UPPER SHOAL CREEK WATERSHED

WATER QUALITY ANALYSIS

FAPRI-UMC Report 01-04

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Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Environmental Protection Agency.

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

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

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

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EXECUTIVE SUMMARY

Between 1992 and 1999, concentrations of fecal coliform bacteria in Shoal Creek averaged more than 5,000 colonies per 100 ml, due to very high counts in 1992-1993. These concentrations greatly exceed the Missouri limit of 200 colonies per 100 ml for the stated uses of Shoal Creek. This resulted in upper Shoal Creek, from Capps Creek upstream for 13.5 miles, being placed on the Missouri 1998 303(d) list of impaired water bodies. Given the rural nature of the watershed, the large number of poultry operations, and the large amount of grazing pastures on which poultry litter is spread, animal agriculture is perceived as the source of elevated levels of bacteria found in Shoal Creek. However, other sources need to be considered, namely horses and dogs, failing septic tanks, and wildlife. The Food and Agricultural Policy Research Institute at the University of Missouri (FAPRI), with significant input from the local community, has developed this analysis defining how current agricultural practices in the upper Shoal Creek Watershed affect water quality. The intent is to provide local producers and planners the information for making decisions with respect to protecting their water resources and their intended use. Part of this report is the basis for the bacteria TMDL submitted by the Missouri Department of Natural Resources to EPA.

FAPRI's approach combines computer simulation modeling, analytical facts, and interdisciplinary perspectives that allow stakeholders to simultaneously evaluate many different economic and environmental perspectives. FAPRI, in conjunction with the USDA Natural Resources Conservation Service (NRCS) and other local sources of information, identified soils and production practices that are common to the watershed. A watershed scale computer simulation model was built to identify the relative contributions of bacteria and nutrients from the subbasins and land uses in the watershed. In cooperation with Dr. John Jones from the department of Fish and Wildlife at the University of Missouri-Columbia and USGS, they monitored the flows and water quality of Shoal Creek. Dr. Charles Carson, professor of veterinary pathobiology with the World Health Organization Collaborating Center for Enteric Zoonoses at the University of Missouri directed the laboratory analyses of fecal material using Repeat Element Polymerase Chain reaction (RepPCR) techniques to identify the sources of the bacteria found in the water.

The data shows that the highest fecal coliform loads come from cattle. At low flow, these loadings are deposited by cattle defecating directly in the streams; at higher flow, the loadings are transported from the pastures to the streams by surface runoff. Poultry litter causes very high loading during periods of high surface runoff.

Several scenarios were investigated with the model in order to assess which alternative management practices would lead to stream fecal coliform concentrations that respect the water quality criteria. Removing the cattle from the stream and ensuring no sanitary discharge into the streams significantly reduce the fecal loads at low flows. Filter strips decrease the impact of bacteria deposited on the pastures. A 66 % reduction of surface loadings along with at least 50 % less cows being in the streams is projected to bring the percentage of samples exceeding 400 colonies/100 ml to less than 10 %. However, all the simulated alternatives produced some concentration values above 200 colonies/100ml during the recreation season.

The phosphorus loadings travel with surface runoff. They come mostly from poultry litter applications and from the phosphorus already contained in the soil. Nitrates travel through the soil profile and reach the shallow aquifer. The contribution of groundwater nitrogen to the stream nitrogen loadings is the most important. Small amounts of nitrogen travel with surface runoff.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Introduction

Between 1992 and 1999, concentrations of fecal coliform bacteria in Shoal Creek averaged more than 5,000 colonies per 100 ml, due to very high counts in 1992-1993. Fecal coliform are non-pathogenic (do not cause illness) bacteria that are found in the gut of warm blooded animals and are used as indicators of the risk of waterborne disease from pathogenic bacteria or viruses. These concentrations greatly exceed the Missouri limit of 200 colonies per 100 ml for the stated uses of Shoal Creek. This resulted in upper Shoal Creek, from Capps Creek upstream for 13.5 miles, being placed on the Missouri 1998 303(d) list of impaired water bodies.

Given the rural nature of the watershed, the large number of poultry operations, and the large amount of grazing pastures on which poultry litter is spread, animal agriculture is perceived as the source of elevated levels of bacteria found in Shoal Creek. However, other sources need to be considered such as humans, horses, dogs, and wildlife. Although these sources are not present in large numbers, the proximity of their location to the stream makes them potential polluters. Similarly, failing septic tanks or the absence of a proper onsite wastewater treatment system can be a significant source of bacteria. Along with bacteria, elevated concentrations of nutrients (nitrogen and phosphorus) are measured in Shoal Creek.

This study is intended to estimate when and how much nutrient and pathogen pollution occurs, the source of the nutrients and pathogens, and the projected impact of alternative management practices implemented at the watershed level on the water quality of Shoal Creek. It relies on the analysis of monitoring data and the results of a hydrologic model to determine the current (baseline) water quality characteristics and the impacts of the proposed management changes. The monitoring data include the data collected during this project as well as data from other sources including:

- the Upper Shoal Creek poultry litter/nutrient management demonstration 319 project (Southwest Missouri RC&D, 2000).
- the AGNPS-SALT project in Capps Creek.
- USGS data collected by John S. Schumacher and published in several reports (Schumacher, 2001; Schumacher, 2003).
- George's poultry processing plant located in Butterfield. The data is on file at the regional MDNR office in Springfield, MO.
- Crowder College (Luttrel, 1992 – 2003).

This report presents the results of the analysis of the present practices and different alternatives at the watershed level. Separate reports will include economic and environmental assessment results at the farm level for various types of farm typical of the watershed.

Geography

Location

The upper Shoal Creek watershed is a 367 km^2 watershed (90 000 acres or 143 square mile) located in Barry County in southwestern Missouri. A small portion of it lies in the eastern border of Newton County. It is approximately 27 km (17 miles) long. U.S. Highway 71 and Missouri Highways 18 and 52 provide access to the watershed. Shoal Creek flows in a northwesterly direction to the Spring River, and eventually into the Grand Lake of the Cherokees in Oklahoma.

Several tributaries drain the watershed from the east to the west (Figure 1). Subbasins have been delineated that follow the drainage areas of these tributaries. In the south one can find the head waters of Shoal Creek. Shoal Creek flows in a northerly direction with its tributaries merging from the southeast: first Woodward Branch, a very small tributary that meanders through pastures; then Pogue Creek, which drains part of the town of Butterfield and receives runoff from fields irrigated with liquid waste from the George's poultry processing plant; followed by Joyce Creek; and finally Capps Creek, including its South Fork.

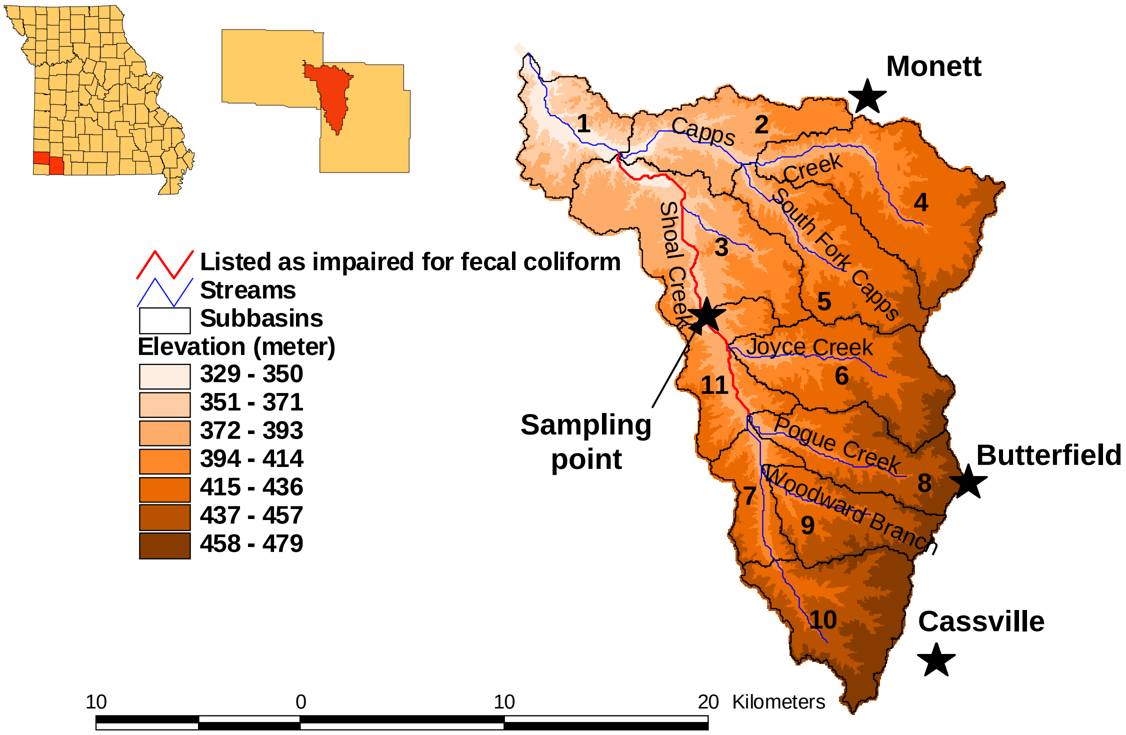


Figure 1. Shoal Creek and its tributaries

Area characteristics

The Shoal Creek watershed is located in the *Highland Ozark* Area, Major Land Resource Area (MLRA) 116A (USDA, 2002). This area, located across Arkansas, Missouri, and Oklahoma, is part of the northeast and central farming forest region. The *Highland Ozark* MLRA has approximately 70 % forest, 20 % pasture mainly of introduced grasses and legumes, and 10 % cropland. Feed grains and hay are the main crops. Summer droughts and steep slopes limit the use of the land for crop production. Shallow wells or springs are often used for livestock needs. Deeper wells supply drinking water and water for high volume uses. This area supports oak-hickory and oak-hickory-pine forests. In the southwest, one can find glade openings that have bedrock outcrops or are shallow to bedrock. These glades support a combination of introduced and native tall-prairie grasses consisting mainly of Indian grass, little bluestem, and dropseeds. Introduced grasses include fescue, annual crab grasses, and Kentucky bluegrass. The pastures are mostly in fescue grass over-seeded with red clover.

Topography

Elevations in the watershed range from 330 m (1080 ft) at the watershed outlet to 480 m (1570 ft) at the southeastern boundary. Stream valleys are narrow and have steep gradients. Slopes greater than 10 % are concentrated in the northwestern part of the watershed and on either side of Shoal Creek. In the eastern part of the watershed, slopes are gentle to moderate, all being less than 10 % and most of them less than 5 %.

Hydrogeology

Two aquifers lie under the Shoal Creek watershed. The Ozark aquifer is a high-yielding, deep confined aquifer of generally very good quality (MDNR, 1997). It provides for municipal, agricultural, and industrial water. Although Neosho and Joplin, in Newton County, use surface water from Shoal Creek to meet most of their water supply needs, both towns also use wells into the Ozark aquifer on an emergency or supplementary basis.

The Springfield plateau aquifer is an unconfined shallow aquifer located about 60 m (200 ft) below the ground surface that is recharged by precipitation. The aquifer is generally of good quality and was the main water supply resource until the mid-1950s. Since then, the contamination of the aquifer around Springfield and other places has prompted stricter regulations for wells. Most of the domestic water is now pumped from the deep Ozark aquifer but the Springfield plateau aquifer still provides agricultural and industrial water. The karst developments that are typical of the Springfield plateau aquifer are mostly located north and east of the Shoal Creek watershed in Greene and Christian counties. In the Shoal Creek watershed some of the Shoal Creek tributaries are intermittent and springs are indicative of a karst system. However, there are few sinkholes and no caves in the watershed. Schumacher (2001) reports sinkholes only in the Capps Creek subbasin in the northeast part of the watershed.

Soils

All the soils in the Shoal Creek watershed are characterized by 30 % or more rock content in the surface layer and 40 % or more for bottom layers. This contributes to low water content of these soils. In addition, karst features increase the amount of water that bypasses the soil profile and rapidly reaches the aquifer.

Two regions appear in the soil map of the Shoal Creek watershed (Figure 2). In the northwestern corner of the watershed, the soils are predominantly from the Clarksville-Noark-Nixa association that consists of very deep, gently sloping, well drained to somewhat excessively drained, very gravelly, silty soils. In the rest of the watershed, the soils are predominantly from the Scholten-Tonti association that consists of very deep, moderately well drained, silty, and gravelly soils that have a fragipan. The association is about 50 % Scholten, 35 % Tonti, and 16 % minor soils.

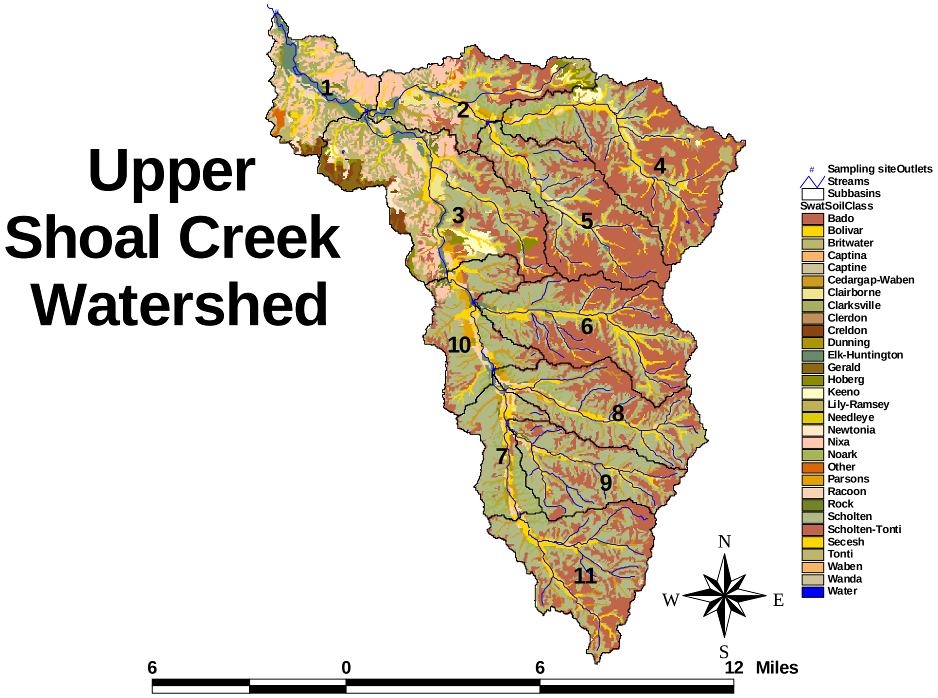


Figure 2. Soils of the Shoal Creek Watershed

Land use

The analysis of the 1992 satellite imagery (Figure 3) gives a global view of the watershed land uses using four major categories: cropland, grassland, forest, and water. The watershed was modeled mostly of grassland (89 %) with some wooded areas (11 %). Given the small amount of cropland (less than 5 %), this category was not accounted for in the model. There are no significant urban areas and there are no water body other than Shoal Creek and its tributaries. Table 1 details the area and the percentages of grassland and forest in each of the subbasins.

Table 1. Land use in the Shoal Creek Watershed

	Subbasin number											Water-shed
	1	2	3	4	5	6	7	8	9	10	11	
Forest (%)	39	17	16	0	6	8	14	8	8	12	10	11
Grassland (%)	61	83	84	100	94	92	86	92	93	88	90	89
Area (km^2)	22.9	29.3	53.3	51.5	37.6	40.3	15.9	30.4	25.3	23.6	36.1	366.3
Area (acres)	5667	7247	13175	12731	9297	9954	3936	7504	6247	5835	8912	90503

The grassland designation includes hay, pasture, and land enrolled in the Conservation Reserve Program (CRP). Hay and CRP land, which are sometimes considered cropland, behave more like grassland in terms of runoff, erosion, and nutrient loads and have been left in this class. Cattle graze pastures that are commonly fertilized with poultry litter and/or commercial nitrogen.

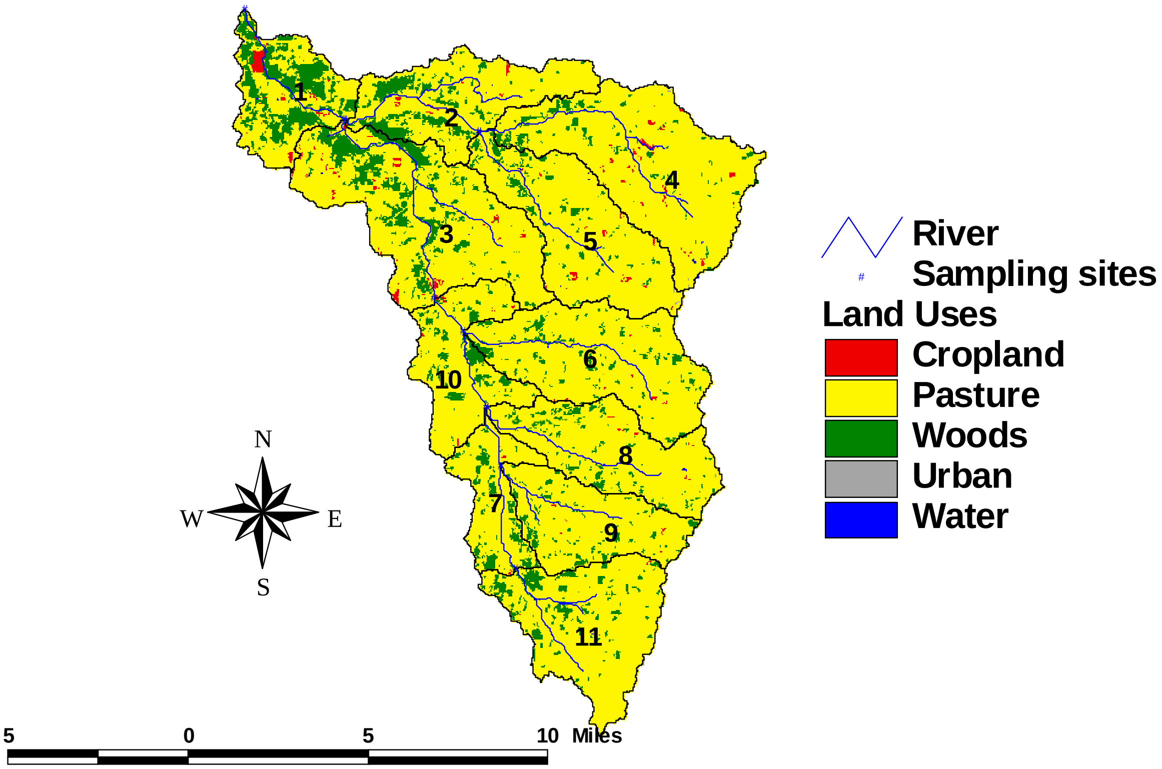


Figure 3. Land use distribution map of the Shoal Creek Watershed

Wooded areas are mostly located in the western part of the watershed, on either side of Shoal Creek where the slopes are greater than 5 %. These slopes may be grazed but they cannot be fertilized or harvested for hay. Apart from subbasin 1, where forest represents 40 % of the subbasin, woods cover about 15 % of the land in subbasin 2, 3, and 7, and 10 % or less in the central and eastern part of the watershed. Overall, wooded areas represent 11 % of the watershed.

Weather

Measured daily weather data from the Cassville and Monett weather stations was used for this analysis. Pat Guinan at the Missouri Climate Center at the University of Missouri Department of Atmospheric Science provided official daily temperatures and precipitations recorded at these stations. Monthly statistical characteristics for precipitation and temperatures in Springfield were used to fill in any missing data. Average monthly radiation, wind speed, dew point and humidity data were obtained from the Springfield weather station because these parameters are not available in Monett or in Cassville. Springfield is located 65 km (41 miles) northeast of Monett.

Based on weather data from 1970 to 1999, the average annual precipitation is similar at the three stations, about 1143 mm (45 in). Annual precipitation is slightly higher in Monett with 1163 mm (45.8 in), followed by Springfield with 1156 mm (45.5 in), and Cassville with 1143 mm (45 in) with a variation of less than 2 % between Cassville and Monett. However, on a monthly basis, variations can be larger and in a different order (Figure 4). During the months of May, June, August, and September, Monett receives more rain than does Cassville, as much as 25 % more in June. However, in February, March, July, and December, Cassville receives more precipitation, 25 % more in December.

