appendix f

SWAT modeling of the st. joseph river watershed

michigan and indiana

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SWAT Modeling of the St. Joseph River Watershed, Michigan and Indian

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1.0 Introduction

The U.S. Environmental Protection Agency issued new requirements for watershed management plans funded through Section 319 grants. These requirements call for additional quantification of sources of pollutants and expected reductions in pollutants with recommended best management practices (BMPs). Because the St. Joseph River watershed is so large (4,685 square miles), GIS-based models are necessary to understand current non-point source loading conditions and to model watershed changes and the associated non-point source loading. To achieve the Nine Elements through supplemental Work Plan efforts, the watershed was modeled with the Soil and Water Assessment Tool (SWAT) in this study. This model uses land cover, elevation and soils data, climatological information, point source loadings and in-stream characteristics (e.g., dams) to identify sediment, nutrient and other pollutant loads from individual subwatersheds to the mouth of the basin. It was also used to assess predicted load reductions for agriculture by applying a suite of BMPs in critical agricultural tributary subwatersheds: namely the Elkhart River, the Pigeon River, and the Fawn River.

SWAT is a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Neitsch et al., 2002b) SWAT has been used extensively in the U.S. for TMDL applications. For example, the Ohio EPA employed SWAT for its TMDL development for the Stillwater River watershed, a subwatershed of the Great Miami River. The US EPA has accepted SWAT as a major modeling tool for TMDL development (OH EPA, 2003). SWAT has also been incorporated into US EPA's BASINS (Better Assessment Science Integrating point and Nonpoint Sources) system, developed for watershed and water quality-based assessment and integrated analysis of point and nonpoint sources. BASINS integrates a geographic information system (GIS), national watershed and meteorological data, and state-of-the-art environmental assessment and modeling tools into one convenient package. The SWAT modeling work in this study was conducted within the BASINS system (version 3.0).

2.0 Model Input

SWAT requires an assortment of input data layers for model set-up and watershed simulations. Locally provided data were used in this study whenever possible. Best available GIS data products from US EPA and US Geological Survey (USGS) were downloaded, processed, and incorporated into the BASINS-SWAT system for the modeling study.

2.1 Geophysical Datasets

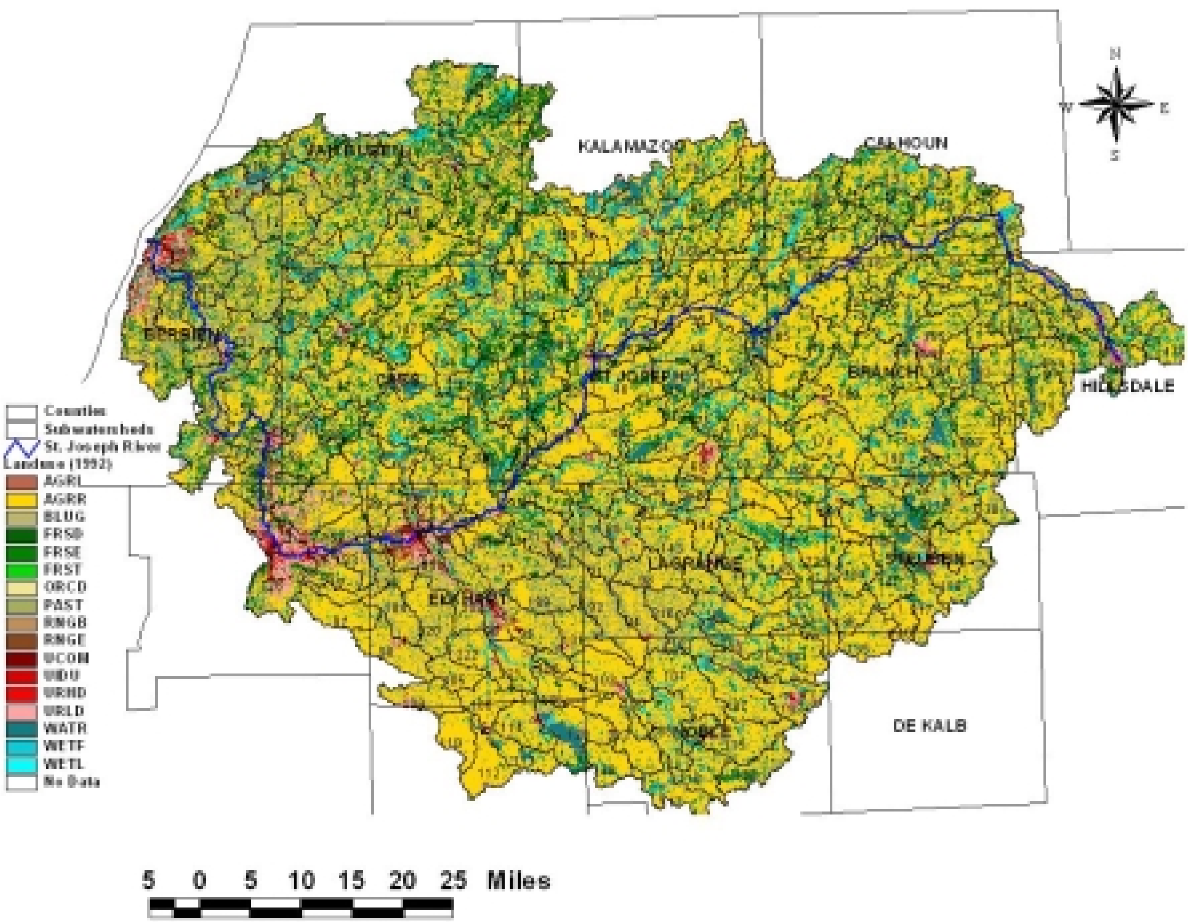
The 30-meter resolution Digital Elevation Model (DEM) datasets for the counties of the St. Joseph River watershed were obtained from state agencies in Michigan and Indiana. Processed by ArcView® GIS 3.2 software package, the datasets were "mosaiced" together to create a seamless file. The resulting grid file was utilized in SWAT modeling to delineate subwatersheds and obtain slope conditions of each subwatershed or for the entire watershed.

The GIS data layer of the stream network of the entire St. Joseph River watershed was obtained from the National Hydrography Dataset (NHD), produced by USGS and available on the web (http://nhd.usgs.gov). The DEM and NHD datasets together were used to delineate 229 subwatersheds[a] for the watershed as the basic units of SWAT modeling (Figure 1).

USGS has also compiled landuse data based primarily on the classification of Landsat Thematic Mapper 1992 satellite imagery data in National Land Cover Data Set for the entire contiguous United States. A 21-class land cover classification scheme was used in the data layer. This dataset (http://landcover.usgs.gov/natllandcover.asp) is in a 30-meter resolution raster format.

Data for the area encompassing the St. Joseph watershed were downloaded from the website and processed to be incorporated the BASINS-SWAT interface. Figure 1 shows the 1992 land cover distribution for the St. Joseph River watershed.

Figure 1: The St. Joseph River Watershed



[a] These subwatersheds are the basic units on which the subwatersheds used in the Watershed Management Plan (WMP) are based. However, the numbering of subwatersheds in this study is different from that in the WMP.

The BASINS built-in state soil data layer—State Soil Geographic (STATSGO) Database—was used in the modeling. The STATSGO database was developed by USDA-NRCS and incorporated by US EPA into the BASINS system. Landuse classes and soil types were overlaid to define the Hydrologic Response Units (HRUs)[b] for each of the 229 subwatersheds for the SWAT model. For the purpose of this study, the dominant landuse class and soil type for each subwatershed were used, resulting in one HRU per subwatershed (see Secton 7.0 for more discussion). Table 1 provides the landuse class for each of the subwatersheds. There were 214 agricultural row crop subwatersheds, 4 deciduous forest, 7 pasture, 2 urban low density residential land subwatersheds and 2 water body dominated subwatersheds.

Weather data (daily precipitation, daily maximum, and minimum temperatures) from 10 stations in and around the St. Joseph River watershed (Berrien Spring/St. Joseph, MI; Dowagiac, MI; Three Rivers, MI; Coldwater, MI; Hillsdale, MI; South Bend, IN; LaGrange, IN; Steuben, IN; Elkhart, IN; and Columbia, IN;) were obtained from National Oceanic and Atmospheric Administration (NOAA)'s National Climatic Data Center for the period from January 1, 1986 to December 31, 2004. As a result, SWAT modeling in this study was also conducted for the same period of time. Specifically, model calibration was run from January 1, 1986 through December 31, 1995 and model validation and scenario simulation were run from January 1, 1996 through December 31, 2004. Monthly datasets were downloaded, assembled, and processed for each station to form SWAT weather input files. Data processing included unit transformation, missing data estimation, and database file building.

Because loading reductions due to changes in agricultural management practices are only relative to the initial loading, accurate calibration was not necessarily critical in deriving loading reduction potentials for a particular subwatershed. This is likely to be true as long as model parameters are reasonably calibrated to reflect local conditions.

2.2 Point Source Loading Data

Annual point source flow and nutrient loading data were obtained from the BASINS built-in PCS (Permit Compliance System) database. This database provides loading data from point sources in 75 subwatersheds. However, not all the point sources reported in the PCS database have all the sediment and nutrient loading information for all the years modeled in this study. Whenever missing, annual loading data for a particular point source and a particular loading parameter were filled with the average values of all available data from previous years. It should be noted here that although data gaps were encountered for many point sources, the PCS database does provide loading information for most of the major point sources. Therefore, the majority of the loadings from point sources were captured in the model. Furthermore, the St. Joseph River watershed is well known for its agricultural nonpoint source dominated sediment and nutrient loadings. Consequently, missing loading data from minor point sources should not induce any significant error in the modeled loadings from the watershed.

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[b] HRUs are basic modeling units in SWAT. Each HRU has a unique combination of one land use and one soil type.

Table 1: SWAT subwatershed information for the St. Joseph River watershed.

