LITTLE SAC RIVER WATERSHED

FECAL COLIFORM
TOTAL MAXIMUM DAILY LOAD

FAPRI-UMC Report #11-06

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

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

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

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EXECUTIVE SUMMARY

The weekly fecal coliform monitoring at two sites of the Little Sac River show that the water quality standard for whole body contact (swimming) was violated at both sites during the 2004 recreation season. Both the mean and the geometric mean of fecal coliform concentrations were higher than 200 colonies/100 ml.

The bacterial source tracking data show that the highest fecal coliform loads come from unknown sources, geese, and human. The data also show that cattle and horses are contributors to the bacterial load in the stream. At base flow, these loadings potentially come from the springs located in the upper part of the watershed or from direct inputs to the stream (illegal discharges, cattle in stream, wildlife). The load from the wastewater treatment plant represents only 3% of the stream bacterial loading.

More monitoring of the spring is needed to better characterize bacterial contamination of the springs and the sources of the contamination. In a karst environment, the contamination of the springs occurs easily because of the fast pathways between the ground surface and the shallow aquifer: sinkholes, cracks, and loosing streams. Addressing the contamination of the springs should be a major component of any management aimed at reducing the bacterial loading in the Little Sac River.

The contamination from geese proved to be a major issue. During storm flow conditions, the loadings are transported from the landscape and urban areas to the streams by surface runoff. This problem can be addressed in urban areas through various means from education, to harassment, to eggs destruction.

Different scenarios were investigated with the model in order to assess which set of alternative management practices could potentially lead to stream fecal coliform concentrations that respect the water quality criteria. Several efforts are ongoing to address the various sources of bacterial loading to the Little Sac River including best management practices (BMPs) to address agricultural sources and urban storm runoff. Future monitoring efforts could also track changes in bacteria loadings as ongoing efforts continue. Based on needs identified by future data, a second phase of this TMDL could outline a plan for additional BMPs.

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Introduction

Since 1999, concentrations of fecal coliform bacteria in Little Sac River averaged more than 200 colonies per 100 ml, which exceeds the Missouri limit of 200 colonies per 100 ml for the stated uses of Little Sac River. This resulted in Little Sac River being placed on the Missouri 1998 and 2002 303(d) list of impaired water bodies.

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 and urban practices in the Little Sac River Watershed affect fecal coliform concentrations. 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.

FAPRI's approach combines computer simulation modeling, analytical facts, and interdisciplinary perspectives that allow stakeholders to simultaneously evaluate many environmental perspectives. Fecal coliform concentrations were monitored at two sites for one year. 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 to identify the sources of the bacteria found in the water. 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 from the subbasins and land uses in the watershed.

Background Information

Geography

The Little Sac River is a tributary of Stockton Lake within the Osage River Basin. The river begins at the north edge of Springfield as it leaves Fellows and McDaniel Lakes. Much of its flow is treated effluent from the Springfield Northwest Wastewater Treatment Plant (WWTP). The Little Sac River Watershed includes 726 km^2 (180,000 acres or 166 square miles) of mostly woods and pastures in Greene and Polk Counties in southwest Missouri. Its channel is approximately 66 km (41.5 miles) long and is spring fed. Interstate Highway 44, U.S. Highways 65 and 160, and Missouri Highway 13 provide access to the watershed.

Several tributaries drain the watershed (Figure 1). Subbasins have been delineated that follow the drainage areas of these tributaries. In the south one can find the South Dry Sac River that drains the area north of Springfield and the head waters of Little Sac River that come out of Fellows and Mc Daniel Lakes. Little Sac River then flows in a northerly direction with the North Dry Sac River merging from the southeast and Asher Creek coming from the south. In the North of the watershed, Slagle Creek comes from the east and merges into the Little Sac River just before it enters Stockton Lake.

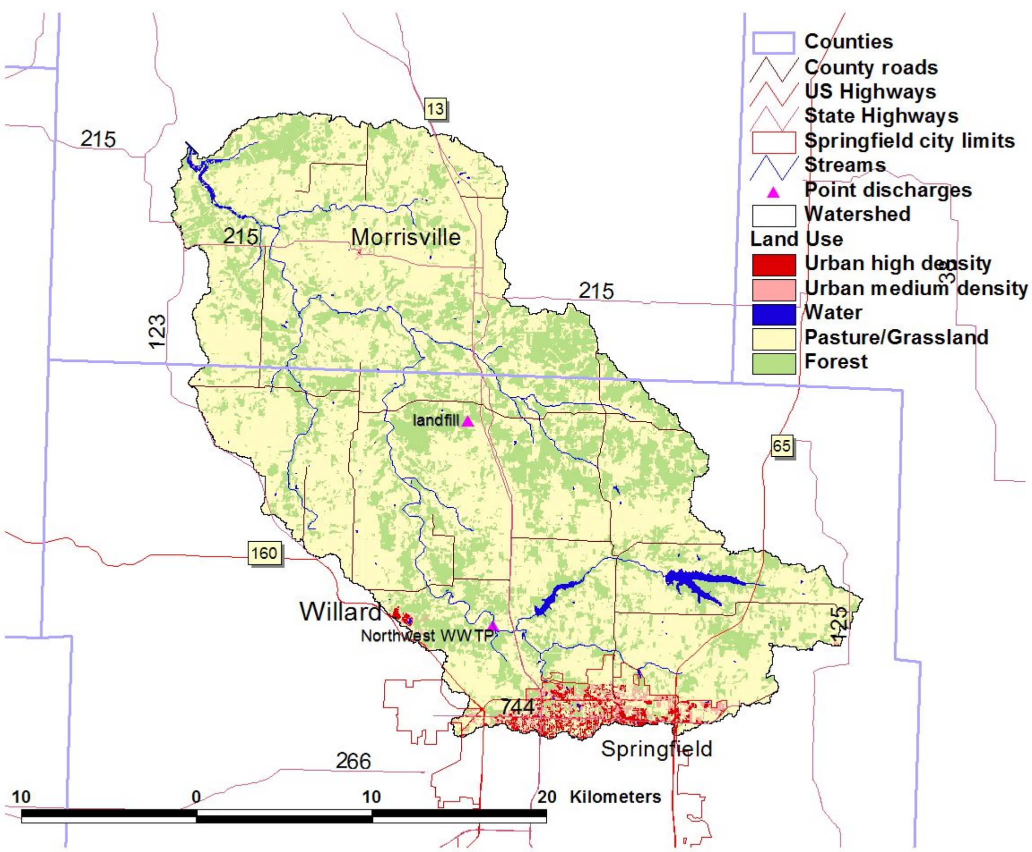

Figure 1. Little Sac River and its tributaries

Area characteristics

The Little Sac River Watershed is located in the Ozark Border Area, Major Land Resource Area (MLRA) 116B (USDA, 2002). This area, located in Missouri, is part of the northeast and central farming forest region. The Ozark Border MLRA is comprised of approximately 35 % forest, 25 % pasture mainly of introduced grasses and legumes, and 40 % 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. Deep wells supply drinking water and water for high volume uses. This area supports oak-hickory forests. The grassland supports a combination of introduced and native tall-prairie grasses consisting mainly of indian grass, little bluestem, big bluestem, and switch grass. Introduced grasses include fescue, annual crab grasses, and Kentucky bluegrass. The pastures are mostly in fescue grass over-seeded with red clover.

Elevations in the watershed range from 270 m (885 ft) at the watershed outlet to 455 m (1490 ft) at the southeastern boundary. The major part of the watershed consists of rolling plains. On the east side, broad upland areas divide the Little Sac watershed from the Pomme de Terre watershed.

Two aquifers lie under the Little Sac River 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. 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 a 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 south and east of the Little Sac River Watershed, in Greene County.

The analysis of the 1992 satellite imagery (Figure 1) gives a global view of the watershed land uses using four major categories: urban, grassland, forest, and water. The watershed consists mostly of grassland (67 %) and forests (30 %). 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. Urban areas are found in 2.4% of the watershed. This is the north part of Springfield. Even though they include only a small percentage of the watershed, urban areas are part of this analysis because of their specificity and high contamination potential. Finally, two reservoirs, Fellows and Mc Daniel Lakes, cover 0.6 % of the watershed.

Defining the problem

The Little Sac River is a tributary of Stockton Lake within the Osage River Basin. The river begins at the north edge of Springfield as it leaves Fellows Lake and McDaniel Lake. The Fulbright and Murray landfills lie along the banks of the river and for many years leached low levels of cyanide, toxic metals, and organic compounds into the river. When the new Springfield Northwest wastewater treatment plant (Northwest WWTP) was built, a leachate interceptor drain was built to collect leachate, which was then treated at the plant. Later studies found toxic compounds were only infrequently found in the river. Currently, the landfills are not thought to discharge leachate directly into the river.

The Northwest WWTP has had occasional problems with disinfection of its wastewater that have led to the discharge of large amounts of bacteria in the Little Sac River. However, in general, the plant discharges of bacteria do not explain the bacteria loadings in the river, suggesting that nonpoint sources, upstream and downstream of the wastewater plant, are part of the problem. The shallow aquifer and karst terrain of sinkholes, springs, and caves associated with the Little Sac River allow serious groundwater contamination from transportation and other urban spills, leaking underground tanks and septic tank contamination.

In 1998, the segment of Little Sac River from above the Northwest WWTP to Stockton Lake was placed on the Missouri Department of Natural Resources list of impaired streams (303d list) because of high fecal coliform concentrations. In 2002, the segment was increased from 43 km (27 miles) on the 1998 303d list to 46 km (29 miles) (MDNR Division of Environmental Quality, 2002). Various monitoring studies (Smith, 2002; MDNR, 2002) and the data collected during this study show that the concentrations have been and remain elevated beyond acceptable levels for recreational purposes.

Public involvement related to the study

A watershed steering committee was formed in January 2004 to participate in the assessment of the Little Sac River Watershed by FAPRI. The group was drawn from the steering committee that serves for the USEPA 319 project entitled "Little Sac Watershed Restoration Project" and conducted by the Watershed Committee of the Ozarks. There are 13 members including cattle producers, watershed citizens, Soil and Water Conservation District (SWCD) board members, and personnel from the Natural Resources Conservation Service (NRCS). The group insisted that there was a need for more resource information about their watershed to identify the water quality baseline.

Source Assessment

There are several sources in the watershed that could explain the high concentrations of fecal coliform found in the water. All of them are potential sources of bacteria and nutrients.

Livestock

Livestock in the Little Sac River Watershed include mainly beef cattle. Greene and Polk counties agricultural facts adjusted for the size of the Little Sac River Watershed indicate that there were about 9,296 and 21,700 cow/calf pairs in the Polk County and Greene County parts of the watershed, respectively, in 2002 (Missouri Agricultural Statistics Service, 2003). These animals consume biomass, destroy some, and produce manure that is deposited on the grass.

Horses

Horses are present in the watershed and the DNA analyses of the water samples collected at both sites have confirmed the presence of horse fecal coliform in the creek. Greene and Polk counties agricultural statistics adjusted for the size of the Little Sac Watershed indicate that 2,235 horses live in the watershed. Small numbers of horses are found in any one farm, except for a few larger ranches in Greene County. These animals graze year-round.

Septic tanks

The 2000 census indicates that there were 11,183 and 104,517 housing units in Polk and Greene County, respectively. Out of these, 89% and 93% are occupied in Polk and Greene County, respectively, with an average of 2.5 and 2.4 people per household. Excluding the households in Springfield (69,650) and Willard (1,226) because both towns have a waste water treatment system, leaves 31,299 occupied households in Greene County that, in all likelihood, have a septic tank. Assuming that the distribution of units that use a septic tank is uniform across the rural areas of Polk and Greene County, the number of septic tanks for occupied housing units in the Little Sac River Watershed is estimated to be 1, 691 and 18,466 in Polk and Greene County, respectively.

No study clearly estimates how many septic systems fail or do not properly function in Southwest Missouri. Such assessment would be valuable for this karst region where failing systems increase greatly the risk of contaminating the groundwater. 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, 1970-1989, and after 1989. 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 1).

Table 1. Estimated septic tanks in the Little Sac River Watershed

Structure age	Number of units			Failure rate (%)	Number failed
	Polk	Greene	Total		
Pre - 1970	676	7,646	8,322	40	3,329
1970 - 1984	594	6,942	7,536	20	1,507
Post 1984	421	3,878	4,299	5	215
Total	1, 691	18,466	20,157	25	5,051

Wildlife

Wildlife in the Little Sac River Watershed includes many animals, most of them difficult to inventory. There is no wildlife inventory at the county level in Missouri. Only one set of patterns from wildlife were included in the DNA source-tracking database: wild geese, migratory and resident. Estimates from the Missouri Department of Conservation about waterfowl population and densities in 2004 can help quantify the Canada goose population. The goose population density around Springfield is thought to be medium (Brad Jump, personal communication) and equal to 2.15 geese per square miles in the spring of 2004. A small winter population of resident Canada geese exists that is difficult to estimate.

There are numerous wildlife species in the watershed including but not limited to deer, raccoons, rodents, and ducks. We have not included these species in the database because it would be impossible to find enough feces samples from these hosts to characterize a host class for each of them. Instead, we accept the fact that a fraction of the *E. coli* isolates will not be assigned a source and will therefore be characterized as other.

Permitted facilities

There are only three facilities that have fecal coliform included in their permit. A children home has a design concentration of 400 colonies/100 ml; the Northwest WWTP has a design average concentration of 400 colonies/100 ml from April to October (Northwest WWTP web site http://www.ci.springfield.mo.us/egov/publicworks/sanitary/nw_plant.html); and the Pleasant View school has an average concentration of 400 colonies/100 ml with a maximum concentration of 1000 colonies/100 ml (MDNR, 2004).

Because of its discharge (6.4 millions gallons per day (MGD) by design, 3.5 MGD actual), the Northwest WWTP is a major potential pollution source. From April 1 to October 31, the effluent is treated with chlorination followed by de-chlorination. During the last three years, the average fecal coliform concentration reported by the plant between April 1 and October 31 is less than 10 colonies/100 ml. Data collected during this study from April to June 2004 show an average effluent concentration of 72 colonies/100 ml.

Storm runoff from urban areas

Springfield has a separate sewer system and storm runoff from urban areas is directly discharged in the South Fork of the Dry Sac River that flows east to west, north of Springfield. Urban runoff may contain large amounts of bacteria due to the presence of pets, birds, small rodents, squirrels, etc. Storm runoff also may contain sanitary sewage. In fact, bacteriologists (Sandra McLellan, personal communication) who have attempted to characterize urban storm runoff have found it very difficult to find urban storm runoff not contaminated with sanitary sewage. In this watershed, storm runoff may reach the shallow aquifer due to the numerous sinkholes that exist.

Urban storm runoff has been monitored by the City of Springfield, as part of the NPDES storm water permit. Six in-stream points have been sampled by the city, one of them, Pea Ridge Creek at Farm Road 102, being in the Little Sac River Watershed. Both ambient dry-weather samples as well as storm event samples were collected at these points. The description and the monitoring data are included in the 2002-2003 and 2003-2004 NPDES permit report (City of Springfield, 2004). The fecal concentration in the wet weather sample collected on Pea Ridge Creek on April 7, 2003 was 670 colonies/100 ml. On March 25, 2004, it was 160 colonies/100 ml. The average concentration of the two samples collected during dry weather in 2003 was 400 colonies/100 ml. The average concentration of the three samples collected during dry weather in 2004 was 360 colonies/100 ml.

Water Quality Data

Fecal coliform concentrations

After a tour of the watershed and considering of the locations of the USGS flow gauges and the sampling points of the 319 project conducted by the Watershed Committee of the Ozarks, two sampling points were selected. These are indicated on the watershed map (Figure 2). The stream at these points is well mixed and easy to access. The upstream point helps characterize the impact of the upstream urban areas and the waste water treatment plant. Water is collected from the bridge of Farm Road 129 (FR129), off of Route O, 1 mile downstream of the Northwest WWTP. The location is accessible under all weather conditions. The other point characterizes the whole watershed and is downstream of several known swimming/wading areas. The water is collected from the bridge of Route 215 (RD215), about 2 miles west of Morrisville. This site is also accessible under all weather conditions. A continuously recording stream flow gauging station is maintained by USGS at a site approximately 0.25 river miles downstream from the bridge on State highway 215 (station 06918740). The collection of water samples started in November 2003 and ended in October 2004 at these two sites.

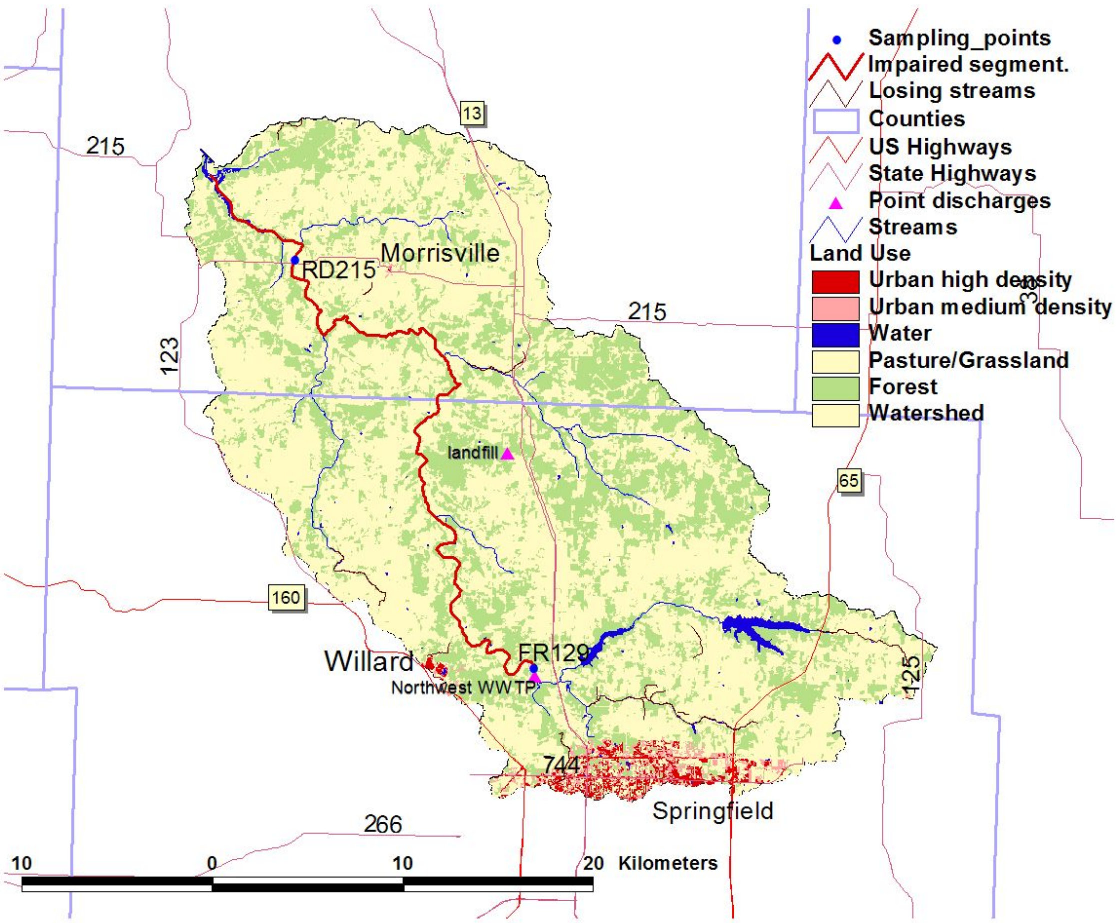

Figure 2. Location of the sampling points on Little Sac River

Little Sac water samples have been collected once a month in November 2003, December 2003, January 2004, and February 2004. Since the beginning of March 2004, samples have been collected at both locations once a week, yielding 52 samples. Samples were also collected in a non-systematic way at the outlet of the Northwest WWTP. All samples were collected for bacterial analysis. No flow value was measured as we used the values provided by USGS. The methodology for collecting and analyzing these samples is detailed in Baffaut and Rogers (2005). Fecal coliform concentrations obtained in all samples are presented in Appendix A.

The fecal coliform concentrations vary, with most concentrations between 100 and 2000 colonies/100 ml (Figure 3). Concentrations higher than 2000 colonies/100 ml are frequently associated with increased flow, even when the flow increase is small or moderate. The maximum concentrations are not shown on the graph for reasons of scale. On March 9, 2004 and on October 12, 2004, the concentrations measured at Farm Road 129 were 12,000 and 14,800 colonies/100 ml, respectively. Average bacteria concentrations for the two sites are summarized in Table 2 and 3.