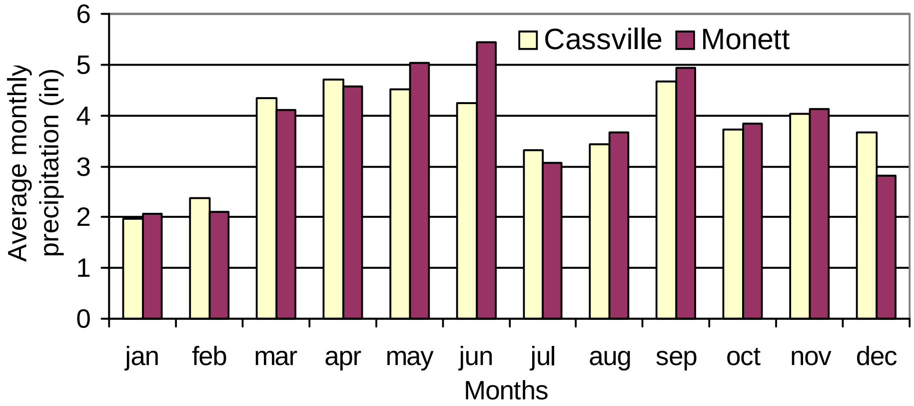


Figure 4. Average monthly precipitation in Cassville and Monett, MO

Designated water uses

Definitions of stream classifications and designated uses may be found in the Code of Missouri State Regulations at 10 CSR20-7.031. Shoal Creek and Capps Creek are designated for:

- cool and cold water fisheries,
- whole body contact (swimming), and
- boating and canoeing.

In addition, Shoal Creek and all its tributaries in this watershed are designated streams for:

- livestock and wildlife watering and
- warm water aquatic life.

Impairment description

In 1998, the segment of Shoal Creek that starts from about one mile upstream of the mouth of Woodward Creek to the mouth of Capps Creek was placed on the Missouri Department of Natural Resources (MDNR, 2000) list of impaired streams (303d list) because of high fecal coliform concentrations. Various monitoring studies since 1992 (Luttrel, 1992-2003; Schumacher, 2001) and the data collected during this study show that the concentrations have been and remain elevated beyond acceptable levels for recreational purposes.

Specific Criteria

Missouri's Water Quality Standards at 10 CSR 20-7.031(4)(C) state that for whole body contact the fecal coliform concentration shall not exceed 200 colonies per 100 milliliters of water (200 colonies/100 ml) when flow is not affected by storm runoff during the recreational season (April 1-October 31). Federal guidelines also suggest rating waters as impaired if more than 10 % of all samples exceed 400 colonies/100 ml or if there are any closures of swimming areas due to high bacteria levels. Athough there are no official swimming areas along Shoal Creek or its tributaries, several swimming holes are used by the population.

The Missouri criterion stipulates that only flows not affected by storm flows should be considered. As this restriction would not be acceptable for EPA (Genereaux, 2003; Kinerson, 2002), we use a proposed standard of a 30-days geometric average of 200 colonies/100 ml and no more than 10 % of all samples exceeding 400 colonies/100 ml. A geometric average tends to indicate the range of concentrations most often encountered whereas an arithmetic average increases the impact of infrequent very high bacteria concentrations. A criteria based on a geometric average is in place in many states and accepted by EPA along with the allowance for 10 % of the samples having concentrations higher than 400 colonies/100ml.

There is no phosphorus water quality standard and the current nitrate nitrogen standard is fixed at 10 mg/l. It intends to protect drinking water supplies as it relates to human health. EPA is currently developing nutrient water quality benchmarks for phosphorus and nitrates in order to protect biological life.

Public involvement

A watershed steering committee was formed in January 2000 to participate in the holistic assessment of the Shoal Creek watershed by FAPRI. The group has changed somewhat since 2000 according to the availabilities and interests of the members. There are 13 members including poultry and cattle producers, a veterinarian, Soil and Water Conservation District (SWCD) board members, and personnel from the Natural Resources Conservation Service (NRCS). The group indicated they were interested in receiving help to arrive at a locally driven water quality management plan for this watershed that would address not only pathogen issues but also potential nutrient problems and economic constraints. They insisted that there was a need for more resource information about their watershed to better identify the water quality baseline and that any part of the discussion and/or decision-making process need to include economically sound alternatives.

Following the meeting, a holistic study of the watershed was undertaken that attempts to include all aspects of the problems in the watershed: environmental aspects including pathogens and nutrients, and economic aspects. Simultaneously, farm panels were formed to analyze the environmental impacts and economic situations of specific types of agricultural operations. The results of a previous analysis for a representative broiler farm in Lawrence and Barry Counties are valid for the Shoal Creek watershed (FAPRI, 1999). Two additional farm analyses were conducted in southwest Missouri: a cow-calf farm in the Shoal Creek watershed and a confinement dairy in Christian County. Specific reports describe the procedure and the results of these analyses (FAPRI, 2003, a and b).

Identification of Pollutant Sources

There are no point sources in the watershed that can explain the high concentrations of fecal coliform found in the water. On the other hand there are many potential non point sources due to the agricultural and rural nature of this watershed: livestock, poultry litter spread on pastures, failing septic tanks, wildlife, and other domestic animals including horses and dogs. In addition the George's plant may be a source of fecal contamination. George's plant is a poultry processing plant located in Butterfield at the upstream end of Pogue Creek. The waste from the plant is first separated into solids and liquids. The liquid is sprayed on land where reed canary grass is grown and harvested during the growing season. Since the effluent is spread on reed canary grass hay fields, it should be considered a non point source. All of these sources are potential sources of bacteria and nutrients.

Livestock

Livestock in the Shoal Creek Watershed include mainly beef cattle and dairy. Barry County agricultural facts adjusted for the size of the Shoal Creek watershed indicate that there were about 7600 cow/calf pairs in the watershed and 120 steers and bulls in 1998 (Missouri Agricultural Statistics Service, 2003). NRCS sources indicate 25 dairy farms in the watershed as of 1999. Given an average size of 60 cows per farm, this would represent about 1500 cows. It is estimated that about half are kept in confinement and the rest of them are grazing. A total of about 8000 animal graze year round in the watershed. Beef cattle and dairy cows are counted together for the purpose of estimating the grazing density. These animals consume biomass, destroy some, and produce manure that is deposited on the grass.

The cattle are rotated about once a month through the pastures year-round. Daily rotational grazing is being demonstrated on a few dairy farms but the practice is not implemented on a scale large enough to impact the water quality. When cattle have access to the creek the model estimates that 3 % and 10 % of the cattle are in the creek in the winter and summer, respectively. Cattle are put in summer pastures around June 30, 30 days after hay is harvested. Summer pastures are about 20 ha (50 acres) large and are grazed by 20 to 30 heads, i.e. a grazing density of about 2 ha (5 acres) per cow/calf pair. It takes 40 to 50 days until the grass runs out (2.5 cm high), after which the cattle are moved to a different pasture or hay supplemented. It is estimated that 30 % to 35 % of the grass is efficiently used. Grazing ends around October 31 after which cattle are hay supplemented in the winter pastures until April 15.

Poultry litter spread on pastures

Grassland areas are used for grazing, hay production, and fescue seed production. In the spring, about 50 % of the pastures are fertilized with poultry litter at a rate of 2 tons per acre. Another 25 % of the pasture acres and all the hay and fescue seed fields are fertilized with inorganic nitrogen fertilizer. A quarter or a third of the grassland is never fertilized for technical reasons (too high slope for example) or financial reasons (inability to buy the fertilizer or the litter). On the hay fields, fescue seed swathing and harvest takes place in late May to early June, and hay harvesting occurs in early June.

There are approximately 80 poultry producers in the watershed. Poultry operation sizes range from one barn to CAFO class IB (14 to 30 houses). A total of about 325 houses are currently (1999) operating in the watershed. The Missouri Department of Natural Resources (DNR) has identified the location of these poultry operations and the data has enabled us to develop a poultry litter production map. The assumption is that each house produces 120 to 125 tons of poultry litter per year, including decake, and that it is spread within 10 miles of the poultry house. Using this information and the number of pasture acres in each subbasin, assuming one application every other year on every spreadable acre, poultry litter application rates were estimated across the watershed (Figure 5).

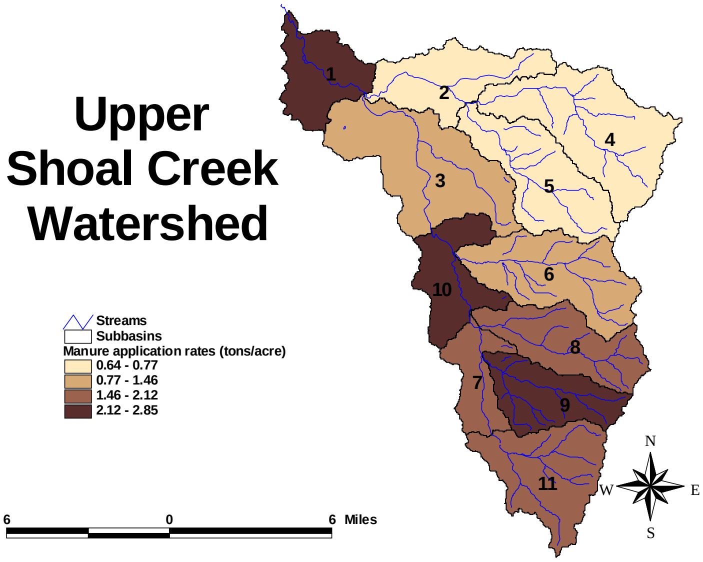


Figure 5. Poultry litter application rates

From 1996 until 2000, a 319 project was undertaken with the goal to reduce the nutrient load of Shoal Creek. One effort of this project was to collect and analyze poultry litter samples throughout the watershed. A report published by the Southwest Missouri Resource Conservation & Development (RC&D, 2000) presents the average results of this monitoring effort. We report here the mean nitrogen, phosphorus, and potassium contents of the 175 poultry litter samples that were collected (Table 2).

Table 2. Nutrient content of poultry litter in the Shoal Creek watershed

	% water	N fraction of dry weight	P fraction of dry weight	K fraction of dry weight
Mean	26	0.041	0.018	0.026
Standard deviation	8	0.007	0.006	0.006

One phase of the 319 project was to assess the nutrient content of the soils throughout the Shoal creek watershed. Several samples were collected every month and their nitrates and phosphorus content was assessed. Phosphorus content was measured using the Meilich test. Values should be divided by 1.5 to obtain Bray 1 values. Figure 6 shows the mean values of phosphorus and nitrates found in the samples each month. Although there is a lot of variability from month to month, monthly concentration values reveal a decrease of the soil phosphorus of about one third the initial 330 kg/ha (300 lbs/a). Nitrates, on the other hand, remain at the same level.

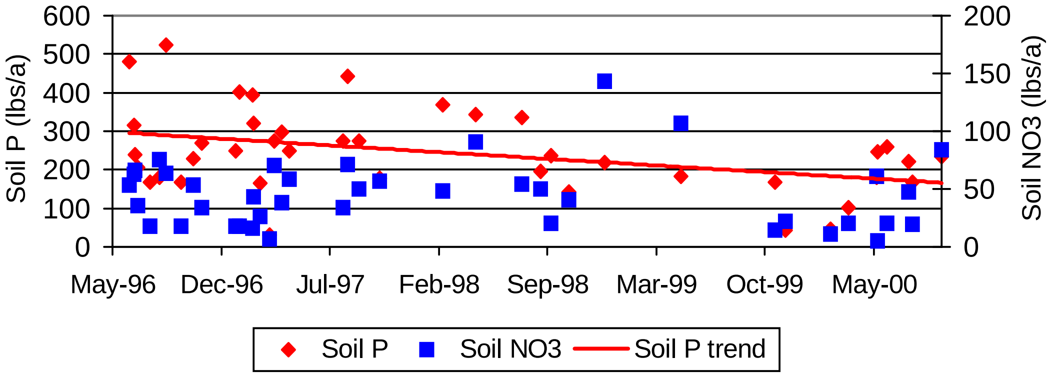


Figure 6. Average phosphorus and nitrate content of Shoal Creek soils

Other domestic animals

Dogs are also included as a potential source of bacteria. There are 66 licensed or registered puppy farms in Barry County, the highest number in Missouri. The waste from dog farms is approximately 50 % solids and 50 % liquid. All waste has to be carried away from the facility to avoid health or odor problems in the operation. However, there are no regulations on the disposal of this waste, which is often just spread in a nearby field. Although the amount of waste generated by these operations is small in comparison to other types of animals in the watershed, DNA analyses of water samples collected in Shoal Creek have shown that dogs are a source of bacterial pollution and should be taken into account.

Horses are present in the watershed and the DNA analyses of the water samples collected at the Highway 97 Bridge have confirmed the presence of horse fecal coliform in the creek. Although a horse pasture just above our sampling point could explain the findings, other horses in the watershed may also contribute to the load. There has not been any attempt to identify the specific geographic origin of the patterns we detected. Overall, the percentage of horse fecal coliform is highest during late spring and summer and the horses owners should be made aware of the potential fecal coliform contributions to Shoal Creek.

Septic tanks

The Barry County Census indicates that there were 15,964 housing units in 2000, 13,398 of which were occupied with an average of 2.5 people. The 1990 census indicates that 67.4 % of these occupied units were not connected to a public sewage system, i.e. they used a septic tank for sewage disposal system. Assuming the same percentage for 2000, that would represent 9,030 units in Barry County. These units are all likely to be in rural areas such as the Upper Shoal

Creek Watershed. Assuming that the distribution of units that use a septic tank is uniform across Barry County, the number of septic tanks in the upper Shoal Creek Watershed is estimated to be 1, 642.

The rate of failure of these units can be estimated from their construction date, also determined from the 1990 Census data. Three categories of units were considered: before 1970, 1970-1984, and after 1984. The rates of failure were assumed to be 40 %, 20 %, and 5 %, respectively. These rates have been used in Virginia for the development of TMDLs and were backed up by studies done in that area that found 30 % of all septic tanks were either failing or not functioning at all (Virginia Department of Environmental Quality, 2002). Using these rates and the number of septic systems in the watershed, we estimated the number of failing systems (Table 3).

Table 3. Estimated septic tanks in the Shoal Creek Watershed

Structure age	Number of units	Failure rate (%)	Number failed
Pre - 1970	652	40	261
1970 - 1984	545	20	109
Post 1984	445	5	22
Total	1, 642	24	392

Wildlife

Wildlife in the Shoal Creek watershed includes many animals, most of them difficult to inventory. There is no wildlife inventory at the county level in Missouri. Three sets of patterns from wildlife are included in the DNA source-tracking database: deer, wild turkeys, and geese. Numbers from the Missouri Department of Conservation about deer harvest in 2000 and 2001 for Barry County can help quantify the deer population. There is no information about the other wildlife species in the watershed, other than they have been seen in the watershed.

Deer harvest numbers in Barry County for 1999, 2000, and 2001 are 1329, 1601, and 2041, respectively, for an average of 1660/year. Assuming that 40 to 70 % of the antlered bucks and 25 % of the does are harvested each year, the ratio of antlered bucks to does is 1:3, and that the antlered bucks represent about 20 % of all the deer, we estimate the deer population in Barry County at 5724 to 7216. In the absence of additional data to determine the distribution of deer within Barry County, we used a uniform distribution that results in 2.9 to 3.6 dear/km^2 (68 to 86 acres/deer). Assuming the deer are concentrated in or near wooded areas, the deer density in the watershed woodland is 26 to 33 deer/km^2 of wooded land, about 8 acres/deer.

George's poultry processing plant

The poultry processing plant is a permitted facility with a record on file at the regional office of MDNR in Springfield. Data obtained from MDNR show that an average of 76 mm/month (3 in) of effluent is spread on 153 ha (380 acres) since July 1997. The irrigated area was increased from 105 ha (260 acres) to 153 ha (380 acres) in July 1997. They plan to increase from 153 ha to 242 ha (600 acres). At the same time, the plant is planning to increase its processing capacity, which will with time increase the applied volume of wastewater. The analysis has been done on the basis of 76 mm/month of wastewater over 153 ha of canary grass hay.

Data on file at the Missouri DNR include annual yields of hay harvested, daily records of wastewater applied, weekly nutrient and sediment analyses of wastewater samples (BOD, TSS, TKN, Phosphates, NO_2+NO_3, and NH_3), and monthly COD, NO_3, and NH_3 content in Dilbeck Spring and monitoring well samples. It does not include fecal coliform or *E.coli* concentrations in the wastewater or in the spring and well samples.

Water Quantity and Quality Monitoring

Flow data

In the spring 1999, the United States Geological Survey (USGS) installed a stream gauging station on Shoal Creek immediately downstream of the Highway 97 bridge (Schumacher, 2001). This station, equipped with a submersible pressure transducer to record stage, allows measurement records every 15 minutes. Flow data are available from May 1999 until present with an interruption from May 2000 until May 2001. A rating curve was developed by USGS using instantaneous discharge measurements. The 15 minutes flow values were then averaged over 24-hour periods to obtain average daily flow values (Figure 7).

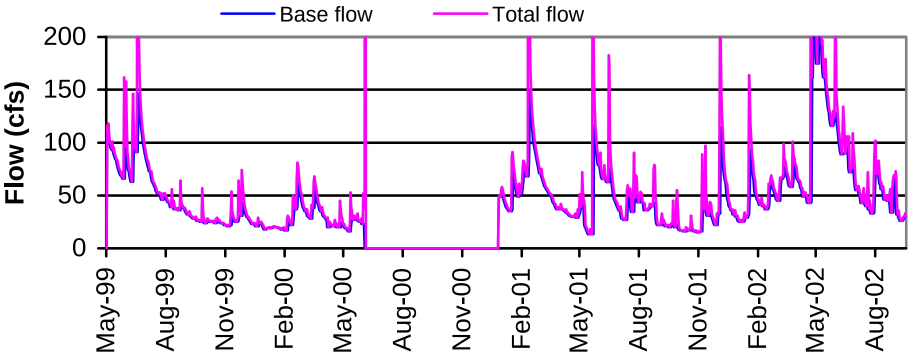


Figure 7. Average daily flow values at the gauging station on Shoal Creek

The USGS HYSEP program (Sloto and Crouse, 1996) was applied to the daily flow values to separate hydrographs into surface runoff and baseflow. Shoal Creek is a stream that is mostly fed by return flow (groundwater flow). Over the monitoring period, the ratio of base flow to total flow of Shoal Creek was 83 %. On a monthly basis, the ratio varied from 60 % in wet months to more than 90 % during drought periods. However, during storm events, surface runoff can be very large and the Shoal Creek flows reach very high values. The watershed reacts very rapidly and within a few days, the flows return to lower values. The peak flow values recorded since May 1999 were 18 m^3/s (636 cfs) on July 1, 1999, 20 m^3/s (734 cfs) on June 17, 2000, and 14 m^3/s (505 cfs) on June 3, 2001. In 2002, it reached 57 m^3/s (2031 cfs) on May 8 and 47 m^3/s (1646 cfs) on May 17. The lowest flows were recorded during winter 2000. Between January and

February 2000, the flows reached values less than 0.56 m^3/s (20 cfs), which is the 7-day average minimum flow with a 2-year recurrence interval (Skelton, 1970).

The precipitation during this period has been particularly low. From May 1999 to May 2000, the total precipitation recorded in Springfield was 826 mm (32.5 in), about 330 mm (13 in) less than the average annual precipitation based on the last 30 years. Precipitation remained low during the summer 2000 and winter 2001. These flows are, therefore, characteristic of a drought period. This should be kept in mind in the rest of the analysis.

Nutrient concentrations

During the course of the 319 project, grab samples were collected monthly at ten sites in the Shoal Creek watershed, including four spring sites and six stream sites (Figure 8). These samples were analyzed for nutrient content. The water quality data are partially reproduced in this document. Stream flow was not measured or estimated during this monitoring effort.

