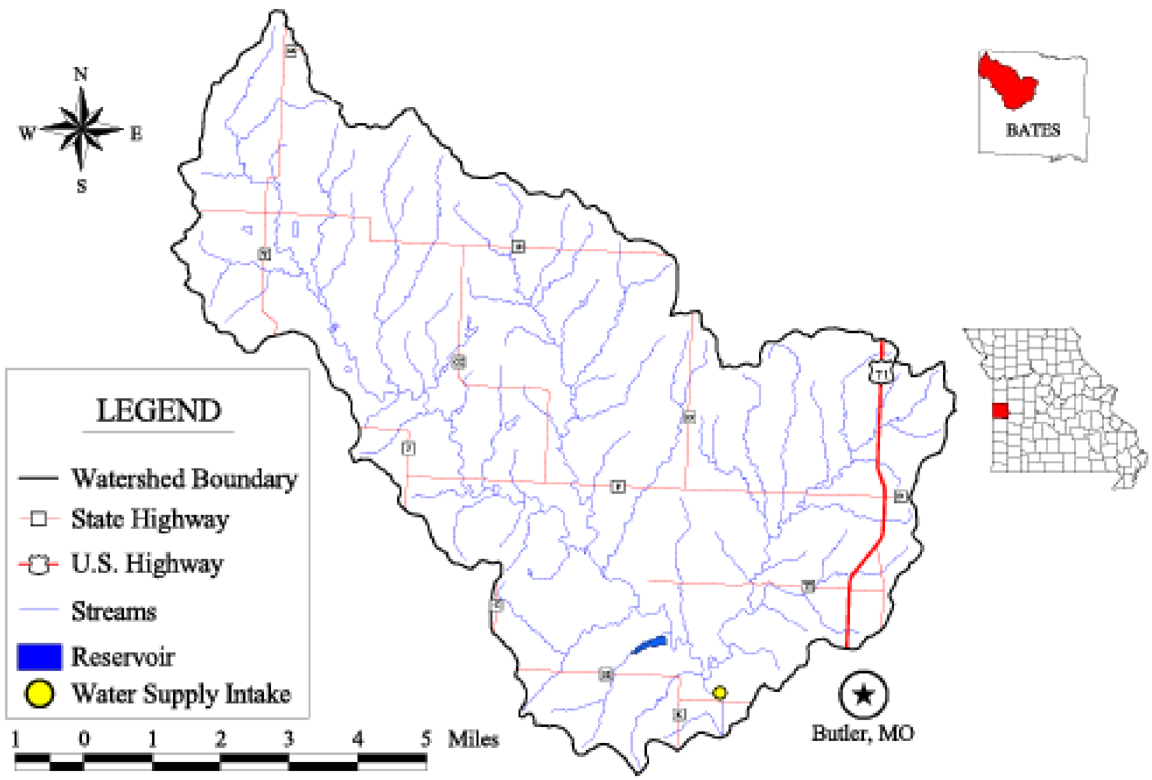

Figure 1. Location map of the Miami Creek Watershed above Mound Branch

The city of Butler, located north of the watershed outlet, and five rural water districts use water from Miami Creek as their primary water supply. Historically, this intake is used 60 to 65 % of the time (Bates County Soil and Water Conservation District, 1998). Butler Lake provides water for another 20-25% of the time. During dry summer conditions (10-20% of the time), water is pumped out of the Marais des Cygnes River, located south of the watershed. The water is treated at a treatment plant at the Miami Creek water intake before being distributed. Miami Creek is the largest source of drinking water supply for the city of Butler and five other rural water districts. Following publication of a news article that reported the presence of atrazine - an herbicide that controls weeds in corn and sorghum fields -in the water supply, atrazine became a concern to the local community, and the Bates County Soil and Water Conservation District (BCSWCD) initiated a watershed resource assessment and planning project.

The watershed is primarily agricultural with cropland, grassland and forest. It includes several hog, beef, and dairy confinement operations. However, the majority of animals living in the watershed graze freely on pasture and have unrestricted access to the creek.

This study is intended to estimate when and how much pollution by pesticides and nutrients occurs, the source of the pesticides and nutrients, and the impact of alternative management practices implemented at the watershed level on the water quality of Miami Creek. It relies on the development of a computer simulation model to determine the current (baseline) water characteristics in the stream and the impacts of the proposed management changes. This report presents the results concerning the analysis of the present practices and different alternatives at the watershed level. A separate report presents the environmental assessment results at the farm level (Lansford, 2000). A final report will include both analyses as well as the economical assessment results at the farm level.

Study area

Soils

The soils of Miami Creek watershed are predominantly of the Kenoma-Hartwell-Deepwater association (Figure 2), which is a very deep, nearly level to gently sloping, moderately well drained and somewhat poorly drained soil that formed in parent material weathered from shale. Kenoma and Hartwell soils cover about 56% and 20%, respectively, of the watershed cropland and are considered the dominant cropland soils in this study. Kenoma soils cover 47% of the watershed grassland. Other dominant grassland soils in the watershed include Deepwater, Bates, Summit and Balltown. Verdigris soils are mostly found in channels and bottom slopes around 1%, and are associated with woodland, and generally located along the river channels.

Kenoma silt loams are found on upland ridge tops and side slopes between 1 and 4%. This soil has a very slow permeability, a moderate available water capacity and organic matter content, and is in the hydrologic group D. Its capacity to induce runoff is rated as medium. The soil is suited for corn, soybeans, and small grains, but erosion remains a hazard. Well managed pasture and hay crops help reduce soil erosion.

Hartwell silt loams are found on broad upland divides, on slopes between 0 and 2%. This soil has a slow permeability and a high available water capacity that make it easily wet and limit its suitability for grazing. A seasonal perched water table at a depth of 0.5 to 1.5 feet (15 to 45 cm) exists from November through April. This soil is well suited for hay crops, both for fescue and warm season grasses, and is in the hydrologic group D.

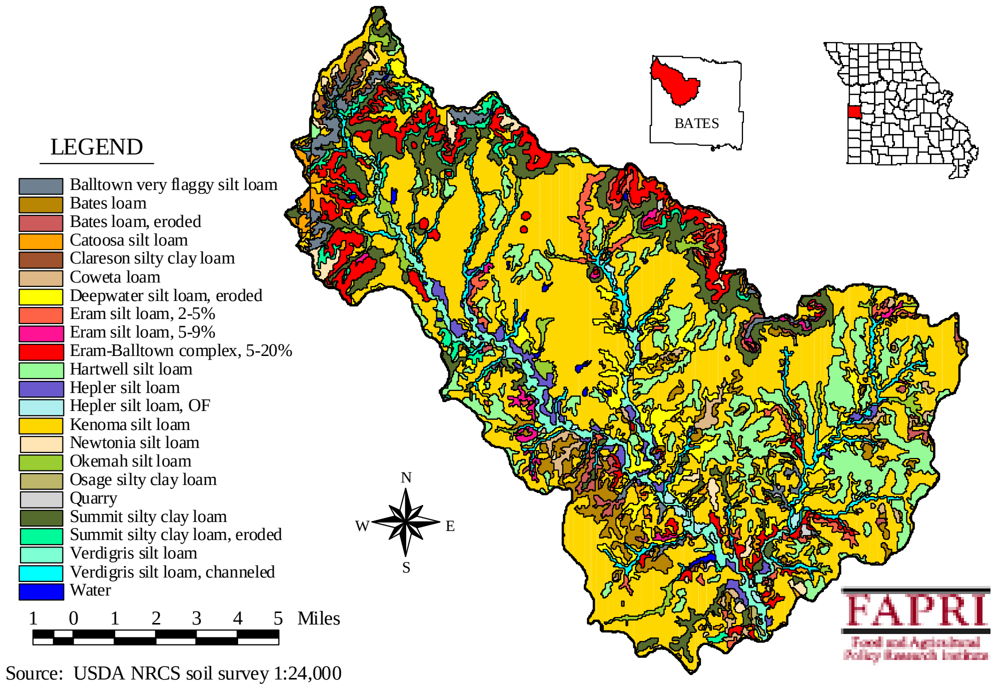

Figure 2. Soils distribution map of the Miami Creek Watershed.

For modeling purposes, the Miami Creek watershed was divided in ten (10) subbasins (Figure 3). A Geographic Information System (GIS) was used to select predominant soils for each land use in each subbasin. Table 1 shows the resulting soil distribution used in the model.

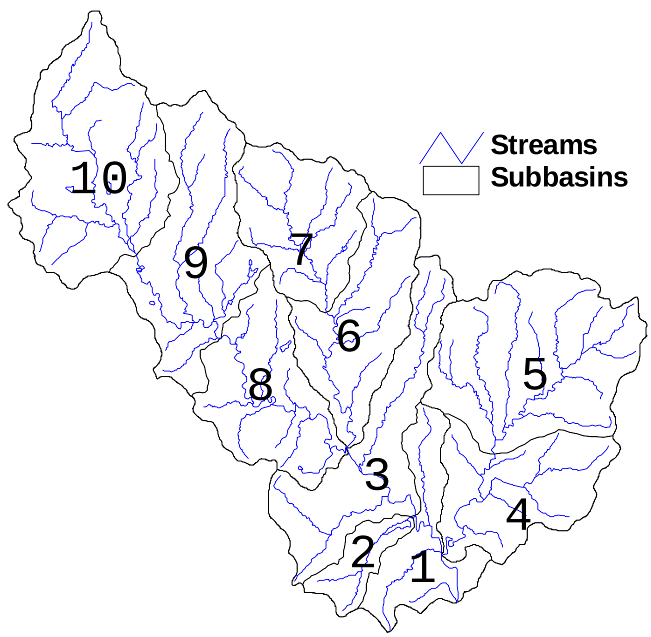

Figure 3. Miami Creek Watershed subbasins.

Table 1. Soils distribution used in the model by land use in each subbasin.

Subbasin	*Cropland*	*%*	*Grassland*	*%*	*Forest*
1	Kenoma silt loam Hartwell silt loam	58 % 42 %	Kenoma silt loam	100 %	Verdigris silt loam
2	Kenoma silt loam	100 %	Kenoma silt loam	100 %	Verdigris silt loam
3	Kenoma silt loam Hartwell silt loam	56 % 44 %	Kenoma silt loam	100 %	Verdigris silt loam
4	Kenoma silt loam Hartwell silt loam	64 % 36 %	Kenoma silt loam Hartwell silt loam	74 % 26 %	Verdigris silt loam
5	Kenoma silt loam Hartwell silt loam	78 % 22 %	Kenoma silt loam Hartwell silt loam	75 % 25 %	Verdigris silt loam
6	Kenoma silt loam Hartwell silt loam	86 % 14 %	Kenoma silt loam Deepwater silt loam, Eroded	64 % 36 %	Verdigris silt loam
7	Kenoma silt loam Hartwell silt loam	55 % 45 %	Kenoma silt loam	100 %	Verdigris silt loam
8	Kenoma silt loam Hartwell silt loam	83 % 17 %	Kenoma silt loam Bates loam	65 % 35 %	Verdigris silt loam
9	Kenoma silt loam Hartwell silt loam	66 % 34 %	Kenoma silt loam	100 %	Verdigris silt loam
10	Kenoma silt loam Hartwell silt loam	77 % 23 %	Kenoma silt loam Summit silty clay loam Balltown very flaggy silt loam	32 % 41 % 27 %	Verdigris silt loam

Land Use

Land use distribution

Land use distribution in Miami Creek Watershed was determined using various sources. The analysis of 1992 satellite imagery (Figure 4) gave a global view of the watershed land uses using four major categories: cropland, grassland, forest, and water. Table 2 presents the results aggregated in the four main land use groups. The grassland designation (66%) includes hay (15%), pasture (36%), and land enrolled in the Conservation Reserve Program (CRP) (15%). Hay and CRP land, which are sometimes considered cropland, behave more like grassland in terms of runoff, erosion, and nutrient loads and have been left in this class.

As an indication of how land use might have changed since 1992 in Miami Creek Watershed, the Bates county statistics (Missouri Agricultural Statistics Service) show a 12% increase of cropland from 1992 to 1997, mostly caused by a 40% increase in soybeans acreage. Corn, hay, and wheat acreage remained similar.

In order to use a land distribution that better reflects the current land uses in the watershed, 1997 farm history records were analyzed. These records specify for each tract of land that is reported, the type of agricultural use: CRP, hay, pasture, or crop including the specific crop being grown on that tract. Total amounts of the different categories were derived for each subbasin. Since not all tracts of land are reported, the results were adjusted to reflect the total area of the watershed. Forest and water acreage was estimated using the 1992 satellite imagery and was supposed to have remained constant between 1992 and 1997.

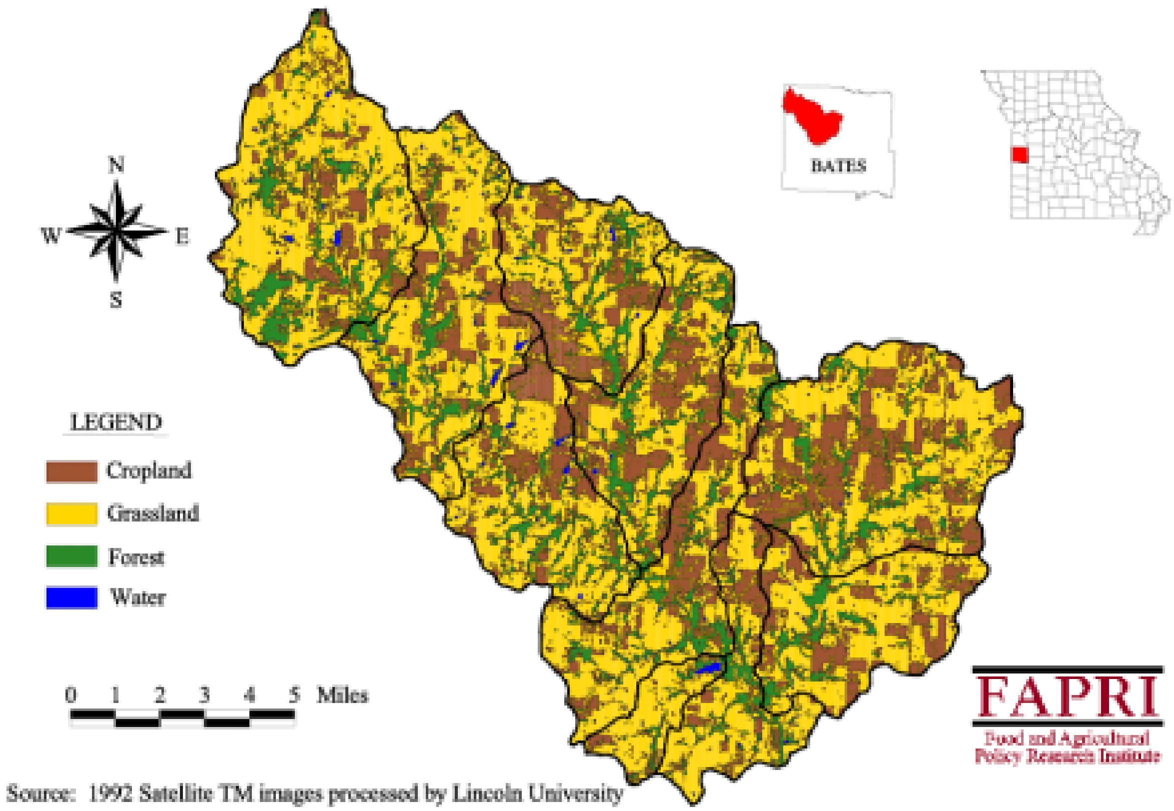

Figure 4. Land use distribution map of the Miami Creek Watershed

Table 2. Land use distribution in Miami Creek Watershed.