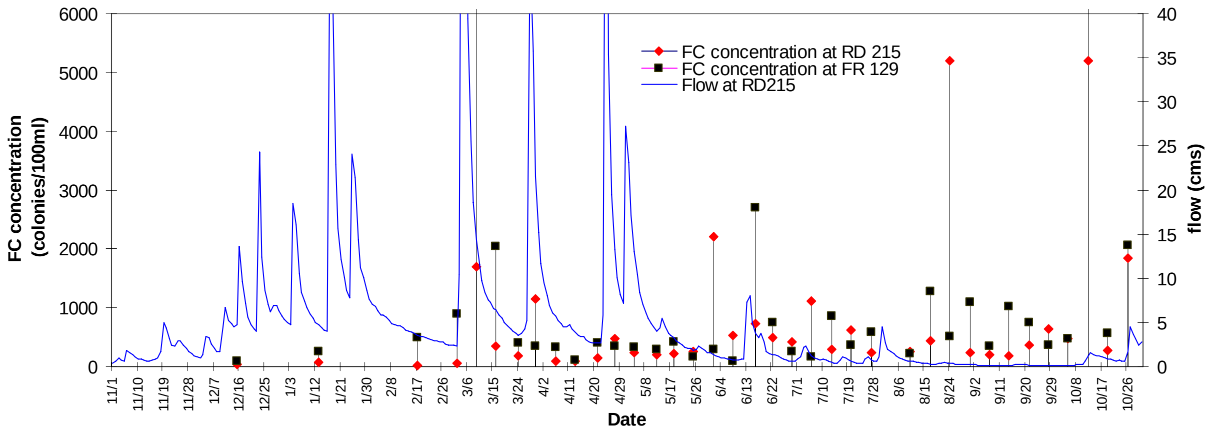

Figure 3. Weekly fecal and *E.coli* concentrations in Little Sac River

Table 2. Fecal coliform concentrations in the Little Sac River at Farm Road 129

	November to mid-March	Mid-March to mid-June	Mid-June to mid-August	Mid-August to October
Maximum	12000	2700	850	14800
Min	90	85	160	210
Mean	2632	478	456	2089
Std deviation	4642	676	275	4249
Geometric mean	797	314	383	951

Table 3. Fecal coliform concentrations in the Little Sac River at Road 215

	November to mid-March	Mid-March to mid-June	Mid-June to mid-August	Mid-August to October
Maximum	1700	2200	1120	5200
Min	11	84	230	180
Mean	369	500	490	1368
Std deviation	663	592	312	1951
Geometric mean	99	312	423	625

These values show that the bacteria criteria for whole body contact recreation waters is violated during the 2004 recreation season. Statistical analyses (t-test and f-test) show that there is no significant difference in the average fecal coliform concentrations of each site. A more complete analysis of the fecal coliform concentrations is presented in the report that details the bacteria monitoring and bacterial source tracking aspects of this study (Baffaut and Rogers, 2005).

Bacterial Source Tracking

All water samples sent to the University of Missouri were processed for bacterial source tracking. This technique attempts to identify the source of the contamination by linking the DNA of the *E. coli* bacteria contained in the samples to the DNA of *E. coli* from known sources. Although we determined concentrations of fecal coliform in the water samples, the bacterial source tracking is based only on the *E. coli* strains. Those represent a subset of the fecal coliform group but are more specific and better suited for this type of analysis. The method relies on the fact that each animal species hosts unique strains of *E. coli* bacteria that are adapted to the intestinal characteristics and the diet of that particular host. A description of the method is given in Baffaut and Rogers (2005).

A library of DNA patterns has been developed that is specific to animals and humans living in the Little Sac River Watershed. With the help of employees from NRCS, landscape samples from cattle, horses, wild geese, septic tanks, and sewage were collected, analyzed, and processed to build a database specific to this watershed. Table 4 shows the number of isolates included in the database. The Northwest WWTP treats sanitary sewage collected within Springfield city limits. This sewage may contain bacteria from sources not expected to be found in sanitary sewage because of infiltrations and inflows (I/I) in the sewer system. However, these are likely to be other than cattle, horses, or septic tanks because these are not typically found within city limits. There is a possibility that some goose isolates get mixed up into the sewage.

Table 4. Number of isolates included in the Little Sac database

Host	Number of samples	Number of isolates
Cattle	10	206
Horse	9	209
Septic tank	7	198
Wild goose	9	209
North Springfield Waste Water Treatment Plant	40	207

From 7 to 20 *E. coli* isolates were obtained from each water sample 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, a threshold of 80% similarity between the patterns of unknown origin and a database pattern and quality grades of a, b, or c were selected to determine the host of an *E. coli* colony. Patterns that could not be associated to any host class with sufficient certainty were qualified as “others”. The causes for uncertainty of the host class for these isolates include missing potential sources in the database (rodents, dogs, etc.), an incomplete database for the species represented, and/or technological issues in the extraction, processing, and pattern matching of the isolates.

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: sewage, cattle, horses, septic tanks, and wild geese.

The percentages of isolates identified in each host class are summarized in Tables 5 and 6. Overall, the proportions of isolates associated with the WWTP are 16% for the upstream site (1 mile downstream of the WWTP) compared to 13% for the downstream site. At the upstream site, 15% of the isolates are associated to geese; they represent 27% of the isolates at the downstream site. This unexpected result is in line with results obtained in other watersheds where geese are abundant. Cattle and horses represent 9% and 7% of the isolates each at the upstream site, 14% and 10% each at the downstream site. Very few isolates are associated with septic tank effluent (2% at each site). The largest source seems to be what is currently unknown, 51% at the upstream site and 34% at the downstream site.

Table 5. Percentage of isolates identified in each host class during different seasons at FR 129

Season	Cattle	Horse	Geese	Sewage	Septic	Others
November to mid-March	4%	8%	1%	27%	2%	59%
Mid-March to mid-June	12%	9%	16%	19%	4%	40%
Mid-June to mid-August	9%	5%	30%	11%	1%	44%
Mid-August to October	7%	4%	15%	10%	2%	62%

Table 6. Percentage of isolates identified in each host class during different seasons at RD 215

Season	Cattle	Horse	Geese	Sewage	Septic	Others
November to mid-March	10%	20%	10%	14%	1%	46%
Mid-March to mid-June	13%	10%	27%	17%	3%	31%
Mid-June to mid-August	14%	10%	38%	13%	2%	22%
Mid-August to October	18%	4%	31%	9%	2%	36%

The results are consistent with the location of the sites and the surrounding land use: proportionally more WWTP isolates and less cattle and horse at the upstream site. Geese seem to be everywhere in the watershed; they explain 30% to 40% of the loading at the downstream site during the recreation season. Chronologically, we also see more WWTP associated isolates at the upstream site in the winter (mid-November to mid-March) when the effluent is not disinfected. After April 1, less WWTP associated isolates are detected. What is detected is not explained by the bacteria found in the outlet discharge itself, implying that there are other sources of sewage than the WWTP. At the downstream site, the seasonal variations of the sewage contribution are not significant. Cattle and horses contribute evenly through the year and in similar amounts in spite of a cattle population that is larger than the equine population. Additional investigations are needed to establish what may cause these numbers. Finally, the proportion of isolates that cannot be matched with one of our database is higher upstream than it is downstream.

As the weather warms up, more isolates match geese. The percentage of isolates matched to goose in winter at the upstream site is very small (1%). It increases in spring, reaches the maximum of 30% in July and August and goes down again during the fall. A similar pattern is observed at the downstream site but the percentages are 10 to 15% higher than at the upstream site.

Sources were analyzed as a function of the flow condition using daily flow values measured at the USGS flow gauge located at the upstream site. Results indicate that:

- The cattle and horse contributions seem to increase when there is storm runoff. However, the differences in percentages are not statistically significant for any of the sources.
- The sewage contribution at the upstream site (FR 129) seems to decrease when there is storm runoff. This indicates that this type of discharge, whether it comes from the treatment plant or from leaks of the sewage system tends to be diluted by cleaner runoff.
- There is as much unknown when it rains as when it does not.

Description of the Applicable Water Quality Standards and Numeric Water Quality Targets

Beneficial uses of Little Sac[1]

- livestock and wildlife watering,
- protection of warm water aquatic life and human health associated with fish consumption,
- cool water fisheries,
- whole body contact (swimming), and
- boating and canoeing.

Use that is impaired

Whole Body Contact Recreation (Swimming)

Standards that apply

The standards that apply are found in the Missouri Water Quality Standards at 10 CSR 20-7.031(4)(C).

"Protections of whole-body-contact recreation are limited to classified waters designated for that use. For periods when the stream or lake is not affected by storm water runoff, the fecal coliform count shall not exceed two hundred colonies per one hundred milliliters (200 colonies/100 ml) during the recreational season in waters designated for whole-body-contact recreation or at any time in losing streams. The recreational season is from April 1 to October 31."

Anti-degradation Policy

Missouri's Water Quality Standards include the EPA "three-tiered" approach to anti-degradation, and may be found at 10 CSR 20-7.031(2).

Tier I defines baseline conditions for all waters and requires that existing beneficial uses are protected. TMDLs would normally be based on this tier, assuring that numeric criteria (such as dissolved oxygen and ammonia) are met to protect uses.

Tier II requires that no degradation of high-quality waters occurs unless limited lowering of quality is shown to be necessary for "economic and social development." A clear implementation policy for this tier has not been developed, although, if sufficient data on high-

[1] 10 CSR 20-7.031 Table H

quality waters are available, TMDLs could be based on maintaining existing conditions rather than the minimal Tier I criteria.

Tier III (the most stringent tier) applies to waters designated in the water quality standards as outstanding state and national resource waters; Tier III requires that no degradation under any conditions occurs. Management may prohibit discharge or certain polluting activities. TMDLs would need to assure no measurable increase in pollutant loading.

This TMDL will result in the protection of existing beneficial uses, which conforms to Missouri's Tier I anti-degradation policy.

Target Determination

The MDNR has recently conducted a Water Quality Standards review. The revision was adopted in November 2005 and includes both the existing fecal coliform criterion of 200 colonies/100ml and the new *Escherichia coli (E.coli)* criterion of 126 colonies/100ml. The fecal coliform criterion is to be phased out by the end of 2008 and replaced with the new criterion, For the purpose of this TMDL, the existing fecal coliform standard will be used.

Calculation of Load Capacity

Load Capacity (LC) is defined as the greatest amount of a pollutant that a waterbody can receive without violating Missouri Water Quality Standards. The TMDL for this watershed is a continuous curve calculated from discrete loading capacities over a range of flow conditions. Specific loading capacities are calculated by taking the flow rate times the 200 colonies/100 ml Water Quality Standard times a conversion factor. This load is divided among the point sources (Waste Load Allocation or WLA) and nonpoint sources (Load Allocation or LA) with an allowance for an explicit Margin of Safety (MOS). The Margin of Safety ensures a conservative estimate of the pollutant load. It is calculated due to the inherent error that exists due to the high number of variables that exist in a dynamic stream system. The resulting equation is:

$$LC = WLA + LA + MOS$$

Model Set-up and Description

The Soil and Water Assessment Tool (SWAT) was used to simulate fecal coliform loading (Arnold et al., 1998). The methodology relies on a mathematical computer simulation that calculates fecal coliform loads and concentrations. The model takes into account climate, physical landscape features, and land management factors. The purpose of using a model is to integrate the flow data and the water quality data in order to establish water quality baseline characteristics.

For modeling purposes, the watershed was divided into sub-basins and further sub-divided into nearly homogeneous units that have a distinct land use, soil type, and management practice. The units are called hydrologic response units (HRU). For the Little Sac River Watershed, the sub-basins were selected on the basis of the natural tributaries to Little Sac River and on the existing water sampling points. Figure 4 shows the subbasins that were utilized. The USGS gauge is at the outlet of subbasin 26, and the sampling point on FR 129 is at the outlet of subbasin 27.

SWAT simulates many of the physical processes that impact water quality. This model requires inputs, some readily available with the use of the GIS technology (elevations, soils, slopes, and 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 NRCS, the Polk County and Greene County SWCDs, the city of Springfield, and the Missouri Agricultural Statistics Service (MASS).

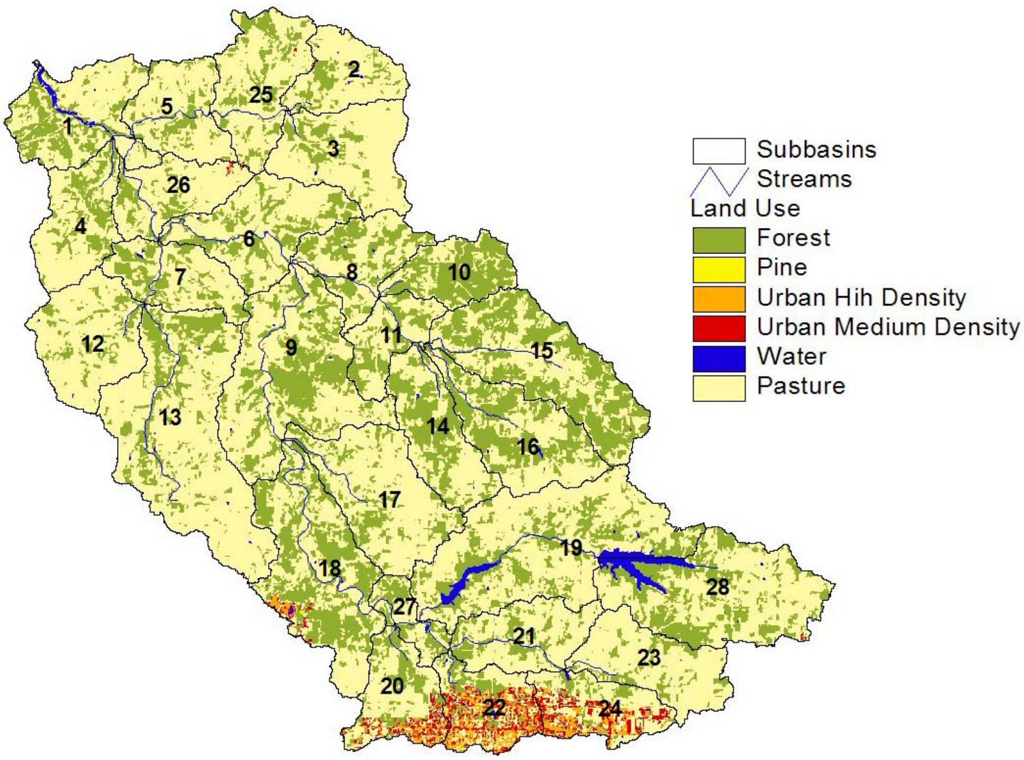

Figure 4. Little Sac River and the subbasins used in the SWAT model

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 in 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 Bolivar, Missouri is assumed to be representative of the daily weather in the northern part of the watershed. The data from the station at Springfield, Missouri is assumed to be representative of the daily weather in the southern part of the watershed. 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 9 % or more of the subbasin area is represented in the model and each soil that represents 11 % or more of that land use area is represented.

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 or on annual weather.

This study is intended to estimate when and how much pathogen pollution occurs and the source of the pathogens. Once a baseline is established, the model evaluates the projected impact of alternative management practices implemented at the watershed level on the fecal coliform concentrations in the Little Sac River. 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:

- MDNR water quality data
- USGS water quality data
- USGS flow data
- Watershed Committee of the Ozarks water quality data from two 319 projects:
    - Adopt-a-Spring Program
    - Current 319 project in the Little Sac River Watershed
- City of Springfield, Missouri water quality data (City of Springfield, 2004), and
- Fullbright Spring Protection Study (Wright Water Engineers, 1995).

<u>Flow data</u>

Flow data is used during the model calibration to adjust the model parameters within reasonable ranges in order to:

- obtain simulated flow values that match measured ones, and
- obtain a simulated ratio of groundwater flow and surface runoff that matches the ratio estimated from measured data.

Daily flow data are available at the downstream site (2 miles west of Morrisville, close to the Bridge on Highway 215) from October 1968 until present. The average daily flow value from October 1969 to September 2002 was 6.8 m^3/s (240 cfs). The highest peak flow values recorded since October 1968 were 527 m^3/s (18,597 cfs) on September 25, 1993; 374 m^3/s (13,198 cfs) on February23, 1985; and 360 m^3/s (12,704 cfs) on October 1, 1986. The lowest flows were recorded in late summer and early fall of 1980 when the data indicate flow values less than 0.057 m^3/s (2 cfs) for several days.

The USGS HYSEP program (Sloto and Crouse, 1996) was applied to the daily flow values to separate hydrographs into surface runoff and baseflow. Baseflow is the part of stream flow that is contributed by the shallow aquifer and the springs. Baseflow varies with the depth of water in the shallow aquifer. It typically responds to rainfall with a longer delay than surface runoff. Little Sac River is a stream that is mostly fed by groundwater flow. Using the years 1969 to 2003, the average annual ratio of base flow to total flow of Little Sac River was 52 %. On a monthly basis, the ratio varied from 40 % in wet months to more than 90 % during drought periods. The base flow value was, on average 3.54 m^3/s.

Input Data Requirements

The SWAT model requires input data to describe the climate, hydrology, soils, and land use characteristics of the watershed. The different types and sources of input data used to develop the TMDL for the Little Sac River 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 in Springfield and Bolivar from 1961 to 2003 and provided by Pat Guinan from the Missouri Climate Center at the University of Missouri Department of Soil, Environmental, and Atmospheric Science. Monthly statistical characteristics for precipitation and temperatures were calculated from this data and then 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 Bolivar.

The average annual precipitation is similar at the two stations, 1076 mm (42.4 in) in Bolivar, and 1072 mm (42.2 in) in Springfield. However, on a monthly basis, variations can be larger and in a different order (Figure 5).

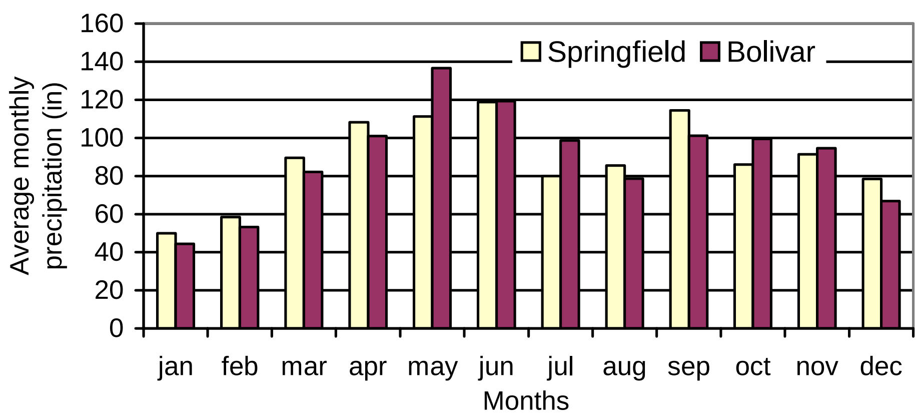

Figure 5. Average monthly precipitation in Springfield and Bolivar, MO

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 AVSWATX. Soil slopes and slope lengths were assigned depending on the soil and topographic 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 0.85. All other parameters are left at their default value. The table showing the values of the non-default hydrology parameters is in Appendix B.

Most of the main channel characteristics were left as defined by the AVSWATX 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. Very high hydraulic conductivities were given to the South Fork of the Dry Sac River and its tributaries because these are loosing streams. For the erodibility and cover factor, the default values provided by SWAT were used. The channel characteristics are shown in Appendix B.

The watershed includes two reservoirs: Fellows Lake (subbasin 28) and McDaniel Lake (subbasin 19) on the upstream reach of the Little Sac River. These two lakes are used for water supply. Storage versus water level information was obtained from the Springfield City Utilities and entered in the model. Water imports from the Stockton Lake and withdrawals for consumption were entered as well. The assumption was made in the model that there is no outflow out of the reservoir unless the water level reaches above the spillway, in which case enough water is released to return water elevation to the spillway level. The storage versus water level information and the historical net withdrawals (withdrawal less inflow) are presented in Appendix C.

Soil data. Soil maps and soil characteristics from the Soil Survey Geographic (SSURGO) database were used for this analysis. Data for Greene and Polk Counties were obtained from the USDA data website in April and May 2004. This data is the same as is in the Missouri Cooperative Soil Surveys. Overall, the watershed is dominated by the presence of Goss silt loams (44%), Wilderness silt loams (12%), Alsup silt loams (9%), Needleye silt loams (6%), and Pomme silt loams (6%). A total of 117 HRU were defined in the model.