Sub.†	LU‡	Area (ac)	County	Ag. mgt¶	Manure§	Sub.	Landuse	Area (ac)	County	Ag. mgt	Manure
1	AGRR	19,958	Van Buren	CS-m	S	59	AGRR	7,751	Branch	CS	--
2	AGRR	18,168	Van Buren	CS-m	F	60	AGRR	15,062	Lagrange	CH	F
3	AGRR	4,892	Van Buren	CS-m	F	61	AGRR	8,021	St. Joe (MI)	CS	--
4	AGRR	17,069	Van Buren	CS-m	F	62	AGRR	6,874	Lagrange	CH	F
5	AGRR	9,851	Van Buren	CS-m	F	63	AGRR	10,769	St. Joe (MI)	CS	--
6	AGRR	17,772	Van Buren	CS-m	F	64	AGRR	8,359	Lagrange	CH	F
7	AGRR	26,747	Van Buren	CS-m	S	65	AGRR	4,272	Cass	CS-m	S
8	AGRR	21,801	Van Buren	CS-m	F	66	AGRR	22,452	St. Joe (MI)	CS	--
9	AGRR	10,433	Van Buren	CS-m	S	67	AGRR	6,974	Lagrange	CH	S
10	FRSD	8,998	Berrien	--	--	68	AGRR	12,599	Lagrange	CH	F
11	AGRR	12,006	Van Buren	CS-m	S	69	AGRR	10,908	Steuben	CS	--
12	AGRR	18,620	Van Buren	CS-m	F	70	AGRR	10,632	Elkhart	CS	--
13	AGRR	24,639	Calhoun	CS	--	71	AGRR	12,757	Elkhart	CS	--
14	AGRR	10,311	Calhoun	CS	--	72	AGRR	11,967	St. Joe (IN)	CS-m	S
15	URLD	5,987	Berrien	--	--	73	AGRR	22,862	St. Joe (IN)	CS-m	S
16	AGRR	13,899	Branch	CH	F	74	AGRR	17,209	Lagrange	CH	S
17	AGRR	15,798	Kalamazoo	CS	--	75	AGRR	16,213	Lagrange	CH	S
18	AGRR	12,226	Calhoun	CS	--	76	AGRR	5,576	Elkhart	CS	--
19	AGRR	7,246	Branch	CS	--	77	AGRR	19,759	Elkhart	CS	--
20	AGRR	17,482	Kalamazoo	CS	--	78	AGRR	10,530	Elkhart	CS	--
21	AGRR	3,085	Kalamazoo	CS	--	79	AGRR	3,958	Elkhart	CS	--
22	PAST	15,564	Berrien	--	--	80	AGRR	7,923	Elkhart	CS	--
23	PAST	7,779	Berrien	--	--	81	URLD	196	Elkhart	--	--
24	AGRR	32,884	Van Buren	CS-m	S	82	AGRR	4,100	Elkhart	CS	--
25	AGRR	14,923	Branch	CH	S	83	WATR	121	Elkhart	--	--
26	AGRR	12,730	Kalamazoo	CS	--	84	WATR	52	Elkhart	--	--
27	AGRR	14,225	Branch	CS-m	S	85	AGRR	8,909	Elkhart	CS	--
28	AGRR	19,305	Branch	CH	F	86	AGRR	3,548	Elkhart	CS	--
29	AGRR	11,360	Cass	CS-m	S	87	AGRR	9,123	Lagrange	CH	S
30	AGRR	25,284	Cass	CS-m	F	88	AGRR	11,086	Lagrange	CH	S
31	AGRR	22,407	Cass	CS-m	S	89	AGRR	22,614	Cass	CS-m	S
32	AGRR	4,496	St. Joe (MI)	CS	--	90	AGRR	12,148	Elkhart	CS	--
33	AGRR	14,953	St. Joe (MI)	CS	--	91	AGRR	6,918	Lagrange	CH	S
34	AGRR	10,287	St. Joe (MI)	CS	--	92	AGRR	20,765	Lagrange	CH	S
35	AGRR	4,055	St. Joe (MI)	CS	--	93	AGRR	12,121	Lagrange	CH	F
36	AGRR	11,162	Cass	CS-m	F	94	AGRR	12,079	Lagrange	CH	F
37	AGRR	9,833	Cass	CS-m	F	95	AGRR	14,469	Elkhart	CS	--
38	AGRR	3,844	St. Joe (MI)	CS	--	96	AGRR	4,941	Elkhart	CS	--
39	AGRR	11,811	Hillsdale	CS	--	97	AGRR	12,554	St. Joe (IN)	CS-m	S
40	AGRR	8,313	Hillsdale	CS	--	98	AGRR	14,569	Elkhart	CS	--
41	AGRR	23,578	St. Joe (MI)	CS	--	99	AGRR	9,416	Lagrange	CH	F
42	AGRR	12,820	Branch	CS	--	100	AGRR	13,964	Noble	CH	F
43	AGRR	20,904	Branch	CS	--	101	AGRR	12,411	Elkhart	CS	--
44	AGRR	21,481	St. Joe (MI)	CS	--	102	AGRR	15,681	Noble	CH	F
45	AGRR	12,345	St. Joe (MI)	CS	--	103	AGRR	9,426	Noble	CH	F
46	AGRR	16,393	St. Joe (MI)	CS	--	104	AGRR	10,958	Noble	CH	S
47	AGRR	21,284	Cass	CS-m	S	105	AGRR	7,994	Elkhart	CS	--
48	FRSD	15,838	St. Joe (MI)	--	--	106	AGRR	10,918	Elkhart	CS	--
49	AGRR	17,746	St. Joe (MI)	CS	--	107	AGRR	19,224	Noble	CH	S
50	AGRR	13,110	Cass	CS-m	F	108	AGRR	17,083	Noble	CH	F
51	AGRR	14,992	Berrien	CS	--	109	AGRR	11,559	Elkhart	CS	--
52	AGRR	23,977	Berrien	CS	--	110	AGRR	9,635	Kosciusko	CS	--
53	AGRR	14,195	St. Joe (MI)	CS	--	111	AGRR	686	Kosciusko	CS	--
54	AGRR	15,248	St. Joe (MI)	CS	--	112	AGRR	12,009	Kosciusko	CS	--
55	AGRR	12,114	Cass	CS-m	F	113	AGRR	9,152	Kosciusko	CS	--
56	AGRR	8,848	Branch	CS	--	114	AGRR	13,340	Kosciusko	CS	--
57	FRSD	4,812	Berrien	--	--	115	AGRR	15,852	Noble	CH	F
58	AGRR	15,157	Cass	CS-m	S	116	AGRR	11,008	Noble	CH	F

Table 1: SWAT subwatershed information for the St. Joseph River watershed (Continued).

Sub.	Landuse	Area (ac)	County	Ag. mgt	Manure	Sub.	Landuse	Area (ac)	County	Ag. mgt	Manure
117	AGRR	11,421	Noble	CH	F	176	AGRR	17,556	Steuben	CS	--
118	AGRR	15,016	Hillsdale	CS	--	177	AGRR	8,010	Branch	CS-m	F
119	AGRR	8,950	Hillsdale	CS	--	178	AGRR	13,485	Hillsdale	CS	--
120	AGRR	2,344	Calhoun	CS	--	179	AGRR	19,896	Hillsdale	CS	--
121	AGRR	16,348	Calhoun	CS	--	180	AGRR	34,602	Branch	CS	--
122	PAST	13,483	Berrien	--	--	181	AGRR	4,548	Berrien	CS	--
123	PAST	15,924	Berrien	--	--	182	AGRR	11,311	St. Joe (IN)	CS-m	F
124	PAST	9,963	Berrien	--	--	183	AGRR	9,409	St. Joe (IN)	CS-m	S
125	AGRR	13,701	St. Joe (IN)	CS-m	F	184	AGRR	10,609	Elkhart	CS	--
126	AGRR	20,938	St. Joe (IN)	CS-m	F	185	AGRR	3,815	Elkhart	CS	--
127	AGRR	11,590	Elkhart	CS	--	186	AGRR	8,664	Elkhart	CS	--
128	AGRR	9,611	Noble	CH	S	187	AGRR	16,867	Noble	CH	S
129	AGRR	19,458	Kosciusko	CS	--	188	AGRR	12,398	Steuben	CS	--
130	AGRR	4,136	Noble	CH	F	189	AGRR	13,049	Elkhart	CS	--
131	AGRR	5,068	Noble	CH	F	190	AGRR	12,443	Branch	CH	S
132	AGRR	11,759	Noble	CH	S	191	AGRR	9,999	Branch	CS-m	F
133	AGRR	12,621	Noble	CH	F	192	AGRR	12,367	Branch	CH	S
134	AGRR	12,187	Noble	CH	S	193	AGRR	18,682	Branch	CS-m	F
135	AGRR	11,492	De Kalb	CS	--	194	AGRR	10,532	Branch	CH	F
136	AGRR	10,955	Steuben	CS	--	195	AGRR	12,642	Branch	CS-m	S
137	AGRR	12,432	Lagrange	CH	S	196	AGRR	3,083	Branch	CS	--
138	AGRR	7,961	Steuben	CS	--	197	AGRR	14,016	Branch	CS-m	S
139	AGRR	14,004	Steuben	CS	--	198	AGRR	11,351	Branch	CS	--
140	AGRR	6,450	Steuben	CS	--	199	AGRR	17,753	St. Joe (MI)	CS	--
141	AGRR	12,837	Steuben	CS	--	200	AGRR	9,706	Calhoun	CS	--
142	AGRR	11,322	Lagrange	CH	F	201	AGRR	12,696	Kalamazoo	CS	--
143	AGRR	19,567	Lagrange	CH	S	202	AGRR	8,489	Kalamazoo	CS	--
144	AGRR	10,432	Lagrange	CH	F	203	AGRR	7,466	St. Joe (MI)	CS	--
145	AGRR	13,281	Van Buren	CS-m	S	204	AGRR	27,607	St. Joe (MI)	CS	--
146	AGRR	10,184	Van Buren	CS-m	F	205	AGRR	16,999	St. Joe (MI)	CS	--
147	AGRR	23,182	Cass	CS-m	S	206	AGRR	19,589	Cass	CS-m	S
148	AGRR	14,912	Cass	CS-m	F	207	AGRR	14,866	Cass	CS-m	F
149	AGRR	17,497	Cass	CS-m	F	208	AGRR	14,517	Elkhart	CS	--
150	AGRR	9,386	Cass	CS-m	S	209	AGRR	20,796	Berrien	CS	--
151	AGRR	15,313	Cass	CS-m	F	210	AGRR	16,131	Berrien	CS	--
152	AGRR	8,928	Cass	CS-m	F	211	AGRR	32,180	Berrien	CS	--
153	AGRR	25,569	Cass	CS-m	F	212	AGRR	9,897	Berrien	CS	--
154	AGRR	13,650	Cass	CS-m	F	213	AGRR	12,952	Hillsdale	CS	--
155	AGRR	3,224	St. Joe (MI)	CS	--	214	AGRR	18,005	Hillsdale	CS	--
156	AGRR	10,315	Kalamazoo	CS	--	215	AGRR	18,928	Kalamazoo	CS	--
157	AGRR	7,626	St. Joe (MI)	CS	--	216	PAST	8,835	Lagrange	--	--
158	AGRR	8,906	St. Joe (MI)	CS	--	217	AGRR	10,253	Steuben	CS	--
159	AGRR	5,782	St. Joe (MI)	CS	--	218	AGRR	15,304	Steuben	CS	--
160	AGRR	11,550	Kalamazoo	CS	--	219	AGRR	8,298	St. Joe (IN)	CS-m	S
161	AGRR	19,353	Kalamazoo	CS	--	220	AGRR	15,991	Elkhart	CS	--
162	AGRR	20,075	Kalamazoo	CS	--	221	AGRR	13,718	Elkhart	CS	--
163	AGRR	17,967	Kalamazoo	CS	--	222	AGRR	11,543	Elkhart	CS	--
164	AGRR	16,602	Calhoun	CS	--	223	AGRR	15,408	Noble	CH	S
165	AGRR	14,217	Branch	CS	--	224	AGRR	10,619	Steuben	CS	--
166	AGRR	28,073	Branch	CS	--	225	AGRR	13,910	Lagrange	CH	S
167	AGRR	3,238	Branch	CS	--	226	FRSD	18,618	Van Buren	--	--
168	AGRR	15,868	Calhoun	CS	--	227	PAST	24,022	Berrien	--	--
169	AGRR	10,393	Calhoun	CS	--	228	AGRR	8,674	Cass	CS-m	S
170	AGRR	8,169	Hillsdale	CS	--	229	AGRR	12,559	St. Joe (MI)	CS	
171	AGRR	12,179	St. Joe (MI)	CS	--						
172	AGRR	4,733	St. Joe (MI)	CS	--						
173	AGRR	19,225	St. Joe (MI)	CS	--						
174	AGRR	17,925	Branch	CS	--						
175	AGRR	7,435	Steuben	CS	--						

† Subwatershed number (see Figure 1).
‡ Landuse types: AGRR: (Agricultural) Row Crop; FRSD: Deciduous Forest; URLD: (Urban) Low Density Residential; PAST: Pasture.
¶ Agricultural management types: CH: corn silage (5 yr)-hay (5 yr) with manure; CS: corn-soybean; CS-m: corn-soybean with manure;
§ Manure application season; F: fall, S: spring.

2.3 Dams and Ponds

A dam dataset was part of the BASINS built-in database and was used in the SWAT modeling with some modification. Locations of dams in the watershed were identified to the subwatersheds delineated in this study. Depending on the location of the subwatersheds and the streams on which the dams were located, impoundments were modeled as either dams (defined in SWAT as impoundments located on the main stream of a subwatershed), or ponds (impoundments located elsewhere in a subwatershed) in the model. As a result, impoundments were modeled in 29 subwatersheds as dams and in 4 subwatersheds as ponds.

2.4 Agricultural Land Management Information

Agricultural land management practices are key inputs for SWAT simulations. A detailed, realistic set of management scenarios was developed for SWAT by consulting county and state USDA-NRCS officials for each agricultural subwatersheds (Table 1). The key information in these management scenarios included crop rotations, timing and types of tillage, fertilizer and atrazine applications, and fertilizer and atrazine application rates. For the purpose of this study, three major types of agricultural land management scenarios were constructed: 1) 5-year corn silage followed by 5-yr hay with dairy manure being applied during the corn silage years; 2) corn-soybean rotation; and 3) corn-soybean rotation with swine manure being applied for corn.

To realistically simulate the current flow and nutrient loadings from the watershed, it is important to know the distribution of land management scenarios for the 214 agricultural row crop subwatersheds. Subwatershed-specific agricultural management data were not available for the St. Joseph River watershed. Instead, county-level estimates were provided by the USDA-NRCS officials. To segregate county-level information into the subwatershed level, a subwatershed was assigned to a county based on where the majority of its area is located (Figure 1 and Table 1).

