

Watershed Resources Inventory and Data Input for the SWAT model

Topography

The 60-m DEM was used. The automatic delineation tool that is part of AVSWATX was utilized to delineate subbasins. Efforts were taken to match subbasins outlets with existing flow gauges and water quality stations. The average size is 150 km² and they vary from 35 to 325 km². The subbasins almost match the HUC 14 watershed boundaries.

Soils

The STATSGO soil map was used. Characteristics from the STATSGO database were generally used, replaced in some instances by characteristics from the SSURGO database for the same soils. This was done so as to have more detailed soil descriptions than they are in the STATSGO database but have only the main soils represented.

Land use

The 30 m land use / land cover grid built from 1992 satellite images was utilized. A more recent map is now available that was developed from images taken between 2000 and 2004. However, the available flow and water quality data are mainly from 1980 to 2000 and the older map is more appropriate. Grassland (51% of the watershed) was divided into poor condition pasture (25%), fair condition pasture (25%), and septic fields (0.6%). Rural population densities by townships (census information) were used to estimate the area assigned to septic fields. Resulting land use distribution is presented in Table 1.

Table 1. Land use distribution in the James River Basin.

Land use category	Percent of the watershed
Forest	25%
Urban high density	1.5%
Urban areas low-medium density	0.8%
Hay fields	21.5%
Septic tanks	0.6%
Pastures in fair condition	25.3%
Pastures in poor condition	25.3%

Determination of Hydrological response Units (HRU): A threshold of 5% for land use and 25% for soil was used. That means that any land use that represents less than 5% of the land in a subbasin is eliminated from that subbasin. Any soil that covers less than 25% of the area covered by one land use in a subbasin is not considered to be associated to that land use in that subbasin. With 24 subbasins in the watershed, these thresholds result in 243 HRUs.

Weather stations

Five weather stations were utilized to characterize the weather in the James River Basin: Springfield airport, Galena, Ozark, Cassville, and Marshfield (Figure 1). Daily precipitation and temperature data from 1970 to 2004 was provided by Dr. P. Guinan from the Center for Atmospheric Sciences at the University of Missouri. Monthly characteristics were derived from these series of daily values using the Wxparm and Wxgen programs provided by the Agricultural Research Service. When comparing the model's results to measured flow and water quality data, measured daily precipitation and temperature data was used. When evaluating the impact of specific management practices or comparing alternative management plans to a baseline condition, 30 years of daily weather were generated using the monthly characteristics.

Management information

The baseline management practices were estimated from our work in the Shoal Creek watershed and in the Little Sac watershed. Pastures were divided in two sets so that cattle could be moved between different pastures from month to month. Grazing periods alternate between these two sets. Grazing densities in each county were set to respect the number of cattle in that county, the available pasture acres, hay acres, and grazed wood acres. Hay land was assumed to be harvested in June and grazed later in the season. Estimates of cattle number, harvested hay acres, wood, and grass pastures came from the National Agricultural Service Survey (NASS) county summary for 1998 and 2003. An average between these two years was considered to estimate grazing densities. Some wood acres were reserved for winter grazing, assuming that cattle would be moved to wooded pastures that provide some protection from the weather. The grazing rates used in the model are presented in Table 2. The actual grazing density during the summer is half the values indicated in Table 2 because cattle alternate between two pastures.

Table 2. Grazing rates used in the James River Basin model, per county.

Grazing period	Barry County	Greene County	Stone County	Christian County	Webster County
grass grazing density (summer, acres/cow-calf)	2.9	3.3	4.9	3.5	2.8
wood grazing density (winter, acres/cow-calf)	1.0	0.7	1.2	0.8	0.8
hay grazing (summer, acres/cow-calf)	1.4	1.9	1.1	1.7	1.3
Total average grazing density (all year, acres/cow-calf)	5.3	5.9	7.2	6.0	4.9

Grazing periods, fertilizations, and harvesting of hay are detailed in Table 3 and 4 for fair condition pastures, hay land, and grazed woodland. Poor condition pastures were managed similarly but were fertilized only every other year. As a result, the ground cover was set at a lower value.

The management of urban areas was assumed to be similar to the management of urban areas in North Springfield (Table 5). It assumed mowing twice a week in the peak of the

growing season, with lower frequencies later. Forests are assumed to be mature forests. No forest harvesting or planting was represented in the model.