Land Use	Acres	% Area
Cropland	18,378	23
Grassland	53,377	66
Forest	8,410	11
Water	352	< 1
Total	80,517	100

Note: Based on 1992 satellite imagery.

Management

The crops grown in the Miami Creek watershed are predominantly corn, wheat and soybeans, with some double cropped soybeans following winter wheat. Sorghum was not included in this assessment because of its relatively small acreage in the watershed. Because of the similarity between corn and sorghum management, sorghum acreage was incorporated into the corn acreage. All the rotations found in the watershed were grouped into seven representative rotations:

1. Soybeans – Wheat
2. Continuous Corn
3. Corn – Soybeans
4. Corn – Soybeans – Soybeans
5. Corn – Soybeans –Wheat
6. Corn – Soybeans – Wheat – Double crop soybeans
7. Corn – Wheat – Double crop soybeans – Corn

The description and timing of tillage operations, as well as fertilizer and pesticide applications are detailed in Appendix B for each of these rotations. The rotations amount to 29% of cropland being in corn, 29% in wheat and 42% in soybeans. Approximately 2370 acres, 45%, of the wheat acres are double cropped with soybeans. Figure 5 shows the land use distribution in each subbasin. Subbasins 5 and 6 have the largest percent of row crops and subbasins 1, 2, and 10 have the highest proportion of grassland and forest.

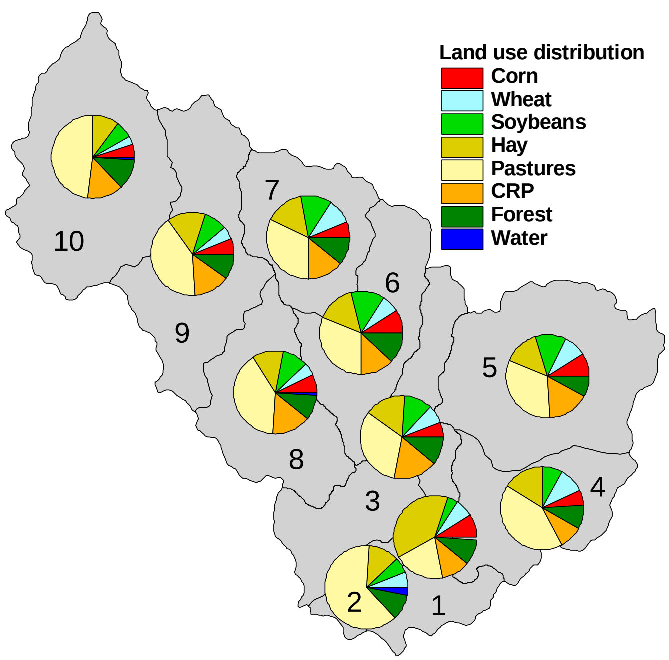

Figure 5. Subbasin land use distribution in the Miami Creek Watershed

As mentioned earlier, the production of soybeans has increased in Bates County from 1992 to 1997 and keeps increasing in 1998, 1999 and 2000 (MASS, 2000). The acreage of other crops remained stable and it seems that the additional soybeans acreage has been planted at the expense of pasture acres. Grazing livestock (beef cattle) has also increased by 10% between 1992 and 1997.

Livestock in the Miami Creek Watershed include cattle, dairy, hogs, and a few horses. In order to simplify the model, and since the majority of it is cattle, we have averaged the animal weight and the waste production over the whole watershed. As will be seen later in the report, the problems come mainly from cropland and would not be sensitive to a greater detail of the livestock distribution in the watershed. Even though several confined animal feeding operations (CAFO) exist in the watershed, those were not considered in this study in an effort to gain maximum cooperation from the watershed stakeholders and not point the finger directly at anyone.

The cattle roam freely through the pastures year-round. Whatever is not grazed is used as hay and harvested in late April if time permits and again in late August. Rotational grazing is being demonstrated on a few farms, but the practice is not implemented on a scale large enough to impact the water quality. Although cattle are generally allowed access to the creek, this model does not simulate it and the amounts of nutrients calculated by the model do not reflect this direct input to the water. Considering the type and total number of livestock grazing in the watershed, the grazing density averages a little less than 1 animal per acre, which represents approximately a deposit of dry manure of 5 lbs/acre/day.

Weather

Measured daily weather data from the Butler weather station was used for this simulation. Pat Guinan at the Missouri Climate Center at the University of Missouri Department of Soil and Atmospheric Science provided official daily temperatures and precipitations recorded at the station. Monthly statistical characteristics for precipitation and temperatures in Butler were used to fill in any missing data. Average monthly radiation, wind speed, dew point and humidity data were obtained from the Appleton City weather station because such parameters are not available in Butler. Appleton City is located 17 miles (27 km) east of Butler.

Methodology

Process

The methodology relies on a mathematical computer simulation model that calculates sediment, nutrient, and pesticide loads at the outlet of the watershed or any of the subbasins. The purpose of using a model is to establish water quality baseline characteristics resulting from current management practices whenever there is no or limited monitoring data. The watershed is divided into subbasins, further sub-divided into nearly homogeneous units that have a distinct land use, soil type, and management practice. The analysis of the subbasin results indicates areas in the watershed that may contribute most to pesticide, nutrient, and sediment problems in Miami Creek. Furthermore, the model is used to evaluate the potential changes in environmental impacts if the farmers adopt changes in their management practices.

The environmental model used in this study is the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998). SWAT simulates many of the physical processes that impact water quality. The evaluation of the current and proposed management practices is based on the calculated values of water, sediments, and chemical yields on a daily, monthly, or annual basis.

This model requires considerable inputs, some readily available with the use of the GIS technology (elevations, soils, slopes, land use) and some specific to the area and not readily known (crop rotations, crop management practices, manure management practices, grazing practices). A local steering committee helped determine the area specific inputs to this model. Additional watershed inputs came from other agencies, mainly the Natural Resources Conservation Service (NRCS), the Farm Service Agency (FSA), the Bates County Soil and Water Conservation District (BCSWCD), and the Missouri Agricultural Statistics Service (MASS). To validate the input given to the model, calculated values for crop yield, surface runoff, sediment yields, and agricultural chemicals movement were compared to available measured values or estimated amounts.

Watershed Model

The SWAT model is a physically based computer simulation model developed with funds from the USDA Agricultural Research Service and the Texas Agricultural Experimental Station at the Blackland Research Center. SWAT can be used whenever measured water quality indicators are unavailable and/or to obtain long-term characteristics of these indicators and crop yields. Its primary use is to assess the water quality of a watershed and estimate the impacts of alternative management practices on crop yields and water quality. The inputs of the model are the physical description of the watershed (topography, soils, and hydraulic characteristics of the drainage) and the management practices for the watershed. The model uses daily rainfall and temperature as the driving force and calculates flow values, sediment, nutrient and pesticide yields and concentrations, as well as crop yields. The program includes the equations that represent the physical processes that control water movement, sediment erosion and transport, crop growth, nutrient cycling and transport, chemical transport, and other processes on a daily time step. The model output allows the analysis of water quality at the outlet of each subbasin of the watershed as well as in reservoirs on a daily, monthly, or annual basis.

Model Validation

The model depicting the current condition of the watershed accounts for the physical properties of the watershed (soils, climate, stream channel data, reservoir data) and the 1998 farming practices. Given the lack of flow and water quality data from the watershed, we could not perform a proper model calibration and validation. Instead we will show that the results are credible and that the various sources of information in or near the watershed give them some strength. There is no plan at this point for collecting flow and / or water quality data, in addition to what is currently collected by the NRCS.

Model assumptions and limitations

In order to facilitate the watershed modeling process, several assumptions were made about the watershed. These assumptions, which have an impact on the outcome of the model, are listed below.

1. Measured daily rainfall and temperature data from the official weather station in Butler, Missouri is representative of the daily weather in the watershed. This assumption is rather acceptable since Butler is located 1.5 mile east of the watershed boundary.

However, the localized nature of convective summer events can introduce some errors in the model's results compared to measured variables.

2. In each subbasin, the properties of the "predominant" soils for each land use describe the soil characteristics for that soil-land use association.

3. Crop management operations (tillage, pesticide application, nutrient application, planting, and harvest) are defined by fixed dates. The model does not modify these dates based on precipitation events.

4. Crop management in the watershed is predominantly minimum till (30% residue) with rows up and down the hill. Winter wheat and double-cropped soybeans are drilled.

Crop yields

Average crop yields reported by the Missouri Agricultural Statistics Service (MASS) for Bates County from 1991 to 1999 are listed in Table 3. Since yields statistics are not available for the Miami Creek watershed, we compared MASS county yields to the average yields calculated by the model. In order to compare yields resulting from management practices not too different from what is assumed in the model, we limited the comparison period to the last eight years, 1991 to 1999. Average calculated yields are also listed in Table 3. Model yields do not capture pest damage, weed competition, or the impossibility of planting due to wet weather and therefore tend to be higher than measured yields. This is especially true for the soybean yields, which were over-predicted by 80% and 70% in 1993 and 1995, respectively, which had wet springs during which the soybeans growth was affected by excess moisture and lack of soil aeration.

Table 3. Comparison of county wide and calculated average crop yields (1991-1999).

	Corn (bushels/acre)	Soybeans (bushels/acre)	Wheat (bushels/acre)
Average yield (MASS)	93.4	31.2	43.4
Average yield (calculated by SWAT)	101.8	39.1	49.3
Percent difference	9 %	22 %	13 %

Figure 6 shows the differences year by year between the yields calculated by the model and the reported yields between 1991 and 1999. Although it would be possible to evaluate the impacts of weed competition, pest damage, and/or lack of aeration on nitrogen and water uptake, residues left on the ground, and crop yields with field and farm scale models such as EPIC or APEX, such work would be beyond the scope of this analysis.

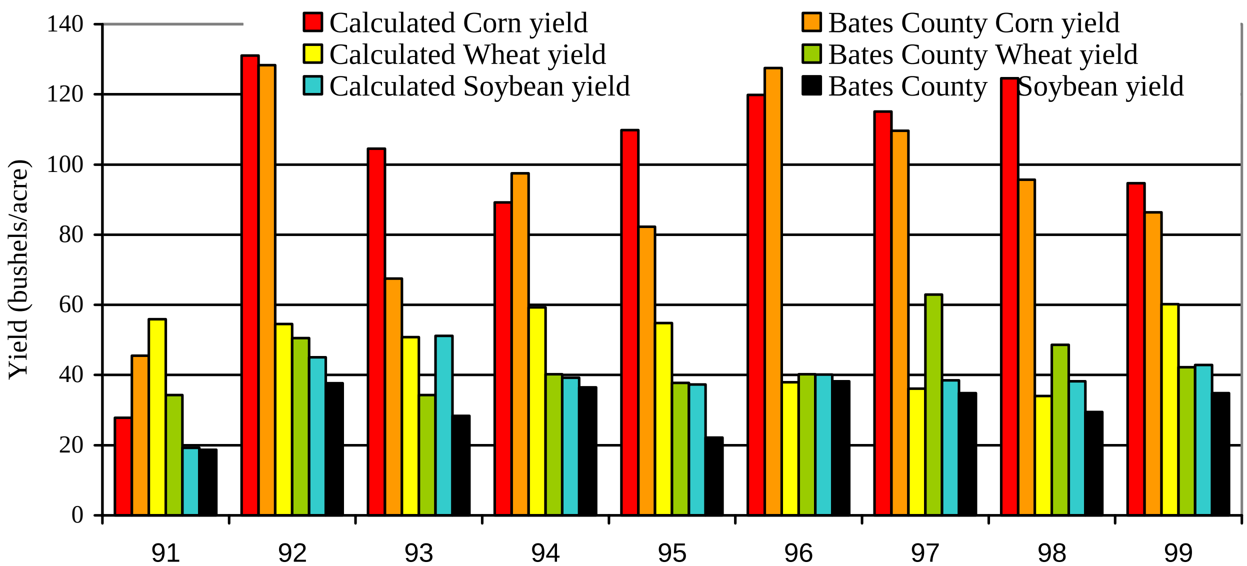

Figure 6. Calculated and reported crop yields between 1991 and 1999.

Surface runoff

On any wet day, surface runoff is estimated in the model using a modification of the curve number method. The method includes a provision for estimating runoff from frozen soils. Mathematical formulations that represent percolation, lateral subsurface flow, groundwater flow, and plant water uptake are combined with the basic conservation of mass equation to arrive at the estimations of return flow, soil water content, evaporation, and evapotranspiration. Daily flow values are estimated using a modification of the rational formula that includes a stochastic component to estimate the rainfall intensity.

Measured daily rainfall and temperatures from the Butler weather station were used in this study. Based on the data from 1979 to 1999, the average annual precipitation is 43.2 inches, more than the long-term average of 38 inches indicated in the report on Surface Water Resources of Missouri, (MDNR, 1995). On an average annual basis between 1979 and 1999, the model estimated a surface runoff of 8.4 inches, a return flow of 1.5 inches for a total runoff of 9.9 inches. There is no record of any flow measurement in Miami Creek but the regional estimates given in the Surface Water Resources Report indicate an average annual total runoff of 8 inches. Given the difference in average annual precipitation, these numbers appear reasonable.

Flow gauges exist on the Osage River above Shell City and on the South Grand River near Clinton, in Henry County. When comparing Miami Creek calculated daily flow values to those measured at the stations on the Osage and South Grand River, results appear reasonable (Figure 7): the peak flows correspond for the three rivers, and the durations of the peaks reflect the size of the drainage areas at each point. A smaller drainage area produces smaller peaks and the flow returns to base flow faster (Viessman et al., 1977). The drainage area of the Osage River above Shell City is 5,410 square miles, and the drainage area of the South Grand River near Clinton is 1270 square miles or about ten times the size of the Miami Creek watershed. A plot of the drainage area versus the average annual flow on a logarithmic scale shows that the three points that correspond to the three watersheds are in alignment, a result that gives strength to our results (Figure 8).

