MODELING THE INFLUENCE OF CLIMATE AND MANAGEMENT PRACTICES ON WATER QUALITY IN GOODWATER CREEK EXPERIMENTAL WATERSHED

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by
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ON WATER QUALITY IN GOODWATER CREEK EXPERIMENTAL WATERSHED

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ABSTRACT

The objective of this study was to use statistical regression to determine relationships among weather, runoff, water quality, and best management practice (BMP) implementation in reducing atrazine loadings and concentrations in the 7,250-ha Goodwater Creek Experimental Watershed in Audrain and Boone Counties in Northeast Missouri. This study examined data collected from 1993 through 2003. During that period the amount of area protected by BMPs, such as grassed waterways, increased by 10%, and the use of conservation tillage and no-till in Audrain County increased from 45% to 80%. Flow and water quality constituents were monitored at the outlet of the watershed. Annual, monthly and seasonal regressions were conducted among water quality indicators, climatic variables, and an index that incorporated the change in area protected by BMPs during that period. Results showed significant decreases in atrazine concentrations for June and the combined months of April, May, and June. No significant trends were observed for atrazine loadings. Covariate analysis of the effect of BMP protected area on atrazine concentrations showed that the time period analyzed was important. More specific atrazine application data could allow for a better analysis, rather than a comparing data on a monthly or seasonal time period. Inputs were developed for the Soil and Water Assessment Tool (SWAT) program. The SWAT model was able to simulate decreased atrazine concentrations with as little as 4.5% of the watershed protected by grassed waterways. Changes in the amount of land in conventional, conservation, and no-till tillage systems also affected the simulated atrazine concentrations.

CHAPTER 1

INTRODUCTION

The United States Department of Agriculture (USDA) Conservation Effects Assessment Project (CEAP) was initiated to quantify the benefits of conservation practices on a national scale. Water quality benefits cannot be detected at that scale. Water quality response to management practices has been studied and developed at field scales, but impacts may be unknown for larger areas. It is necessary to study the impact in small watersheds to gain perspective on the benefits of implemented practices and what kind of response can be detected at larger scales. Goodwater Creek Experimental Watershed (GCEW) is on such a scale (7,250 ha). It was established in 1971 and became the principal field research site for the Missouri Management Systems Evaluation Area (MSEA) project in 1990.

The objective of this study was to use statistical regression to determine relationships among weather, runoff, water quality, and management practice (BMP) implementation. The study used statistical analysis and modeling of data collected from GCEW to identify trends in atrazine loadings and concentrations.

Multiple factors play a role in the outcome of the atrazine levels in Goodwater Creek, and statistical modeling alone did not fully explain the contribution of these factors. To estimate the impact of weather, BMPs, and tillage on Goodwater Creek, the Soil and Water Assessment Tool (SWAT) was used. Soil and Water Assessment Tool is a process-based model capable of modeling atrazine transport and degradation in a watershed. Model inputs had been previously developed for Goodwater Creek consisting of the topography, soils, management, and hydrologic characteristics of the watershed. The model was then calibrated for atrazine and used to examine the effect of different scenarios on atrazine levels in the watershed. These scenarios included the implementation of grassed waterways and changes in tillage systems within the watershed. Statistical analysis and SWAT modeling of the watershed was useful in determining possible causes for observed trends within the data.

CHAPTER 2

LITERATURE REVIEW

2.1 Area Description

The 7,250-ha GCEW lies within the Central Claypan Soil Major Land Resource Area (MLRA 113; NRCS, 2002) of Audrain and northeast Boone Counties (fig. 2.1), about 45 km north of Columbia, MO. Goodwater Creek is a tributary of Young's Creek, 14-digit hydrologic unit code (HUC) 07110006030001, itself divided into the Lower and Upper Young's Creek watersheds. Young's Creek is part of the Salt River system, which drains to Mark Twain Reservoir. Mark Twain Reservoir serves recreational use and is the public drinking water supply for approximately 42,000 people. The consistently high spring and summer time atrazine levels have been an on-going concern for Mark Twain Reservoir. It was listed on the Environmental Protection Agency's 303(d) impaired water listing for atrazine. It was removed from the 2002 list for atrazine but remains on it for mercury contamination in Largemouth Bass (MO Department of Natural Resources, 2004). The water quality issues in Goodwater Creek watershed are representative of those in the Salt River system: high pesticides, nutrients, and sediment loadings.

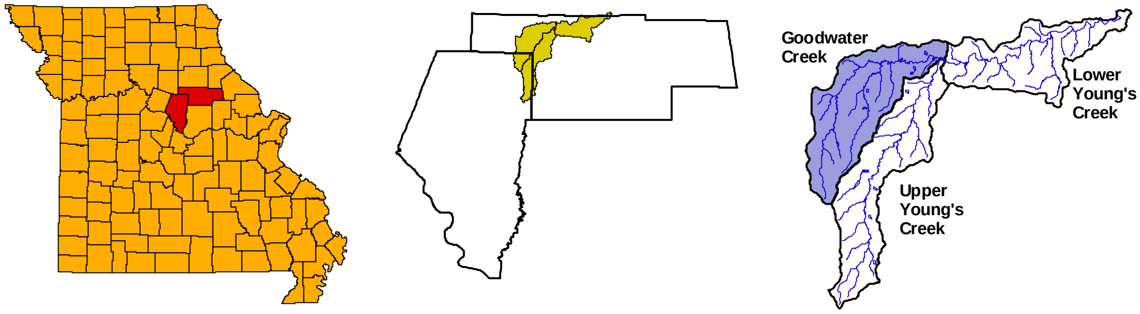

Figure 2.1 Location of the GCEW.

Soils within the basin were formed in Wisconsin and Illinoian loess overlying pre-Illinoian glacial till. Illuviation of the high clay content loess resulted in the formation of argillic horizons located 0.15 to 0.30 m below the soil surface containing 40-60% smectitic clays. The Adco-Putnam-Mexico soil association predominates in the flatter upland areas, and these soils tend to be less eroded and have greater depths to the claypan than the terrace areas. The Mexico-Leonard soil associations occur in more sloping terrace and alluvial areas where the depth to claypan is often <15 cm on side slopes because of erosion. The claypan is not present within alluvial areas immediately adjacent to streams. The naturally formed claypan represents the key hydrologic feature of the basin, and it is the direct cause of the high runoff potential of these soils. Most soils within the basin are classified in the hydrologic group C or D by the USDA Natural Resources Conservation Service (NRCS).

Claypan soils are characterized by the presence of a subsoil horizon with an abrupt and large increase in clay content compared to the overlying materials occurring within a short vertical distance in the soil profile (Soil Survey Staff, 1992; Soil Science Society of America, 1997). In the Midwestern U.S., the high-clay subsoil horizon in these soils occurs at depths varying from 13 to 46 cm with clay content ranging from 350 to 600 g kg^{-1} (Soil Conservation Service, 1981; Miles and Hammer, 1989; Natural Resources Conservation Service, 2001; Blanco-Canqui et al., 2002). The Midwestern U.S. claypan region encompasses an area of about 4 million ha within Missouri, Illinois, and Kansas (Anderson et al., 1990). The relatively low saturated hydraulic conductivity of the claypan perches water in the surface horizon creating a high probability of runoff in most years during the winter and spring periods (Blanco-Canqui et al., 2002). Due to the high shrink-swell potential of the smectitic clays present in these soils, there is also a high probability of annual shrinkage cracks forming in these soils during the late summer and early fall periods, which enhances the recharge of shallow aquifers during the fall and early winter periods each year (Baer and Anderson, 1997).

2.2 Atrazine

Atrazine (2-chloro-4-ethylamino-6-isopropylamino-S-tirazine) is an herbicide that is applied both pre- and/or post-emergence to stop broadleaf and grassy weeds in major crops such as corn and sorghum. It is sold under the trade names AAtrex®, Atratol®, Bullet®, and Lariat®. Atrazine has a wide range of reported property values. Table 2.1 is adapted from Hornsby et al. (1996).

Table 2.1 Reported Values for Atrazine (Hornsby et al., 1996)

Property	Values from Literature	Selected Default Values
Water Solubility (mg L^{-1})	20C: 30-70, 33, 52, 70; 27C: 33	33
Field Half Life (days)	18, 43, 45, 47-110, 48, 58, 60, 64, 74, 90, 119, 120	60
Sorption Coefficient (ml g^{-1})	38, 57-139, 72, 88, 102, 107, 111, 127, 149, 157, 163, 169, 170, 174	100
Vapor Pressure (mm Hg)	10C: 5.7×10^{-8}; 20C: 3×10^{-7}; 25C: 2.89×10^{-7}, 6.6×10^{-7}; 30C: 1.4×10^{-6}; 50C: 2.3×10^{-5}	2.89×10^{-7}
pK_b	25C: 12.32	12.32

The selected default values were chosen after efforts by the USDA Soil Conservation Service (SCS) in 1987 to develop a standard set of environmental parameters. Though the selection of which value to use is somewhat arbitrary, it created a standard to compare pesticides to each other so that modelers would use consistent values (Hornsby et al. 1996). In fact, the selected values are the default values used in the SWAT pesticide database.

Atrazine's high water solubility and low sorption coefficient cause most atrazine to be transported by water. Of atrazine removed from fields, 75 to 100% is in the water phase, leaving 25% or less to be removed through sediment losses (Wauchope, 1978; Baker et al., 1978; Baker and Johnson, 1979; Arora et al., 1996). Therefore soluble atrazine in runoff is the major pathway of atrazine loss.

Though the default half life for atrazine is 60 days, half life is a measure that varies widely and is dependent on soil texture, soil water content, temperature, and other environmental conditions. Atrazine concentration measurements in Goodwater Creek have resulted in dramatically shorter dissipation half lives. Ghidey et al. (1997) studied the spatial and temporal variability of atrazine from a 35-ha watershed located inside GCEW. Less than 2.5% of the atrazine applied was lost in runoff, and there was little subsurface movement of atrazine. Yet the concentration decreased rapidly over the growing season. The dissipation half life for atrazine was found to be 12 days. Ghidey et al. (2005a) studied the transport of atrazine from the corn phase of three cropping systems, also within Goodwater Creek watershed. The three cropping systems studied were: (CS1) mulch tillage corn-soybean rotation where atrazine was surface applied and incorporated, (CS2) no-till corn-soybean rotation with atrazine surface applied and not incorporated, and (CS5) no-till corn-soybean-wheat with a split atrazine application in 1997 and 1999, and not incorporated. Atrazine concentrations were studied for six growing seasons from 1997 to 2002. An event-based study of the herbicide concentrations showed that the half life for atrazine in CS1 was 11 days, CS2 was 3.9 days, and in CS5 was 5.8 days.

Typical atrazine management on tilled (conventional or conservation) corn consists of one application of 2.25 kg ha^{-1} during or shortly after planting at the end of April or beginning of May. In a no-till system, atrazine would be applied at 1.12 kg ha^{-1} about one month before planting to kill weeds. A second application would follow no-till planting (1 to 2 weeks after) at 1.25 kg ha^{-1}. No-till planting is typically two to three weeks later than conventional corn planting, possibly less during dry and warm planting seasons. Education efforts through the MSEA project in Goodwater Creek encouraged farmers to apply less atrazine after planting (1.25 instead of 2.25 kg ha^{-1})

followed with a second application later in June, if necessary. The second application could be atrazine or another herbicide.

Donald et al. (1998) used GCEW to study the spatial and temporal variability of herbicide concentrations within the watershed and to monitor changes in herbicide concentrations discharged form the watershed. Data were collected from 1993 to 1994 for atrazine, deethylatrazine, deisopropylatrazine, and metolachlor. Water samples were taken at all stream-road intersections. Samples were taken each year once before herbicide application, three times from May to June, and once more later in the year. Additionally, weekly grab and event-triggered automated samples were taken at weirs located 1.6, 14.5, and 17.7 km (1, 9, and 11 mi) upstream of the watershed outlet from 1992 through 1996. Herbicide maps showed that contamination was seasonal and widespread throughout the watershed. Temporal studies of herbicides showed seasonal cycles and peak concentrations in May. The maximum atrazine concentrations leaving the watershed were greater than reported in other studies for watersheds with lighter textured soils without claypans. However, only about 20% of the watershed was in corn or sorghum, which receive atrazine applications. The study concluded that alternative forms of weed management needed to be implemented to reduce herbicide use, and better management needed to be used to control the runoff in claypan watersheds.

Hall et al. (1972) studied atrazine losses in runoff and soil sediment from plots over a 2-yr period (1967-1968). Corn plots were established on Hagerstown silty clay loam with 14% slope. Atrazine was surface applied pre-emergence to corn at seven rates (0, 0.6, 1.1, 2.2, 4.5, 6.7, and 9.0 kg ha^{-1}) with one replicate. Effluent samples were collected and analyzed for atrazine in solution and adsorbed to soil. Soil core samples were also collected to measure the rate of atrazine dissipation over the two growing seasons. Average atrazine losses for runoff and sediment were 2.4 and 0.16%, respectively, of total applied in 1967. The next year, the average overall loss for runoff and sediment was 0.01%. Soil cores taken one month after application in 1967 showed that an average of 67.9% of the atrazine remained in the soil with levels dropping to 21.4% three months later. At the same sampling intervals the next year, 15.9 and 5.4% of the total applied atrazine remained in the soil. In 1969, oats were planted to survey the residual atrazine. Atrazine toxicity was found, especially in the plots with the two highest treatments of atrazine.

2.3 Management Practices

Arora et al. (1996) studied the effectiveness of vegetative filter strips (VFS) consisting mainly of bromegrass at retaining herbicides (atrazine, metoachlor, cyanazine) in surface runoff under natural rainfall conditions in central Iowa. The surface runoff originated from a Canisteo silty clay loam source area of 0.41 ha with an average slope of 3%. The source area was fall chisel-plowed, spring disked, and planted in corn. Atrazine was applied at 2.12 kg ha^{-1}. All runoff from the field was collected and redistributed onto the VFS plots using weirs to regulate flows. Two source to VFS area ratios were used: 15:1 and 30:1. The study took place over 2 years in 1993 and 1994 with data collected for 15 runoff events. Herbicide retention was mostly dependent on the antecedent moisture conditions of the VFS. The VFS were found to retain 11 to 100% of atrazine. The different area ratios did not indicate statistically different results. Infiltration was found to be the key process for herbicide retention; however, sediment retention represented about 5% of atrazine retention. Since the strips were found to retain 40 to 100% of the sediment, VFS would be more effective for more strongly adsorbed herbicides.

Boyd et al. (2003) studied the effectiveness of VFS (consisting mainly of brome grass) at reducing the transport of sediment and pesticides (atrazine, acetochlor, and chlorpyrifos) with surface runoff under natural rainfall conditions in central Iowa. In the study, Atrazine was surface applied at 1.68 kg ha^{-1} at the time of planting onto a 0.58-ha field. The field mainly consisted of Canisteo silty clay loam with an average slope of 3.5%. All runoff from the field was collected and redistributed onto the VFS plots using weirs to regulate flows. Pesticide concentrations were also measured from a single subsurface drainage tile pipe. Two source to VFS area ratios were used: 15:1 and 45:1. Five runoff events occurred during the study in May and June of 1999. The study found that rainfall timing and intensity, hydrology, source to VFS area ratios, and adsorption property of the pesticide all affected transport. Atrazine and acetochlor loss were highly dependent on infiltration efficiency of the VFS, and sediment trapping efficiency had less impact because the herbicides are only moderately adsorbed. A smaller source to VFS area ratio provided reduction in atrazine loss in water; however, the means were not significantly different between the two ratios. Atrazine concentration measurements taken the subsurface drainage tile were not detectable at the relatively high limit of detection, so it is not possible to infer very much from these measurements. The greatest statistical differences between the two area ratios were observed with smaller events.

Misra et al. (1996) evaluated the source area to VFS ratio effectiveness in removing two nominal concentrations of herbicide dissolved in runoff water under simulated rainfall. Tests were conducted on brome grass-covered Storden loam soil with average slopes of 2 to 3%. Rainfall was simulated using a 15.2-m diameter, rotating, overhead-boom simulator at a rate of 6.35 cm h^{-1} for 1 h. Source area to VFS ratios used were 15:1 and 30:1. The upslope runoff rate was assumed to be 1.22 cm h^{-1} and inflow was supplied to the VFS at either 57 or 114 L min^{-1}. Herbicides (atrazine, metachlor, and cyanazine) were added to the inflow at two nominal concentrations: 0.1 and 1.0 mg L^{-1}. Additionally, potassium bromide (KBr) was added to the inflow as a tracer at a concentration of 100 mg L^{-1}. Reductions of 37 and 41% were measured for atrazine in the 15:1 and 30:1 plots, respectively. No significant difference between the drainage area ratios in the removal of herbicide was found. Significantly different reductions of 29 and 49% were measured for atrazine inflow concentrations of 0.1 and 1.0 mg L^{-1}, respectively. It was determined that infiltration was the major factor in the reduction of herbicides using the KBr tracer.

Arora et al. (2003) conducted a study to compare two source area to vegetative buffer strip (VBS) ratios and their effectiveness at reduction of pesticides (atrazine, metolachlor, and chlorpyrifos) under simulated rainfall. Vegetative buffer strips were established from mainly brome grass on a Clarion loam soil. The vegetated buffer strip plots were pre-wetted with 25 mm of simulated rainfall using a sprinkler system for 30 min to replicate antecedent moisture conditions that might occur prior to runoff in natural rainfall. No rain was simulated onto the plots during the experiment to prevent dilution of pesticides. Water was pumped onto the plots at a variable rate (faster then slower to simulate a natural hydrograph) equivalent to a 10.7-mm runoff event. Pesticide-treated soil was added to the runoff water so that sediment concentrations were similar to expected concentrations. Pesticides were added to the soil at the nominal concentration of 100 mg of each pesticide per kg of soil creating concentrations similar to the top 2 cm of soil one day after surface pesticide application. Inflows to VBS plots were designed to simulate 15:1 and 30:1 source area to VBS ratios. Results showed that the 15:1 and 30:1 ratios allowed for 38.8 and 30.4% runoff infiltration, respectively. Sediment was reduced by 90.1 and 86.8% for the 15:1 and 30:1 ratios, respectively. On average, the 15:1 source to VBS ratio reduced total atrazine by 52.5%, and the 30:1 ratio reduced total atrazine by 46.8%. These results were not statistically different, which leads to the conclusion that either more replicates were needed to determine significance or less area can reduce sediment and pesticides as effectively as a greater area.

Baker et al. (1978) compared the effect of tillage systems on pesticide losses using simulated rainfall. A randomized complete block design was used to assign six tillage practices (conventional, till-plant, chisel, plow, disk, ridge-plant, and fluted coulter) to plots of corn with two replications. Plots were established on Ida (sandy clay loam), Tama (sandy clay loam), and Kenyon (silt loam) soils with average slopes of 12.2, 4.7, and 4.8%, respectively. Fonofos insecticide was applied at planting for all plots and incorporated except on the Ida soil plots. The period between application and rain simulation was 16 to 23 days for Ida soil, 11 to 17 days for Kenyon soil, and 28 to 35 days for Tama soil. Herbicides alachlor and cyanazine were applied about 48 h before simulations at 2.24 kg ha^{-1}. Rain simulations were designed around a 50-yr return period for Central Iowa with a 1.4-h rain at 6.35 cm h^{-1}, followed by a 1-h rain at 6.35 cm h^{-1}the next morning and a 0.5-h rain at 12.70 cm h^{-1}. Results showed that pesticide concentrations in runoff water were correlated with the amount of residue cover, and pesticide concentrations in sediment were usually not correlated with residue cover except for fonofos on Tama and Kenyon soils and cyanazine on Tama soil. Total fonofos loss averaged 1.8% of total applied, and the major carrier was sediment. Therefore, tillage practices that decrease erosion should also decrease fonofos loss. The residue on the soil surface was found to intercept the sprayed on herbicides and to hold the herbicide less tightly than the soil might, making it susceptible to washing. Herbicide loss in sediment ranged from 5 to 10% and was less than the ratio of water to sediment lost allowing the conclusion that water was the main transporter of herbicides. Decreased herbicide losses resulting from decreased runoff through conservation tillage were negated by runoff having higher herbicide concentrations. Conventionally tilled plots lost 8.0 and 9.7% of the total alachlor and cyanazine applied, respectively, whereas conservation tillage plots lost 7.9 and 11.0%, respectively.

Baker and Johnson (1979) examined pesticide losses in runoff from small watersheds continuously planted with corn under different tillage systems. Six watersheds ranging in size from 0.55 to 1.75 ha were instrumented in Castana, Iowa. Soils were silt loams from loess parent material. Average slopes for the watersheds ranged from 12 to 18% with soil organic matter content ranging from 1 to 3%. The three tillage systems studied were conventional till, till-plant, and ridge-planting. The systems had residues of 3, 20, and 45%, respectively. Herbicides (atrazine, alachlor, or cyanazine) were broadcast applied immediately after planting. Atrazine was applied at a rate of 2.24 kg ha^{-1} and not incorporated. An insecticide, fonofos, was also applied. Atrazine half life was estimated to be 51 days in the study. The greatest pesticide losses were attributed to the first runoff event, with decreasing losses with subsequent runoff events. Pesticides remained concentrated in the top 5 cm of soil. Eighty to 90% of the average herbicide transport losses were attributed to water transport. Ridge-planting and till-plant reduced soil loss 10 and 35%, respectively. Runoff amounts for both conservation till systems were about 40% less than the conventional till system. Atrazine and cyanazine were found to have losses of 59% for ridge-plant and 42% for till-plant compared to losses from conventional till. In the second year of the study, 1973, conservation tillage herbicide concentrations were twice those of conventional tillage on average for the first runoff event occurring 15 days after application. This is thought to be due to herbicide washing off of residue. The average total growing season losses for all pesticides were less than 2%.

Shipitalo et al. (1997) studied runoff from chisel plowed and no-till watersheds for herbicide losses in a corn soybean rotation with a rye cover crop after soybean harvest. Two chisel plowed watersheds and two no–till watersheds were monitored for four years in the North Appalachian Experimental Watershed near Coshocton, OH. Chisel plowed watersheds had slopes of 13 and 7% with Rayne silt and Keene silt soils, respectively. No-till watersheds had slopes of 11 and 10%, both with Coshocton silt soil. Alachlor, atrazine, Linuron®, and metribuzin were sampled in runoff. Average atrazine losses were 0.31%, which was the greatest of the four herbicides studied. Atrazine concentrations often exceeded the health advisory level-maximum contaminant level (HAL-MCL) of 3 $\mu g\ L^{-1}$ and were detectable both after harvest and in soybean rotation years. Linuron® is a comparable herbicide to atrazine, and the Linuron® average losses were significantly less than atrazine losses. Additionally, Linuron® was rarely detected after corn harvest or during soybean rotation years. Average herbicide losses were always greater for no-till fields as was runoff. This was believed to be due to the hydrologic characteristics of the watersheds and not solely due to tillage practice.

2.4. SWAT

Soil and Water Assessment Tool is a processed based, physical model that was developed by the USDA-ARS for modeling nonpoint source pollution from agricultural sources (Arnold et al., 1998; Nietsch et al., 2002). SWAT is a long-term watershed-scale model and is not designed to model single-event or field scale-outcomes. The SWAT program models many environmental processes from runoff, erosion, and chemical transport.

The SWAT model manages pesticides through several equations. Some of the key equations for atrazine are listed below, but a complete explanation of pesticide transport and transformation can be found in the Soil and Water Assessment Tool Theoretical Documentation version 2000 (Nietsch et al., 2002). The process of calculating pesticide at the outlet of the watershed starts right after application. Some pesticide may end up on foliage. The program calculates degradation on the foliage based on a foliar half life (HLIFE_F). Rain events may wash off some of the pesticide on the leaves which is also calculated. Once in the soil, degradation is calculated again with the soil half life (HLIFE_S). The concentration of pesticide in each soil layer is calculated and degradations are figured separately and independently.

Pesticide is often transported in solution or adsorbed to sediment that is eroded. The SWAT program partitions pesticides between soluble and adsorbed phases based on the adsorption coefficient of the pesticide (K_P). However, different soils may have varying organic carbon contents which affect the ability of the pesticide to adsorb to soil. The normalized organic carbon coefficient (K_{OC}) is used to correct the K_P. Soluble pesticide may be transported with runoff, lateral flow, or percolation. Pesticide adsorbed to soil particles may be transported to the channel along with runoff. In large watersheds, with increased time to concentration, adjustments may be made to increase storage in the watershed and delay the arrival of runoff using the SURLAG parameter. This could have significant effect on when a pesticide is detected at the outlet of a watershed.

Pesticides can undergo several processes once in the channel. Pesticides may partition into solid and liquid phases depending on the pesticide's adsorption coefficient and the amount of suspended sediment in the channel. Pesticide will be lost through degradation or volatilization. Particulate sediment can settle out of suspension and become part of the channel bed.

Pesticide in the sediment of the channel can partition back into the liquid phase, degrade, or resuspend with sediment. Attached pesticide in the channel bed can be lost by burial where the pesticide cannot degrade or reenter the system. Diffusion can also cause pesticide in the liquid phase to attach to the sediment in the channel bed, depending on pesticide concentration.

Ramanarayanan et al. (2005) used the SWAT model to study the transport and fate of isoxaflutole and RPA 202248 in semistatic water bodies. Isoxaflutole is a soil-applied corn herbicide and requires less active ingredient per application than atrazine. RPA 202248 is the metabolite of isoxaflutole. These two compounds were combined and designated as total relevant residue (TRR). A conceptual model was developed to understand the drivers and processes affecting the TRR. This model was implemented through SWAT. The study summarized the assessment of four watersheds: La Belle Lake and Grindstone watersheds in Missouri, Bluestem Reservoir watershed in Nebraska, and Rathbun Reservoir watershed in Iowa. Information about purchase and application of isoxaflutole was collected for the watersheds. Water quality had also been monitored for the watersheds from 2000 to 2004. An unknown source of isoxaflutole in the La Belle watershed (there was no known use within the watershed) created a unique opportunity to calibrate the degradation of TRR. The TRR degradation was applied in the other watershed's models. Long-term simulations were conducted from 1983 to 2002 on the three other watersheds. Through simulation and analysis, the study concluded that the SWAT program could adequately model the fate and transport of the TRR in a watershed and water body. This could allow less extensive water quality monitoring. There were four factors that provided the greatest influence on the TRR: (1) management practices, (2) watershed morphology, (3) magnitude and timing of runoff events, and (4) rate of degradation within the water body. Time series analysis of the long-term modeling indicated that there was no evidence of long-term accumulation of the TRR despite possible estimated persistence because the degradation rate for TRR is 460 days.