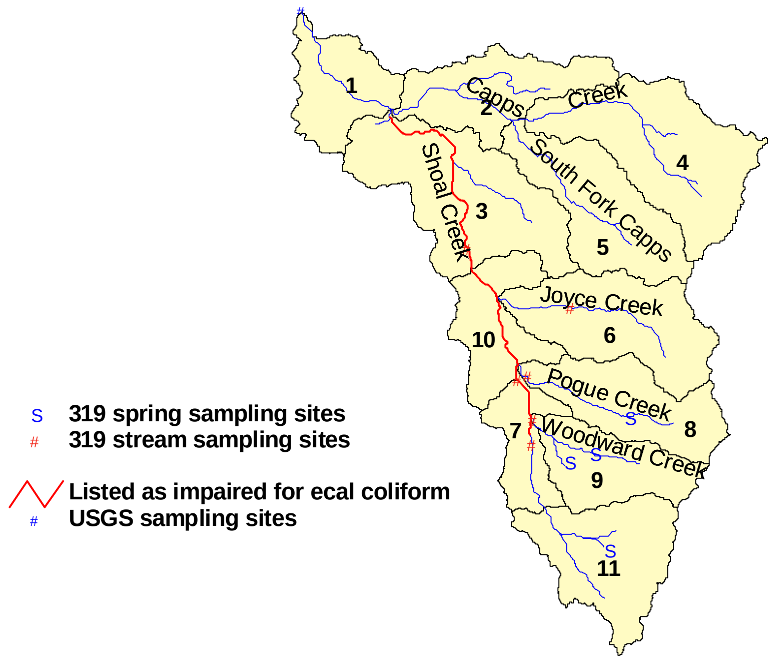
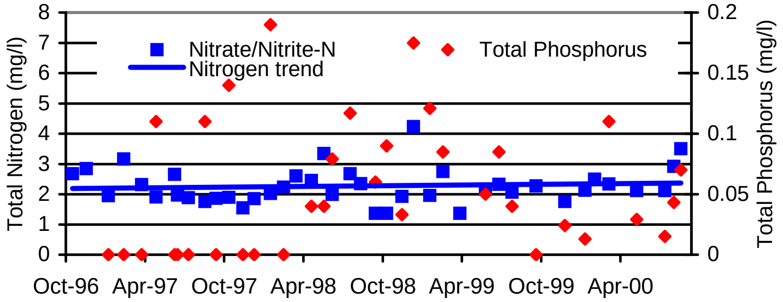


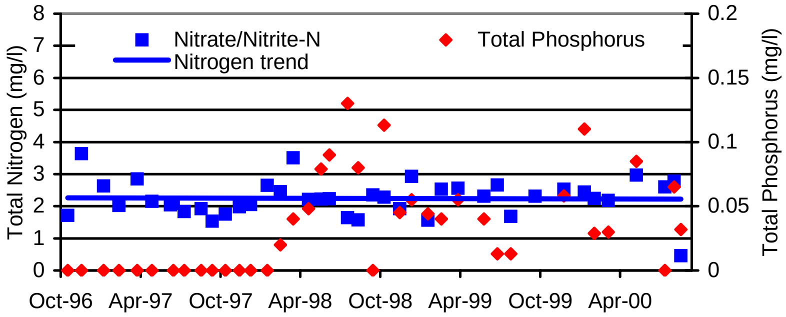
Figure 8. Location of the sampling sites in Shoal Creek Watershed

Nitrogen concentrations at the ten 319 project sites vary between 2 and 4 parts per million (ppm) or milligrams per liter (mg/l). No sample shows a nitrogen concentration greater than 10 ppm and concentrations greater than 4 ppm are rare (less than 2 % of the samples), except in Pogue Creek and Dilbeck Spring with more than 50 % of the samples greater than 4 ppm. Concentrations at the six stream sites (Figure 9) are in general lower than they are at the corresponding spring sites (Figure 10), possibly indicating important nitrogen losses through leaching. Increasing trends of 0.5 to 1 ppm over five years were detected in the nitrogen concentrations for the four springs. A seasonal pattern was detected in the concentration measured in Dilbeck Spring, in Pogue Creek, and to a lesser extent, in Shoal Creek. The nitrogen concentrations increase during the winter and decrease during the summer months.

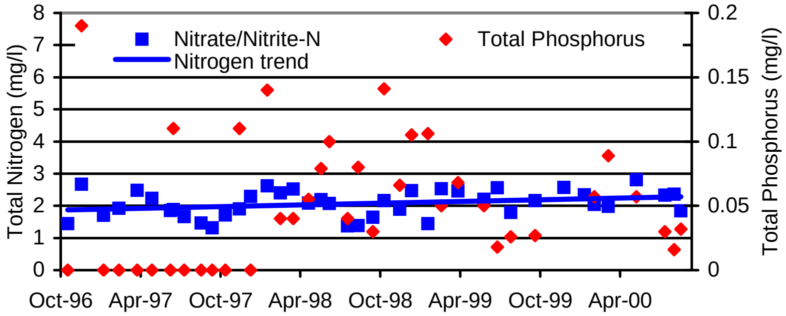
Because of a different measurement method that did not allow the measurement of small amounts of phosphorus, phosphorus concentrations measured before 1998 were excluded from the analysis. Generally the phosphorus concentrations vary more than the nitrogen concentrations at both the spring and stream sites, from 0 to 0.15 ppm. The seasonal pattern that was apparent for nitrogen concentrations can be seen for phosphorus concentrations at Dilbeck Spring and in Pogue Creek but practically disappears for all the other sites.



a) Shoal Creek before Woodward

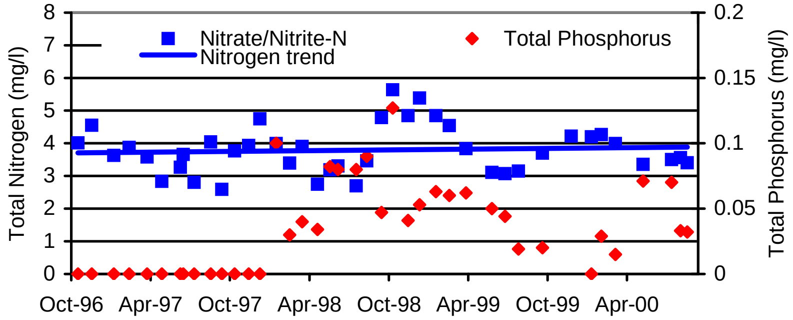


b) Woodward Creek

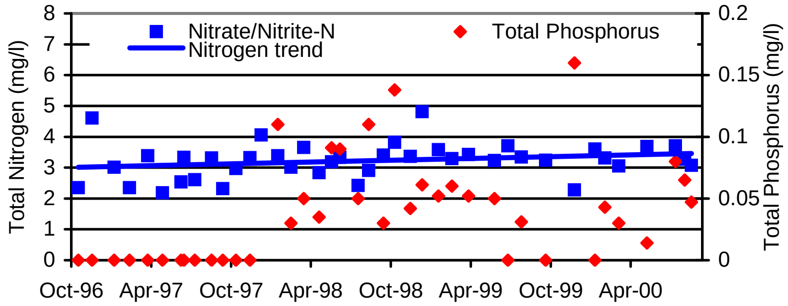


c) Shoal Creek before Pogue

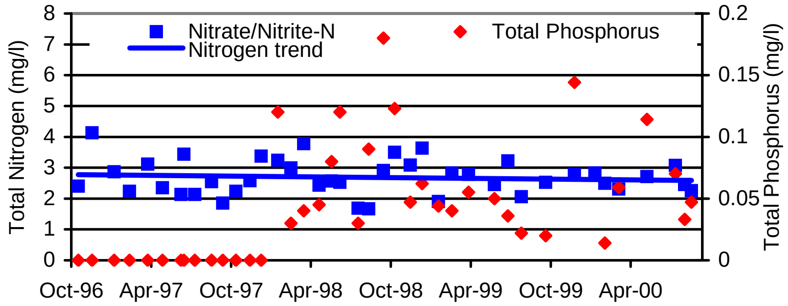
Figure 9. Nitrogen and phosphorus concentrations at six stream sites



d) Pogue Creek

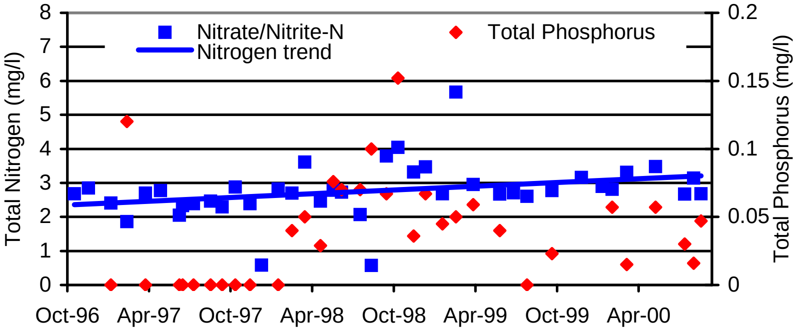


e) Joyce Creek

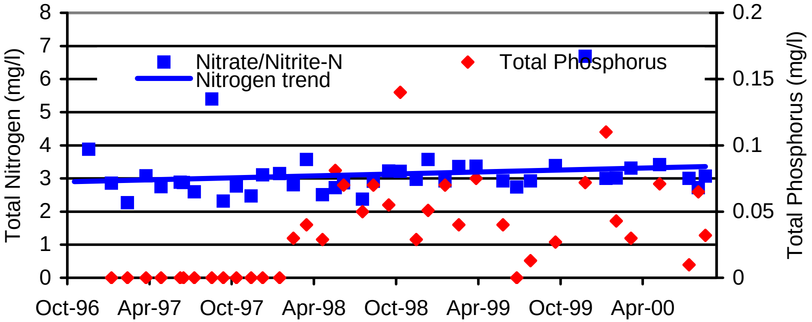


f) Shoal Creek at HWY 97

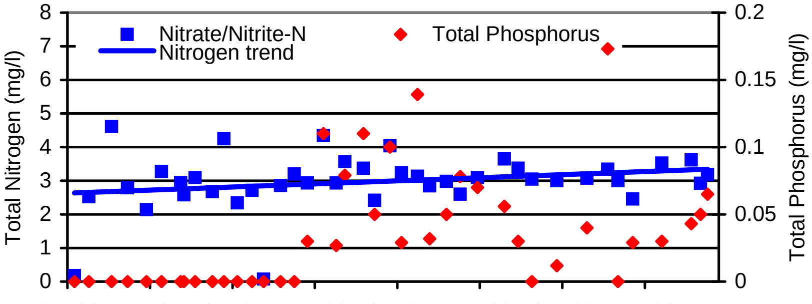
Figure 9 (cont'd). Nitrogen and phosphorus concentrations at six stream sites



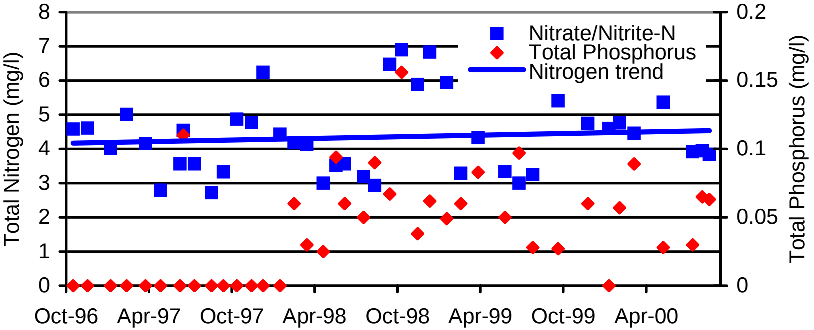
a) Talbert Spring



b) Vineyard Spring



c) Henderson Spring



d) Dilbeck Spring

Figure 10. Nitrogen and phosphorus concentrations at four spring sites

Other nutrient data include the data collected at the sampling station near the Highway 97 bridge. Beginning in May 2001, dissolved and total nutrients are collected weekly from March through November and monthly from December through February. Nitrogen concentrations are very stable between 3 and 4 ppm until May 2003 when they decrease to reach less than 2 ppm in July 2003. Phosphorus concentrations vary between 30 and 70 ppb for phosphorus during base flow conditions (Figures 11 and 12).

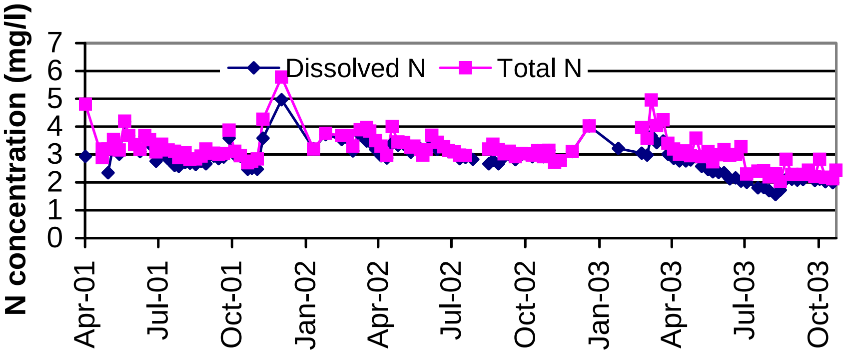


Figure 11. Nitrogen concentrations measured near the Highway 97 bridge

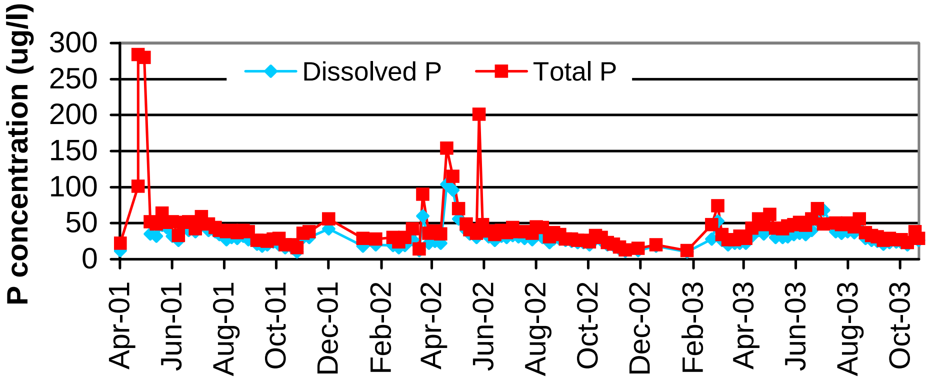


Figure 12. Phosphorus concentrations measured near the Highway 97 bridge

An intense storm event in May 2001 caused phosphorus concentrations to surge to values close to 300 ppb. An automatic sampler (ISCO) at the USGS sampling station recorded several events since June 2001. Samples are collected every 20 minutes and composites samples are analyzed for nutrients. The phosphorus concentrations measured in these samples show a large increase when there is significant runoff. Nitrogen concentrations, on the other hand, first decrease when the flow starts to increase, then increase beyond the initial level at the end of the event when flow values start to decrease.

One can note that overall, the phosphorus concentrations are lower than what was measured at the same site during the 319 project. The average total phosphorus concentration of the samples collected since May 2001 is 44 ppb. The average total phosphorus concentration of the 319 samples collected at that location was 60 ppb. Nitrogen concentrations, on the other hand, seem to increase. The current average of dissolved nitrogen is 2.9 ppm compared with 2.7 ppm during the 319 project.

Bacteria concentrations

Starting in May 2001, weekly samples are collected at the Highway 97 bridge and analyzed for fecal coliform and *E. coli*. Samples filtered on site were analyzed for *E. coli* from May to October 2001 and for fecal coliform after that. The methodology for collecting and analyzing these samples is detailed in Appendix A. Samples are also sent to the University of Missouri and analyzed for *E. coli* DNA source tracking beginning in October 2001.

The *E.coli* and fecal coliform concentrations vary mostly between 100 and 800 colonies/100ml (Figure 13). Concentrations higher than 1000 colonies/100ml are frequently associated with increased flow, even when the flow increase is small or moderate. The maximum concentration is not shown on the graph for reasons of scale. On May 7, 2002, the field measurement showed a concentration of 13,500 colonies/100 ml.

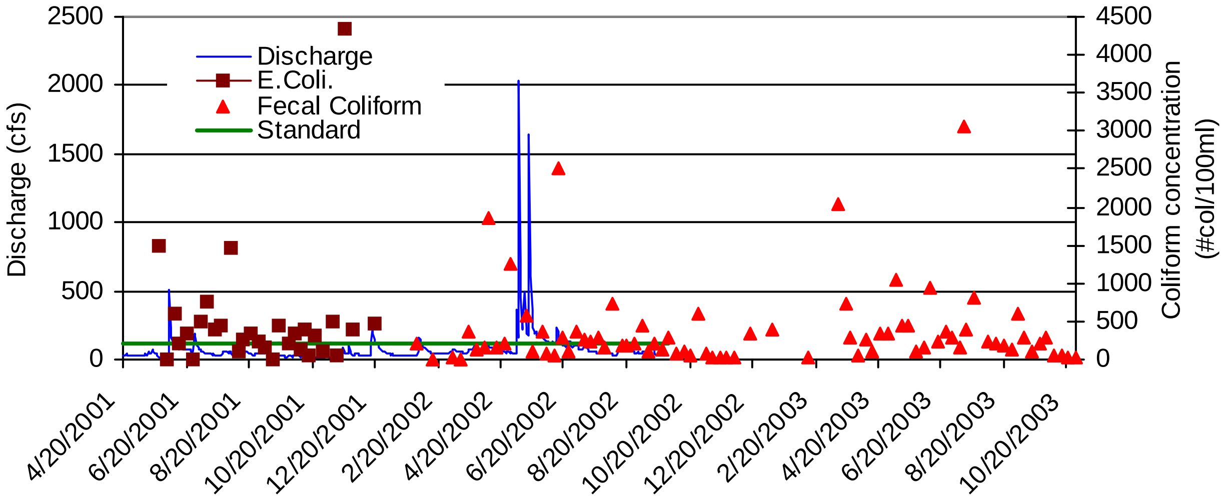


Figure 13. Weekly fecal and *E.coli* concentrations in Shoal Creek

Average bacteria concentrations since May 2001 are summarized in Table 4. During the first recreation season (June through October 2001), the geometric mean of the *E.coli* concentrations reached 187 colonies/100 ml. April and May were excluded because good samples were not collected; only one sample was collected in May and it had too many colonies to count. The real mean value is, therefore, likely to be higher than 187 colonies/100 ml. Eleven samples out of 27 (41 %) had a concentration greater or equal to 400 colonies/100 ml.

Table 4. Averages of bacteria concentrations in Shoal Creek water

Period	Arithmetic averages (colonies/100ml)	Geometric averages (colonies/100ml)	Number of samples exceeding 400 colonies/100ml
June 01 – Oct 01	1396	187	11 (27)*
Nov 01 – Mar 02	592	98	4 (11)
Apr 02 – Oct 02	816	275	8 (32)
Nov 02 – Mar 03	363	117	2 (11)
Apr 03 – Oct 03	384	219	8 (31)

* The number in parentheses indicates the total number of samples analyzed to calculate the average.

These values show that the bacteria criteria for whole body contact recreation waters is violated during the 2001, 2002 and 2003 recreation seasons.

Source Identification

Beginning in October 2001, the samples sent to the University of Missouri were analyzed for DNA source tracking. This technique attempts to identify the source of the contamination by linking the DNA of the bacteria contained in the samples to the DNA of known sources. The method relies on the fact that each animal species hosts unique strains of fecal bacteria that are adapted to the intestinal characteristics and the diet of that particular host. A description of the method is given in Appendix B.

A library of DNA patterns has been developed that is specific to animals and humans living in southwest Missouri. Some hosts that we have not been able to sample in southwest Missouri are characterized by patterns from the central region of Missouri. As the samples are added to the database, identification results may change.

From 13 to 21 isolates are obtained from each water samples and processed to obtain patterns. Using pattern recognition software, the method estimates the similarity between the unknown patterns and the patterns in the database. Even though the software always matches the unknown pattern with a known pattern, only the three highest degrees (out of six) of similarity are retained. The contribution of each potential source is indicated by the relative presence of that particular pattern in the total array of water isolates and expressed as a percentage. DNA analyses of the samples determine what proportions of fecal coliform come from each potential source: human, cattle, poultry, domestic animals, and wildlife. The human class includes both human samples and samples collected in wastewater. The poultry class includes chicken and turkeys. Domestic animals include dogs and horses. Wildlife includes wild turkeys, deer, and geese.

By prorating these percentages to the concentrations of fecal coliform in the water samples, the contributions from every potential source are determined. Figure 14 shows these contributions for weekly samples during the recreation season as well as monthly samples over the winter (December to February). The whole-body contact water quality criterion applies only during the recreation season and we used this data to estimate the contributions from each host class during that season.

The percentages of isolates identified in each host class are summarized in Table 5. Cattle presence is detected all year round; cattle patterns were identified in all samples but 2 in percentages that varied from 5 % to 80 %. The average percentage of cattle patterns detected during the 2002 and 2003 recreation season was 40 % and 51 %, respectively; it was lower during the winter.

Human impacts were detected also all year round with higher detection rates during the winter and spring months. Human or sewage patterns were identified in 65 out of the 85 samples in proportions from 5 % to 66 %.

Poultry presence, either chicken or turkeys, was detected in 68 of the 87 samples collected, mostly from March to July and September to November. These periods correspond to the times when poultry litter is spread on the pastures. They were detected in greater number during or following rain events. More chicken than turkeys were detected, especially during the winter and summer 2003.

Wildlife is mostly detected in the winter. Wildlife includes deer, geese, and wild turkeys. While these animals may be present all year round, there may be two reasons they are only detected during the winter: their winter habitat is closer to water and/or since there is less bacteria from other sources, the percentage of patterns that characterize wildlife goes up. On average during the recreation season, wildlife represents 6 % of all the isolates, most of it being from geese.

Domestic animals include dogs and horses. They represent 19 % of the isolates during the recreation season: 9 % are dogs and 10 % are horses. A horse pasture is located just upstream of the sampling site, which may explain the high percentage of horse isolates.