Management practices. Pastures are 95% fescue and 5% warm season grasses; only fescue will be represented in the model. Some fescue pastures are over-seeded with legumes (red clover or lespedeza) at the time of fertilization. This can happen every year down to every 2 or 3 years. The over-seeding rate is 3 to 4 lbs/a. About 50% of the fertilized pastures are over-seeded. The management depends on whether the goal is fescue seed production or cattle grazing. Before fescue came in the 50s and 60s, the agricultural land was cropped with oats, barley, wheat, and some corn. Many terraces were built all over the watershed and have been gradually disappearing since they are not used in a pasture management system. Wild grasses such as cheat grass or bluegrass remain under the trees and provide a significant part of the cattle diet and feed but have not been included in the model. This is not expected to produce significant differences in the results regarding flow and water quality.

Pastures are fertilized in March with 17-17-17, or some other commercial fertilizer with a slightly higher amount of N compared to phosphate or potash. Pastures are fertilized with cattle in them if needed. Within 16 to 30 km (10 to 20 miles) of Dallas county, some pastures are fertilized with turkey litter at a rate of 2 t/a. Because this represents only a small fraction of the watershed, it was not represented in the model. Because some pastures are too steep, too bushy, or because of a lack of money, only 70% of the pastures are fertilized. In the model, we assumed that 100% of the pastures are fertilized with 300 lbs/a of 17-17-17.

Most producers rotate cattle across three pastures, including one with a winter area. The average producer has 30-35 cows and the grazing density is 1.2 to 2 ha (3 to 5 acres) per cow-calf. The cattle are rotated every 40 to 60 days through the pastures year-round. The pond level (the most common source of water) often determines cattle movement. Rotational grazing (rotations every two weeks or less) is practiced by 10% of the producers. Cattle are put in pastures in mid-March. The average pasture size is 16 ha (40 acres) on a 32 ha (80 acre) field that includes areas with bushes and trees that are accessible to cattle but not hayed or fertilized. Grazing ends around December 15 after which cattle are hay supplemented in the winter pastures until March 25. There are about 5 km (3 miles) of buffers that NRCS has been involved with in Polk County. The width of these buffers is 15 m (50 ft) on first or second order streams; (30 m) 100 feet on third order stream.

Polk County is first in hay production in Missouri and tenth in the nation. Hay cutting takes place between June1 and July 15, ideally in the first part of June. Only 30 to 40% of the grassland is harvested for hay and produces a hay yield of 4.5 metric tons/ha (~2 t/a). The rest is mowed every other year. 20% of the harvested grassland is hayed a second time in September. The model assumes only one hay cut in late spring. The full management of grassland and the rotation of cattle between different pastures are summarized in Appendix D.

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 7 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 7: Daily feed requirements and manure production for grazing cow-calf

Animal	Animal weight	Daily manure weight[a]	Moisture content[a](%)	Daily dry manure weight	Daily Dry Feed[b]
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
Total	632 kg	46.7 kg	88.4	5.42 kg	5.9 – 13.0 kg

[a]*Source, USDA , 2000*
[b]*Source, National Research Council, 1976*

In urban areas, management operations include street sweeping, lawn fertilization, and lawn mowing. State-maintained thoroughfares that lie within the Springfield city limits are cleaned by the Missouri Department of Transportation. The City of Springfield sweeps and cleans major arterial roads weekly. Collector roads and residential roads are swept six times per year (City of Springfield, 2004). The model will use this cleaning frequency since secondary roads are the most likely place where one will find nutrients and bacteria rather than toxic compounds and oils that are more characteristic of major arterial roads. Fertilization and mowing practices were established with the help of the Little Sac Watershed Steering Committee and are detailed in Table D.3 of Appendix D.

Spring data. The upstream part of the watershed (south half) includes many springs that account for a major part of the Little Sac flow, especially during dry periods. While there are some data about these springs, the information is not as thorough as would be needed to build an accurate model of the watershed hydrology. Except for a few springs, the recharge areas are not known. Data on springs location and flow information was obtained from the MDNR Geological

Survey through the Missouri Spatial Digital Information Service [MDNR, 2004(b)]. Figure 6 shows the known and identified springs and sinkholes in the Little Sac River Watershed.

For some springs, a range of flow values or an average flow is available. We assumed that the springs for which the information is not available are small ones that would not contribute significantly to the flow. The range of flow values was utilized to derive average monthly flow values. These estimations assume that spring flow is highest in March and April, and lowest in September. The derivation of monthly flow values is detailed in Appendix E. As will be seen with the calibration of the model, this assumption produces reasonable values of monthly flows even though it does not take into account the variation of spring flows with precipitation events.

Recently, the Watershed Committee of the Ozarks has been coordinating and expanding the Adopt-A-Spring program. Through this project, springs are sampled once every three months and analyzed for several water quality indicators including nutrients and bacteria. The nitrate, phosphorus, and *E. coli* concentrations measured at Sanders, Doling, Ritter East, Ritter West, Stoddard, and Hoffmeister springs are shown in Appendix E.

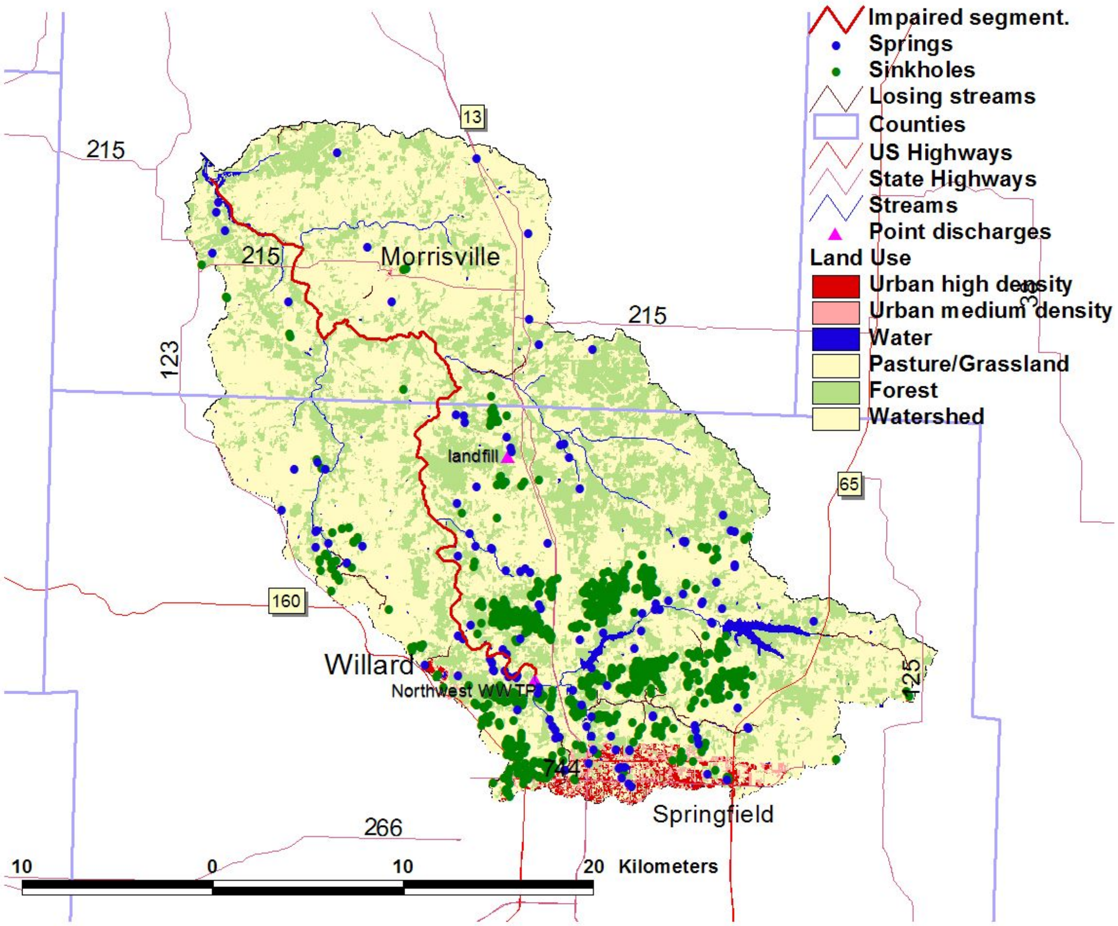

Figure 6. Springs and sinkholes in the Little Sac Watershed

The *E. coli* concentrations vary substantially from sample to sample and from spring to spring. However, there is not enough data to relate these concentrations to other factors. We used the information to calculate an average *E. coli* concentration for each of these springs. The same procedure was used for nitrogen-nitrate and ortho-P. The average concentrations of *E.coli*, nitrogen-nitrate, and ortho-phosphorus are presented in Table 8. Only the springs located in the Little Sac watershed that have been sampled six or more times since June 2000 are included.

The *E. coli* based water quality standard (126 colonies/100 ml) is lower than the fecal coliform standard (200 colonies/100 ml) for whole body contact. *E. coli* constitues a sub-group of the fecal coliform group. Most *E.coli* strains are fecal *E. coli*, i.e.: they live in the guts of warm blooded animals. Some *E. coli* strains, however, do live outside of this environment. In particular, they have been reported in paper mills. However, in the absence of paper mills in this area, we can assume that, in any water sample, the fecal coliform concentration will be greater than the *E.coli* concentration. Therefore, if an *E. coli* concentration exceeds the fecal coliform water quality criteria, the fecal coliform concentration of that sample will definitely exceed it. These average results show that in many of these springs, *E. coli* concentrations exceed the *E. coli* and the fecal coliform whole body contact water quality standards. The nitrogen-nitrate concentrations in spring flow are stable at around 1.0 mg/l, a value that is higher than the 0.3 mg/l level, indicating eutrophication. On the other hand, the phosphorus (ortho-P) concentrations are very variable from sample to sample and from spring to spring.

Table 8. Average *E. coli* and nutrient concentrations at selected springs of the Little Sac River Watershed

Spring Name	Subbasin Number	Average *E. coli* concentrations (colonies/100 ml)	Average NO_3-N concentrations (mg/l)	Average P concentrations (mg/l)
Doling	22	655	1.2	0.13
Sanders	24	251	1.1	0.37
Ritter East	20	992	1.0	0.36
Ritter West	20	417	1.2	0.18
Stoddard	18	21	1.0	0.06
Hoffmeister	19	3589	0.6	0.20

Accounting for pollutant sources

As seen in Figure 6, there are many springs in the watershed that are not included in the Adopt-a-Spring program. For the purpose of this study, we have assigned these average *E. coli* concentrations to the spring flow in the corresponding subbasin. If no water quality data are available for any of the springs in a subbasin, no bacteria or nutrient loading was specified in that subbasin. Given the importance of spring flow in this watershed, it is important that more monitoring be conducted for these springs.

Point sources. The only major permitted facility is the Northwest WWTP. The permit specifies that the average daily fecal coliform concentration has to be less than 400 colonies per 100 ml for a design flow of 23,700 m^3/d (6.4 MGD), or 0.274 m^3/s (9.67 ft^3/s). The maximum daily limit is 1000 colonies/100 ml. The bacterial daily load is therefore 9.47 10^{10} colonies per day. The permit also includes an ammonia-nitrogen maximum concentration of 2 mg/l. There is no requirement regarding the effluent phosphorus content.

Other permitted facilities in the watershed that have a bacteria requirement include a high school (in subbasin 19) and a children's home (subbasin 8). Table 9 shows the design flows and the fecal coliform permit requirement. There are no concentrated animal feeding operations or animal feeding operations in the watershed that have a bacteria permit.

Table 9. Fecal coliform permitted facilities in the Little Sac River Watershed

Facility Name	Design flow (MGD[a])	Design flow (m^3/day)	Monthly average FC permit (colonies/100 ml)	Maximum daily FC permit (colonies/100 ml)
Springfield NW WTTP	6.4	23,680	400	1000
Pleasant View School	0.008	29.6	400	1000
Good Samaritan Boys Ranch	0.006	22.2	400	1000

[a] millions gallons per day

Non-point sources. The bacterial load from grazing cattle is taken into account through the grazing operations on pastures and calculated by the model. The fecal coliform counts are calculated proportionally to the density of grazing animals. Fecal coliform die-off is simulated while on the land or in the soil; it is also simulated once bacteria is in the runoff or in the stream.

Similarly, the bacterial load from grazing and/or riding horses can be taken into account by the grazing operations on pastures. Since we do not know of a seasonal aspect of the equine population or activities, we have estimated a constant year-round grazing density for the Greene and Polk County fractions of the watershed. Table 10 reports the number of horses and cow/calf pairs in Polk and Greene counties given by the 2002 Agricultural census, and the proportional number in the corresponding fraction of the watershed.

Table 10. Horse population in the Little Sac River Watershed

	Horses in each county	Cow/calf in each county	Horses in the fraction of the watershed	Cow/calf in the fraction of the watershed	Grassland (ha)	Horse density (#/ha)	Cattle density (#/ha)
Greene	3,789	36,780	2,235	21,700	32,884	0.068	0.660
Polk	2,824	54,682	480	9,296	15,992	0.030	0.581
Total	6,613	91,462	2,715	30,996	48,876	0.056	0.634

No input from septic tanks is represented in the model because the percentage of the bacterial load associated with this specific source is very small.

The bacterial and nutrient loads associated with geese are taken into account through continuous grazing operations on pastures. The goose density for medium density strata from the 2004 spring (April) survey of Canada goose was 2.15 geese per square mile (Raedeke and

Graber, 2004), based on the survey of two square miles plots. We assumed it doubles in summer to reflect the hatching and growing of young birds. As suggested by the bacterial source tracking results, the winter goose density was calculated as 25% of the spring density. Table 11 presents the grazing densities and feces deposit rates for each part of the year.

The manure deposit rates were divided by the fraction of grassland in a subbasin relative to its total area. This was done to reflect that geese are most often found on grassland and not in wooded or urban areas (except for city parks, which fall in the category of grassland). Manure deposit rates for each subbasin are given in Appendix F.

Table 11. Manure deposited by geese

Season	Goose density (geese / square mile)	Goose density (geese/ha)	Manure deposited per goose[a] (g dm/day[b])	Manure deposit rate (kg/ha)
November to mid-March	0.54	0.0021	104	0.00022
Mid-March to mid-June	2.15	0.0084	104	0.00087
Mid-June to mid-August	4.30	0.0168	104	0.00175
Mid-August to October	3.23	0.0126	104	0.00131

[a]See Appendix F for detailed information on geese.
[b]g of dry matter per day.

Nutrient content of animal manure. The surface runoff loadings are calculated by the model as a function of the manure deposited on the land. The nutrient content for beef and horse manure were taken as given in the SWAT database. The nutrient content of goose manure is given in appendix F.

Bacteria content of animal manure. 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, horse, and goose production rates (Table 12).

Table 12. Fecal coliform production rates for different animals

Animal	Colonies/animal/day	Reference:
Beef cow	5.4E+9	Metcalf & Eddy, 1991
Horse	4.2E+08	ASAE, 1998
Goose	4.9E+10	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.

One can note that the number of horses in the watershed is one tenth that of cattle. Combined with the fact the fecal coliform count per horse is one order of magnitude less than that of cattle, it is surprising to see as much horse as cattle fecal coliform in the bacterial source tracking results. Possible explanations include a larger presence of horses grazing close to a stream, deposits that occur during horse rides, and/or a slower decay rate of fecal coliform coming from horse compared to cattle. Additional investigations are needed to explain this discrepancy.

Urban runoff. The SWAT model does not currently simulate the accumulation of fecal coliform on impervious areas and its subsequent wash-off by storm runoff. To remedy this situation, we calculated an average concentration for all urban storm runoff. Using wet weather data published in the NPDES permit annual reports (City of Springfield, 2003 and 2004) and wet weather urban runoff data published in 1995 (Wright Water Engineers, 1995), the average fecal coliform concentration of urban runoff was calculated to be 549 ± 238 colonies/100 ml and coded in the model. A summary of the data used to derive this average concentration can be found in Appendix G.

The nutrient load associated with urban storm runoff is the sum of the nutrient load on impervious areas and from pervious areas. On pervious areas, the nutrient load is a function of soils, slopes, land cover, and land management, just as it would be calculated on non-urban land. On impervious areas, the nutrient load is a function of the amount of particles that accumulate on and wash off the impervious surfaces and of their nutrient content. In the absence of data specific to Springfield, we have used the nitrogen and phosphorus content given in the SWAT database for medium and high density urban areas.

Groundwater contamination. In karst areas, loosing streams, sinkholes, and cracks are fast ways by which bacteria and other pollutants can reach the shallow aquifer. These pollutants then reappear in springs or in the streams that are recharged by groundwater. The transport of bacteria and nutrients through karst features cannot be simulated with SWAT. The model does, however, give the possibility to specify bacterial concentration and nutrient loadings in the flow coming from the springs. These values are specified by the user, not calculated by the model.

The Adopt-a-Spring program in Springfield provides some data relative to the contamination of springs around Springfield. The average *E. coli* concentration of the samples collected since 2000 has been used to characterize each monitored spring. These values were presented in Table 8. For springs that have not been monitored, no bacteria value was entered. The Adopt-A-Spring monitoring program will provide additional data that can be entered in the model as they become available. It would be interesting but beyond the scope of this study to determine more precisely the sources of spring water contamination.

An average nitrate-N concentration of 1.0 mg/l was used for all springs and for the groundwater because of the small variability of nitrate content from sample to sample and from spring to spring. For soluble P, we have used the ortho-P values given in Table 8 for each spring. The lowest measured value of 0.01 mg/l has been used for springs that are not monitored and for groundwater. Again, additional measurement will provide information to update the model.

Direct non point source inputs. Fecal coliform and nutrient loads that are deposited by cattle, horses, or geese directly into the streams are treated as direct non-point source loadings in the model. It is very difficult to estimate the amount of manure directly deposited by these animals into the water. Studies have shown that, provided they have alternative drinking sources and provided they are not affected by fescue toxicity, cattle will prefer not to go in the water (Sheffield et al., 1997). Geese, on the other hand, do spend a significant amount of time in the water. Horses and rural residences are often located near streams for esthetics and water supply. Direct non point source inputs also include inputs of sewage from illegal discharges and failing septic tanks.

We have not specified any direct deposits in the stream from geese, cattle, or other animals. Although we know that these inputs do exist, they are difficult to estimate. While the time spent by cattle in the streams was estimated in the Shoal Creek study, we know that it will be less in this watershed because the water is cooler, it flows faster, and the banks are steeper. In addition, the information from the steering committee is that the main drinking source for cattle is a pond. As for geese, an estimation of the time they spend in the water and how much waste is directly deposited in water was not available.

Bacteria decay

The decay of bacteria is calculated by the model for bacteria on the land and in the stream using decay rates given as model inputs. Based on the values cited in the literature (Crane and Moore ,1986; Reddy, Kahleel, and Overcash, 1981), the following values of decay rates and half-life were used. For bacteria on land, a half-life of 2.15 days was chosen. The corresponding decay rate is 0.32 days^{-1}. A tenth of this value was used for bacteria adsorbed to soil particles. In addition, the decay rates on land and in the water can vary with the air or water temperature. The default value of the adjustment factor (1.07) is used in the model.

For bacteria in stream water, a half-life was determined from data collected by USGS in Shoal Creek (Schumacher, 2003). The average decay rate was 0.084 hour^{-1} (2.1 days^{-1}) or a half-life of 8.3 hours at a temperature of 25^{o}C. After the temperature adjustment, the value should be 1.48 days^{-1} at 20 ^{o}C. However, because it is spring fed, the temperature of the Little Sac River is typically lower than estimated by the model. A decay rate that corresponds to a 15 ^{o}C temperature, 1.05 days^{-1} was, therefore, used.

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 in this report. The model has been calibrated using available data namely:

- the Greene and Polk County hay yields reported to USDA,
- the daily flow values at the Road 215 USGS gauge from 1981 to 2002,
- the daily flow values on the Dry Sac from 1996 to 2002, and
- the bacterial concentration values from this 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. The average simulated crop yield from 1980 to 2002 is 5.0 ± 0.2 metric t/ha (2.2 ± 0.08 t/a) and is within the confidence interval of the average reported yield for Greene and Polk Counties for the period 1981-2002 (2.02 ± 0.06 t/a) (National Agricultural Statistics Service, 2005). This 9% difference is acceptable given uncertainties such as hay moisture content or harvest efficiency.