Vazquez-Amabile et al. (2006) analyzed nonpoint-source pollution caused by atrazine using SWAT. St. Joseph River watershed is 2,809 km^2 situated on the borders of Northeast Indiana, Northwest Ohio, and South Central Michigan. St. Joseph River watershed is mostly agricultural with corn and soybeans being the major crops. The dominant soil textures in the watershed are silt loam, silty clay loam, and clay loam, with 24.1% of the watershed's soils hydrologic class B and 72.6% hydrologic class C. Water quality data were used from 10 sampling sites within the watershed from 1996 though

2002. The model was first calibrated and validated for streamflow and then for atrazine. Calibration of the atrazine model involved reducing the pesticide percolation coefficient (PERCOP) and increasing the foliar wash off fraction of pesticide (WOF). Additionally, atrazine application dates also had to be delayed until three days after planting. The study completed risk analysis on atrazine by running simulations for 50 years using observed weather for three scenarios: (1) early planting, (2) average planting, and (3) late planting. Though the SWAT model does not perform risk analysis, it produces enough information to complete one. The study concluded that SWAT performed well in predicting the general trend of atrazine concentrations. The model output showed that the MCL of 3 μg L^{-1} was often exceeded between May and July. The study found that date of application was very important to the model's ability to predict concentrations and that improved data through remote sensing may help to produce better crop area estimate for improved modeling.

CHAPTER 3

MATERIALS AND METHODS

3.1 Instrumentation and Data Collection

The USDA-ARS Cropping System and Water Quality Research Unit (CSWQRU) in Columbia, MO has been collecting and maintaining data from GWEC. They are currently working to make the data available in a web-compatible format. A complete summary of datasets existing for GCEW has been described by Sadler et al. (2006).

Topography of the watershed is nearly level, with most areas having 0-3% slopes, but the natural drainage system is well developed (fig. 3.1). The GCEW includes part of Centralia, a small town (population 3,700) located at the southern end of the watershed. The remainder of the watershed is mostly agricultural with row crops (70% consisting of corn, wheat, soybeans, and sorghum), grassland (10%), and woodland (10%). Audrain and Boone counties receive about 1000 mm precipitation per year, 75% of it during March through October. The average temperature is 0^{o}C in the winter and 22.5^{o}C in the summer.

Rainfall within the watershed has been monitored continually from 1971 to the present. An automated weather station was installed in 1991 and is located in the southeast portion of the watershed (fig. 3.1) at a MSEA established research field. Precipitation events were also measured throughout the watershed using recording rain gauges. There are 18 variables associated with the climatic database, including precipitation, wind speed and direction, solar radiation, temperature, and humidity. Observations for most of the climatic variables are recorded on a mean hourly or daily basis and stored in a climatic database.

In 1971, the watershed was instrumented with broad-crested v-notch concrete runoff weirs to measure streamflow. Weirs were installed so that three nested sub-watersheds were created. Weir 1 was installed 1.6 km (1 mi) from the watershed outlet and gauged 99.9% of the watershed. Weir 9 gauged 43.6% of the watershed and was installed 14.5 km (9 mi) from the outlet. The smallest sub-watershed was gauged by weir 11 that covered 16.7% of the watershed and was installed 17.7 km (11 mi) from the outlet. Data from weirs 9 and 11 were not available for use at the time of this study, and only data from weir 1 were used in this study. Figure 3.1 shows the locations of the rain gauges, weather station, and weirs within the watershed.

Stream surveying and flow measurements were used to develop a rating curve for Goodwater Creek (E.J. Sadler, personal communication, October 2006, fig. 3.2). Since Goodwater Creek is a dynamic stream, new points are periodically added after a stream survey. Streamflow discharge from the weir was separated into base flow, which accounts for about 15%, and surface runoff, which accounts for about 85% of total streamflow, by analysis of runoff hydrographs (Alberts et al., 1995). Mean annual streamflow (surface runoff plus base flow) is 292 mm in Goodwater Creek watershed, which is about 30 percent of mean annual precipitation (Anonymous, 1995).

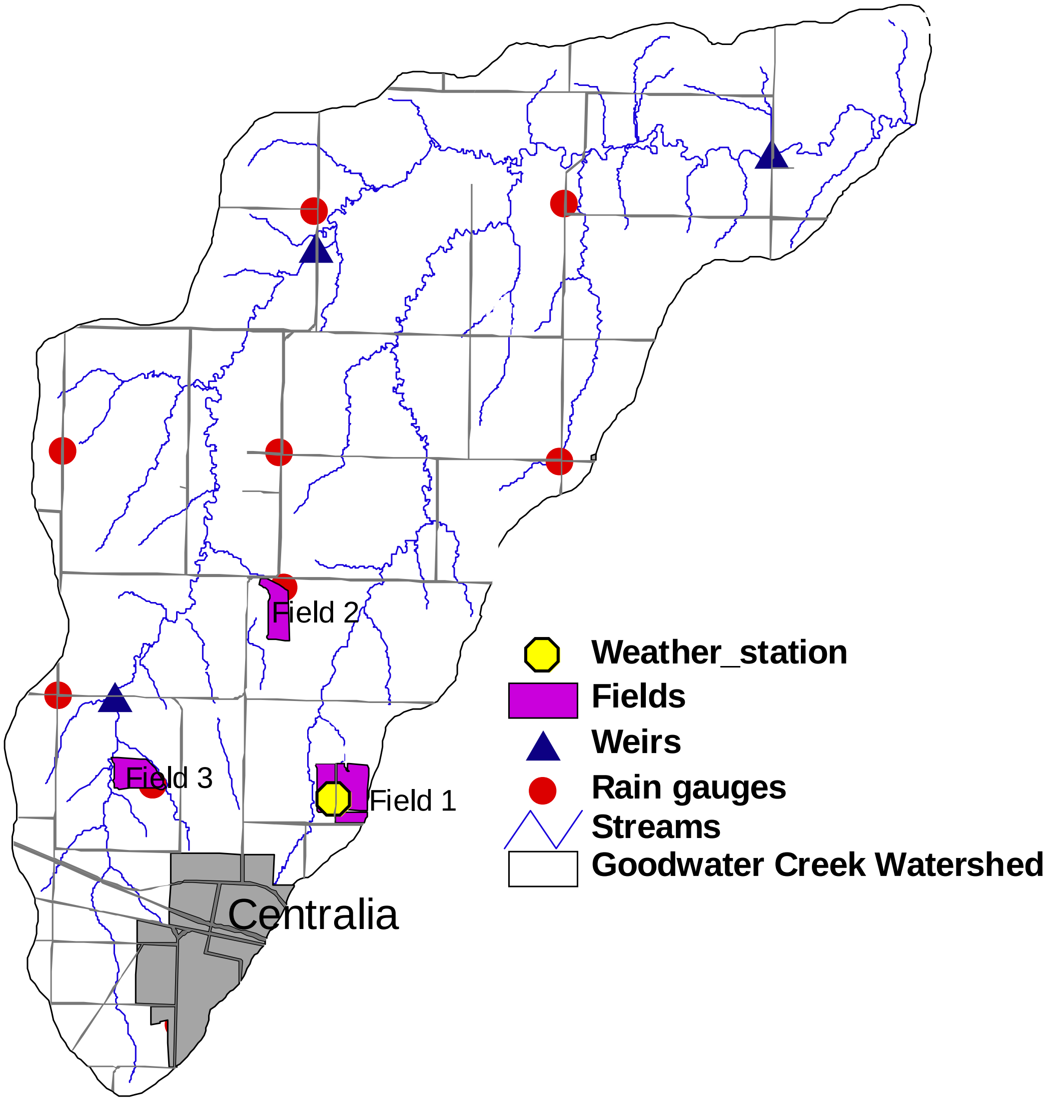

Figure 3.1 Research infrastructure of the GCEW.

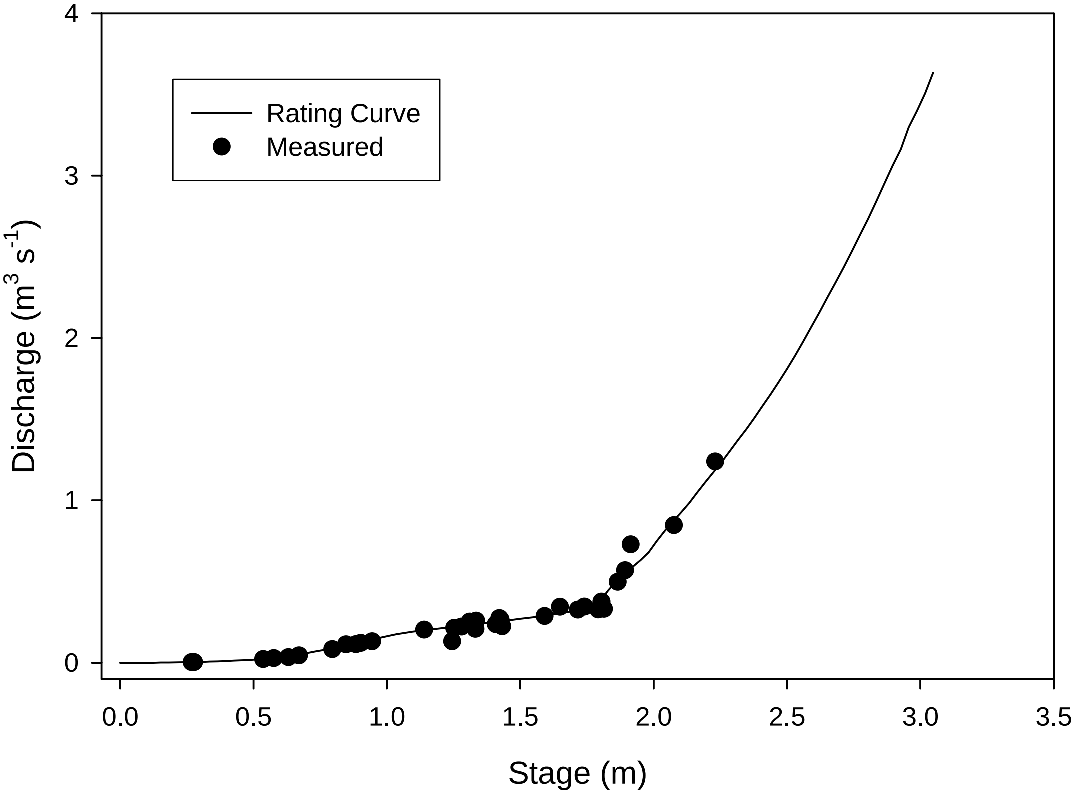

Figure 3.2 Weir 1 rating curve for GCEW.

Goodwater Creek became a part of the Missouri MSEA project in 1991 and water quality monitoring was increased after the initiation of the program. Surface water quality has been evaluated from analyses of weekly grab samples collected at the weir and from analyses of automated samples collected with a flow-proportional automated sampler installed at the weir 1. Streamflow was measured continually using a Teledyne Isco (Lincoln, NE) 3230 bubbler level sensing monitor. Automated water samples were taken with an Teledyne Isco 3700 refrigerated unit. The automated sampler is programmed to take samples throughout rain events and is activated to sense for events when stage exceeds 0.15 m stage height (the threshold of flow over the weir).

Water quality at weir 1 has been monitored since fall of 1991. Samples were analyzed for concentrations of sediment, nutrients (NO_3-N, NH_4-N, and PO_4-P), and herbicides (acetochlor, alachlor, atrazine, deethylatrazine, deisopropylatrazine, metolachlor, and metribuzin). Some herbicides were not analyzed for this entire period of record, but all herbicides listed above have been analyzed for a minimum of nine years. Atrazine was selected for evaluation in this project due to its high level of use in the watershed, and the available data which extend from 1993 to 2003.

Atrazine samples were refrigerated until processing and filtered through 0.45 μm nylon filters. Gas chromatography (GC) was used for analysis until conversion to gas chromatography and mass spectrometry (GCMS) in March 1998. Detection limits were 0.04 μg L^{-1} for GC and 0.003 μg L^{-1} for GCMS. All samples were analyzed by the CSWQRU (Lerch et al., 1995, 2003).

A computer program was used to create a continuous dataset of atrazine concentrations and loads. There were several obstacles in creating this dataset. One major hurdle was that streamflow and atrazine samples do not necessarily coordinate in time. Streamflow data were logged on 5-min intervals. Grab samples were collected weekly, and date and time were recorded for each sample. Auto samples were triggered by runoff events with start and stop times, and one concentration was assumed for the entire sample over that period. The program first compared sample times with the times recorded for runoff. If a sample occured when there was no runoff data point, the program created a point within the runoff dataset for that time and used linear interpolation to calculate a flow value from the record just before and after the point to be added. Next the atrazine sample file was joined with the runoff times, and concentrations were applied at the point in time at which they occurred. In the case of an auto sample, the concentration was applied across the sampling period.

The program used specific rules to apply the atrazine concentrations across the runoff data where corresponding atrazine concentrations did not exist. The first concentration after a runoff event began was applied as the concentration from when the hydrograph began. There was usually some time between samples. Linear interpolations were used to calculate concentrations from sampling period midpoint to sampling period midpoint (in the case of a grab sample, the midpoint was the point in time when the sample was taken). Grab samples that occurred during auto samples were ignored.

After concentrations were applied across the runoff record, calculations were used to compute load by integrating to find the volume of runoff and multiplying it by the corresponding concentration. This was summed to create a load record with a daily time step. To get back to a daily concentration, loads were divided by the daily flow. During data analyses, daily concentration and loads were only used on the days where an atrazine sample occurred. This was done to remove error that could be caused by the rules for applying concentrations across the runoff data used in the program.

3.2 Management Practices

One of the objectives of this study was to determine whether BMPs implemented within Goodwater Creek have had a quantifiable impact on water quality. In order to do this, a record of BMPs implemented within the watershed was established. Location, type, and area protected by BMPs that were established in 1990 or later were provided by NRCS offices from Boone and Audrain counties. The main BMPs in the watershed include vegetative waterways and terraces (with and without underground outlets). Other minor BMPs in the watershed consist of conservation reserve program (CRP), vegetative filter strips, vegetative buffers, water diversions, lagoons, and prescribed grazing. From 1990 through 1993, 360 ha of the watershed area (5%) was protected by BMPs. By 2003, that amount increased to 1,068 ha (14.7%) (Table 3.1). Figure 3.3 shows the amount of area protected by BMPs.

Table 3.1 Increase in BMP Protected Area from 1993-2003

BMP	Area (ha) protected by: 1993	Area (ha) protected by: 2003	Increase
Terraces	105	209	99%
Vegetative waterways	224	657	193%
Other BMPs	32	202	531%
Total	360	1,068	197%

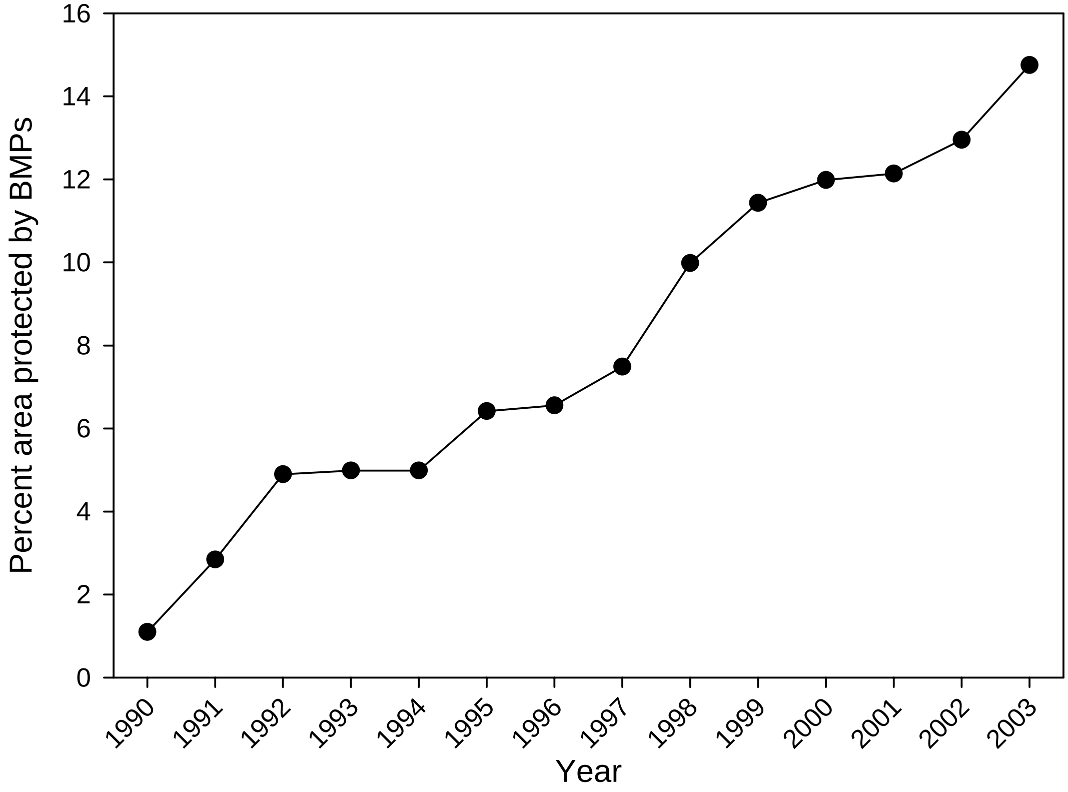

Figure 3.3 Percent area protected by BMPs in GCEW.

Through the MSEA project, educational efforts were made to promote conservation tillage and no-till practices, and better equipment was made available through the Soil and Water Conservation District (SWCD). These two factors resulted in a large increase in conservation and no-till implementation in the 1990's. Data collected for Audrain County shows that most of the change in tillage practice occurred from 1992 to 1994. Implementation has remained stable with about 70 to 80% of cropped land in Audrain County in conservation and no-till practices from 1995 to 1998 (fig. 3.4, CTIC, 2006).

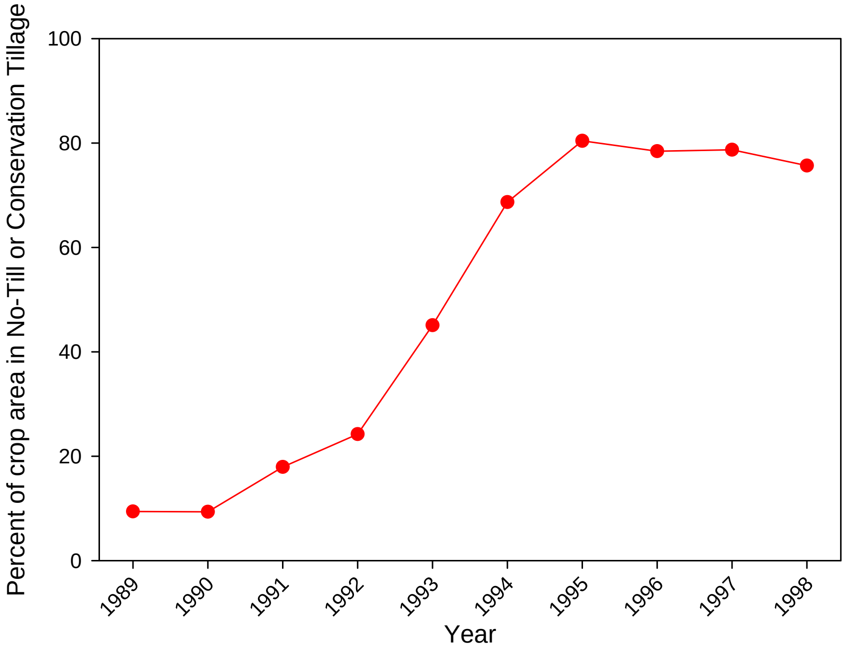

Figure 3.4 Percent of Audrain County crop area in no-till and conservation till.

To represent the BMP increases within Goodwater creek watershed for statistical purposes, datasets were created that accounted for the percent of the watershed in BMPs. The amount of area protected by BMPs was constant throughout the year since that was the smallest time interval for which information was available. Two datasets were created. The first represented all practices in the watershed. The second represented only the area protected by grassed waterways. A third dataset was examined to represent the amount of the watershed in conservation and no till systems, but there were not enough years of information to use this variable to show any significant trends. Table 3.2 shows percent by year for all BMPs and grassed waterways.

Table 3.2 Percent of GCEW Protected by All BMPs or Grassed Waterways by Year

Year	All BMPs	Grassed Waterways
1993	5.0	3.1
1994	5.0	3.1
1995	6.4	3.9
1996	6.6	3.9
1997	7.5	3.9
1998	10.0	6.0
1999	11.4	6.6
2000	12.0	6.6
2001	12.1	6.6
2002	13.0	7.3
2003	14.8	9.0

3.3 Statistical Analysis and Modeling

Both the concentration and loading of atrazine were evaluated for statistical trends. Data were examined with SAS (version 9.1) using the Regression (REG) and General Linear Model (GLM) procedures. Both REG and GLM procedures are regression procedures. The REG procedure performs a linear regression. The GLM procedure uses the method of least squares to fit the general linear model (SAS, 2002).

Different time periods were studied to see distinction in trends on a monthly, seasonal, and yearly timescale. To determine what periods of time best explained the most data regarding atrazine concentrations and loading, the REG procedure and the model selection procedure RSQUARE (which selects a model based on the highest r^2 in a range of model sizes) were used.

After determining what time periods to examine, the REG and GLM procedures were used to determine the significance and direction of models tested. Annual data were centered on the year 1998 to reduce the variance inflation factor (VIF). The STEPWISE model selection command was also used with the REG procedure to find additional significant models.

The covariate procedure was used to better examine the effect of BMPs on reducing atrazine losses in the watershed. Daily precipitation was selected as the covariate and the percent of area protected by BMPs was selected for treatment. There were several classes of treatment that corresponded to the percent area protected by BMPs. The SAS program evaluated the atrazine data for each class by determining the slope of a regression for data within that class. The slopes of the various classes were tested for parallelism using the GLM procedure. If the slopes were found to be parallel, the LSMEANS procedure was used to compute the least squares means adjusted to the covariate mean. The adjusted means for each class were then compared, pair-wise, to test for significance. If the slopes were not found to be parallel, the slopes for each class of treatment were compared using a contrast.

3.4 SWAT Modeling

A model pre-calibrated for flow was used as the basis for an atrazine calibrated model (Ghidey et al., 2005b). The model was developed using AVSWAT-X for SWAT

2005. The watershed was set up with seven subbasins. Thresholds were applied to reduce the number of land uses and soils in the watershed. To be included, a land use had to occupy at least 7% and a soil had to cover at least 10% of the subbasin in which it was located. That resulted in 15 landuses and 11 soils, creating 317 hydrologic response units (HRUs). Appendix A shows land use and soil type for watershed as well as the HRU composition of each subbasin.

The model calibration period was 1993-1998. The validation period was 1999-2003. The model calibration and validation were evaluated through the linear regression (r^2) method and the Nash and Sutcliffe (1970) efficiency equation:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n} \left(Q_{mi} - Q_{ci}\right)^2}{\sum_{i=1}^{n} \left(Q_{mi} - Q_{av}\right)^2} \tag{3.1}$$

where E_{NS} is the efficiency of the model, Q_{mi} are measured values, Q_{ci} are simulated values, and Q_{av} is the average measured value. The r^2 method measured the correlation between measured and simulated data. The Nash and Sutcliffe equation measures how simulated data plotted against observed data fit a 1:1 line with a value of 1 being the best. Tables of the original and calibrated input parameters and the results of the calibration and validation periods can be found in Appendix B (F. Ghidey, personal communication, June 2006).

The baseline model uses real weather data collected from within the watershed including temperature, rainfall, solar radiation, wind speed, and relative humidity (Sadler et al., 2006). Simulations were run from the first day of 1992 through the last day of 2003. Rainfall parameters were set to skewed normal. The Priestly-Taylor method was used to calculate potential ET. Muskingum channel routing method was used with active channel dimensions. Other basin inputs were set to default unless otherwise specified in table B.2 and B.3 of Appendix B due to calibration modifications (F. Ghidey, personal communication, June 2006).

Early in the development of the model, simulations showed that a constant date of application of atrazine was not appropriate for all years. In some years, it resulted in atrazine being applied on the same day as a rain event. To address this problem, a 12-yr management rotation was used to apply atrazine on a reasonable date when it was not raining. These dates were determined through studying weather records and corn planting progress records for Missouri's Northeast district (G. Danekas, personal communication, June 2004). Management files and other input parameters for crops and their various tillage systems can be found in Appendix C. Appendix D shows corn planting progress records and hydrographs used to determine atrazine application dates (E.J. Sadler, personal communication, Nov. 2006).

Initial study of atrazine in the flow-calibrated model showed that atrazine levels spiked to artificially high levels and then retreated very quickly. Several solutions were implemented to improve the predicted atrazine levels in the model. The flow-calibrated model did not include the approximately 200 ha of riparian areas in the watershed. The riparian areas were accounted for by adding 12-m wide filterstrips (FILTERW) in 50% of the corn, soybean, sorghum, and wheat HRUs. Filterstrips were added based on the percent of area the subbasins occupied in the watershed. A list of which land uses had filterstrips added can be found in table E.1-E.7 in Appendix E. Studies completed on GCEW indicated that dissipation half lives as sampled from within the creek are much less than the SWAT herbicide database value of 60 days (Ghidey et al., 1997, 2005a). The half life for atrazine was changed to 12 days (HLIFE_S) based on these studies. All other parameters were left at their default values.

Calibration of the model for atrazine was evaluated using frequency duration curves of atrazine loadings and concentrations at the outlet of the watershed (subbasin 7). The curves are created by ranking values in ascending order and using the Cunnane plotting positioning formula (Bobée and Ashkar, 1991):

$$P_k = \frac{k - 0.4}{N + 0.2} \tag{3.2}$$

where N is the rank of the data point and k is the corresponding data point. The Cunnane formula assigns a frequency to the point. The simulated values are compared to the observed data.

Two scenarios were run to better understand the effect of BMPs and alternative tillage systems. The first scenario was designed to see if SWAT outputs a difference based on the maximum amount of area protected by grassed waterways. The maximum was in 2003 when 9% of the watershed was protected by grassed waterways. To implement the BMP in SWAT, a 12-m wide filterstrip (FILTERW) was used and the subbasin slope length (SLSUBBSN) was decreased by 50%. To implement the BMP on an appropriate amount of area, it was assumed that half of the waterways existed on soybean HRUs and half existed on corn HRUs, but atrazine is not applied to soybeans so the filterstrips were only added to corn fields. Therefore, approximately 326 ha of corn HRUs had grassed waterways added to them. Each of the three corn tillage systems (conventional, conservation, and no-till) received 1/3 of the 326 ha. The locations of the

HRUs that had added filterstrips were arbitrary because each tillage system received equal amounts. Table 3.3 shows the distribution of area for grassed waterways by tillage systems and subbasin.

Table 3.3 Distribution of Grassed Waterways (ha)

Subbasin	Conventional	Conservation	No-Till
1	0	0	38.0
2	0	41.7	0
3	58.7	40.2	0
4	32.0	0	0
5	20.9	0	20.4
6	0	27.2	0
7	0	0	48.2
Total	111.6	109.1	106.6

The second scenario studied the difference in increased conservation and no-till management. According to the Audrain county tillage systems records (CTIC, 2006), 1993 had the least area in conservation and no-till tillage, and 1995 had the greatest (the public domain data ended in 1998). Two management schemes were created where the tillage systems for corn were redistributed to match the tillage distributions of 1993 and 1995. Table 3.4 shows the area distribution for the two scenarios. Appendix F lists percent area of each tillage system for the baseline, minimum, and maximum tillage distribution models.