Table 5. Percentages of isolates identified in each host class during different seasons

Host class	% Cattle	% Domestic animals	% Poultry	% Human	% Wildlife
Winter 2001-2002	19	3	10	27	41
2002 recreation season	40	16	31	6	7
Winter 2002-2003	35	20	25	13	7
2003 recreation season	51	22	6	15	6

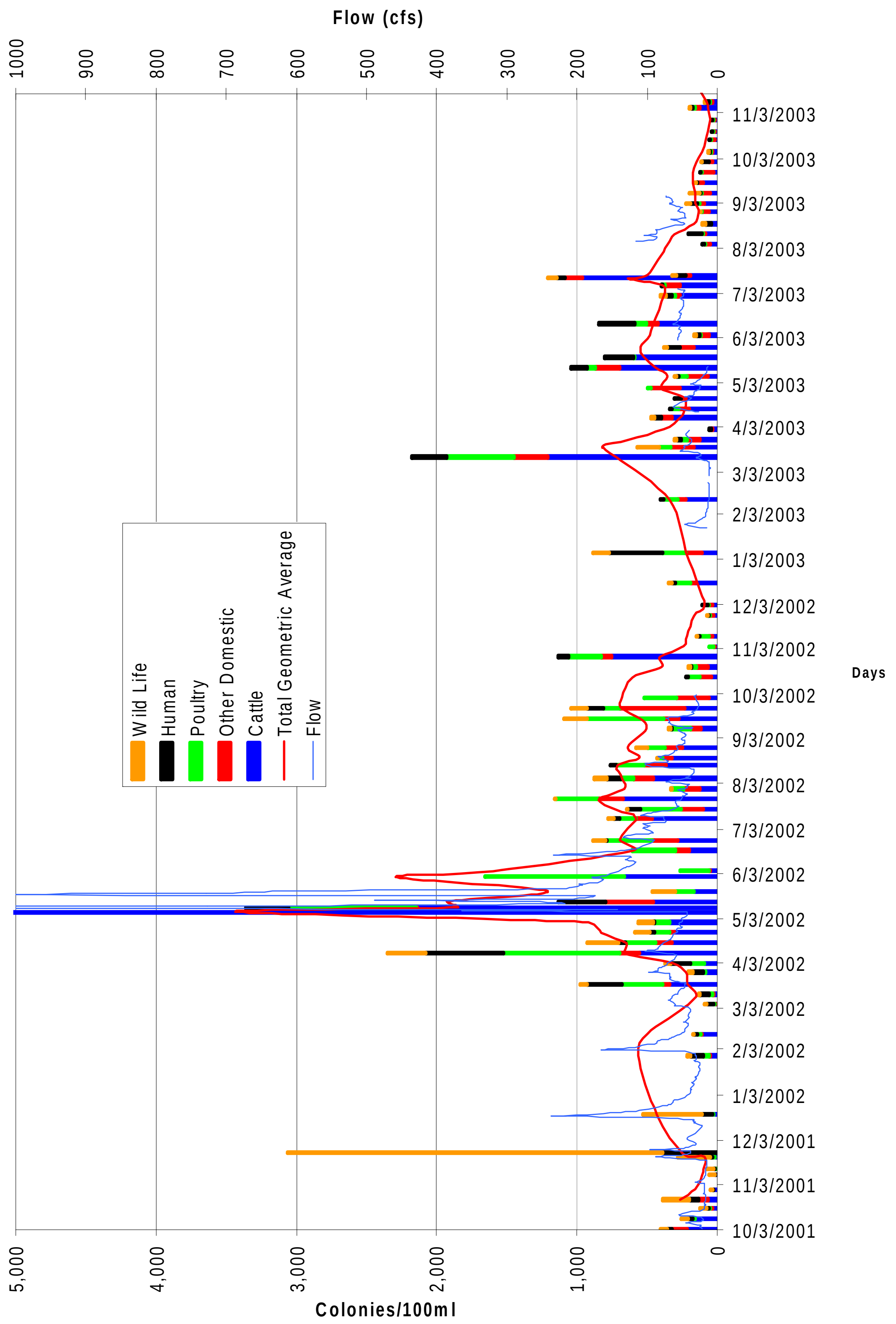


Figure 14. Contributions from potential sources to bacteria concentrations

Modeling process

Model description

The methodology relies on a mathematical computer simulation model that calculates sediment, nutrient, and bacteria loads at the outlet of the watershed or any of the subbasins. The model complements the information given by the flow and water quality data in order to establish water quality baseline characteristics resulting from the current management practices. The watershed is divided into subbasins that are further sub-divided into nearly homogeneous units with distinct land uses, soil types, and management practices. The analysis of the subbasin results indicates areas in the watershed that may contribute in greater amount to the pollutant load of Shoal Creek. The model is also used to evaluate the potential changes in environmental impacts if the stakeholders in the watershed adopt changes in their management practices.

The environmental model used in this study is the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) in its 2000 version. SWAT simulates many of the physical processes that impact water quality. This model requires considerable inputs, some readily available with the use of the GIS technology (elevations, soils, slopes, land use) and some specific to the area and not readily known (pasture management, litter management, and grazing practices). A local steering committee helped determine the area specific inputs to this model. Additional watershed inputs came from other agencies, mainly the Natural Resources Conservation Service (NRCS), the Barry County Soil and Water Conservation District (BCSWCD), and the Missouri Agricultural Statistics Service (MASS).

The model uses daily rainfall and temperature as the driving force and calculates flow values, sediment, pollutant loads and concentrations, as well as crop yields. The program includes the equations that represent the physical processes that control water movement, sediment erosion and transport, crop growth, nutrient cycling and transport, chemical transport, and other processes on a daily time step. It simulates non-point source runoff and associated pollutant loads and routes them through the secondary and primary channel network. Direct inflows and their associated loads can be added anywhere in the watershed with the flow and pollutant loads being added to what is already in the stream. Comparison of measured and calculated values for surface runoff, hay yields, and agricultural chemicals movement validate the input given to the model. The model output allows the analysis of water quality at the outlet of each subbasin of the watershed.

Model assumptions and limitations

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

1. Measured daily rainfall and temperature data from the official weather stations in Monett, Missouri is assumed to be representative of the daily weather in the northern part of the watershed (north of Highway 97). The data from the station of Cassville, Missouri is assumed to be representative of the daily weather in the southern part of the watershed. This assumption is rather acceptable since Monett and Cassville are located 1mile north and 3.5 miles southwest of the watershed boundary. However, the localized nature of

convective summer events can introduce some errors in the model's results compared to measured variables.

2. In each subbasin, each land use representing 8 % or more of the subbasin area is represented in the model and each soil that represents 16 % or more of that land use area is represented. The soil and land use combinations are described in the next paragraph.
3. Management operations (grazing, nutrient application, seed harvest, and hay cuts) are defined by fixed dates. The model does not modify these dates based on precipitation events.
4. The different pasture management practices that are currently used were summarized in one four-year management rotation that is overall representative of what is being done in the watershed. This management scenario is described in the next paragraph.

Input Data Requirements

The SWAT model requires a wide variety of input data to describe the hydrology, soils, and land use characteristics of the watershed. The different types and sources of input data used to develop the TMDL for the Shoal Creek watershed are discussed below.

Climatological data

Weather data required to use the model include measured daily precipitation and maximum and minimum temperature. These were taken from the weather stations at Monett and Cassville from 1970 to 2002 and provided by Pat Guinan from the Missouri Climate Center at the University of Missouri Department of Atmospheric Science. Missing data was filled using precipitation or temperature data from the station at Springfield when available. Otherwise, the model generated them using the monthly precipitation and temperature characteristics in Cassville and Monett. The other meteorological data needed to conduct the simulations, i.e., radiation, wind speed, and dew point temperatures, were generated using monthly characteristic of the Springfield weather station. The Springfield characteristics are part of the SWAT weather database.

Hydraulic and hydrology model parameters

The hydrology parameters required by the model were defined on the basis of the soil, land use, and topographic characteristics. Secondary channels' hydraulic characteristics for each subbasin were left as defined by the SWAT GIS interface AVSWAT2000. Soil slopes and slope lengths were assigned depending on the soil characteristics. Overland Manning coefficients were assigned depending on the land use. The atmospheric CO_2 concentration is 350 ppm. The soil evaporation compensation factor (ESCO) is 0.9. All other parameters are left at their default value. The table showing the values of the non-default hydrology parameters is in Appendix C.

Most of the main channel characteristics were left as defined by the AVSWAT interface. Slope values were recalculated using elevation data for the stream extremities. In case of discrepancy, the value based on elevation was kept. Manning coefficients were estimated by visual comparison of the streams with descriptions and photos found in Chow (1988). Hydraulic conductivities were estimated based on the soil characteristics in the channel. For the erodibility and cover factor, the default values provided by SWAT were used. The channel characteristics are shown in Table 6.

Table 6. Main channel characteristics of the Shoal Creek Watershed

Subbasin	Channel width (m)	Channel depth (m)	Channel slope (m/m)	Channel length (km)	Manning coefficient	Hydraulic conductivity (mm/hr)	Erodibility factor	Cover factor	Alpha for the banks
1	44.552	1.379	0.002	7.986	0.035	25.00	0.1	0.2	0.5
2	22.634	0.878	0.003	14.304	0.035	25.00	0.1	0.2	0.5
3	33.246	1.134	0.002	18.637	0.035	25.00	0.1	0.2	0.5
4	13.734	0.629	0.004	16.147	0.040	25.00	0.1	0.2	0.5
5	11.373	0.555	0.005	10.438	0.040	25.00	0.1	0.2	0.5
6	11.849	0.570	0.005	10.898	0.040	50.00	0.1	0.2	0.5
7	17.515	0.740	0.003	7.969	0.045	50.00	0.1	0.2	0.5
8	10.001	0.509	0.005	9.761	0.050	50.00	0.1	0.2	0.5
9	8.959	0.473	0.006	6.823	0.080	50.00	0.1	0.2	0.5
10	28.262	1.018	0.003	6.114	0.050	50.00	0.1	0.2	0.5
11	11.088	0.545	0.004	9.349	0.125	50.00	0.1	0.2	0.5

Soil data

For the purpose of modeling, only certain soils were retained as being dominant (Table 7). The associations were defined by overlaying the GIS soil and land use layers in AVSWAT with a threshold of 8 % for the land use and 16 % for the soils. Pastures were associated to either the Scholten-Tonti complex or the Scholten soils. In the northwest corner of the watershed, some pasture acres were associated to the Nixa soils and in the Joyce Creek subbasin some were associated to the Secesh soils to characterize grassland located at the foot of the slopes. Woodland was associated in the northwest corner to the Nixa and Clarksville soils. The rest of the watershed was mostly associated to the Scholten-Tonti complex and the Scholten soils withsome associated to the Noark soils.

Table 7. Dominant soil–land use combinations used in the model

Subbasin	Pastures	Woodland
1	Nixa silt loam	Nixa and Clarksville silt loams
2	Scholten-Tonti complex	Nixa and Clarksville silt loams
3	Scholten-Tonti complex	Nixa and Clarksville silt loams
4	Scholten-Tonti complex and Scholten silt loam	No woodland
5	Scholten-Tonti complex and Scholten silt loam	Scholten-Tonti complex, Scholten, and Noark silt loam
6	Scholten-Tonti complex, Scholten, and Secesh silt loams	Scholten-Tonti complex and Scholten silt loam
7	Scholten-Tonti complex	Noark silt loam
8	Scholten-Tonti complex and Scholten silt loam	Scholten-Tonti complex and Scholten silt loam

9	Scholten-Tonti complex and Scholten silt loam	Scholten silt loam
10	Scholten-Tonti complex and Scholten silt loam	Scholten silt loam
11	Scholten-Tonti complex and Scholten silt loam	Scholten silt loam

Management practices

The distribution of grasses in the pastures is as follows:

- 80 % are in fescue, yielding 5.6 – 6.7 T/ha (2.5 – 3 tons/ac). Every 2 years, in midFebruary, 60 % of the fescue is over seeded with clover at about 6.7 kg/ha (6 lbs/ac). Barry County average hay yields varied around 4.5 T/ha (2 tons/ac) during the 1990s (Missouri Agricultural Statistics Service, 2003).
- 20 % are a mix of orchard grass and alfalfa, or orchard grass and red clover.

Knowing that 80 % of the pastures are in fescue, we considered it the representative grass growing in the watershed. Alfalfa and orchard grasses that grow on 20 % of the pastures are not represented in the model. We also assumed that half of these fescue pastures are over-seeded with red clover. Because the SWAT model does not allow two different plants growing at the same time in the same field, we chose to build an imaginary plant that is an average between fescue and red clover, a legume that fixes nitrogen at half the rate that clover would normally do. Since a legume fixes the nitrogen it needs, we have suppressed the commercial nitrogen application in the management scenario. The resulting parameters of this fabricated plant are given in Appendix D.

The management scenario retained as representative of the grassland management practices used in the watershed is described hereafter. Knowing that half of the pastures receive poultry litter every year, we assumed that the number of acres fertilized in this manner is constant from one year to the other, i.e., there is a rotation between pastures fertilized with poultry litter and pastures either not fertilized or fertilized with commercial fertilizer. Similarly, knowing that 25 % of the pastures are fertilized with commercial nitrogen, we assumed that each fescue pasture would be fertilized with commercial nitrogen once every four years. Fescue seeds and hay cutting are done on these fields at the end of May. A quarter of the pasture acres are not fertilized in any given year, reflecting that some producers do not fertilize their pastures. This rotation probably represents an improvement over the real management of the watershed pastures. In reality, some pastures tend to receive litter every year and some may receive very little fertilizer, leading to some unacceptable phosphorus levels in the first and nitrogen deficiencies in the latter. However, the rotation is an acceptable compromise between the actual watershed practices and the needed computer efficiency of the model. The different operations that take place in the pastures are described in detail in Appendix E.

Grazing occurs on pastures year round. From January first until the end of June only 50 % of the acres are available for grazing since 25 % are kept for hay and fescue seed, and another 25 % are kept for hay only. Grazing intensities are 5 acres per cow/calf pair once hay is harvested and slightly less than 3 acres per cow/calf pair before. From November through April, cattle are left in the pastures and supplemented with hay. This results in no biomass uptake from the pasture, grass being trampled, and manure deposited on the soil.

The daily grazing rate of a cow/calf pair and the daily manure production are both subject to considerable variability due to several factors: species, animal health, feed availability, and feed palatability. In this analysis, we used the numbers given in Table 8 that result in averages of 5.4 kg (12 lbs) of dry manure being produced by a cow-calf pair daily, and 9.5 kg (21 lbs) of feed being consumed.

Table 8: Daily feed requirements and manure production for grazing cow-calf

Animal	Animal weight	Daily Manure weight[1]	Moisture content[1] (%)	Daily dry manure weight	Daily Dry Feed[2]
Grazing cow	500 kg	37.5 kg	88.4	4.35 kg	5.9 – 8.5 kg
Grazing calf	132 kg	9.2 kg	88.4	1.07 kg	0 – 4.5 kg

[1] *Source, USDA , 2000*
[2] *Source, National Research Council, 1976*

Accounting for pollutant sources

Fecal coliform and nutrient loads that are deposited by cattle directly in the streams are treated as direct nonpoint source loadings in the model. To estimate the contributions from septic tanks, we also treated the sewage from houses within 75 m (250 ft) of a stream as direct nonpoint source loadings. Fecal coliform that is applied or deposited on land is treated as nonpoint source loading; all or part of that load may be transported to the stream as a result of surface runoff during rainfall events. Direct nonpoint source loadings are applied to the stream reach in each subbasin as appropriate. There is only one permitted fecal coliform point source in the Shoal Creek watershed, Camp Barnabas, located downstream of the Highway 97 Bridge. The permit includes fecal coliform daily maximum limits of 1000 colonies per 100 ml for a design flow of 44,400 liters (12,000 gallons) per day, or 0.0005 m^3/s (0.0186 ft^3/s), and monthly averages of 400 colonies per 100 ml. The other permitted facility in the watershed, George's plant, is not permitted any fecal coliform discharge.

The nonpoint source loadings were applied as poultry litter spread on pastures or animals grazing and depositing manure. The fecal coliform counts are calculated proportionally to the litter or the manure applied or deposited. Thus, they vary with each subbasin, land use, and land management. Fecal coliform die-off is simulated during dry days while on the land or in the soil, and in the streams. To account for seasonal differences in the likelihood of cattle to spend time in the streams, direct nonpoint source loadings are varied by month.

Modeling bacteria fate and transport

Fecal coliform die-off is modeled in SWAT using an exponential first order decay process given by the equation

$$C_t = C_0 e^{-KtC_{adjT}^{(T-20)}} , \qquad [1]$$

where C_t = concentration at time t, C_0 = initial concentration, K = decay rate (day^{-1}), t = time (days), C_{adjT} = temperate adjustment factor, and T = temperature (^{o}C). SWAT divides bacteria in two classes of organisms that correspond to two decay rates on the land, in the soil, and in the water. The decay rates are considered to be the same for all animals; only the amounts of slow and fast decaying bacteria change between animal species. In most experiments, only one rate is calculated, usually after a relatively small number of days. This would therefore correspond to the fast decaying bacteria. A review of literature provided estimates of land and soil decay rates for manures and litter in the Shoal Creek watershed (Table 9).

The same equation is used to simulate bacteria decay in the stream. The decay of bacteria during the time it takes for a volume of water to be transported through a stream reach is calculated for each stream reach. The flow rate and the channel characteristics are used to estimate the routing time. For bacteria decay in the stream, only one rate is used for all types of bacteria. In addition, the decay rate on land and in the water is allowed to vary with the air or water temperature. An adjustment factor of 1.07 is used in the model, which is the default value for SWAT.

Table 9. Half-life of susceptible and persistent coliform bacteria from different hosts

Waste type	Temperature	Bacteria	half-life (days)	Reference
Cattle	20 oC	FC	1 - 3.3	
Chicken litter	20 oC	FC	0.9-1.2	Crane et al. (1980)
Poultry waste		FC	8.6	Giddens et al. (1973)[b]
Stream water	4-6 oC	*E.coli*	0.1 – 0.15	McFeters and Stuart (1972)[a]
Stream water	4-6 oC	*E.coli*	1	McFeters and Stuart (1972)[a]
Stream water		FC	1.08	Canale et al. (1973)[b]

[a] Cited in Crane and Moore (1986)
[b] Cited in Reddy, Kahleel, and Overcash (1981)

Based on the values cited in the literature, the following values of half-life and decay rates were used for bacteria on land and adsorbed to soil particles. For bacteria on land, a half-life of 3 days was chosen as an average between the values found in the literature for cattle and poultry waste. The corresponding decay rate is 0.23 days^{-1}. A tenth of this value was used for bacteria adsorbed to soil particles.

For bacteria in stream water, a half-life was determined from data collected by USGS (Schumacher, 2003). A dye test was conducted in July 2001 between the outlet of subbasin 7 and the outlet of subbasin 10. Samples were collected regularly and analyzed for dye concentration. The samples that corresponded to the peak dye concentrations were processed to measure the die-off rates for fecal coliform and *E.coli*. The results showed that the rates were slightly different at both locations but similar for fecal coliform and *E .coli*. The average decay rate was 0.084 hour^{-1} or a half-life of 8.3 hours. This value (2.01 days^{-1}) was used in the model.

Modeling non-point sources

Non-point source fecal coliform loads are those that are deposited or applied on the land. They can reach the stream through two different paths: with surface runoff that carries the bacteria over the land surface or through preferential pathways that exist because of the karst features in the watershed. In the last case, bacteria can reach the underground waterways and reappear in springs. These loads include the bacteria loadings contained in the poultry litter spread on the pastures, from the manure deposited by the grazing cattle, from the septic fields, and deposited by the wildlife in the forests.

The transport of bacteria and nutrients through karst features cannot be simulated with SWAT. Only the transport of nitrogen (nitrates) through subsurface flow is modeled. Bacteria concentration values from spring samples (Appendix F) show that these springs are contaminated. However, there is no scientific basis at this point to estimate how much pollutant travels this way.

The surface runoff loadings are calculated by the model as a function of the litter spread or the manure deposited on the land. The inputs required by the model for bacteria fate and transport are the bacteria content of each type of manure, which were estimated from values found in the literature. They are based on best estimates of wildlife, cattle, and poultry litter production rates (Table 10).

Table 10. Fecal coliform production rates for different animals in counts/animal/day

Animal	Count	Reference:
Beef cow	5.4E+9	Metcalf & Eddy, 1991
Hog	1.1E+10	ASAE, 1998
Horse	4.2E+08	ASAE, 1998
Chicken	1.4E+08	ASAE, 1998
Turkey	9.3E+07	ASAE, 1998
Goose	4.9E+10	Best professional judgment
Deer	5.0E+08	Best professional judgment
Raccoon	1.3E+08	Best professional judgment
Dog	4.1E+09	LIRPB, 1978

Because in SWAT every value relative to manure is calculated and entered on a dry matter basis, bacteria content entered in the fertilizer data base was adjusted for moisture content and manure production for each animal. Wildlife is not currently considered since DNA tracking showed that wildlife would be responsible for a very small fraction of the total bacteria load during the recreation season. This may change as the results from the 2003 recreation season become available.

Poultry litter is different from poultry waste because the litter is a mix of animal waste and another material, usually wood shavings or rice hulls. In addition, the poultry litter that is spread on the pastures is the result of 3 to 4 flocks of turkeys or 5 to 6 flocks chicken being grown in the barn within a year. Hartel et al. (2000) report fecal coliform concentrations ranging from 10^3 to 10^7 counts per gram (dry weight) of fresh poultry litter. Schumacher (2003) reports fecal coliform and *E.coli* concentrations in broiler and turkey litter ranging from 17,000 to

47,000 counts/g. Both Hartel and Schumacher noted that the bacteria count decreases rapidly to less than 100 counts/g when the litter is composted. As a worst-case scenario, the bacteria content of poultry litter has been fixed to 10^7 counts/g.