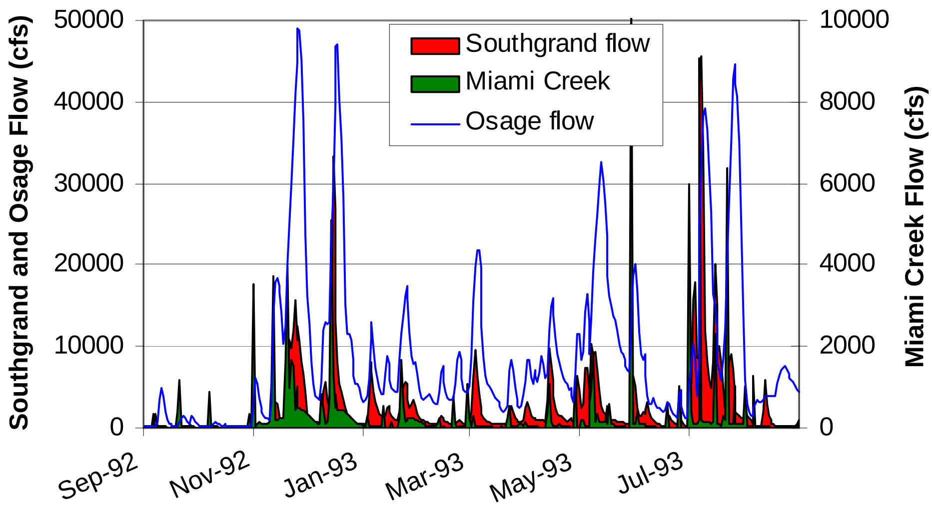

Figure 7. Comparison of the flow patterns of the Osage River and South Grand River with the calculated Miami Creek flows from September 1992 to August 1993.

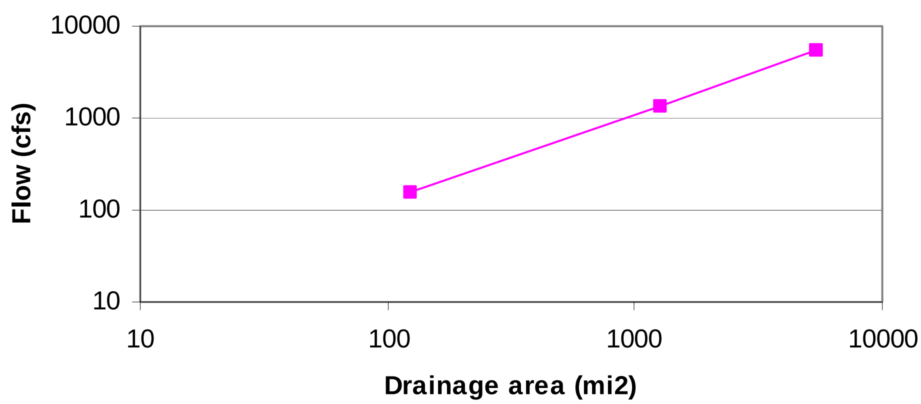

Figure 8. Relationship between the drainage area and the average annual flow for Osage River, South Grand River, and Miami Creek Watersheds.

Soil erosion

The soil erosion calculated by the model is based on the Universal Soil Loss Equation (USLE) (Wishmeier and Smith, 1978), and estimates the amount of soil movement from a field slope, which may then be deposited in other places such as a terrace channel, depression, or a flat or vegetated area before it enters a stream channel. The SWAT model actually uses a modification of USLE to calculate erosion on a daily basis as opposed to an annual basis. Thus the seasonal variability of the precipitation is implicitly taken into account. Annual erosion is obtained by cumulating the daily values. Frozen conditions and snowmelt are also considered by keeping track of the soil and air temperatures. The calculations implemented in SWAT are therefore very similar to what would be calculated with the RUSLE equation, one difference being the modification of the cover factor in RUSLE. This modification is currently being implemented in the EPIC model, which we used for the field scale analysis (Lansford, 2000).

Annual average soil erosion rates were calculated for each crop rotation across the watershed and compared to values from the Land-Use and Treatment (LU&T) sheets for Kenoma 3% slope and Hartwell 1% slope soils obtained from Brad Powell (BCSWCD). Results presented in Table 4 show that the values calculated by the model on an event basis and averaged to obtain average annual values are comparable to what is commonly accepted using the USLE on an annual basis.

Table 4. Comparison of USLE model and USLE LU&T sheets erosion values.

Rotation	Soil	USLE Model (t/a)	USLE LU&T (t/a)	Model Sediment yield (t/a)
Hay	Kenoma	1	0	1
Bean/Wheat	Hartwell	2	4	2
Corn-Bean	Kenoma	9	11	11
Corn-Bean-Wheat	Kenoma	6	8	9

The differences in the USLE soil erosion values can be explained by the difference in slopes and slope lengths used in both cases. In addition, the methodology followed to calculate LU&T sheet values uses an annual rainfall index as opposed to an event rainfall index used in the model.

Table 4 also presents the calculated sediments yields. The sediment yield is the amount of soil actually reaching the stream. It takes into account potential deposition areas along the hillslope as well as gully erosion. Sediment yield is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977), equation similar to the USLE in which the rainfall erosion index is replaced by a runoff erosion index that is function of the runoff volume and peak flow rate. The equations used to calculate this “runoff” factor have been developed from daily sediment yields at the outlet of different watersheds and are included in the SWAT model. When slopes are significant, MUSLE estimations are usually more than the USLE values. No information on sediment yields is available for the Miami Creek Watershed.

Atrazine concentrations

The Miami Creek / Drexel Lake 319 project includes the collection of water samples each quarter and their analysis for atrazine and fecal coliform. These grab samples (the collection of water in a container from a stream by hand) are collected in conjunction with a rainfall event. Samples were collected in June, September, and December 1997, March, April, September, and November 1998 and 1999. Samples collected in 2000 were not available at the time of our analysis. Among all the samples collected, only those collected in April contained any atrazine, i.e.: none of the 1997 samples contained any.

Pesticide losses occur because of many processes, among which: volatilization, degradation, plant uptake, soil adsorption, leaching, and runoff. According to experimental data (Leonard, 1990), losses of pesticide in runoff or through leaching are proportional to the amount of pesticide on the ground surface, and to the flow rate. Consequently, for two successive events of identical runoff rate, the pesticide concentration in runoff during the second one will be less than the concentration during the first one as less pesticide is available to be transported by runoff. In addition, some of the pesticide has been volatized or degraded.

Figures 9, 10, and 11 show the calculated and measured concentrations of atrazine in runoff at three different locations in the watershed: the watershed outlet, and subbasin 6 and 4 outlets. Grab samples that contained some atrazine were collected at these locations on April 28, 1998 and April 27, 1999. Samples were not collected at the watershed outlet until September 1998, and only the April 1999 sample at that location contained atrazine. Grab samples collected at other times had no atrazine, as does the model show on those dates. The model does a reasonable job at reproducing the levels of atrazine found in grab samples collected from the river.

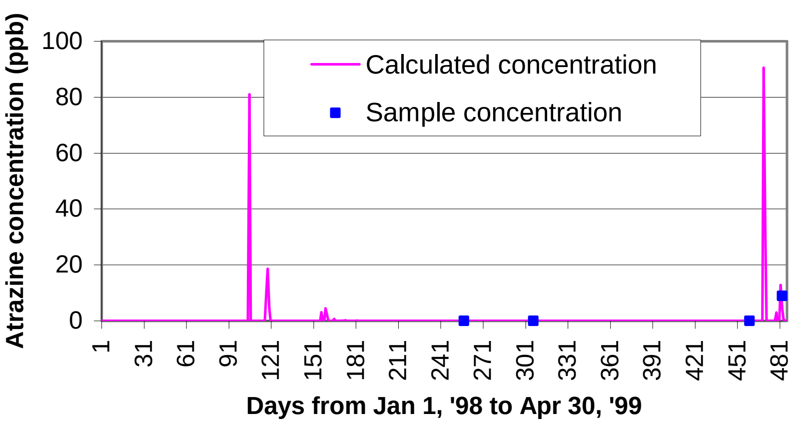

Figure 9. Daily atrazine concentration at the watershed outlet.

In both instances, the peak atrazine concentration rates for the year appear to have been missed by a week, as a previous rain event washed the chemical off the land. On both years, a precipitation of similar depth (between 2 and 3 inches) occurred on April 15, just a few days after the pesticide was applied on or around April 12th. As more pesticide was available on the ground, these events are very likely to have resulted in higher atrazine concentrations, as estimated by the model.

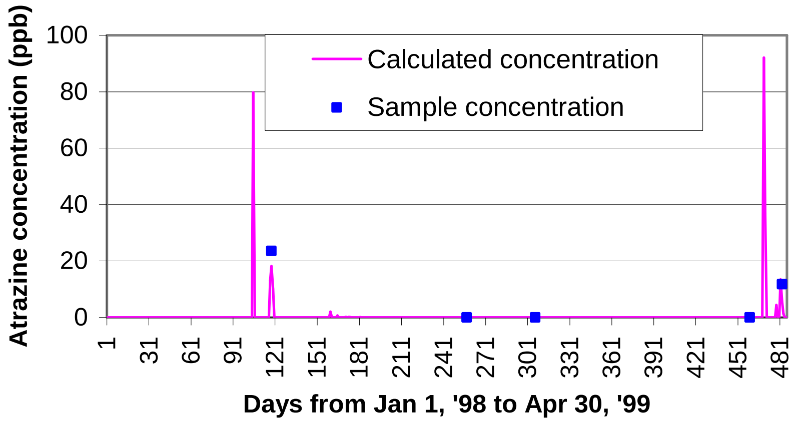

Figure 10. Daily atrazine concentration at the outlet of subbasin 4.

This watershed reacts very quickly with pollutant concentrations rising when it rains and going back to low levels within a day or two. Grab samples concentrations may not characterize the average daily concentration in a watershed that reacts quickly. As less pesticide is available during the precipitation event, atrazine in runoff is likely to decrease. The peak daily concentration often occurs early in the event, sometimes before the peak flow rate. We do not know when the samples were collected relatively to the precipitation event.

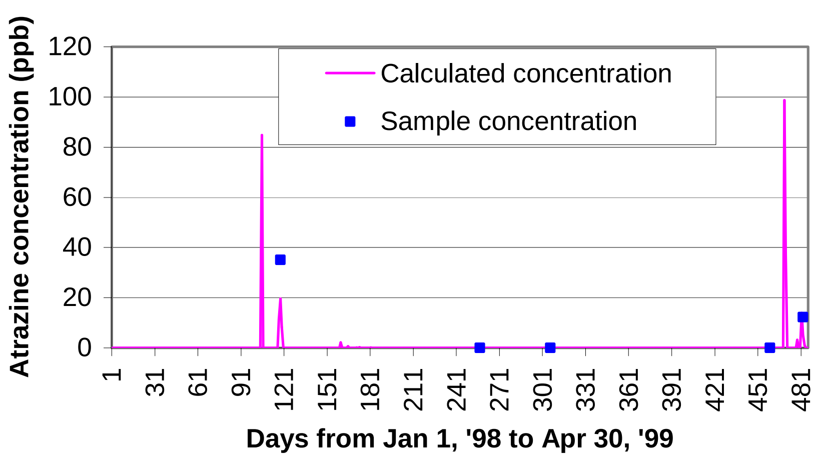

Figure 11. Daily atrazine concentration at the outlet of subbasin 6.

Nutrients

Dissolved nutrients include nitrogen as nitrates and dissolved phosphorous. Nutrients adsorbed to soil particles and transported by sediment include organic nitrogen and organic phosphorous. No available data from the watershed is available for comparison with the model results. However grab samples collected monthly in Mound Branch Creek, a tributary of Miami Creek located east of the watershed, indicate nitrate concentration between 0.5 and 3 ppm (mg/l) during 1999. Mound Branch has similar characteristics than Miami Creek in terms of slopes, soils, and land use. Grab samples are collected monthly, not necessarily in conjunction with a runoff event, upstream and downstream of the Butler treatment plant discharge point, almost at the outlet of the Mound Branch watershed.

Figure 12 shows daily estimated nitrate concentrations in Miami Creek in 1999 whenever the estimated flow is larger than 1 cfs. This limitation was introduced to exclude events characterized by low runoff and nutrient loads that produce high concentrations because there is little flow. According to the model results, these low runoff events happen mostly during the summer months, and are different from the spring events that are characterized by large runoff volumes and nutrient loads and high nutrient concentrations.

As noted previously for other pollutants, the watershed reacts rapidly. Concentrations can rise one day and return to below the EPA/MDNR standard the next. Calculated values are in the range of the concentrations obtained in Mound Branch Creek. In the absence of additional data, we can only verify that the values calculated by the model are reasonable, as will be seen in the result section.

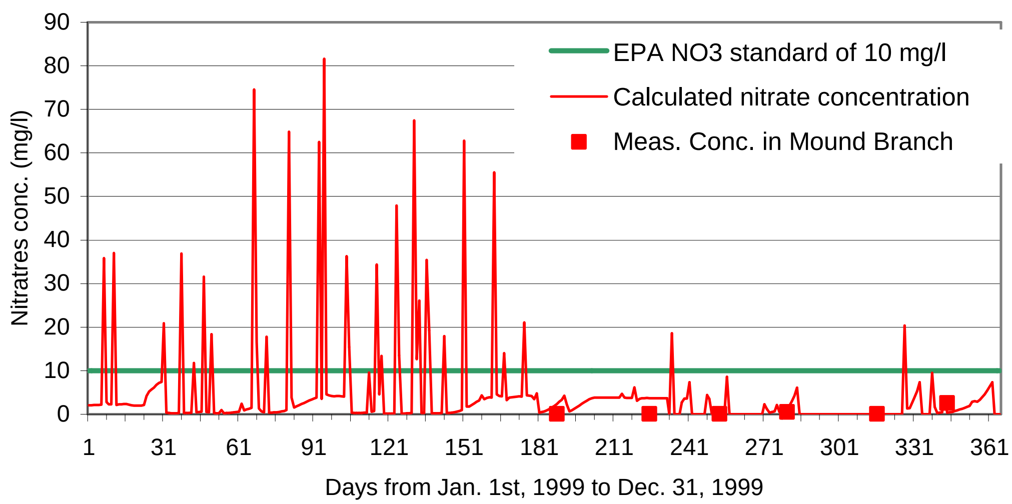

Figure 12. Daily 1999 calculated nitrate concentrations in Miami Creek.

Baseline Results

Baseline Runoff

The estimated runoff from the Miami Creek watershed averages 9.9 inches annually from an average annual precipitation of 43.2 inches over the 1979-1999 period, i.e. a runoff coefficient of 0.23. As shown in Figure 13, runoff appears to be the highest between the months of April and June (about 40% of the annual runoff occurs then) and lowest in August and January.