Table 3.4 Percent Area in Tillage Systems

Year	Conventional	Conservation	No-Till
1993	42.85	23.15	34.00
1995	27.12	39.83	43.05

CHAPTER 4

RESULTS

4.1 Atrazine Usage and Climate

To get a more complete understanding of atrazine levels within Goodwater Creek watershed, a better understanding of influencing factors is needed. One of the greatest influencing factors is the amount of atrazine applied in the watershed. The only crops grown in Missouri that would receive atrazine are corn and sorghum. Data for Audrain county showed that there was a significant increase ($P>0.001$) for area in corn production from 1993 through 2003. The opposite was true for sorghum production, with a significant decrease ($P>0.006$). Despite the diverging trends, the increase in corn production out-weighs the area taken out of sorghum production. Figure 4.1 shows corn and sorghum production for Audrain County. Table G.1 in Appendix G lists area in production by crop for Audrain County.

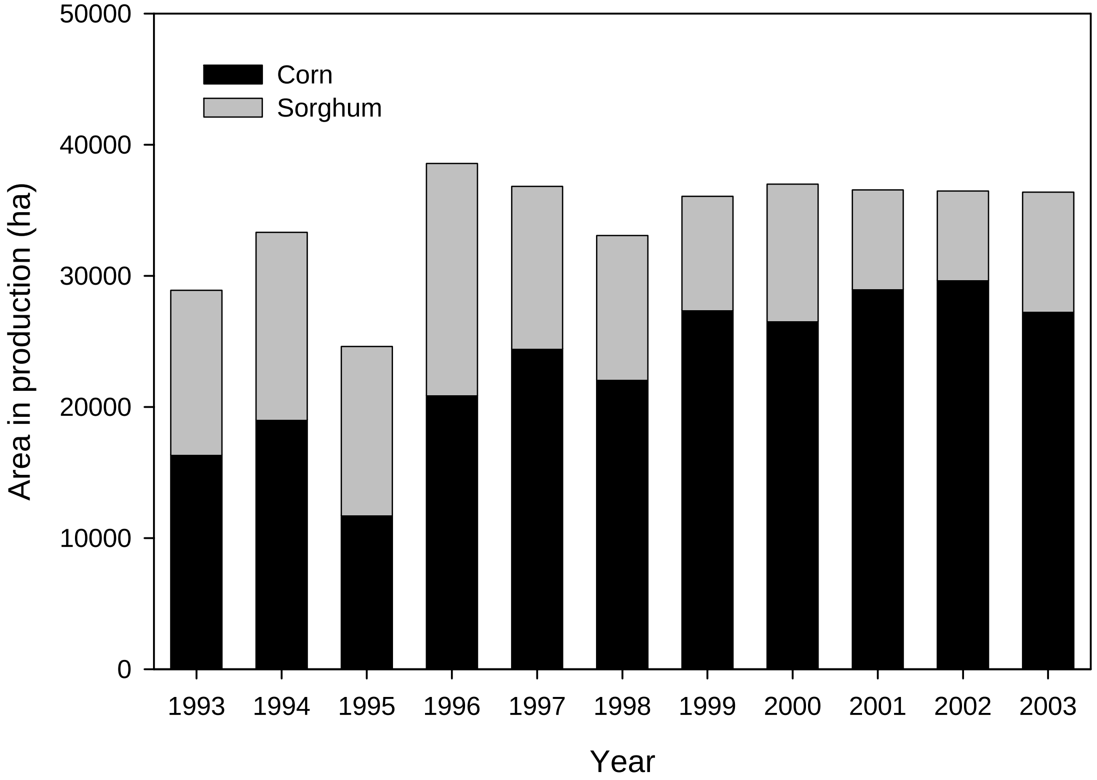

Figure. 4.1 Area in corn and sorghum production for Audrain County.

Statewide atrazine application data for Missouri were available from the National Agricultural Statistics Service (NASS) database. These data indicate an increasing area in Missouri corn production ($P>0.049$), the relative percent of corn area receiving atrazine has remained the same (fig. 4.2). This results in a greater total amount of atrazine applied per year ($P>0.009$, fig. 4.3). Table G.2 in Appendix G lists details of Missouri's atrazine usage. Missouri-wide data for atrazine application for sorghum was available for only 2003 with 94% of sorghum treated with atrazine and a total application of 132,000 kg. No specific county-level information was available on the amount of atrazine applied.

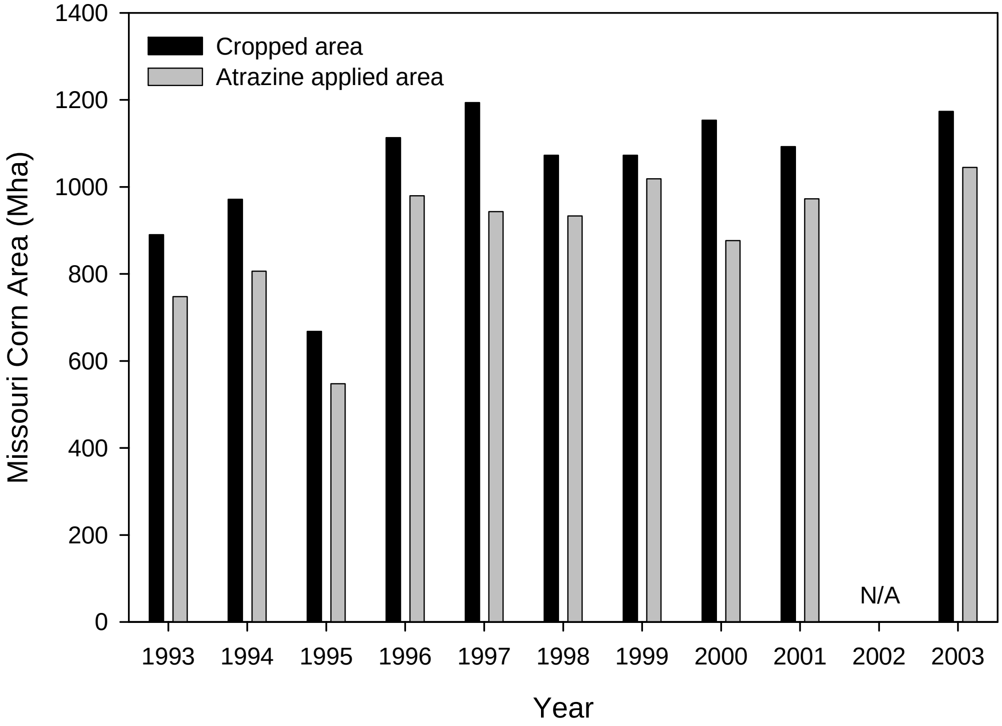

Figure 4.2 Total area of corn production and atrazine application in Missouri.

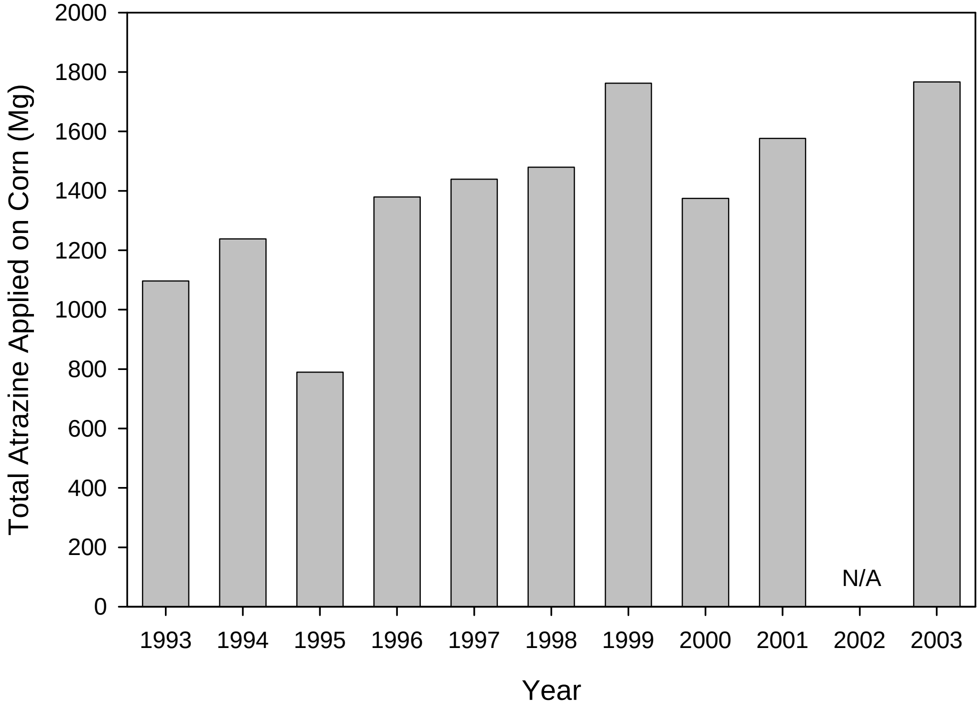

Figure 4.3 Total atrazine applied to corn by year for Missouri.

Weather and runoff data were analyzed for possible trends using the REG procedure. No significant change in precipitation was found for the 11-yr time period (P>0.394). To some extent, there was a decreasing trend in precipitation for April across all years (P>0.117, table 4.1). This reflects a drier spring season starting about 2000. A look at the planting progress records shows that producers took advantage of dry spring weather and completed their planting earlier in the season. Changes in precipitation for May and June were not significant (P>0.426 and P>0.694, respectively). A drier April also had less runoff (P>0.134). Although the relationship is not highly significant, it is expected with less rainfall. The total time period had a similar decrease in runoff (P>0.132), but there was no decrease in precipitation.

Table 4.1 Average Daily Precipitation by Year

	Average Daily Precipitation (mm)				
Year	All Months	April, May, & June	April	May	June
1993	3.75	4.42	5.43	2.95	4.94
1994	2.42	4.25	8.84	1.07	2.95
1995	2.96	5.89	4.35	8.94	4.28
1996	2.35	3.47	2.19	5.59	2.56
1997	2.56	3.31	2.77	3.96	3.16
1998	3.29	4.18	2.81	2.21	7.59
1999	2.41	5.02	6.12	2.91	6.11
2000	2.48	3.04	0.79	2.93	5.41
2001	2.96	4.80	3.67	5.60	5.10
2002	2.42	4.62	4.53	7.52	1.72
2003	2.93	4.28	3.32	4.15	5.37

Observation of the maximum and minimum daily temperatures over time show definite increases for the watershed. Table 4.2 lists minimum and maximum temperatures for the watershed for April, May, and June. Both maximum and minimum temperature increased over the entire time period (P>0.003 and P>0.108, respectively) and particularly for April (P>0.0004 and P>0.0008, respectively, fig. 4.4). The increase in temperatures may suggest earlier vegetative growth. This is especially important for vegetative BMPs that may have been more effective earlier in the year than in previous years.

Table 4.2 Average Daily Minimum and Maximum Temperature for April, May, and June by Year

	Average Daily Minimum Temperature (^oC)			Average Daily Maximum Temperature (^oC)		
Year	April	May	June	April	May	June
1993	5.63	12.75	17.43	15.69	22.73	27.88
1994	6.57	10.97	18.46	18.11	22.87	29.36
1995	5.46	11.17	17.14	16.90	19.86	27.27
1996	4.39	13.05	17.54	17.11	23.08	27.62
1997	3.84	9.26	17.74	14.89	20.76	26.50
1998	6.67	15.30	17.73	16.81	26.07	27.57
1999	8.36	12.39	17.45	18.42	23.11	27.75
2000	5.18	14.24	16.43	19.06	25.50	26.16
2001	9.91	13.70	16.84	21.87	23.29	27.02
2002	7.14	10.38	18.68	19.24	21.52	29.42
2003	7.79	12.80	15.98	18.80	22.56	26.05

Kucharik (2006) conducted a study to further examine the trend of earlier corn planting across the Corn Belt. Using NASS planting progress records and National Centers for Environmental Prediction (NCEP) climate data, Kucharik analyzed the trends from 1979 through 2005. Results showed that some planting was occurring earlier, with a regional weighted average of 0.48 days year^{-1} earlier, and that corn planting is now averaging 2 weeks earlier than in the 1980's. Corn planting progress records obtained for the NE region of Missouri (G. Danekas, personal communication, June 2004) show planting progress and streamflow from 1993 to 2003 (Appendix D). Planting progress variation for this region appeared to be heavily dependent on weather.

Kucharik concluded that earlier planting trends probably had more to do with enhanced corn species that could survive in suboptimal temperatures, improvements in planting equipment, and adoption of time-saving management practices such as conservation tillage than with spring warming. However, the statistical trends proved that there was spring warming in GCEW and this could be a factor in earlier planting for the watershed.

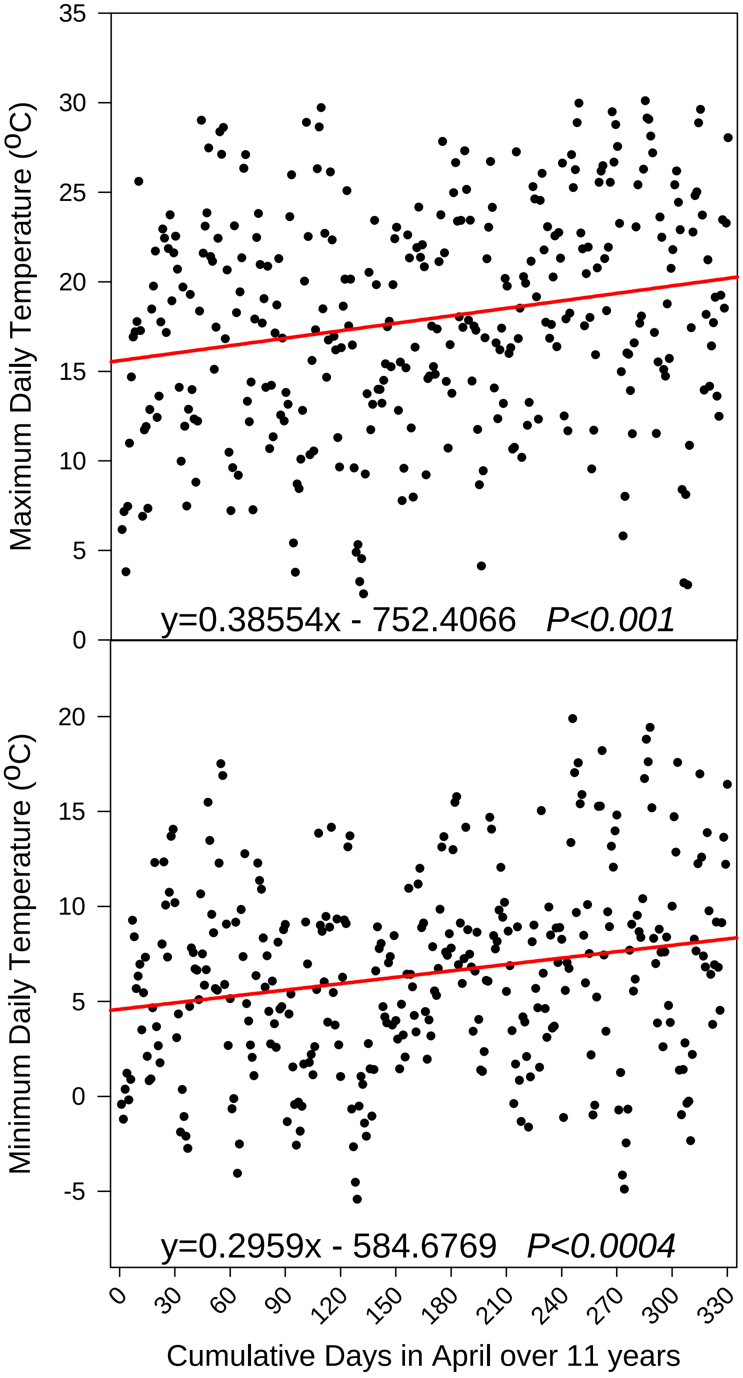

Figure 4.4 Temperature trends for April from 1993-2003. Regression equation is a function of temperature and year.

4.2 Atrazine Concentration Trends

Figure 4.5 shows that the atrazine concentrations vary seasonally. The highest concentrations are in the months of April, May, and June with diminishing concentrations through the rest of the year. A statistical regression of all months showed that April, May, and June were the peak months for atrazine concentration and loading. Over the 11-yr period, 808 days had samples taken, with 113 days sampled for atrazine in April, 119 in May, and 89 in June. Regressions were calculated for individual months of April, May, and June for all years; the combined period of April, May, and June for all years; and all twelve months for all years.

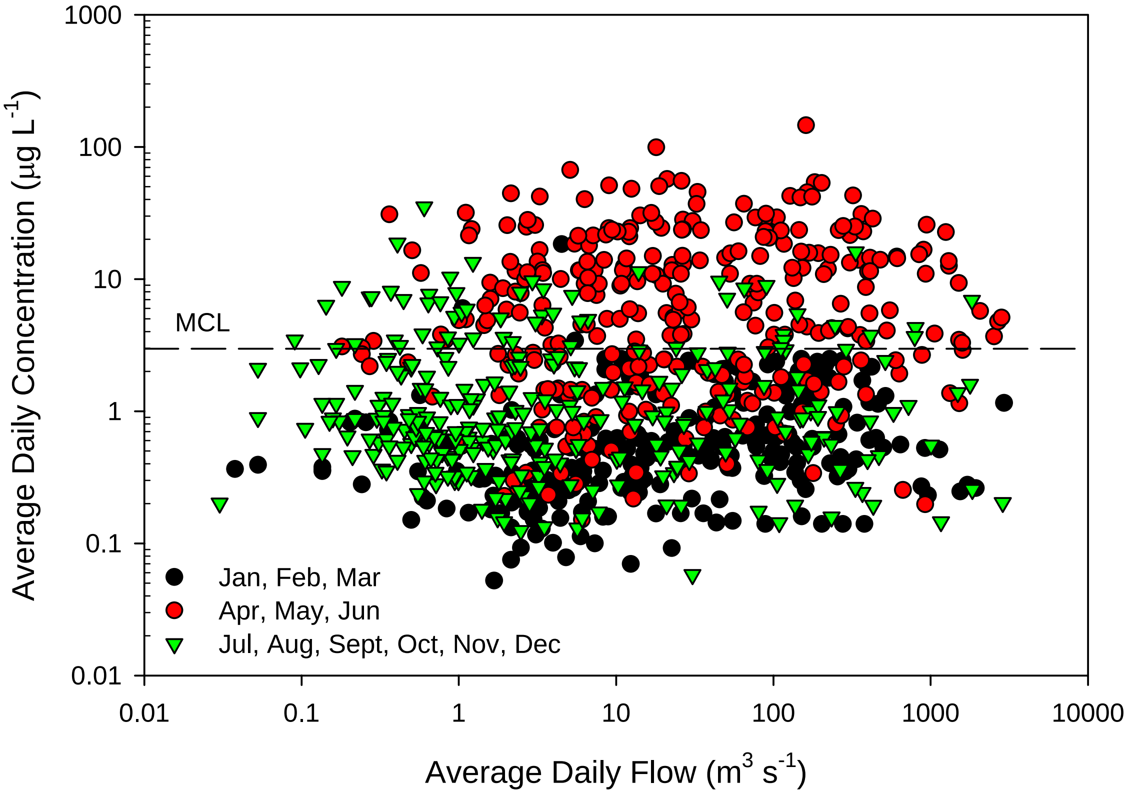

Figure 4.5 Average daily flow versus atrazine concentration for all years.

The collective 3-month period yields a decrease in concentration records ($P>0.036$); however, a decrease in concentration for all twelve months of the time period has not been detected (fig. 4.6). There was no significant change in atrazine concentrations for April or May over time ($P>0.245$ and $P>0.135$, respectively, fig. 4.7). June showed a significant decrease ($P>0.0001$) (fig. 4.7). The trends in concentration over time could be attributed to earlier planting and atrazine application by producers to kill weeds in no-till systems. The earlier application of atrazine allows the chemical more time to degrade, leaving less to be detected in June. The drier years may have led to the overall decrease in atrazine for the 3-month period by allowing the product to stay in the field and degrade, causing less availability for wash off over time.

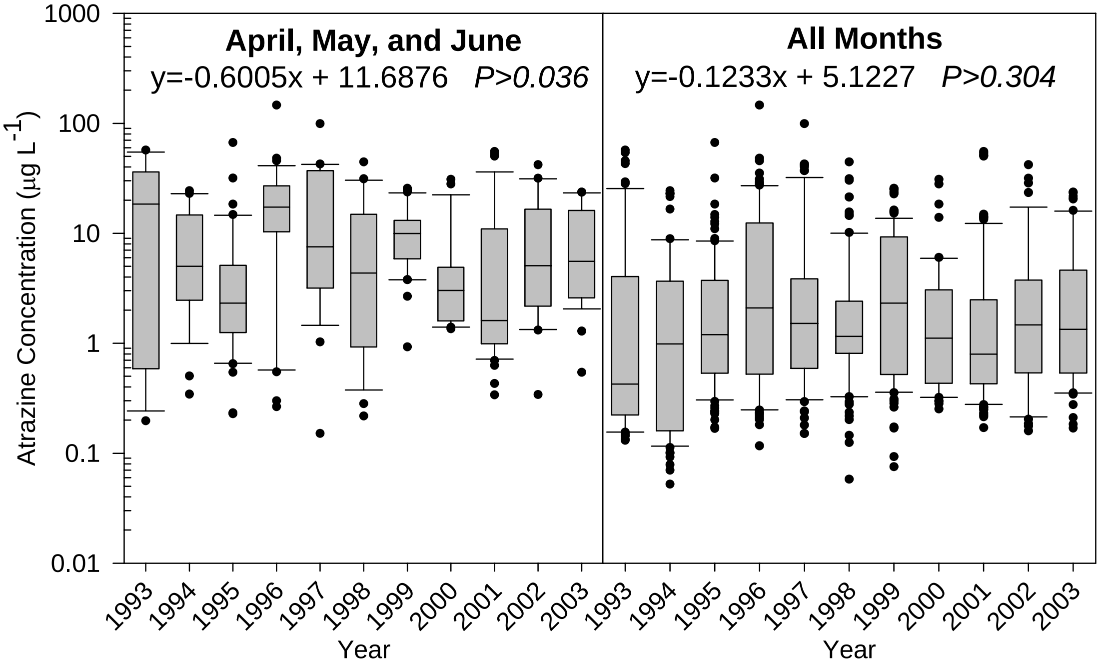

Figure. 4.6 Atrazine concentrations for the season of April, May, and June, and all twelve months. Box lines represent lower and upper quartiles and median. Lines extend to 10 and 90% limits and outliers remain as points. Regression equation is a function of concentration and year.

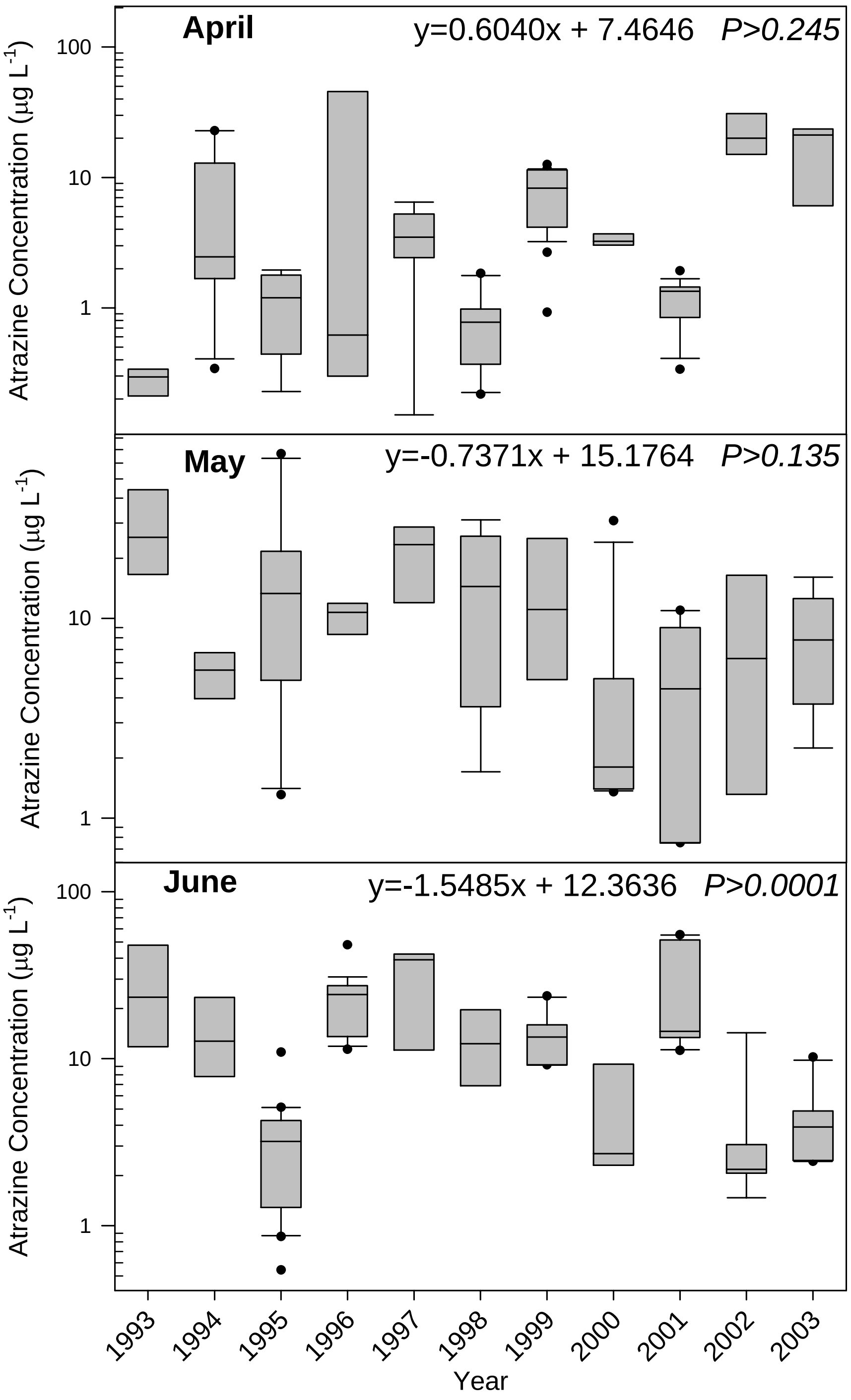

Figure. 4.7 Atrazine concentrations for April, May, and June. Box lines represent lower and upper quartiles and median. Lines extend to 10 and 90% limits and outliers remain as points. Regression equation is a function of concentration and year.

4.3 Atrazine Loading Trends

Analysis of atrazine loadings for all twelve months or for the season of April, May, and June yield were not significant (P>0.638 and P>0.339, respectively, fig 4.8). The monthly analyses of April, May, and June do not yield significant linear trends (P>0.971, P>0.253, and P>0.885, fig 4.9). Although there were significant decreasing trends for concentration for the month of June and the season of April, May, and June, the same trends were not seen in the loading data.