The inputs required for nutrients fate and transport are the nutrient content of the manure in mineral and organic forms. The values for George's plant used in the model (Table 11) come from the data on file with MDNR. The phosphorus is assumed to be equally divided between mineral and organic forms. The nitrogen that is not ammonia is assumed to be in organic form. There are no data on file that describe the bacteria content of the effluent from George's plant and none has been included in the model.

Table 11. Nutrient content of manure and effluent in the Shoal Creek watershed

	Mineral N	Mineral P	Organic N	Organic P
Cow-calf manure	1.6 %	0.4 %	2.9 %	0.7 %
Broiler litter	3.5 %	0.7 %	2.0 %	1.6 %
Georges effluent	20 mg/l (NH_3)	10.5 mg/l	50 mg/l	10.5 mg/l
Septic tank effluent	18 mg/l (NH_3)	6.3 mg/l	57 mg/l	12.7 mg/l

Modeling direct non point source inputs

Direct non point source inputs are those that are directly deposited in the stream. Direct non point source inputs include deposits made by cattle that stand in the stream and inputs of sewage from illegal discharges and failing septic tanks. For cattle standing in the stream, a percentage of the herds that have access to a stream was determined and validated with the steering committee. All cattle that have access were considered to spend some time in the stream. That length of time and, therefore, the amount of waste directly deposited is allowed to vary monthly to account for the seasonal changes of temperature. The results are presented in Table 12. The number of pastures with access to a stream was determined by overlaying a GIS stream map on the land use map. Overall, 25 % of the pastures in the Shoal Creek watershed have access to a primary stream reach. Secondary stream reaches were not considered.

Table 12. Percentage of cattle waste directly deposited in the stream in pastures with stream access

	Percentage of daily waste directly deposited		Percentage of daily waste directly deposited
January	3	July	10
February	3	August	10
March	3	September	7
April	4	October	4
May	4	November	3
June	7	December	3

Model Calibration

The model depicting the current condition of the watershed accounts for the physical properties of the watershed (soils, climate, stream channel data) and the current farming practices as described by the technical advisory committee, the watershed steering committee and the different farm panels of the watershed. The model has been calibrated using available data namely:

- the Barry and Newton County hay yields reported to USDA,
- the daily flow values at the USGS gauge between May 1999 and present,
- the weekly water quality data collected between May 2001 and present, and
- the monthly water quality data from the 319 project.

Crop yields

Correct representation of the crop yields ensures that the correct amounts of moisture and nutrients are taken up by the vegetation and removed from the hydrologic system. Figure 15 shows the simulated and reported crop yields as in Barry and Newton Counties. The average simulated crop yield from 1990 to 2002 is 4.5 T/ha (2.0 t/a), the average reported yield for Barry and Newton Counties for the same period. Reported values from earlier years are lower and significantly different from the simulated values (not shown) because the use of poultry litter has increased over the last 30 years, which has led to a hay yield increase. Pastures were fertilized with poultry litter only as the poultry industry became important in the area.

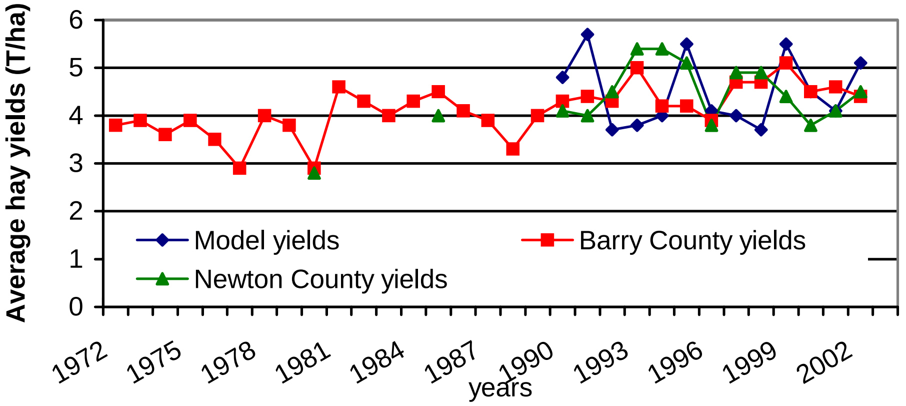


Figure 15. Comparison of simulated and reported hay yields

Runoff

The model was calibrated using almost two years of daily values measured at the Highway 97 Bridge. The monitoring periods are May 17, 1999 to June 20, 2000, and January 12, 2001, to present. Since the measured flow data were not available until the end of 2002, we did not consider 2002 to calibrate the model. 2002 and 2003 are used for verification of the model. Figure 16 shows the measured and simulated stream flows from May 1999 to September 2002.

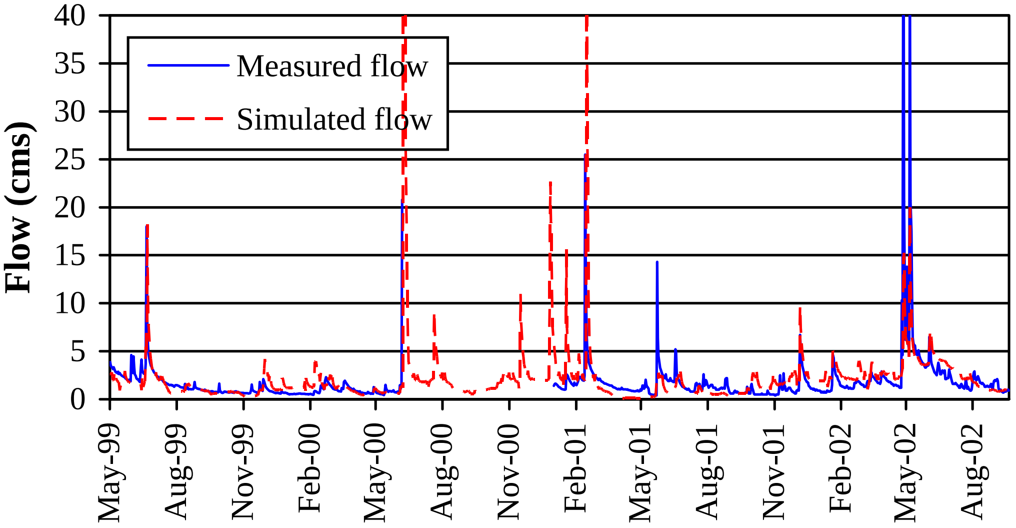


Figure 16. Comparison of measured and simulated flows between 1999 and 2002

The weather stations are outside of the watershed, which introduces some uncertainty in the actual watershed precipitation and in the calibration of the flow data by comparing measured and predicted values. Summer thunderstorms can be localized. To insure that the overall statistical characteristics of the flow values are well reproduced, we compared the flow frequency curves (Figure 17). While many peak flow values are overestimated, the fit between the two curves is satisfactory 90 to 95 % of the time.

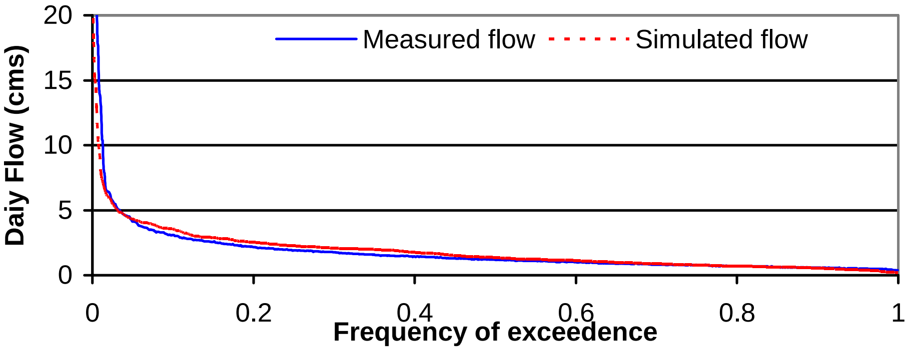


Figure 17. Frequency curve of daily flow values from 1999 to 2002

Nutrient concentrations

The nutrient parameters of the model were calibrated using the monthly concentration values measured during the 319 project as well as the values collected at the Highway 97 Bridge since May 2001. This data is summarized in Appendix G. Again, the calibration was performed on the basis of frequency curves. Figures 18 and 19 show the frequency curves obtained from measured and simulated concentrations values of nitrates and dissolved phosphorus, respectively. To do an accurate comparison, only the simulated values for the days when a sample was collected are considered.

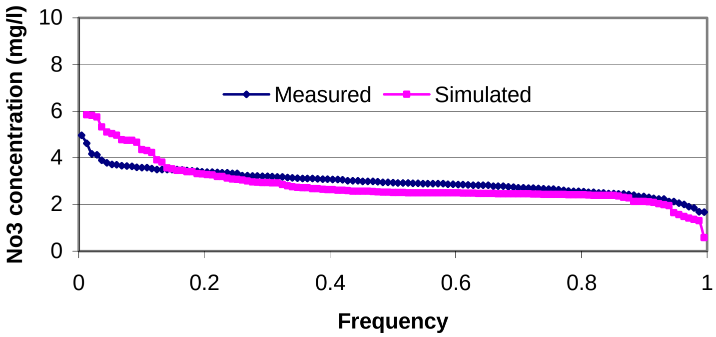


Figure 18. Frequency curve for measured and simulated nitrate concentrations

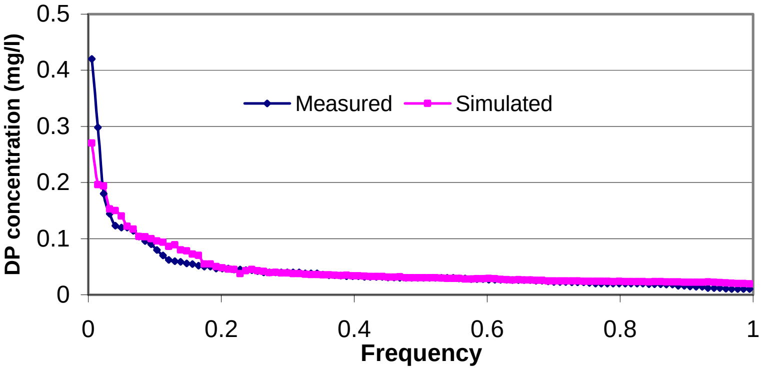


Figure 19. Frequency curve of measured and simulated dissolved phosphorus

A 2000 USGS study showed that the springs and wells in the watershed are contaminated with nitrates and phosphorus, which led us to assume that the shallow aquifer was contaminated as well. SWAT2000 does not track nutrients in the shallow aquifer but it is possible to specify a nutrient concentration for the groundwater in each subbasin. These concentrations have been set between 0.015 and 0.03 mg/l for phosphorus and between 2.0 and 3.5 mg/l for nitrates. These concentrations give results that match the nutrient concentrations at base flow.

Using the data collected during the 319 project, measured frequency curves were also developed at the outlet of Woodward, Pogue, and Joyce Creek and at the Route W crossing on Shoal Creek. The fit between measured and simulated nitrate concentrations is generally good for average conditions, with some discrepancy at higher concentrations. The fit for dissolved phosphorus concentrations is better at the highway bridge than it is for other sampling locations, with the largest differences being for the higher concentrations. A possible explanation is the higher number of points there and the better estimations of average daily loads during storm events using the storm samples collected with the automatic sampler.

Data from the automated sampler showed that during storm events the surface runoff carries large loads of dissolved phosphorus while it dilutes the nitrates transported in the stream. Appendix H details the flow and nutrient concentrations derived from samples collected by the automatic sampler.

Fecal coliform concentrations

The bacteria parameters of the model were calibrated using fecal coliform concentrations measured in 2001 and 2002 and listed in Appendix G. As for flow and nutrient, the calibration was based on the frequency curves. Figure 20 shows the frequency curves obtained from measured and simulated values for 2001 and 2002. In order to clearly show the curves in the range of values frequently observed, the extremely high concentrations obtained during strong spring storms are not shown. These reach and go beyond 10,000 colonies/100ml. Again, only the simulated values for the days when a sample was collected are considered.

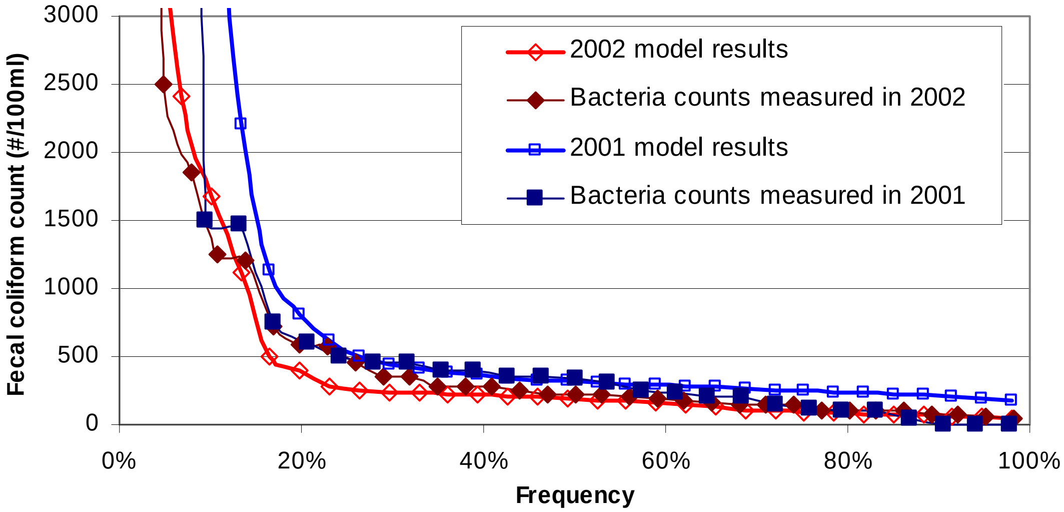


Figure 20. Frequency curve of measured and simulated fecal coliform concentrations

Fecal coliform concentrations measured in samples collected at a spring in 2002 (Appendix F) and the 2002 USGS study show that the groundwater is contaminated with fecal coliform as well. Although the concentrations are on average much lower than they are in the stream, they did reach values close to 1000 colonies/100 ml on certain days. This input of bacteria from the groundwater cannot currently be taken into account by SWAT and the results are likely to be underestimating fecal coliform concentrations during or shortly after rainy days.

Results

The model calibrated with flow and water quality data collected between 1996 and 2002 was run for 50 years of generated weather. The daily precipitation and minimum and maximum temperatures are calculated by the model as a function of the monthly characteristics of these variables at the Cassville and Monett stations. The characteristics were derived based on the last 30 years of recorded weather at these stations. For other variables, such as humidity and wind speed, the monthly characteristics are those from the Springfield station. The long term characteristics for flow, nitrate, phosphorus, and bacteria concentrations, and nitrate, phosphorus, and bacteria loads were derived from the results of this run.

Flow

The water's pathways from the land surface to the stream are very important in regard to the pollutants it can transport. In the model, three pathways are possible: surface runoff, subsurface runoff, and return flow. Surface runoff is the part of the flow that travels on the ground surface. Subsurface flow is the part of the flow that infiltrates up to a restrictive layer and then reaches the stream by traveling along that restrictive layer. Return flow is the part of the flow that infiltrates through the complete soil profile, reaches the shallow aquifer and returns to the stream through the aquifer. Groundwater flow includes the subsurface flow and the return flow. Some of the water that infiltrates past the soil profile can reach the deep aquifer. This water is lost from the system when dealing with watersheds the size of the Shoal Creek Watershed. Tables 13 and 14 detail the average monthly surface runoff and groundwater contributions to the stream flow in the southern and northern parts of the watershed. Table 15 summarizes the average annual results. The groundwater flow represents more than half of the Shoal Creek flow in the southern part of the watershed; in May and from July to November it represents two thirds or more of the flow. In the northern part, the groundwater flow is a little less than half of the total flow (45 %).

Table 13. Monthly flow contributions in the south part of the Shoal Creek Watershed

	Jan	Feb	Mar	Apr	May	Jun
Precipitation (mm)	45	57	92	118	129	130
Surface runoff (mm)	20	23	22	14	7	17
Groundwater flow (mm)	26	22	13	10	14	16
	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)	78	94	97	91	97	91
Surface runoff (mm)	5	7	7	5	12	30
Groundwater flow (mm)	16	13	14	19	22	26

Table 14. Monthly flow contributions in the north part of the Shoal Creek Watershed

Month	Jan	Feb	Mar	Apr	May	Jun
Precipitation (mm)	43	57	87	105	135	149
Surface runoff (mm)	10	19	13	10	7	17
Groundwater flow (mm)	17	12	6	5	5	7
	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)	85	67	101	80	101	80
Surface runoff (mm)	11	2	9	4	17	21
Groundwater flow (mm)	9	7	5	8	11	16

This can be explained in part by lower total precipitation in the north than in the south and also by the presence of the Nixa silt loam in the northern part of the watershed that retains more water than Scholten and Tonti silt loams. Less water seeps through the soil profile to reach the shallow aquifer and provide return flow during the dry months of the summer. The differences in total water yields and groundwater contributions will help explain the differences in nutrient and bacteria transport.

Table 15. Average annual flow contributions in the Shoal Creek Watershed

	Precipitation (mm)	Surface Runoff (mm)	Ground Water (mm)	Total yield (mm)
North	1090	140	107	264
South	1119	171	207	413
Whole watershed	1104	154	154	334

Nutrients

The sources of nutrients in the Shoal Creek watershed are multiple: cattle manure and poultry litter; fertilizer applied to pastures; direct non point sources such as cows standing in the stream and failing septic systems; and atmospheric deposition. In addition, legumes can fix their own nitrogen when needed and the soil and the groundwater contain nutrients. The SWAT model can simulate the fate and movement of nitrogen and phosphorus and estimate the nutrient loadings from each subbasin and the nutrient concentrations in the stream.

The maps in Figures 21 and 22 show the total nitrogen and phosphorus loadings for each subbasin in the Shoal Creek watershed. The nitrogen loadings result from nitrate transport in surface runoff, lateral flow, and groundwater flow and from the transport of organic nitrogen attached to eroded sediment particles. The phosphorus loadings results from mineral phosphorus transport in surface runoff and groundwater flow. Eroded sediment particles can carry mineral as well as organic phosphorus.

The differences in phosphorus loadings between the different subbasins can be explained by the differences in nutrient inputs (poultry litter application rates) and annual amounts of surface runoff. Both the application rates and the amounts of surface runoff are lower in the northern part of the watershed than in the south and they result in lower phosphorus loadings. One exception is subbasin 1 that has a high litter application rate due to limited amounts of spreadable acres.

The difference in nitrogen loadings are more pronounced between the northern and southern watershed and can be linked to the amount of groundwater, the main pathway for nitrogen to reach the stream. The southern watershed yields twice as much groundwater as the north.