Runoff. The model was calibrated using 10 years of daily values, from 1981 to 1990, measured at the USGS gauge by the bridge over Road 215 (Figure 7). The period from 1991 to 2002 served for verification of the model (Figure 8). On both figures, the flows are presented with a logarithmic scale to better see the variations.

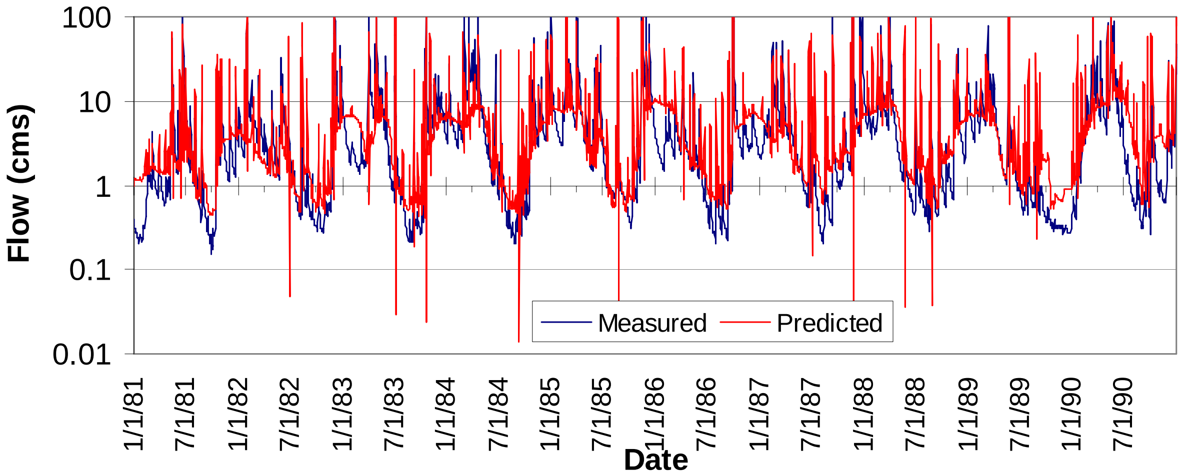

Figure 7. Comparison of measured and simulated flows at Road 215 from 1981 to 1990

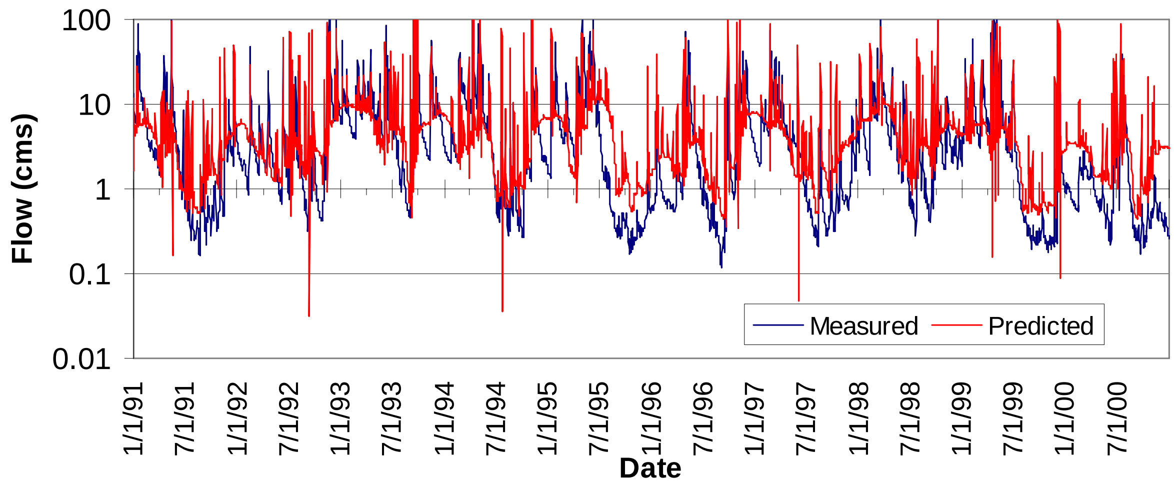

Figure 8. Comparison of measured and simulated flows at Road 215 from 1991 to 2002

The main source of uncertainty and model error is the contribution from the springs. Information was available only for the most important springs, and for those only a range of values was available. As explained before, monthly flow values were estimated by fitting a sinusoidal curve that would peak in March and be the lowest in September. In the model, these estimated flow values are fixed and independent from the rainfall. In reality, spring flow varies with rainfall in the recharge area of that spring.

In spite of this unknown, the overall statistical characteristics of the flow values are well reproduced, as shown with the flow frequency curves (Figure 9). While many peak flow values are overestimated, the fit between the two curves is satisfactory.

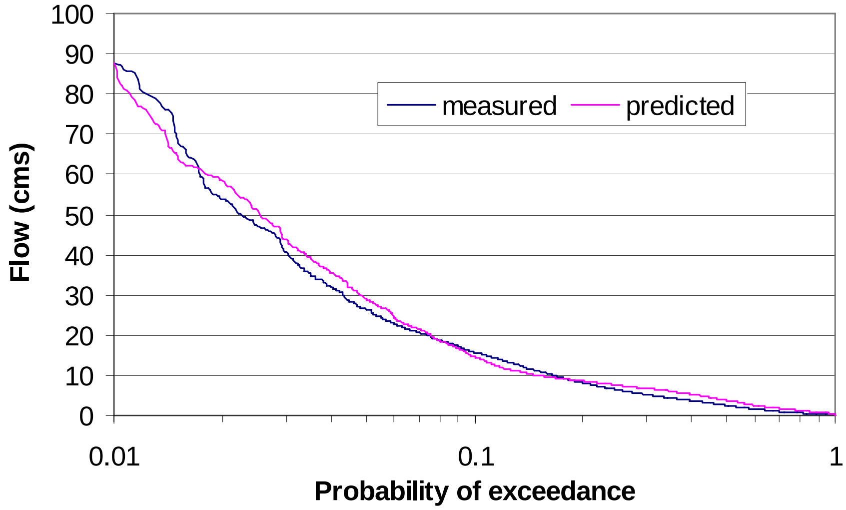

Figure 9. Frequency curve of daily flow values from 1981 to 1990

The goodness of fit of the model is indicated by several indicators. The percent deviation between simulated and measured quantities and the Nash-Sutcliffe coefficient are commonly used indicators. The percent deviation should be less than 10% and the Nash-Sutcliffe coefficient should be more than 0.5 for the model to be acceptable and more than 0.7 to be satisfactory. Table 13 presents the values of these indicators for total flow and for its base flow component, calculated on a monthly basis. The Nash-Sutcliffe coefficients calculated with daily values are 0.49 and 0.51for the 81-90 and 91-2000 periods, respectively.

Table 13. Total flow calibration indicators for the Little Sac model

	81-90	91-00
Average measured:	7.5	7.0
Averaged predicted	8.1	7.5
Difference	8%	6%
Nash-Sutcliffe	0.70	0.72

Table 14. Base flow calibration indicators for the Little Sac model

	81-90	91-00
Average measured:	3.3	3.3
Averaged predicted	3.2	3.2
Difference	-3%	-2%
Nash-Sutcliffe	0.55	0.47

Fecal coliform concentrations. The bacteria parameters of the model were calibrated using fecal coliform concentrations measured in 2003 and 2004 and listed in Appendix A. The calibration was based on the frequency curves. Figures 10 and 11 show the frequency curves obtained from measured and simulated values at the two sampling sites from April 1 to October 31. 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/100 ml.

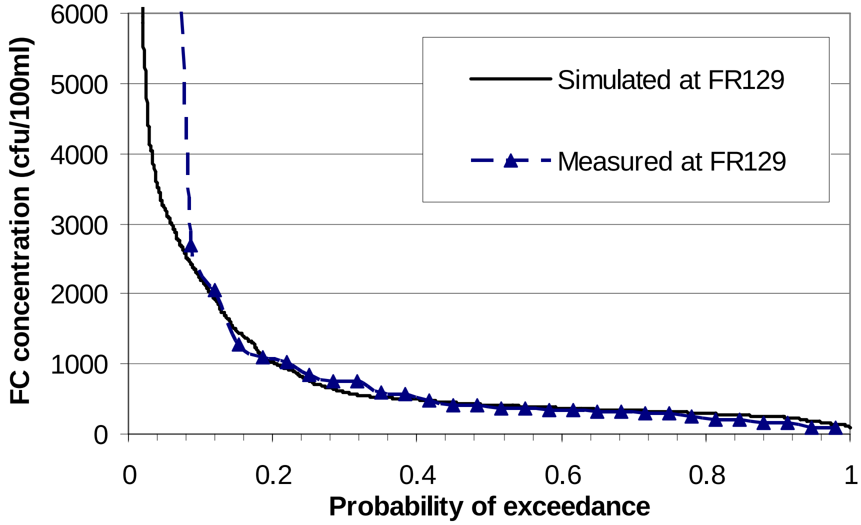

Figure 10. Frequency curve of fecal coliform concentrations at FR129

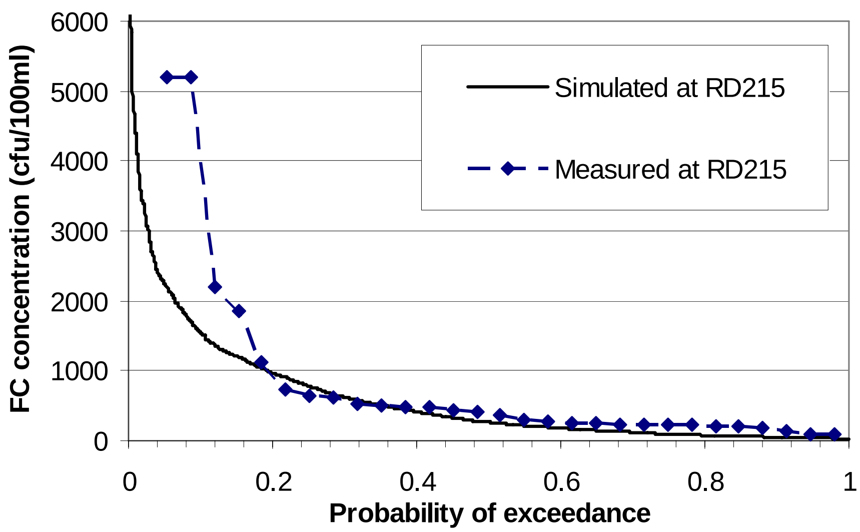

Figure 11. Frequency curve of fecal coliform concentrations at RD215

These curves show:

- A good match at FR129 for base and medium concentrations.
- An under-estimation of the base load at RD215. This was expected since we suspect there are some direct goose inputs as well as some contamination of the springs located in the drainage area of that sampling point. We do not have any data on these springs.
- It is difficult to determine the goodness of fit in the higher range of fecal coliform concentrations because of the small number of data points available in that range.

Load Capacity and Actual Load

Daily loads can be calculated by multiplying the daily flow value by the daily fecal coliform concentration and adjusting to obtain the desired unit of colonies/day. An average daily load was then calculated over the recreation seasons from 1981 to 1990.

$$Daily\_load = flow[m^3/s] \bullet FC\_concentration[colonies/100ml] \bullet 86400[s/day] \bullet 10000[100ml/m^3]$$

The flow values predicted by the model at Road 215 and Farm Road 129 from 1981 to 1990 were used to calculate the load capacity at these two sites. We have selected a 10-year long period for practical reasons dealing with the ease of manipulating large amounts of daily values and the running time of the model. During calibration of the flow component of the model, we have compared the flow values during the 1981-1990 decade and 1991-2000 decade (See Table 13, page 27). Those are very similar decades in terms of flow and are expected to produce similar results in terms of pollutant concentrations. The annual variability of the results will be implicitly included in our calculation of the MOS.

The fecal coliform concentration of 200 colonies/100 ml is the water quality standard used for this calculation. Similarly, the flow values were multiplied by the predicted fecal coliform concentration to estimate the actual load. The resulting loads and necessary reductions are presented in Table 15.

Table15. Load capacity and necessary reductions at FR129 and RD215.

	Load capacity (colonies/day)	Actual average daily load (colonies/day)	Needed reduction
FR129	4.16E+11	2.39E+12	83 %
RD215	1.20E+12	3.98E+12	70 %

During storm flow conditions, the flows are higher and the load capacity is therefore higher. In Table 16 (and later in Table 21), we have separated base flow, medium flow and storm flow conditions. Flows are characterized as storm flows when the base flow represents less than

53% of the total flow. They are characterized as base flows when the base flow represents more than 83% of the total flow. Loads indicated in this table are daily loads averaged over the number of days where the flow condition exists. The results show that the needed reduction is smaller during base flow conditions and highest during medium flow conditions. These load capacities and current loads are also shown in Table 21.

Table16. Load capacity for different flow conditions and necessary reductions at FR129 and RD215.

		Load capacity (colonies/day)	Actual average daily load (colonies/day)	Needed reduction
FR129	Base flows	1.90 E+11	5.09 E+11	63%
	Medium flows	2.54 E+11	2.03 E+12	87%
	Storm flows	1.34 E+12	9.42 E+12	86%
RD215	Base flows	4.38 E+11	6.76 E+11	35%
	Medium flows	5.09 E+11	2.20 E+12	77%
	Storm flow	3.17 E+12	1.16 E+13	73%

Waste Load Allocation (Point Source Loads)

Northwest WWTP

The only major point source load in the watershed is the Northwest WWTP. The other point source loads include the high school in subbasin 19 and the children home in sub-basin 8. Table 9 showed the design flows and the fecal coliform permit requirement. Table 17 shows the corresponding design load for these facilities. We have also included the actual outflow and outflow concentration for the Northwest WWTP. The actual outflow value comes from the MDNR list of permitted facilities (MDNR, 2004(a)). The actual concentration of 72 cfu/100 ml is the average concentration measured in the samples we collected in 2004 (Appendix A). We did not include in this average the high value of April 6 because it is likely the result of the creosote incident that occurred on March 31, 2004 and does not reflect the plant in normal operation.

Table 17. Fecal coliform loads from permitted facilities in the Little Sac River Watershed

Facility name and permit number	FC permit (col/100 ml)	FC permit load (col/day)	Actual Flow (m3/day)	Actual FC concentration (col/100 ml)	Actual load (col/day)
Springfield NW WTTP MO0103039	400	9.47E+10	13690	72	9.86E+09
Pleasant View School MO0103039	400	1.18E+08	19	Unknown	Unknown
Good Samaritan Boys Ranch MO0123277	400	8.88E+07	15	Unknown	Unknown

Only the load from the waste water treatment plant is significant compared with the stream load capacity (Table 16). However, the actual load is only a small fraction of that stream load measured at FR129, which is one mile downstream from the outfall. Depending on the flow conditions, the actual load discharged by the Northwest WWTP represents between 1% and 5% of the actual stream load. The permitted load represents 24% of the stream load capacity.

The loads from the high school and the children's home are very small compared to that from the Northwest WWTP. The total waste load allocation is therefore equal to 9.47E+10 colonies per day (Table 21).

Load Quantification

Scenario analyses allowed us to estimate with the model the load contributions from each source. The contribution from a source is estimated by subtracting the load when that source is not present in the model from the load obtained when that source is present. Five sources were considered: cattle, geese runoff, urban runoff, springs, and the Northwest WWTP. The actual composition of the bacteria loadings in the springs is not known. Some of these sources typically form the base load: springs and the treatment plant. They contribute to the stream loadings all the time. The other ones are storm runoff loadings: urban runoff, geese runoff, and cattle runoff. These occur only when a storm event produces runoff that brings pollutants to the stream.

The results of these scenario analyses show that the cattle loading constitutes 66% and 77% of the total loading at FR129 and RD215, respectively. Comparatively, the cattle loading as indicated by the bacterial source tracking is only 9% and 18% of the total load at FR129 and RD215, respectively. There are reasons why the bacterial load from grazing cattle is not reaching the streams. One of them being that only the outside of a cow pie comes into contact with rain or runoff and the bacteria that remains inside is not available for dissolution in water or for adsorption to soil particles. Because the overall concentrations are in the correct range, and to better match the bacterial source tracking results, we will assume that only 19% of the cattle loading predicted by the model actually comes from cattle, the rest will be assigned to horses and other unknown sources.

The results of the scenario analyses based on 10 years simulation from 1981 to 1990 are presented in Tables 18 and 19. These results are to be compared with the results of the bacterial source tracking presented earlier and summarized in Table 20 for the 2004 recreation season. This table presents the results in terms of loadings and not concentrations as it was done previously in Tables 5 and 6. This explains the small differences in percentages.

At base flow, the fecal coliform loading is the base load. At FR 129 it is almost entirely explained by the bacteria coming through the springs. The sources are not known because we did not sample the springs for bacterial source tracking. However, since the springs are the main source of water in the Little Sac River at base flow, it is expected that the sources will be similar to what has been found at both sites. The Northwest WWTP accounts for only 3% of the stream loading at base flow (50% of the time). One should note that there is a lack of information on spring flow and pollutant concentrations in the north part of the watershed. As this information becomes available, the model can be updated.

Table 18. Average predicted daily loadings at FR129, by source

	Actual Northwest WTTP	Urban runoff	Cattle	other Unknown	Goose	Springs	Total
Base load (%)	9.86E+09 (3%)	0.00	0.00	0.00	0.00	2.97E+11 (97%)	3.07E+11 (100%)
Surface load (%)	0.00	1.34E+11 (6%)	3.01E+11 (14%)	1.28 E+12 (61%)	3.71E+11 (18%)	0.00	2.09E+12 (100%)
Total load (%)	9.86E+09 (0%)	1.34E+11 (6%)	3.01E+11 (13%)	1.28E+12 (54%)	3.71E+11 (15%)	2.97E+11 (12%)	2.39E+12 (100%)

Table 19. Average predicted daily loadings at RD215, by source

	Actual Northwest WTTP	Urban runoff	Cattle	other Unknown	Goose	Springs	Total
Base load (%)	3.45E+09 (2%)	0.00	0.00	0.00	0.00	1.54E+11 (98%)	1.57E+11 (100%)
Surface load (%)	0.00	8.46E+10 (2%)	5.43E+11 (14%)	2.53E+12 (66%)	6.59E+11 (17%)	0.00	3.82E+12 (100%)
Total load (%)	3.45E+09 (0%)	8.46E+10 (2%)	5.43E+11 (14%)	2.53E+12 (64%)	6.59E+11 (17%)	1.54E+11 (4%)	3.98E+12 (100%)

Table 20. Average measured load fraction in each host class during the 2004 recreation season

	Sewage	Septic	Cattle	Horses	Goose	Unknown	Total
FR 129	12%	2%	9%	10%	16%	52%	100%
RD 215	9%	2%	18%	12%	31%	27%	100%

This analysis indicates that the wastewater treatment plant contributes only 3% of the base load at FR 129. Given that the bacterial source tracking shows that 12% of the load is caused by sewage, it necessarily means that there are other sources of sewage than the Northwest WWTP in the watershed. Unfortunately, the pathways from surface loadings to spring flow or groundwater are more difficult to track and there is a lack of understanding how bacteria survives and moves in and through the soil. The recharge areas of the springs are not all known and there is a lack of information on flow and water quality characteristics of the spring flow.

A strict comparison of these tables is not possible because urban runoff and spring flow were not described per se as hosts in the rep PCR database. Urban runoff is likely to contain many isolates from the unknown category (dogs, cats, urban birds, rodents, etc.). Spring flow is likely to contain all sources of bacteria included in the database as well as others. Bacterial source tracking of urban runoff and spring flow could provide the missing information.

During storm events, the average daily loading increases by more than one order of magnitude at both sites. The main sources during storm flow conditions are the surface loadings: cattle and other unknown surface loadings (76 to 81%), goose (18%), and urban pollution (2% at RD215, 6% at FR129). Apart from the impact of urban runoff, there are more cattle and goose, and less unknown loadings predicted by the model at the downstream site.

Margin of Safety (MOS)

The measurement and simulation of fecal coliform concentrations and nutrient concentrations are full of uncertainties and possible sources of errors including:

- 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, and
- the potential decay or growth of bacteria between the time of sampling and the time of analysis.