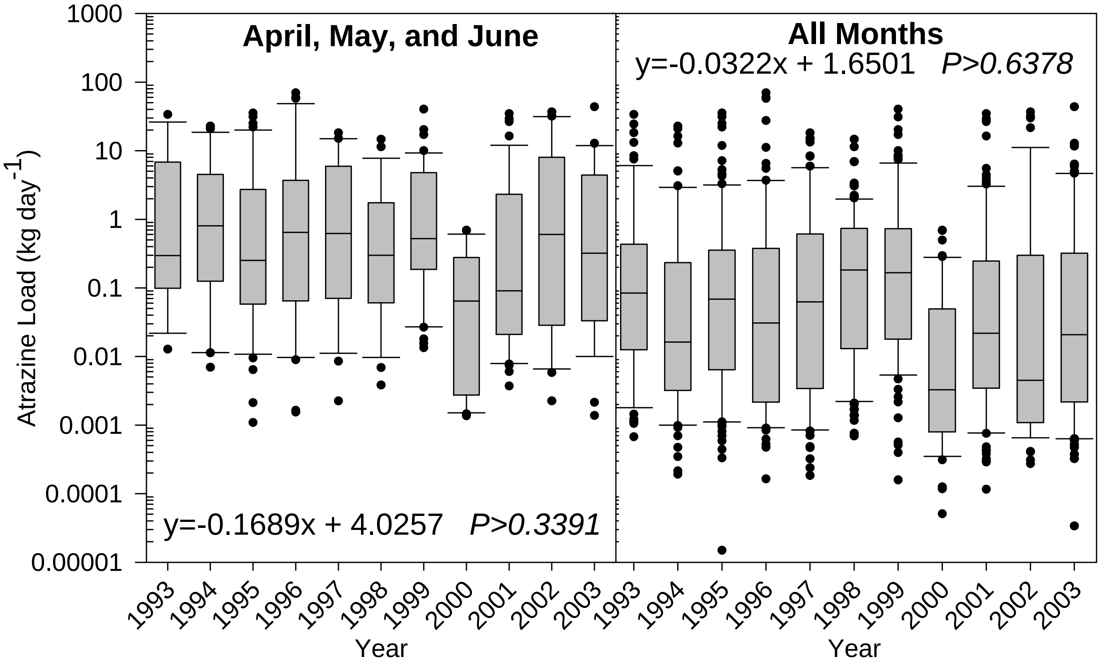

Figure. 4.8 Atrazine loads for the season of April, May, and June, and all twelve months. Box lines represent lower and upper quartiles and median. Lines extend to 10 and 90% limits and outliers remain as points. Regression equation is a function of load and year.

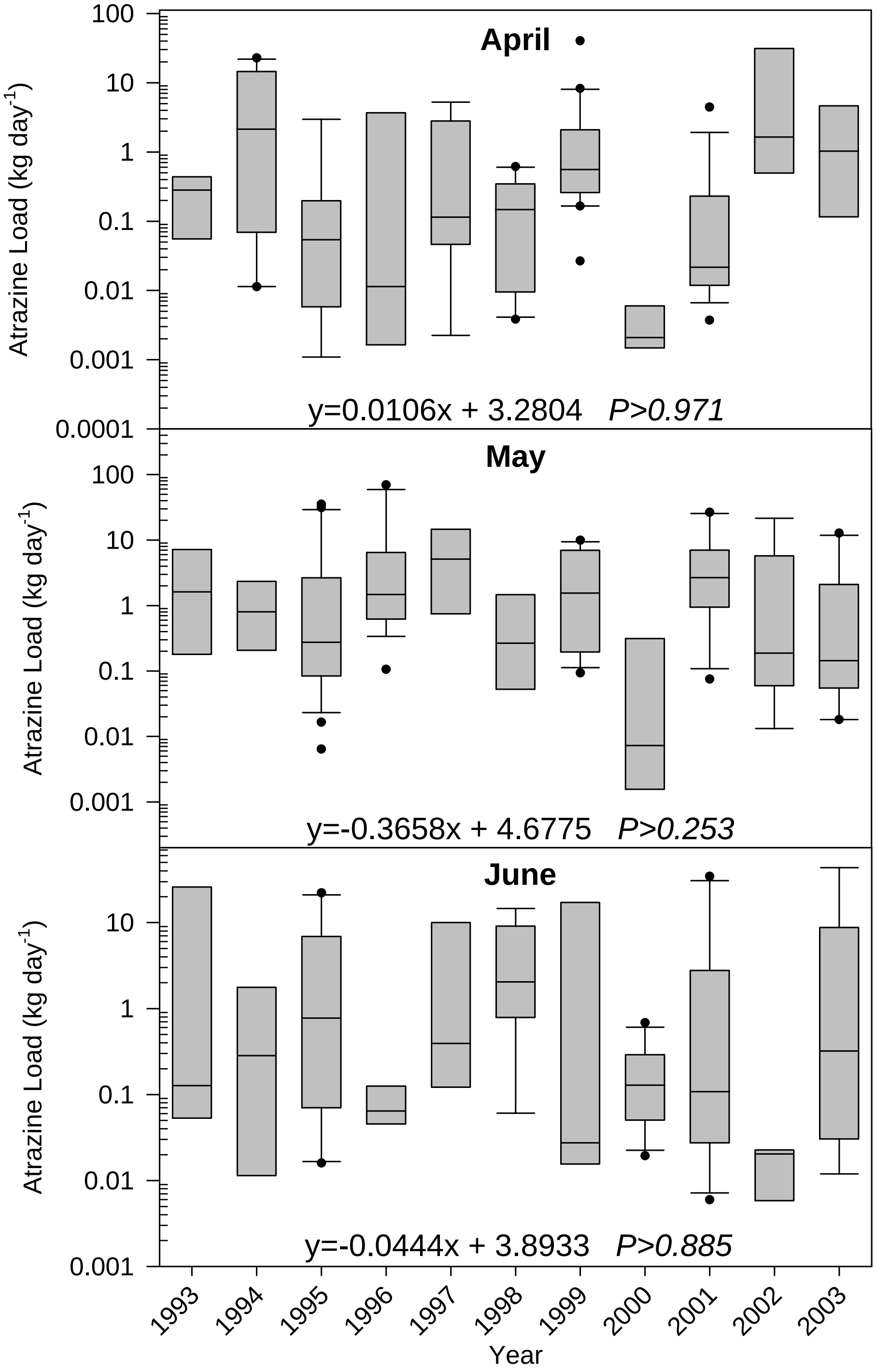

Figure. 4.9 Atrazine loads for April, May, and June. Box lines represent lower and upper quartiles and median. Lines extend to 10 and 90% limits and outliers remain as points. Regression equation is a function of load and year.

4.4 Effect of BMPs

A covariate analysis was used to better understand the effect of BMPs on atrazine. Daily precipitation was chosen as the covariate and the treatment corresponded to various levels of BMP implementation within the watershed. The basic concept was to say that if all years had the same precipitation, in what years would BMPs have been most effective? To answer this question, two sets of BMP implementations were examined. The first set included all BMPs implemented in the watershed and the second was a subset of the first, containing only the area protected by grassed waterways. Table 4.3 shows the treatment classes and their corresponding area and years. There are fewer classes than years in the study since additional BMPs were not installed in all years.

Table 4.3 Treatment Classes and Corresponding Area Protected by BMPs and Years

All BMPs			Only Grassed Waterways		
Class	% Area	Years	Class	% Area	Years
1	4.98	1993, 1994	1	3.09	1993, 1994
2	6.42	1995	2	3.92	1995-1997
3	6.55	1996	3	5.99	1998
4	7.48	1997	4	6.63	1999-2001
5	9.98	1998	5	7.31	2002
6	11.43	1999	6	9.05	2003
7	11.99	2000			
8	12.14	2001			
9	12.95	2002			
10	14.75	2003			

Only concentrations were examined for covariate analysis since precipitation and load are highly correlated with each other. Data were examined on a monthly, seasonal, and yearly basis as before. The slopes of the precipitation vs. atrazine concentrations for each class were found to be parallel for both the total BMP implementation and the waterway subset, with the exception of April for the total BMP implementation. Tables 4.4 and 4.5 summarize the results of the covariate analysis.

Table 4.4 Results Ranked in Ascending Order by Adjusted Mean Concentration for Area Protected by All Types of BMPs

All BMPs							
May		June		April, May, & June		All Months	
Class	Mean Conc. (μg L^{-1})	Class	Mean Conc. (μg L^{-1})	Class	Mean Conc. (μg L^{-1})	Class	Mean Conc. (μg L^{-1})
2	3.17	8	4.93	7	5.54	7	3.28
9	3.60	7	5.69	2	6.35	5	3.35
10	4.33	9	7.96	8	9.04	2	3.47
7	6.77	10	8.20	10	9.33	10	4.25
6	14.14	3	10.29	5	9.62	8	4.67
5	15.48	5	14.22	6	10.74	1	4.84
1	21.69	6	14.81	9	11.45	6	5.52
3	23.24	1	17.39	1	13.92	9	5.60
8	29.02	2	17.98	4	20.35	4	7.34
4	37.82	4	22.16	3	21.81	3	9.80

Table 4.5 Results Ranked in Ascending Order by Adjusted Mean Concentration for Area Protected by Grassed Waterways

Grassed Waterways									
April		May		June		April, May, & June		All Months	
Class	Mean Conc. (μg L^{-1})	Class	Mean Conc. (μg L^{-1})	Class	Mean Conc. (μg L^{-1})	Class	Mean Conc. (μg L^{-1})	Class	Mean Conc. (μg L^{-1})
3	0.76	5	3.54	4	7.14	4	8.97	3	3.36
4	4.82	6	4.43	5	8.09	6	9.32	6	4.26
1	5.53	3	15.29	6	8.21	3	9.63	4	4.68
2	9.50	2	16.68	3	14.09	5	11.43	1	4.85
6	16.80	4	17.69	2	17.04	1	13.97	5	5.59
5	21.63	1	21.63	1	17.38	2	14.86	2	6.63

Contrasting the slopes for April showed that class 3 was significantly different from every other class. The slopes of the concentration data for all other classes were zero but class 3 has a significant increasing slope ($P<0.0001$). The raw data show that April 1996 (corresponds to class 3) had relatively low atrazine concentrations until the last two days of the month, and there was a very large change in concentration caused by a moderate runoff event. This does not necessarily indicate any change in effectiveness of the BMPs.

Examining the time periods that did have parallel slopes, the covariate was not significant in any time period for all BMPs or only grassed waterways. This would indicate that there is no relationship between atrazine concentration and precipitation. This does not necessarily mean that there was no difference due to treatment. A pair-wise comparison of the classes showed that some treatments were significantly different; however, there was nothing unifying that would denote trends due to treatment. For analysis of all BMPs, class 3 (corresponding to 1996) proved significantly different ($\alpha=0.05$) against many other classes for the time periods of May, for the season of April, May, and June, and for all months. There were several runoff events during April, May, and June, and concentration levels tended to stay elevated after the end of an event contrary to most years where the concentration will quickly subside after an event. It may be that the combination of management, climate, and vegetative factors caused atrazine to move into lateral or groundwater flow so that concentrations lagged the runoff events, and atrazine persisted in the stream more than expected.

For analysis of grassed waterways, classes 5 and 6 (corresponding to 2002 and 2003) proved significantly different ($\alpha=0.05$) against many other classes for April and May. Class 2 (corresponding to 1995 through 1997) was different for the time periods of June, for the season of April, May, and June, and for all months. The possibility of atrazine in lateral and groundwater flow could also be affecting the results for class 2 as with the analysis of all types of BMPs. Additionally, classes 5 and 6 have the highest adjusted means in April and the lowest in May. This might be a good example of timing. Atrazine is most vulnerable to loss immediately after application. The situation with classes 5 and 6 could be the result of much of the atrazine washing off in April and less atrazine prone to wash off in May. If that was the situation, it may not be appropriate to compare on a monthly basis, but rather the time periods directly after atrazine applications. Comparing timescales greater than one month may also not have much significance, since months that are not prone to atrazine losses may have too much influence.

4.5 SWAT Modeling

Definitive conclusions about observed trends in atrazine levels cannot be made from statistical analyses alone. Environmental, management, and other interacting factors contributed to the trends. During the 11 yr that atrazine samples were collected from weir 1, there were changes to the amount of area protected by BMPs and changes to the distribution of tillage systems in GCEW. These changes were reflected through modifications of inputs in the SWAT model. The effects of these scenarios were simulated while holding weather constant to better understand their influence on atrazine levels.

Individual curves for April, May, and June were created to evaluate the model since those months accounted for the majority of atrazine losses. The model was calibrated for atrazine over the entire time period (1993-2003) and no validation period was used. This was done because scenarios were only run for the 1993-2003 period. Since there are not observed atrazine data for everyday of the 11-yr study period, only simulated values from days when a grab or auto sample were taken were used. Only the model output for soluble atrazine was used since the model was not calibrated for sediment and consequently sediment adsorbed atrazine. Figures 4.10 and 4.11 show the monthly frequency duration curves for observed and simulated loads and concentrations. The simulated loadings and concentrations peaks were greater than observed data. Observed and simulated curves were more closely matched when probability of occurrence was greater than 20%.

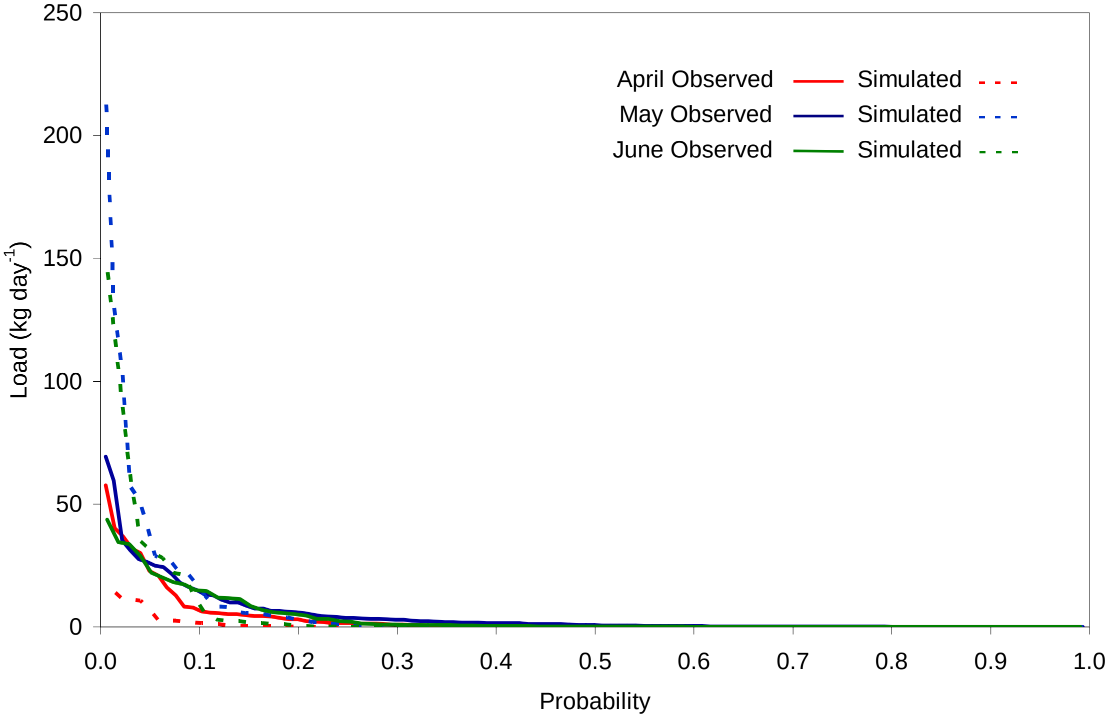

Figure 4.10 Loading frequency duration curves for April, May, and June for both simulated and observed data.

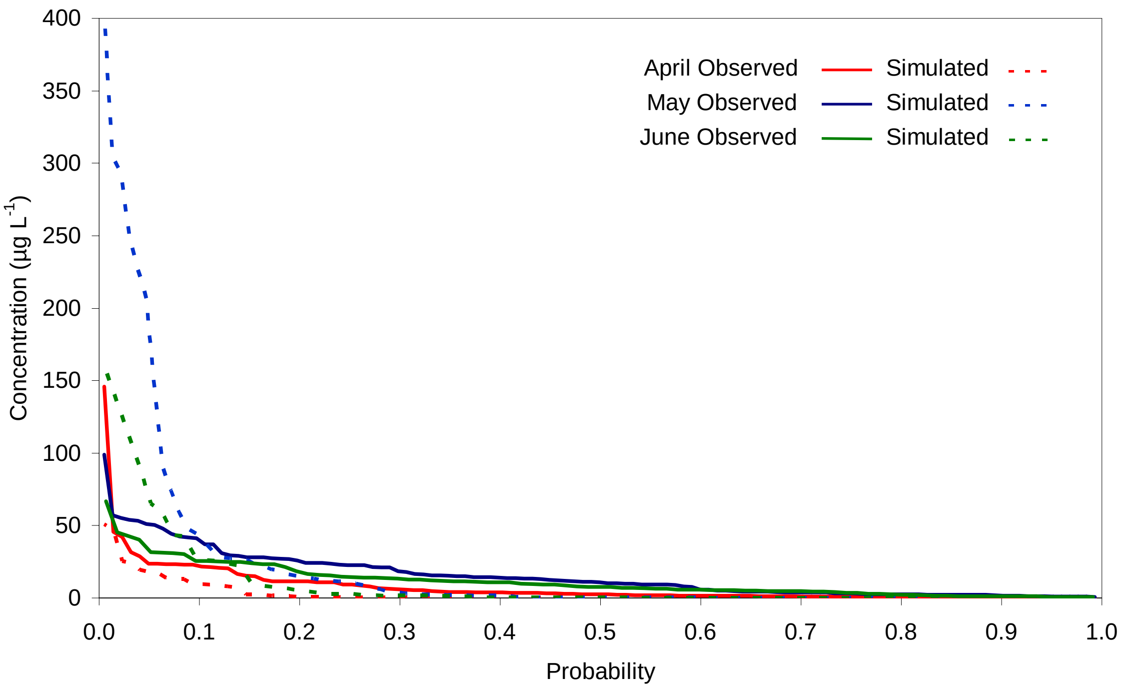

Figure 4.11 Concentration frequency duration curves for April, May, and June for both simulated and observed data.

Several other calibration attempts were made, such as decreasing the amount of atrazine applied within the watershed, applying 20% of the total application every other day for a 10-day period, and staggering the dates of application over a 2-week period starting from the most upstream subbasin and moving downstream, the reverse of that (downstream to upstream), and adding tillage operations after atrazine applications on no-till landuses. Additionally within these calibration attempts, the pesticide percolation coefficient (PERCOP) was adjusted from the default value of 0.5 to 0.2 and the channel pesticide reaction coefficient (CHPST_REA) was increased from the default of 0.007 to 0.02. It was possible to reduce the peak loadings and concentrations that occurred less than 10% of the time, but this severely underestimated the other 90% of the time. Because of that, these changes to the calibration were not kept.

First, the simulated dataset from the baseline scenario was run through SAS to test if SWAT would be able to reproduce the trends found in the measured atrazine data by only taking weather into account. Only the trends for concentrations were compared since the strongest trends were seen in the concentration data. The linear regressions were compared for significance (α=0.05), and the direction of the regression was compared if found significant. Table 4.6 shows a comparison of observed and simulated trends.

Table 4.6 Comparison of Trends for Measured and Simulated Output where Regression is in Terms of Concentration (μg L^{-1}) and Year

	Measured		Simulated	
Timeframe	Regression Equation		Regression Equation	
April	y=0.6040x+7.4646	P>0.245	y=-0.3942x+790.6753	P>0.136
May	y=-0.7371x+15.1764	P>0.135	y=3.3772x-6724.7573	P>0.085
June	y=-1.5485x+12.3636	P>0.0001	y=-3.1071x+11.8436	P>0.002
April, May, & June	y=-0.6005x+11.6876	P>0.036	y=0.0594x+11.9359	P>0.942
All Months	y=-0.1233x+5.1227	P>0.304	y=0.1444x+4.4713	P>0.630

The comparison of the trends only compares the SWAT model's ability to reproduce effects caused by the weather and watershed hydrology on atrazine concentration to measured data. Although trends in observed data were not perfectly reproduced by the SWAT model, it was able to reproduce the significant decrease in June. Regressions that were not significant in the observed data were also not shown to be significant in the modeled output. However the SWAT model was not able to simulate the decline in concentration across the season of April, May, and June over the 11-yr period. The data showed no trends for April or May; therefore the seasonal trend of April, May, and June could be an artifact of the strong trend in June. The SWAT model may not have been able to reproduce this trend because it did not simulate a trend as strong as the observed data for June.

The baseline SWAT model output was compared to the output from the scenario that simulated increased area protected by grassed waterways. The comparisons were for all months and for the combined months of April, May, and June using a paired t-test. The baseline output for both time periods was significantly different from the grassed waterway scenario output. Table 4.7 lists simple statistics for atrazine concentrations from the SWAT output. Adding waterways lowered the mean, median, and variance compared to the baseline. Waterways helped to reduce the peak concentrations. The SWAT standard output file showed that the same amount of atrazine was applied and decayed for both the baseline and the grassed waterway scenario, but about 26% less atrazine on average was transported in runoff for the entire watershed in the grassed waterway scenario compared to the baseline.

Table 4.7 Simple Statistics for Atrazine Concentration from the SWAT Output Comparing the Baseline Model to a Scenario with Added Grassed Waterways

	April, May, and June		All Months	
	Baseline (μg L^{-1})	Added Waterways (μg L^{-1})	Baseline (μg L^{-1})	Added Waterways (μg L^{-1})
Mean	11.9	8.87	4.45	3.31
Median	$2.20\text{x}10^{-1}$	$1.92\text{x}10^{-1}$	$1.68\text{x}10^{-3}$	$1.38\ \text{x}10^{-3}$
Variance	$1.85\text{x}10^{3}$	$1.10\text{x}10^{3}$	$7.07\text{x}10^{2}$	$4.19\text{x}10^{2}$

Next, two scenarios with differing tillage distributions were run to see the effect on atrazine concentrations due to increased conservation and no-till. The first scenario had a tillage system distribution with the maximum rate of conventional tillage (corresponding with the tillage distribution of 1993), and the other had a tillage system distribution with the maximum rate of no-till and conservation tillage (corresponding to the tillage distribution of 1995). The daily concentration output from the scenarios were compared using a paired t-test for the combined months of April, May, and June, and for all months. The two tillage distribution scenarios were found to be significantly different for both time periods. More conservation tillage and no-till area also increased the mean, median, and variance. This is expected because more atrazine is applied with no-till and decreased tillage keeps atrazine on the surface layer where it is vulnerable to wash off. Table 4.8 lists simple statistics for atrazine concentrations from the SWAT output.

Table 4.8 Simple Statistics for Atrazine Concentration from the SWAT Output Comparing Tillage System Distributions

	April, May, and June		All Months	
	Decreased Conservation and No-Till (μg L^{-1})	Increased Conservation and No-Till (μg L^{-1})	Decreased Conservation. and No-Till (μg L^{-1})	Increased Conservation and No-Till (μg L^{-1})
Mean	12.0	12.8	4.48	4.77
Median	$1.96\text{x}10^{-3}$	$2.33\text{x}10^{-3}$	$1.64\text{x}10^{-3}$	$1.75\text{x}10^{-3}$
Variance	$1.96\text{x}10^{3}$	$2.19\text{x}10^{3}$	$7.46\text{x}10^{2}$	$8.34\text{x}10^{2}$

CHAPTER 5

CONCLUSIONS

The objective of this study was to use statistical regression to determine relationships among weather, runoff, water quality, and management practice (BMP) implementation. Analysis of atrazine data was done on a monthly, seasonal, and annual basis. None of these time periods revealed significant trends for atrazine loading. Significant decreasing trends were observed for concentration data over the month of June and the season of April, May, and June.

Many interacting factors may have affected atrazine concentrations. Increased corn acreage in Audrain County could have increased atrazine usage in the county and also in GCEW. There was an effort by educators to get producers to use less atrazine. In contrast, adoption of no-till may have increased atrazine use and possibly increased vulnerability of atrazine loss.

Temperature data showed that there had been a warming trend in April and crop planting progress records suggest that producers may have been planting earlier in Northeast Missouri and GWEC. In addition to warming temperatures, improved equipment and better species of corn might have allowed earlier planting as suggested by Kucharik (2006). Earlier planting and atrazine application may have caused enough degradation of atrazine in the fields that concentrations were decreasing in June because there was less atrazine left on the fields. Warmer temperatures may have also increased vegetative growth for more effective vegetative BMPs.

The amount of area protected by BMPs increased throughout the 11-yr period. Covariate analysis of BMP implemented area showed that for all BMPs and grassed waterways there was no relationship between the concentration and amount of area protected by BMPs. The analysis showed that classes corresponding to 1996 were significantly different with high atrazine concentrations that were sustained after events ended when levels would normally return to levels associated with normal base flow. This could mean that a unique set of interacting management, climate, and other factors caused atrazine to move in lateral or groundwater flow. The covariate analyses showed that classes that had the highest atrazine levels, after adjusting to the mean of the covariate, in one month could have the lowest adjusted levels the next month. This indicates that the timescale used for this analysis may not be ideal. If more detailed data concerning the timing of atrazine application existed, it might be more useful to compare corresponding time periods after applications each year.

The baseline SWAT model was able to reproduce the observed decreasing trend in June but not the trend observed over April, May, and June. The data for April and May did not have significant trends; therefore June's data could have been a main contributor to the seasonal trend. The SWAT model's inability to reproduce the seasonal trend may be a combined effect caused by the difficulties in modeling April and May and not producing a strong enough trend in June. Furthermore, the baseline model only used weather to simulate the trends and other influencing factors were not represented in the model.

Comparing the baseline model to the scenario where 4.5% of the area was protected by grassed waterways showed a significant reduction in atrazine concentrations. The model estimated that the addition of grassed waterways reduced average annual soluble atrazine in runoff by 26%, mostly by reducing the peak concentrations.

The two tillage system distribution scenarios proved significantly different. Increased no-till in the watershed also increased atrazine concentrations. No-till requires greater applications of atrazine, and pesticide on crop residues may have a greater vulnerability to loss. However, no-till and conservation tillage systems usually provide greater protection from soil loss so there may be some trade off. The SWAT model was not calibrated for sediment so this was not investigated.

Best management practices within the watershed are providing protection from atrazine losses as well as possible protection from soil and nutrient losses. Quantifiable benefits from BMPs were difficult to determine due to other contributing factors. Because these factors are often not controllable, it is important to continue education of watershed stakeholders, research new and innovative methods to reduce nonpoint pollution, and encourage good stewardship through continued use of good land and resource management practices.