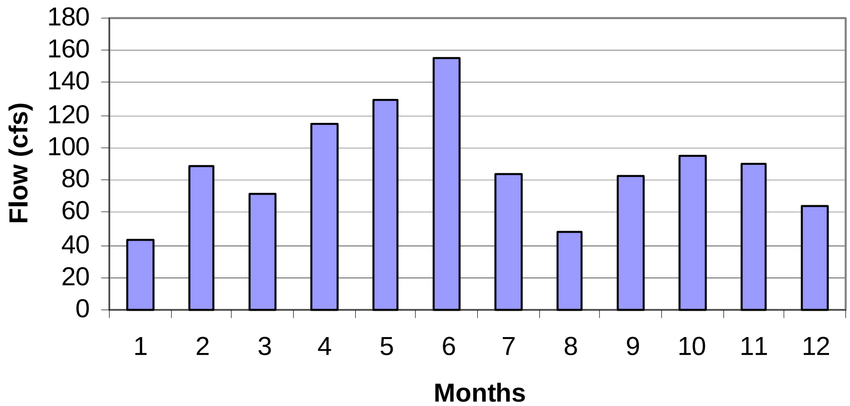

Figure 13. Average estimated monthly flows in the Miami Creek Watershed.

Baseline Sediments

Soil erosion and sediment yield are both calculated in the watershed model. As discussed earlier, soil erosion is calculated using the USLE, and generally estimates the amount of soil movement from a field, which may then be deposited in other places such as a terrace channel, depression, or a flat or vegetated area before it enters a stream channel (Wishmeier and Smith, 1978). Erosion can decrease land productivity where it occurs but is not a direct indicator of water quality concerns. Sediment yield, the amount of soil leaving the field and entering a stream channel, may be more closely related to water quality control issues.

Soil erosion

Estimated erosion values for each rotation used in the model are shown in Table 5. These values represent the average annual erosion and sediment yield values estimated for each rotation, averaged across all the subbasins of the watershed. Practices assume rows up and down the hill and minimum tillage. It is assumed that the bean-wheat rotation is grown on Hartwell soil (1% slope) and all other crop rotations are grown on Kenoma soil (2.5% slope). One exception to this is in Subbasin 2 where the bean-wheat rotation is grown on Kenoma soil. For a detailed description of each rotation, the reader can refer to Appendix B. A short description of the main corn, soybeans and wheat practices are described hereafter.

Corn is raw planted on April 10 after a nitrogen application and a disc operation in March. Fall fertilization and tillage occurred in November. Pesticides are applied shortly after planting time and in late May. After the harvest in mid-October, dry fertilizer is applied and the fields are lightly tilled in November, ready for a new crop of soybeans or corn.

Soybeans are row planted in May after pesticide applications and tillage operations at the end of April. Harvest is at the beginning of October. If wheat follows the harvest at the beginning of October, it is drilled after dry fertilizer application and disking. Nitrogen is applied in March and wheat is harvested in late June. A double crop of soybeans may be drilled soon after and harvested in mid October.

The soil loss tolerance value for Kenoma and Hartwell soils are 3 and 4 t/a/yr, respectively. The average erosion from the bean-wheat rotation (modeled on Hartwell soils with a slope of 1%) is lower than the tolerance value but all other row-crop rotations (on Kenoma soils with a slope of 2.5%) produce erosion that is higher than the tolerance level. These erosion values are calculated for up and down the hill practices and no terracing.

Rotations that include corn and soybeans have the highest average erosion rate and sediment yield. Adding wheat to the rotation generally decreases the erosion rate, because wheat provides some ground cover during the winter, and has more stable residue for a longer portion of the season. Sediment yields are further reduced with the addition of double cropped soybeans during the summer months. Estimated erosion on forest and grasses (pasture, hay, and CRP) is minimal.

Table 5. Average estimated USLE erosion and MUSLE sediment yields for each land use.

Land Use	Estimated average erosion rate (t/a/yr)	Estimated average erosion rate (mm/yr)	Estimated average sediment yield (t/a/yr)
Grassland			
Pasture	0	0	0
Hay	1	0.2	1
CRP	0	0	0
Forest	0	0	0
Crop land			
Soybeans-wheat	2	0.4	2
Corn-soybeans	9	1.9	11
Corn-soybeans-soybeans	9	1.7	10
Continuous corn	8	1.8	10
Corn-soybeans-wheat	6	1.5	9
Corn-corn-wheat double cropped beans	5	1.5	9
Corn-soybeans- wheat double cropped beans	6	1.2	7

The estimated erosion rates expressed in millimeters of soil per year are calculated using the density of the first soil layer. For the most common rotations, corn-soybeans-wheat and corn-soybeans-wheat-double cropped soybeans, this results in 1.5 mm of soil per year being lost. Given that the first layer of a Kenoma silt loam is 15 cm deep, it would take about 100 years to loose it completely.

Sediment yields

The sediment yield calculated for each row-crop rotation ranges from 2 to 11 t/a/yr. This value is averaged over all subbasins and includes sediment from gully erosion but not from stream bank degradation. The calculated sediment yields reaching the streams in each subbasin range from 0.4 to 2.5 t/a/yr with subbasins 5 and 6, which have the highest percentage of crop land, having the highest values (Figure 14). While these values include sediment originating from all land uses, including forest and grassland, as noted before, the bulk of the calculated sediment is contributed by row crop acreage. Subbasin 2 contributes very little sediment to the streams (0.4 t/a/yr) due to the lower percentage of crop land in this subbasin (less than 10 %) compared to the average percentage in the watershed (23 %).

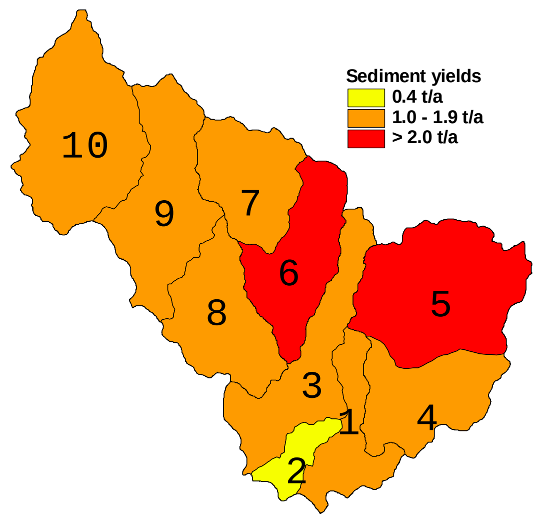

Figure 14. Calculated sediment yields from each subbasin.

The model results show that some of the sediment that reaches the streams is deposited in the stream channels. Except in subbasin 1, the sediment reaching the stream reach is larger than what is leaving it (Figure 15). The estimated sediment yields leaving each subbasin in the stream represent a net loss ranging from 0.3 to 0.7 t/a/yr relative to their respective drainage area.

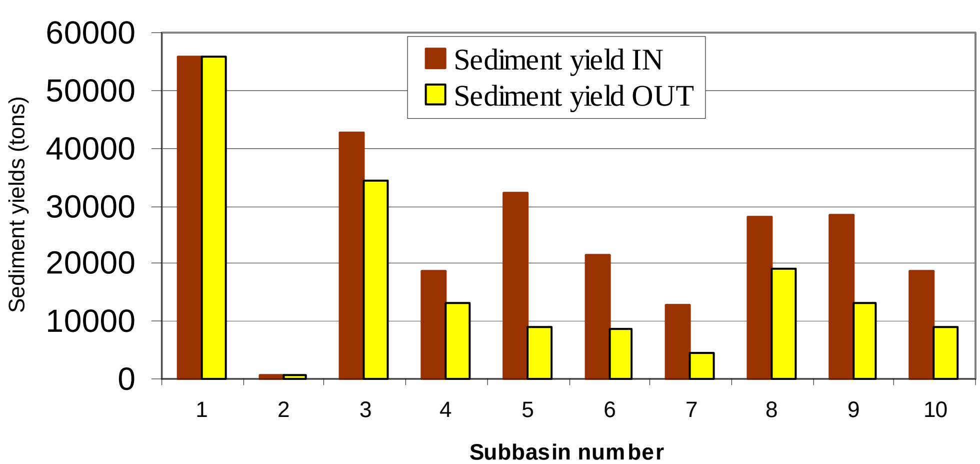

Figure 15. Estimated average annual sediment transport in each reach.

In terms of timing, about half (53%) of the estimated sediment contributed to the streams come between April and June (Figure 16). The high spring precipitations, a mix of long low intensity events and shorter high intensity events, combined with little ground cover contribute to these higher erosion rates at that time.

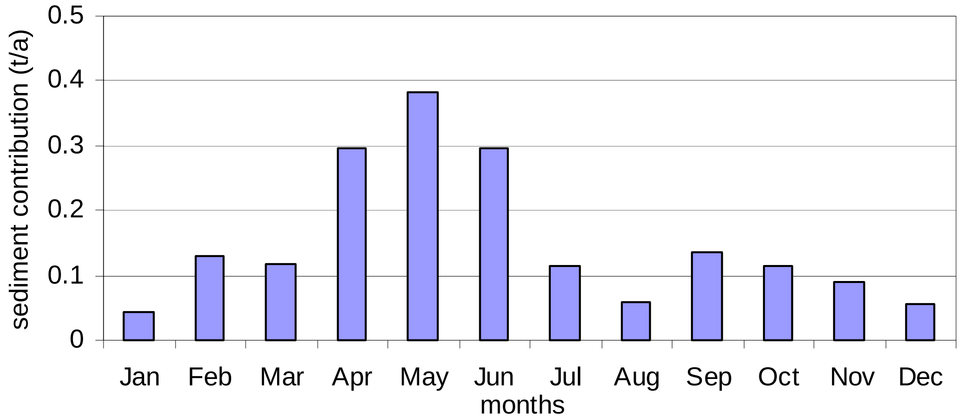

Figure 16. Estimated average monthly sediment yields reaching the streams.

Annual variability

Erosion and sediment yields vary tremendously from year to year. The standard deviation of annual sediment yields is 75% of the average annual value. Figure 17 shows the yearly values of the sediment yield reaching the watershed outlet along with the cumulative average value. Annual averages estimated from only a few years can be significantly biased if those few years do not represent the whole range of commonly found climatic conditions. As shown in Figure 16, it takes more than 15 years for the average to stabilize within 10 percent of its final value. This points out the importance of data collection over several years before estimating an average annual value. It is also important that the climatic conditions during these years represent a complete set of conditions, i.e. normal, dry, and wet years with precipitation events during different periods of the year.

As it is, with a coefficient of variation of 74 %, there is some uncertainty in the calculated value of the average annual sediment yield. To reduce the impact of annual variability on the average annual results, we could have used a longer simulation period of 30 or 50 years. However, we would have been faced with changing weather patterns in the second half of this century, which are beyond the scope of this analysis.

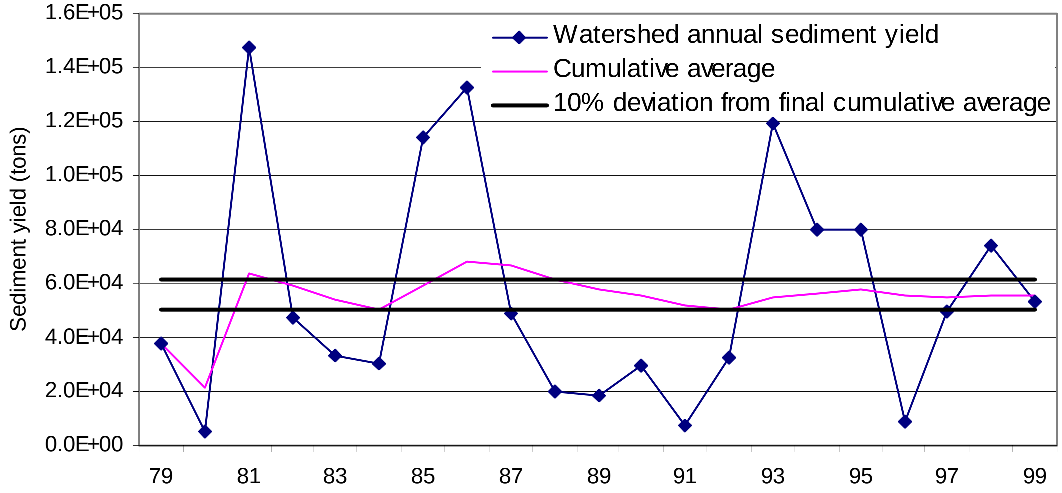

Figure 17. Variability of calculated average annual sediment yields.

Conclusions

The following conclusions concerning sediment yields can be reached based on the analysis of the baseline conditions:

- Row crop acreage is the largest source of sediment yield calculated by the model.
- Because of their larger percentage of row crop acreage, subbasins 5 and 6 produce the largest amount of sediment per acre.
- Any change in the percentage of row crop acreage in the watershed will cause a corresponding increase or decrease in sediment yields.
- A large fraction of the sediment yield reaching the channel is deposited in the reach and not transported to the next one.
- Sediment yields vary extremely from year to year.
- The importance of sediment contributions from non-agricultural sources such as road ditches and stream banks is unknown.
- More than half of the erosion occurs in the spring, from April to June.

Baseline Atrazine

Atrazine losses

This watershed simulation assumes an atrazine application rate of 1 pound of active ingredient per acre (lb ai/ac) on April 12, for all corn planted, for a total of 5,478 lbs ai/yr. No tillage operation takes place after April 12 until fall. This type of application was in place in 1998 and is assumed for the whole simulation period from 1979 to 1999. The purpose here is to evaluate the long-term effects of the current agricultural practices including the pesticide application practices. To this end, we simulate the same practices over a simulation period that is long enough to include all weather patterns. This also allows us to compare baseline practices to alternative management practices, when all else remains unchanged.

Some triazine concentrations were measured prior 1998. However, the management practices at that time included more atrazine being spread and a tillage operation after the atrazine application. The measurements therefore do not reflect the concentrations the 1998 practices are likely to generate and have not been considered in this study.

As shown in Table 6, the estimated atrazine lost in the runoff is on average 10% of the total atrazine applied on the fields, which itself is directly proportional to the corn acreage. This represents the averaged estimated amount of atrazine lost over the 21 years period of the simulation. Corn acreage varies across the subbasins.

Table 6. Average annual corn acreage, atrazine applications, and estimated atrazine runoff in the Miami Creek Watershed subbasins.

Subbasin	Corn Acres	Total Annual Atrazine Application (lb ai/yr)	Estimated Average Annual Atrazine in Runoff (lb ai/yr)	Percent lost
1	413	413	41	10 %
2	0	0	0	0 %
3	486	486	47	10 %
4	496	496	49	10 %
5	1143	1143	114	10 %
6	689	689	69	10 %
7	411	411	41	10 %
8	528	528	52	10 %
9	592	592	67	11 %
10	636	636	66	10 %
Total	5394	5394	546	10 %

When looking at the annual values there is, again, a significant degree of variability. Between 1979 and 1999, the estimated atrazine lost in surface runoff ranges from 2 to 40% of the total amount applied (Figure 18). Not only does atrazine become a water quality and health issue when it is found in the water, the loss also represents the amount of pesticide that is not helping to control weeds. The amount of atrazine coming from each subbasin is proportional to the amount of corn sprayed in that subbasin. Subbasin 5, with the largest corn acreage, also contributes the largest average annual load of atrazine (113 lbs). The model does not show any atrazine from subbasin 2, which drains into Butler Lake, because the amount of corn grown there is very small and has not been represented in the model.