There is also some uncertainty in the estimation of the load capacity that is due to the daily variation of flow. Various methods are used to account for the inherent uncertainty of the TMDL process. Generally, a margin of safety (MOS) is applied. The MOS could be explicit (e.g. 10% lower than the load allocation) or implicit by using conservative estimates of source loading. In this case, we have used a conservative estimate of the loadings and we have calculated a confidence interval that takes into account the daily variability of the load estimation. This 95% confidence interval is calculated as:

$$1.96 * (\sigma / \sqrt{N})$$

where σ is the standard deviation of the daily load capacity, and N is the number of values on which the average is based (here 2140 or 10 years of 214 days from April1 to October 31). It represents the 95% variation of the daily load capacity given the natural variability of flow in the Little Sac River.

Uncertainties and Potential Sources of Error

Bacterial Source Tracking Uncertainties

The results of a Jacknife analysis of the Little Sac bacterial source tracking library of known patterns are shown in Table 21. These results indicate the frequency of correct identification when one pattern is removed from the database and presented as an unknown. They also indicate to what class these patterns were attributed when incorrectly identified.

Table 21. Jacknife analysis of the Little Sac library

	[sewage]	[horse]	[goose]	[cattle]	[septic]
[sewage]	**73.4**	4.3	3.4	1.5	2.0
[horse]	7.3	**90.4**	2.4	3.9	0.5
[goose]	12.1	2.4	**90.0**	2.4	0.0
[cattle]	2.4	2.4	3.4	**91.8**	0.0
[septic]	4.8	0.5	1.0	0.5	**97.5**
[total]	100.0	100.0	100.0	100.0	100.0

The bold numbers represent the percentage of correct identification

The horse, goose, cattle, and septic patterns were correctly identified 90% or more of the time. Only the sewage patterns were incorrectly identified more than 25% of the time, and when incorrectly identified it was most often attributed to goose. This may be due to the greater diversity of patterns in the sewage class due to the wide variation of diets among people in a city and the variety of waste being flushed through the system (pet waste for example).

Currently the library holds 200 patterns per host class, an amount that is comparable to what has been used in some published studies (Hassan et al., 2005). However, some authors now advocate 600 to 1000 patterns per host class (Sadowsky, 2006). To improve on the current results, additional samples could be collected in the landscape to obtain more patterns in each class. In addition, the samples should respect the diversity of patterns within each source. Ideally, samples should be collected from many septic tanks, many cattle production operations, and many horse ranches. One should keep in mind that it is also important to include an equal number of patterns in each of them.

In addition to more patterns in each class, additional classes could be characterized. At both sites, a large percentage of the patterns extracted from water samples could not be identified with sufficient certainty (51% at the upstream site, and 34% at the downstream site) and were classified as unknown. The five classes selected in this analysis were indicated as the preferable classes to include during a meeting with the steering committee after presentations of the possibilities and limitations of the methodology were made. One has to keep in mind the costs associated with additional classes and the limitations of the pattern matching software when many different host classes are present. While it is impossible to characterize all the sources in a watershed of this size, possible additional host classes are wildlife (deer, rodents, other types of wild birds) and pets (dogs). One option is also to characterize urban runoff as one class by itself.

Another source of uncertainty is the variation of sources from sample to sample. Water samples were collected weekly at each site and 20 colonies were randomly selected for identification. The percentages result from the distribution of sources within these 20 colonies, averaged over all the samples collected. The results show some variation across the samples (Table 22 and 23) but the 95% confidence intervals of the mean percentages over all the samples indicate that these values are nevertheless useful indications of what can be expected.

Table 22. Variations of sources distribution across the samples collected at FR129

	cattle	equine	goose	sewer	septic	other
Mean percentage	9%	7%	15%	16%	2%	51%
MAX	35%	25%	50%	58%	11%	100%
MIN	0%	0%	0%	0%	0%	6%
STDEV	9%	7%	14%	14%	4%	22%
95% confidence interval of the mean	**3%**	**2%**	**5%**	**4%**	**1%**	**7%**

Table 23. Variations of sources distribution across the samples collected at RD215

	cattle	equine	goose	sewer	septic	other
Average percentage	14%	10%	27%	13%	2%	34%
MAX	32%	44%	90%	74%	11%	73%
MIN	0%	0%	0%	0%	0%	0%
STDEV	8%	11%	18%	15%	3%	17%
95% confidence interval of the mean	**3%**	**4%**	**6%**	**5%**	**1%**	**5%**

In summary, although bacterial source tracking has some inherent uncertainties associated with the methodology, the results are sufficiently consistent that what they indicate can be used to define and direct some preliminary actions. To further reduce the uncertainties and with additional funding, the size of the library can be increased both in terms of number of classes and in the number of patterns per class.

Need for additional data

During the development of the model, it became clear that, in spite of springs playing a critical role in the watershed hydrology (flow and water quality), there are little existing data about them. More flow and water quality data are needed to characterize these springs. They are especially important in the upstream part of the watershed because they constitute the major part of the base flow of the Little Sac River at Farm Road 129. One possibility could be to start monitoring the largest springs during base flow and storm flow. After reviewing the data collected at these sites, recommendations should be made about monitoring secondary springs. Should the monitoring of these springs show that there is a water quality problem, it will be critical to determine the source of the contamination and the spring recharge area in order to develop an effective protection plan.

Another need uncovered during the development of the model is the characterization of urban runoff water quality. There are very few studies on this topic and the study sites were located in different states (Wisconsin). The results may or may not be transferable to Missouri and the city of Springfield. Regarding the bacteria concentration of urban runoff, we have used the available local data. The samples collected and analyzed for fecal coliform by the City of Springfield were from various sites. We chose to use the average bacteria concentration obtained from these samples and assign that average concentration (549 colonies/100ml) to all urban runoff. However, other studies indicate much higher concentration of fecal coliform in urban runoff (as much as 50,000 colonies/100ml, [Nationwide Urban Runoff Program, EPA 1983], 5,000 colonies/100ml [Wright Water Engineers, 2006], or anywhere from 100 to 240,000 colonies/100 ml [Salmore et al., 2006]). Studies generally indicate a very large variation from sample to sample. There is a need to characterize urban runoff bacteria content in Springfield and understand how it varies with other factors such as time since the last rain event, temperature, rain depth, population density, and percent of impervious area.

Finally there is a need to measure stream bacteria concentration during runoff events. While we know that they are likely to be much higher than during base flow, it is difficult to obtain enough runoff event samples to have a good estimate of typical runoff events concentrations. Sampling runoff events on a regular basis requires the use of a refrigerated auto-sampler. It is complicated by the fact that samples need to be transported to the laboratory and analyzed within 6 hours.

Model Uncertainties

The model reflects the uncertainties that exist in the available data. In the absence of good water quality data that characterize the springs and with some data indicating that the springs may be contaminated, we selected that option to be represented in the model. Another possibility would be that direct, illegal pipes discharge contaminated effluent in the stream. Similarly, available data do not allow us to determine whether cattle and horses (and potentially other wildlife) contaminate the streams because they have direct access to it or whether the bacteria moves from the ground surface to the groundwater through preferential paths such as sinkholes and cracks in the soil profile. The current model gives preference to a contamination of the springs and does not include any direct, illegal discharge or direct deposits from animals.

The SWAT model is limited in its abilities to completely represent springs. Spring flow is considered a point discharge. In this case, the flow is specified monthly. However, there is evidence that spring flow varies as a function of rain events, although with a greater delay than surface runoff does. Such representation is not currently possible in this model. Similarly, spring water quality is characterized in the model by a constant pollutant concentration even though the evidence shows that these concentrations vary with rain events.

Finally, there is limited knowledge about bacteria survival in the soil and in groundwater. Preliminary studies suggest that bacteria can survive longer because of the lack of light and a constant cool temperature. As additional knowledge is verified and accepted by the scientific community, it can be incorporated in models like SWAT.

TMDL Results and Required Load Reduction

Results are presented in Table 24. In that table, the load capacity (LC) is what would be present in the stream if the fecal coliform concentration was 200 colonies/100 ml. The margin of safety (MOS) is estimated as explained above. The waste load allocation (WLA) is estimated from the design flow of the Northwest WWTP and the permitted monthly average of the daily fecal coliform concentration in the outflow (Table 17). The non-point source load allocation (LA) is estimated as the load capacity less the margin of safety and the waste load allocation.

Table 24. Fecal coliform load allocation and percent reduction needed to meet water quality standards, by flow condition

	Base flows (more than 83% of total flow is base flow)		Medium flows (base flow is less than 83% but more than 53% of total flow)		Extreme flows (base flow is less than 53% of total flow)	
Location	FR 129	RD 215	FR 129	RD 215	FR 129	RD 215
Load capacity (colonies/day)	1.90E+11	4.38E+11	2.54E+11	5.09E+11	1.34E+12	3.17E+12
MOS (colonies/day)	1.14E+10	2.73E+10	2.02E+10	4.79E+10	1.06E+11	5.62E+11
Waste load allocation (colonies/day)	9.47E+10	9.47E+10	9.47E+10	9.47E+10	9.47E+10	9.47E+10
Load allocation (colonies/day)	8.36E+10	3.16E+11	1.40E+11	3.66E+11	1.14E+12	2.51E+12
Current load from data (colonies/day)	NA	2.48E+11	NA	5.78E+11	NA	2.94E+12
Current load from model (colonies/day)	5.09E+11	6.76E+11	2.03E+12	2.20E+12	9.42E+12	1.16E+13
Reduction (colonies/day)	3.31E+11	[0; 2.65E+11][a]	1.80E+12	[1.17E+11; 1.73E+12][a]	8.19E+12	[3.30E+11; 9.04E+12][a]
Reduction (%)	65%	[0; 39%][a]	88%	[20%; 79%][a]	87%	[11%; 78%][a]

[a] The first number represents the reduction needed from the load estimated with measured data, the second number represents the reduction needed from the load estimated with the model.

The reduction in non-point source loadings required to meet the required water quality criteria and taking into account the margin of safety is calculated as:

Reduction = current load – LC + MOS

It is also equal to: Reduction = current load – LA – WLA

Results are presented for three flow ranges because the sources, the magnitude of the loads, and therefore the remediation means are different. Base flow conditions are defined by more than 83% of the total flow being from base flow. It includes dry conditions and small events. Medium flow conditions are characterized by base flow being between 53% and 83% of total flow. Extreme flows conditions are caused by large storms.

The current load can be estimated from measured data when both bacteria concentration and flow measurements are available (RD 215). Observed data sets, including this one, are sparsely collected because of resource constraints. Limitations in the information content occur due to this sparse sampling. The gaps that exist between each water quality sample are very important for water quality constituents that vary quickly in time, such as bacteria concentrations. They often lead to under estimations of the loadings. Otherwise, the current load can be estimated with the model. The current load estimated with measured data at RD215 shows that the daily load at base flow appears to not exceed the load capacity. However, when estimated with the model, it exceeds the load capacity. No estimate from measured data is possible at FR129 because the flows are not measured there.

Seasonal Variation

Little Sac River is designated for whole body contact recreation during the period from April 1 to October 31. From spring to summer, human activities increase in and around the stream, cattle contributions increase from calves becoming young steers, and geese contributions increase from eggs hatching in the spring and young goslings growing through the season.

The bacterial sources do reflect these variations, with goose contributions varying according to their seasonal activities and population densities. However, the measured fecal coliform concentrations did not indicate any variation from season to season and there is no reason to introduce a seasonal variation in the maximum daily load.

Monitoring Plans

Monitoring fecal coliform concentrations and the bacterial source tracking that were undertaken in this study have been terminated at the end of October 2004. Additional water quality monitoring is needed to further define the sources of bacteria and their comparative magnitude. Future monitoring efforts could also track changes in the bacteria loading as ongoing and planned efforts outlined in the Implementation Plan continue.

Monitoring the flows of the Little Sac River at RD215 is under the responsibility of USGS and will likely be on-going. The following water quality monitoring will likely also be on-going:

- Monitoring by MDNR at several sites on the river.
- Monitoring of swimming holes by the Greene County Department of Health. One of these site is located on the Little Sac River at Farm Road 125, very close to the FR129 site.
- Monitoring by USGS at the Walnut Grove site, west of the landfill, on Route BB.
- Weekly monitoring by the Watershed Committee of the Ozarks at 23 sites from 2004 to 2007.

Ongoing monitoring efforts should include testing for both fecal coliform and *E. coli* bacteria. A revision to the Missouri Water Quality Standards was adopted in November 2005 that includes both the existing fecal coliform criterion and the new *E. coli* criterion of 126 colonies/100ml for the Whole Body Contact-A designated use. The fecal coliform criterion is to be phased out by the end of 2008 and replaced by the *E. coli* criterion. However testing for fecal coliform should still be included for easy comparison with past studies.

The following additional monitoring is needed but will be dependent on procurement of funding.

- The Adopt-A-Spring program coordinated by the Watershed Committee of the Ozarks provides some data about a few springs in the Little Sac River Watershed. Given that the spring loads may be a significant source of bacterial contamination in the river, a more systematic monitoring of the springs in the little Sac watershed should be considered in future monitoring plans. This monitoring would show whether the contamination at base flow is caused by the contamination of the springs or from direct inputs to the stream (illegal discharges, cattle in streams, wildlife). The sources of contamination of the springs could be determined using rep-PCR bacterial source tracking with the database that was developed in this study. Such determination would confirm or disprove that the sources are similar to the sources that have been identified in the river. Spring monitoring efforts could be prioritized according to their flow contribution. Monitoring should include water quality and flow monitoring and better definition of recharge areas.

- Sediment sampling, including bacterial source tracking for source determination, should be considered to investigate the possibility of storage in river bed sediment of bacteria and its subsequent re-suspension during storm events.

Implementation

Efforts have already occurred in the Little Sac River Watershed to deal with excessive nutrients and bacteria reaching the creek. From 1992 to 1998, an EPA 319 grant provided education on agricultural management practices and on-site wastewater systems in the drainage areas of the Fellows and McDaniel Lakes. The grant supplied funding for the demonstration of management practices, water quality monitoring, and education/outreach activities. From 1995 to 2000, a different project, also funded with 319 funds, addressed the issues of storm water runoff and urban development impacts upon the water quality of Fulbright Spring. Another 319 project started in 2004 addresses the whole Little Sac River Watershed. It addresses the issues of nutrients and bacteria through water quality monitoring, education/outreach, and implementation of cost-shared practices including alternative watering systems for livestock, stream bank stabilization, managed grazing systems, fencing wooded areas, plugging abandoned wells, spring developments, seeding to native grasses, and sinkholes protection.

Several Agricultural Non-Point Source Special Area Land Treatment (AgNPS-SALT) projects are and have been conducted by the Greene and Polk County SWCDs in the Little Sac River Watershed. The Middle Little Sac River AgNPS-SALT project (2001-2007) aims to improve water quality in the middle section of the watershed and provides 75% cost-share for practices similar to what is proposed in the most recent 319 project, described above. The Upper Little Sac River AgNPS-SALT project (1997-2002) aimed to maintain the quality of the drinking water resources (Fellows and McDaniel Lakes, Fulbright Spring) while enhancing economic sustainability for agricultural producers through education and improved land management practices.

In 1995, the City of Springfield began its Infiltration and Inflow (I/I) Program with a primary objective to reduce to the maximum extent practicable the occurrence of sanitary sewer overflows. A Sewer System Evaluation Survey was completed system wide in 2003. Since the inception of the program, the City has committed over $16 million to fund the program, resulting in rehabilitation of 64,559 linear feet of sanitary sewer lines and 12,583 manholes. Currently, approximately 11,000 linear feet of the Pea Ridge trunk sewer, located in the Pea Ridge tributary watershed of the Little Sac watershed, is being reconstructed to reduce I/I and sanitary sewer overflows. Ten percent of annual sanitary sewer revenues are earmarked to finance ongoing I/I reduction efforts.

The City of Springfield has implemented a variety of efforts to address the quality of urban runoff. In 1999, Springfield City Council enacted the Water Quality Protection Policy that requires all new developments in sensitive watersheds, including the South Dry Sac and Pea Ridge tributaries of the Little Sac River, as well as in sinkhole watersheds, to be designed with BMPs that minimize the effects of urban runoff on the quality of receiving waters. In 2005, the City extended the requirement for BMPs on all new developments citywide through the implementation of its revised Storm Water Drainage Design Criteria Manual. Since receiving its National Pollutant Discharge Elimination System (NPDES) Storm Water Permit in 2002, the City has implemented a variety of activities to address storm water quality including public education, illicit discharge detection and elimination, stream and runoff monitoring, inspection of industries, and others. In fall 2006, the Springfield-Greene County Parks Department is proposing a countywide sales tax, a portion of which will fund waterways improvements aimed at reducing sediment, bacteria, and nutrient loading. The proposed improvements include projects located in the Pea Ridge watershed.

The results in Table 24 show that at FR129, the loads need to be reduced by 70 to 90%. The first step to achieve that reduction is to reduce the loads from the spring flows by that amount. A second step is to address the transport of bacteria with storm runoff.

Several scenarios were run to illustrate how alternative management practices can 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/100 ml. The following scenarios were considered:

- scenario 1: an 85% reduction of the spring bacterial contamination,
- scenario 2: scenario 1 + a 30% reduction of the goose contribution, and
- scenario 3: scenario 2 and a 50% reduction of urban storm runoff contributions.

The reduction of the springs' bacterial contamination is considered here because it has been determined that they are responsible for more than 97% of the load at FR129 at base flow. This determination is based on the data that is currently available. As additional springs monitoring data better characterize their water quality, this will be updated.

A 30% reduction of the goose population back is a starting point for the purpose of estimating what it would do on the general bacteria levels in the watershed. A publication by the Missouri Conservation Commission gives details about giant Canada geese and the methods used to control their numbers (MDC, 2002). Canada goose control activities include habitat modification, exclusion, harassment, chemical repellents, and lethal control.

Reductions of urban runoff fecal coliform loadings to the stream can be attained with detention basins or with edge-of-impervious-area vegetation buffer strips. The 50% reduction is also a starting point for the purpose of estimating what it would do on the stream bacteria concentrations. As mentioned earlier, several efforts are already directed at encouraging enhanced urban designs that minimize urban runoff.

The frequency curves that result from the simulation of the scenarios with the model are shown in Figure 12 and 13. Table 25 summarizes the how often the 30-day geometric mean is greater than 200 colonies/100ml. Assuming the hypothesis that the springs themselves are contaminated, scenario 1 would bring the most improvement. If the base flow concentrations can be controlled by addressing spring flow contamination, concentrations below 200 colonies/100 ml will be assured 70% of the time, compared to 3% in the current conditions. The geometric mean would be below that concentration 66% of the time compared to almost never in the current conditions. The reduction of the contamination from geese and from urban areas will help storm flows. Further reduction can be achieved by reducing the bacterial load of storm runoff from rural areas.

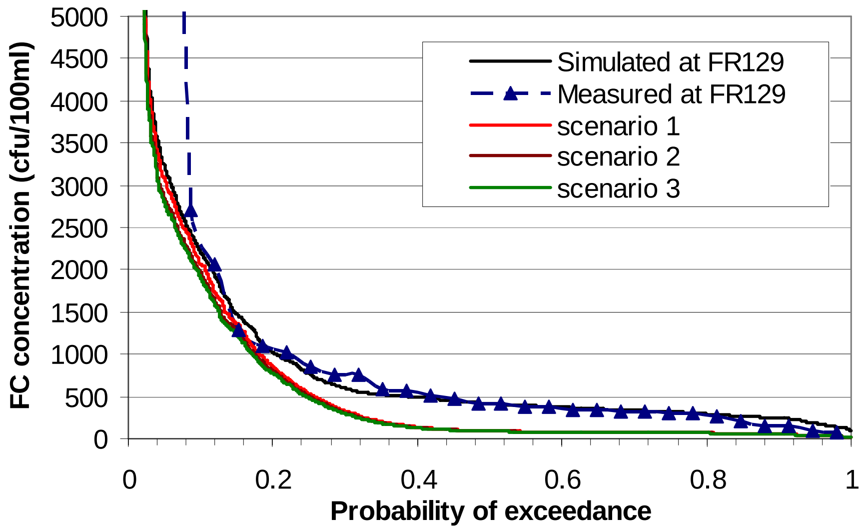

Figure 12. Comparison of the concentration frequency curves from scenarios 1 to 3 at FR129

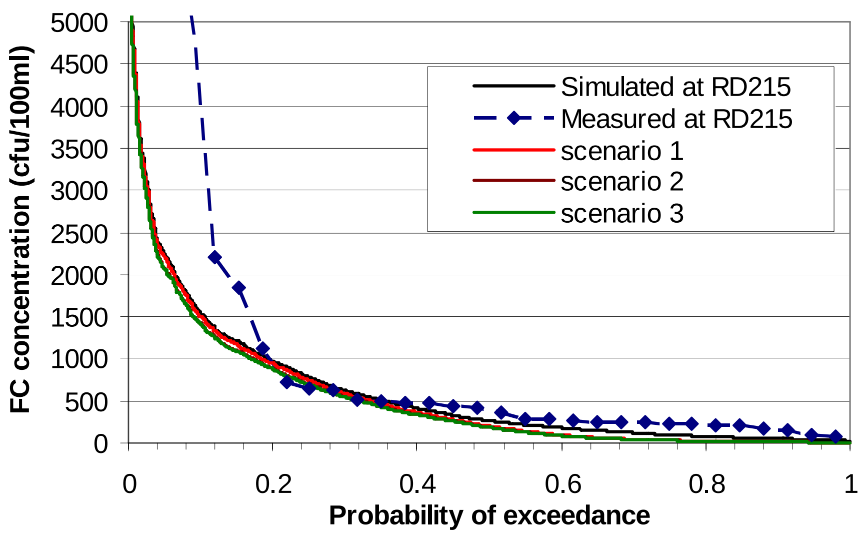

Figure 13. Comparison of the concentration frequency curves from scenarios 1 to 3 at RD215

Table 25. Bacteria allocation scenarios for the Little Sac watershed.