5.1 Future Research

There is a great opportunity for future research as more data become available from GCEW. Atrazine was the only herbicide in this study, but several other water quality analytes were sampled in GCEW and should be examined to determine the impact of BMPs on water quality improvement. Only data from weir 1 were used in this study, but when data from weirs 9 and 11 become available they may allow for analyses at a sub-watershed level. It is also important to continue developing alternative statistical procedures, such as time series analysis, to better analyze datasets and quantify the impacts of BMPs in GCEW.

APPENDIX A

LAND USE, SOIL, AND SUBBASIN COMPOSITION

Table A.1 SWAT Land Use Report for GCEW for All Subbasins

```
MULTIPLE HRUs LandUse/Soil OPTION      THRESHOLDS : 7 / 10 [%]
Number of HRUs: 317
Number of Subbasins: 7

-----------------------------------------------------------------------------------------
                                              Area [ha]   Area [acres] %Wat.Area

WATERSHED:                                    6978.8700     17245.1367

LANDUSE:
                     Corn notilll-->CNNT       315.4684       779.5381      4.52
         Grain Sorgh Conservation-->GSCP       205.4571       507.6949      2.94
             Grain Sorghum conven-->GSCT       270.3569       668.0653      3.87
                Corn Conservation-->CNCP       203.6614       503.2575      2.92
                Corn Conventional-->CNCT       272.4789       673.3090      3.90
                     Wheat notill-->WTNT       939.2961      2321.0476     13.46
                   Soybean notill-->SBNT      1780.8186      4400.4917     25.52
               Wheat Conservation-->WTCP       204.0672       504.2604      2.92
               Wheat conventional-->WTCT        75.2037       185.8321      1.08
                     Forest-Mixed-->FRST       610.1666      1507.7522      8.74
          Residential-Low Density-->URLD       545.7218      1348.5058      7.82
             Soybean Conservation-->SBCP       482.4393      1192.1316      6.91
             Soybean Conventional-->SBCT       541.1601      1337.2338      7.75
                Smooth Bromegrass-->BROS       418.2436      1033.5008      5.99
             Grain Sorghum notill-->GSNT       114.3304       282.5161      1.64
SOIL:
                              MO01960022       188.9634       466.9381      2.71
                              MO01950012       298.5215       737.6616      4.28
                               MO00710C2       122.7326       303.2784      1.76
                                 MO00733       512.4850      1266.3760      7.34
                                 MO00734       629.4590      1555.4246      9.02
                               MO00723B2       242.6291       599.5485      3.48
                                MO00727B      2392.9256      5913.0389     34.29
                               MO00727B2      1549.8615      3829.7852     22.21
                                 MO00728        52.3022       129.2414      0.75
                              MO01950000       676.8943      1672.6397      9.70
                              MO01950004       312.0958       771.2043      4.47

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                                     Area [ha]   Area [acres] %Wat.Area %Sub.Area

SUBBASIN # 1                          942.2200      2328.2727     13.50

LANDUSE:
            Corn notilll-->CNNT        38.1946        94.3808      0.55      4.05
Grain Sorgh Conservation-->GSCP        26.1856        64.7060      0.38      2.78
    Grain Sorghum conven-->GSCT        33.6743        83.2110      0.48      3.57
       Corn Conservation-->CNCP        25.0518        61.9043      0.36      2.66
       Corn Conventional-->CNCT        31.4690        77.7614      0.45      3.34
            Wheat notill-->WTNT        98.5737       243.5806      1.41     10.46
          Soybean notill-->SBNT       225.1122       556.2634      3.23     23.89
      Wheat Conservation-->WTCP        22.4736        55.5334      0.32      2.39
      Wheat conventional-->WTCT         6.6387        16.4046      0.10      0.70
 Residential-Low Density-->URLD       290.3593       717.4924      4.16     30.82
    Soybean Conservation-->SBCP        61.1501       151.1049      0.88      6.49
    Soybean Conventional-->SBCT        69.4366       171.5812      0.99      7.37
    Grain Sorghum notill-->GSNT        13.9005        34.3488      0.20      1.48

SOIL:
                     MO01950012       167.5482       414.0200      2.40     17.78
                     MO01950000       371.7997       918.7358      5.33     39.46
                     MO01950004       237.7249       587.4302      3.41     25.23
                     MO01960022       165.1471       408.0868      2.37     17.53
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HRUs:
1               CNNT/MO01950004        13.6746        33.7905      0.20      1.45    1
2               CNNT/MO01960022        14.7485        36.4444      0.21      1.57    2
3               CNNT/MO01950000         9.7715        24.1459      0.14      1.04    3
4               GSCP/MO01950012         3.7203         9.1930      0.05      0.39    4
5               GSCP/MO01950004         6.5131        16.0942      0.09      0.69    5
6               GSCP/MO01960022         4.0376         9.9770      0.06      0.43    6
7               GSCP/MO01950000        11.9147        29.4417      0.17      1.26    7
8               GSCT/MO01950012         4.9062        12.1235      0.07      0.52    8
9               GSCT/MO01950004         8.1777        20.2074      0.12      0.87    9
10              GSCT/MO01960022         5.0436        12.4630      0.07      0.54   10
11              GSCT/MO01950000        15.5469        38.4171      0.22      1.65   11
12              CNCP/MO01950004         8.9969        22.2319      0.13      0.95   12
13              CNCP/MO01960022         9.5669        23.6402      0.14      1.02   13
14              CNCP/MO01950000         6.4880        16.0322      0.09      0.69   14
15              CNCT/MO01950004        11.2910        27.9005      0.16      1.20   15
16              CNCT/MO01960022        12.0581        29.7962      0.17      1.28   16
17              CNCT/MO01950000         8.1199        20.0647      0.12      0.86   17
18              WTNT/MO01950004        42.3461       104.6393      0.61      4.49   18
19              WTNT/MO01960022        27.5167        67.9953      0.39      2.92   19
20              WTNT/MO01950000        28.7109        70.9460      0.41      3.05   20
21              SBNT/MO01950004        82.8786       204.7972      1.19      8.80   21
22              SBNT/MO01960022        51.9402       128.3469      0.74      5.51   22
23              SBNT/MO01950000        90.2933       223.1194      1.29      9.58   23
24              WTCP/MO01950004         9.5798        23.6721      0.14      1.02   24
25              WTCP/MO01960022         6.2336        15.4035      0.09      0.66   25
26              WTCP/MO01950000         6.6602        16.4578      0.10      0.71   26
27              WTCT/MO01950004         2.9380         7.2600      0.04      0.31   27
28              WTCT/MO01960022         1.8993         4.6931      0.03      0.20   28
29              WTCT/MO01950000         1.8014         4.4514      0.03      0.19   29
30              URLD/MO01950012       156.8424       387.5653      2.25     16.65   30
31              URLD/MO01950000       133.5170       329.9271      1.91     14.17   31
32              SBCP/MO01950004        22.5224        55.6540      0.32      2.39   32
33              SBCP/MO01960022        14.1201        34.8915      0.20      1.50   33
34              SBCP/MO01950000        24.5076        60.5594      0.35      2.60   34
35              SBCT/MO01950004        25.5190        63.0588      0.37      2.71   35
36              SBCT/MO01960022        15.9666        39.4542      0.23      1.69   36
37              SBCT/MO01950000        27.9510        69.0682      0.40      2.97   37
38              GSNT/MO01950012         2.0794         5.1382      0.03      0.22   38
39              GSNT/MO01950004         3.2878         8.1243      0.05      0.35   39
40              GSNT/MO01960022         2.0160         4.9816      0.03      0.21   40
41              GSNT/MO01950000         6.5174        16.1047      0.09      0.69   41

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                                    Area [ha]   Area [acres] %Wat.Area %Sub.Area

SUBBASIN # 2                         1090.5000      2694.6800     15.63

LANDUSE:
            Corn notilll-->CNNT        64.7308       159.9530      0.93      5.94
Grain Sorgh Conservation-->GSCP        33.2525        82.1687      0.48      3.05
    Grain Sorghum conven-->GSCT        43.7614       108.1367      0.63      4.01
       Corn Conservation-->CNCP        41.6304       102.8707      0.60      3.82
       Corn Conventional-->CNCT        53.1536       131.3453      0.76      4.87
            Wheat notill-->WTNT       129.6620       320.4013      1.86     11.89
          Soybean notill-->SBNT       278.5925       688.4161      3.99     25.55
      Wheat Conservation-->WTCP        28.3449        70.0416      0.41      2.60
      Wheat conventional-->WTCT        10.1581        25.1013      0.15      0.93
            Forest-Mixed-->FRST       123.8347       306.0017      1.77     11.36
 Residential-Low Density-->URLD       102.9265       254.3365      1.47      9.44
    Soybean Conservation-->SBCP        75.4646       186.4767      1.08      6.92
    Soybean Conventional-->SBCT        86.4796       213.6955      1.24      7.93
    Grain Sorghum notill-->GSNT        18.5083        45.7351      0.27      1.70

SOIL:
                       MO00727B       435.7504      1076.7610      6.24     39.96
                        MO00733        73.8204       182.4138      1.06      6.77
                        MO00734       119.4375       295.1361      1.71     10.95
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                   MO01950012         73.0415        180.4891        1.05       6.70
                   MO01950000         84.6113        209.0787        1.21       7.76
                    MO00727B2        189.6910        468.7359        2.72      17.39
                   MO01960022         23.8163         58.8513        0.34       2.18
                    MO00723B2         90.3317        223.2140        1.29       8.28

HRUs:
42             CNNT/MO00727B2         10.0087         24.7319        0.14       0.92    1
43              CNNT/MO00727B         13.1233         32.4285        0.19       1.20    2
44            CNNT/MO01950012         16.3651         40.4391        0.23       1.50    3
45            CNNT/MO01960022          9.7273         24.0367        0.14       0.89    4
46            CNNT/MO01950000         15.5063         38.3169        0.22       1.42    5
47               GSCP/MO00734          7.8705         19.4485        0.11       0.72    6
48              GSCP/MO00727B         16.2176         40.0745        0.23       1.49    7
49            GSCP/MO01950000          9.1644         22.6457        0.13       0.84    8
50               GSCT/MO00734         10.3164         25.4923        0.15       0.95    9
51              GSCT/MO00727B         21.2218         52.4402        0.30       1.95   10
52            GSCT/MO01950000         12.2233         30.2043        0.18       1.12   11
53             CNCP/MO00727B2          6.4700         15.9877        0.09       0.59   12
54              CNCP/MO00727B          8.6186         21.2971        0.12       0.79   13
55            CNCP/MO01950012         10.4308         25.7749        0.15       0.96   14
56            CNCP/MO01960022          6.2203         15.3706        0.09       0.57   15
57            CNCP/MO01950000          9.8907         24.4405        0.14       0.91   16
58             CNCT/MO00727B2          8.7269         21.5647        0.13       0.80   17
59              CNCT/MO00727B         10.8278         26.7561        0.16       0.99   18
60            CNCT/MO01950012         13.2084         32.6387        0.19       1.21   19
61            CNCT/MO01960022          7.8687         19.4440        0.11       0.72   20
62            CNCT/MO01950000         12.5217         30.9417        0.18       1.15   21
63             WTNT/MO00727B2         37.5718         92.8418        0.54       3.45   22
64             WTNT/MO00723B2         31.0861         76.8153        0.45       2.85   23
65              WTNT/MO00727B         61.0041        150.7443        0.87       5.59   24
66               SBNT/MO00734         61.2075        151.2469        0.88       5.61   25
67             SBNT/MO00727B2         59.7691        147.6925        0.86       5.48   26
68              SBNT/MO00727B        157.6159        389.4767        2.26      14.45   27
69             WTCP/MO00727B2          8.1201         20.0651        0.12       0.74   28
70             WTCP/MO00723B2          6.7951         16.7910        0.10       0.62   29
71              WTCP/MO00727B         13.4297         33.1855        0.19       1.23   30
72             WTCT/MO00727B2          3.0557          7.5507        0.04       0.28   31
73             WTCT/MO00723B2          2.4362          6.0199        0.03       0.22   32
74              WTCT/MO00727B          4.6663         11.5307        0.07       0.43   33
75             FRST/MO00723B2         50.0143        123.5878        0.72       4.59   34
76               FRST/MO00733         73.8204        182.4138        1.06       6.77   35
77             URLD/MO00727B2         21.7379         53.7155        0.31       1.99   36
78              URLD/MO00727B         28.0856         69.4010        0.40       2.58   37
79            URLD/MO01950012         33.0371         81.6364        0.47       3.03   38
80            URLD/MO01950000         20.0658         49.5836        0.29       1.84   39
81               SBCP/MO00734         16.5859         40.9847        0.24       1.52   40
82             SBCP/MO00727B2         16.1945         40.0174        0.23       1.49   41
83              SBCP/MO00727B         42.6841        105.4747        0.61       3.91   42
84               SBCT/MO00734         19.1117         47.2260        0.27       1.75   43
85             SBCT/MO00727B2         18.0363         44.5687        0.26       1.65   44
86              SBCT/MO00727B         49.3316        121.9008        0.71       4.52   45
87               GSNT/MO00734          4.3455         10.7378        0.06       0.40   46
88              GSNT/MO00727B          8.9238         22.0512        0.13       0.82   47
89            GSNT/MO01950000          5.2391         12.9460        0.08       0.48   48

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                                    Area [ha]   Area [acres] %Wat.Area %Sub.Area

SUBBASIN # 3                        1034.7000      2556.7954     14.83

LANDUSE:
            Corn notilll-->CNNT       62.8360       155.2710      0.90      6.07
Grain Sorgh Conservation-->GSCP       10.1883        25.1758      0.15      0.98
    Grain Sorghum conven-->GSCT       13.0593        32.2703      0.19      1.26
       Corn Conservation-->CNCP       40.1907        99.3133      0.58      3.88
       Corn Conventional-->CNCT       58.7209       145.1022      0.84      5.68
            Wheat notill-->WTNT      169.5895       419.0641      2.43     16.39
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          Soybean notill-->SBNT       228.8920       565.6036      3.28     22.12
      Wheat Conservation-->WTCP        36.1861        89.4176      0.52      3.50
      Wheat conventional-->WTCT        14.4061        35.5982      0.21      1.39
 Residential-Low Density-->URLD       152.4360       376.6769      2.18     14.73
    Soybean Conservation-->SBCP        62.0033       153.2133      0.89      5.99
    Soybean Conventional-->SBCT        63.9987       158.1440      0.92      6.19
       Smooth Bromegrass-->BROS       116.8213       288.6713      1.67     11.29
    Grain Sorghum notill-->GSNT         5.3718        13.2741      0.08      0.52

SOIL:
                       MO00727B       251.6035       621.7249      3.61     24.32
                        MO00734        44.2583       109.3644      0.63      4.28
                     MO01950012        57.9318       143.1524      0.83      5.60
                     MO01950000       220.4833       544.8252      3.16     21.31
                     MO01950004        74.3709       183.7741      1.07      7.19