Table 3. Management and cattle rotation on fair condition summer 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
	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
	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 4. Management and cattle rotation on hay fields and wooded 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

Table 5. Management of lawns and streets in residential areas

Operation	Date / Timing
Street sweeping	Six times a year in January, March, May, July, September, and November.
Fertilization of lawns	March 5: 70 lbs/a N, 27 lbs/a P
Mowing of lawns	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.

Septic fields were assumed to be in good condition grass. A daily application of effluent was applied on these areas that reflect the estimated effluent production per household and the nutrient and bacteria content of the effluent. The variation in population density across the watershed was represented by a larger or smaller fraction of the subbasin being used by these septic fields. The following assumptions were made to characterize septage:

- 1/8 acre per septic field
- Average daily water consumption: 70 gallons per person
- Average daily effluent production: 58 gallons per person
- Average number of people per household: 2.5

- Average daily septage release (failing tank): 1.884 kg/day/household on a dry basis
- Average daily septage release (working tank): 0.942 kg/day/household on a dry basis
- Total nitrogen as a fraction of septage for a working tank: 0.036
- Total nitrogen as a fraction of septage for a failing tank: 0.02
- Total phosphorus as a fraction of septage for a working tank: 0.013
- Total phosphorus as a fraction of septage for a failing tank: 0.0086

Point sources

Numerous waste water treatment plant (WWTP) discharge their effluent in the James River or in its tributaries. Permit records and report information were utilized to estimate flow, nutrient, and bacteria outflow from these WWTPs from 1970 until present in order to calibrate the model. For the purpose of comparing alternative management scenarios, current discharges were specified in the model.

Table 6 presents the design and actual flows from the treatment plants that exist in the James River Basin along with the phosphorus concentration discharged prior and after 2000.

The concentrations for the Springfield plant were estimated from phosphorus loads and discharged volumes presented on the plant's web site. Prior 1993, there was an initial period during which phosphorus was not a concern. Based on a discharge of 30 MGD in 1992, the maximum capacity at that time, and a phosphorus load of 1800 lbs/day, the daily phosphorus load in 1992, we calculated that the average concentration was 7.3 mg/l. According to the graphs presented by the City of Springfield, there was more than 90% reduction in loadings from 1993 to 2001, due to reductions in cleaning agents used by the Springfield population and the installation of phosphorus removal devices at the treatment plant. The estimated daily load of phosphorus discharged in the James River by the Springfield plant has been 110 lbs/day on average since 2001 for an average daily flow of 39 MGD. These estimates result in an average concentration of 0.3 mg/l. (Source: http://www.ci.springfield.mo.us/egov/publicworks/sanitary/sw_plant.html).

Estimates on phosphorus for other plants came from the information presented in the 2000 James River Total Maximum Daily Load (TMDL) document. The compliance schedule contained in the rule is as follows:

- Facilities with a design flow of 1,000,000 gallons/day or greater must comply with the rule by 2003.
- Facilities with a design flow of 100,000 – 999,999 gallons/day must meet an interim phosphorus limit of 1.0 mg/L by 2003 and must attain full compliance with the 0.5 mg/L requirement by 2007.
- Facilities with a discharge of 22,500 – 99,999 gallons/day have no interim limits and must attain full compliance with the 0.5 mg/L monthly average for phosphorus by 2007.

For other plants and for conditions prior 2000, the concentration was set at 5 mg/l. Flow estimates were taken in the NPDES list of permitted facilities (Missouri Department of Natural Resources, 2006).

Permitted maximum fecal coliform bacteria concentration of outflow is 400 colonies/100ml and ammonia-N is 2 mg/l. The typical effluent characteristics regarding these two pollutants at the Springfield wastewater treatment plant are 10 colonies/100 ml and .2 mg/l, respectively, according to their website. Nitrate-N and ammonia-N are the two principal forms of nitrogen released by a municipal wastewater treatment plant. We have not found any good data on nitrate-N or total nitrogen content of effluent from municipal wastewater facilities in Southwest Missouri. Nitrate-N concentration has been set at 5.0 mg/l. These values were used to calculate daily loads of bacteria and nutrients into the James River and its tributaries.