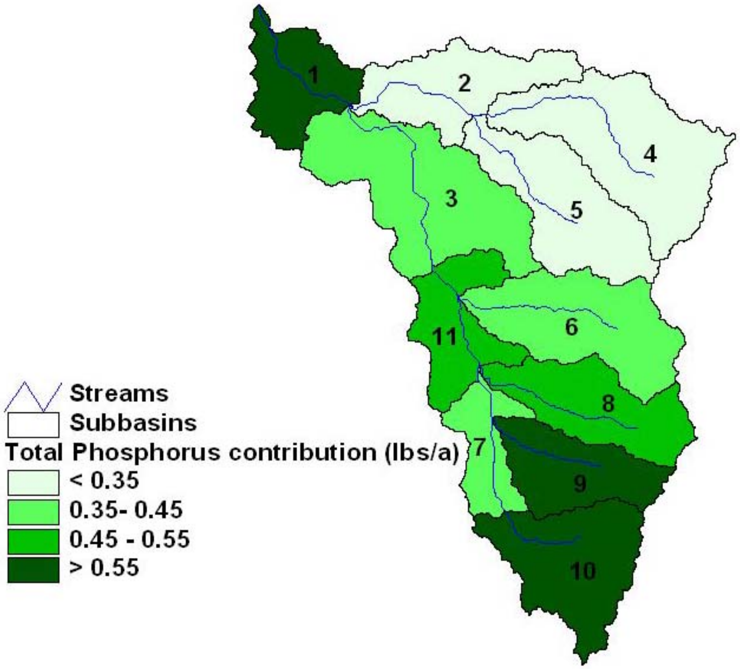


Figure 21. Total phosphorus loadings from each subbasin

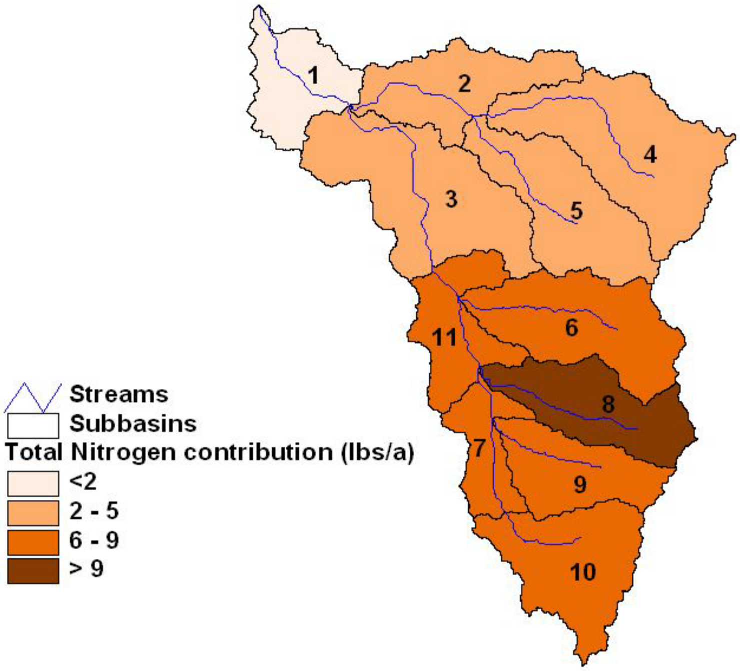


Figure 22. Total nitrogen loadings from each subbasin

The proportions of nitrogen and phosphorus that moves with the different flow path are detailed in Table 16. The model estimates that more than 95 % of the nitrogen reaches the stream in dissolved form with almost 60 % of it reaching the shallow aquifer and returning to the stream with the base flow. This explains the very stable nitrogen concentrations measured in the Shoal Creek watershed. Conversely, 87 % of the phosphorus moves with surface runoff, either in dissolved form or attached to sediment particles. The latter fraction includes organic phosphorus and mineral phosphorus attached to soil particles. The direct nonpoint sources of nutrients in

Shoal Creek, i.e., cattle manure directly deposited in the streams and effluent leaching from failing septic tanks, account for 2 % of the nitrogen loads and 7 % of the phosphorus load over the whole watershed.

Table 16. Percentages of nutrients moving with different means of transport in the Shoal Creek Watershed

	Phosphorus	Nitrogen
Surface runoff (soluble)	65	11
Sediment	22	3
Lateral flow	n/a	25
Groundwater	6	59
Direct nonpoint sources	7	2
Total	100	100

The proportions of nitrogen and phosphorus that come from the different sources are detailed in Table 17. These were estimated by scenario analysis. Management scenarios were developed in which one source of nutrients was removed, all other factors remaining constant. The difference at the watershed outlet between a scenario and the baseline gives the contribution from that source. None of these scenarios produces a significantly higher sediment yield, which insures that the differences are not due to an increase of erosion. The contributions from natural sources are obtained by subtracting each source contribution from the baseline loadings. Intrinsic sources include nitrogen from rain, nitrogen fixed by legumes, and nitrogen and phosphorus present in the soil.

Table 17. Percentage of nutrient from each source based on the Shoal Creek loadings at the watershed outlet

	Mineral P[1]	Organic P	Nitrates NO_3	Organic N	Total P	Total N
Direct nonpoint sources	3	17	0	30	6	2
George’s irrigation	1	-1	0	-1	0	0
Poultry	41	32	3	10	39	3
Grazing	6	3	3	3	5	3
N applications	2	-2	4	-1	2	3
Groundwater	9	0	64	0	7	61
Intrinsic sources	38	51	26	59	41	28
Total	100	100	100	100	100	100
Total (in pounds)	29,258	8,813	475,090	21,080	38,071	496,170

The negative values of organic phosphorus and nitrogen correspond to cases where the fertilizer applications increase the biomass growth and the lack of it produces a slight erosion increase due to lack of canopy and ground cover. Organic nutrients are adsorbed to soil particles.

The results show that 40 % of the phosphorus loadings come from “intrinsic sources.” The main source of intrinsic phosphorus is what is already in the soil. The loadings in these conditions were estimated by assuming that all the pastures are hay fields harvested once a year in June without being fertilized with poultry litter or nitrogen, no grazing is taking place at any time, and the groundwater does not bring any nutrient. The results show that the phosphorus loadings would still be around 40 % of what they currently are. The other main source of phosphorus is poultry litter, which accounts for another 40 % of the current loadings.

The intrinsic nitrogen sources include soil nitrogen, legume fixation, and atmospheric deposition; they account for 28 % of the current loadings. The bulk of the nitrogen comes from groundwater (61 %) and the external sources of nitrogen (N applications, grazing, poultry litter, direct non-point sources) account only for 11 % of the total nitrogen loadings at the watershed outlet. Since the SWAT model does not track the movement of nitrogen in the shallow aquifer, it is difficult to link the nitrogen sources to the amount of nitrogen that leaches through the soil profile, the groundwater nitrogen concentrations, and to the amount that reaches the stream with return flow. The average nitrate-N concentration measured in the springs and wells of the Shoal Creek watershed is 3 to 4 mg/l (Mugel, 2002).

Mugel also showed that the range of measured nitrate concentration is rather large, spanning from less than the detection level (0.02 mg/l) to 18 mg/l. It is not certain where all the nitrogen found in the shallow aquifer comes from. These groundwater concentrations may be the result of processes not included in the model. For example, the infiltration of water through the karst features and the associated transport of dissolved nutrients are not well represented with the SWAT model. The leaching of nutrients from septic tanks needs to be better represented. Also, groundwater nutrient concentrations may be the remnant of past management practices when more land was utilized to grow row crops, tomatoes, and strawberries.

Figures 23 and 24 show the frequency curves of nitrates and dissolved phosphorus concentrations at the Highway 97 bridge in the middle of the watershed. Three curves are shown on these figures: the middle one is the average of the 50 curves built from each set of 365 daily simulated values, the two others correspond to one standard deviation above and below the average and characterize a 70 % confidence interval. The dissolved form of each nutrient was selected because it represents 90 % and 70 % of the nitrogen and phosphorus load, respectively. Curves at the outlet of the watershed are very similar with some slight differences on either end of the curves.

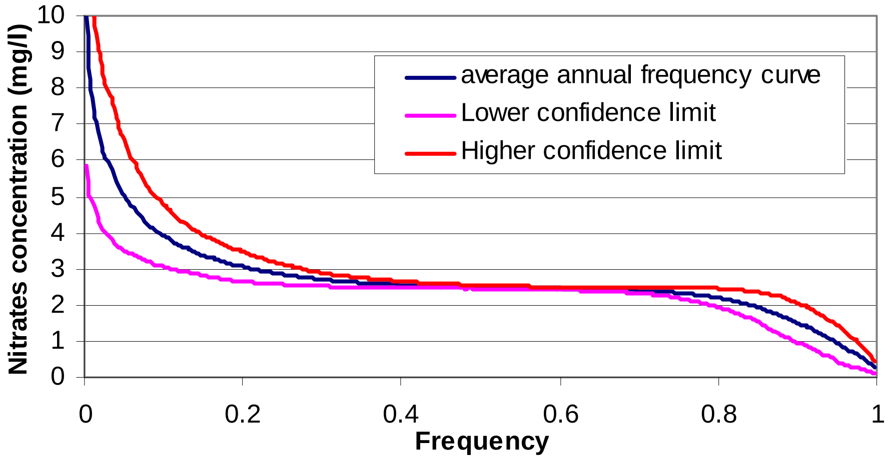


Figure 23. Frequency curves of nitrates concentrations at the Highway 97 Bridge

The median concentration of nitrates is 2.5 mg/l and 90 % of the concentrations are below 3.95 mg/l. For phosphorus, the median concentration of dissolved phosphorus is 0.033 mg/l and 90 % of the concentration values are less than 0.15 mg/l. The uncertainty due to inter-annual variability is very small for the medium and lower range of nitrates and dissolved phosphorus concentrations, respectively. It increases for higher and lower nitrate concentrations. The phosphorus concentration of 0.037 mg/l, which Oklahoma set as a maximum value for its scenic rivers, is exceeded 45 % of the time. This value is controversial for the rivers that flow in Missouri and Arkansas before entering Oklahoma and the Grand Lake of the Cherokees.

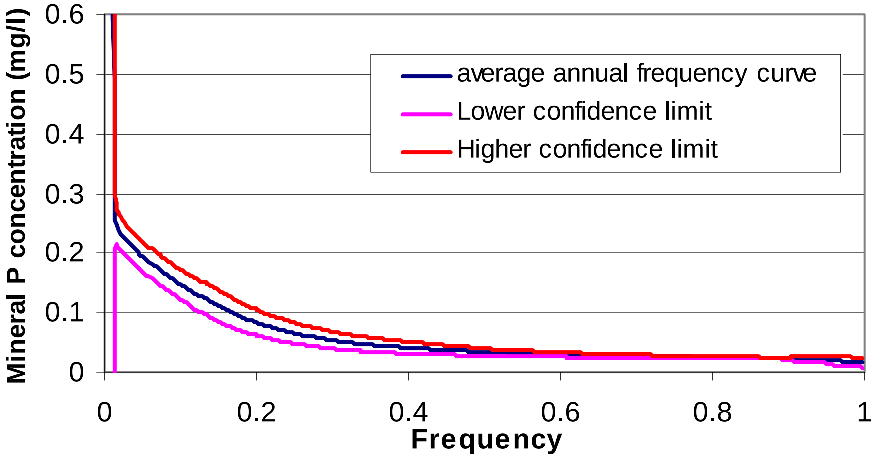


Figure 24. Frequency curves of dissolved phosphorus concentrations at the Highway 97 Bridge

Plots of phosphorus concentrations versus flow values (not shown) show that some of the high phosphorus concentrations correspond to high flow conditions but a lot of them occur also under low flow conditions. Under these conditions, the nutrient loadings (groundwater, direct contributions from cows standing in the streams, and septic tanks) can yield high concentrations because there is little water in the stream. The large confidence interval for higher phosphorus concentrations corresponds to such conditions.

Overall, the phosphorus loadings are mostly associated with storm runoff. Nitrogen loadings are distributed among all flow conditions because the bulk of them are brought to the stream through groundwater, which occurs all the time. Table 18 displays the distribution of the nutrient annual loadings under three classes of flow conditions: base flows, medium flows, and high flows. Base flows include the flow conditions that are exceeded more than 50 % of the time, medium flows are those that occur between 15 % and 50 % of the time, and storm flows are those that occur less than 15 % of the time.

Table 18. Percentages of annual nutrient loadings that travel with base, medium, and storm flow

	Base flow	Medium flow	Storm flow	Total
Org N	28	16	56	100
Org P	17	13	70	100
NO3	23	46	31	100
Min P	6	15	78	100
Total N	30	30	40	100
Total P	9	9	81	100

Bacteria

To estimate and compare the impacts from the different sources of bacteria, scenarios were run with the model with each of the bacteria sources turned on. As for the calibration of the model for bacteria fate and movement, the results are analyzed for the recreation season only.

The concentration frequency curve with all sources included is shown in Figure 25 along with the curves obtained from the data collected during the 2001 and 2002 recreation seasons. By using the average based on 50 years of simulation plus or minus one standard deviation, we show a 70 % confidence interval.

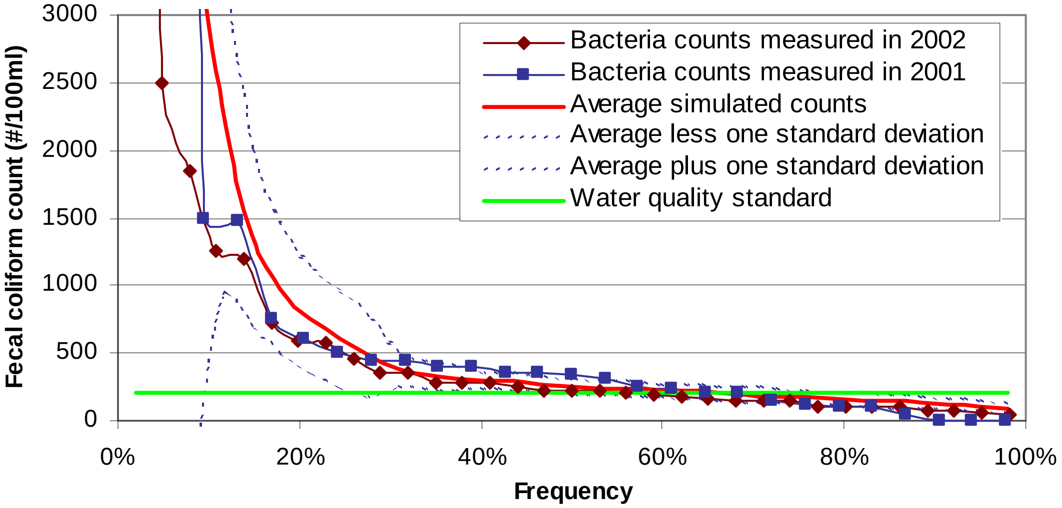


Figure 25. Average and 70 % confidence interval of the predicted fecal coliform concentration frequency curve

The bacteria concentrations are due to nonpoint source direct inputs at low flow values and to nonpoint source loadings during runoff events. These inputs result from the hypotheses made about the number of illegal connections, the number of cows that stand in the stream, and the loadings in the pastures. Other scenarios were simulated to estimate the loadings from the different sources:

- cattle direct deposits only,
- nonpoint source direct inputs only (cattle + sanitary),
- nonpoint source loadings from grazing cattle only, and
- nonpoint source loadings from poultry litter only.

Analysis of the results show that direct nonpoint source inputs control the stream loads and bacteria concentrations 50 % of the time. Bacteria loadings carried by surface runoff control the stream loadings and concentration 15 % of the time. During the rest of the year (35 % of the time), the loadings brought by surface runoff are of the same magnitude as those directly contributed to the stream. Contributions from each source can be estimated during the three different types of flow and are given in Table 19.

During base flow, cattle bring most of the bacteria load and sanitary sewage brings the rest. During periods of mixed base and storm runoff, cattle again brings the largest amount of fecal coliform both from contributions deposited directly in the streams and from the pasture loadings carried by surface runoff. Poultry litter causes a significant loading only during periods of high surface runoff, less than 15 % of the time. Poultry litter is spread in the spring when the largest storm events are recorded. Poultry litter is also spread in large quantities at once. This increases the one-time loading but decreases the probability that a spreading is followed by a rain event, thus allowing more bacteria decay before the next rain. However, if a rain event does occur soon after spreading, the bacteria load is very high.

Table 19. Percentages of fecal coliform loadings from each source as estimated by the model

Flow type	Base flow	Medium flow	Storm flow	All flows
Cattle in streams	82	31	1	3
Sanitary sewage	17	6	0	0
Grazing cattle	1	63	28	29
Poultry litter	0	0	71	68
All sources	100	100	100	100

Although it appears that poultry litter is the major contributor to the Shoal Creek bacteria load, different answers emerge when we consider the flow conditions during which people are likely to enjoy the stream for recreation purposes. When considering annual loadings, the results show that poultry litter contributes two-thirds of the total load; however, this loading occurs only during wet weather. During the rest of the time, the bacteria loadings in the stream are due to sources other than poultry litter.

The measurement and simulation of fecal coliform concentrations and nutrient concentrations are full of uncertainties and possible sources of errors. Sources of errors during sampling and measurement include:

- the variability of bacteria or nutrient concentrations within the cross-section of a stream, i.e., two samples taken at different points within the same cross-section can have very different concentrations,
- the variability of bacteria or nutrient concentrations during a given day and, therefore, the meaning of a sample value relative to an average daily concentration; i.e., two samples taken from the same place at different times can vary,
- the potential contamination of monitoring equipment, and
- the potential decay or growth of bacteria between the time of sampling and the time of analysis.

The sources of errors and uncertainties for the simulation of pollutant concentrations include the uncertainty on the average daily coliform production of cows and humans, the bacteria and nutrient content of poultry litter, and the decay rate of bacteria from different sources on and in the soil and in the water. In addition, while we know that cows spend a significant amount of time standing in the streams, it is difficult to determine how much time this is or how the percentage of manure defecated is related to time. This study was also not designed to assess if and how much pollutant travels through karst features.

Alternative Scenario Analysis

Several scenarios were run in order to assess which alternative management practices would lead to stream fecal coliform concentrations that would respect the water quality criteria of 200 colonies/100 ml with less than 10 % of the samples exceeding 400 colonies/100ml. The following scenarios were considered:

- scenario 1: no septic discharge, a 50 % reduction of cattle standing in the streams, and a 50 % reduction of the nonpoint source load,
- scenario 2: no septic discharge, no cattle standing in the streams, and a 50 % reduction of the nonpoint source load,
- scenario 3: no septic discharge, a 50 % reduction of cattle standing in the streams, and a 66 % reduction of the nonpoint source load, and
- scenario 4: no septic discharge, no cattle standing in the streams, and a 66 % reduction NPS load.

The reduction of sanitary sewage is considered here because it is already in the law that no sanitary sewage should leave a septic system. Pumping, a routine maintenance procedure, should take place every three years for a household of four people. After many years of zero maintenance, the entire bacteria load may bypass the tank and, when the septic field is placed next to a stream, much is likely to reach the stream. Large amounts of education are necessary, possibly in combination with other mandatory programs, to replace failing septic systems and encourage the proper maintenance of the functioning ones.

A 50 % reduction in the number of cattle standing in the streams could be accomplished through a combination of localized stream fencing, providing shade and feeding areas away from the stream, and a diversified diet to avoid fescue toxicity. Fescue toxicity elevates the body temperature of the cows, which incites them to seek water to “cool down.” A 100 % reduction would require the implementation of alternative drinking sources for cattle.

A reduction of the surface runoff fecal coliform loadings to the stream could be attained with vegetated filter strips at the stream edge of the pastures. The model assumes that a 10 meter (30 ft) filter strip would provide a 50 % reduction and a 12 meter (40 ft) strip would provide a 66 % reduction. These reduction coefficients are based on studies conducted in Kentucky and elsewhere that showed degrees of reduction between 50 and 100 % (Coyne et al., 1995; Glenne, 1984; Young, Huntrods, and Anderson, 1980).

The frequency curves that result from the simulation of the scenarios with the model are shown in Figure 26. It shows that 85 to 90 % of concentration values that result from the implementation of scenarios 3 and 4 are lower than 200 colonies per 100 ml, with less than 10 % of the values being more than 400 colonies/100 ml. However, when looking at the variation of the 30-days average concentrations with time, scenario 3 produces a geometric average that goes above 200 colonies/100ml every year. Scenario 4 only has a few similar events over the last 10 years, limited to when poultry litter is applied just before rain events (Figure 27).

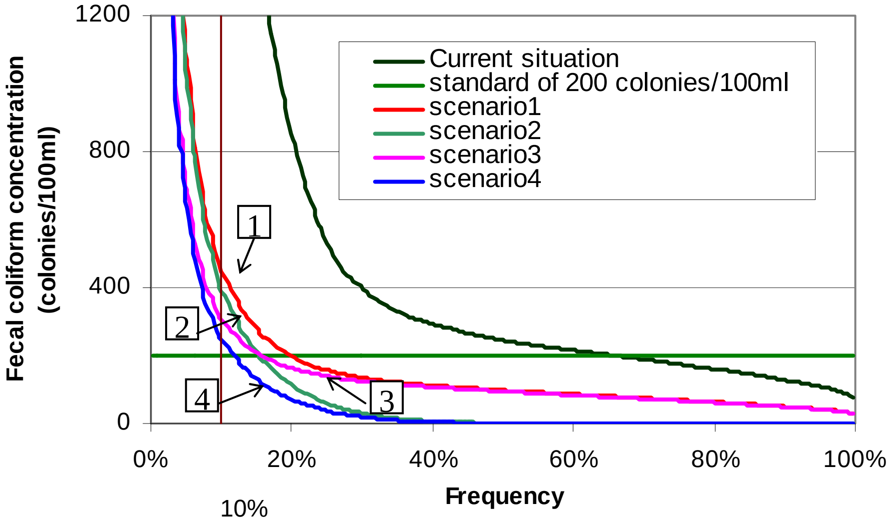


Figure 26. Comparison of the concentration frequency curves from scenarios 1 to 4

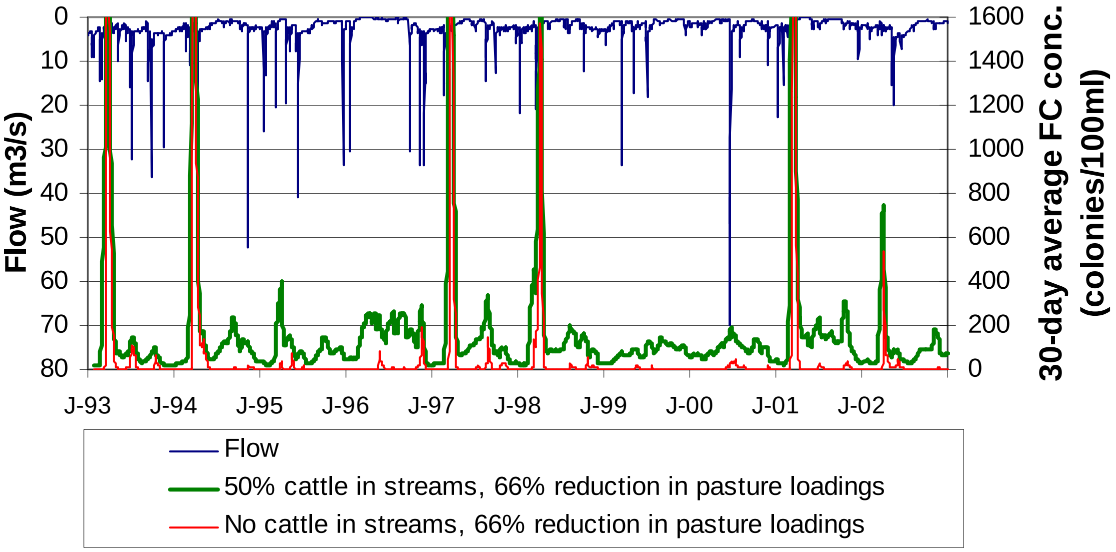


Figure 27. Simulated 30-day geometric average for scenarios 3 and 4 from 1993 to 2002

Summary and Conclusions

Results of this study indicate that 25 % to 50 % of the samples collected at the Highway 97 bridge during the 2001, 2002, and 2003 recreation seasons had concentrations of fecal coliform bacteria that exceeded the Missouri water quality standard for swimming waters of 200 colonies/100 ml. The analyses showed important variations from sample to sample.