                      MO00727B2       386.0522       953.9543      5.53     37.31

HRUs:
90               CNNT/MO00727B2        15.7454        38.9078      0.23      1.52    1
91               >CNNT/MO00727B        20.8528        51.5282      0.30      2.02    2
92              CNNT/MO01950000        26.2378        64.8349      0.38      2.54    3
93                 GSCP/MO00734         2.9433         7.2732      0.04      0.28    4
94               GSCP/MO00727B2         3.7393         9.2400      0.05      0.36    5
95                GSCP/MO00727B         2.2501         5.5601      0.03      0.22    6
96              GSCP/MO01950000         1.2555         3.1024      0.02      0.12    7
97                 GSCT/MO00734         3.9568         9.7776      0.06      0.38    8
98               GSCT/MO00727B2         4.7018        11.6185      0.07      0.45    9
99                GSCT/MO00727B         2.8353         7.0062      0.04      0.27   10
100             GSCT/MO01950000         1.5653         3.8680      0.02      0.15   11
101              CNCP/MO00727B2        10.1593        25.1042      0.15      0.98   12
102               CNCP/MO00727B        13.3263        32.9299      0.19      1.29   13
103             CNCP/MO01950000        16.7051        41.2791      0.24      1.61   14
104              CNCT/MO00727B2        13.4273        33.1794      0.19      1.30   15
105               CNCT/MO00727B        16.9586        41.9055      0.24      1.64   16
106             CNCT/MO01950004         8.3405        20.6097      0.12      0.81   17
107             CNCT/MO01950000        19.9945        49.4075      0.29      1.93   18
108                WTNT/MO00734        27.4421        67.8108      0.39      2.65   19
109              WTNT/MO00727B2        82.9577       204.9927      1.19      8.02   20
110               WTNT/MO00727B        59.1897       146.2606      0.85      5.72   21
111              SBNT/MO00727B2        80.2227       198.2343      1.15      7.75   22
112               SBNT/MO00727B        54.3229       134.2346      0.78      5.25   23
113             SBNT/MO01950004        43.8244       108.2922      0.63      4.24   24
114             SBNT/MO01950000        50.5220       124.8424      0.72      4.88   25
115                WTCP/MO00734         5.7392        14.1817      0.08      0.55   26
116              WTCP/MO00727B2        17.8037        43.9939      0.26      1.72   27
117               WTCP/MO00727B        12.6432        31.2420      0.18      1.22   28
118                WTCT/MO00734         2.4676         6.0976      0.04      0.24   29
119              WTCT/MO00727B2         6.9226        17.1061      0.10      0.67   30
120               WTCT/MO00727B         5.0159        12.3945      0.07      0.48   31
121              URLD/MO00727B2        19.7257        48.7433      0.28      1.91   32
122             URLD/MO01950012        57.9318       143.1524      0.83      5.60   33
123             URLD/MO01950000        74.7784       184.7811      1.07      7.23   34
124              SBCP/MO00727B2        21.7447        53.7322      0.31      2.10   35
125               SBCP/MO00727B        14.7211        36.3766      0.21      1.42   36
126             SBCP/MO01950004        11.8696        29.3303      0.17      1.15   37
127             SBCP/MO01950000        13.6680        33.7742      0.20      1.32   38
128              SBCT/MO00727B2        23.2883        57.5465      0.33      2.25   39
129               SBCT/MO00727B        15.2417        37.6630      0.22      1.47   40
130             SBCT/MO01950004        10.3364        25.5419      0.15      1.00   41
131             SBCT/MO01950000        15.1323        37.3926      0.22      1.46   42
132              BROS/MO00727B2        83.7199       206.8761      1.20      8.09   43
133               BROS/MO00727B        33.1014        81.7952      0.47      3.20   44
134                GSNT/MO00734         1.7092         4.2236      0.02      0.17   45
135              GSNT/MO00727B2         1.8936         4.6792      0.03      0.18   46
136               GSNT/MO00727B         1.1446         2.8284      0.02      0.11   47
137             GSNT/MO01950000         0.6244         1.5429      0.01      0.06   48

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                                    Area [ha]   Area [acres] %Wat.Area %Sub.Area

SUBBASIN # 4                          862.3800      2130.9841     12.36

LANDUSE:
            Corn notilll-->CNNT        39.5695        97.7782      0.57      4.59
Grain Sorgh Conservation-->GSCP        13.8615        34.2525      0.20      1.61
    Grain Sorghum conven-->GSCT        18.3510        45.3463      0.26      2.13
       Corn Conservation-->CNCP        25.2837        62.4773      0.36      2.93
       Corn Conventional-->CNCT        32.0156        79.1122      0.46      3.71
            Wheat notill-->WTNT       141.2633       349.0688      2.02     16.38
          Soybean notill-->SBNT       223.6779       552.7192      3.21     25.94
      Wheat Conservation-->WTCP        29.8108        73.6639      0.43      3.46
      Wheat conventional-->WTCT        12.3086        30.4151      0.18      1.43
            Forest-Mixed-->FRST       102.8120       254.0537      1.47     11.92
    Soybean Conservation-->SBCP        60.4507       149.3767      0.87      7.01
    Soybean Conventional-->SBCT        70.5430       174.3154      1.01      8.18
       Smooth Bromegrass-->BROS        84.6238       209.1096      1.21      9.81
    Grain Sorghum notill-->GSNT         7.8086        19.2954      0.11      0.91

SOIL:
                       MO00727B       342.9468       847.4387      4.91     39.77
                        MO00733        84.9632       209.9484      1.22      9.85
                      MO00710C2        30.3884        75.0913      0.44      3.52
                        MO00734       176.5817       436.3421      2.53     20.48
                        MO00728         9.8995        24.4621      0.14      1.15
                      MO00727B2       211.4606       522.5297      3.03     24.52
                      MO00723B2         6.1398        15.1718      0.09      0.71

HRUs:
138                CNNT/MO00734        12.8744        31.8134      0.18      1.49    1
139              CNNT/MO00727B2         9.4455        23.3404      0.14      1.10    2
140               CNNT/MO00727B        17.2495        42.6244      0.25      2.00    3
141                GSCP/MO00734         5.0098        12.3795      0.07      0.58    4
142              GSCP/MO00727B2         3.5886         8.8676      0.05      0.42    5
143              GSCP/MO00723B2         2.1031         5.1969      0.03      0.24    6
144               GSCP/MO00727B         3.1600         7.8085      0.05      0.37    7
145                GSCT/MO00734         6.6841        16.5167      0.10      0.78    8
146              GSCT/MO00727B2         4.7650        11.7746      0.07      0.55    9
147              GSCT/MO00723B2         2.8207         6.9701      0.04      0.33   10
148               GSCT/MO00727B         4.0813        10.0850      0.06      0.47   11
149                CNCP/MO00734         8.2139        20.2970      0.12      0.95   12
150              CNCP/MO00727B2         6.0362        14.9157      0.09      0.70   13
151               CNCP/MO00727B        11.0336        27.2647      0.16      1.28   14
152                CNCT/MO00734        10.4058        25.7132      0.15      1.21   15
153              CNCT/MO00727B2         7.6430        18.8863      0.11      0.89   16
154               CNCT/MO00727B        13.9668        34.5127      0.20      1.62   17
155                WTNT/MO00734        33.1787        81.9862      0.48      3.85   18
156              WTNT/MO00727B2        30.7185        75.9071      0.44      3.56   19
157               WTNT/MO00727B        77.3661       191.1755      1.11      8.97   20
158                SBNT/MO00734        55.1596       136.3021      0.79      6.40   21
159              SBNT/MO00727B2        60.6606       149.8954      0.87      7.03   22
160               SBNT/MO00727B       107.8577       266.5217      1.55     12.51   23
161                WTCP/MO00734         7.0140        17.3319      0.10      0.81   24
162              WTCP/MO00727B2         6.4951        16.0497      0.09      0.75   25
163               WTCP/MO00727B        16.3017        40.2823      0.23      1.89   26
164                WTCT/MO00734         2.8765         7.1080      0.04      0.33   27
165              WTCT/MO00727B2         2.6618         6.5775      0.04      0.31   28
166               WTCT/MO00727B         6.7702        16.7295      0.10      0.79   29
167              FRST/MO00727B2        14.9851        37.0290      0.21      1.74   30
168              FRST/MO00710C2        17.9054        44.2451      0.26      2.08   31
169                FRST/MO00733        69.9215       172.7795      1.00      8.11   32
170                SBCP/MO00734        14.9086        36.8398      0.21      1.73   33
171              SBCP/MO00727B2        16.3913        40.5036      0.23      1.90   34
172               SBCP/MO00727B        29.1509        72.0333      0.42      3.38   35
173                SBCT/MO00734        17.3898        42.9711      0.25      2.02   36
174              SBCT/MO00727B2        19.1448        47.3077      0.27      2.22   37
175               SBCT/MO00727B        34.0084        84.0365      0.49      3.94   38
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176              BROS/MO00727B2        26.8913        66.4498       0.39      3.12   39
177                BROS/MO00728         9.8995        24.4621       0.14      1.15   40
178              BROS/MO00710C2        12.4830        30.8462       0.18      1.45   41
179               BROS/MO00727B        20.3082        50.1826       0.29      2.35   42
180                BROS/MO00733        15.0417        37.1689       0.22      1.74   43
181                GSNT/MO00734         2.8665         7.0833       0.04      0.33   44
182              GSNT/MO00727B2         2.0337         5.0253       0.03      0.24   45
183              GSNT/MO00723B2         1.2160         3.0048       0.02      0.14   46
184               GSNT/MO00727B         1.6924         4.1819       0.02      0.20   47

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                                     Area [ha]   Area [acres] %Wat.Area %Sub.Area

SUBBASIN # 5                          598.1500      1478.0586       8.57

LANDUSE:
            Corn notilll-->CNNT        20.4294        50.4821       0.29      3.42
Grain Sorgh Conservation-->GSCP        20.4022        50.4148       0.29      3.41
    Grain Sorghum conven-->GSCT        27.0289        66.7899       0.39      4.52
       Corn Conservation-->CNCP        13.2272        32.6851       0.19      2.21
       Corn Conventional-->CNCT        20.8903        51.6209       0.30      3.49
            Wheat notill-->WTNT        71.8574       177.5632       1.03     12.01
          Soybean notill-->SBNT       174.2739       430.6395       2.50     29.14
      Wheat Conservation-->WTCP        15.6495        38.6707       0.22      2.62
      Wheat conventional-->WTCT         5.7448        14.1957       0.08      0.96
            Forest-Mixed-->FRST        62.7757       155.1219       0.90     10.49
    Soybean Conservation-->SBCP        47.1972       116.6267       0.68      7.89
    Soybean Conventional-->SBCT        50.4617       124.6934       0.72      8.44
       Smooth Bromegrass-->BROS        56.7024       140.1146       0.81      9.48
    Grain Sorghum notill-->GSNT        11.5093        28.4400       0.16      1.92

SOIL:
                       MO00727B       245.3377       606.2418       3.52     41.02
                        MO00733        49.0989       121.3259       0.70      8.21
                      MO00710C2        38.0510        94.0259       0.55      6.36
                        MO00734        73.6402       181.9686       1.06     12.31
                      MO00727B2       168.9682       417.5288       2.42     28.25
                      MO00723B2        23.0539        56.9674       0.33      3.85

HRUs:
185                CNNT/MO00734         3.3526         8.2845       0.05      0.56    1
186              CNNT/MO00727B2         5.3076        13.1154       0.08      0.89    2
187               CNNT/MO00727B        11.7692        29.0822       0.17      1.97    3
188              GSCP/MO00727B2         5.3960        13.3337       0.08      0.90    4
189              GSCP/MO00710C2         4.9574        12.2500       0.07      0.83    5
190               GSCP/MO00727B         7.2375        17.8841       0.10      1.21    6
191                GSCP/MO00733         2.8113         6.9469       0.04      0.47    7
192                GSCT/MO00734         2.8326         6.9994       0.04      0.47    8
193              GSCT/MO00727B2         6.3830        15.7726       0.09      1.07    9
194              GSCT/MO00710C2         5.9611        14.7301       0.09      1.00   10
195               GSCT/MO00727B         8.4614        20.9084       0.12      1.41   11
196                GSCT/MO00733         3.3910         8.3793       0.05      0.57   12
197                CNCP/MO00734         2.1437         5.2972       0.03      0.36   13
198              CNCP/MO00727B2         3.4511         8.5278       0.05      0.58   14
199               CNCP/MO00727B         7.6324        18.8601       0.11      1.28   15
200                CNCT/MO00734         4.2866        10.5924       0.06      0.72   16
201              CNCT/MO00727B2         4.4868        11.0870       0.06      0.75   17
202               CNCT/MO00727B        12.1169        29.9415       0.17      2.03   18
203                WTNT/MO00734        11.1850        27.6387       0.16      1.87   19
204              WTNT/MO00727B2        15.2605        37.7095       0.22      2.55   20
205              WTNT/MO00710C2        12.6160        31.1748       0.18      2.11   21
206               WTNT/MO00727B        32.7958        81.0402       0.47      5.48   22
207                SBNT/MO00734        29.5569        73.0366       0.42      4.94   23
208              SBNT/MO00727B2        59.7800       147.7193       0.86      9.99   24
209               SBNT/MO00727B        84.9370       209.8836       1.22     14.20   25
210                WTCP/MO00734         2.3822         5.8866       0.03      0.40   26
211              WTCP/MO00727B2         3.3615         8.3065       0.05      0.56   27
212              WTCP/MO00710C2         2.6818         6.6270       0.04      0.45   28
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213               WTCP/MO00727B         7.2239        17.8506      0.10      1.21   29
214                WTCT/MO00734         0.9676         2.3910      0.01      0.16   30
215              WTCT/MO00727B2         1.1670         2.8836      0.02      0.20   31
216              WTCT/MO00710C2         1.0760         2.6589      0.02      0.18   32
217               WTCT/MO00727B         2.5342         6.2622      0.04      0.42   33
218              FRST/MO00723B2        11.3509        28.0486      0.16      1.90   34
219               FRST/MO00727B         9.9948        24.6975      0.14      1.67   35
220                FRST/MO00733        41.4301       102.3758      0.59      6.93   36
221                SBCP/MO00734         7.9984        19.7644      0.11      1.34   37
222              SBCP/MO00727B2        16.1740        39.9668      0.23      2.70   38
223               SBCP/MO00727B        23.0248        56.8954      0.33      3.85   39
224                SBCT/MO00734         7.7146        19.0632      0.11      1.29   40
225              SBCT/MO00727B2        18.7332        46.2907      0.27      3.13   41
226               SBCT/MO00727B        24.0139        59.3395      0.34      4.01   42
227              BROS/MO00727B2        26.7604        66.1263      0.38      4.47   43
228              BROS/MO00710C2         8.1884        20.2340      0.12      1.37   44
229              BROS/MO00723B2        11.7031        28.9188      0.17      1.96   45
230               BROS/MO00727B        10.0506        24.8354      0.14      1.68   46
231                GSNT/MO00734         1.2200         3.0146      0.02      0.20   47
232              GSNT/MO00727B2         2.7072         6.6896      0.04      0.45   48
233              GSNT/MO00710C2         2.5702         6.3511      0.04      0.43   49
234               GSNT/MO00727B         3.5454         8.7609      0.05      0.59   50
235                GSNT/MO00733         1.4666         3.6239      0.02      0.25   51