For agricultural land with manure applications, it is difficult to determine the timing of the application. An algorithm based on randomly assigned numbers was used. Specifically, a computer generated random number was assigned to each manure-application subwatershed and the first digit after the decimal point was separated from the number. If this particular digit was an even number, the corresponding subwatershed was assigned to have spring manure application. Otherwise, fall manure application was assigned (Table 1).

Three sets of management scenario files were developed for the model. These three sets of files were different in fertilizer (including manure) and atrazine application rates, fertilizer types, and tillage practices. These differences reflect the changing of farming practices in the past two decades in the watershed. For the model, the first set was applied to simulations run from 1986 through 1995 and the second to simulations run from 1996 through 2004. The third set was used to simulate agricultural BMPs.

3.0 Model Calibration

Calibration procedures were formed following the advice provided in some key publications by the principal SWAT model developer, Dr. Jeff Arnold, and his colleagues at the USDA ARS-Blackland (Texas) Research Center (Arnold et al, 2000; Santhi et al, 2002; and Neitsch et al, 2002b). Table 2 provides a list of the model parameters whose values were calibrated in this study against observed data. Model calibration was focused on the simulated loads of the St. Joseph River near Niles, MI, where flow data from a USGS gage station (USGS station No. 04101500) are readily available for the simulation time period. The drainage area covered by the St. Joseph River at this gage station is 78% of the total watershed area.

Table 2: Input parameters calibrated in SWAT modeling. [1]

Parameter Name	**Model Processes**	**Description**	**Model Range**	**Actual Value/ Change used**
CN2	Flow	Curve number	±10%	-8
ESCO	Flow	Soil evaporation compensation factor	0.00 to 1.00	0.5
SOL_AWC	Flow	Soil available water capacity	±0.04	+0.03
SMFMN	Flow	Minimum melt rate for snow during the year	0.00 to 10	1.00
BLAI	Flow	Maximum potential leaf area index	0.5 to 10	Corn - 5.0 Corn silage - 6.0
USLE_C	Sediment	Universal Soil Loss Equation C factor	0.0001 to 1	Soybean: 0.150 Corn-C [2]: 0.065 Soybean-C: 0.030 Corn Silage-C: 0.150
USLE_P	Sediment	Universal Soil Loss Equation P factor	0.1 to 1.0	0.65
SLSUBBSN	Sediment	Average slope length (m)	NA	-10%
SLOPE	Sediment	Average slope steepness (m/m)	NA	-10%
BIOMIX	Sediment/ Nutrients	Biological mixing efficiency	0 to 1.0	0.40
SPCON	Sediment	Linear factor for channel sediment routing	0.0001 to 0.01	0.001
SPEXP	Sediment	Exponential factor for channel sediment routing	1.0 to 1.5	1.0 (default)
PPERCO	Mineral P	Phosphorus percolation coefficient	10.0 to 17.5	10 (default)
PHOSKD	Mineral P	Phosphorus soil partitioning coefficient	100 to 200	200 (default 175)
FRY_LY1	Nutrients	Fraction of fertilizer applied to top 10mm of soil	0.000 to 1.000	0.15
SOL_ORGP	Organic P	Initial organic P concentration in the upper soil layer	NA	0.1 mg/kg
SOL_LABP	Mineral P	Initial mineral (labile) P concentration in the upper soil layer	NA	0.1 mg/kg
SOL_ORGN	Organic N	Initial organic N concentration in the upper soil layer	NA	2,000 mg/kg
RS2	Mineral P	Benthos (sediment) source rate for soluble P at 20 ^{o}C	0.001 to 0.1	0.001
RS5	Total P	Settling rate for organic P at 20 ^{o}C	0.001 to 0.1	0.1
BC4	Total P	Rate constant for organic P mineralization at 20 ^{o}C	0.01 to 0.70	0.01
RHOQ	Total P	Local algal respiration rate at 20 ^{o}C	0.05 to 0.5	0.05
CHPST_KOC	Pesticide	Pesticide partition coefficient	0 to 0.100	0.000 (default)

CHPST_REA	Pesticide	Rate constant for degradation or removal of pesticide in the water	0 to 0.100	0.010
CHPST_VOL	Pesticide	Volatilization mass-transfer coefficient	0 to 10	0.12
CHPST_STL	Pesticide	Pesticide settling velocity	0 to 10	5.000
SEDPST_REA	Pesticide	Rate constant for degradation or removal of pesticide in the sediment	0 to 0.1	0.100
PERCOP	Pesticide	Pesticide percolation coefficient	0 to 1.00	0.50 (default)
BLAI	Flow/Sediment	Maximum potential leaf area index	0.5 to 10	Corn: 5.0 Corn Silage: 6.0
HEAT UNITS	Crop growth	Heat units	NA	Soybean: 1,300 Corn/Corn Silage:1,500 Alfalfa: 1,250

[1] See Santhi et al. (2001) and Arnold et al. (2000) for discussions and more information.
[2] "C" stands for conservation tillage (no till in this study)

Although the model simulations were conducted from 1986 through 1995, model calibration was performed for the period of 1991-1995, allowing the first five years of the simulations to be the model setup period (Neitsch et al, 2002b). Flow calibration was based on data from the USGS gage station near Niles. Cursory sediment and nutrient calibrations were also attempted in this study based on limited USGS monitoring data at the same station. However, because monitoring frequency for nutrients and sediment at this station was only once every two months (or less), accurate monthly loading calibration was not possible. Monitoring data were used only to verify the general range and magnitude of sediment and nutrient load values simulated by the model.

Statistical estimates of the long-term (1975-1990) average loads of TP and TSS from the watershed by Robertson (1997) were used as the primary calibration points for these two parameters. The Lake Michigan Mass Balance Study (http://www.epa.gov/glnpo/lmmb; US EPA) estimated loadings of total nitrogen (TN) and atrazine from the St. Joseph River for 1994 and 1995. However, it is not clear from the information available on the Study's website how the loadings were calculated. It is likely that some modeling was involved because the atrazine report of the Study (http://www.epa.gov/glnpo/lmmb/results/atra_final.pdf) indicates that only 11 samples were taken at the mouth of the river from April to October of 1995. In addition, no significant correlation between river flow and atrazine concentration was found for the St. Joseph River. For TN load, information on how the values were derived was not available on the website. Despite these uncertainties, to our knowledge, the Lake Michigan Mass Balance Study provides the only known estimates of loadings of TN and atrazine for the St. Joseph River to date. Therefore, these estimates were used in this study for cursory calibration for TN and atrazine for the SWAT model.

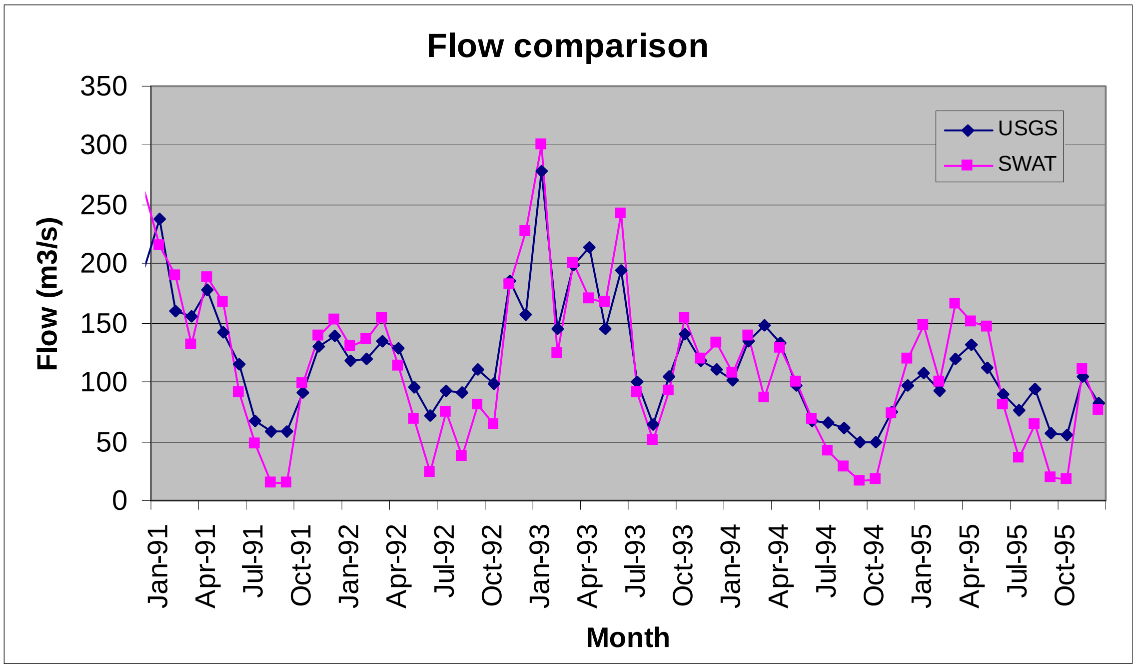
4.0 Calibration Results

As noted above, rigorous calibration of the model was not practical due to inadequate monitoring data and the limited scope of this study. The following are flow calibration conducted at the outlet of subwatershed # 181 that coincides with the USGS gage station near Niles, MI (Figure 1), and cursory calibrations for TP, TSS, TN, and atrazine. The calibrations for these pollutants are presented in tables only.

4.1 Flow

SWAT model prediction of monthly flows from January 1991 to December 1995 in comparison to the USGS data is shown in Figure 2 for the Niles station on the St. Joseph River main stem. Statistics for the simulation are also presented in the figure as a table.

Figure 2: SWAT monthly flow and USGS gage station data comparison near Niles, MI (USGS Station No. 04101500) for the period of January 1991 to December 1995.



	Average flow rate * (m^3/s)	R^2	RMSE (m^3/s)	Nash-Sutcliffe Efficiency**
This study	111	0.83	28	0.64
Description	*USGS value: 116*	*Best value 1.0*	*Smaller is better*	*Best value 1.0*

* Average monthly flow rate for the comparison period: Jan. 1991 through Dec. 1995.

** Values ≥ 0.50 are generally accepted as adequate (Santhi et al. [2001])

4.2 Nutrients and Atrazine

It should be noted that model calibration and Robertson's estimates (Robertson, 1997) have different time spans and are not directly comparable. Robertson's study used a flow-concentration correlation to estimate loads. As Richards (1998) pointed out, such a method tends to underestimates loads due to frequent concentration data gaps at high flows. Therefore, the comparisons of TP and sediment between model results and Robertson's estimates were intended only to be a rough model adjustment process, not a rigorous calibration.

Table 3: Cursory model calibration results near Niles, MI and some reference estimates from outside sources.

	TP (kg/yr)	Sediment (metric tons/yr)			TN (kg/yr)	Atrazine (kg/yr)
This study (1991-1995)	371,737	96,857	This study	1994	6,592,000	232
				1995	12,535,000	5,465
Robertson (1975-1990)	275,352	96,848	LMMB*	1994	~ 6,700,000	~ 310
				1995	~ 7,400,000	~ 470

* Lake Michigan Mass Balance Study result charts (http://www.epa.gov/glnpo/lmmb)

Total nitrogen and atrazine calibrations were hampered by uncertainties regarding the results from the Lake Michigan Mass Balance Study and the short term nature of the LMMB study. Table 3 indicates that the 1994 results from the model match the LMMB numbers fairly well but the 1995 results overestimated TN and atrazine substantially compared to LMMB numbers. This is probably due to the high precipitation recorded in the watershed in April and May of 1995, especially between May 8 and May 31 of 1995 after the atrazine application date (May 8 every year) used in the model. For example, at the Three River climatic station in 1994, there were 118 mm of rain in April and May and 24 mm between May 8 and May 31. In 1995, these two numbers were 192mm and 82 mm, respectively. While farmers can adjust pesticide and fertilizer application dates according to the weather condition, the way SWAT model was set up in this study did not allow such adjustment, resulting in high loadings of atrazine and TN in 1995.

Overall, model calibration yielded results that agreed generally with estimates based on monitoring data (Table 3). Rigorous calibration was not possible considering data availability and the scope of this study.

5.0 Model Validation

Due to the lack of any load estimates from outside sources for the St. Joseph River watershed after 1995, model validation was conducted only for flow at USGS gage stations where continuous flow data are available on the USGS website up to September 2003. The station near Niles, MI was chosen because it was the same station that the model calibration was conducted. Two other stations were also chosen for the validation because the drainage areas they represent were of interest to the watershed management planning—the station at Goshen, Indiana, draining most of the Elkhart River watershed and the station near Scott, Indiana, draining most of the Pigeon River watershed. Flow validation was done at these three sites for the last five full calendar years (1998 – 2002) of available USGS gage station data. Tables 4 through 6 show the validation results.