Table 6. Characterization of wastewater discharges in the James River Basin.

Name	Design flow [MGD]	Actual flow prior 2000 [MGD]	Actual flow after 2000 [MGD]	P concentration prior 2000 [mg/l]	P concentration after 2003 [mg/l]
Springfield WWTP	49	30*	39**	7.3	0.3
Rogerville	0.112	0.083	0.083	5.0	1.0
Seymour/MDOC/Fordland	0.444	0.344	0.344	5.0	1.0
Sparta	0.094	0.060	0.060	5.0	5.0
Galena WWTP	0.060	0.035	0.035	5.0	5.0
Exeter/Washburn	0.121	0.081	0.081	5.0	5.0
Cassville	0.700	0.630	0.630	5.0	5.0
Purdy municipal	0.120	0.096	0.096	5.0	5.0
Clever	0.210	0.070	0.070	5.0	1.0
Crane	0.300	0.150	0.150	5.0	1.0
Nixa/Ozark	2.596	1.193	1.193	5.0	0.5
FreemontHills/English Village	1.700	1.160	1.160	5.0	0.5

* This daily flow corresponds to the year 1992. We assumed the plant reached maximum capacity since an expansion was scheduled and was operating in 1993.

** Current average daily flow indicated on the Springfield web site.

Bacteria concentration in septage

The University of Massachusetts Septic Tank Handbook indicates a concentration of 1.0 E+09 to 1.0 E+12 colonies/100 ml in wastewater and a 0% reduction through a septic tank. EPA indicates a lower concentration of 1.0 E+06 to 2.0 E+09 colonies/100 ml in what is released to the soil absorption system (SAS). The simulations have been done on the basis on the geometric average of the lower and upper bounds of the range given by EPA with no differentiation between a working and failing system other than the amount of septage released.

USLE Cover factor

Differences in land management often result in changes in the soil ground cover, leading to increased or decreased soil erosion. The parameter that reflects the ground cover is the Universal Soil Loss Equation (USLE) Cover (C) factor. The SWAT model uses the minimum value of the C factor to calculate a daily C factor as a function of plant growth (Table 7). This value varies between 0 for a completely protected soil (no erosion) and 1 for a completely bare soil (no ground cover).

Table 7. Minimum values of the USLE C factor used in the James River Basin model.

Ground cover description	Minimum value of the USLE C factor
Forest – Wooded areas	0.001
Forest – Grazed	0.059
Hay fields	0.003
Urban lawns	0.003
Septic fields	0.003
Pasture – fair condition	0.003
Pasture – poor condition	0.11

Initial Soil Phosphorus

To evaluate the impact of phosphorus management on pastures and lawns, different values of phosphorus concentrations in the top soil layer, both labile and organic, were specified. The phosphorus management, reduced applications of phosphorus fertilizer, eventually will lead to reduced phosphorus concentrations in the soil, the effect of which we are investigating with the model. The concentrations used in the model are presented in Table 8.

Table 8. Initial phosphorus concentration in the top soil layer for different model runs.

	Labile P (ppm)	Organic P (ppm)	Total P (ppm)	Total P (kg/ha)
Lawns – baseline	5	60	65	127
Lawns – current average	2.5	30	32.5	63
Lawns – reduced P	1.25	15	16.25	32
Pasture fair condition	6	60	66	129
Pasture poor condition	5	60	65	127
Septic fields	4	60	64	125

Calibration and Validation of the model

The model was calibrated for flow based on the 1973-1986 period, e.g. input parameters were adjusted so that measured flow and pollutant concentrations match values predicted by the model during this period. The years 2001-2004 served for validation of the model: we verified that the measured flow concentrations match values predicted by the model during this period, without adjusting any input parameter value. For pollutant concentrations, data was extensive enough only for the years 2001 to 2004 and these were used for calibration.

The goodness of fit of the model is evaluated by visual comparison of measured and estimated hydrographs and plots of pollutant concentrations with time. In addition, several calibration indicators were used to quantify how well the model reproduces the measured values. The percent deviation gives a measure of how the annual flow deviates from what has been measured. It is calculated as:

$$\text{Dev} = \frac{Q_{\text{predicted}} - Q_{\text{measured}}}{Q_{\text{measured}}} \cdot 100$$

A positive value indicates an over-prediction; a negative value indicates an under-prediction. Acceptable results are obtained when the flow deviation is less than 10%.