	% Violation of WQS[a] criterion		Reduction in Fecal coliform loadings to the stream (%)				
Scenario ID	30-day Geomean 200 col/100ml	Single sample 400 col/100ml	Springs	Geese	Urban runoff	Cattle & horses	Septics
Baseline	99%	54%	0%	0%	0%	0%	0%
1	44%	28%	85%	0%	0%	0%	0%
2	42%	27%	85%	30%	0%	0%	0%
3	41%	27%	85%	30%	50%	0%	0%

[a]Water Quality Standard

We cannot simulate the impact of disinfecting effluent from the Northwest WWTP year round on the fecal coliform concentration during the recreation season because SWAT does not simulate the survival of bacteria in stream bed sediments and their subsequent re-suspension during storm events. However, if sediment sampling shows that significant amounts of bacteria survive or grow in stream bed sediment, it may be worthwhile to disinfect the effluent year-round. Determining the source of the bacteria can confirm that they originated from sewage.

Economic considerations

The following considers what the costs and consequences may be of meeting and not meeting the bacteria water quality criteria in the Little Sac River. Our initial plan was to use the existing economic analyses from the Shoal Creek area farms and from the 10 southwest Missouri counties to provide a general assessment of economic impacts. However, the issues in the Little Sac River Watershed are different than in Shoal Creek. Results from bacterial source tracking point to sewage and wildlife as primary sources of bacteria. Livestock is secondary and poultry is not a big issue as only a few turkey operations exist in a small part of the watershed.

Cost of not meeting the water quality criteria

The use that is impaired by high concentrations of bacterial is the recreational use of the river. The problem is heightened by the unusual quantities of identified pathogens that we found in the water and the landscape samples (Baffaut, 2005): *Plesiomonas shigelloides, E. coli* 0157:H7, enteropathogenic *E.coli*-AD, *Klebsiella pneumoniae,* and *Aeromonas caviae*. The health impacts of these organisms include gastro-enteritis in humans and cattle. Although not life-threatening to otherwise healthy individuals, it can be more serious in people with a weak immune system: young, elderly, and people with a chronic disease. An epidemiologic study or even a count estimate for these pathogens are beyond the scope of this analysis but would be required to infer a rate of illness and an associated cost. A 1997 study reports the isolation of *Plesiomonas shigelloides* in catfish filets, which would indicate the potential transmission of this pathogen through fish consumption. However, one can assume that if the fish is cooked, the risk of contamination is minimal.

Cost of meeting the water quality criteria

The origins of the bacteria found in the river are one or a combination of:

1. Groundwater contamination through sinkholes and other karst features
2. Direct illegal connections
3. Leaks from the Springfield sewer system
4. Direct deposits from livestock and wildlife
5. Re-suspension of bacteria buried in sediments
6. Storm runoff bacteria

Contamination pathways 1 to 4 may exist all the time, sources 5 and 6 can only be present during or shortly after storm events. The bacterial source tracking results in the little Sac River watershed also pointed to a large amount of unknown sources. These sources are likely to be wildlife not included in our database (deer, small rodents, resident or other wild birds), pets from urban areas, or septic tanks. It is less likely to be from geese, cattle, horse, or waste water sewage because these classes were well described in our database.

The analysis of the available water quality data suggest that a significant amount of bacteria makes its way to the groundwater and resurfaces in spring water. The groundwater contamination pathways may be through sinkholes or through cracks typical of karst geology. Loading estimates derived from this scarce data show that it could be sufficient to explain the low flow concentrations measured in the Little Sac River.

The measures that may reduce the bacterial loadings are presented in Table 26 along with the pathway through which it affects the water in the river. Table 27 shows unit costs of the reduction measures for which we were able to determine one.

Table 26. Potential bacteria loading reduction methods in the Little Sac River Watershed

	Reduction measure	*How it affects bacteria loading in the stream*
1.	Reduction of the geese population	Directs deposits, storm runoff
2.	Sewer system inspection and repair	Leaks to the groundwater
3.	Stream exclusion for cattle and horses	Direct deposits
4.	Storm runoff detention ponds	Urban runoff
5.	Buffers	Surface runoff
6.	Septic tanks maintenance and repair	Groundwater contamination
7.	Sinkhole protection from cattle and horse	Groundwater contamination
8.	Detection and elimination of illegal discharges	Direct deposits
9.	Year-round disinfection of WWTP outflow	Re-suspension of buried bacteria
10.	Education and outreach	Direct deposits, storm runoff, groundwater contamination

Measures 1, 4 and 5 will definitely reduce the bacteria loadings at low flow (measure 1 only) and during storm events. A reduction of the geese population (measure 1) will reduce the bacteria loadings in the stream even though we are not certain how bacteria from geese reach the stream (direct deposit or storm runoff). Measured 4 and 5, storm runoff detention ponds and buffers, can help reduce bacteria loadings in urban and rural areas. Costs for vegetative barriers and wooded riparian buffers are indicated in Table 27. These costs are based on estimates given by NRCS for Greene County (NRCS, 2005). Costs for detention ponds depend on the size of the pond and the specific conditions of the site. They are based on land acquisition costs and also carry long-term maintenance costs. Estimates for typical overall cost per acre and maintenance are given in Table 27. Measure 10, education and outreach, could help reduce bacteria loadings in the stream at both base flow and storm flow conditions by providing information to property owners in the watershed on agricultural and urban storm water runoff best management practices.

Whether the other potential measures will help depends on how the bacteria reach the stream. For sewage, the economic assessment is contingent on the identification of the sewage sources (leaks, septic tanks, burying of bacteria in sediment, or illegal connections). If we assume untreated winter outflow from the WWTP is the source of bacteria buried in sediment, then the cost is essentially the additional cost of year round treatment. This can be estimated to $11,476 per year in addition to the current cost of $16,264, i.e.; a 70% increase (see Appendix H). If we assume the source is from septic systems and other human sources, the costs are impossible to estimate with any accuracy without narrowing down the source of the waste. However, we include as an indication in Table 27 the costs of septic tank inspection, pumping, and replacement. We also include the cost of water sample analysis; intensive bacteria and nutrient sampling along the stream can provide information that leads to the identification of illegal discharges. Water sample analysis costs are based on the price list from the University of Missouri Soil and Plant Testing Laboratory.

For livestock, it is contingent on the identification of the mode of contamination: direct deposits, grazing in sinkholes areas, surface runoff transport. If we discover that most of the contamination from cattle and horses is due to animals being in the stream to drink, it can be solved by excluding them from the stream. Costs of fencing are included in Table 27. If we think that grazing occurring in sinkholes areas is the source, education and exclusion from these areas might help. The associated costs would be for fencing and for vegetative barriers. Otherwise, well-designed buffers (vegetative barriers and riparian buffers) can filter the surface runoff from the pastures.

Table 27. Costs of measures to reduce bacteria loadings

Reduction measure	*Costs*	
Reduction of the geese population	Unknown but a goal of MDC	
Sewer system inspection and repair		
Septic tank inspection	$350.00 per tank	
Septic tank pumping (maintenance)	$85.00 - $150.00 per tank	
Septic tanks replacement (with installation)	$4,000.00	conventional system
	$12,000.00	advanced system adapted to karst
Stream and sinkhole exclusion (fencing)	$1.38 - $1.79 per linear foot of barbed wire fencing	
Vegetative buffer	$20.00 - $50.00 per acre	
Riparian wooded buffers	$800.00 - $1000.00 per acre	
Storm runoff detention ponds		
Excavation, grading, seeding, erosion control	$3.00 - $4.00 per cu.yd = $15,000 - $24,000/acre	
Concrete work	$227.00 - $336.00 per cu.yd x 5 - 10 cu.yd/acre	
	$1,135 – 3,360/acre	
Land acquisition	$5,000 - $100,000 / acre	
Total Construction Cost (low to average land acquisition cost)	$20,000 - $80,000 / acre	
Maintenance Cost	$1,000/acre/year	
Water sampling Nutrient and bacteria analysis	$20.00 - $30.00 / sample for analysis	
Bacterial Source Tracking	$50.00 - $100.00 / isolate for analysis	
Year-round disinfection of WWTP outflow	$11,476 per year	

Questions that need to be addressed to narrow down the possibilities of contamination pathways include:

1. The magnitude and the sources of fecal contamination in the springs. The cost of such a project would depend on the number of springs being sampled and the frequency of the sampling. The comparison of the spring and the stream contamination will provide an estimate of bacteria loadings from direct deposits.

2. Whether bacteria loading released at the Northwest WWTP in winter are stored in river sediment and released by spring storm events. A study by Jamieson et al. (2005) showed that enteric bacteria can survive in bed sediment for longer periods than in water. Sediment sampling and bacterial source tracking are required to determine the source of bacteria in sediment.

Reasonable Assurances

The numerous past and current projects in the Little Sac River Watershed demonstrate the interest that the stakeholders have in the water quality of their stream. Other projects, not directly related to the Little Sac watershed, are managed by the City of Springfield with the participation of the Watershed Committee of the Ozarks. One project, the Show-Me Yards addresses residential lawns and gardens. Its aim is to reduce nutrient and other pollutant runoff from backyards. Another project demonstrates new urban development techniques to minimize runoff and runoff pollution from urban areas. The new watershed center at Valley Mill will provide numerous opportunities for education and demonstration. Two aspects need to be addressed more specifically: the contribution from geese, and the contamination of the springs.

Given all this activity, it is likely that the water quality in the Little Sac watershed will improve. Regarding the Northwest WWTP and other permitted facilities that discharge into the Little Sac River or its tributaries, the department has the authority to write and enforce NPDES permits. Inclusion of effluent limits into a state NPDES permit, and daily monitoring of the effluent reported to the department, should provide reasonable assurance that in stream water quality standards will be met. Both bacterial source tracking results and model results have shown that the current discharge from the WWTP is not a significant source of contamination during the recreation season. The current outflow fecal coliform concentration has been estimated at 72 colonies/100 ml on average. However, model results when the WWTP outflow fecal coliform concentration increases to 400 and 1000 colonies/100 ml (the average monthly and maximum daily limits given in the permit, respectively) show that it would significantly increase the stream concentrations at base flow (Figure 14). In addition, the possible storage in river bed sediment of bacteria released during the winter and subsequently re-suspended during storm events needs to be investigated.

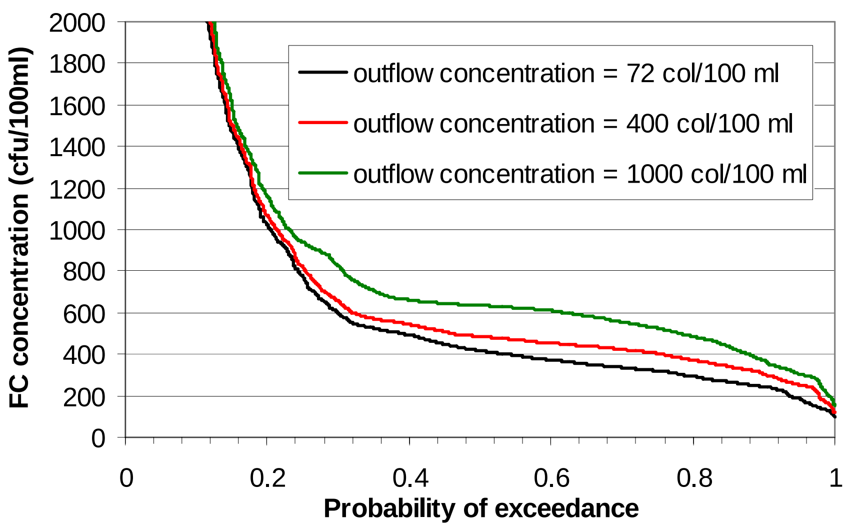

Figure 14. Simulated impact of the concentration of the Northwest WWTP outflow on stream concentrations

Public Participation

Several steering committees meetings took place in Morrisville to explain the purpose of the TMDL and the process of developing it, and to provide input to FAPRI's study. In addition, three public meetings took place in Springfield on December 1, 2004, and February 4 and May 3, 2005. The purpose of these meetings was to present the results of the bacterial source tracking, familiarize citizens and government personnel with the TMDL concept and development, and present the load allocations. These meetings also provided opportunities for citizens and local agencies to provide input and feedback into the implementation plan.

Summary and Conclusions

Results of this study indicate that 25 % to 50 % of the samples collected during the 2004 recreation season 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 showed that the hosts of these bacteria colonies include the following sources present in the watershed: cattle, sewage, geese, and horses. At Farm Road 129, 15% of the bacteria were attributed to geese, 16% to sewage, 9% to cattle, 7% to horses, and 2% to septic. At Farm Road 215, 27% of the bacteria were attributed to geese, 13% to sewage, 14% to cattle, 10% to horses, and 2% to septic. However, more than half (51%) of the fecal coliform at Farm Road 129 and 34% at Road 215 could not be identified with our database. Only 3% of the bacteria identified as coming from sewage can be attributed to the Northwest WWTP treated effluent, implying that there are other sources of sewage.

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. The model was calibrated using long term flow data and water quality data measured in 2004.

A TMDL for each site was determined based on the simulated flows and the water quality standard of 200 colonies/100 ml. Model results show that the average daily load at FR129 needs to be reduced by 70% to 90% in order to meet the whole body contact fecal coliform criteria throughout all flow conditions. At base flow, the loadings potentially come from contamination of the springs or from direct input to streams (illegal discharges, cattle in streams, wildlife). While there are some data about these springs, the information is not as thorough as would be needed to build an accurate model of the watershed hydrology. The Northwest WWTP contributes only 2 to 4% of the average daily base load at FR129.

Alternative scenarios were run to evaluate the impact of a decrease of input loadings in the watershed. They showed that addressing the contamination of the springs would bring the most relief to the stream in terms of average daily load if it is determined that these springs are contaminated. Additional water quality monitoring is needed, particularly of the springs, to further define the sources of bacteria and their comparative significance. Future monitoring efforts could also track changes in the bacteria loadings as ongoing efforts continue.

Appendices

Appendix A - Water Quality Data
Appendix B - Hydrology Parameters
Appendix C - Lake Information
Appendix D – Management Practices
Appendix E - Spring flow derivation and water quality data
Appendix F - Information on goose
Appendix G - Urban Storm Runoff
Appendic H – Estimation of UV disinfection costs

References

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

Baffaut C. and W. Rogers. 2005. Little Sac River Watershed – Bacterial Source Tracking Analysis, Food and Agricultural Policy Research Institute, University of Missouri, FAPRI-UNC Report #06-05, April 2005.

City of Springfield. 2003. NPDES Storm Water Permit Annual Report 2002-2003, http://www.ci.springfield.mo.us/egov/publicworks/storm_water/stormwater_docs.html.

City of Springfield. 2004. NPDES Storm Water Permit Annual Report 2003-2004, http://www.ci.springfield.mo.us/egov/publicworks/storm_water/stormwater_docs.html.

Chow V.T. 1988. *Open-channel Hydraulics*. Second Edition. McGraw-Hill. New York.

Crane S.R. and J.A. Moore. 1986. Modeling enteric bacterial die-off: A review. *Water, Air, and Soil Pollution* 27(1986):411-439.

Jamieson R.C., D.M. Joy, H. Lee, R. Kostaschuk, and R.J. Gordon. 2005. resuspension of Sediment-Associated *Escherechia coli* in a Natural Stream. *Journal of Environmental Quality* 2005(34):403-407.

Hassan, W.M., S.Y. Wang, and R.D. Ellender. 2005. Methods to Increase Fidelity of Repetitive Extragenic palindromic PCR Fingerprint-Based Bacterial Source Tracking Efforts, *Applied and Environmental MMicrobiology*, 71(1):512-518.

Long Island Regional Planning Board (LIRPB). 1978. *Long Island Comprehensive Waste Treatment Management Plan. Volume II: Summary Documentation*. Nassau-Suffolk Regional Planning Board, Hauppauge, NY.

Metcalf & Eddy, Inc., G. Tchobanoglous, F.L. Burton, and H.D. Stensel 2003. *Wastewater Engineering: Treatment and Reuse*. Fourth edition. McGraw-Hill. New York.

Missouri Agricultural Statistics Service. Accessed in 2005. http://agebb.missouri.edu/mass/agrifact/index.htm.

Missouri Department of Conservation, 2002. *Controlling Conflicts with Urban Canada Geese in Missouri.* Jefferson City, Missouri.

Missouri Department of Natural Resources, Division of Environmental Quality. 2002. *2002 303(d) List for Missouri*. http://www.dnr.state.mo.us/wpscd/wpcp/waterquality/303d.htm

Missouri Department of Natural Resources. 2004(a). Missouri National Pollutant Discharge Elimination System (NPDES) Facilities, vector digital data, http://msdisweb.missouri.edu/, MDNR, Water Pollution Control Program.

Missouri Department of Natural Resources. 2004(b). Missouri Springs, vector digital data, http://msdisweb.missouri.edu/, MDNR, Geological Survey and Resource Assessment.

Missouri Department of Natural Resources, Division of Geology and Land Survey. 1997. *Groundwater Resources of Missouri*. D.E. Miller and J.E. Vandike, eds. Missouri State Water Plan Series, Vol. 2. Rolla, MO.

National Agricultural Statistics Service. 2005. Quick Stats: Agricultural Statistics Database, http://www.nass.usda.gov/QuickStats/, accessed in 2005.

National Research Council. 1976. *Nutrient Requirements of Beef Cattle.* Fifth edition. Series: Nutrient requirements of domestic animals. National Academy of Sciences, Washington, D.C.

Natural resources and Conservation Service. 2005. National Protracts Costs Lists provided by the Central NTSC and ITC. http://www.programs.tx.nrcs.usda.gov/nationalcosts/, accessed in 2005.

Raedeke, A.H. and D.A. Graber. 2004. *Missouri waterfowl status, 2004.* Missouri Department of Conservation, http://www.conservation.state.mo.us/hunt/wtrfowl/reports/, accessed December 2004.

Reddy K.R., R. Kahleel, and M.R. Overcash. 1981. Behavior and transport of microbial pathogens and indicator organisms in soils treated with organic wastes. *Journal Environmental Quality* 10(3):255-266.

Salmore A.K., E.J. Hollis, and S.L. McLellan. 2006. Delineation of a chemical and biological signature for stormwater pollution in an urban river. Journal of Water Health 2006 (247-262).

Schumacher J.G. 2003. Personal communication.

Sheffield R.E., S. Mostaghini, D.H. Vaughan, E.R. Collins, and V.G. Allen. 1997. Off-stream Water Sources for grazing Cattle as a Stream Bank Stabilization and Water Quality BMP. *Transactiosn of the ASAE.* 40(3):595-604.

Sloto R.A. and M.Y. Crouse. 1996. *HYSEP: A computer program for streamflow hydrograph separation and analysis.* U.S. Geological Survey Water-Resources Investigations Report 96-4040, 46 p. or http://water.usgs.gov/software/hysep.html (Accessed in 2002).

Smith, B. 2002. Water quality in the Little Sac River near Springfield, Missouri, 1999-2001. U.S. Geological Survey Water-Resources Investigations Report 02-4154, 64p.