Table 4. Flow validation results for USGS gage station near Niles, MI (USGS Station No. 04101500) from January 1998 through December 2002.

	Average flow rate * (m^3/s)	R^2	RMSE (m^3/s)	Nash-Sutcliffe Efficiency**
This study	112	0.85	37	0.50
Description	*USGS value: 104*	*Best value 1.0*	*Smaller is better*	*Best value 1.0*

* Average monthly flow rate for the comparison period: Jan. 1998 through Dec. 2002.

** Values ≥ 0.50 are generally accepted as adequate (Santhi et al. [2001])

Table 5. Flow validation results for USGS gage station at Goshen, IN (USGS Station No. 04100500) from January 1998 through December 2002.

	Average flow rate * (m^3/s)	R^2	RMSE (m^3/s)	Nash-Sutcliffe Efficiency**
This study	17.2	0.73	7.7	0.56
Description	*USGS value: 16.0*	*Best value 1.0*	*Smaller is better*	*Best value 1.0*

* Average monthly flow rate for the comparison period: Jan. 1998 through Dec. 2002.

** Values ≥ 0.50 are generally accepted as adequate (Santhi et al. [2001])

Table 6. Flow validation results for USGS gage station near Scott, IN (USGS Station No. 04099750) from January 1998 through December 2002.

	Average flow rate * (m^3/s)	R^2	RMSE (m^3/s)	Nash-Sutcliffe Efficiency**
This study	9.5	0.61	4.3	0.50
Description	*USGS value: 9.8*	*Best value 1.0*	*Smaller is better*	*Best value 1.0*

* Average monthly flow rate for the comparison period: Jan. 1998 through Dec. 2002.

** Values ≥ 0.50 are generally accepted as adequate (Santhi et al. [2001])

Validation results show that our model with calibrated parameters generated flow predictions at three different sites that match their flow gage station recordings with acceptable statistics.

6.0 Baseline Simulation Results

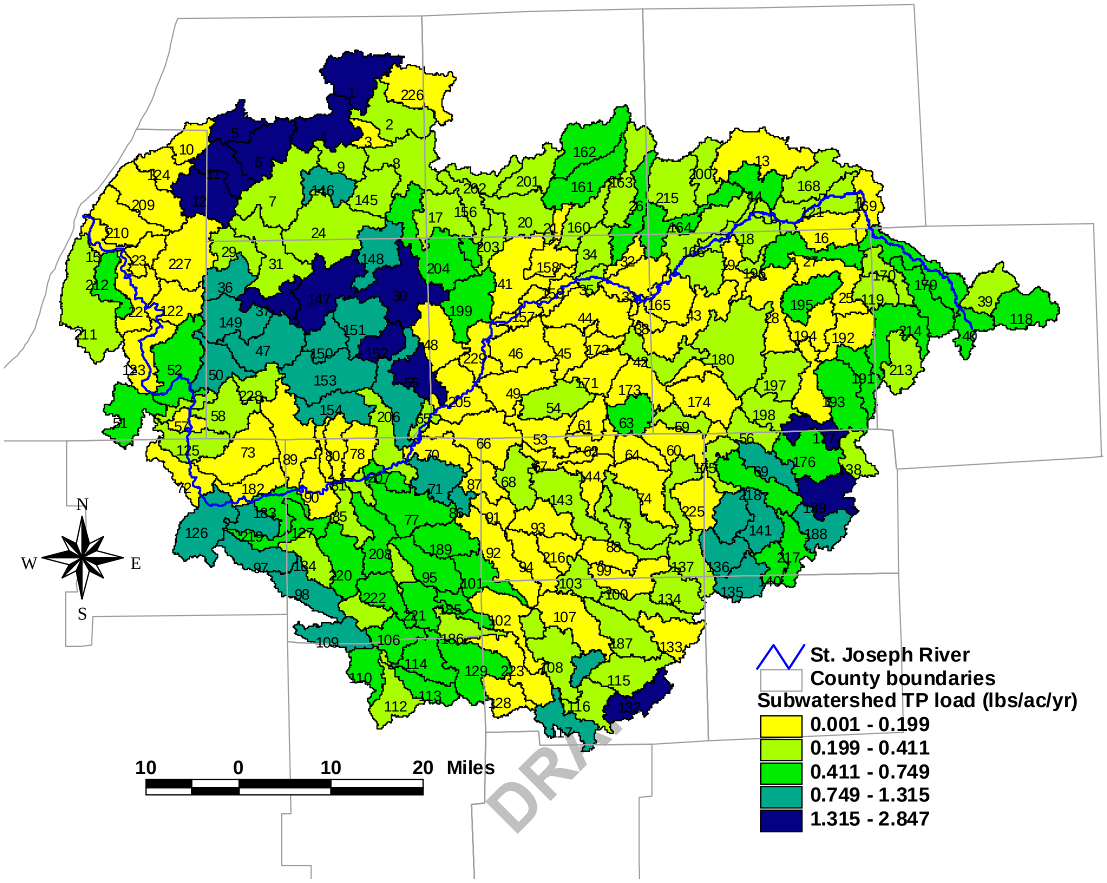
Figures 3-5 show the range of the annual loads of TP, sediment, and TN, respectively, for each subwatershed in the St Joseph River watershed. These loading values were the average annual values from 2000 through 2004 as simulated by the SWAT model. They were used as the baseline loading conditions to which the simulated loads from BMP implementation were compared in Sections 6.2-6.4 of this report. The Appendix to this report tabulates the per acre loads for each subwatershed.

Comparing to the results (http://www.stjoeriver.net/wmp/tasks/nps_load_model.htm) from the empirical nonpoint source loading modeling conducted earlier for the initial development of the St. Joseph River watershed management plan, TP and sediment loading values from SWAT and the empirical model are similar in that the general trend is an increase in loadings from the east part of watershed to the west part. This likely reflects the same increasing trend of the amount of precipitation these parts of the watershed receive annually. The two models also both show high loadings for the same parts of the watershed, for example, subwatersheds in Elkhart and Kosciusko Counties in Indiana, where high agricultural land use occurs.

The advantages of the empirical nonpoint source loading model lie on its straightforward landuse-based load computations (http://www.stjoeriver.net/wmp/docs/nps_model_report.PDF). As a result, the empirical model represents landuse distributions truthfully. This character makes this easy-to-use model very useful in comparing pollutant loads from watersheds with different landuse distributions, especially in watersheds where small proportions of non-dominant landuse types exist (e.g., urban lands and forests in agricultural dominated watersheds). However, by not including in the loading equations important parameters such as soil types, slopes, and land management practices (e.g., crop rotations), and watershed processes such as the movement of pollutants on the land or in the runoff (e.g., sediment deposition), the empirical model cannot account for loading changes resulting from the variation of these parameters and watershed

Figure 3

ıbwatershed Total Phosphorus Loading of of the St. Joseph River Wate

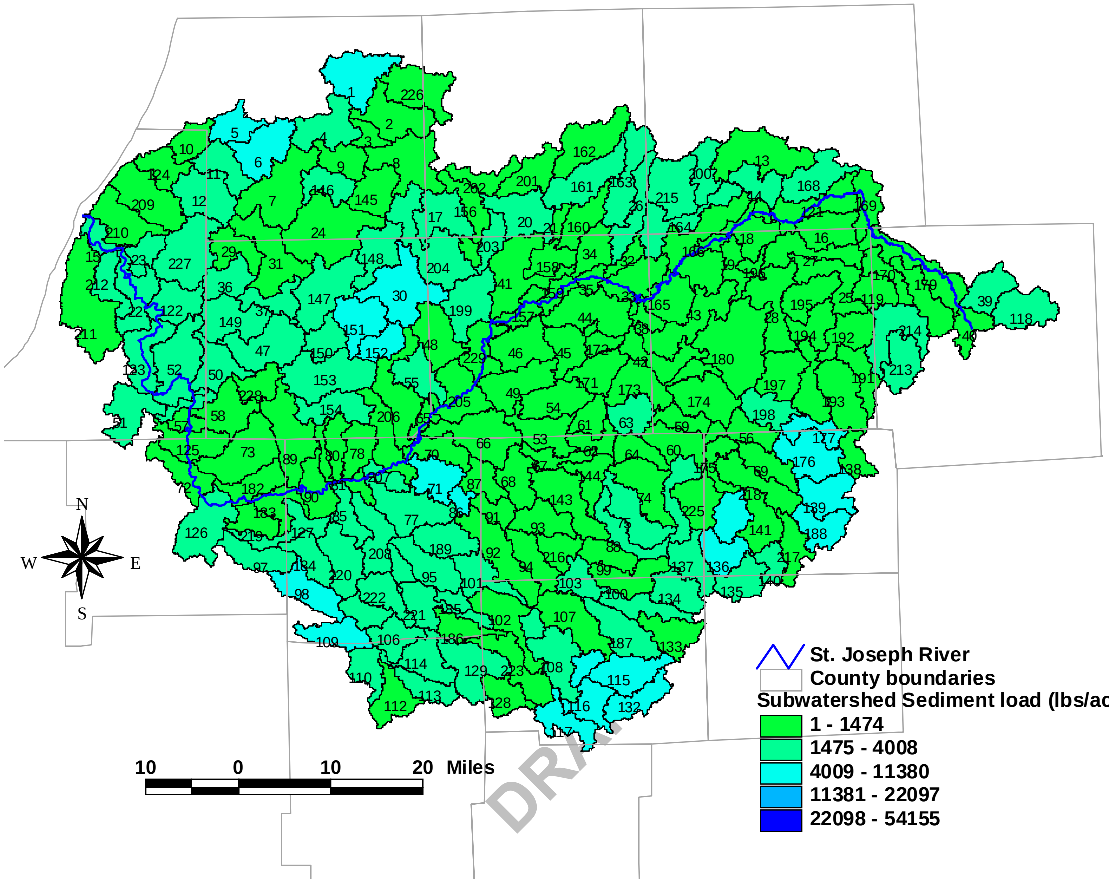


processes. Consequently, the empirical model has only a very limited applicability in estimating BMP effectiveness where it is necessary to change these parameters and simulate these processes.

SWAT, as a physically based model, specifically uses these parameters and simulates important watershed processes. It can truthfully represent agricultural cropping systems, simulates the hydrological cycle and the fate and transport of sediment, nutrients, and agricultural chemicals as they move across the watershed in various media, using daily climatic information and taking into account watershed characteristics. As such, SWAT is well suited for applications for load estimates involving watersheds with variable soil and landscape conditions and changing land management practices (e.g., agricultural BMPs). On the other hand, because SWAT simulates the various watershed processes, there is a high demand for data, expertise, and other resources for a satisfactory SWAT modeling study. In addition, the current version of SWAT in the BASINS interface requires a very high number of HRUs to truly represent the landuse distribution of a watershed that is the size of the St. Joseph River and has highly dispersed