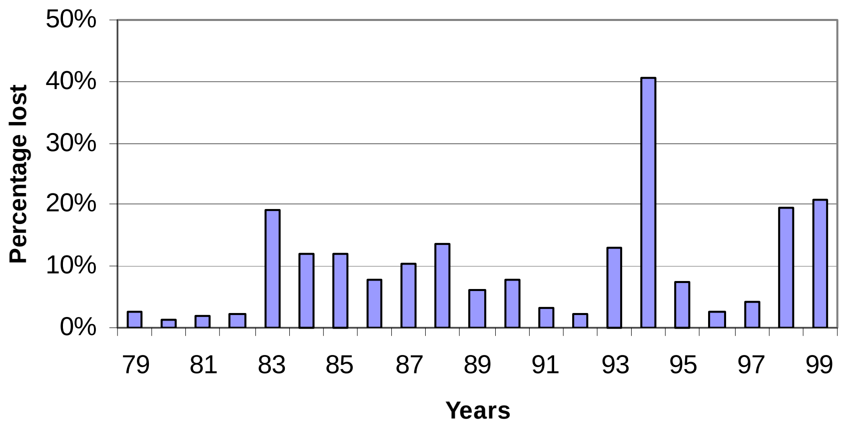

Figure 18. Estimated percentage of atrazine lost from the watershed between 1979 and 1999.

Atrazine loss is dependent on application timing with respect to rainfall. 1993 was a high rainfall year, but it occurred well after the atrazine application. The calculated atrazine loss for that year was 13%. On the other hand, there was about three times more rain in April 1994 during the atrazine application timeframe and the loss was 40%.

Atrazine concentrations

In terms of concentration of atrazine in the creek, daily concentrations estimated by the model reach very high levels several days each year in April (Figure 19). However, the watershed drains rapidly and the contaminated water moves downstream within a day or two. Concentrations therefore tend to return to low levels within a very short period of time. Nonetheless, since these peak concentrations are very high, average values of calculated daily concentrations over the month of April are above the EPA drinking water standard of 3 ppb (Figure 20). High concentrations are also present in May but not as often. Atrazine concentrations during months other than April and May are low.

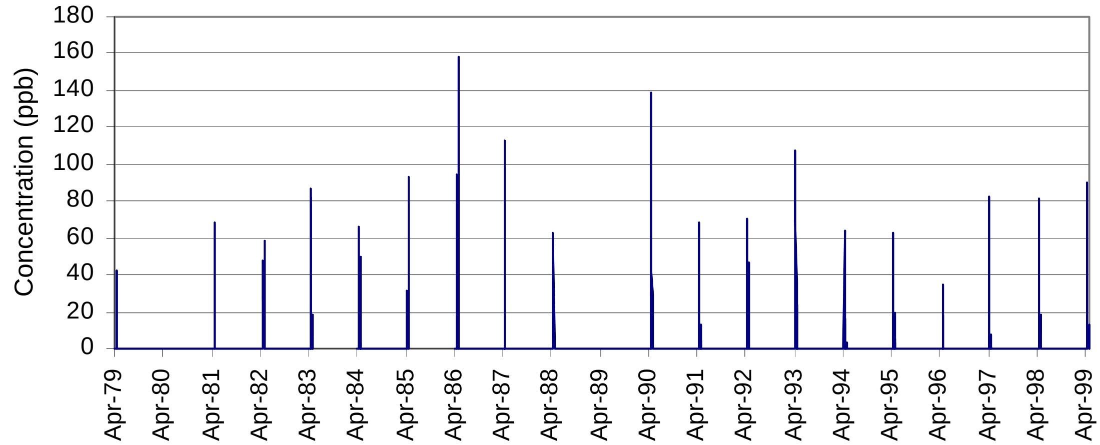

Figure 19. Daily calculated atrazine concentration at the outlet of the watershed.

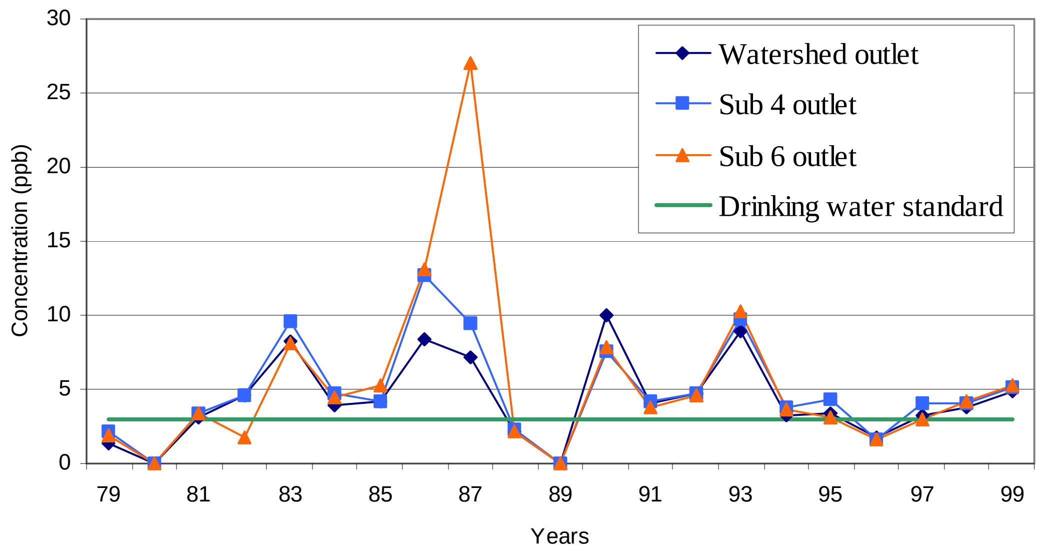

Figure 20. Average calculated daily concentrations of atrazine during April.

It is interesting to know the number of days during which the concentration is higher than a given level. This leads to the curves shown in Figure 21, which were built from calculated values of daily atrazine concentrations over the 21-year period. These curves indicate the percentage of the time that the concentration exceeds a certain value. From this we determine that the 3 ppb threshold is exceeded at the watershed outlet between 4 and 5 days on average in April. Slightly lower values are observed in May and the threshold is exceeded less than 1% of the time in June, about 1 day every three years on average. In April, however, the concentration levels also reach 70 ppb or more 3% of the time, i.e. 1 day on average.

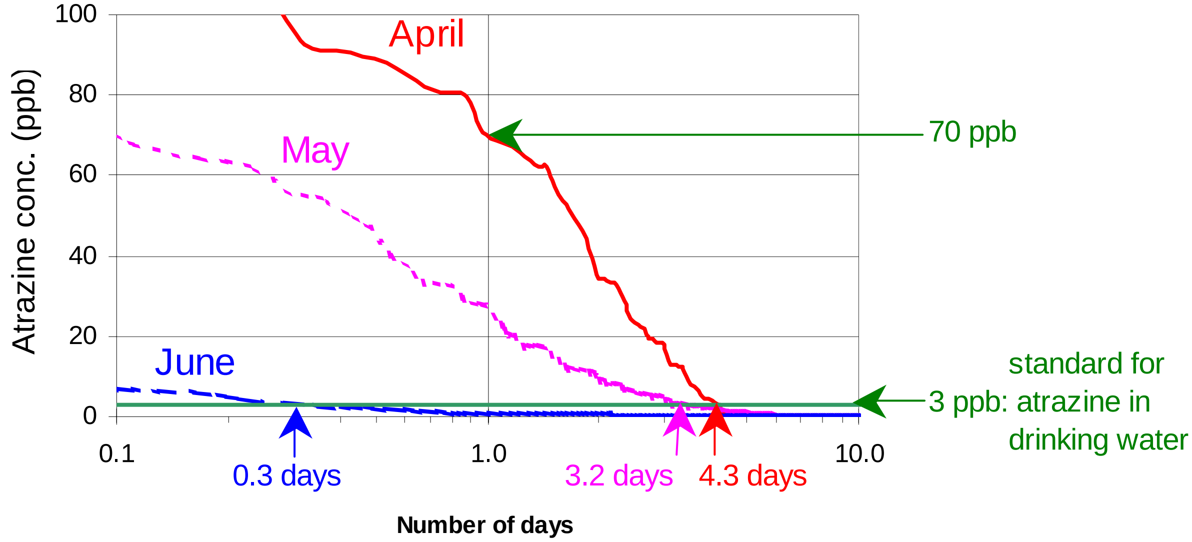

Figure 21. Estimated number of days that daily atrazine concentration is equaled or exceeded at the watershed outlet.

Conclusions

The following conclusions can be reached concerning the estimated levels of atrazine in Miami Creek, under baseline conditions.

- Estimated concentrations of atrazine in the creek exceed the EPA/MDNR standard of 3 ppb every year several days in April and May.
- Because corn is the major crop treated with atrazine, the atrazine discharged by the surface runoff in the creek is proportional to the corn acreage in the drainage area. Any increase or decrease in corn acreage will cause a relative increase or decrease in atrazine amounts found in Miami Creek.

Baseline Nutrients

As discussed before, dissolved nutrients include nitrogen as nitrates and dissolved phosphorus. Nutrients adsorbed to soil particles and transported by the sediment include organic nitrogen and organic phosphorus.

Nitrogen losses

The estimated amount of nitrogen at the outlet of the Miami Creek Watershed varies between 4 and 29 lbs/a/yr over the 21-years period with an average of 16 lbs/a/yr (Figure 22). These losses come primarily from cropland (Table 7). Even though one third of the watershed consists in pastures grazed by cattle, the manure deposited on the grass does not produce a significant impact in terms of nitrogen found in Miami Creek. Beef manure nitrogen is mostly in organic form that binds with soil particles. Because there is little erosion from pastures, very little of that nitrogen is found in the stream.

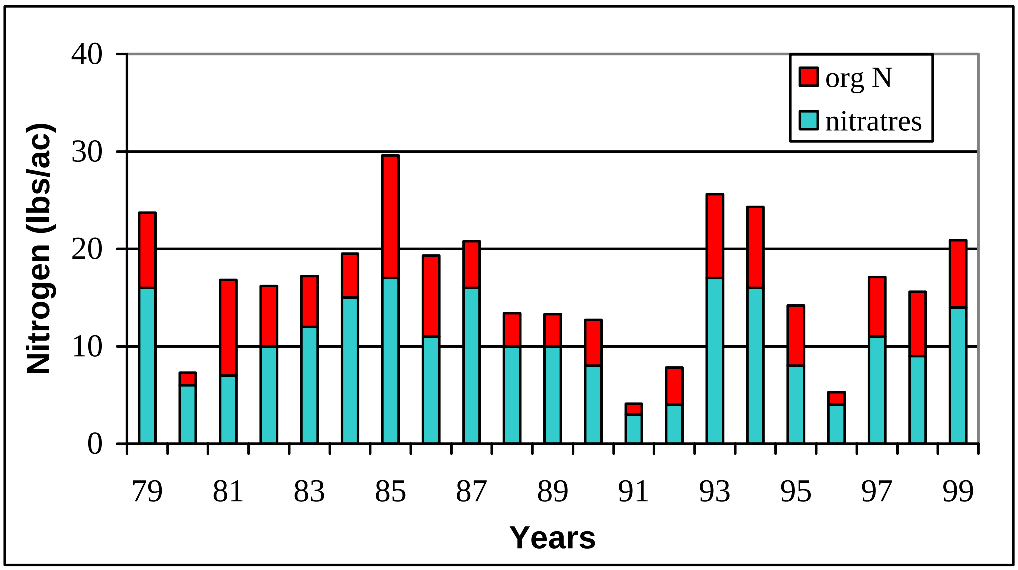

Figure 22. Estimated total nitrogen losses at the outlet of the Miami Creek Watershed.

Table 7. Estimated nitrogen losses by land use.

Land use	Nitrogen as nitrates lbs/a	Organic Nitrogen lbs/a	Total Nitrogen lbs/a
Grassland			
Pasture	6	2	8
Hay	8	12	20
CRP	6	1	7
Forest	0	0	0
Cropland			
Soybeans - wheat	23	16	39
Corn - soybeans	39	68	106
Corn - soybeans - soybeans	37	62	98
Continuous Corn	46	64	110
Corn - soybeans - wheat	38	53	91
Corn - corn - wheat - double cropped soybeans	38	46	84
Corn - soybeans - wheat double cropped soybeans	27	48	75

At the watershed outlet, nitrogen is mostly found in the form of inorganic nitrogen, i.e.: as nitrates dissolved in the water. The nitrates are transported rapidly by the surface runoff and have only a limited time to be denitrified. Consequently, what each subbasin contributes is found at the outlet of the watershed. On the other hand, organic nitrogen is transported with the sediment of which a large fraction is deposited in the flatter channels. Consequently, the amount of organic nitrogen leaving the watershed is significantly less than what the subbasins are contributing.

All the subbasins except 2 produce 20 or more lbs/a of total nitrogen per year on average (Figure 23). These numbers represent averages over all the land uses in the subbasin, including forest and grassland, which have low nitrogen losses. Subbasin 2 produces substantially less nitrogen, about 11 lbs/a, due to the fact that it has significantly less row crop acreage. Although subbasin 1 has lower row crop acreage compared to the other subbasins, corn is grown there in a continuous corn rotation, which causes high sediment yields and high organic nitrogen losses.

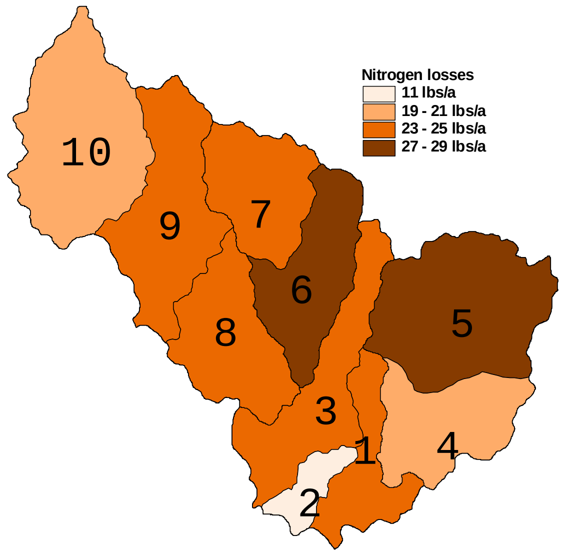

Figure 23. Estimated nitrogen losses from each subbasin.