DNA analyses of these samples collected during the 2002 and 2003 recreation seasons showed that the hosts of these bacteria colonies include all the potential sources present in the watershed: cattle, humans, poultry, wildlife, and domestic animals such as horses and dogs. Almost half of the isolates were identified as coming from cattle. Poultry isolates represented

30 % and 6 % of the isolates in 2002 and 2003 respectively. The difference is explained by the difference in rain amounts in 2002 and 2003 with higher percentages obtained in samples collected during and shortly after rainy days.

Measurements of nutrient concentrations in the samples indicate very high percentages of nitrates and dissolved phosphorus compared to total nitrogen and total phosphorus. The nitrate-N concentrations are very stable, around 3 mg/l. They decrease during storm events and slightly increase shortly after. The dissolved phosphorus concentrations vary between 0.030 and 0.070 mg/l but they increase to values as high as 0.9 mg/l during storm events.

A model was built using SWAT that includes mathematical representation of the many processes that control the movement of water on and in the soil, plant growth, and the fate and movement of nitrogen, phosphorus, and bacteria. Inputs were collected using soil and land use maps, weather records, and information given by the watershed steering committee and well as three farm panels that correspond to three distinct types of agricultural enterprises in the watershed. The model was calibrated using flow and water quality data measured since May 2000.

These results show that 40 % of the phosphorus loadings come from intrinsic sources, i.e., what is already in the soil, and poultry litter accounts for another 40 % of the current loadings. The bulk of the nitrogen (61 %) comes through groundwater. The intrinsic nitrogen sources account for 28 % of the current loadings and the external sources of nitrogen for 11 %. Improvements in modeling septic tank leaching and kart hydrogeology would allow a better linkage of the nutrient leaching with the groundwater nitrogen concentrations. While the stream transports nitrogen in fairly constant concentrations at all times, the phosphorus loadings associated with storm runoff account for 80 % of the annual phosphorus loadings.

Removing the cattle from the stream and ensuring no sanitary discharge into the streams significantly reduce the fecal loads at low flows. Filter strips decrease the impact of bacteria deposited on the pastures. A 66 % reduction of surface loadings along with at least 50 % less cows being in the streams brings the percentage of samples exceeding 400 colonies/100 ml to less than 10 %. However there would still be samples exceeding 200 colonies/100ml. All the alternatives considered produced some concentration values above 200 colonies/100ml during the recreation season.

Appendix A

Collection and Bacteria Analysis of Shoal Creek Water Samples

Duplicate water samples are collected in sterile plastic bags. Ten and twenty milliliters are vacuum filtered on site through a sterile membrane with a pore size of 0.45 micron. The membrane retains the bacteria and the filters are then placed in petri dishes containing sterile pads and a media for bacterial growth. This media is the content of one 1.8-2.0 ml HACH® PourRite™ m-FC with rosolic acid broth ampule designed to grow fecal coliform bacteria. The dishes are then incubated at 44.5 °C for 24 hours. Upon completion of the incubation the colonies on the plates are counted using a low power microscope and the count corrected to reflect the number of colonies in 100 ml of water. The final number is the average between the two volumes filtered if they both result in an acceptable number of colonies on the plate, i.e., a number of colonies that is neither too low (less than 10) or too high (more than 40) to count them. Otherwise, the plate yielding the number of colonies the closest to the acceptable range is retained. The technique provides an estimate of the number of fecal coliform bacteria that form colonies when cultured (USEPA, 2001).

A third sterile plastic bag is filled with stream water and put on ice in a cooler. Within 6 hours, it is brought to the laboratory of the Department of Veterinary Pathobiology at the University of Missouri in Columbia. The samples are processed in a similar way as in the field, except in a laboratory setting 6 hours later, it uses the dilution method, and utilizes a different growth media designed to grow *E. coli* colonies. Three volumes of water (0.5 ml, 5 ml, and 50 ml) are extracted from the bag and diluted to form 50 ml samples. These samples are then filtered on a membrane that contains the growth media and incubated at 44.5 °C overnight. Upon completion of the incubation, the colonies on the plates are counted with the naked eye and the count corrected to reflect the number of colonies in 100 ml of water. The counts from the three dilutions are then averaged. In addition, final confirmation of isolates as fecal *E. coli* is accomplished with a BBL Crystal identification Systems Enteric/Nonfermenter system (Becton Dickinson) with indole and oxidase tests. The source tracking process begins then using some of the *E. coli* cultures grown (See Appendix B).

Appendix B

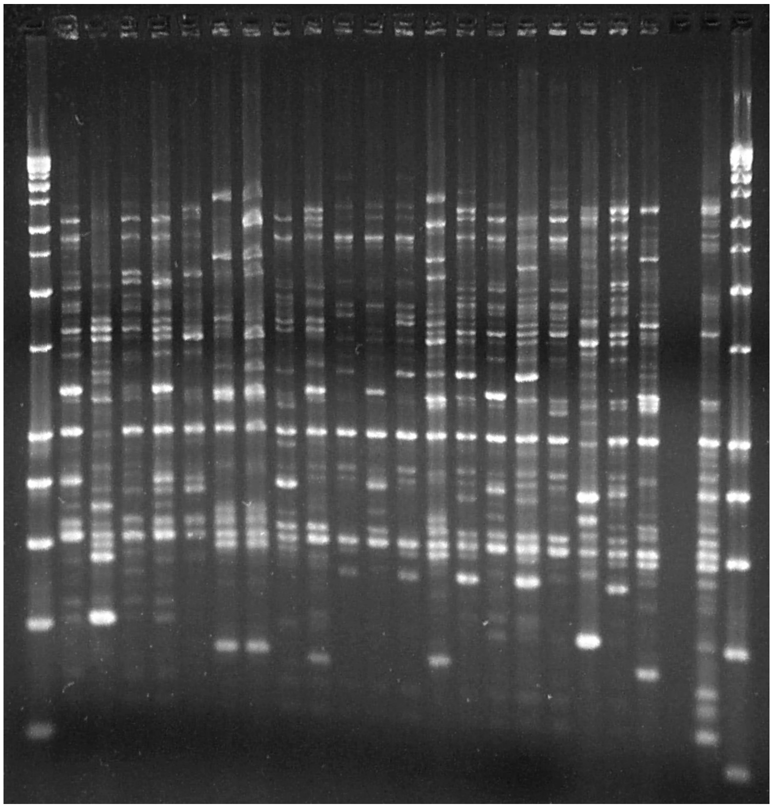
Source Tracking Methodology

REP PCR METHODOLOGY

Total fecal E. Coli counts are determined (Appendix A). The colonies of the fecal coliform present in the water sample are first incubated in petri dishes for 24 hours at a temperature of 44.5 ^{o}C. Isolates (single strains of the bacteria) are then selected for repetitive extragenic palindromic polymerase chain reaction (rep-PCR) processing.

The DNA sequences of the genetic material are extracted from the cells. Primers are then used to target specific stretches. PCR is used to amplify these small amounts of genetic information and obtain large numbers of copies of this DNA sequence from the isolates. PCR can rapidly amplify a single DNA molecule into many billions of molecules. The amplified DNA sequences are then run through electrophoresis (Hager, 2002). Electrophoresis consists in incorporating the genetic material into a gel and applying an electric field. The various negatively charged fragments of DNA move toward the anode and end up at different locations in the gel, resulting in the formation of a "bar-code" type of assembly. This pattern represents the genomic "signature" of the associated *E.coli* isolate. The large amount of genetic material obtained with PCR enables the visualization of these bands. The details of the rep-PCR methodology are specified in Carson et al. (2003) and Dombeck et al. (2000).

The following picture shows fingerprints obtained from a Shoal Creek water sample. A variety of different patterns are detectable visually – possibly indicative of numerous sources of pollution. Common patterns appear in several lanes. The number of times particular patterns are represented is related to the relative contribution of the associated pollution source. DNA size markers are in the two outside lanes.



Appendix C

Hydrology Parameters

Table C1. Model parameters for each land use / soil combination

Large subbasin	Landuse	Soil	CN II	Channel Length (km)	Channel slope (m/m)	Channel width (m)	Hydraulic conductivity (mm/hr)	Channel n	Overland n	Slope length (m)	Slope (m/m)
1	pasture	Nixa	79	9.76	0.005	8.5	12.5	0.07	0.4	63.4	0.058
1	forest	Nixa	73	9.76	0.005	8.5	12.5	0.07	0.8	63.4	0.058
1	forest	Clarksville	60	9.76	0.005	8.5	12.5	0.07	0.8	47.2	0.1
2	pasture	Scholten_Tonti	79	15.59	0.006	9.8	12.5	0.07	0.4	66.4	0.051
2	forest	Nixa	73	15.59	0.006	9.8	12.5	0.07	0.8	63.4	0.051
2	forest	Clarksville	60	15.59	0.006	9.8	12.5	0.07	0.8	47.2	0.1
3	pasture	Scholten_Tonti	79	15.59	0.007	14.0	12.5	0.07	0.4	66.4	0.048
3	forest	Nixa	73	15.59	0.007	14.0	12.5	0.07	0.8	63.4	0.048
3	forest	Clarksville	60	15.59	0.007	14.0	12.5	0.07	0.8	47.2	0.1
4	pasture	Scholten_Tonti	79	17.39	0.006	13.7	12.5	0.07	0.4	66.4	0.035
4	pasture	Scholten	79	17.39	0.006	13.7	12.5	0.07	0.4	55.2	0.035
5	pasture	Scholten_Tonti	79	14.36	0.007	11.4	12.5	0.07	0.4	66.4	0.04
5	pasture	Scholten	79	14.36	0.007	11.4	12.5	0.07	0.4	55.2	0.04
5	forest	Scholten_Tonti	73	14.36	0.007	11.4	12.5	0.07	0.8	66.4	0.04
5	forest	Scholten	73	14.36	0.007	11.4	12.5	0.07	0.8	55.2	0.04
5	forest	Noark	60	14.36	0.007	11.4	12.5	0.07	0.8	63.4	0.05
6	pasture	Scholten_Tonti	79	14.08	0.007	11.8	12.5	0.07	0.4	66.4	0.039
6	pasture	Scholten	79	14.08	0.007	11.8	12.5	0.07	0.4	55.2	0.039
6	pasture	secesh	69	14.08	0.007	11.8	12.5	0.07	0.4	62.8	0.009
6	forest	Scholten_Tonti	73	14.08	0.007	11.8	12.5	0.07	0.8	66.4	0.039
6	forest	Scholten	73	14.08	0.007	11.8	12.5	0.07	0.8	55.2	0.039
7	pasture	Scholten	79	9.72	0.007	6.8	12.5	0.05	0.4	55.2	0.054
7	forest	Scholten	73	9.72	0.007	6.8	12.5	0.05	0.8	55.2	0.054
7	forest	Noark	60	9.72	0.007	6.8	12.5	0.05	0.8	63.4	0.054
8	georges	Scholten_Tonti	79	13.40	0.007	10.0	12.5	0.15	0.4	66.4	0.01
8	pasture	Scholten_Tonti	79	13.40	0.007	10.0	12.5	0.15	0.4	66.4	0.045
8	pasture	Scholten	79	13.40	0.007	10.0	12.5	0.15	0.4	55.2	0.045
8	forest	Scholten_Tonti	73	13.40	0.007	10.0	12.5	0.15	0.8	66.4	0.045
8	forest	Scholten	73	13.40	0.007	10.0	12.5	0.15	0.8	55.2	0.045
9	pasture	Scholten_Tonti	79	10.75	0.008	9.0	12.5	0.15	0.4	66.4	0.043
9	pasture	Scholten	79	10.75	0.008	9.0	12.5	0.15	0.4	55.2	0.043
9	forest	Scholten	73	10.75	0.008	9.0	12.5	0.15	0.8	55.2	0.043
10	pasture	Scholten_Tonti	79	9.24	0.007	8.6	12.5	0.045	0.4	66.4	0.051
10	pasture	Scholten	79	9.24	0.007	8.6	12.5	0.045	0.4	55.2	0.051
10	forest	Scholten	73	9.24	0.007	8.6	12.5	0.045	0.8	55.2	0.051
11	pasture	Scholten_Tonti	79	9.72	0.007	6.0	12.5	0.15	0.4	66.4	0.039
11	pasture	Scholten	79	9.72	0.007	6.0	12.5	0.15	0.4	55.2	0.039
11	forest	Scholten	73	9.72	0.007	6.0	12.5	0.15	0.8	55.2	0.039

Appendix D

Crop Parameters

Crop parameters used by the SWAT model for an imaginary plant that combines fescue and red clover characteristics.

Radiation use efficiency: 25 (kg/ha) / (MJ/m2)
Harvest Index: 0.90
Maximum potential leaf area index: 4.0
Fraction of the plant growing season at 1st point on the leaf area development curve: 0.15
Fraction of the maximum leaf area index at 1st point on the leaf area development curve: 0.01
Fraction of the plant growing season at 2nd point on the leaf area development curve: 0.50
Fraction of the maximum leaf area index at 2nd point on the leaf area development curve: 0.95
Fraction of the growing season when the leaf are declines: 0.78
Maximum canopy height: 1.20 m (47 inches)
Maximum root depth: 1.75 m (70 inches)
Optimal temperature for plant growth: 18 deg C (64 deg F)
Minimum temperature for plant growth: 2.5 deg C (36.5 deg F)
Normal fraction of nitrogen in seeds: 0.0442 kg N / kg seeds
Normal fraction of phosphorus in seeds: 0.0036 kg P / kg seeds
N fraction in the plant at emergence: 0.0525
N fraction in the plant at 50 % maturity: 0.0245
N fraction in the plant at maturity: 0.0196
P fraction in the plant at emergence: 0.0079
P fraction in the plant at 50 % maturity: 0.0031
P fraction in the plant at maturity: 0.0023
Lower limit of harvest index: 0.5
Minimum value of the USLE crop and management factor (C factor): 0.003
Maximum stomatal conductance: 0.006 m/s
Threshold vapor pressure deficit: 4 kPa
Rate of decline in radiation used efficiency per unit increase in vapor pressure deficit: 0.75
Rate of decline in leaf conductance per unit increase in vapor pressure deficit: 9.00
Elevated CO_2 atmospheric concentration at the 2nd point on the radiation use efficiency curve: 660 ppm
Biomass / energy ratio corresponding to the previous CO_2 level.: 34
Plant residue decomposition coefficient: 0.05

Appendix E

Pasture Management

PASTURES GROWING A MIX OF FESCUE AND RED CLOVER

Year 1: Seed harvest and commercial fertilizer
March 15: Nitrogen application at 100 kg/ha (90 lbs/a)
May 25: Fescue seed harvest
May 27: Fescue straw baled
June 30: Grazing starts
Aug 15: Grazing stops
Oct 1: Grazing starts
Nov 15: Grazing stops

Year 2: Pasture with fertilization
Feb 15: Poultry fertilization
Mar 1: Grazing starts with supplemental food (no biomass consumed)
Apr 15: Grazing stops on that field
Jun 1: Grazing starts again (no supplement)
Jun 30: Grazing stops
Aug 15: Grazing starts
Oct 1: Grazing stops
Nov 15: Grazing starts (with supplement) until December 31.

Year 3: Hay harvest and poultry fertilization
Mar 30: Poultry fertilization
June 1: Hay harvest
Aug 15: Grazing starts
Oct 1: Grazing stops
Nov 15: Grazing starts (with supplement) until December 31.

Year 4: Pasture without fertilization
Apr 1: Grazing starts on that field
May 15: Grazing stops
Jun 30: Grazing starts
Aug 15: Grazing stops
Oct 1: Grazing starts
Nov 15: Grazing stops.

The watershed is modeled with an equal number of pastures with only fescue and with a mix of fescue and clover. The fescue only pastures are fertilized with nitrogen at a rate of 100 kg/ha (90 lbs/a) once every four years. The poultry application dates vary throughout the watershed between February 15 and April 30, with most of it applied in March.

UNFERTILIZED PASTURES.

Year 1
Apr 1: Grazing starts
May 15: Grazing stops
Jun 30: Grazing starts
Aug 15: Grazing stops
Oct 1: Grazing starts
Nov 15: Grazing stops

Year 2
Feb 15: Grazing starts
Apr 1: Grazing stops
May 15: Grazing starts
Jun 30: Grazing stops
Aug 15: Grazing starts
Oct 1: Grazing stops
Nov 15: Grazing starts until December 31 (with supplement)

Appendix F

Spring Data

Table F1. Selected *E. coli* densities and nutrient concentrations at various springs in the Shoal Creek Watershed

Date	Location	Bacteria type	Bacteria count (col./100ml)	NO2-3 (mg/l)	Total P (mg/l)	Source
04/15/03	Spring 22	Fecal coliform	1	Not measured		FAPRI
04/22/03	Spring 22	Fecal coliform	13	Not measured		FAPRI
04/29/03	Spring 22	Fecal coliform	47	Not measured		FAPRI
05/07/03	Spring 22	Fecal coliform	14	Not measured		FAPRI
05/13/03	Spring 22	Fecal coliform	15	Not measured		FAPRI
05/20/03	Spring 22	Fecal coliform	63	Not measured		FAPRI
05/27/03	Spring 22	Fecal coliform	6	Not measured		FAPRI
06/04/03	Spring 22	Fecal coliform	37	Not measured		FAPRI
06/10/03	Spring 22	Fecal coliform	8	Not measured		FAPRI
06/17/03	Spring 22	Fecal coliform	12	Not measured		FAPRI
06/24/03	Spring 22	Fecal coliform	2	Not measured		FAPRI
07/01/03	Spring 22	Fecal coliform	24	Not measured		FAPRI
07/08/03	Spring 22	Fecal coliform	8	Not measured		FAPRI
07/15/03	Spring 22	Fecal coliform	370	Not measured		FAPRI
07/22/03	Spring 22	Fecal coliform	40	Not measured		FAPRI
08/05/03	Spring 22	Fecal coliform	24	Not measured		FAPRI
08/19/03	Spring 22	Fecal coliform	4	Not measured		FAPRI
08/27/03	Spring 22	Fecal coliform	2	Not measured		FAPRI
09/02/03	Spring 22	Fecal coliform	990	Not measured		FAPRI
09/09/03	Spring 22	Fecal coliform	90	Not measured		FAPRI
09/16/03	Spring 22	Fecal coliform	24	Not measured		FAPRI
10/17/01	Spring 22	Fecal coliform	220	Not measured		FAPRI
11/09/01	Spring 22	Fecal coliform	93	Not measured		FAPRI
04/09/03	Pioneer Spring	*E. coli*	220	Not measured		FAPRI
05/10/00	Fly Spring	*E. coli*	2700	4.0	< 0.02	USGS [a]
05/12/00	Hawkins Spring	*E. coli*	400	3.5	0.03	USGS [a]
05/11/00	Hill Spring	*E. coli*	2100	5.0	0.14	USGS [a]
05/11/00	Zerbert Spring	*E. coli*	1100	3.1	< 0.02	USGS [a]
10/02/00	Fly Spring	*E. coli*	520	4.1	< 0.02	USGS [a]
10/03/00	Hawkins Spring	*E. coli*	33	3.6	0.04	USGS [a]
10/03/00	Hill Spring	*E. coli*	2000	5.9	< 0.02	USGS [a]

[a] Mugel, 2000

Appendix G

Water Quality Data

Abbreviations and units for chemical constituents and notations used in tables G1 and G2