Figure 4

Subwatershed Sediment Loading of of the St. Joseph River Watershed

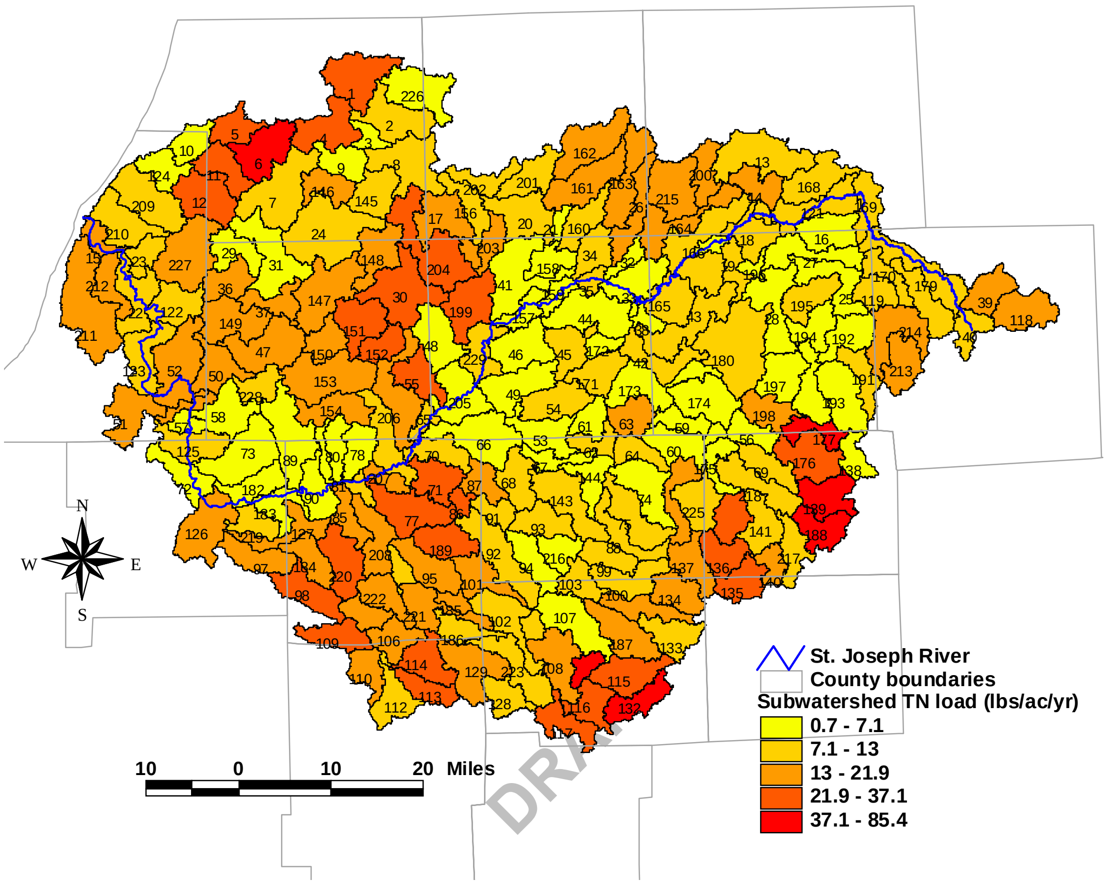


locations of different landuses (see Section 7.0). As a result, some important landuses, such as urban lands and forests, that occupy small areas in some subwatersheds were omitted in this study.

With these differences established between SWAT and the empirical nonpoint source model, we can interpret the discrepancies of the baseline loading estimates from the SWAT (Figures 3-5) and the empirical model (http://www.stjoeriver.net/wmp/tasks/nps_load_model.htm). The most obvious difference is the magnitude of loading values from each subwatershed. Because the empirical model was calibrated against loading values derived from monitoring data at Niles, MI (http://www.stjoeriver.net/wmp/docs/nps_model_report.PDF), which is located on the lower reach of the St. Joseph River, and because the model does not consider the fate and transport of pollutants, it essentially assumes that one pound of, for example, phosphorus load generated in subwatersheds near the headwaters of the St. Joseph River has the same chance to reach Niles as one pound of phosphorus generated in a subwatershed only one mile upstream of Niles. As such, the calibration process was forced to adjust parameters to give low pollutant loading values for all subwatersheds in order to compensate for load losses occurring during the transport of pollutants generated from remote parts of the watershed. Consequently, loading values are low compared to SWAT values, which are the loads from each subwatershed before transport losses

Figure 5

Subwatershed Total Nitrogen Loading of of the St. Joseph River Waters



occur. It is therefore, fair to say that the SWAT model generated loading values for each subwatersheds that are more realistic than the empirical model. However, again, it should be pointed out here that the value of the empirical model resides more on how the loads estimated for the subwatersheds compare to each other than the absolute values of these estimates.

In terms of relative values, there are also some differences between the two models. For example, compared to other subwatersheds, Figures 3-5 show high TP, sediment, and TN loadings for the subwatersheds in Cass County, MI (e.g., subwatershed # 30, 151, and 152), while the empirical model generally gave low to moderate loadings. Cass County has a high concentration of swine manure application on its farm land (personal communications with USDA-NRCS personnel) and the average slope for the land in these subwatersheds is around 3-4%, much higher than the watershed average of 2% (from SWAT model parameter calculations performed by the BASINS interface). Combined, these two factors produced high pollutant loads in the SWAT model for these subwatersheds. On the other hand, in this study, the SWAT model assumed most of these subwatersheds were composed of only agricultural land based on the fact that agricultural row cropping occupies the majority (over 50%) of the land in these subwatersheds. The empirical model, however, considered all the landuse types including about 20% of forest but not the land management and slope factors. As a result, the empirical model produced lower loadings. One can conclude from this comparison that although SWAT may have over-estimated loads from these subwatersheds due to the omission of forest lands, it can be decided with confidence that the agricultural land in these subwatersheds in Cass County, MI is a source of high TP, sediment, and TN loadings.

Another example is those subwatersheds with substantial urban lands (e.g., subwatershed # 61, 72, 210). The empirical model, on a relative term, generally produced highest load estimates of TP and sediment for these subwatersheds, but SWAT did not, apparently due to the omission of urban lands in SWAT. In such cases, one should give more consideration to the empirical model results when undertaking watershed management planning for these subwatersheds.

6.1 BMP Simulation Results

Tributary watersheds that are largely agricultural and have the highest watershed restoration scores (http://www.stjoeriver.net/wmp/tasks/task4/subshed_scoring.htm) based on planning project efforts were examined using SWAT to assess phosphorus, nitrogen, sediment and atrazine loading, and BMP effectiveness. Representing more than one-third of the entire St. Joseph River watershed, the following agricultural tributary watersheds were examined here (Figure 6):

- The Elkhart River (and all tributaries – 37 subwatersheds)
- The Pigeon River (and all tributaries – 20 subwatersheds)
- The Fawn River (all stretches – 11 subwatersheds)

This study examined the load and concentration reductions resulting from a combination of agricultural BMPs and hypothetical BMP implementation rates (% of land implemented with the BMP). Results were interpreted as the load or concentration reductions expressed at the mouth of each tributary watersheds. It is important to note here that load and concentration reductions were expressed at the mouth of each tributary watershed because due to in-stream settling, resuspension, and/or algal uptake/release, load reduction achieved at subwatershed level can be diminished at downstream observation points. Table 7 shows the simulated BMP implementation scenarios.

As Table 7 indicates, there are 15 BMP scenarios (types of BMPs times number of implementation rates) examined in this study. Which subwatersheds will be implemented with BMPs was decided randomly for each tributary watershed using computer generated random numbers. The random assignment process was repeated until the selected subwatersheds totaled approximately the desired land area percentage (25, 50, or 75%) of the tributary watershed.

Conservation tillage of corn or corn silage rotation was simulated in SWAT with reduced C factors in the Modified Universal Soil Loss Equation (MUSLE; see Table 2) and the removal of tillage practices in the agricultural management input files. Nutrient management (fertilizer application rate reduction) was simulated with a 25% reduction of fertilizer and manure application rates. Installation of filter strips was simulated by adding a 5 meter edge-of-field filter strips in selected subwatersheds (HRUs). Contour farming was simulated with a reduced (by 0.3 units) of the P factor in the MUSLE (see Table 2).

Figure 6. The Three Major Agricultural Tributary Watersheds

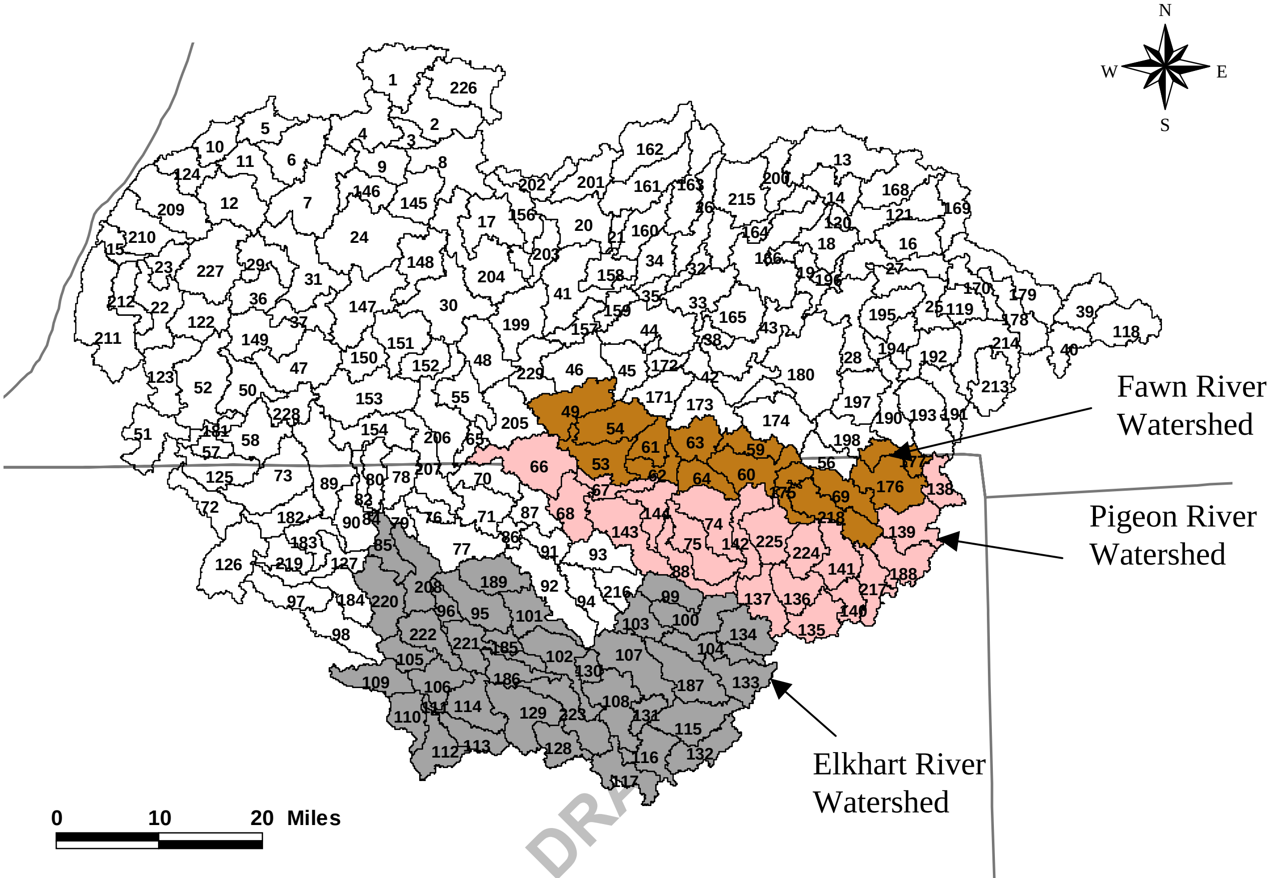


Table 7: BMP implementation scenarios simulated in this study.

BMP Application to: [1]	**25% of the Tributary Watersheds**	**50% of the Tributary Watersheds**	**75% of the Tributary Watersheds**
Conservation tillage [2]	x	x	x
Nutrient management (25% decrease in fertilizer usage) [3]	x	x	x
Filter strips [4]	x	x	x
Contour farming	x	x	x
Combination of the three most Efficient BMPs above	x	x	x

[1] BMP application rates as a percentage of the total agricultural land in the watershed. It's assumed that these BMPs are not currently implemented in the watershed.
[2] No-till for corn or corn silage; most of the farmers in the watershed currently do no-till for soybean.
[3] Fertilization application rate reduction of 25% over the current application rates (including manure application).
[4] Edge-of-field filter strips (15 ft [5 meters] wide, 5% of the total land area).

6.2 Load Reductions

At the mouth of each of the three tributary watersheds, the 5-year average (2000 through 2004) annual loads of TP, sediment, TN, and atrazine obtained from the current condition simulation were used as the baseline. The same 5-year average annual loads of these pollutants were also obtained for the 15 BMP scenarios. The difference between each BMP scenario and the current baseline condition was then used to indicate the load reduction achieved by this BMP scenario.