Phosphorus losses

The estimated amounts of dissolved phosphorus at the outlet of the Miami Creek Watershed vary between 0.1 and 1.5 lbs/ac, with an average of 0.6 lbs/ac. Annual losses of organic phosphorus transported with sediment vary between 0.1 and 1.1 lbs/ac, with an average of 0.5 lbs/ac (Figure 24). This sums up to an average annual loss of 1.1 lbs of total phosphorus per acre. As with sediment, atrazine, and nitrogen, there is substantial annual variability in the total loads of phosphorus coming out of the watershed. The bulk of the phosphorus load is transported with the sediment and the phosphorus losses from row crop rotations with high sediment yields are high (Table 8).

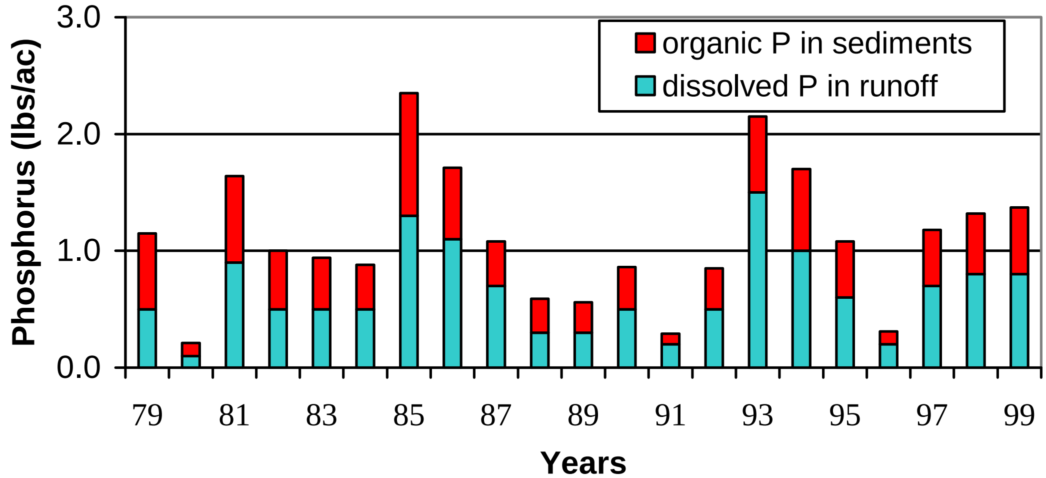

Figure 24. Estimated total phosphorus losses in the Miami Creek Watershed.

Table 8. Estimated phosphorus losses by land-use.

Land use	Runoff Phosphorus lbs/ac	Organic Phosphorus lbs/ac	Total Phosphorus lbs/ac
Grassland			
Pasture	1	0	1
Hay	1	1	2
CRP	0	0	1
Forest	0	0	0
Cropland			
Soybeans - wheat	1	2	3
Corn - soybeans	0	9	9
Corn - soybeans - soybeans	0	8	8
Continuous Corn	1	8	9
Corn - soybeans - wheat	1	7	8
Corn - corn - wheat -double cropped soybeans	1	6	7
Corn - soybeans -wheat - double cropped soybeans	1	6	7

On a subbasin level, estimated phosphorus losses averaged over all land use vary between 1 and 3 lbs/a (Figure 25), two thirds of it being transported by sediment. However, since a large part of the sediment is deposited in the channels, the high losses from the subbasins are not reflected in the phosphorus load at the watershed outlet. Subbasin 2, which has very little cropland, has the lowest phosphorus yield (1.1 lbs/a) while subbasins 5 and 6, with the largest amount of cropland, lose the largest amounts of phosphorus in surface runoff.

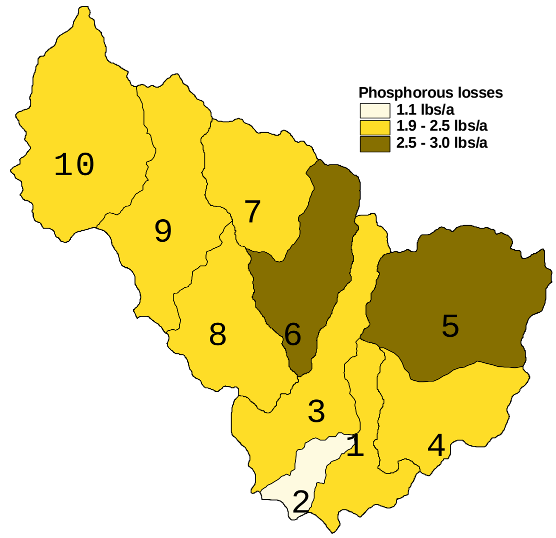

Figure 25. Estimated phosphorus losses from each subbasin.

Conclusions

The following conclusions can be reached concerning the baseline nutrient loads in Miami Creek.

- The nutrient load in the runoff is related to the row crop and pasture acreage.
- Row crop areas contribute to the surface runoff nitrogen either in dissolved form (nitrates) or adsorbed to soil particles (organic N). They contribute to the phosphorus load because of erosion/sediment.
- Pastures do not contribute to the nitrate surface runoff and dissolved phosphorus because the nutrients contained in the manure are mostly in an organic form and bind with soil particles. Since there is little erosion from pastures, there is little organic N or P coming from pastures.
- Ways to decrease the nutrient load include conservation measures that will decrease crop land erosion on Kenoma soil.

Alternatives

Description of Alternatives

The baseline information about the management practices was collected in 1997 and updated in 1999. It depicted the systems in place in 1998. During that data collection effort, producers identified four alternatives they wished to be evaluated. The first three alternatives gradually reduce the amount of tillage applied to the field, ultimately moving to a no-till management system in the third alternative. In alternative 1, all field cultivation operations are suppressed, all other things being similar. In alternative 2, no-till practices are used for spring soybeans, double cropped soybeans and wheat. The fourth alternative is fairly similar to the baseline production system, with field cultivation substituted for all disking operations. In addition, Roundup-Ready™ seeds are used for soybeans and corn whenever no-till practices are implemented, i.e. Roundup-Ready™ soybeans are used in alternative 2 and 3 and Roundup-Ready™ corn is used in alternative 3. For a detailed breakdown of the management systems, see Appendix C.

Comparison of Alternatives and Result Variability

Alternatives are usually compared on the basis of average annual values to avoid "weather biased" results. In order to include all likely weather patterns, several years are included, 21 in this case. However, some uncertainty still remains and it is important to understand the underlying or background variability in comparing the various production alternatives. In many cases, this weather induced variability will be larger than that caused by changes in management practices. As discussed in the baseline section, there is a great deal of year-to-year variability in runoff, sediment yields, and pollutant and nutrients yields due to weather. Table 9 presents some of the key variables of interest and the extent to which these terms change in the baseline due to the weather variability.

Table 9: Variability of model outputs due to annual variability.

	Mean	Standard deviation	95% confidence interval	Half width of the confidence interval[1]
Outlet runoff	9.7 in	5.8 in	[7.2 in; 12.1 in]	25%
Outlet Sediment yield	0.7 t/a	0.5 t/a	[0.50 t/a; 0.9 t/a]	32%
Outlet nitrates	11 lbs/a	4.4 lbs/a	[8.8 lbs/a; 12.6 lbs/a]	18%
Outlet Organic N	6 lbs/a	3 lbs/a	[4.5 lbs/a; 7 lbs/a]	22%
Outlet runoff P	0.6 lbs/a	0.4 lbs/a	[0.5 lbs/a; 0.8 lbs/a]	25%
Outlet organic P	0.5 lbs/a	0.25 lbs/a	[0.4 lbs/a; 0.6 lbs/a]	22%
Outlet Atrazine	542 lbs	504 lbs	[326lbs; 757 lbs]	40%
Sediment yield from SUB 5	2.5 t/a	1.4 t/a	[1.9 t/a; 3.1 t/a]	25%
Nitrates yield from SUB 5	13 lbs/a	5.3 lbs/a	[10.6 lbs/a; 15.2 lbs/a]	18%

1: The half width is expressed in percentage relative to the mean.

In addition, some result variability comes from the inherent uncertainty of the model's input parameters. Although we try to determine the inputs of the model with as much certainty as we can, some uncertainty always remains. Some parameters are not measured in the watershed and have been estimated using data from nearby or similar watersheds. Others are variable within a sub-basin and the input value actually represents an average value of the parameter over the area. The uncertainties of all the input parameters can be combined to calculate the uncertainty of the output. Table 10 presents the extent to which these terms change due to input parameter variability.

Table 10. Variability of annual average outputs due to input parameters uncertainty.

	Results	Standard deviation	95% confidence interval	Half width of the confidence interval[1]
Outlet runoff	9.7 in	0.4 in	[8.9 in; 10.5 in]	8 %
Outlet sediment yield	0.7 t/a	0.2 t/a	[0.3 t/a; 1.1 t/a]	56 %
Outlet nitrate yield	11 lbs/a	1.1 lbs/a	[9 lbs/a; 13 lbs/a]	19 %
Outlet atrazine yield	542 lbs	93 lbs	[364 lbs; 728 lbs]	33 %
Sediment yield from SUB 5	2.5 t/a	0.7 t/a	[1.2 t/a; 3.7 t/a]	16 %
Nitrates from SUB 5	13 lbs/a	1.05 t/a	[11 lbs/a; 15 lbs/a]	16 %

1: The half width is expressed in percentage relative to the mean.

In general, based on these 21 years of analysis, the uncertainty of the results due to the annual variability is larger than the uncertainty due to the variability of the input parameters. When examining the various alternative production systems, it is thus necessary to understand the extent to which this natural variability may overcome the effects of alternative tillage in any given year.

Results

Surface runoff

By leaving more residues on the ground, no-till practices slow down the surface runoff and increase the amount of infiltration. The average surface runoff from each sub-basin is estimated to decrease as the amount of tillage is reduced (Figure 26). However, these reduction amounts (between 2% and 7%) are well below the year-to-year weather induced fluctuation. They are not significant compared to the 95% confidence interval of the mean runoff values (± 25% of the mean value) and would not be verifiable experimentally.

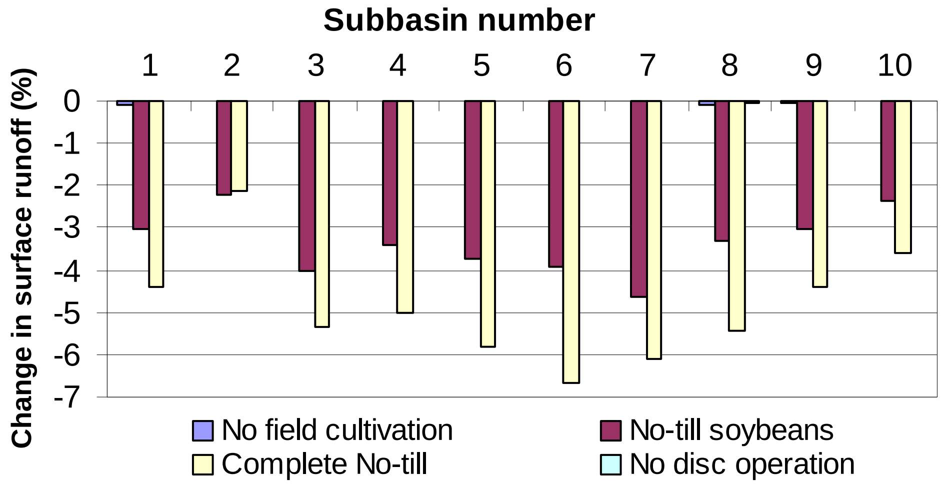

Figure 26. Estimated change in surface runoff between the baseline and the alternatives.

Sediments

The estimated amount of sediment reaching the stream in each subbasin is estimated to significantly decrease when no-till practices are introduced (Figure 27). The decrease is close to 30% for no-till soybeans and wheat and 40% when all crops are no-tilled.

The amount of sediment transported by a stream is limited either by what is coming into it, or by how much it can transport (its carrying capacity) given its size and its slope. In this case, the amount of sediment contributed to the streams in each subbasin is still larger than the carrying capacity of these stream reaches. The average annual estimated sediment yield at the watershed outlet decreases only slightly, i.e. 51 000 tons/year when no-till practices are adopted versus 56000 tons/year under the baseline management practices. The main benefit of adopting no-till practices is that less sediment and therefore less nutrient and pesticides adsorbed to soil particles settles at the bottom of the stream.

In subbasin 2, the decrease is less important due to lower crop acreage. The sediment reaching the stream, and in this subbasin Butler Lake, was the lowest of all subbasins in the watershed. Any decrease in sediment reaching the reservoir will lengthen its life. Adopting no-till practices in this subbasin may therefore be beneficial as well.

Eliminating field cultivation or replacing disking by field cultivation has no significant impact on the amount of sediment that reaches the streams.

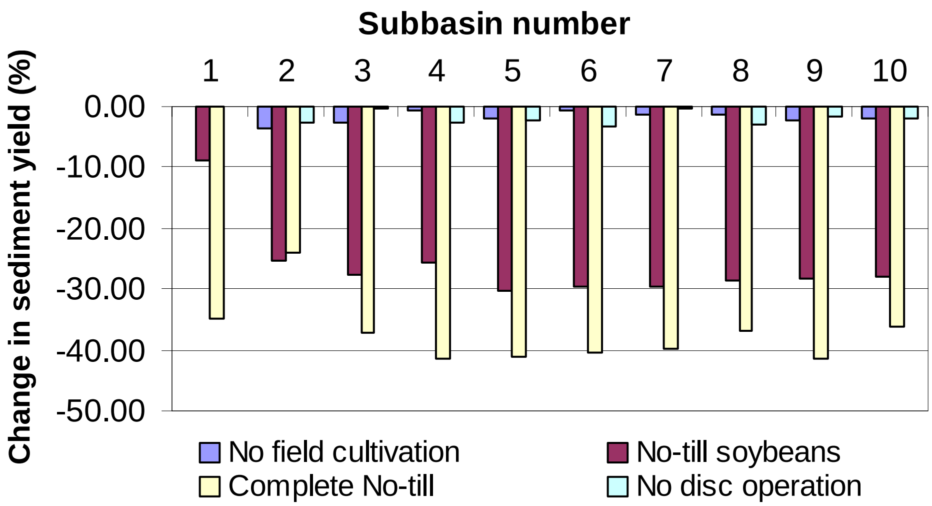

Figure 27. Estimated change in sediment reaching the streams between the baseline and the alternatives.

As explained previously, most of the erosion (53%) occurs between April and June with conventional management practices. When no-till practices are implemented, the leftover residues provide ground cover at this time of the year when there is little vegetation growing. The importance of the spring precipitation relative to the rest of the year decreases when no-till practices are implemented (46% of the erosion occurs then), but remains nevertheless high.

Nitrogen

The amount of nitrates, which are transported in dissolved form with the runoff, is not significantly reduced in any of the alternative management systems. The runoff, which does not significantly decrease with the adoption of no-till practices, dissolves the same amount of nitrogen and transports it to the stream. The estimated amount of organic nitrogen, which is adsorbed to soil particles and transported by them, is reduced by 20% and 35% when no-till management practices are adopted for soybeans and corn, respectively (Figure 28).