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                                     Area [ha]   Area [acres] %Wat.Area %Sub.Area

SUBBASIN # 6                         1133.5600      2801.0834     16.24

LANDUSE:
            Corn notilll-->CNNT        41.7007       103.0445      0.60      3.68
Grain Sorgh Conservation-->GSCP        50.9856       125.9879      0.73      4.50
    Grain Sorghum conven-->GSCT        67.3469       166.4177      0.97      5.94
       Corn Conservation-->CNCP        27.2184        67.2581      0.39      2.40
       Corn Conventional-->CNCT        37.0311        91.5057      0.53      3.27
            Wheat notill-->WTNT       154.3288       381.3542      2.21     13.61
          Soybean notill-->SBNT       319.2418       788.8625      4.57     28.16
      Wheat Conservation-->WTCP        33.9671        83.9344      0.49      3.00
      Wheat conventional-->WTCT        11.8479        29.2767      0.17      1.05
            Forest-Mixed-->FRST       178.0786       440.0410      2.55     15.71
    Soybean Conservation-->SBCP        86.5477       213.8638      1.24      7.64
    Soybean Conventional-->SBCT        96.6740       238.8863      1.39      8.53
    Grain Sorghum notill-->GSNT        28.5913        70.6506      0.41      2.52

SOIL:
                       MO00727B       425.7105      1051.9520      6.10     37.56
                      MO00710C2        54.2932       134.1612      0.78      4.79
                        MO00733       161.9368       400.1539      2.32     14.29
                        MO00734        73.2355       180.9687      1.05      6.46
                      MO00727B2       418.3839      1033.8476      6.00     36.91

HRUs:
236              CNNT/MO00727B2        15.3452        37.9188      0.22      1.35    1
237               CNNT/MO00727B        26.3555        65.1257      0.38      2.33    2
238              GSCP/MO00727B2        28.5643        70.5837      0.41      2.52    3
239               GSCP/MO00727B        12.1355        29.9874      0.17      1.07    4
240                GSCP/MO00733        10.2858        25.4168      0.15      0.91    5
241              GSCT/MO00727B2        38.0329        93.9812      0.54      3.36    6
242               GSCT/MO00727B        15.4214        38.1070      0.22      1.36    7
243                GSCT/MO00733        13.8926        34.3294      0.20      1.23    8
244              CNCP/MO00727B2        10.0389        24.8066      0.14      0.89    9
245               CNCP/MO00727B        17.1795        42.4515      0.25      1.52   10
246              CNCT/MO00727B2        14.4141        35.6179      0.21      1.27   11
247               CNCT/MO00727B        22.6170        55.8878      0.32      2.00   12
248              WTNT/MO00727B2        63.5720       157.0896      0.91      5.61   13
249              WTNT/MO00710C2        22.6895        56.0670      0.33      2.00   14
250               WTNT/MO00727B        68.0673       168.1977      0.98      6.00   15
251                SBNT/MO00734        46.3343       114.4943      0.66      4.09   16
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252              SBNT/MO00727B2       122.2282       302.0320      1.75     10.78   17
253               SBNT/MO00727B       150.6794       372.3362      2.16     13.29   18
254              WTCP/MO00727B2        13.9253        34.4101      0.20      1.23   19
255              WTCP/MO00710C2         4.8383        11.9556      0.07      0.43   20
256               WTCP/MO00727B        15.2035        37.5686      0.22      1.34   21
257              WTCT/MO00727B2         4.9672        12.2741      0.07      0.44   22
258              WTCT/MO00710C2         1.9211         4.7471      0.03      0.17   23
259               WTCT/MO00727B         4.9596        12.2555      0.07      0.44   24
260              FRST/MO00727B2        21.5068        53.1444      0.31      1.90   25
261              FRST/MO00710C2        24.8443        61.3915      0.36      2.19   26
262                FRST/MO00733       131.7274       325.5051      1.89     11.62   27
263                SBCP/MO00734        12.5282        30.9579      0.18      1.11   28
264              SBCP/MO00727B2        33.1395        81.8895      0.47      2.92   29
265               SBCP/MO00727B        40.8800       101.0165      0.59      3.61   30
266                SBCT/MO00734        14.3730        35.5165      0.21      1.27   31
267              SBCT/MO00727B2        36.3719        89.8767      0.52      3.21   32
268               SBCT/MO00727B        45.9291       113.4931      0.66      4.05   33
269              GSNT/MO00727B2        16.2777        40.2230      0.23      1.44   34
270               GSNT/MO00727B         6.2828        15.5251      0.09      0.55   35
271                GSNT/MO00733         6.0309        14.9026      0.09      0.53   36

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                                     Area [ha]   Area [acres] %Wat.Area %Sub.Area

SUBBASIN # 7                         1317.3600      3255.2624     18.88

LANDUSE:
            Corn notilll-->CNNT        48.0074       118.6286      0.69      3.64
Grain Sorgh Conservation-->GSCP        50.5814       124.9892      0.72      3.84
    Grain Sorghum conven-->GSCT        67.1348       165.8935      0.96      5.10
       Corn Conservation-->CNCP        31.0592        76.7488      0.45      2.36
       Corn Conventional-->CNCT        39.1984        96.8613      0.56      2.98
            Wheat notill-->WTNT       174.0214       430.0155      2.49     13.21
          Soybean notill-->SBNT       331.0283       817.9874      4.74     25.13
      Wheat Conservation-->WTCP        37.6354        92.9989      0.54      2.86
      Wheat conventional-->WTCT        14.0994        34.8404      0.20      1.07
            Forest-Mixed-->FRST       142.6656       352.5339      2.04     10.83
    Soybean Conservation-->SBCP        89.6257       221.4695      1.28      6.80
    Soybean Conventional-->SBCT       103.5665       255.9180      1.48      7.86
       Smooth Bromegrass-->BROS       160.0960       395.6053      2.29     12.15
    Grain Sorghum notill-->GSNT        28.6405        70.7720      0.41      2.17

SOIL:
                       MO00727B       691.5767      1708.9205      9.91     52.50
                        MO00733       142.6656       352.5339      2.04     10.83
                        MO00734       142.3058       351.6447      2.04     10.80
                        MO00728        42.4027       104.7793      0.61      3.22
                      MO00727B2       175.3056       433.1888      2.51     13.31
                      MO00723B2       123.1036       304.1952      1.76      9.34

HRUs:
272                CNNT/MO00734        10.3464        25.5665      0.15      0.79    1
273                CNNT/MO00728         8.1383        20.1103      0.12      0.62    2
274               CNNT/MO00727B        29.5226        72.9518      0.42      2.24    3
275                GSCP/MO00734         7.4164        18.3262      0.11      0.56    4
276              GSCP/MO00727B2         7.1103        17.5698      0.10      0.54    5
277              GSCP/MO00723B2         9.7389        24.0653      0.14      0.74    6
278               GSCP/MO00727B        26.3159        65.0279      0.38      2.00    7
279                GSCT/MO00734         9.9263        24.5284      0.14      0.75    8
280              GSCT/MO00727B2         9.3470        23.0970      0.13      0.71    9
281              GSCT/MO00723B2        13.0219        32.1777      0.19      0.99   10
282               GSCT/MO00727B        34.8396        86.0904      0.50      2.64   11
283                CNCP/MO00734         6.6390        16.4054      0.10      0.50   12
284                CNCP/MO00728         5.2371        12.9412      0.08      0.40   13
285               CNCP/MO00727B        19.1830        47.4021      0.27      1.46   14
286                CNCT/MO00734         8.4201        20.8064      0.12      0.64   15
287                CNCT/MO00728         6.6162        16.3489      0.09      0.50   16
288               CNCT/MO00727B        24.1622        59.7060      0.35      1.83   17
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289              WTNT/MO00727B2        39.4361        97.4485      0.57      2.99   18
290              WTNT/MO00723B2        26.3047        65.0003      0.38      2.00   19
291               WTNT/MO00727B       108.2806       267.5667      1.55      8.22   20
292                SBNT/MO00734        60.1114       148.5384      0.86      4.56   21
293              SBNT/MO00727B2        50.8637       125.6868      0.73      3.86   22
294              SBNT/MO00723B2        38.2724        94.5730      0.55      2.91   23
295               SBNT/MO00727B       181.7807       449.1892      2.60     13.80   24
296              WTCP/MO00727B2         8.5397        21.1021      0.12      0.65   25
297              WTCP/MO00723B2         5.6481        13.9567      0.08      0.43   26
298               WTCP/MO00727B        23.4476        57.9401      0.34      1.78   27
299              WTCT/MO00727B2         3.1826         7.8644      0.05      0.24   28
300              WTCT/MO00723B2         2.1782         5.3824      0.03      0.17   29
301               WTCT/MO00727B         8.7387        21.5937      0.13      0.66   30
302                FRST/MO00733       142.6656       352.5339      2.04     10.83   31
303                SBCP/MO00734        16.2473        40.1478      0.23      1.23   32
304              SBCP/MO00727B2        13.7881        34.0712      0.20      1.05   33
305              SBCP/MO00723B2        10.3611        25.6029      0.15      0.79   34
306               SBCP/MO00727B        49.2292       121.6477      0.71      3.74   35
307                SBCT/MO00734        18.9287        46.7736      0.27      1.44   36
308              SBCT/MO00727B2        15.8327        39.1233      0.23      1.20   37
309              SBCT/MO00723B2        11.9819        29.6079      0.17      0.91   38
310               SBCT/MO00727B        56.8233       140.4131      0.81      4.31   39
311              BROS/MO00727B2        23.2565        57.4680      0.33      1.77   40
312                BROS/MO00728        22.4111        55.3789      0.32      1.70   41
313               BROS/MO00727B       114.4285       282.7584      1.64      8.69   42
314                GSNT/MO00734         4.2702        10.5520      0.06      0.32   43
315              GSNT/MO00727B2         3.9489         9.7579      0.06      0.30   44
316              GSNT/MO00723B2         5.5964        13.8290      0.08      0.42   45
317               GSNT/MO00727B        14.8250        36.6333      0.21      1.13   46
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APPENDIX B

FLOW CALIBRATION INPUTS AND RESULTS

Table B.1 Default Results for GCEW Flow Calibration (1993-1998)

	Annual Streamflow (mm)	
Year	**Measured**	**Estimated**
1993	472.4	521.0
1994	130.6	218.8
1995	231.3	257.7
1996	97.9	186.6
1997	289.1	303.2
1998	447.4	438.1
Average Streamflow	278.1	320.9
Average Surface Flow	236.4	282.1

	Annual		**Monthly**		**Weekly**		**Daily**	
	R^2	E_{NS}	R^2	E_{NS}	R^2	E_{NS}	R^2	E_{NS}
Streamflow	0.95	0.85	0.71	0.68	0.58	0.57	0.33	0.33
Surface Flow	0.95	0.80	0.71	0.68	0.58	0.56	0.33	0.33

Table B.2 Parameters Adjusted for GWEC Flow Calibration

Basin Response		
Parameter	**Default**	**Calibrated Value**
SURLAG	4.0	6.0
SMTMP	0.5	-2.5
MSK_CO1	0.0	1.0
MSK_CO2	3.5	2.5
MSK_X	0.2	0.3
CH_N2	0.014	0.014
Surface Water		
Parameter	**Default**	**Calibrated Value**
ESCO	0.85	0.75
Soil_K	1.08-3.28	1.51-32.40
Channel Width, m	Min = 4.96	Min = 4.0
	Max = 16.48	Max = 10.0
Channel Depth, m	Min = 0.319	Min = 0.319
	Max = 0.71	Max = 1.50

Table B.3 Adjustment of GCEW Subbasin's Channel Width and Depth

	Default values		**Calibrated Values**	
Subbasin	**Width (m)**	**Depth (m)**	**Width (m)**	**Depth (m)**
1	4.96	0.319	4.00	0.319
2	7.86	0.434	6.00	0.600
3	5.24	0.331	4.00	0.331
4	9.72	0.500	7.50	0.900
5	6.98	0.397	6.00	0.600
6	14.53	0.653	9.00	1.200
7	16.48	0.710	10.00	1.500

Table B.4 Results of GCEW Flow Calibration (1993-1998)

	Annual Streamflow (mm)	
Year	**Measured**	**Estimated**
1993	472.4	479.0
1994	130.6	203.8
1995	231.3	238.7
1996	97.9	162.6
1997	289.1	256.9
1998	447.4	423.8
Average Streamflow	278.1	294.1
Average Surface Flow	236.4	251.3

	Annual		**Monthly**		**Weekly**		**Daily**	
	R^2	E_{NS}	R^2	E_{NS}	R^2	E_{NS}	R^2	E_{NS}
Streamflow	0.94	0.91	0.75	0.71	0.69	0.68	0.51	0.51
Surface Flow	0.94	0.91	0.75	0.72	0.69	0.69	0.51	0.51

Table B.5 Results of GCEW Flow Evaluation (1999–2003)

	Annual Streamflow (mm)	
Year	**Measured**	**Estimated**
1999	273.0	305.0
2000	138.5	176.8
2001	328.2	274.5
2002	163.1	171.8
2003	350.8	299.9
Average Streamflow	250.7	245.6
Average Surface Flow	213.1	214.7

	Annual		**Monthly**		**Weekly**		**Daily**	
	R^2	E_{NS}	R^2	E_{NS}	R^2	E_{NS}	R^2	E_{NS}
Streamflow	0.84	0.78	0.73	0.70	0.77	0.74	0.58	0.54
Surface Flow	0.84	0.79	0.73	0.71	0.77	0.75	0.58	0.55

APPENDIX C

SWAT LANDUSE MANAGEMENT

Table C.1 Management Schedule for Conventional Till Corn

Corn, Conventional Till

Management	Year											
	1	2	3	4	5	6	7	8	9	10	11	12
Fertilizer Application • Anhydrous Ammonia @ 168 kg ha^{-1} (injected)	3/25	4/14	3/30	4/29	3/15	3/25	4/4	4/14	3/5	3/15	3/8	3/15
Fertilizer Application (30-80-80) • Elemental Nitrogen @ 33.6 kg ha^{-1} • Elemental Phosphorous @ 39.4 kg ha^{-1}	4/11	5/1	4/16	5/16	4/1	4/11	4/21	5/1	3/22	4/1	3/25	4/1
Disking (Disc Plow Ge23ft)	4/11	5/1	4/16	5/16	4/1	4/11	4/21	5/1	3/22	4/1	3/25	4/1
Planting	5/5	5/25	5/10	6/9	4/25	5/5	5/15	5/25	4/15	4/25	4/18	4/25
Pesticide Application • Atrazine @ 2.25 kg ha^{-1}	5/18	6/7	5/23	6/22	5/8	5/18	5/28	6/7	4/28	5/8	5/1	5/8
Cultivation (Row Cultivator Ge15ft)	6/6	6/27	6/11	7/11	5/27	6/6	6/16	6/26	5/17	5/27	5/20	5/27
Harvest / Kill	10/11	10/31	10/16	11/15	10/1	10/11	10/21	10/31	9/21	10/1	9/24	10/1
Generic Fall Plowing	11/11	12/1	11/16	12/16	11/1	11/11	11/21	12/1	10/21	11/1	10/25	11/1

Table C.2 Management Schedule for Conservation Till Corn

Corn, Conservation Till												
Management	Year											
	1	2	3	4	5	6	7	8	9	10	11	12
Fertilizer Application • Anhydrous Ammonia @ 168 kg ha^{-1} (injected)	3/25	4/14	3/30	4/29	3/15	3/25	4/4	4/14	3/5	3/15	3/8	3/15
Fertilizer Application (30-80-80) • Elemental Nitrogen @ 33.6 kg ha^{-1} • Elemental Phosphorous @ 39.4 kg ha^{-1}	4/11	5/1	4/16	5/16	4/1	4/11	4/21	5/1	3/22	4/1	3/25	4/1
Generic Conservation Plow	4/11	5/1	4/16	5/16	4/1	4/11	4/21	5/1	3/22	4/1	3/25	4/1
Planting	5/5	5/25	5/10	6/9	4/25	5/5	5/15	5/25	4/15	4/25	4/18	4/25
Pesticide Application • Atrazine @ 2.25 kg ha^{-1}	5/18	6/7	5/23	6/22	5/8	5/18	5/28	6/7	4/28	5/8	5/1	5/8
Cultivation (Row Cultivator Ge15ft)	6/6	6/27	6/11	7/11	5/27	6/6	6/16	6/26	5/17	5/27	5/20	5/27
Harvest / Kill	10/11	10/31	10/16	11/15	10/1	10/11	10/21	10/31	9/21	10/1	9/24	10/1
Generic Fall Plowing	11/11	12/1	11/16	12/16	11/1	11/11	11/21	12/1	10/21	11/1	10/25	11/1

Table C.3 Management Schedule for No-Till Corn

Corn, No-Till												
Management	Year											
	1	2	3	4	5	6	7	8	9	10	11	12
Fertilizer Application • Anhydrous Ammonia @ 168 kg ha^{-1} (knifed)	3/23	4/12	3/28	4/27	3/13	3/23	4/2	4/12	3/3	3/13	3/6	3/25
Fertilizer Application (30-80-80) • Elemental Nitrogen @ 33.6 kg ha^{-1} • Elemental Phosphorous @ 39.4 kg ha^{-1}	4/8	4/28	4/13	5/13	3/29	4/8	4/18	4/28	3/19	3/29	3/22	4/10
Pesticide Application • Atrazine @ 1.25 kg ha^{-1}	4/8	4/28	4/13	5/13	3/29	4/8	4/18	4/28	3/19	3/29	3/22	4/10
No-Till Mixing	4/8	4/28	4/13	5/13	3/29	4/8	4/18	4/28	3/19	3/29	3/22	4/10
Planting	5/5	5/25	5/10	6/9	4/25	5/5	5/15	5/25	4/15	4/25	4/18	4/7
Pesticide Application • Atrazine @ 1.25 kg ha^{-1}	5/16	6/5	5/21	6/20	5/6	5/16	5/26	6/5	4/26	5/6	4/29	5/18
Harvest / Kill	10/8	10/28	10/13	11/12	9/28	10/8	10/18	10/28	9/18	9/28	9/21	10/10

Table C.4 Management Schedule for Conventional Till Grain Sorghum

Grain Sorghum, Conventional Till

Management	Year											
	1	2	3	4	5	6	7	8	9	10	11	12
Fertilizer Application • Anhydrous Ammonia @ 168 kg ha^{-1} (injected)	3/25	4/14	3/30	4/29	3/15	3/25	4/4	4/14	3/5	3/15	3/8	3/15
Fertilizer Application (30-80-80) • Elemental Nitrogen @ 33.6 kg ha^{-1} • Elemental Phosphorous @ 39.4 kg ha^{-1}	4/11	5/1	4/16	5/16	4/1	4/11	4/21	5/1	3/22	4/1	3/25	4/1
Disking (Disc Plow Ge23ft)	4/11	5/1	4/16	5/16	4/1	4/11	4/21	5/1	3/22	4/1	3/25	4/1
Planting	5/5	5/25	5/10	6/9	4/25	5/5	5/15	5/25	4/15	4/25	4/18	4/25
Pesticide Application • Atrazine @ 2.25 kg ha^{-1}	5/18	6/7	5/23	6/22	5/8	5/18	5/28	6/7	4/28	5/8	5/1	5/8
Cultivation (Row Cultivator Ge15ft)	6/6	6/27	6/11	7/11	5/27	6/6	6/16	6/26	5/17	5/27	5/20	5/27