Table 8. Load reduction (%) as manifested at the mouth of the Fawn River

	Implementation rate (% of total land)		
	25%	50%	75%
Total P			
Fert [a]	10.8	14.0	20.8
No-till [b]	17.9	21.1	24.9
Filter [c]	24.9	31.9	47.0
Contour [d]	16.0	20.2	28.5
Combo [e]	35.2	44.8	64.1
Sediment			
Fert	0.0	0.0	0.0
No-till	5.6	23.0	39.5
Filter	6.9	22.0	39.6
Contour	8.3	19.6	33.5
Combo	10.3	34.1	61.4
Total N			
Fert	0.9	2.0	2.4
No-till	14.6	25.4	46.5
Filter	14.6	20.1	39.4
Contour	9.5	13.1	25.0
Combo	23.3	36.3	67.1
Atrazine			
Fert	0	0	0
No-till	7.1	18.8	31.7
Filter	13.7	22.9	37.6
Contour	0.0	0.0	0.0
Combo	16.7	30.7	50.7

[a] Fertilization application rate reduction of 25%
[b] No-till for corn or corn silage
[c] Edge-of-field filter strips
[d] Contour farming
[e] Combination of no-till, edge-of-field filter strips, and contour farming

Table 9. Load reduction (%) as manifested at the mouth of the Pigeon River

	Implementation rate (% of total land)		
	25%	50%	75%
Total P			
Fert [a]	6.1	13.2	19.9
No-till [b]	3.7	12.3	19.0
Filter [c]	12.0	28.4	42.6
Contour [d]	14.8	23.6	31.5
Combo [e]	15.9	38.7	58.3
Sediment			
Fert	0.0	0.0	0.0
No-till	0.0	0.0	4.4
Filter	16.8	28.3	47.5
Contour	9.6	19.7	34.3
Combo	24.8	34.1	61.4
Total N			
Fert	0.0	0.0	0.5
No-till	4.0	16.8	28.7
Filter	9.8	26.1	38.8
Contour	9.9	19.3	26.8
Combo	13.7	37.7	57.8
Atrazine			
Fert	0.0	0.0	0.0
No-till	8.1	24.5	27.8
Filter	10.2	30.2	44.6
Contour	0.0	0.0	0.0
Combo	13.5	40.1	56.0

[a] Fertilization application rate reduction of 25%
[b] No-till for corn or corn silage
[c] Edge-of-field filter strips
[d] Contour farming
[e] Combination of no-till, edge-of-field filter strips, and contour farming

Results in Table 8 show that for the Fawn River watershed, the no-till and the edge-of-field filter strips BMPs have the highest load reductions, especially at the 50% application rate. No-till is particularly effective for sediment and TN. In addition, no-till also shows a higher increase than filter trips in effectiveness for sediment, TN, and atrazine when the application rate goes from 25% to 50%. This can have a significant cost implication considering it is more expensive to install filter strips than implementing no-till (see Section 6.2).

Numbers in Table 9 suggest that for the Pigeon River watershed, filter strips are the most effective BMP in most cases and become even more so as the implementation rate increases.

This is different from the Fawn River, where no-till is relatively more effective in reducing loads. These two watersheds are substantially different in their soil hydrologic properties. The Pigeon River flows through predominately heavy clay loam soils (Wesley and Duffy, 1999) and has 67% (area) of its soils being hydrologic group B (56%) or C (11%) soils. The Fawn River watershed, on the other hand, has 64% of hydrologic group A soils that drains better and produces much less runoff. Because filter strips work to filter pollutants out of surface runoff, it can be expected that they are more effective when runoff is higher.

In addition to different soils, the two watersheds also have different crops. The Fawn River is corn-soybean dominant (81%) while the Pigeon has a significant presence of corn silage-hay (52%). The results in Tables 8 and 9 are likely an indication of the higher load reduction efficiency of edge-of-field filter strips in a corn silage-hay rotation than corn-soybean. It is thus clear from this modeling study that in order to achieve the best load reductions, it is important to consider local soil and cropping conditions when BMPs are chosen.

Table 10. Load reduction (%) as manifested at the mouth of the Elkhart River

	Implementation rate (% of total land)		
	25%	50%	75%
Total P			
Fert [a]	4.9	10.5	16.1
No-till [b]	2.4	7.7	9.9
Filter [c]	11.2	23.5	37.0
Contour [d]	6.7	14.3	22.1
Combo [e]	14.5	31.3	48.4
Sediment			
Fert	0.0	0.0	0.0
No-till	13.3	27.1	58.3
Filter	12.0	24.3	52.4
Contour	10.5	19.9	41.2
Combo	19.1	34.1	61.4
Total N			
Fert	0.0	0.0	0.0
No-till	7.7	16.5	28.2
Filter	12.1	23.3	36.1
Contour	6.0	13.5	21.6
Combo	17.3	34.0	53.4
Atrazine			
Fert	0.0	0.0	0.0
No-till	8.6	22.7	39.4
Filter	11.6	25.6	46.9
Contour	0.0	0.0	0.0
Combo	15.1	34.1	63.0

[a] Fertilization application rate reduction of 25%
[b] No-till for corn or corn silage
[c] Edge-of-field filter strips
[d] Contour farming
[e] Combination of no-till, edge-of-field filter strips, and contour farming

Examining Table 10 reveals that edge-of-field filter strips are most effective in load reductions, except for sediment where it comes to a close second to no-till. Similar to the Pigeon River watershed, the Elkhart River has soils dominated by hydrologic groups B (80%) and C (20%) and crop rotations marked by a significant presence of corn silage-hay (51%). Therefore, it is not surprise that filter strips are the best performing BMP in the watershed.

When individual pollutants are examined, edge-of-field filter strips are always most effective in reducing total phosphorus loading. Contour farming is second. In the Fawn River watershed, where soils are more permeable and the corn-soybean rotation dominates, no-till for corn is as effective as contour farming, particularly when the implementation is at or below 50%. For sediment, no-till performs as well as or even better than filter strips in the Fawn River and Elkhart River watersheds, but is nearly not effective at all in the Pigeon. Total nitrogen reduction is achieved best by filter strips while no-till and contour farming have a comparable effectiveness in all three watersheds.

In general, Tables 8-10 suggest that no-till and edge-of-field filter strips almost always provide the highest load reductions compared to fertilizer reduction and contour farming. The “combo” option (combination of no-till, edge-of-field filter strips, and contour farming), as expected, gives the highest overall load reductions in all cases. However, the combination of three BMPs do not yield reductions that are the summation of these three BMPs. They are smaller than the summation, indicating the diminishing return of adding multiple BMPs on the same land. In addition, when cost is considered (see Section 6.3), the applicability of multiple BMPs may be further discounted.

6.3 Cost of BMPs

Absent a detailed survey, watershed specific costs of conducting various agricultural management practices in the St. Joseph River watershed were difficult to determine. It was therefore decided that for purposes of this study, literature values would be used. Direct payments to farmers to induce no-till vary widely among different localities and individual farmers. Many farmers in the upper Midwest have adopted no-till or other forms of onservation tillage even without any incentive payment. In addition, farm-level economic cost-benefit analyses often indicate a net profit with the adoption of conservation tillage or no-till (e.g., Haper, 1996; Massey, 1997; and Forster, 2002). A recent study on the cost of nutrient and sediment reduction in the Chesapeake Bay watershed (U.S. EPA, 2003a) cited a net farm cost of $2.72/acre/year for applying conservation tillage. Kurkalova et al. (2003) used a modeling approach based on the contingent valuations literature that computed directly the subsidies needed for adoption of conservation tillage in Iowa. They incorporated an adoption premium related to uncertainty in addition to changes in expected profit because the adoption premium may exceed the profit gain. Consequently, the farmer would require a subsidy to adopt the practice. They concluded that it would need an annual subsidy of $2.85 per acre for a corn-soybean rotation (1992 dollars).

Among the literature reviewed for this study, the Kurkalova et al. (2003) estimate represented the most rigorous evaluation of subsidies for inducing conservation tillage (including no-till) in the upper Midwest. Therefore, the average of the annual subsidies for corn and soybean from their study was used for this analysis. Applying a Producer Price Index increase of 8.1% from 1992 to 2003, this number was translated into $3.08 per acre in 2003 dollars.

Costs for implementing nutrient management on cropland correspond to equipment and labor for soil testing, hiring a consultant to design the plan, and the costs of any additional passes over the field to fertilize. Assuming a 3-year useful life for a plan once it is developed, and including the costs of soil testing, implementation, (and in some cases, cost savings and yield increases), net cost estimates range from -$30/acre/yr (i.e., a net cost savings) to $14/acre/yr in 2001 dollars (U.S. EPA, 2003a). In this study, a cost of $2.64/acre/yr in 2003 dollars was used as cited by U.S. EPA in its National Management Measures for the Control of Non-point Pollution from Agriculture (U.S. EPA, 2003b).

Costs for installing edge-of-field grass filter strips consist of a one-time establishment expense and an annual rental for the land used for filter strips. Devlin et al. (2003) suggested an establishment cost of $100 per acre. Rental cost for the land in the St. Joseph River watershed was obtained from a survey conducted by Schwab and Wittenberg (2004) for Michigan agricultural lands. For the watershed, the average rent of $93.50 per acre per year for tiled, non-tiled, and irrigated lands in the two survey districts that include counties in the watershed was used. Contour farming cost was obtained from Devlin et al.(2003) directly at $6.80 per acre.

Following the convention of cost-benefit analysis, net present worth values were calculated for these agricultural management practices based on the acreage of practice adoption, a 15-year BMP implementation time (assuming farmers committed to the BMPs for the same time period as Conservation Reserve Enhancement Programs [CREP] in Michigan and Indiana), and a five percent interest rate. Cost-effectiveness of these practices on a per pound basis were then calculated by dividing the net present worth by the total load reduction achieved over the 15-year period.

Table 11. Total cost ($K) for BMP implementation in the Fawn River watershed.

	Implementation rate (% of total land)		
	25%	50%	75%
Fert [a]	76	150	229
No-till [b]	89	175	267
Filter [c]	342	675	1,033
Contour [d]	196	386	590
Combo [e]	626	1,236	1,890

[a] Fertilization application rate reduction of 25%

[b] No-till for corn or corn silage

[c] Edge-of-field filter strips

[d] Contour farming

[e] Combination of no-till, edge-of-field filter strips, and contour farming

Table 12. Total cost ($K) for BMP implementation in the Pigeon River watershed.

	Implementation rate (% of total land)		
	25%	50%	75%
Fert [a]	114	227	345
No-till [b]	133	264	401
Filter [c]	514	1,019	1,550
Contour [d]	294	583	886
Combo [e]	940	1,866	2,838

[a] Fertilization application rate reduction of 25%

[b] No-till for corn or corn silage

[c] Edge-of-field filter strips

[d] Contour farming

[e] Combination of no-till, edge-of-field filter strips, and contour farming

Table 13. Total cost ($K) for BMP implementation in the Fawn River watershed.

	Implementation rate (% of total land)		
	25%	50%	75%
Fert [a]	204	400	601
No-till [b]	238	466	700
Filter [c]	918	1,802	2,704
Contour [d]	524	1,030	1,545
Combo [e]	1,680	3,298	4,949

[a] Fertilization application rate reduction of 25%

[b] No-till for corn or corn silage

[c] Edge-of-field filter strips

[d] Contour farming

[e] Combination of no-till, edge-of-field filter strips, and contour farming

Tables 11-13 shows the total cost for implementing each BMP in each of the three watersheds. In addition to the per acre costs of BMPs, these total costs are mainly a function of the size of the watershed. Tables 14-16 clearly shows the cost-effectiveness of no-till for corn in all three tributary watersheds and for all pollutants considered in the model. The exceptions are for TP in the Pigeon (Table 15) and Elkhart (Table 16) Rivers watersheds and sediment in the Pigeon River (Table 15) watershed. In these two watersheds, as explained in the last section, the soil conditions and the significant presence of hay growing land render no-till less effective in reducing loadings. Considering cost evidently makes edge-of-field filter strips a less attractive BMP than otherwise

Table 14. Cost of load reduction ($/lb) as manifested at the mouth of the Fawn River

	Implementation rate (% of total land)		
	25%	50%	75%
Total P ($/lb)			
Fert [a]	13.68	20.84	21.40
No-till [b]	9.59	16.06	20.86
Filter [c]	26.69	41.03	42.60
Contour [d]	23.64	37.04	40.21
Combo [e]	34.49	53.57	57.17
Sediment ($/ton)			
Fert	NA	NA	NA
No-till	39.12	18.93	16.85
Filter	124.38	76.36	64.90
Contour	58.50	49.05	43.93
Combo	151.64	90.26	76.71
Total N ($/lb)			
Fert	4.64	4.28	5.52
No-till	0.35	0.40	0.33
Filter	1.35	1.93	1.51
Contour	1.19	1.70	1.36
Combo	1.55	1.96	1.62
Atrazine ($/lb)			
Fert	NA	NA	NA
No-till	559	417	379
Filter	1,120	1,324	1,235
Contour	NA	NA	NA
Combo	1,688	1,809	1,677