University of Missouri. 1997. Canada Geese- Blessing or Bane, *The Waterline, Newsletter for the lakes of Missouri Volunteers Program*, Vol.1, Number 2, September 1997.

USDA, 2004. http://soildatamart.nrcs.usda.gov/ (accessed in 2005).

USDA. 2000. National Engineering Handbook. Part 651. *Agricultural Waste Management Field Handbook*, Chapter 4: Agricultural Waste Characteristics. Washington, D.C., also available at: http://www.ftw.nrcs.usda.gov/awmfh.html (accessed May 2003).

USDA Natural Resources Conservation Service. 2002. *Land Resource Regions and Major Land Resource Areas of the United States.* Agricultural Handbook 296. USDA/NRCS, Washington, D.C.

U.S. EPA. 1983. Results of the Nationwide Urban Runoff Program, Vol. 1, Final report. NTIS PB84-185552

Virginia Department of Environmental Quality. 2002. *Fecal coliform TMDL for Naked Creek in Augusta and Rockingham Counties, Virginia.* Virginia Department of Environmental Quality, Richmond.

Wright Water Engineers, 1995. *Fullbright Spring Protection Study*. Available on the City of Springfield web site, (accessed in 2005): http://www.ci.springfield.mo.us/egov/publicworks/storm_water/stormwater_docs.html, August 1995.

Wright Water Engineers, 2006. Personal communication.

Appendix A

Water Quality Data

Table A1. Fecal coliform counts at the WWTP outlet and in Little Sac at FR129 and RD215.

Date	FC at WWTP outlet (colonies/100 ml)	FC at FR129 (1 mile from WWTP) (colonies/100 ml)	FC at RD215 (Morrisville) (colonies/100 ml)
11-19-03		NA	NA
12-15-03		90	38
1-13-04		260	69
2-17-04		500	11
3-2-04		890	55
3-9-04		12,000	1700
3-16-04		2050	340
3-23-04		410	180
3-30-04	No growth	350	1140
4-6-04	7500	320	84
4-13-04	340	102	94
4-20-04	34	410	148
4-27-04	2	340	480
5-4-04	50	320	240
5-12-04	100	300	200
5-18-04	74	420	220
5-25-04	2 (not *E. coli*)	160	260
6-1-04	34	300	2200
6-8-04	20	85	520
6-16-04	65	2700	730
6-22-04	No growth	750	500
6-29-04		260	420
7-6-04		160	215
7-13-04		850	290
7-20-04		370	620
7-27-04		590	230
8-10-04		210	250
8-17-04		1280	430
8-24-04		210	5200
8-31-04		1090	240
9-7-04		340	200
9-14-04		1030	180
9-21-04		750	360
9-28-04		370	640
10-5-04		480	470
10-12-04		14800	5200
10-19-04		570	280
10-26-04		2060	1850

Appendix B

Hydrology Parameters

Table B1. Model parameters for each land use / soil combination

Subbasin	HRU	Landuse	Soil	Fraction of watershed	Slope length (m)	Slope (m/m)	Overland Manning n	Initial residue (kg/ha)
1	1	PASTURE	MO16773000	0.412094	60.976	0.04	0.15	200
1	2	PASTURE	MO16770008	0.284905	60.976	0.04	0.15	200
1	3	FOREST	MO16770009	0.104268	60.976	0.08	0.1	400
1	4	FOREST	MO16770004	0.096957	60.976	0.16	0.1	400
1	5	FOREST	MO16715001	0.101776	60.976	0.16	0.1	400
2	1	PASTURE	MO16770012	0.811383	60.976	0.048	0.15	200
2	2	FOREST	MO16770013	0.106137	60.976	0.051	0.1	400
2	3	FOREST	MO16773002	0.08248	60.976	0.08	0.1	400
3	1	PASTURE	MO16770000	0.467808	60.976	0.045	0.15	200
3	2	PASTURE	MO16770012	0.379464	60.976	0.035	0.15	200
3	3	FOREST	MO16770009	0.081177	60.976	0.08	0.1	400
3	4	FOREST	MO16770004	0.071551	60.976	0.15	0.1	400
4	1	PASTURE	MO16770009	0.260742	60.976	0.08	0.15	200
4	2	PASTURE	MO16773008	0.229282	60.976	0.02	0.15	200
4	3	PASTURE	MO16773000	0.22734	60.976	0.03	0.15	200
4	4	FOREST	MO16770009	0.089897	60.976	0.08	0.1	400
4	5	FOREST	MO16770004	0.110993	60.976	0.15	0.1	400
4	6	FOREST	MO16715000	0.081746	60.976	0.05	0.1	200
5	1	PASTURE	MO16770008	0.802818	60.976	0.05	0.15	200
5	2	FOREST	MO16770004	0.134028	60.976	0.24	0.1	400
5	3	FOREST	MO16770008	0.063155	60.976	0.077	0.1	400
6	1	PASTURE	MO16770009	0.297234	60.976	0.08	0.15	200
6	2	PASTURE	MO16773000	0.404982	60.976	0.064	0.15	200
6	3	FOREST	MO16770009	0.096973	60.976	0.08	0.1	400
6	4	FOREST	MO16770003	0.129841	60.976	0.08	0.1	400
6	5	FOREST	MO16770010	0.07097	60.976	0.15	0.1	400
7	1	PASTURE	MO16770009	0.283402	60.976	0.08	0.15	200
7	2	PASTURE	MO16773000	0.395805	60.976	0.055	0.15	200
7	3	FOREST	MO16770003	0.320793	60.976	0.1	0.1	400
8	1	PASTURE	MO16773000	0.272663	60.976	0.05	0.15	200
8	2	PASTURE	MO16770008	0.337977	60.976	0.075	0.15	200
8	3	FOREST	MO16770009	0.11496	60.976	0.081	0.1	400
8	4	FOREST	MO16770004	0.188506	60.976	0.15	0.1	400
8	5	FOREST	MO16770008	0.085894	60.976	0.05	0.1	400
9	1	PASTURE	MO60643D	0.636167	60.976	0.08	0.15	200
9	2	FOREST	MO60640E	0.11734	60.976	0.11	0.1	400
9	3	FOREST	MO60644E	0.105493	60.976	0.05	0.1	400
9	4	FOREST	MO60643D	0.141	60.976	0.08	0.1	400
10	1	PASTURE	MO16770009	0.084605	36.585	0.08	0.15	200
10	2	PASTURE	MO16773008	0.097291	36.585	0.02	0.15	200
10	3	PASTURE	MO16770004	0.068024	36.585	0.15	0.15	200
10	4	PASTURE	MO16770008	0.093396	36.585	0.03	0.15	200
10	5	FOREST	MO16770009	0.227424	36.585	0.08	0.1	400
10	6	FOREST	MO16770004	0.429261	36.585	0.15	0.1	400

Subbasin	HRU	Landuse	Soil	Fraction of watershed	Slope length (m)	Slope (m/m)	Overland Manning n	Initial residue (kg/ha)
11	1	PASTURE	MO60643D	0.620685	60.976	0.088	0.15	200
11	2	FOREST	MO60640E	0.171357	60.976	0.088	0.1	400
11	3	FOREST	MO60643D	0.207958	60.976	0.088	0.1	400
12	1	PASTURE	MO6063D	0.313519	60.976	0.061	0.15	200
12	2	PASTURE	MO60630C	0.252191	60.976	0.065	0.15	200
12	3	PASTURE	MO6062B	0.290867	60.976	0.05	0.15	200
12	4	FOREST	MO60640E	0.0377	60.976	0.1	0.1	400
12	5	FOREST	MO6063D	0.034094	60.976	0.08	0.1	400
12	6	FOREST	MO60695	0.03464	60.976	0.061	0.1	400
12	7	FOREST	MO60643D	0.03699	60.976	0.061	0.1	400
13	1	PASTURE	MO6062B	0.253641	60.976	0.05	0.15	200
13	2	PASTURE	MO60643D	0.228824	60.976	0.052	0.15	200
13	3	PASTURE	MO6066B	0.313009	60.976	0.04	0.15	200
13	4	FOREST	MO60640E	0.056968	60.976	0.12	0.1	400
13	5	FOREST	MO60643D	0.147559	60.976	0.052	0.1	400
14	1	PASTURE	MO6069B	0.178856	60.976	0.03	0.15	200
14	2	PASTURE	MO60621B	0.170769	60.976	0.05	0.15	200
14	3	PASTURE	MO60643D	0.196671	60.976	0.07	0.15	200
14	4	FOREST	MO60640E	0.152713	60.976	0.13	0.1	400
14	5	FOREST	MO6065C	0.114359	60.976	0.05	0.1	400
14	6	FOREST	MO60643D	0.186633	60.976	0.08	0.1	400
15	1	PASTURE	MO60632C	0.208818	60.976	0.09	0.15	200
15	2	PASTURE	MO60643D	0.254296	60.976	0.091	0.15	200
15	3	FOREST	MO60640E	0.286468	60.976	0.11	0.1	400
15	4	FOREST	MO60643D	0.250419	60.976	0.07	0.1	400
16	1	PASTURE	MO6069B	0.299317	60.976	0.03	0.15	200
16	2	PASTURE	MO60643D	0.246369	60.976	0.08	0.15	200
16	3	FOREST	MO60640E	0.202993	60.976	0.14	0.1	400
16	4	FOREST	MO60643D	0.251322	60.976	0.076	0.1	400
17	1	PASTURE	MO6065C	0.783622	91.463	0.048	0.15	200
17	2	FOREST	MO6065C	0.062169	91.463	0.048	0.1	400
17	3	FOREST	MO60644E	0.094574	91.463	0.048	0.1	400
17	4	FOREST	MO60643D	0.059635	91.463	0.05	0.1	400
18	1	PASTURE	MO60683D	0.204356	60.976	0.08	0.15	200
18	2	PASTURE	MO60621B	0.120363	60.976	0.05	0.15	200
18	3	PASTURE	MO60653B	0.095419	60.976	0.05	0.15	200
18	4	PASTURE	MO60643D	0.11302	60.976	0.08	0.15	200
18	5	FOREST	MO60683D	0.316503	60.976	0.08	0.1	400
18	6	FOREST	MO60644E	0.15034	60.976	0.08	0.1	400
19	1	PASTURE	MO6065C	0.179807	60.976	0.052	0.15	200
19	2	PASTURE	MO6069B	0.212629	60.976	0.03	0.15	200
19	3	PASTURE	MO60643D	0.325184	60.976	0.065	0.15	200
19	4	FOREST	MO6065C	0.084419	60.976	0.052	0.1	400
19	5	FOREST	MO60643D	0.197961	60.976	0.052	0.1	400
20	1	PASTURE	MO60633B	0.228362	60.976	0.05	0.15	200

Subbasin	HRU	Landuse	Soil	Fraction of watershed	Slope length (m)	Slope (m/m)	Overland Manning n	Initial residue (kg/ha)
20	2	PASTURE	MO60653B	0.209869	60.976	0.05	0.15	200
20	3	PASTURE	MO60643D	0.1787	60.976	0.052	0.15	200
20	4	FOREST	MO60633B	0.045813	60.976	0.05	0.1	400
20	5	FOREST	MO60644E	0.040051	60.976	0.051	0.1	400
20	6	FOREST	MO60653B	0.084797	60.976	0.05	0.1	400
20	7	FOREST	MO60643D	0.107277	60.976	0.051	0.1	400
20	8	URBAN	MO60633B	0.022727	60.976	0.05	0.1	100
20	9	URBAN	MO60681B	0.018475	60.976	0.051	0.1	100
20	10	URBAN	MO60653B	0.03674	60.976	0.05	0.1	100
20	11	URBAN	MO60643D	0.027189	60.976	0.051	0.1	100
21	1	PASTURE	MO6065C	0.172948	60.976	0.057	0.15	200
21	2	PASTURE	MO60653B	0.239792	60.976	0.05	0.15	200
21	3	PASTURE	MO60643D	0.333803	60.976	0.06	0.15	200
21	4	FOREST	MO6065C	0.057252	60.976	0.057	0.1	400
21	5	FOREST	MO60644E	0.073881	60.976	0.057	0.1	400
21	6	FOREST	MO60643D	0.122324	60.976	0.06	0.1	400
22	1	URBAN	MO6065C	0.068964	91.463	0.048	0.1	50
22	2	URBAN	MO60681B	0.069221	91.463	0.048	0.1	50
22	3	URBAN	MO60653B	0.063629	91.463	0.048	0.1	50
22	4	URBAN	MO60643D	0.040427	91.463	0.05	0.1	50
22	5	PASTURE	MO6065C	0.094616	91.463	0.048	0.15	200
22	6	PASTURE	MO60681B	0.083659	91.463	0.048	0.15	200
22	7	PASTURE	MO60653B	0.116451	91.463	0.048	0.15	200
22	8	PASTURE	MO60643D	0.072462	91.463	0.05	0.15	200
22	9	FOREST	MO60695	0.025909	91.463	0.048	0.1	400
22	10	FOREST	MO60644E	0.040065	91.463	0.048	0.1	400
22	11	FOREST	MO60653B	0.051542	91.463	0.048	0.1	400
22	12	FOREST	MO60643D	0.061851	91.463	0.05	0.1	400
22	13	URBAN	MO6065C	0.078356	91.463	0.048	0.1	100
22	14	URBAN	MO60681B	0.043417	91.463	0.048	0.1	100
22	15	URBAN	MO60653B	0.054835	91.463	0.048	0.1	100
22	16	URBAN	MO60643D	0.034597	91.463	0.05	0.1	100
23	1	PASTURE	MO6065C	0.170961	91.463	0.037	0.15	200
23	2	PASTURE	MO6069B	0.310466	91.463	0.03	0.15	200
23	3	PASTURE	MO60681B	0.219092	91.463	0.037	0.15	200
23	4	PASTURE	MO60643D	0.141288	91.463	0.05	0.15	200
23	5	FOREST	MO6065C	0.038008	91.463	0.037	0.1	400
23	6	FOREST	MO6069B	0.050202	91.463	0.03	0.1	400
23	7	FOREST	MO60643D	0.069984	91.463	0.05	0.1	400
24	1	URBAN	MO60633B	0.063816	91.463	0.038	0.1	50
24	2	URBAN	MO6066B	0.081604	91.463	0.038	0.1	50
24	3	PASTURE	MO60633B	0.280543	91.463	0.03	0.15	200
24	4	PASTURE	MO60643D	0.272258	91.463	0.05	0.15	200
24	5	FOREST	MO60644E	0.036284	91.463	0.03	0.1	400
24	6	FOREST	MO60643D	0.052955	91.463	0.05	0.1	400

Subbasin	HRU	Landuse	Soil	Fraction of watershed	Slope length (m)	Slope (m/m)	Overland Manning n	Initial residue (kg/ha)
24	7	FOREST	MO606931	0.035794	91.463	0.02	0.1	400
24	8	URBAN	MO60633B	0.059611	91.463	0.038	0.1	100
24	9	URBAN	MO60621B	0.037382	91.463	0.038	0.1	100
24	10	URBAN	MO6066B	0.042735	91.463	0.038	0.1	100
24	11	URBAN	MO6061B	0.037019	91.463	0.03	0.1	100
25	1	PASTURE	MO16770009	0.380605	60.976	0.08	0.15	200
25	2	PASTURE	MO16770008	0.374897	60.976	0.03	0.15	200
25	3	FOREST	MO16770009	0.078657	60.976	0.08	0.1	400
25	4	FOREST	MO16770003	0.069582	60.976	0.08	0.1	400
25	5	FOREST	MO16770004	0.096259	60.976	0.15	0.1	400
26	1	PASTURE	MO16770009	0.250734	60.976	0.08	0.15	200
26	2	PASTURE	MO16773000	0.331433	60.976	0.04	0.15	200
26	3	PASTURE	MO16770008	0.234105	60.976	0.05	0.15	200
26	4	FOREST	MO16770009	0.05053	60.976	0.08	0.1	400
26	5	FOREST	MO16770003	0.043173	60.976	0.08	0.1	400
26	6	FOREST	MO16770004	0.090025	60.976	0.15	0.1	400
27	1	PASTURE	MO60655	0.074669	60.976	0.074	0.15	200
27	2	PASTURE	MO60683D	0.142778	60.976	0.09	0.15	200
27	3	PASTURE	MO60621B	0.083322	60.976	0.05	0.15	200
27	4	PASTURE	MO60653B	0.139149	60.976	0.05	0.15	200
27	5	PASTURE	MO60643D	0.12282	60.976	0.07	0.15	200
27	6	FOREST	MO60655	0.053425	60.976	0.074	0.1	400
27	7	FOREST	MO60683D	0.187238	60.976	0.1	0.1	400
27	8	FOREST	MO60644E	0.056171	60.976	0.08	0.1	400
27	9	FOREST	MO60653B	0.080013	60.976	0.05	0.1	400
27	10	FOREST	MO60643D	0.060415	60.976	0.08	0.1	400
28	1	PASTURE	MO6065C	0.185872	91.463	0.06	0.15	200
28	2	PASTURE	MO6069B	0.272257	91.463	0.03	0.15	200
28	3	PASTURE	MO60681B	0.190179	91.463	0.048	0.15	200
28	4	FOREST	MO6065C	0.111946	91.463	0.06	0.1	400
28	5	FOREST	MO6069B	0.061958	91.463	0.03	0.1	400
28	6	FOREST	MO60681B	0.06699	91.463	0.048	0.1	400
28	7	FOREST	MO60643D	0.110799	91.463	0.07	0.1	400

Table B2. Main subbasin characteristics of the Little Sac Watershed

SUBBASIN	Area (ha)	Length (m)	SLOPE (%)	Channel Width (m)	Depth (m)
1	2590	9937	6.8	9.1	0.48
2	1566	7802	5.1	6.7	0.39
3	2510	9083	5.2	8.9	0.47
4	1965	9513	6.0	7.7	0.43
5	1837	8668	7.7	7.4	0.42
6	2706	12871	7.8	9.3	0.49
7	1742	7241	7.7	7.2	0.41
8	1852	9146	8.1	7.4	0.42
9	4740	17430	8.0	13.1	0.61
10	1498	8564	10.3	6.5	0.38
11	1285	6611	8.8	6.0	0.36
12	2498	9267	6.1	8.9	0.47
13	5919	20367	5.2	14.9	0.67
14	2137	12361	6.8	8.1	0.44
15	3819	15467	9.1	11.5	0.56
16	2737	12509	7.6	9.4	0.49
17	3164	14330	4.8	10.2	0.52
18	4105	19411	7.4	12.0	0.57
19	5652	19055	5.2	14.5	0.65
20	1784	9211	5.1	7.3	0.41
21	1886	9982	5.7	7.5	0.42
22	1693	8842	4.8	7.0	0.40
23	2190	10211	3.7	8.2	0.45
24	1705	7129	3.8	7.1	0.40
25	2394	9143	6.8	8.7	0.46
26	1674	9466	6.6	7.0	0.40
27	766	6332	7.4	4.4	0.29
28	4198	13479	4.8	12.1	0.58

Table B3. Main channel characteristics of the Little Sac River Watershed

Subbasin	Channel width (m)	Channel depth (m)	Channel slope (m/m)	Channel length (km)	Manning coefficient	Hydraulic conductivity (mm/hr)	Alpha for the banks
1	39.2	3.6	0.000	8.048	0.03	5	0.750
2	6.7	0.4	0.003	0.872	0.03	5	0.750
3	8.9	0.5	0.006	1.487	0.03	5	0.750
4	7.7	0.4	0.005	2.829	0.03	5	0.750
5	18.3	0.8	0.002	5.708	0.03	5	0.750
6	32.2	3.0	0.001	9.323	0.03	5	0.750
7	13.0	1.6	0.003	4.064	0.03	5	0.750
8	15.1	1.8	0.002	5.103	0.03	5	0.750
9	24.4	2.6	0.002	11.591	0.03	5	0.750
10	6.5	0.4	0.007	1.562	0.03	5	0.750
11	12.7	1.6	0.003	3.646	0.03	5	0.750
12	8.9	0.5	0.005	2.170	0.03	5	0.750
13	9.5	1.3	0.004	12.948	0.03	5	0.750
14	8.1	0.4	0.006	3.285	0.03	5	0.750
15	11.5	0.6	0.004	7.602	0.03	5	0.750
16	9.4	0.5	0.005	6.847	0.03	5	0.750
17	10.2	0.5	0.005	5.957	0.03	5	0.750
18	20.8	2.3	0.001	14.760	0.03	5	0.750
19	12.6	1.6	0.005	11.401	0.03	15	0.750
20	7.3	0.4	0.003	2.347	0.03	15	0.750
21	9.3	1.3	0.004	6.851	0.03	60	0.750
22	7.0	0.4	0.006	2.336	0.03	60	0.750
23	8.2	0.4	0.006	3.084	0.03	60	0.750
24	7.1	0.4	0.001	0.064	0.03	60	0.750
25	9.8	1.4	0.003	4.343	0.03	5	0.750
26	34.9	3.7	0.001	5.311	0.03	5	0.750
27	18.7	2.2	0.002	5.977	0.03	15	0.750
28	12.1	0.6	0.001	5.939	0.03	60	0.750

Appendix C

Lake Information

Fellows Lake

The information about Fellows Lake comes from the Natural Gas and Water Department, Springfield City Utilities.