Abbreviation	**Description**
NO_{23}-N	Total nitrate plus nitrite as N, in milligrams per liter
TP	Total phosphorus as P, in milligrams per liter
pH	pH, in standard units
EC	Electrical conductivity,
Temperature	Temperature in degrees Celcius
Stage	Water level in feet
KSP	Specific conductance (temperature corrected conductivity), in microsiemens per square centimeter
E. coli	*Escherichia coli* density in colonies per 100 milliliters
FC	Fecal coliform density, in colonies per 100 milliliters
SRP	Soluble reactive phosphorus (dissolved ortho-phosphate) in milligrams per liter
TDP	Total dissolved phosphorus in milligrams per liter
TN	Total nitrogen as N, in milligrams per liter
TSS	Total suspended solids, in milligrams per liter
uCHL	Uncorrected chlorophyll for degradation products, in micrograms per milliliter
CHL	Chlorophyll concentration, in micrograms per milliliter
PHAEO	Phaeophytin concentration, in micrograms per milliliter

Table G1. Data collected at the Highway 97 bridge during the 319 project from 1996 to 2000

Date Collected	NO_{23}-N (mg/l)	TP [a] (mg/l)	pH	EC ($\mu S/cm^2$)	Temperature (^{o}C)
10/17/96	2.40	Not detected			
11/18/96	4.13	Not detected			
01/08/97	2.87	Not detected			
02/13/97	2.24	Not detected			
03/27/97	3.11	Not detected			
04/30/97	2.35	Not detected			
06/12/97	2.13	Not detected			
06/19/97	3.44	Not detected	8.3	298	22.1
07/14/97	2.13	Not detected			
08/22/97	2.55	Not detected	7.6	305	21.7
09/17/97	1.85	Not detected	8.6	323	21.7
10/17/97	2.24	Not detected	8.8	316	14.9
11/19/97	2.58	Not detected	8.9	336	7.9
12/15/97	3.37	Not detected	8.8	312	7.3
01/22/98	3.24	0.120	7.3	281	7.4
02/22/98	2.99	0.030	8.4	285	9.0
03/23/98	3.78	0.040	8.8	231	9.7
04/28/98	2.43	0.045	8.9	290	11.3
05/27/98	2.57	0.080	8.1	292	17.0
06/15/98	2.53	0.120	8.3	328	20.1
07/27/98	1.69	0.030			
08/21/98	1.67	0.090			
09/24/98	2.91	0.180			
10/20/98	3.50	0.123			
11/25/98	3.08	0.047	8.8	353	12.3
12/22/98	3.63	0.062		362	3.6
01/29/99	1.90	0.044	7.9	329	8.6
03/01/99	2.83	0.040	9.0	317	10.8
04/09/99	2.78	0.055		288	14.3
06/08/99	2.45	0.050		293	23.5
07/09/99	3.22	0.036	8.5	281	20.4
08/09/99	2.06	0.022			
10/04/99	2.53	0.020	8.4	332	15.4
12/10/99	2.78	0.144	8.0	268	11.1
01/26/00	2.83	Not detected	7.6	339	3.0
02/18/00	2.49	0.014	8.3	309	8.0
03/22/00	2.31	0.059	8.1	257	11.9
05/26/00	2.71	0.114	8.3	295	20.5
07/31/00	3.07	0.070		278	21.9
08/21/00	2.45	0.033			
09/06/00	2.26	0.047			

[a] The initial sensitivity of the phosphorus test (0.1 mg/l) was not sufficient at the beginning of the study to detect any phosphorus in the water (in 1996 and 1997). The test was subsequently replaced by a more sensitive one in 1998.

Table G2. Water quality data collected weekly at the highway 97 bridge since 2001

DATE	STAGE ft	KSP $\mu S/cm^2$	*E. coli* #/100ml	FC #/100ml	SRP mg/l	TDP mg/l	TP mg/l
04/20/01		247				0.012	0.022
05/11/01	1.62	280	TNTC				0.101
05/11/01	1.58	270	TNTC				0.284
05/18/01	1.59	258	27000		0.224		0.280
05/25/01	1.37	300	1500		0.031	0.035	0.052
06/01/01	1.32	320	1		0.032	0.032	0.049
06/08/01	1.98	280	600		0.047	0.047	0.064
06/13/01	1.82	290	200		0.038	0.044	0.051
06/20/01	1.73	300	350		0.032	0.032	0.052
06/27/01	1.68	295	1		0.026	0.026	0.033
07/03/01	1.72	283	500		0.045	0.045	0.051
07/09/01	1.56	307	750		0.040	0.040	0.052
07/17/01	1.49	300	400		0.034	0.038	0.042
07/24/01	1.42	315	450		0.046	0.052	0.059
08/01/01	1.65	320	1475		0.040	0.040	0.049
08/09/01	1.72	310	100		0.038	0.038	0.044
08/14/01	1.59	320	250		0.034	0.034	0.040
08/22/01	1.56	322	350		0.026	0.027	0.038
08/28/01	1.83	318	236		0.024	0.030	0.040
09/04/01	1.75	324	150		0.024	0.029	0.037
09/11/01	1.76	327	1		0.029	0.032	0.040
09/17/01	1.79	320	450		0.027	0.027	0.038
09/27/01	1.68	343	200		0.021	0.021	0.026
10/03/01	1.66	336	340		0.020	0.018	0.026
10/09/01	1.68	326	125		0.024	0.020	0.025
10/13/01	1.76	334	400				
10/16/01	1.69	343	50		0.027	0.024	0.028
10/23/01	1.64	346	312		0.017	0.020	0.029
10/30/01	1.68	350	100		0.016	0.016	0.020
11/08/01	1.65	344	500		0.014	0.015	0.020
11/13/01	1.63	344	60		0.010	0.010	0.016
11/20/01	1.93	332	4350		0.022	0.030	0.036
11/27/01	1.78	330	400		0.028	0.030	0.038
12/20/01	2.18	266	475		0.039	0.042	0.056
01/29/02		316	140	200		0.018	0.029
02/13/02	1.68	282		2	0.020	0.020	0.028
03/05/02	1.74	276		17	0.018	0.019	0.030
03/12/02	1.68	280	1	1	0.016	0.016	0.024
03/19/02	1.66	288		375	0.018	0.019	0.030

DATE	NO_{23}-N mg/l	TN mg/l	TSS mg/l	uCHL µg/l	CHL µg/l	PHAEO µg/l
04/20/01	2.934	4.81				
05/11/01		2.88	34.2	8.8	5	5.9
05/11/01		3.20	35.0	11.1	6.6	7
05/18/01	2.340	3.19	28.4	8.7	6	4
05/25/01	3.384	3.54	8.2	3.3	1.8	2.4
06/01/01	3.012	3.16	6.8	2.5	1.2	1.9
06/08/01	4.176	4.20	8.2	2.4	1.4	1.6
06/13/01	3.667	3.68	7.0	2.3	1.5	1.2
06/20/01	3.360	3.36	2.6	1.6	1	0.8
06/27/01	3.109	3.18	2.8	1.3	1	0.8
07/03/01	3.646	3.68	4.3	2.1	1.2	1.3
07/09/01	3.384	3.53	6.8	2.7	1.4	2
07/17/01	2.763	3.09	2.6	2.7	1.9	1.2
07/24/01	3.020	3.37	3.1	2.5	1.6	1.4
08/01/01	2.834	3.16	3.7	2.1	1.4	1.1
08/09/01	2.612	3.12	2.1	1.8	1.2	1
08/14/01	2.572	2.88	2.9	2	1.2	1
08/22/01	2.717	3.06	2.6	2	1	1.8
08/28/01	2.695	2.83	4.0	2.6	1.2	2.4
09/04/01	2.639	2.84	3.0	2	0.9	1.9
09/11/01	2.749	2.94	2.2	1.8	1	1.4
09/17/01	2.662	3.19	3.2	2.5	1.2	2.2
09/27/01	2.938	3.05	1.8	1.4	0.7	1.2
10/03/01	2.853	3.00	2.0	1.3	0.6	1.1
10/09/01	2.908	3.04	1.5	1.4	0.9	0.6
10/13/01						
10/16/01	3.588	3.87	1.2	0.8	0.5	0.6
10/23/01	2.988	3.12	1.8	2.2	1.4	1.1
10/30/01	2.944	2.95	0.9	1.4	1	0.8
11/08/01	2.468	2.70	1.0	1.3	0.8	0.9
11/13/01	2.502	2.76	1.0	1.4	0.8	1
11/20/01	2.470	2.84	1.8	2.1	1.4	1.2
11/27/01	3.586	4.27	1.0	1.7	1	1.1
12/20/01	4.970	5.78	5.2			
01/29/02	3.209	3.20	3.4	5.7	4.1	2.8
02/13/02	3.715	3.76	2.3	2.1	1.4	1.3
03/05/02	3.536	3.68	3.0	2.2	1.4	1.3
03/12/02	3.579	3.68	3.1	2.3	1.4	1.5
03/19/02	3.130	3.30	3.9	3.6	2.1	2.5

Table G2. Water quality data collected weekly at the highway 97 bridge since 2001

DATE	STAGE ft	KSP µS/cm^2	*E. coli* #/100ml	FC #/100ml	SRP mg/l	TDP mg/l	TP mg/l
03/28/02	1.85	260		130	0.026	0.027	0.042
04/05/02	1.73	279		300	0.010	0.012	0.014
04/09/02	1.88	268		1850	0.052	0.060	0.090
04/16/02	1.75	270		150	0.018	0.022	0.036
04/23/02	1.67	286		220	0.018	0.025	0.039
04/30/02	1.58	298		1250	0.018	0.022	0.035
05/07/02	2.06	250		13500	0.092	0.0104	0.154
05/14/02	2.65	220		575	0.089	0.096	0.115
5/21/02	2.58	229		105	0.069	0.056	0.070
5/30/02	2.65	252		530	0.055	0.040	0.049
6/3/02	2.13	261		68	0.029	0.035	0.041
6/11/02	2.1	275		57	0.030	0.030	0.036
6/14/02	2.4			2500			0.201
6/18/02	2.09	268		280	0.038	0.038	0.048
6/25/02	2.22	296		125	0.031	0.031	0.039
7/2/02	2.04	296		360	0.024	0.026	0.034
7/10/02	1.82	300		255	0.032	0.032	0.040
7/16/02	1.8	299		225	0.028	0.030	0.037
7/23/02	1.89	304		285	0.030	0.033	0.044
7/30/02	1.94	310		146	0.031	0.031	0.038
8/6/02	2.1	313		720	0.028	0.029	0.038
8/15/02	2.19	314		180	0.027	0.027	0.036
8/20/02	2.12	313		192	0.026	0.033	0.045
8/27/02	2	318		220	0.026	0.030	0.044
9/4/02	1.92	318		455	0.022	0.023	0.031
09/09/02	no access	322		105	0.028	0.028	0.037
09/16/02	1.95	322		206	0.034	0.028	0.034
09/23/02	1.82	321		142	missing	0.026	0.028
09/30/02	1.78	324		282	0.020	0.025	0.028
10/07/02	1.72	318		75	0.022	0.023	0.026
10/14/02	1.69	332		110	0.016	0.023	0.026
10/21/02	1.68	329		40	0.016	0.020	0.024
10/28/02	1.73	316		590	0.024	0.028	0.033
11/04/02	1.69	332		80	0.022	0.026	0.030
11/11/02	1.76	336		34	0.018	0.020	0.023
11/18/02	1.74	338		20	0.015	0.019	0.021
11/25/02	1.69	337		33	0.016	0.014	0.017
12/02/02	1.69	334		30	0.010	0.011	0.013

DATE	NO_{23}-N mg/l	TN mg/l	TSS mg/l	uCHL µg/l	CHL µg/l	PHAEO µg/l
03/28/02	3.698	3.88	6.5	3	1.9	1.9
04/05/02	3.478	3.96	5.6	3.5	2.5	1.6
04/09/02	3.458	3.84	11.0	5.4	3.6	2.8
04/16/02	3.182	3.50	8.6	4.5	2.4	3.1
04/23/02	2.952	3.30	8.2	4.3	2	3.5
04/30/02	2.873	2.97	7.6	4.8	2.2	4
05/07/02	3.400	4.00	15.5	6.7	4.2	3.9
05/14/02	3.333	3.45	14.9	1.4	0.9	0.7
5/21/02	3.364	3.43	10.8	0.9	0.7	0.4
5/30/02	3.086	3.27	5.8	2.4	1.8	0.9
6/3/02	3.222	3.3	6.3	2.8	1.4	3
6/11/02	3.212	3.17	5.1	3	1.5	4.3
6/14/02		2.98	20.2			
6/18/02	3.187	3.17	5.6	2.4	1.2	2.6
6/25/02	3.497	3.69	6.7	3.4	1.6	4
7/2/02	3.188	3.44	4.8	3.8	1.8	4.5
7/10/02	3.236	3.28	5.9	4.0	1.8	4.8
7/16/02	3.12	3.14	5.4	3.0	1.4	3.4
7/23/02	3.07	3.09	6.2	2.8	1.2	3.6
7/30/02	2.85	2.98	6.3	2.7	1.1	3.4
8/6/02	2.90	2.97	7.2			
8/15/02	2.83		7			
8/20/02			6.4			
8/27/02			6.3			
9/4/02	2.67	3.20	5.4	2.2	1.2	1.4
09/09/02	2.78	3.37	5.0	2.0	1.0	1.6
09/16/02	2.66	3.17	4.9	1.9	1.0	1.4
09/23/02	2.92	3.02	2.6	1.1	0.6	0.8
09/30/02	2.97	3.12	2.5	1.5	0.6	1.8
10/07/02	2.82	2.92	1.8	1.4	0.6	1.5
10/14/02	2.99	3.04	1.0	1.2	0.5	1.2
10/21/02	3.02	3.02	1.8	1.3	0.6	1.2
10/28/02	2.92	2.98	1.9	1.4	0.8	1.3
11/04/02	3.14	3.14	1.0	0.8	0.4	0.8
11/11/02	2.92	2.92	0.6	1.0	0.5	0.9
11/18/02	3.15	3.15	1.0	0.9	0.5	0.8
11/25/02	2.72	2.72	1.3	1.0	0.6	1.0
12/02/02	2.78	2.78		0.8	0.7	0.2

Table G2. Water quality data collected weekly at the highway 97 bridge since 2001

DATE	STAGE ft	KSP µS/cm^2	*E. coli* #/100ml	FC #/100ml	SRP mg/l	TDP mg/l	TP mg/l
12/17/02	1.64	307		330	0.010	0.012	0.015
01/07/03	1.65	295		380	0.014	0.018	0.020
02/12/03	1.58	300		19	0.08	0.010	0.012
03/13/03	1.94	266		2050	0.016	0.028	0.048
03/20/03	1.95	265		720	0.040	0.053	0.074
03/25/03	1.89	258		300	0.019	0.026	0.034
04/01/03	1.77	272		43	0.016	0.020	0.027
04/09/03	1.78	288		250	0.020	0.022	0.027
04/15/03	1.65	282		100	0.017	0.022	0.032
04/22/03	1.61	280		330	0.016	0.022	0.029
04/29/03	1.59	292		352	0.022	0.032	0.043
05/07/03		303		1050	0.034	0.040	0.056
05/13/03		312		440	missing	0.035	0.048
05/20/03		310		442	0.038	0.044	0.062
05/27/03		310		115	0.026	0.030	0.043
06/04/03		308		163	0.026	0.030	0.042
06/10/03		322		930	0.026	0.031	0.046
06/17/03		313		223	0.028	0.034	0.048
06/24/03		318		360	0.035		
07/01/03		310		275	0.030	0.034	0.047
07/08/03	1.69	320		162	0.033	0.040	0.056
07/13/03	1.87	259		3050			
07/15/03	1.69	305		400	0.053	0.053	0.070
07/22/03	1.7	306		800	0.040	0.049	0.068
08/05/03	1.48	312		235	0.033	0.050	0.038
08/12/03	1.7	326		222	0.029	0.048	0.036
08/19/03	1.63	322		185		0.050	0.038
08/27/03	1.39	320		140		0.045	0.037
09/02/03	1.64	313		597		0.056	0.042
09/09/03	1.56	327		277		0.037	0.029
09/16/03	1.59	324		105		0.033	0.026
09/23/03				222		0.031	0.025
09/30/03				294			
10/07/03				42		0.029	0.023
10/15/03				64			
10/21/03				17			
10/28/03				33			

DATE	NO_{23}-N mg/l	TN mg/l	TSS mg/l	uCHL µg/l	CHL µg/l	PHAEO µg/l
12/17/02	3.10	3.10	1.4	2.4	2.0	1.1
01/07/03	4.02	4.02	0.8	1.5	1.2	0.7
02/12/03	3.22		0.8	2.0	1.6	1.1
03/13/03	3.05	3.96	11.7	11.3	9.1	6.1
03/20/03	2.98	3.58	8.6	8.0	6.1	5.3
03/25/03	3.67	4.95	5.7	4.9	3.4	4.4
04/01/03	3.42	4.04	3.8	2.9	2.0	2.3
04/09/03	3.48	4.24	3.0	2.1	1.3	2.1
04/15/03	3.01	3.4	7.5	3.8	2.5	3.3
04/22/03	2.86	3.19	4.7	2.6	1.7	2.4
04/29/03	2.77	3.01	6.4	3.6	2.2	4
05/07/03	2.77	3.13	11.6	4.8	2.6	5.5
05/13/03	2.81	2.95	12.3	3.2	1.5	4.4
05/20/03	2.92	3.59	14.6	3.7	1.8	5.1
05/27/03	2.58	2.92	10.2	2.6	1.3	3.5
06/04/03	2.46	3.1	10.3	2.3	1.1	3.4
06/10/03	2.38	2.74	12.5	2.5	1.2	3.8
06/17/03	2.36	2.99	11.9	2.5	1.2	3.5
06/24/03	2.35	3.17	11.5	2.6	1.2	3.9
07/01/03	2.13	2.97	11.8	2.3	1.2	3.4
07/08/03	2.14	3	11.7	2.5	1.3	3.6
07/13/03						
07/15/03	2.05	3.28	13.2	2	1	2.8
07/22/03	2	2.3	15.3	4.2	2.5	4.4
08/05/03	1.8	2.4	8.5	2.1	1	2.7
08/12/03	1.82	2.41	10.8	2.3	1.1	3
08/19/03	1.7	2.19	8.6	2.2	1.1	3
08/27/03	1.56	2.31	6.7	2.1	1.1	2.5
09/02/03	1.72	2.04	9.9	2.3	1.2	2.9
09/09/03	2.12	2.83	7.5	1.3	0.7	1.5
09/16/03	2.12	2.29	6.2	1.2	0.7	1.3
09/23/03	2.08	2.28	6.0	1.3	0.7	1.6
09/30/03	2.1	2.29	5.4	1.5	0.9	1.6
10/07/03	2.24	2.44	5.5	1.2	0.6	1.4
10/15/03	2.06	2.21	3.3	1.1	0.6	1.2
10/21/03		2.83	3.4	1.1	0.7	1.1
10/28/03		2.18	3.3	1	0.5	1.2

Appendix H

Storm Data

Table H1. Individual storm event data

		Concentrations			Loads		
date	volume	TP mg/l	TDP mg/l	TN mg/l	TP kg	TDP kg	TN kg
06/28/01	254069	0.262	0.181	3.82	67	46	971
06/28/01	344647	0.428	0.288	5.08	148	99	1751
06/29/01	103562	0.174	0.118	4.96	18	12	514
06/29/01	73249	0.132	0.087	3.88	10	6	284
06/29/01	54418	0.108	0.075	5.79	6	4	315
05/06/02	136550						
05/06/02	277064	0.380	0.260	4.26	105	72	1180
05/06/02	348650	1.110	0.582	4.26	387	275	1485
05/06/02	117042	0.985	0.613	4.54	115	347	531
05/06/02	67151	0.660	0.470	4.17	44	378	280
05/06/02	52624	0.465	0.333	3.80	24	396	200
05/06/02	48750	0.380	0.261	3.47	19	409	169
05/17/02	697237				0		
05/17/02	1163149				0		
05/17/02	1426463	0.756	0.574	3.65	1078	819	5207
05/17/02	1454497	1.039	0.896	3.32	1511	1303	4829
05/17/02	878937	1.165	0.842	2.95	1024	740	2593
05/17/02	647378	0.817	0.664	2.61	529	430	1690
05/17/02	574663	0.589	0.489	2.15	338	281	1236
05/17/02	541512	0.367		2.20	199	0	1191
05/17/02	518055	0.331	0.279	2.01	171	145	1041
05/17/02	498900	1.380	0.221	2.13	688	110	1063
05/17/02	481764	1.147	0.185	3.16	553	89	1522
05/17/02	468664	1.020	0.160	3.08	478	75	1443
06/13/02	173030	0.934	0.246	3.48	162	43	602
06/13/02	128195	0.786	0.432	2.93	101	55	376
06/13/02	79986	0.565	0.357	2.71	45	29	217
06/13/02	67110	0.391	0.284	2.76	26	19	185
06/13/02	61075	0.269	0.204	2.65	16	12	162

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