[a] Fertilization application rate reduction of 25%
[b] No-till for corn or corn silage
[c] Edge-of-field filter strips
[d] Contour farming
[e] Combination of no-till, edge-of-field filter strips, and contour farming

Table 15. Cost of load reduction ($/lb) as manifested at the mouth of the Pigeon River

	Implementation rate (% of total land)		
	25%	50%	75%
Total P ($/lb)			
Fert [a]	29.85	27.34	27.60
No-till [b]	57.10	34.20	33.77
Filter [c]	68.24	57.28	58.03
Contour [d]	31.69	39.41	44.87
Combo [e]	94.34	76.96	77.68
Sediment ($/ton)			
Fert	NA	NA	NA
No-till	NA	NA	204.87
Filter	68.64	80.83	73.31
Contour	68.93	66.22	57.97
Combo	85.12	100.86	89.18
Total N ($/lb)			
Fert	NA	NA	23.91
No-till	1.14	0.53	0.48
Filter	1.78	1.33	1.36
Contour	1.01	1.03	1.12
Combo	2.33	1.69	1.67
Atrazine ($/lb)			
Fert	NA	NA	NA
No-till	932	614	824
Filter	2,860	1,927	1,981
Contour	NA	NA	NA
Combo	3,966	2,653	2,890

[a] Fertilization application rate reduction of 25%
[b] No-till for corn or corn silage
[c] Edge-of-field filter strips
[d] Contour farming
[e] Combination of no-till, edge-of-field filter strips, and contour farming

suggested by their load reduction effectiveness alone. On the other hand, contour farming, although not always yielding high load reductions, becomes economically more acceptable than filter strips. Even fertilizer eduction shows high cost-effectiveness in the Pigeon and Elkhart Rivers (Tables 15-16) watersheds for TP. These observations are a direct result of the high cost for installing and maintaining filter strips ($100/acre initial establishment plus a rent of $93.50 per acre per year) and the low costs of the no-till ($3.08/acre/yr), contour farming ($6.80/acre), and fertilizer reduction ($2.64/acre/yr) practices.

Table 16. Cost of load reduction ($/lb) as manifested at the mouth of the Elkhart River

	Implementation rate (% of total land)		
	25%	50%	75%
Total P ($/lb)			
Fert [a]	29.86	27.68	26.98
No-till [b]	72.21	43.63	51.47
Filter [c]	59.43	55.46	53.01
Contour [d]	56.46	52.20	50.73
Combo [e]	84.21	76.46	74.09
Sediment ($/ton)			
Fert	NA	NA	NA
No-till	19.40	18.66	13.02
Filter	83.12	80.49	55.98
Contour	54.19	56.11	40.64
Combo	95.26	90.68	64.38
Total N ($/lb)			
Fert	NA	NA	NA
No-till	0.48	0.44	0.39
Filter	1.18	1.20	1.16
Contour	1.36	1.18	1.11
Combo	1.51	1.51	1.44
Atrazine ($/lb)			
Fert	NA	NA	NA
No-till	567	422	364
Filter	1,621	1,446	1,185
Contour	NA	NA	NA
Combo	2,280	1,988	1,614

[a] Fertilization application rate reduction of 25%
[b] No-till for corn or corn silage
[c] Edge-of-field filter strips
[d] Contour farming
[e] Combination of no-till, edge-of-field filter strips, and contour farming

Another important observation from Tables 14-16 is the general trend of increasing cost-effectiveness (decreasing $/lb[ton] values) of the no-till practice with increasing implementation rate of this BMP. This increase in cost-effectiveness for no-till is most prominent when the implementation rate goes from 25% to 50%. Even in the Fawn River watershed (Table 14) where no-till has an increasing per pound cost for TP, the cost increment is slowed from the 50% implementation rate to 75%. The general trend of decreasing per pound (ton) cost with increasing implementation rate is also shown for other three BMPs and the “combo” scenario, but to a lesser degree (e.g., fertilization reduction) or not as consistent (e.g., contour farming). Because increase in total cost with increase in BMP implementation rate is nearly linear (Tables 11-13), the decrease in per pound (ton) cost of load reductions by these BMP is the result of accelerated increase in load reductions when implementation rate increases. This suggests the advantage of large scale BMP implementation efforts.

It should be noted here that when total costs are considered, load reductions for all pollutants concerned are achieved simultaneously with the implementation of any of the BMPs examined here. It is likely that more than one pollutant may be targeted in any particular setting (For the St. Joseph River watershed, nutrients and sediment are of concern). As a result, the most cost-effective BMP for those pollutants would be selected. This study indicates that in such situations, no-till appears to be a BMP of choice for the three major agricultural tributary watersheds examined here in the St. Joseph River watershed.

6.4 Concentration Reductions

Five-year (2000-2004) average concentrations of TP, sediment, and TN were calculated at the mouth of each of the three tributary watersheds to provide an indication of the water quality effect of BMPs. Monthly average concentrations were obtained by dividing monthly loads by monthly flow predicted by the model. These monthly concentration values were then averaged over the 5-year period to give the average concentrations. Due to uncertainties in predicting atrazine loading and the fact that the appearance of atrazine in river water is concentrated in the two month period of May-June (Results of the Lake Michigan Mass Balance Study: Atrazine Data Report, 2001: http://www.epa.gov/glnpo/lmmb/results/atra_final.pdf), 5-year average concentrations for atrazine were not calculated in this study.

It should be noted here that SWAT at its core is a runoff and pollutant loading model. It is not designed to fully simulate concentration changes in the modeled watershed. Therefore, concentrations derived using the method describe above should be treated with care in their application. The values listed in Tables 17-19 are intended to provide an overall picture of the effects of BMPs on concentrations manifested at the mouth of each tributary watershed. They were not calibrated against local monitoring data. Therefore, although these concentration estimates were compared to the average values of available monitoring data at the Niles station on the main stem of the St. Joseph River and found to be on the same order of magnitude (TP: 0.062 mg/L and TSS: 22.7 mg/L [data period: 1986-95], and TN: 2.5 mg/L [data period: 1980-

Table 17. Concentrations (mg/L) [a] calculated at the mouth of the Fawn River

	Implementation rate (% of total land)		
	25%	50%	75%
Total P	Baseline: 0.089 (mg/L)		
Fert [a]	0.079	0.077	0.072
No-till [b]	0.072	0.070	0.066
Filter [c]	0.067	0.062	0.050
Contour [d]	0.057	0.054	0.049
Combo [e]	0.057	0.050	0.035
Sediment	Baseline: 32.0 (mg/L)		
Fert	*32.1*	*32.3*	*32.7*
No-till	30.6	24.7	19.0
Filter	29.7	24.7	18.7
Contour	26.3	23.0	18.6
Combo	28.5	20.5	11.3
Total N	Baseline: 3.3 (mg/L)		
Fert	3.3	3.3	3.3
No-till	2.9	2.5	1.9
Filter	2.9	2.7	2.2
Contour	2.2	2.1	1.9
Combo	2.6	2.2	1.3

[a] 5-year (2000-04) average; calculated by dividing monthly load by monthly flow and then averaging monthly values.
[b] Fertilization application rate reduction of 25%
[c] No-till for corn or corn silage
[d] Edge-of-field filter strips
[e] Contour farming
[f] Combination of no-till, edge-of-field filter strips, and contour farming

Table 18. Concentrations (mg/L) [a] calculated at the mouth of the Pigeon River

	Implementation rate (% of total land)		
	25%	50%	75%
Total P	Baseline: 0.072 (mg/L)		
Fert [a]	0.068	0.063	0.059
No-till [b]	0.069	0.064	0.059
Filter [c]	0.064	0.054	0.045
Contour [d]	0.049	0.044	0.040
Combo [e]	0.061	0.046	0.033
Sediment	Baseline: 34.2 (mg/L)		
Fert	*34.4*	*34.8*	*34.6*
No-till	32.8	34.2	31.0
Filter	28.9	24.6	17.5
Contour	25.7	22.8	18.4
Combo	26.2	20.0	9.4
Total N	Baseline: 3.4 (mg/L)		
Fert	3.4	3.4	3.4
No-till	3.3	2.9	2.4
Filter	3.1	2.6	2.2
Contour	2.4	2.1	1.9
Combo	2.9	2.2	1.5

[a] 5-year (2000-04) average; calculated by dividing monthly load by monthly flow and then averaging monthly values.
[b] Fertilization application rate reduction of 25%
[c] No-till for corn or corn silage
[d] Edge-of-field filter strips
[e] Contour farming
[f] Combination of no-till, edge-of-field filter strips, and contour farming

Table 19. Concentrations (mg/L) [a] calculated at the mouth of the Elkhart River

	Implementation rate (% of total land)		
	25%	50%	75%
Total P	Baseline: 0.085 (mg/L)		
Fert [a]	0.081	0.077	0.073
No-till [b]	0.083	0.078	0.077
Filter [c]	0.076	0.067	0.057
Contour [d]	0.062	0.057	0.053
Combo [e]	0.073	0.060	0.048
Sediment	Baseline: 20.3 (mg/L)		
Fert	*20.4*	*20.6*	*20.9*
No-till	18.2	15.6	9.4
Filter	18.5	16.4	10.5
Contour	18.0	16.3	12.1
Combo	17.1	13.0	4.1
Total N	Baseline: 3.9 (mg/L)		
Fert	*3.9*	*3.9*	*3.9*
No-till	3.6	3.3	2.9
Filter	3.4	3.0	2.5
Contour	2.8	2.6	2.3
Combo	3.2	2.6	1.9

[a] 5-year (2000-04) average; calculated by dividing monthly load by monthly flow and then averaging monthly values.
[b] Fertilization application rate reduction of 25%
[c] No-till for corn or corn silage
[d] Edge-of-field filter strips
[e] Contour farming
[f] Combination of no-till, edge-of-field filter strips, and contour farming

81]), they should not be used as evidence of high or low pollutant levels at these particular tributary watersheds or as water quality goals for these watersheds.

Tables 17-19 show similar BMP effects on pollutant concentrations as on pollutant loadings (Tables 8-10). However, there is one significant difference. Contour farming becomes the most effective BMP in reducing pollutant concentrations in all the watersheds and for nearly all the pollutants. This reveals an important aspect of examining water quality improvement of BMPs through concentration changes. As indicated earlier, this SWAT modeling study used a reduction of the P factor (management practice factor) of the MUSLE equation to simulate the effect of contour farming on soil erosion control. Consequently, contouring farm here reduced soil and associated nutrient loadings from subwatersheds implemented with this BMP but did not reduce runoff from these subwatersheds. Other BMPs, including no-till, filter strips, and the "combo" option, reduced both loadings and flow. As a result, concentrations, as calculated by dividing load by flow, were reduced the most with contour farming. The fertilizer reduction BMP was similar to contour farming in this regard but because it reduced loadings to a much smaller degree than contour farming, its impact on concentration was not as great. In summary, when concentrations are examined, flow amount becomes an important consideration. A potential improvement to this modeling study is the incorporation of a runoff reduction for the contour farming simulations by adjusting the associated curve numbers (CN2; Table 2).

Besides contour farming, edge-of-field filter strips also provide similar concentration improvements for TP for all three tributary watersheds, especially at high implementation rates. No-till, on the other hand, provides comparable concentration improvements for sediment and TN in all three watersheds except for sediment in the Pigeon River.

7.0 Model Caveats and Potential Improvements

This section describes some key limitations of this modeling study. Some suggestions are also provided on how to improve the model for future studies, potentially TMDL development work, that might one day be conducted for the St. Joseph River watershed. Because of its agriculture-dominant nature, the watershed is very well suited to be modeled by SWAT. Results and experience gained from this current study are a valuable source of information for such a future modeling work.

Due to time and budget constraints, this study opted to discretize the entire St. Joseph River watershed into 229 subwatersheds but assign only one HRU to each subwatershed. Jha et al. (2004) reported that the optimal threshold subwatershed sizes, relative to the total drainage area of the entire watershed, required to accurately predict flow, sediment, and nutrients should be between 2 and 5 percent. With 229 subwatersheds, the average size of the subwatersheds in this study obviously meets this criteria. Nevertheless, because only one HRU was used for each subwatershed based on the dominant landuse type and soil type for that subwatershed, the model setup resulted in a landuse distribution that was high in agricultural land (98% including pasture) and low in forest and other landuses. As a comparison, the landuse distribution according the USGS 1992 landuse data (Figure 1) has agricultural land of 71% and forest 16%.