Harvest / Kill	10/11	10/31	10/16	11/15	10/1	10/11	10/21	10/31	9/21	10/1	9/24	10/1
Generic Fall Plowing	11/11	12/1	11/16	12/16	11/1	11/11	11/21	12/1	10/21	11/1	10/25	11/1

Table C.5 Management Schedule for Conservation Till Grain Sorghum

Grain Sorghum, Conservation Till												
Management	Year											
	1	2	3	4	5	6	7	8	9	10	11	12
Fertilizer Application • Anhydrous Ammonia @ 168 kg ha^{-1} (injected)	3/25	4/14	3/30	4/29	3/15	3/25	4/4	4/14	3/5	3/15	3/8	3/15
Fertilizer Application (30-80-80) • Elemental Nitrogen @ 33.6 kg ha^{-1} • Elemental Phosphorous @ 39.4 kg ha^{-1}	4/11	5/1	4/16	5/16	4/1	4/11	4/21	5/1	3/22	4/1	3/25	4/1
Generic Conservation Plow	4/11	5/1	4/16	5/16	4/1	4/11	4/21	5/1	3/22	4/1	3/25	4/1
Planting	5/5	5/25	5/10	6/9	4/25	5/5	5/15	5/25	4/15	4/25	4/18	4/25
Pesticide Application • Atrazine @ 2.25 kg ha^{-1}	5/18	6/7	5/23	6/22	5/8	5/18	5/28	6/7	4/28	5/8	5/1	5/8
Cultivation (Row Cultivator Ge15ft)	6/6	6/26	6/11	7/11	5/27	6/6	6/16	6/26	5/17	5/27	5/20	5/27
Harvest / Kill	10/11	10/31	10/16	11/15	10/1	10/11	10/21	10/31	9/21	10/1	9/24	10/1
Generic Fall Plowing	11/11	12/1	11/16	12/16	11/1	11/11	11/21	12/1	10/21	11/1	10/25	11/1

Table C.6 Management Schedule for No-Till Grain Sorghum

Grain Sorghum, No-Till												
Management	Year											
	1	2	3	4	5	6	7	8	9	10	11	12
Fertilizer Application • Anhydrous Ammonia @168 kg ha^{-1} (knifed)	3/23	4/12	3/28	4/27	3/13	3/23	4/2	4/12	3/3	3/13	3/6	3/25
Fertilizer Application (30-80-80) • Elemental Nitrogen @ 33.6 kg ha^{-1} • Elemental Phosphorous @ 39.4 kg ha^{-1}	4/8	4/28	4/13	5/13	3/29	4/8	4/18	4/28	3/19	3/29	3/22	4/10
Pesticide Application • Atrazine @ 1.25 kg ha^{-1}	4/8	4/28	4/13	5/13	3/29	4/8	4/18	4/28	3/19	3/29	3/22	4/10
No-Till Mixing	4/8	4/28	4/13	5/13	3/29	4/8	4/18	4/28	3/19	3/29	3/22	4/10
Planting	5/5	5/25	5/10	6/9	4/25	5/5	5/15	5/25	4/15	4/25	4/18	4/7
Pesticide Application • Atrazine @ 1.25 kg ha^{-1}	5/16	6/5	5/21	6/20	5/6	5/16	5/26	6/5	4/26	5/6	4/29	5/18
Harvest / Kill	10/8	10/28	10/13	11/12	9/28	10/8	10/18	10/28	9/18	9/28	9/21	10/10

Table C.7 Management Schedule for All Soybean Tillage Systems

Soybean	
Conventional Till	
Management	Date
Fertilizer Application (20-40-60) • Elemental Nitrogen @ 22.4 kg ha^{-1} • Elemental Phosphorous @ 22.0 kg ha^{-1}	5/10
Disking (Disc Plow Ge23ft)	5/10
Planting	5/12
Cultivation (Row cultivator Ge15ft)	6/15
Harvest / Kill	10/1
Generic Fall Plowing	11/1
Conservation Till	
Management	Date
Fertilizer Application (20-40-60) • Elemental Nitrogen @ 22.4 kg ha^{-1} • Elemental Phosphorous @ 22.0 kg ha^{-1}	5/10
Generic Conservation Tillage	5/10
Planting	5/12
Cultivation (Row cultivator Ge15ft)	6/15
Harvest / Kill	10/1
Generic Fall Plowing	11/1
No-Till	
Management	Date
Fertilizer Application (20-40-60) • Elemental Nitrogen @ 22.4 kg ha^{-1} • Elemental Phosphorous @ 22.0 kg ha^{-1}	5/10
No-Till Mixing	5/10
Planting	5/12
Harvest / Kill	10/1

Table C.8 Management Schedule for All Wheat Tillage Systems

Wheat	
Conventional Till	
Management	Date
Fertilizer Application • Anhydrous Ammonia @ 67.2 kg ha^{-1} (injected)	3/15
Harvest / Kill	6/25
Disking (Disc Plow Ge23ft)	10/1
Fertilizer Application (40-60-60) • Elemental Nitrogen @ 44.8 kg ha^{-1} • Elemental Phosphorous @ 30.0 kg ha^{-1}	10/3
Disking (Disc Plow Ge23ft)	10/3
Planting	10/5
Conservation Till	
Management	Date
Fertilizer Application • Anhydrous Ammonia @ 67.2 kg ha^{-1} (injected)	3/15
Harvest / Kill	6/25
Generic Conservation Tillage	10/1
Fertilizer Application (40-60-60) • Elemental Nitrogen @ 44.8 kg ha^{-1} • Elemental Phosphorous @ 30.0 kg ha^{-1}	10/3
Generic Conservation Tillage	10/3
Planting	10/5
No-Till	
Management	Date
Fertilizer Application • Anhydrous Ammonia @ 67.2 kg ha^{-1} (injected)	3/15
Harvest / Kill	6/25
Fertilizer Application (40-60-60) • Elemental Nitrogen @ 44.8 kg ha^{-1} • Elemental Phosphorous @ 30.0 kg ha^{-1}	10/3
No-Till Mixing	10/3
Planting	10/5

Table C.9 Crop Yields and Residue Quantities

Crop	Yield (bu ac^{-1})	Residue amount @ harvest (kg ha^{-1})
Corn	94.20	6331
Grain Sorghum	83.70	5625
Soybean	30.95	1560
Wheat	40.50	4536

Table C.10 Initial Residue Amount (kg ha^{-1}) as of Jan 1

Crop	Conventional	Conservation	No-Till
Corn	317†	4431‡	5698**
Grain Sorghum	281	3938	5063
Soybean	78	1092	1401
Wheat	227	905	905

- For corn, grain sorghum, and soybean:
  - † Approximately 95 % of the harvested residue is lost due to fall conventional tillage operation.
  - ‡ Approximately 30% of the harvested residue is lost due to fall conservation tillage operation.
  - ** Approximately 10% of the harvested residue is decomposed from Oct until Jan

- For Wheat
  - Conventional: approximately 95% of harvested wheat residue is due to decomposition and tillage operation.
  - Conservation and no-till: approximately 80% of the harvested residue is lost due to decomposition.

Table C.11 Curve Number and Operation Curve Number by Crop and Tillage System

	CN2			**CNOP at Planting****		
Crop	Conventional	Conservation	No-Till	Conventional	Conservation	No-Till
Corn	93	83	83	87	83	83
Grain Sorghum	93	83	83	87	83	83
Soybean	93	83	83	87	83	83
Wheat	85	84	83	85	84	84

** CNOP are adjusted at planting date only for conventional tillage

Table C.12 Minimum C-Factor by Crop and Tillage System

Crop	Minimum C-Factor		
	Conventional	Conservation	No-Till
Corn	0.20	0.07	0.02
Grain Sorghum	0.20	0.07	0.05
Soybean	0.25	0.23	0.14
Wheat	0.13	0.07	0.05

APPENDIX D

CORN PLANTING PROGRESS AND HYDROGRAPHS

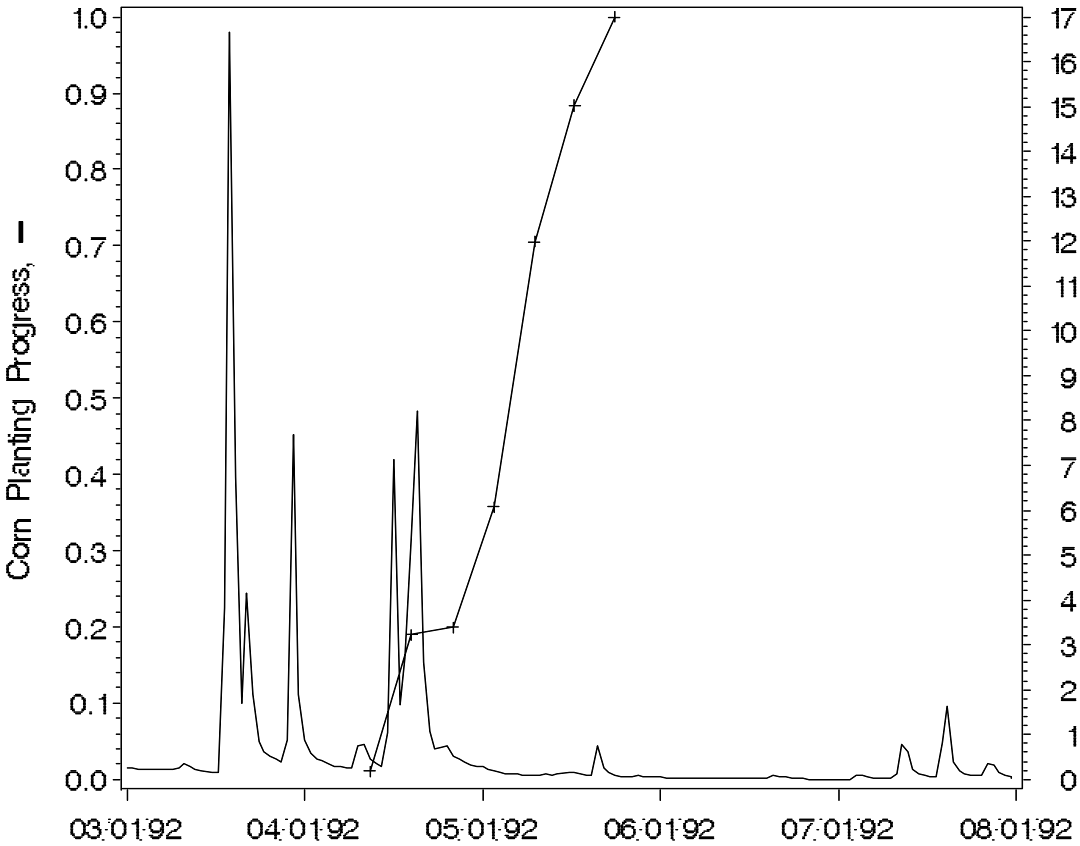

Figure D.1 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 1992.

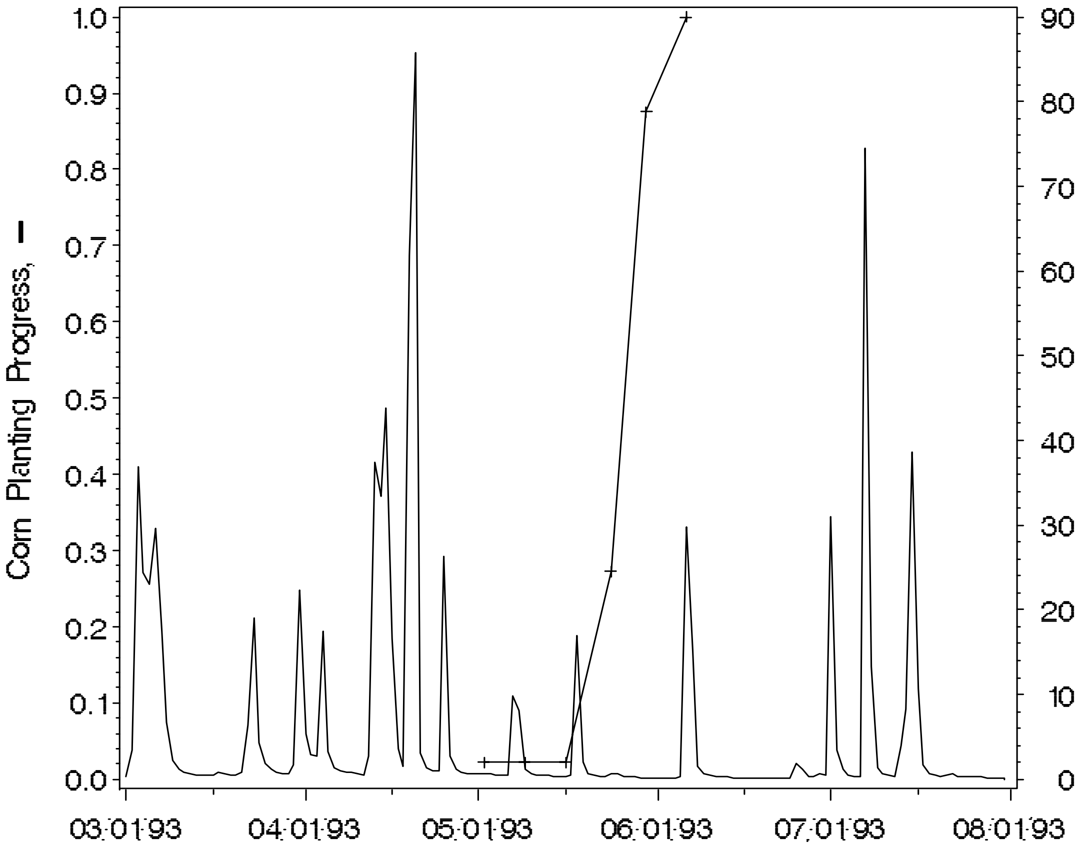

Figure D.2 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 1993.

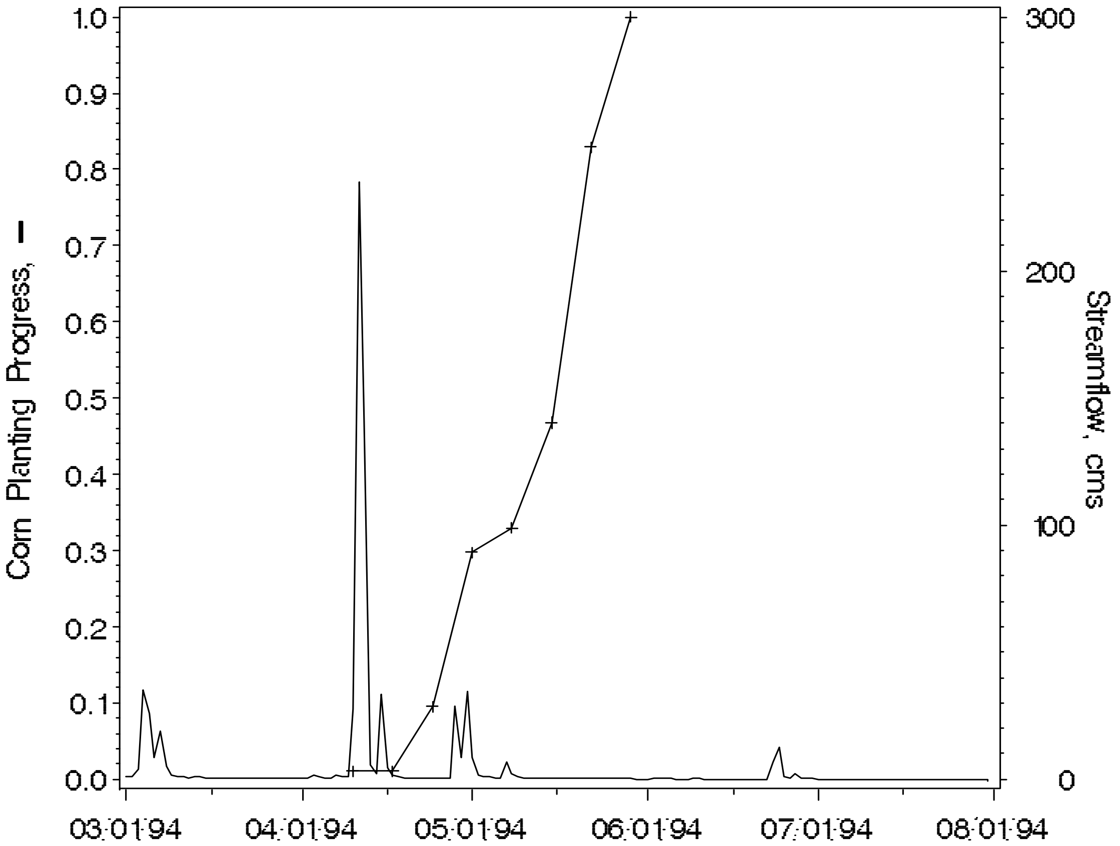

Figure D.3 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 1994.

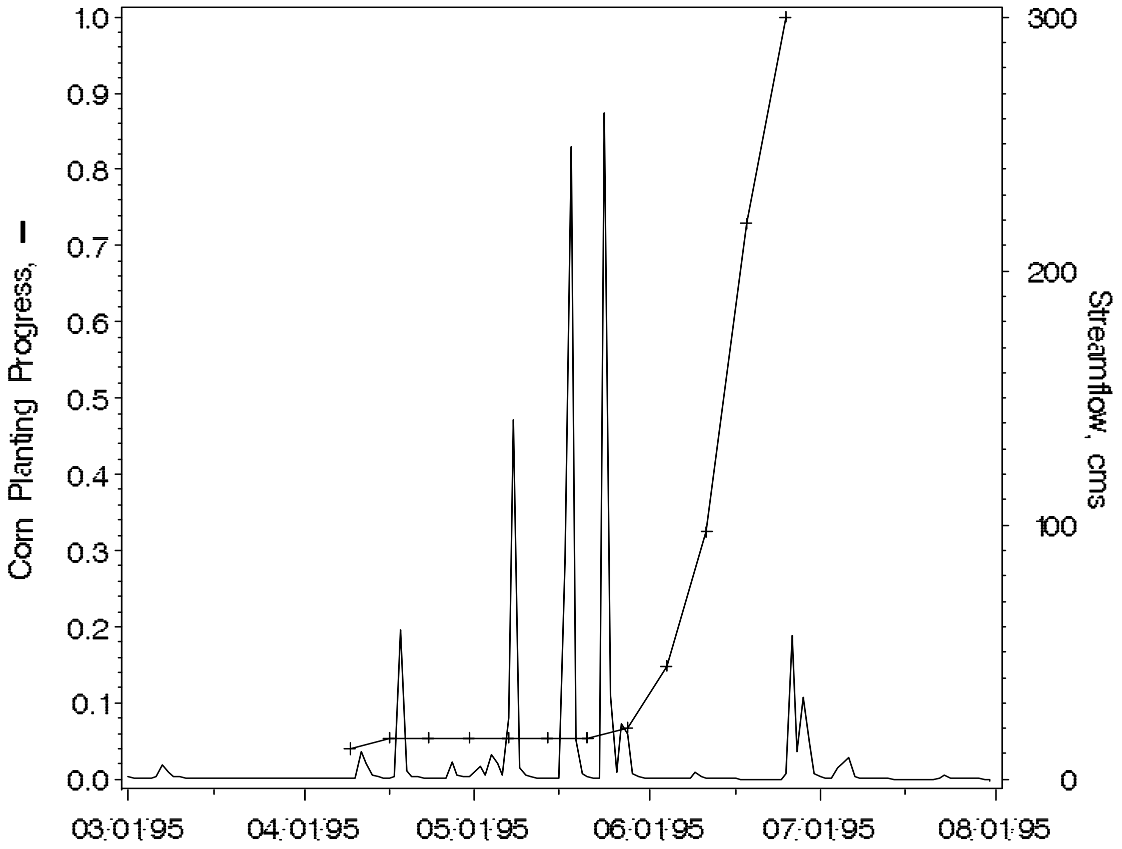

Figure D.4 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 1995.

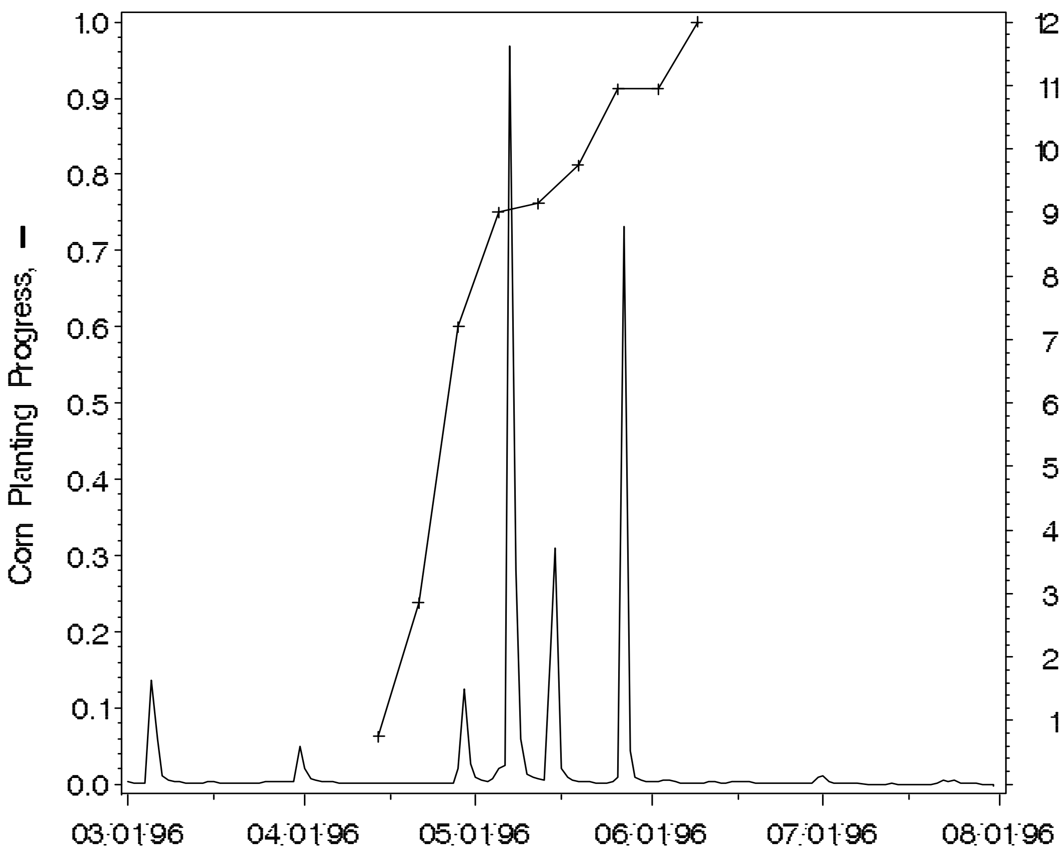

Figure D.5 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 1996.

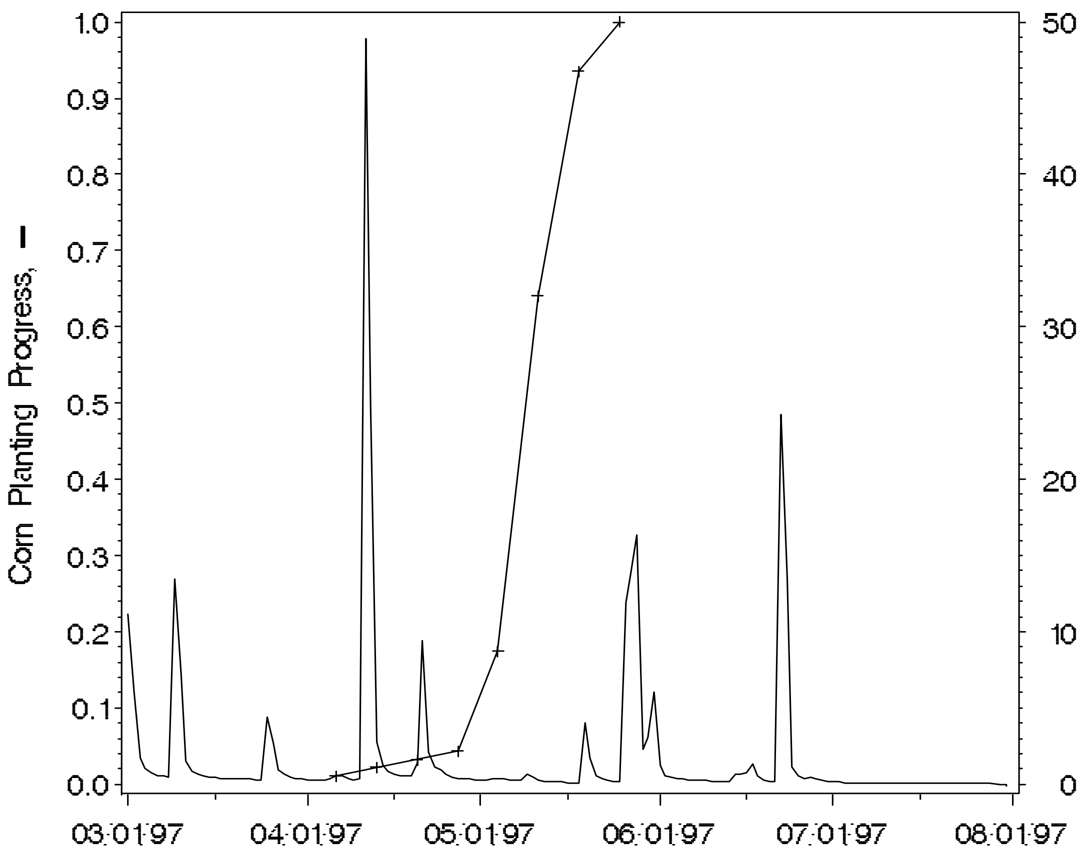

Figure D.6 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 1997.

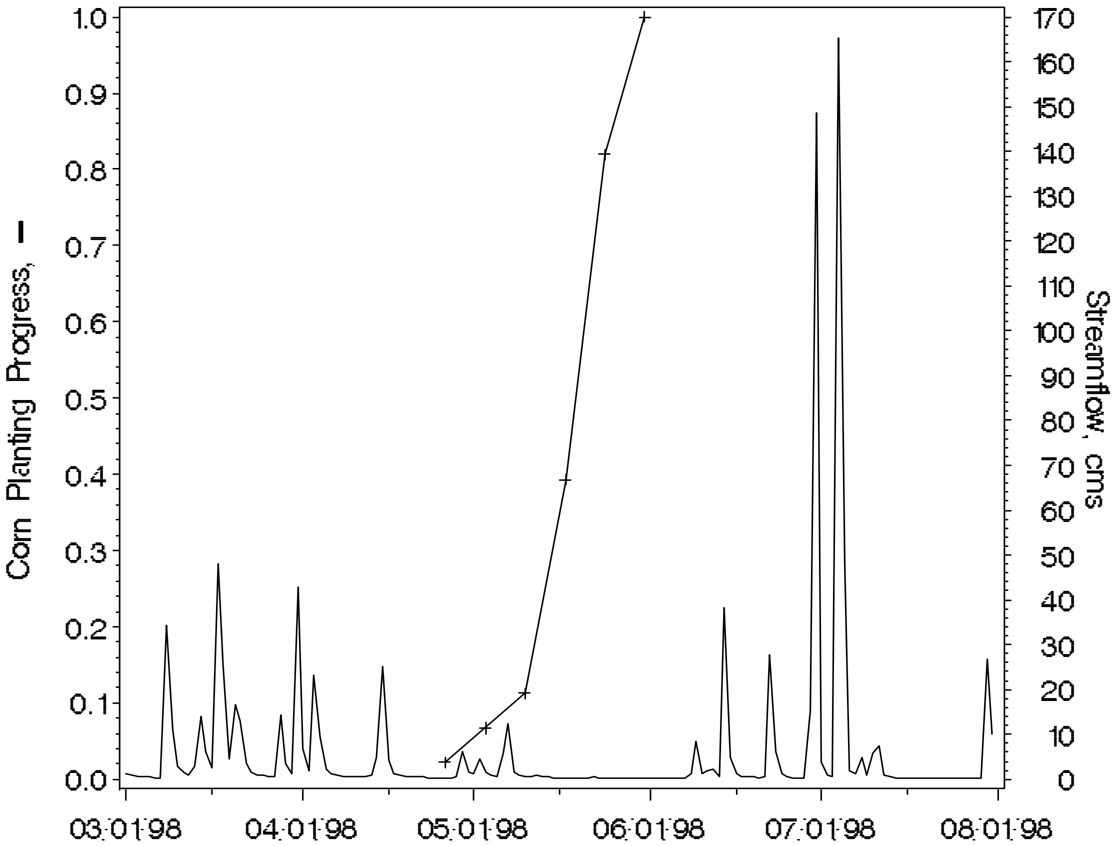

Figure D.7 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 1998.

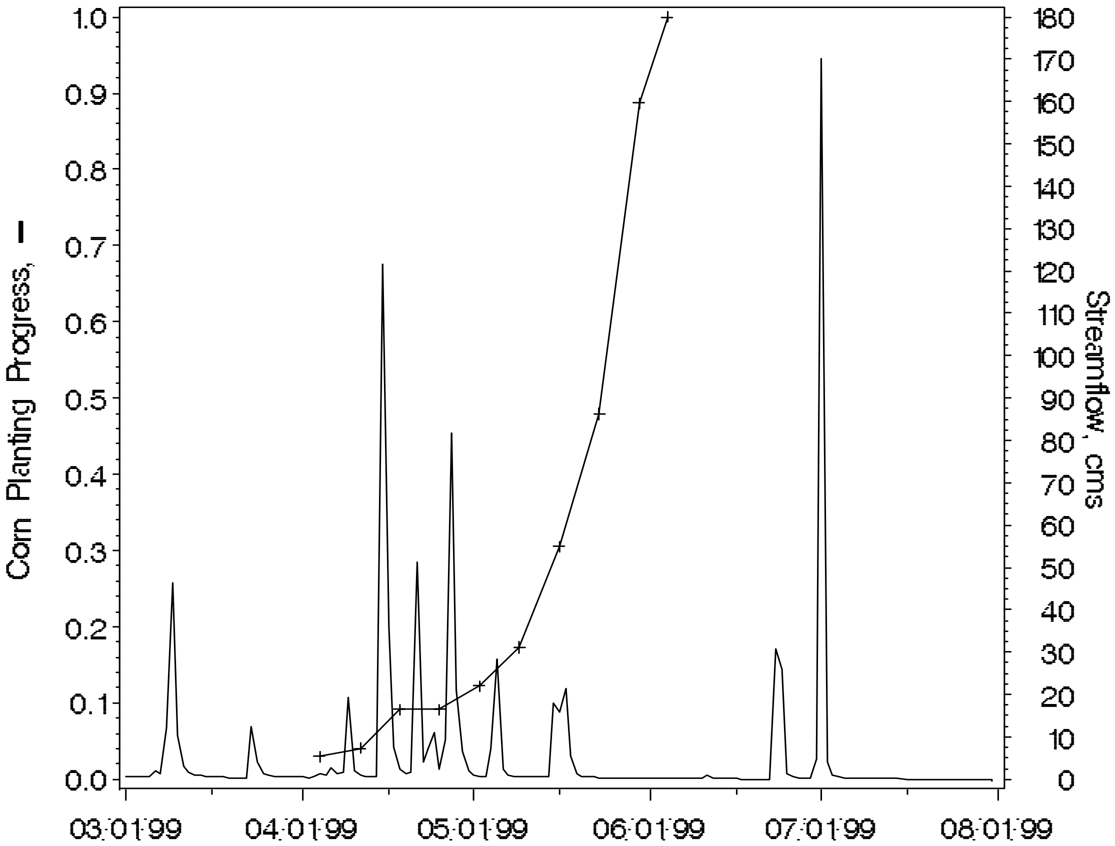

Figure D.8 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 1999.

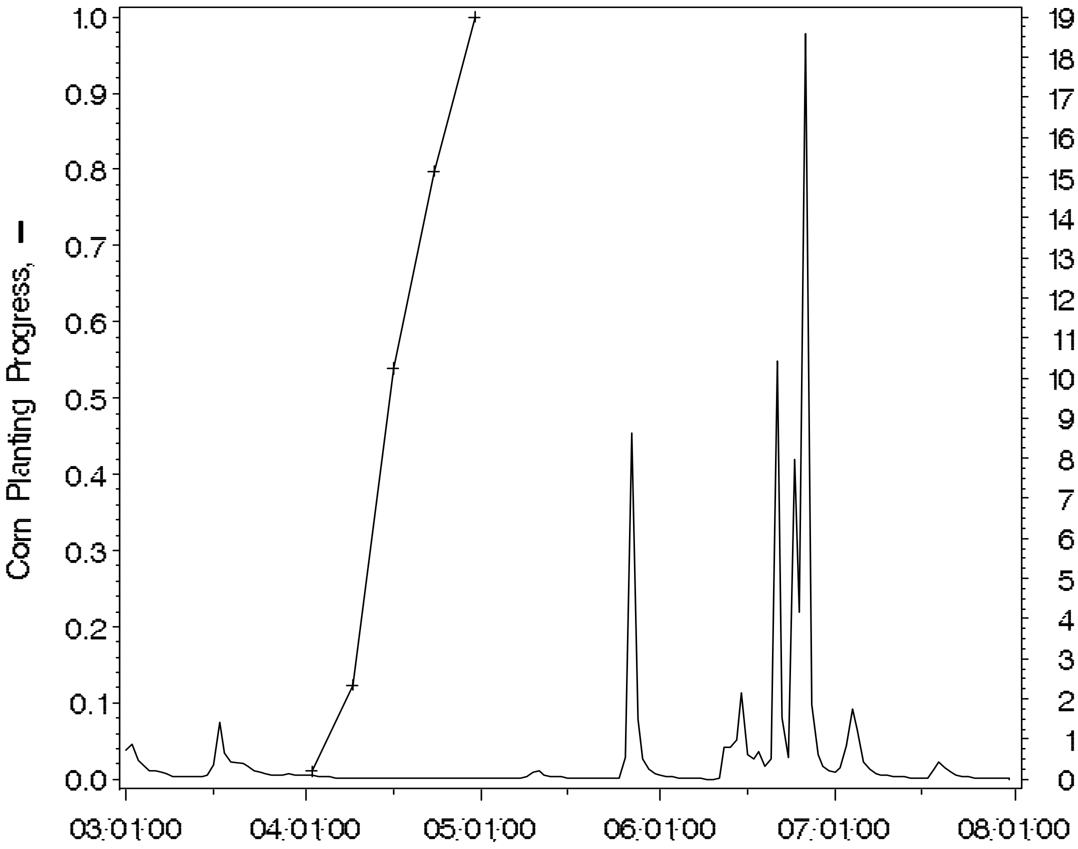

Figure D.9 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 2000.

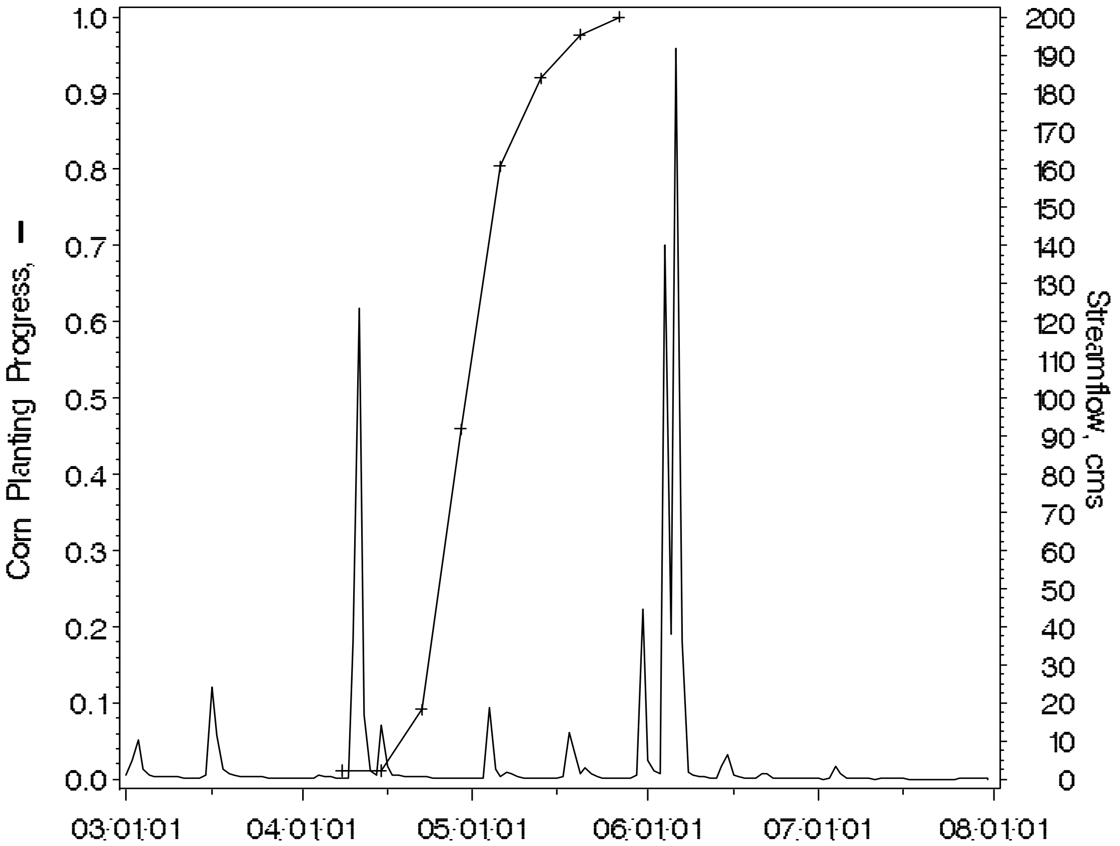

Figure D.10 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 2001.

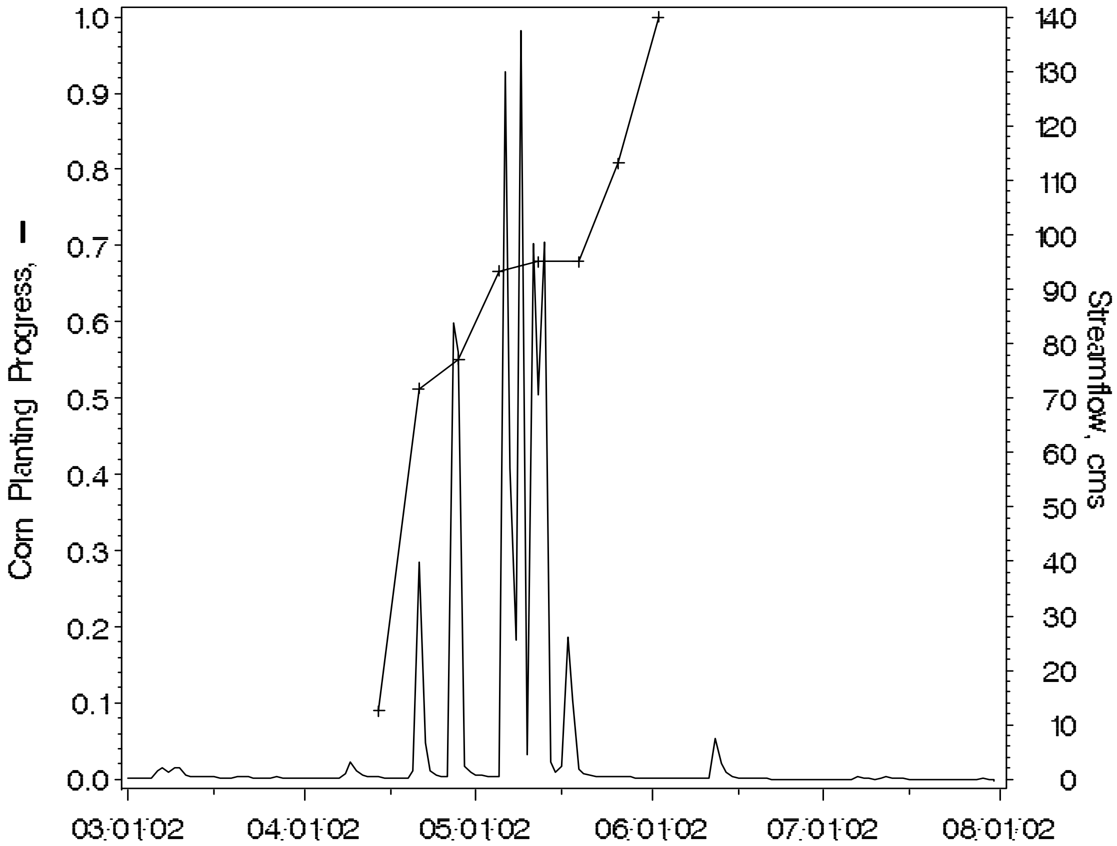

Figure D.11 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 2002.

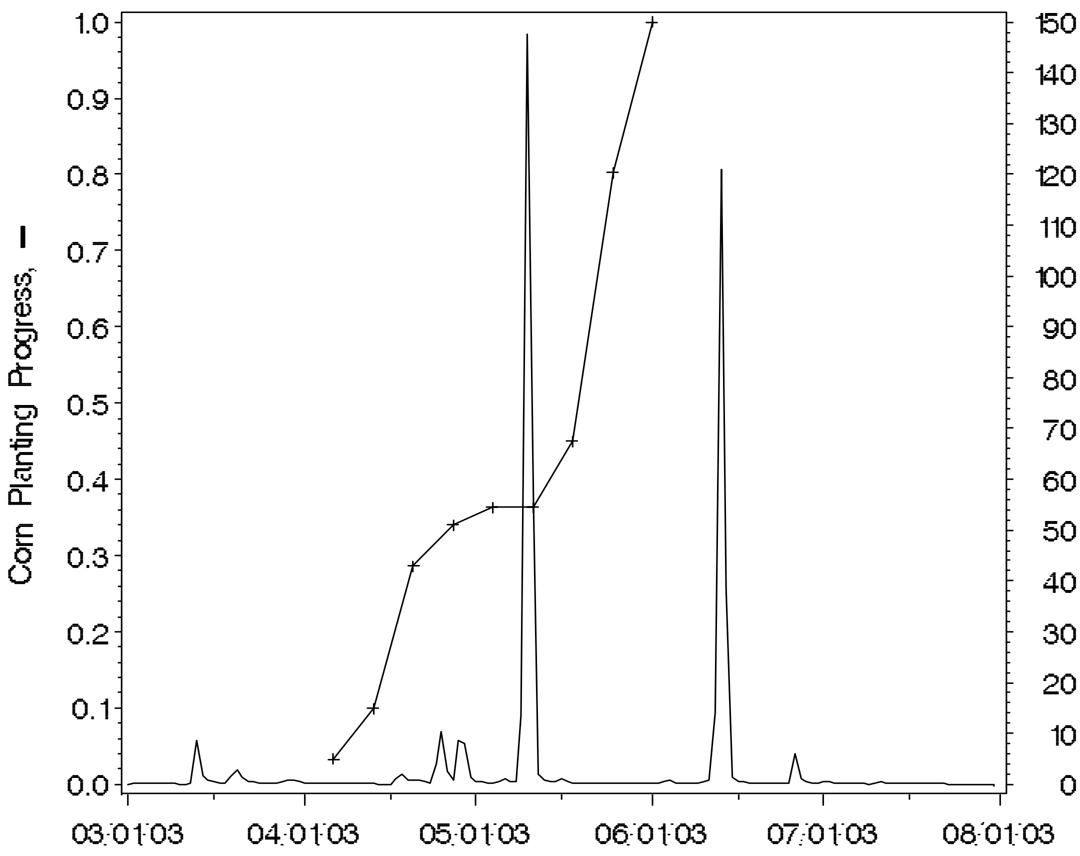

Figure D.12 Streamflow (—) from weir 1 and NE-Missouri district corn planting progress (+) for 2003.

APPENDIX E

AREAS SELECTED FOR RIPARIAN ZONES

Table E.1 Area Protected by Riparian Zones for Subbasin 1

Subbasin #1 Landuse	Area (ha) 942.22	% Watershed 13.5	%Subbasin --
Corn notilll-->CNNT	0.0000	0.00	0.00
Grain Sorgh Conservation-->GSCP	26.1856	0.38	2.78
Grain Sorghum conven-->GSCT	33.6743	0.48	3.57
Corn Conservation-->CNCP	25.0518	0.36	2.66
Corn Conventional-->CNCT	31.4690	0.45	3.34
Wheat notill-->WTNT	98.5737	1.41	10.46
Soybean notill-->SBNT	0.0000	0.00	0.00
Wheat Conservation-->WTCP	22.4736	0.32	2.39
Wheat conventional-->WTCT	0.0000	0.00	0.00
Residential-Low Density-->URLD	0.0000	0.00	0.00
Soybean Conservation-->SBCP	61.1501	0.88	6.49
Soybean Conventional-->SBCT	69.4366	0.99	7.37
Grain Sorghum notill-->GSNT	0.0000	0.00	0.00
Total	368.0147	5.27	39.06

Table E.2 Area Protected by Riparian Zones for Subbasin 2

Subbasin #2 Landuse	Area (ha) 1090.5	% Watershed 15.63	%Subbasin --
Corn notilll-->CNNT	0.0000	0.00	0.00
Grain Sorgh Conservation-->GSCP	0.0000	0.00	0.00
Grain Sorghum conven-->GSCT	0.0000	0.00	0.00
Corn Conservation-->CNCP	0.0000	0.00	0.00
Corn Conventional-->CNCT	53.1536	0.76	4.87
Wheat notill-->WTNT	0.0000	0.00	0.00
Soybean notill-->SBNT	278.5925	3.99	25.55
Wheat Conservation-->WTCP	0.0000	0.00	0.00
Wheat conventional-->WTCT	0.0000	0.00	0.00
Forest-Mixed-->FRST	0.0000	0.00	0.00
Residential-Low Density-->URLD	0.0000	0.00	0.00
Soybean Conservation-->SBCP	0.0000	0.00	0.00
Soybean Conventional-->SBCT	86.4796	1.24	7.93
Grain Sorghum notill-->GSNT	0.0000	0.00	0.00
Total	418.2257	5.99	38.35

Table E.3 Area Protected by Riparian Zones for Subbasin 3

Subbasin #3 Landuse	Area (ha) 1034.7	% Watershed 14.83	%Subbasin --
Corn notilll-->CNNT	62.8360	0.90	6.07
Grain Sorgh Conservation-->GSCP	0.0000	0.00	0.00
Grain Sorghum conven-->GSCT	0.0000	0.00	0.00
Corn Conservation-->CNCP	0.0000	0.00	0.00
Corn Conventional-->CNCT	0.0000	0.00	0.00
Wheat notill-->WTNT	169.5895	2.43	16.39
Soybean notill-->SBNT	0.0000	0.00	0.00
Wheat Conservation-->WTCP	36.1861	0.52	3.50
Wheat conventional-->WTCT	0.0000	0.00	0.00
Residential-Low Density-->URLD	0.0000	0.00	0.00
Soybean Conservation-->SBCP	62.0033	0.89	5.99
Soybean Conventional-->SBCT	63.9987	0.92	6.19
Smooth Bromegrass-->BROS	0.0000	0.00	0.00
Grain Sorghum notill-->GSNT	5.3718	0.08	0.52
Total	399.9854	5.74	38.66

Table E.4 Area Protected by Riparian Zones for Subbasin 4

Subbasin #4 Landuse	Area (ha) 862.38	% Watershed 12.36	%Subbasin --
Corn notilll-->CNNT	39.5695	0.57	4.59
Grain Sorgh Conservation-->GSCP	13.8615	0.20	1.61
Grain Sorghum conven-->GSCT	18.3510	0.26	2.13
Corn Conservation-->CNCP	25.2837	0.36	2.93
Corn Conventional-->CNCT	0.0000	0.00	0.00
Wheat notill-->WTNT	0.0000	0.00	0.00
Soybean notill-->SBNT	223.6779	3.21	25.94
Wheat Conservation-->WTCP	0.0000	0.00	0.00
Wheat conventional-->WTCT	12.3086	0.18	1.43
Forest-Mixed-->FRST	0.0000	0.00	0.00
Soybean Conservation-->SBCP	0.0000	0.00	0.00
Soybean Conventional-->SBCT	0.0000	0.00	0.00
Smooth Bromegrass-->BROS	0.0000	0.00	0.00
Grain Sorghum notill-->GSNT	0.0000	0.00	0.00
Total	333.0522	4.78	38.63

Table E.5 Area Protected by Riparian Zones for Subbasin 5

Subbasin #5 Landuse	Area (ha) 598.15	% Watershed 8.57	%Subbasin --
Corn notilll-->CNNT	0.0000	0.00	0.00
Grain Sorgh Conservation-->GSCP	20.4022	0.29	3.41
Grain Sorghum conven-->GSCT	27.0289	0.39	4.52
Corn Conservation-->CNCP	0.0000	0.00	0.00
Corn Conventional-->CNCT	0.0000	0.00	0.00
Wheat notill-->WTNT	71.8574	1.03	12.01
Soybean notill-->SBNT	0.0000	0.00	0.00
Wheat Conservation-->WTCP	15.6495	0.22	2.62
Wheat conventional-->WTCT	0.0000	0.00	0.00
Forest-Mixed-->FRST	0.0000	0.00	0.00
Soybean Conservation-->SBCP	47.1972	0.68	7.89
Soybean Conventional-->SBCT	50.4617	0.72	8.44
Smooth Bromegrass-->BROS	0.0000	0.00	0.00
Grain Sorghum notill-->GSNT	0.0000	0.00	0.00
Total	232.5969	3.33	38.89

Table E.6 Area Protected by Riparian Zones for Subbasin 6

Subbasin #6 Landuse	Area (ha) 1133.56	% Watershed 16.24	%Subbasin --
Corn notilll-->CNNT	41.7007	0.60	3.68
Grain Sorgh Conservation-->GSCP	50.9856	0.73	4.50
Grain Sorghum conven-->GSCT	0.0000	0.00	0.00
Corn Conservation-->CNCP	0.0000	0.00	0.00
Corn Conventional-->CNCT	0.0000	0.00	0.00
Wheat notill-->WTNT	0.0000	0.00	0.00
Soybean notill-->SBNT	319.2418	4.57	28.16
Wheat Conservation-->WTCP	0.0000	0.00	0.00
Wheat conventional-->WTCT	0.0000	0.00	0.00
Forest-Mixed-->FRST	0.0000	0.00	0.00
Soybean Conservation-->SBCP	0.0000	0.00	0.00
Soybean Conventional-->SBCT	0.0000	0.00	0.00
Grain Sorghum notill-->GSNT	28.5913	0.41	2.52
Total	440.5194	6.31	38.86

Table E.7 Area Protected by Riparian Zones for Subbasin 7

Subbasin #7 Landuse	Area (ha) 1317.36	% Watershed 18.88	%Subbasin --
Corn notilll-->CNNT	0.0000	0.00	0.00
Grain Sorgh Conservation-->GSCP	0.0000	0.00	0.00
Grain Sorghum conven-->GSCT	67.1348	0.96	5.10
Corn Conservation-->CNCP	31.0592	0.45	2.36
Corn Conventional-->CNCT	0.0000	0.00	0.00
Wheat notill-->WTNT	174.0214	2.49	13.21
Soybean notill-->SBNT	0.0000	0.00	0.00
Wheat Conservation-->WTCP	0.0000	0.00	0.00
Wheat conventional-->WTCT	14.0994	0.20	1.07
Forest-Mixed-->FRST	0.0000	0.00	0.00
Soybean Conservation-->SBCP	89.6257	1.28	6.80
Soybean Conventional-->SBCT	103.5665	1.48	7.86
Smooth Bromegrass-->BROS	0.0000	0.00	0.00
Grain Sorghum notill-->GSNT	28.6405	0.41	2.17
Total	508.1475	7.27	38.57

APPENDIX F

TILLAGE DISTRIBUTIONS FOR CORN

Table F.1 Percent of Subbasin Attributed to HRU for Three Tillage System Distributions on Corn

SUBBASIN	HRU	LANDUSE	SOIL	Baseline	Minimum	Maximum
1	1	No-Till	MO01950004	1.45131	1.22365	1.54972
1	2	No-Till	MO01960022	1.56530	1.31976	1.67144
1	3	No-Till	MO01950000	1.03707	0.87439	1.10739
1	12	Consrv	MO01950004	0.95487	0.83539	1.07691
1	13	Consrv	MO01960022	1.01535	0.88830	1.14512
1	14	Consrv	MO01950000	0.68859	0.60243	0.77660
1	15	Convnt	MO01950004	1.19834	1.54550	0.97815
1	16	Convnt	MO01960022	1.27976	1.65051	1.04461
1	17	Convnt	MO01950000	0.86178	1.11144	0.70343
2	1	No-Till	MO00727B2	0.91780	0.76898	0.97389
2	2	No-Till	MO00727B	1.20343	1.00830	1.27698
2	3	No-Till	MO01950012	1.50070	1.25737	1.59242
2	4	No-Till	MO01960022	0.89201	0.74737	0.94653
2	5	No-Till	MO01950000	1.42195	1.19139	1.50886
2	12	Consrv	MO00727B2	0.59331	0.52606	0.67815
2	13	Consrv	MO00727B	0.79034	0.70076	0.90335
2	14	Consrv	MO01950012	0.95651	0.84809	1.09329
2	15	Consrv	MO01960022	0.57040	0.50575	0.65196
2	16	Consrv	MO01950000	0.90699	0.80419	1.03668
2	17	Convnt	MO00727B2	0.80027	1.02910	0.65132
2	18	Convnt	MO00727B	0.99292	1.27683	0.80811
2	19	Convnt	MO01950012	1.21123	1.55756	0.98579
2	20	Convnt	MO01960022	0.72157	0.92789	0.58727
2	21	Convnt	MO01950000	1.14825	1.47658	0.93453
3	1	No-Till	MO00727B2	1.52174	1.33183	1.68672
3	2	No-Till	MO00727B	2.01534	1.76383	2.23384
3	3	No-Till	MO01950000	2.53579	2.21933	2.81072
3	12	Consrv	MO00727B2	0.98186	0.91438	1.17873
3	13	Consrv	MO00727B	1.28794	1.19942	1.54618
3	14	Consrv	MO01950000	1.61449	1.50353	1.93821
3	15	Convnt	MO00727B2	1.29770	1.53169	0.96941
3	16	Convnt	MO00727B	1.63899	1.93451	1.22436
3	17	Convnt	MO01950004	0.80608	0.95142	0.60216
3	18	Convnt	MO01950000	1.93240	2.28083	1.44355
4	1	No-Till	MO00734	1.49290	1.24260	1.57372
4	2	No-Till	MO00727B2	1.09529	0.91166	1.15459
4	3	No-Till	MO00727B	2.00022	1.66487	2.10851
4	12	Consrv	MO00734	0.95247	1.24072	1.57134
4	13	Consrv	MO00727B2	0.69994	0.91177	1.15472
4	14	Consrv	MO00727B	1.27944	1.66664	2.11075
4	15	Convnt	MO00734	1.20663	1.24130	1.57207
4	16	Convnt	MO00727B2	0.88627	0.91173	1.15468

4	17	Convnt	MO00727B	1.61957	1.66610	2.11007
5	1	No-Till	MO00734	0.56050	0.50882	0.64441
5	2	No-Till	MO00727B2	0.88734	0.80553	1.02018
5	3	No-Till	MO00727B	1.96760	1.78620	2.26217
5	13	Consrv	MO00734	0.35839	0.50250	0.63640
5	14	Consrv	MO00727B2	0.57696	0.80896	1.02452
5	15	Consrv	MO00727B	1.27601	1.78910	2.26584
5	16	Convnt	MO00734	0.71664	0.63622	0.80575
5	17	Convnt	MO00727B2	0.75011	0.66593	0.84338
5	18	Convnt	MO00727B	2.02573	1.79840	2.27762
6	1	No-Till	MO00727B2	1.35372	1.16941	1.48102
6	2	No-Till	MO00727B	2.32502	2.00847	2.54366
6	9	Consrv	MO00727B2	0.88561	1.17209	1.48441
6	10	Consrv	MO00727B	1.51554	2.00579	2.54027
6	11	Convnt	MO00727B2	1.27158	1.23697	1.56658
6	12	Convnt	MO00727B	1.99522	1.94091	2.45810
7	1	No-Till	MO00734	0.78539	0.65783	0.83312
7	2	No-Till	MO00728	0.61778	0.51744	0.65532
7	3	No-Till	MO00727B	2.24104	1.87706	2.37724
7	12	Consrv	MO00734	0.50397	0.65245	0.82631
7	13	Consrv	MO00728	0.39755	0.51468	0.65183
7	14	Consrv	MO00727B	1.45617	1.88520	2.38754
7	15	Convnt	MO00734	0.63916	0.65566	0.83037
7	16	Convnt	MO00728	0.50223	0.51519	0.65248
7	17	Convnt	MO00727B	1.83414	1.88148	2.38284

APPENDIX G

CROP DATA

Table G.1 Audrain County Cropped Area in ha (USDA, 2005).

Crop	Year													
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Corn	15216	16390	17199	16349	19020	11736	20882	24443	22096	27397	26547	28975	29663	27276
Sorghum	10360	12019	14690	12545	14285	12869	17685	12383	10967	8660	10441	7568	6799	9105
Wheat	27802	22420	19627	24038	10927	8701	7365	12626	17240	9632	10765	3561	4937	8256
Soybean	45001	53540	47753	44677	53823	49372	49007	54592	53297	63293	60055	61715	63252	63657
Hay	9915	9591	8498	8498	8134	8013	8377	8134	8822	8822	8539	10441	10927	10522

Table G.2 Yearly Record of Atrazine Applied on Corn for Missouri (USDA, 2005)

Year	Area (ha)	Area Atrazine applied (%)	Applications per year	Rate per Application (kg)	Rate per Crop year (kg)	Total applied (kg)
1990	849840	89	1.07	0.58	0.62	1017861
1991	930777	85	1.2	0.58	0.68	1320407
1992	1011714	85	1.1	0.55	0.59	1264162
1993	890308	84	1.1	0.54	0.59	1096333
1994	971246	83	1.1	0.56	0.62	1237854
1995	667731	82	1.2	0.50	0.59	789704.3
1996	1112886	88	1	0.55	0.57	1379374
1997	1193823	79	1	0.59	0.62	1438341
1998	1072417	87	1	0.62	0.64	1479165
1999	1072417	95	1.1	0.61	0.70	1762206
2000	1153354	76	1.1	0.55	0.64	1373931
2001	1092651	89	1.1	0.59	0.65	1576233
2003	1173588	89	1.1	0.58	0.68	1766289
2005	1254525	80	1.1	0.62	0.69	1709136

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