The Nash-Sutcliffe coefficient indicates whether and how much the model simulates flows or pollutant concentrations better than the average annual value of the measured data. An acceptable value should be greater than 0.5 while a good value should be greater than 0.7. Typically, the values are between 0.2 and 0.5 when evaluating the water quality components of the model. In general, it is calculated for measured and predicted values that correspond to the same day. Alternatively it can be calculated for measured and predicted values that correspond to a same frequency of occurrence. In this case, it does not imply that predicted values match measured values but that the range and the distribution of the predicted values match the range and distribution of measured values.

Flow calibration and validation

The calibration and validation indicators for flow are presented in table 9. The percent deviations are within acceptable range toward the outlet of the watershed but they are greater than the 10% threshold at the outlet of the upstream tributaries, especially for Wilson Creek. Possible sources of errors include:

- The use of the 1992 land use and land cover map for simulation of a period prior and after 1990. This could have important effects around the Springfield area and could explain the larger deviations for Wilson Creek.
- The SWAT model was not originally developed for flow simulation in regions that have karst geology. To resolve this problem, we have specified higher hydraulic conductivities (infiltration rates) in losing streams. Practically all the channels in the James River Basin are losing streams. In addition, we have specified springs as point discharges, instead of trying to link their flow to their recharge area. A monthly flow variation is specified to reflect the seasonal flow

conditions. However, that does not accurately simulate spring flow in extremely dry or wet conditions.

Table 9. Measures of flow goodness of fit for the James River Basin SWAT model.

	Wilson Creek Battlefield	James River near Springfield	James River near Boaz	Finley River	James River in Galena
Percent deviations					
1973-1986	13%*	16%	-5%**	No data	6%
2001-2004	23%	2%	5%	-8%	-9%
Daily Nash-Sutcliffe coefficients					
1973-1986	0.11*	0.45	0.47**	No data	0.49
2001-2004	0.27	0.36	0.51	0.33	0.47

* Based on years 1973-1982 due to missing data

** Based on year 1973-1980 due to missing data

Water quality calibration and validation

Bacteria and phosphorus input parameters were calibrated based on fecal coliform concentration and total phosphorus concentrations measures from 2001 to 2004. Existing data from previous years show that the stream pollutant concentrations were mostly dependent on the discharge from the Springfield plant. While it gave a rationale and a basis to estimate the effluent volumes and concentrations with more detail, it did not give any insight for the parameters that control the surface runoff processes.

While the Nash-Sutcliffe coefficient is typically calculated for measured and predicted values that correspond to the same day, it can also be calculated for measured and predicted values that correspond to a same frequency of occurrence. It is then utilized to evaluate how the range and the distribution of the predicted values match the range and distribution of measured values. Table 10 presents the Nash-Sutcliffe coefficients calculated based on values that correspond to the same day (NSpoints) and to the same frequency (NScurve). Only the simulated values for the days when a sample was collected were considered.

Table 10. Measures of water quality goodness of fit for the James River Basin SWAT model.

	Wilson Creek Battlefield	James River near Boaz	Finley River	James River in Galena
Fecal coliform				
NS points	0.18	-155	-0.23	-2
NS curve	0.13	-12	0.18	0.88
Phosphorus				
NS points	0.02	-21	-0.07	-21
NS curve	0.81	-28	0.31	-31

While calibration results in terms of the range and frequencies of pollutant concentrations seem to be satisfactory in the upper branches of the watershed, they are not adequate in the lower branches (Boaz and Galena). Possible reasons include the stream processes and more specifically, the interaction of sediment, nutrient and bacteria. Because of that reason, we cannot trust the model results at the outlet of the watershed. However, we can analyze policies and management scenarios based on the pollutant loads contributed to the stream and the stream loads in the upper parts of the basin: Finley River, James River near Springfield, Wilson Creek, Crane Creek, and Flat Creek.

References

Missouri Department of Natural Resources, D.o.E.Q. 2006. Missouri National Pollutant Discharge Elimination System (NPDES) Facilities [Online]
<http://msdisweb.missouri.edu>. (posted March 1, 2006; verified March 2006).