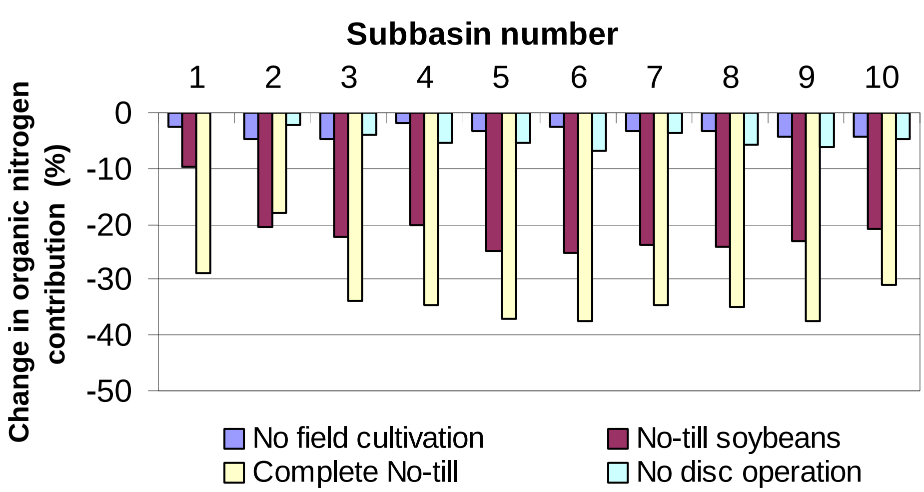

Figure 28: Change in estimated organic N contribution between the baseline and the alternatives.

Phosphorus

When no-till practices are adopted, one should expect an increase (20 to 30%) in the amount of dissolved phosphorus (Figure 29). This is because the phosphorus is not incorporated in the soil and is available for transport by the runoff. However, the estimated amounts of organic phosphorus, which is transported by soil particles, decrease by roughly 30% (Figure 30) as soil losses decrease with the adoption of no-till practices. Because more phosphorus reaches the streams with sediment than with runoff, the total amount of phosphorus reaching the stream decreases by 10 to 20 % (Figure 31).

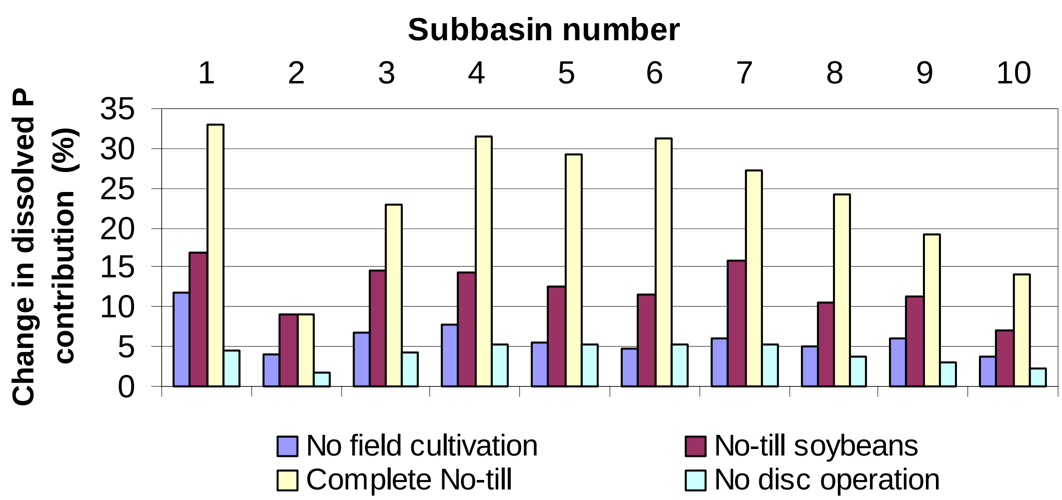

Figure 29. Estimated change in runoff P between the baseline and the alternatives.

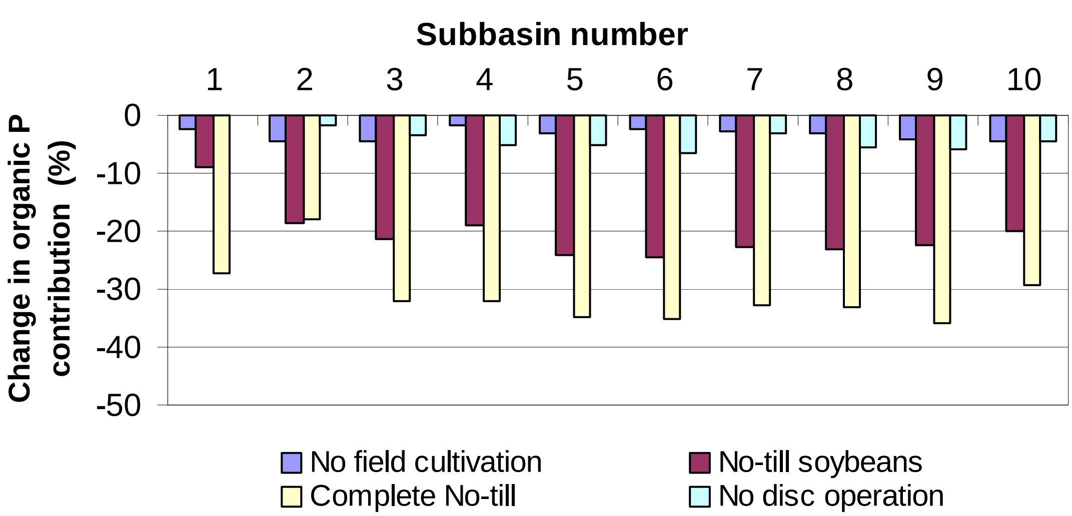

Figure 30. Estimated change in organic P contribution between the baseline and the alternatives.

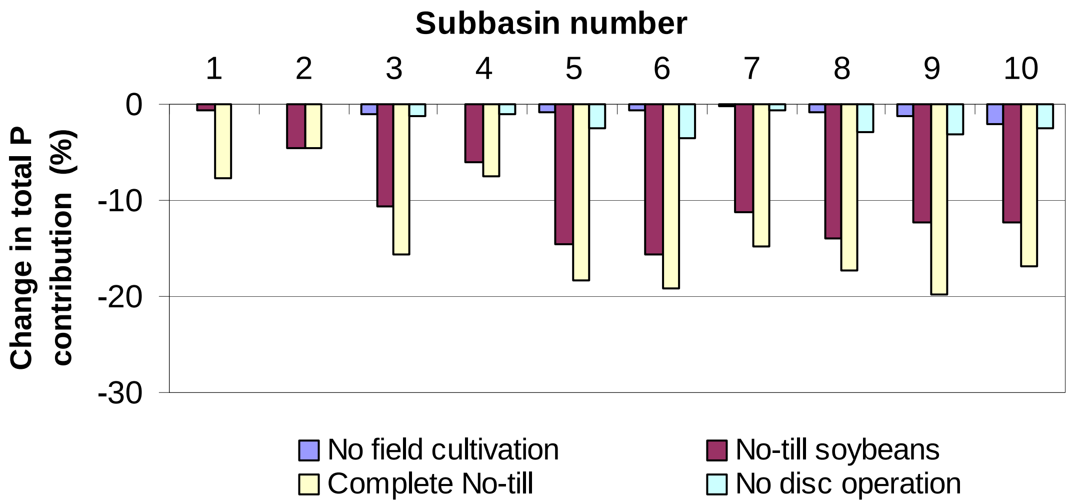

Figure 31. Estimated change in total P contribution between the baseline and the alternatives.

Atrazine

In alternatives 1,2,and 4 the amount of atrazine applied to the fields is identical to what is applied in the baseline. Alternative 2 only affects how wheat and soybeans are grown and has therefore no impact on atrazine, which is only used on corn. Alternative 1 and 4 affect the soil tillage operations on all fields but do not have any significant on the runoff. Since most of the atrazine is dissolved in and moves with the runoff, these alternatives have no impact on how much atrazine moves off the fields and into the streams.

In alternative 3, no-till practices are used for all crops including corn. In all alternative management practices proposed by the panel, no-till practices were associated with the use of Roundup-Ready™ corn and soybeans. Consequently no atrazine is applied; Roundup Ultra™ is used instead and no atrazine is found in the streams. Figure 32 shows that the annual amounts of Roundup™ lost in the streams when no-till practices are used are very small compared to what is applied. This herbicide degrades faster than atrazine (2.5 versus 5 days on foliage, and 47 versus 60 days in soil and water), and binds very strongly to soil particles (atrazine does not). As a result, the Roundup™ concentrations in Miami Creek remain low (Figure 33), even when more chemical is used as a result of the switch to no-till practices and Roundup-Ready™ seeds. Roundup does not have a maximum contaminant level and a public water supply system is not required to monitor the concentration levels.

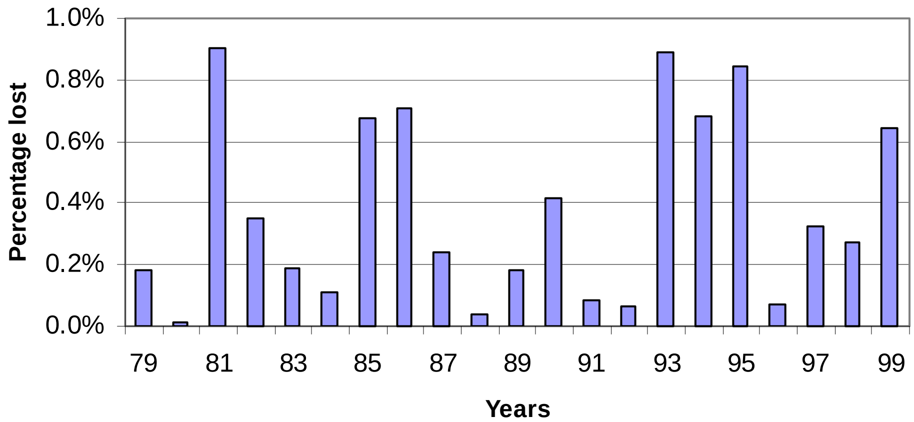

Figure 32. Estimated annual percentages of Roundup™ lost in the watershed.

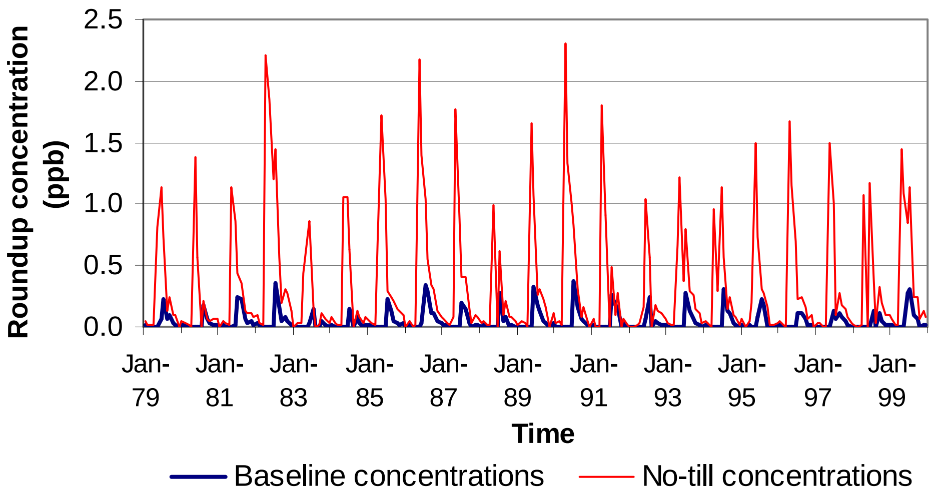

Figure 33. Estimated monthly Roundup™ concentrations in Miami Creek

Yields

By leaving more residues on the ground, no-till practices slow down the surface runoff, increase the amount of infiltration, shelter the ground surface from rain drop impact, and reduce erosion, pesticide, and nutrients losses. One should therefore expect an increase in the crop yields due to the greater availability of soil water and nutrients. This expectation is indeed verified by the model results: corn, wheat, and soybeans yields increased by 12%, 6%, and 11%, respectively, when no-till practices are implemented.

One should note the limitations of these yield estimations. SWAT does not model damages caused by pests, excess moisture, or weed competition: a common problem with no-till cropping. A model that includes pest and excess moisture damages, and weed competition should be used for this. Similarly, the agronomic characteristics of the genetically modified corn and soybeans variety (Roundup Ready™ corn and soybeans) have been assumed identical to those of the traditional variety.

Summary and Conclusions

The Miami Creek Watershed model allowed us to evaluate alternative management practices for the cropland in terms of the amount of runoff, sediment, nutrients and atrazine reaching the streams. The model was built using SWAT that includes mathematical representation of the many processes than control the movement of water on and in the soil, plant growth, and the fate and transport of nitrogen, phosphorus, and pesticides. Inputs were collected using soil and land use maps, farm records, weather records, and information given by a panel of farmers and custom applicators. Only non point sources were considered. Since very little data on the flow and the water quality of Miami Creek exist, regional information was used to give strength to the model. The results are summarized hereafter:

- The proposed alternatives do not produce any significant change in surface runoff contribution.
- Significantly less sediment reaches the streams when no-till practices are adopted. The amount of the reduction increases as more no-till practices are adopted.
- The sediment contributions from the sub-basins are still greater than the carrying capacity of the streams, and the sediment yield leaving the watershed does not decrease significantly. However, less sediment settles at the bottom of the streams.
- As erosion decreases, the estimated loads of organic nitrogen and organic phosphorus decrease as well.
- The estimated loads of nitrates are not significantly reduced.
- The estimated loads of phosphorus transported by the surface runoff increase when no-till practices are adopted because the phosphorus is not incorporated in the soil, does not bind to soil particles, and remains available to be carried off by the runoff.
- Even though the runoff P increases when no-till practices are adopted, the estimated total phosphorus contributions decrease.
- Adopting no-till practices for soybeans and wheat has no impact on atrazine concentration because atrazine is only used on corn.
- The adoption of no-till practices for corn also meant using Roundup™ ready corn and using Roundup™ instead of atrazine to control the weeds. The alternative (number 3) therefore resulted in no atrazine being used in the watershed, and no atrazine being found in the streams. Estimated concentrations of Roundup™ increase when no-till practices are implemented but remain low.

Appendix A

Major Land Resource Areas (MLRA's)

MAJOR LAND RESOURCE AREAS

(source USDA 1981)

Major land resource areas (MLRAs) are geographically associated land resource units. Identification of these large areas is important in statewide agricultural planning and has value in interstate, regional, and national planning. The dominant physical characteristics of MLRAs are described by their land use, elevation and topography, climate, water, soils, and potential natural vegetation. The Miami Creek watershed is part of MLRA 112, the ***Cherokee Prairies Area***.