The equation to estimate the volume of the reservoir (V in 10^3 gallons) as a function of the elevation (X in ft) is:

$$V = 53.787334 \bullet X - 1.826409X^2 + 0.0989748X^3 - 2.282124.10^{-3}X^4 + 2.703102.10^{-5}X^5 - 1.16351.10^{-7}X^6 - 7.3697$$

Table C1. Storage volume and surface area versus elevation for the Fellows Lake

ELEV. (ft)	Water height (ft)	Water height (m)	SURFACE AREA (square ft.)	surface area (ha)	storage volume (10^3 G)	storage volume 10^4 m3
1264	89	27.1	35,709,371	332	10020	3707
1263	88	26.8	35,041,001	326	9790	3622
1262	87	26.5	34,387,991	320	9556	3536
1261	86	26.2	33,750,340	314	9319	3448
1260	85	25.9	33,082,800	308	9080	3359
1250	75	22.9	27,366,077	254	6738	2493
1240	65	19.8	22,341,031	208	4805	1778
1230	55	16.8	17,967,494	167	3394	1256
1220	45	13.7	13,622,729	127	2397	887
1210	35	10.7	9,645,022	90	1663	615
1200	25	7.6	5,257,460	49	1086	402
1190	15	4.6	2,200,402	20	626	232
1180	5	1.5	699,786	7	227	84
1175	0	0.0	0	0	0	0

The net withdrawals, i.e. withdrawals less pumpages into the lake are presented in the following table:

Table C2. Monthly net withdrawals for the Fellows Lake

Month	2003 (millions G)	2004 (millions G)	03-04 Average (millions G)	03-04 average (MGD)	03-04 average ($10^4 m^3$/day)
Oct	219.09	353.95	286.52	9.24	3.4
Nov	-1.32	-310.70	-156.01	-5.57	-2.1
Dec	84.10	-459.88	-187.89	-6.06	-2.2
Jan	82.51	-131.56	-24.53	-0.82	-0.3
Feb	8.81	65.61	37.21	1.20	0.4
Mar	-258.18	249.19	-4.50	-0.15	-0.1
Apr	39.61	250.78	145.20	4.68	1.7
May	44.06	266.43	155.25	5.01	1.9
Jun	132.51	508.59	320.55	10.69	4.0
Jul	372.04	433.79	402.92	13.00	4.8
Aug	404.82	329.99	367.41	12.25	4.5
Sep	305.38	0.00	152.69	4.93	1.8

McDaniel Lake

The equation to estimate the volume of the reservoir (V in 10^3 gallons) as a function of the elevation (X in ft) is:

$$V = 9.8546X + 0.6726X^2 + 0.038116X^3 - 0.0005825X^4$$

Since there was no information of surface area versus water elevation, we estimated it by taking the derivative of the volume equation.

Table C3. Storage volume and surface area versus elevation for the McDaniel Lake

Water height (ft)	Storage volume (10^3 G)	Storage volume (10^4 m^3)	Surface area (ha)
34	1832.278	678	116.4
33	1736.639	643	114.9
32	1642.279	608	113.2
30	1458.285	540	109.4
29	1369.06	507	106.4
28	1281.933	474	103.7
27	1197.072	443	100.8
26	1114.635	412	97.7
25	1034.763	383	94.5
20	677.86	251	76.5
15	398.3064	147	57.2
10	198.097	73	38.4
5	70.48844	26	22.5
0	0		

The net withdrawals, i.e. withdrawals less pumpages into the lake are presented in the following table:

Table C4. Monthly net withdrawals for the McDaniel Lake

Month	2003 (millions G)	2004 (millions G)	03-04 Average (millions G)	03-04 average (MGD)	03-04 average (10^4m3/day)
Oct	258.85	142.59	200.72	6.47	2.4
Nov	108.47	140.47	124.47	4.45	1.6
Dec	-43.74	65.83	11.05	0.36	0.1
Jan	15.80	100.98	58.39	1.95	0.7
Feb	114.52	180.64	147.58	4.76	1.8
Mar	74.41	201.98	138.20	4.61	1.7
Apr	147.73	257.86	202.80	6.54	2.4
May	275.18	299.60	287.39	9.27	3.4
Jun	50.44	264.46	157.45	5.25	1.9
Jul	277.93	268.74	273.34	8.82	3.3
Aug	224.87	122.21	173.54	5.78	2.1
Sep	-37.74	0.00	-18.87	-0.61	-0.2

Appendix D

Management Practices

Grazed pastures

Table D1. Management and cattle rotation on pastures

Year	Operation	Pasture 1	Pasture 2
Year 1	Fertilization	March 5, 300 lbs/a 17-17-17	March 12, 300 lbs/a 17-17-17
	Hay harvest	None	None
	Grazing	Mar 26 – May 15, 51 days	May 16 – July 15, 61 days
		July 16 – Sept 15, 62 days	Nov 1 – Dec 15, 45 days
Year 2	Fertilization	March 20, 300 lbs/a 17-17-17	March 14, 300 lbs/a 17-17-17
	Hay harvest	None	None
	Grazing	May 16 – July 15, 61 days	Mar 26 – May 15, 51 days
		Nov 1 – Dec 15, 45 days	July 16 – Sept 15, 62 days

Table F2. Management and cattle rotation on hay fields and winter areas

Year	Operation	Hay field	Winter location (Woods)
Year 1	Fertilization	March 15, 300 lbs/a 17-17-17	
	Hay harvest	June 10	
	Grazing	Sept 16 – Oct 31, 46 days	Dec 16 – Mar 25, 100 days
Year 2	Fertilization	March 10, 300 lbs/a 17-17-17	
	Hay harvest	June 10	
	Grazing	Sept 16 – Oct 31, 46 days	Dec 16 – Mar 25, 100 days

Urban areas

Table D3. Management of urban areas

Operation	Date / Timing
Street sweeping	Six times a year in January, March, May, July, September, and November.
Fertilization	March 5: 70 lbs/a N, 27 lbs/a P
Mowing	50% grass height is mowed, 50% of clippings return to the ground. Timing: twice a week from mid-April through June, once a week in July, once every 10 days in August and September, and once in October
Grazing / feces deposit	Geese all year round at densities that reflect their life cycle.

Appendix E

Spring Flow Derivation and Water Quality Data

The average daily flow value of the known springs was calculated as:

$$Q(month) = Q_{annual} + Q_{annual} * \frac{2}{3} * \sin\left(\frac{2\pi * Nmonth}{12}\right)$$

where Q(*month*) is the average daily flow at a spring for the month, Q_{annual} is the average annual daily flow value, and *Nmonth* is the number of the month (1 to 12).

This equation results in a sinusoidal curve that has its maximum in March and its minimum in September. The following table presents the known average annual daily flow values and the estimated daily flow values for each month for each of the springs in The Little Sac watershed that have flow information. The model can be updated as more flow information becomes available for the springs.

When several springs exist in one subbasin of the model, these were grouped together. The resulting flow is the sum of the flows for each of them.

Table E1. Springs that have flow information

Name	Subbasin number	Flow or flow range (cfs)	Average daily flow
Pleasant Hope	2	0.2	266 m3/d
Unnamed	9	0.0223	0.17 cfs
Unnamed		0.0446	
Unnamed		0.0033	
Malenosky spring		0.1000	417 m3/d
Birdeye Spring	13	0.0334	0.46 cfs
Unnamed		0.0891	
Asher Cave		0.114	
Hammond		0.2266	1128 m3/d
Aunt Maggie	15	0.05	0.25 cfs
Headlee #2		0.10	612 m3/d
Headlee#1		0.10	
Funt Hill	17	0.2005	0.42 cfs
Funt Hill Cave		0.2228	1036 m3/d
Weiland Spring	18	0.05	
Pertuche Spring		0.02	0.46 cfs
Parrish Spring		0.35	
Stoddard Spring		0.02	
Grace Spring		0.02	1126 m3/d
Crystal Cave	19	0.6907	
Hickory Barren North		0.0401	1.09 cfs
Section 18 Spring		0.0445	
Section 19 Spring		0.0445	
Stafford Spring		0.0446	2662 m3/d
Rhoades Spring		0.2228	

Name	Subbasin number	Flow or flow range (cfs)	Average daily flow
Ritter spring East		3.44	4.86 cfs
Ritter Spring West	20	1.324	11,909 m3/d
Ritter Park Spring		0.100	
Upwelling Spring	21	0.1337	0.29 cfs
Green Lawn N Spring		0.156	709 m3/d
Dickerson Park Spring (Doling)	22	14.300	17.65 cfs
Fulbright Spring		3.350	43,215 m3/d
North Creek Ind Park Spring	24	0.02	1.36 cfs
Valley Mill (Sanders)		1.34	3,330 m3/d

Table E2. *E. coli* densities at selected springs in the Little Sac River Watershed

Doling col/100 ml		Sanders col/100 ml			Ritter east col/100 ml	Ritter west col/100 ml	Stoddard col/100 ml		Hoffmeister col/100 ml	
6/14/00	3076	6/16/00	457	6/16/00	487	143	6/23/00	86	10/10/00	25000
9/21/00	160	9/28/00	325	9/21/00		120	9/6/00	0	12/16/00	0
12/22/00	3076	1/13/01	20	1/13/01	17	3	12/27/00	10	3/24/01	1
3/26/01	32	3/23/01	7	3/23/01	3	3	3/8/01	5	6/15/01	0
6/26/01	1223	6/22/01	613	6/22/01	687	2419	6/20/01		9/19/01	20
9/25/01	63	9/8/01		9/8/01	4611	31	9/13/01		3/27/02	41
3/14/02	5	3/28/02	84	3/28/02	145	197	3/21/02	5	6/28/02	63
12/12/02	173						7/22/02	20		
3/4/03	13									
3/11/03	8									
4/1/03	17									
4/15/03	13									

(Source: Adopt-A-spring Program, Watershed Committee of the Ozarks)

Table E3. Nitrate concentrations at selected springs in the Little Sac River Watershed

Doling mg/l		Sanders mg/l			Ritter east mg/l	Ritter west mg/l	Stoddard mg/l		Hoffmeister mg/l	
6/14/00	5.0	6/16/00	3.8	6/16/00	7.5	6.2	6/23/00	3.3	10/10/00	2.6
9/21/00	5.6	9/28/00	6.5	9/21/00		6.7	9/6/00	5.2	12/16/00	3.9
12/22/00	5.0	1/13/01	5.2	1/13/01	5.3	5.5	12/27/00	5.8	3/24/01	2.4
3/26/01	4.4	3/23/01	4.7	3/23/01	5.0	6.0	3/8/01	4.4	6/15/01	1.9
6/26/01	4.3	6/22/01	5.0	6/22/01	4.8	6.6	6/20/01	4.0	9/19/01	1.9
9/25/01	4.0	9/8/01	4.8	9/8/01	4.7	3.9	9/13/01	4.1	12/17/01	3.7
12/17/01	5.9	12/13/01	4.0	12/13/01	4.0	5.4	12/28/01	4.3	3/27/02	1.9
3/14/02	6.5	3/29/02	5.1	3/29/02	5.2	5.4	3/21/02	5.0	6/28/02	
5/21/02	8.1	6/21/02	4.6	6/21/02	4.4	4.0	7/22/02	4.1		
9/23/02	4.0									
12/12/02	4.4									
3/4/03	6.0									
3/11/03	6.3									
4/1/03	2.4									

(Source: Adopt-A-spring Program, Watershed Committee of the Ozarks)

Table E4. Ortho-P concentrations at selected springs in the Little Sac River Watershed

Doling mg/l		Sanders mg/l			Ritter east mg/l	Ritter west mg/l	Stoddard mg/l		Hoffmeister mg/l	
6/14/00	0.29	6/16/00	0.25	6/16/00	0.13	0.10	6/23/00	0.06	10/10/00	0.19
9/21/00	0.29	9/28/00	0.77	9/21/00		0.06	9/6/00	0.06	12/16/00	0.32
12/22/00	0.19	1/13/01	0.60	1/13/01	0.38	0.35	12/27/00	0.0	3/24/01	0.02
3/26/01	0.05	3/23/01	0.11	3/23/01	0.1	0.12	3/8/01	0.09	6/15/01	0.01
6/26/01	0.21	6/22/01	0.34	6/22/01	0.65	0.25	6/20/01	0.10	9/19/01	0.02
9/25/01	0.07	9/8/01	0.17	9/8/01	0.38	0.05	9/13/01	0.05	12/17/01	0.06
12/17/01	0.18	12/13/01	0.13	12/13/01	0.17	0.13	12/28/01	0.04	3/27/02	0.76
3/14/02	0.05	3/29/02	0.76	3/29/02	0.72	0.19	3/21/02	0.09	6/28/02	
5/21/02	0.21	6/21/02	0.22	6/21/02	0.32	0.33	7/22/02	0.08		
9/23/02	0.05									
12/12/02	0.05									
3/4/03	0.05									
3/11/03	0.03									
4/1/03	0.04									
4/15/03	0.07									

(Source: Adopt-A-spring Program, Watershed Committee of the Ozarks)

Appendix F

Information on Geese

Two studies reported in the September 20, 1990 issue of *Waterline*, (University of Missouri, 1997), give information on the number of droppings per goose and their composition. The results are summarized in the table below. For the purpose of our analysis, we used averages between the values indicated by these studies.

The nutrient content (nitrogen and phosphorus) was divided into equal soluble and organic form, rounded up to 3 digits.

Table F1. Quantity and nutrient composition of goose manure.

Reference	Manny et al.[b]	Kear[c]	Average
Subspecies	Interior	Atlantic	
Dropping frequency	28/day	92/day	
Dry weight/dropping	1.17 grams	1.9 grams	
Dry weight/day	32 grams	175 grams	104 grams
Dry nitrogen/dropping	0.051 grams	0.042 grams	0.047 grams
Dry phosphorus/dropping	0.016 grams	0.019 grams	0.018 grams
Nitrogen fraction	0.044	0.022	0.033
Nitrate fraction			0.016 (48%)
Organic nitrogen fraction			0.017 (52%)
Phosphorus fraction	0.014	0.010	0.012
Dissolved P fraction			0.006 (50%)
Organic P fraction			0.006 (50%)

[b] Manny, B.A., R.G. Wetzel and W.C. Johnson. 1975. Annual contribution of carbon, nitrogen and phosphorus by migrant Canada geese to a hardwater lake. Verh. Internat. Verein. Limnol. 19:949-951.

[c] Kear, J. 1963. The agriculture importance of goose droppings. the 14th Annual Report of the Wildfowl Trust. p. 72-77.

Table F2. Goose droppings deposit rates in each subbasin

Subbasin	Percentage of subbasin in pasture	Rate from November to mid-March (kg/ha)	Rate from mid-March to mid-June (kg/ha)	Rate from mid-June to mid-August (kg/ha)	Rate from mid-August to October (kg/ha)
1	69.7	0.00031	0.00125	0.00251	0.00188
2	81.14	0.00027	0.00108	0.00215	0.00161
3	84.73	0.00026	0.00103	0.00206	0.00155
4	71.74	0.00030	0.00122	0.00244	0.00183
5	80.28	0.00027	0.00109	0.00218	0.00163
6	70.22	0.00031	0.00124	0.00249	0.00187
7	67.92	0.00032	0.00129	0.00257	0.00193
8	61.06	0.00036	0.00143	0.00286	0.00215
9	63.62	0.00034	0.00137	0.00275	0.00206
10	34.33	0.00064	0.00254	0.00509	0.00382
11	62.07	0.00035	0.00141	0.00281	0.00211
12	85.66	0.00025	0.00102	0.00204	0.00153
13	79.55	0.00027	0.00110	0.00220	0.00165
14	54.63	0.00040	0.00160	0.00320	0.00240
15	46.31	0.00047	0.00189	0.00377	0.00283
16	54.57	0.00040	0.00160	0.00320	0.00240
17	78.36	0.00028	0.00111	0.00223	0.00167
18	53.32	0.00041	0.00164	0.00328	0.00246
19	71.76	0.00030	0.00122	0.00243	0.00183
20	61.69	0.00035	0.00142	0.00283	0.00212
21	74.65	0.00029	0.00117	0.00234	0.00176
22	36.72	0.00059	0.00238	0.00476	0.00357
23	84.18	0.00026	0.00104	0.00208	0.00156
24	55.28	0.00040	0.00158	0.00316	0.00237
25	75.55	0.00029	0.00116	0.00231	0.00173
26	81.63	0.00027	0.00107	0.00214	0.00160
27	56.27	0.00039	0.00155	0.00310	0.00233
28	64.83	0.00034	0.00135	0.00269	0.00202

Appendix G

Urban Storm Runoff

Table G1. Selected *E. coli* and nutrient concentrations in urban storm runoff at selected sites in Springfield

Site	Date	FC concentration (colonies/100 ml)	Source
Pearidge	4/7/2003	670	NPDES Report, 2002-2003
Jones spring	4/7/2003	400	NPDES Report, 2002-2003
Galloway Creek	4/7/2003	250	NPDES Report, 2002-2003
Wilson Creek	4/7/2003	220	NPDES Report, 2002-2003
Jordan Creek	4/7/2003	270	NPDES Report, 2002-2003
South Creek	4/7/2003	270	NPDES Report, 2002-2003
Pearidge	3/25/2004	160	NPDES Report, 2003-2004
Jones spring	3/25/2004	10	NPDES Report, 2003-2004
Galloway Creek	3/25/2004	10	NPDES Report, 2003-2004
Wilson Creek	3/25/2004	230	NPDES Report, 2003-2004
Jordan Creek	3/25/2004	300	NPDES Report, 2003-2004
South Creek	3/25/2004	20	NPDES Report, 2003-2004
Site 1	Storm 1[a]	380	Wright Water Engineers, 1995
	Storm 2	1873	Wright Water Engineers, 1995
	Storm 3	218	Wright Water Engineers, 1995
Site 2	Storm 1	650	Wright Water Engineers, 1995
	Storm 2	167	Wright Water Engineers, 1995
	Storm 3	2758	Wright Water Engineers, 1995
Site 3	Storm 1	620	Wright Water Engineers, 1995
	Storm 2	301	Wright Water Engineers, 1995
	Storm 3	2382	Wright Water Engineers, 1995
Site 4	Storm 1	371	Wright Water Engineers, 1995
	Storm 2	188	Wright Water Engineers, 1995
	Storm 3	889	Wright Water Engineers, 1995
Site 5	Storm 1	1030	Wright Water Engineers, 1995
	Storm 2	342	Wright Water Engineers, 1995
	Storm 3	756	Wright Water Engineers, 1995
Site 6	Storm 1	310	Wright Water Engineers, 1995
	Storm 2	195	Wright Water Engineers, 1995
	Storm 3	241	Wright Water Engineers, 1995
Average		549	
Standard deviation		664	
95% confidence interval		238	

[a]Three storms were monitored in the study, which we characterize by storm 1, 2, and 3.

Appendix H

Estimation of UV Disinfection Costs

These costs are based on the following:

- Power cost of $0.06 per kWh
- Labor rate of $40 per hour
- Lamp replacement cost of $150 with replacement every 12,000 hrs
- Ballast replacement cost of $425 with replacement every 12 years
- Cleaning chemical cost of $500 per year

At annual average conditions of 6.8 MGD, the daily costs are:

- Daily Energy Cost	$23
- Daily Equipment O&M Cost	$27
- Daily Labor O&M Cost	$26
- Daily Total O&M Cost	$76

The annual costs of disinfection are therefore:

- Recreation season April 1 – October 31: 214 days	$16,264
- **Winter season November 1 – March 31: 151.25 days**	**$11,476**
- **Year-round disinfection:**	**$27,740**