The ***Cherokee Prairies Area*** of Kansas, Missouri, and Oklahoma, is a part of the Central Feed Grains and Livestock Region. This region is characterized by fertile soil with favorable climate making it one of the outstanding grains producing regions of the world. Much of the grain in the region is fed to beef cattle and hogs on the farms where it is grown. A large amount, however, is shipped to other regions for livestock feed, exported to foreign countries, or processed for food and industrial uses.

The Cherokee Prairies MLRA has approximately 50% cropland, 30% permanent introduced and native grasses, and 10% woodland, usually on steeper slopes and wet bottomland. The remainder is used by urban areas and other miscellaneous land uses. Corn, winter wheat, soybeans, other feed grains, and hay are the main crops grown.

The regional topography consists of gently sloping to rolling dissected plains underlain by sandstone, shale, and limestone. Stream valleys are shallow, and most are narrow. Local relief is in feet (meters). Elevation ranges from 300 to 1200 feet (100-400 meters).

Most of the soils are shallow to deep, and medium and moderately fine textured. Somewhat poorly drained nearly level and gently sloping soils (Parsons and Taloka, Woodson, and Hartwell series) are found on clay-mantled uplands. Well drained and moderately well drained, gently sloping and sloping soils (Dennis, Okemah, Barden, Liberal, Bates, and Eram series) are found on uplands underlain by silty and sandy shale and sandstone. Well drained, gently sloping soils (Lula and Catoosa series) underlain by limestone are found on uplands. Shallower and more stony soils (Clareson, Shidler, Coweta, and Collinsville) are found on steeper slopes of limestone, sandstone, and loamy shale. Gently sloping to moderately sloping clayey soils (Summit series) are underlain by clayey shale and clay beds on foot slopes. In the flood plains of most streams, one can found soils from the Osage, Verdigris, Wynona and Hepler series.

Regional precipitation is moderate with an average annual precipitation of 35 to 41 inches (900 to 1025 mm) and is adequate for crops in many years. Summer droughts can reduce crop yields in some years. Maximum precipitation occurs from late spring through autumn.

The western part of the area supports tall grass prairie vegetation characterized by big bluestem, indiangrass, and switchgrass. Forest vegetation of red oak, white oak, and shagbark hickory grows in the eastern part of the area.

Appendix B

Crop Management

Corn-Soybean Rotation

Year 1

March 10	Apply fertilizer 170 lbs anhydrous
March 25	Disc
April 10	Plant corn
April 12	Apply Axiom @ 15oz/A
	Apply Atrazine @ 1 lb/A
May 31	Apply Hornet @ 2 oz/ac
Oct 10	Harvest
Nov. 5	Apply fertilizer 0-60-80
Nov 6	Light disc

Year 2

April 28	Apply Treflan @ 2 pt/A
	Apply Triscept @ 2.33 pt/A
April 28	Disc
April 28	Field cultivate
May 2	Row plant soybeans
Oct 1	Harvest
Nov. 1	Apply fertilizer 0-70-90
Nov. 2	Chisel plow

Corn-Soybean-Wheat Rotation

Year 1

03/10	Apply anhydrous ammonia 170 lbs
03/25	Disc
04/10	Row plant corn
04/12	Apply Axiom @ 15oz/A
	Apply Atrazine @ 1 lb/A
05/31	Apply Hornet @ 2oz/A
10/01	Harvest
11/05	Apply 0-60-80 (lbs/A elemental) dry fertilizer
11/06	Light disc

Year 2

04/28	Apply Treflan @ 2 pt/A
	Apply Triscept @ 2.33 pt/A
04/28	Disc
04/28	Field cultivate
05/02	Row plant soybeans
10/01	Harvest
10/05	Apply 75-70-90 (lbs/A elemental) dry fertilizer
10/05	Disc
10/10	Drill wheat

Year 3

03/05	Apply 25 lbs/A elemental nitrogen, dry fertilizer
06/20	Harvest
11/01	Apply 0-70-90 dry fertilizer
11/02	Chisel plow

Soybean-Wheat Rotation

Year 1

04/28 Disc
04/28 Field cultivate
04/30 Apply Prowl @ 2.4 pt/A
05/02 Row plant soybeans
07/01 Apply Raptor @ 4 oz/A
10/01 Harvest
10/05 Apply 75-70-dry fertilizer
10/05 Disc
10/10 Drill wheat

Year 2

03/05 Apply 25 lbs/A elemental nitrogen
06/20 Harvest
11/05 Apply 0-60-80 dry fertilizer
11/06 Light disc

Corn – wheat double crop soybeans – corn Rotation

Year 1

03/10 Apply anhydrous ammonia @ 140 units N, (170 lbs)
03/25 Disc
04/10 Row plant corn
04/12 Apply Axiom @ 15oz/A
Apply Atrazine @ 1 lb/A
05/31 Apply Hornet @ 2oz/A
10/01 Harvest
10/05 Apply 75-90-110 (lbs/A elemental) dry fertilizer
10/05 Disc
10/10 Drill wheat

Year 2

03/05 Apply 25 lbs/A elemental nitrogen, dry fertilizer
06/20 Harvest wheat

06/25 Drill Soybeans
06/26 Apply Roundup Ultra @ 1.5 qt/A
08/10 Apply Roundup Ultra @ 1.5 pt/A
10/15 Harvest
11/01 Apply 0-70-90 (lbs/A elemental) dry fertilizer
11/02 Chisel plow

Year 3

03/10 Apply anhydrous ammonia @ 140 units N, (170 lbs)
03/25 Disc
04/10 Row plant corn
04/12 Apply Axiom @ 15oz/A
Apply Atrazine @ 1 lb/A
05/31 Apply Hornet @ 2oz/A
10/01 Harvest
11/01 Apply 0-70-90 (lbs/A elemental) dry fertilizer
11/02 Chisel plow

Corn – soybeans – wheat – double crop soybeans Rotation

Year 1

03/10 Apply anhydrous ammonia @ 170 lbs
03/25 Disc
04/10 Row plant corn
04/12 Apply Axiom @ 15oz/A
Apply Atrazine @ 1 lb/A
05/31 Apply Hornet @ 2oz/A
10/01 Harvest
11/05 Apply 0-60-80 dry fertilizer
11/06 Light disc

Year 2

04/28 Apply Treflan @ 2 pt/A
Apply Triscept @ 2.33 pt/A
04/28 Disc
04/28 Field cultivate
05/02 Row plant soybeans
10/01 Harvest
10/05 Apply 75-90-110 dry fertilizer
10/05 Disc
10/10 Drill wheat

Year 3

03/05 Apply 25 lbs/A elemental nitrogen, dry fertilizer
06/20 Harvest wheat

06/25 Drill Soybeans
06/26 Apply Roundup Ultra @ 1.5 qt/A
08/10 Apply Roundup Ultra @ 1.5 pt/A
10/15 Harvest soybeans
11/01 Apply 0-70-90 dry fertilizer
11/02 Chisel plow

Corn – soybeans – soybeans

Year 1

03/10 Apply anhydrous ammonia 170 lbs
03/25 Disc
04/10 Row plant corn
04/12 Apply Axiom @ 15oz/A
Apply Atrazine @ 1 lb/A
05/31 Apply Hornet @ 2oz/A
10/01 Harvest
11/05 Apply 0-60-80 (lbs/A elemental) dry fertilizer
11/06 Light disc

Year 2

04/28 Apply Treflan @ 2 pt/A
Apply Triscept @ 2.33 pt/A
04/28 Disc
04/28 Field cultivate
05/02 Row plant soybeans
10/01 Harvest
11/05 Apply 0-60-80 (lbs/A elemental) dry fertilizer
11/06 Light disc

Year 3

04/30 Apply Prowl @ 2.4 pt/A
04/28 Disc
04/28 Field cultivate
05/02 Row plant soybeans
07/01 Apply Raptor @ 4 oz/A
10/01 Harvest
11/01 Apply 0-70-90 dry fertilizer
11/02 Chisel plow

Appendix C

Crop Management Alternatives

In the alternatives, corn, wheat, soybeans, and double-cropped soybeans are cropped the same way independently of the rotation. Operations are detailed only for the corn-soybeans-wheat-double cropped soybeans rotation, which includes the four typical crops grown in the watershed.

Alternative 1: Suppress field cultivation operations

Year 1: Corn

03/10	Apply anhydrous ammonia @ 170 lbs
03/25	Disc
04/10	Row plant corn
04/12	Apply Axiom @ 15oz/A
	Apply Atrazine @ 1 lb/A
05/31	Apply Hornet @ 2oz/A
10/01	Harvest
11/05	Apply 0-60-80 dry fertilizer
11/06	Light disc

Year 2: soybeans – drill winter wheat

04/28	Apply Treflan @ 2 pt/A
	Apply Triscept @ 2.33 pt/A
04/28	Disc
05/02	Row plant soybeans
10/01	Harvest
10/05	Apply 75-90-110 dry fertilizer
10/05	Disc
10/10	Drill wheat

Year 3: harvest wheat – double-cropped no-till soybeans

03/05	Apply 25 lbs/A elemental nitrogen, dry fertilizer
06/20	Harvest wheat
06/25	Drill no-till Soybeans
06/26	Apply Roundup Ultra @ 1.5 qt/A
08/10	Apply Roundup Ultra @ 1.5 pt/A
10/15	Harvest soybeans
11/01	Apply 0-70-90 dry fertilizer
11/02	Chisel plow

Alternative 2: Use no-till Roundup-Ready soybeans, and wheat.

Year 1: corn

03/10 Apply anhydrous ammonia @ 170 lbs
03/25 Disc
04/10 Row plant corn
04/12 Apply Axiom @ 15oz/A
Apply Atrazine @ 1 lb/A
05/31 Apply Hornet @ 2oz/A
10/01 Harvest
11/05 Apply 0-60-80 dry fertilizer
11/06 Light disc

Year 2: no-till soybeans – no-till drill winter wheat

04/25 Apply Roundup Ultra @ 1 qt/A
05/02 No-till drill soybeans
07/10 Apply Roundup Ultra @ 1.5 pt/A
10/01 Harvest
10/05 Apply 75-90-110 dry fertilizer
10/10 No-till drill wheat

Year 3: harvest wheat –double-cropped no till soybeans

03/05 Apply 25 lbs/A elemental nitrogen, dry fertilizer
06/20 Harvest wheat

06/25 No-till drill Soybeans
06/26 Apply Roundup Ultra @ 1.5 qt/A
08/10 Apply Roundup Ultra @ 1.5 pt/A
10/15 Harvest soybeans
11/01 Apply 0-70-90 dry fertilizer

Alternative 3: Complete no-till practices

Year 1: no-till corn

03/10 Apply anhydrous ammonia @ 170 lbs
04/10 To-till row plant corn
04/25 Apply Roundup Ultra @ 1.5 qt/A
10/01 Harvest
11/05 Apply 0-60-80 dry fertilizer

Year 2: no-till soybeans and winter wheat

04/25 Apply Roundup Ultra @ 1 qt/A
05/02 Row plant soybeans
07/10 Apply Roundup Ultra ! 1.5 pt/A
10/01 Harvest
10/05 Apply 75-90-110 dry fertilizer
10/10 No-till drill wheat

Year 3: harvest wheat and no-till double-cropped soybeans

03/05 Apply 25 lbs/A elemental nitrogen, dry fertilizer
06/20 Harvest wheat

06/25 No-till drill Soybeans
06/26 Apply Roundup Ultra @ 1.5 qt/A
08/10 Apply Roundup Ultra @ 1.5 pt/A
10/15 Harvest soybeans
11/01 Apply 0-70-90 dry fertilizer

Alternative 4: Replace disc operations by field cultivation.

Year 1: Corn

03/10 Apply anhydrous ammonia @ 170 lbs
03/25 Field cultivate
04/10 Row plant corn
04/12 Apply Axiom @ 15oz/A
Apply Atrazine @ 1 lb/A
05/31 Apply Hornet @ 2oz/A
10/01 Harvest
11/05 Apply 0-60-80 dry fertilizer
11/06 Field cultivate

Year 2: Soybeans and drill winter wheat

04/28 Apply Treflan @ 2 pt/A
Apply Triscept @ 2.33 pt/A
04/28 Field cultivate
05/02 Row plant soybeans
10/01 Harvest
10/05 Apply 75-90-110 dry fertilizer
10/05 Field cultivate
10/10 Drill wheat

Year 3: harvest wheat and double-cropped soybeans

03/05 Apply 25 lbs/A elemental nitrogen, dry fertilizer
06/20 Harvest wheat

06/25 Drill Soybeans
06/26 Apply Roundup Ultra @ 1.5 qt/A
08/10 Apply Roundup Ultra @ 1.5 pt/A
10/15 Harvest soybeans
11/01 Apply 0-70-90 dry fertilizer
11/02 Chisel plow

References

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large area hydrologic modeling and assessment part I: model development. Journal of American Water Resources Association 34 (1):73-89.

Bates County soil and Water Conservation District. 1998. *Miami Creek / Drexel Lake AgNPS Special Area Land Treatment Pilot Project*, Butler, Missouri.

Lansford, V. 2000. *Miami Creek Watershed – Farm-Level Environmental Assessment.* Food and Agricultural policy research Institute, Columbia, Missouri. Working draft.

Leonard R.A. 1990. *Movement of Pesticides into Surface Waters*, in Pesticides in the Soil Environment: Processes, Impacts, and Modeling. Ed.: H.H. Cheng. Number 2 in the Soil Science Society of America Book Series, Soil Science Society of America, Madison, WI.

Missouri Department of Natural Resources, Division of Environmental Quality. January 2000. *Final 1998 303(d) List for Missouri*. http://www.dnr.state.mo.us/deq/wpcp/tmdl/tmdl-list.pdf

Missouri Department of Natural Resources, Division of Geology and Land Survey. 1995. *Surface Water Resources of Missouri*, Missouri State Water Plan Series, Vol. 1. Rolla, MO.

Smith, M., P. Blanchard, W. Johnson, and G. Smith. 1999. *Atrazine Management and Water Quality, A Missouri Guide.* Missouri Manual 167. MU Extension, University of Missouri, Columbia, Missouri.

Viessman, W. Jr., J.W. Knapp, G.L. Lewis, and T.E. Harbaugh. 1977. *Introduction to Hydrology*, Second Edition, IEP series. Harper & Row, Publishers, New York, NY.

Williams J.R. and H.D. Berndt. 1977. Sediment Yield Prediction Based on Watershed Hydrology. Transactions of the American Society of Agricultural Engineers 20 (6):1100-1104.

Wishmeier W.H. and D.D. Smith. 1978. *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning.* US Department of Agriculture, Agricultural Handbook 537. Washington, D.C.

USDA Soil Conservation Service. 1981. *Land Resource Regions and Major Land Resource Areas of The United States.* Agricultural Handbook 296. Washington, D.C.