However, increasing the HRU number (by using a more refined combination of soil type and landuse) for the model to 570 (a little over two HRUs per subwatershed) resulted in a landuse distribution of 94% agriculture and 5% forest. That's only 4% decrease in agricultural land compared to the one HRU per subwatershed scenario. This suggests that in order to truly present the landuse distribution of the St. Joseph River watershed, we may well need three and likely more HRUs per subwatershed. Considering the time and effort necessary to set up the model with so many HRUs for their particular management files and change these files during each simulation for calibration, validation, and BMP simulations;, the computation iterations required to simulate watershed processes for each HRU; and the time needed to process and analyze the model outputs with a high number of HRUs; it was simply not practical to do so with the project time frame and available resources.

However, the over-representation of agricultural land in the watershed did lead to some over-adjustment of parameters in the model (e.g., CN2 and ESCO; Table 2) in order to compensate high flow and loadings for some subwatersheds resulting from this over-representation. As noted above, the shear size of the St Joseph River watershed and the high number of HRUs required to remedy this over-representation make it difficult to correct this over-adjustment of parameters. An obvious way for improvement is a well funded finer scale SWAT study. Another potential improvement to this modeling study would be to choose several representative subwatersheds (e.g., one for agriculture, one for forest, and one for urban) and model them with as many HRUs as needed to fully replicate the landuse and soil distributions in these subwatersheds. Then calibrated parameters from these subwatersheds can be applied to other similar subwatersheds without further calibration or only minor changes. Care, however, should be taken when selecting representative subwatersheds as to ensure these subwatersheds have adequate monitoring data and local agricultural management information for a rigorous calibration.

It should also be pointed out here that because the model was calibrated for TP and TSS against results from Robertson (1997)'s statistical estimates, not monitoring data, and the potential for such estimates to be low (Richards, 1998; see Section 4.2), the over-adjustment of some of the model parameters (e.g., USLE_P and SOL_ORGP) may very well be a result of these lower-than-actual benchmark values used in the calibration.

While SWAT calculates the deposition and re-entraining of sediment carried by surface runoff in the routing channels, it should be noted that the current version of the SWAT model does not have a fully functioning module that simulates the streambank erosion and channel degradation processes (Neitsch et al, 2002a). Therefore, sediment loads from these in-stream processes were not considered in this study. The St. Joseph River watershed Management Planning process developed a simple but effective protocol using field survey results to quantify streambank erosion at road-stream crossings (http://www.stjoeriver.net/wmp/road-stream.htm). In addition, the US Army Corps of Engineers is currently working on a hydraulic sediment model for the watershed. It is expected that that model will provide some key information regarding streambank erosion and channel degradation in the watershed.

It should also be noted that due to the agricultural nature of the SWAT model and the over-representation of agricultural land in the model, urban areas in the watershed were not adequately simulated in the model. This is acceptable considering the focus of this SWAT modeling study was to quantify the effectiveness of agricultural BMPs. However, that is not an indication that pollutant loadings from urban areas are not important. Urban loadings, although small compared to agricultural sources for in entire St. Joseph River watershed, are particularly damaging to local receiving streams due to its concentrated flow and high contents of phosphorus and other pollutants. In addition, the expansion of urban areas in the watershed poses further threats to our efforts to improve water quality of the watershed. The reader is referred to the urban BMP portion of the St. Joseph River Watershed Management Plan for more information.

Finally, it should be pointed out that due to the project scope and more prominently, time constraint, only a portion of the data generated from this modeling study were analyzed to meet current watershed management requirements. There are much more data available for other watershed management applications. For example, load reductions resulting from BMPs for each subwatershed in the three tributary watersheds can be quantified to identify local water quality improvement potentials. Such information will be there for extraction and analysis if a watershed plan implementation phase starts.

In addition, the modeling exercise has established a working SWAT model for the St. Joseph River watershed. Potential improvements to the model setup were also identified. Therefore, the foundation has been laid down for a more comprehensive and finer scale SWAT modeling for the entire St. Joseph River watershed or some of its subwatersheds. This has important implications for any future TMDL or similar modeling work to be conducted in the watershed using the SWAT model.

8.0 Conclusions

This study developed a reasonably calibrated SWAT model for the St. Joseph River watershed, given the limited availability of monitoring data and the scope of the study. The calibrated model was used to simulate the current (baseline) loading conditions of TP, TN, and sediment for each of the 229 subwatersheds delineated in the St. Joseph River watershed, and also atrazine load at the outlets of three major agricultural tributary watersheds (the Fawn River, the Pigeon River, and the Elkhart River).

Comparing results from the SWAT model with those from the empirical nonpoint source loading model showed that these two models generally agreed on the relative capability of subwatersheds in generating TP and sediment loads. It was believed that the SWAT model, by considering land and soil characteristics and pollutant movement on the land and in the water, gave more realistic load estimates than the empirical model. On the other hand, because of omission of minor landuse types (e.g., urban and forest) in the SWAT model in this study, results from the empirical model should be given appropriate consideration for subwatersheds with a significant presence of these minor landuse types.

Five agricultural BMP scenarios were simulated for the three major tributary watersheds to derive the effects of BMP implementation would have on water quality at the mouth of each tributary watersheds. Among the four individual agricultural BMPs considered, edge-of-field filter strips are overall the most effective in reducing loadings for all the pollutants examined. No-till for corn (including corn silage) is particularly effective for sediment and TN in watersheds with more permeable soils and dominated by the corn-soybean rotation (the Fawn River watershed in this study). The combined BMP scenario (no-till, filter strips, and contour farming), as expected, provided the most load reductions in all cases. However, it was shown that effectiveness gains will be diminished when more than one BMPs are implemented on top of one another.

In terms of costs, no-till emerged as the most cost-effective BMP in most cases, due to its low per acre implementing cost ($3.08/ac/yr) and the high per acre cost of establishing ($100/ac) and maintaining ($93.50/ac/yr) filter strips. It was also shown that as the implementation rate (% of watershed covered by a BMP) increased, all BMPs had an increasing cost-effectiveness, suggesting the advantage of large scale BMP implementation efforts.

For the effects of BMPs on pollutant concentrations at the mouth of each tributary watershed, the simulation results revealed that flow reduction was an important factor in deciding the concentrations at watershed outlets. Not considering contour farming (due to inadequate simulation of flow reduction), edge-of-field filter strips provided greatest concentration improvements for TP for all three tributary watersheds, especially at high levels of implementation. No-till, on the other hand, provides comparable concentration improvements for sediment and TN in all three watersheds except for sediment in the Pigeon River.

In summary, in spite of the coarse nature of model setup and the limited monitoring data available for model calibration, this SWAT modeling study yielded valuable quantitative information on the effectiveness of agricultural BMPs in reducing pollutant loads and improving water quality, and the costs associated with these improvements. Based on this study, this report also pointed out the potential improvements that a future finer scale SWAT model can make.

9.0 References

Arnold, J. G., and R.S. Muttiah, and R. Srinivansan, and P. M. Allen. 2000. Regional Estimation of Base Flow and Groundwater Recharge in the Upper Mississippi River Basin. *Journal of Hydrology*. 227:21-40.

Devlin D., et al. 2003. Water Quality Best Management Practices, Effectiveness, and Cost for Reducing Contaminant Losses from Cropland. Kansas State University, February, 2003. Available at http://www.oznet.ksu.edu/library/h20ql2/mf2572.pdf .

Forster, D. L. 2002. Effects of Conservation Tillage on the Performance of Lake Erie Basin Farms. *J. Environ. Qual*. 31:32-37.

Haper, J. K. 1996. *Economics of Conservation Tillage.* Conservation Tillage Series No. 6. The Pennsylvania State University-College of Agricultural Sciences Cooperative Extension. University Park, PA.

Jha, M., P.W. Gassman, S. Secchi, R. Gu, and J. Arnold. 2004. Effect of Watershed Subdivision on SWAT Flow, Sediment, and Nutrient Predictions. *JAWRA*. 40:811-825.

Kurkalova, L., C. Kling, and J. Zhao. 2003. *Green Subsidies in Agriculture: Estimating the Adoption Costs of Conservation Tillage from Observed Behavior.* Working Paper 01-WP 286 April 2003 (Revised). Center for Agricultural and Rural Development. Iowa State U. Available at http://www.econ.iastate.edu/research/webpapers/paper_10354.pdf.
Massey, R. E. 1997. *No-Tillage and Conservation Tillage: Economic Considerations.* University of Missouri-Columbia, Outreach & Extension.

Neitsch, S. L., J. G. Arnold, J. R. Kiniry , R. Srinivasan, and J.R. Williams. 2002a. *Soil and Water Assessment Tool User's Manual—Version 2000*. TWRI Report TR-192. Texas Water Resources Institute, College Station, Texas. Available at http://www.brc.tamus.edu/swat/downloads/doc/swatuserman.pdf.

Neitsch, S. L., J. G. Arnold, J. R. Kiniry , J. R. Williams, and K. W. King. 2002b. *Soil and Water Assessment Tool Theoretical Documentation—Version 2000*. TWRI Report TR-191. Texas Water Resources Institute, College Station, Texas. Available at http://www.brc.tamus.edu/swat/downloads/doc/swat2000theory.pdf.

Ohio Environmental Protection Agency (OH EPA). 2003. *Total Maximum Daily Load for the Stillwater River Basin—Draft Report*. July 2003. Available at http://web.epa.state.oh.us/dsw/tmdl/StillwaterTMDL.html.

Robertson, M. 1997. Regionalized Loads of Sediment and Phosphorus to Lakes Michigan and Superior—High Flow and Long-term Average. *J. Great Lakes. Res.* 23:416-439.

Richards, R.P. 1998. *Estimation of Pollutant Loads in Rivers and Streams: A Guidance Document for NPS programs*. Project report prepared under Grant X998397-01-0, U.S.

Environmental Protection Agency, Region VIII, Denver. 108 p. Available at http://www.heidelberg.edu/wql/Load_Est1.pdf.

Santhi, C., J.G. Arnold, J.R. Williams, W.A. Dugas, and L. Hauck. 2002. Application of a watershed model to evaluate management effects on point and nonpoint source pollution. *Transactions of the ASAE* 44:1559-1570.

Santhi, S., J. G. Arnold, J. R. Williams, W. A. Dugas, R. Srinivasan, and L. M. Hauck. 2001 Validation of the SWAT Model on a Large River Basin with Point and Nonpoint Sources. *JAWRA*. 37:1169-1188.

Schwab, Gerald and E. Wittenberg. 2004. *2003 Michigan Land Values*. Michigan State University Department of Agricultural Economics Report No. 620. April 2004. Available at http://www.aec.msu.edu/agecon/aecreports/aec620.pdf .

Smith, R.A., G.E. Schwarz, R.B. Alexanda. 1997. Regional interpretation of water-quality monitoring data. *Water Resources Research* 33:2781-2798.

U.S. Environmental Protection Agency (U.S. EPA). 2003a. *Economic Analyses of Nutrient and Sediment Reduction Actions to Restore Chesapeake Bay Water Quality*. U.S. EPA Region III-Chesapeake Bay Program Office, Annapolis, MD. September, 2003.

U.S. Environmental Protection Agency (U.S. EPA). 2003b. *National Management Measures for the Control of Nonpoint Pollution from Agriculture*. EPA-841-B-03_004. U.S. EPA-Office of Water, Washington DC. July, 2003.

Wesley, J.K., and J.E. Duffy. 1999. *St. Joseph River Assessment*. Michigan Department of Natural Resources, Fisheries Division, Special Report 24. Ann Arbor, Michigan.

APPENDIX

Annual Subwatershed Pollutant Loadings

Table A: SWAT annual subwatershed loadings (annual average 2000-2004)

Sub.†	Water Course	LU‡	Area (ac)	TP (lbs/ac/yr)	Sediment (lbs/ac/yr)	TN (lbs/ac/yr)
1	Brandywine Creek	AGRR	19,958	1.621	4,461	30.4
2	N Br Paw Paw River	AGRR	18,168	0.267	549	8.5
3	S Br Paw Paw River	AGRR	4,892	0.190	386	5.3
4	Paw Paw River	AGRR	17,069	1.538	2,932	24.0
5	Mud Lake Drain	AGRR	9,851	1.534	5,298	34.0
6	Paw Paw River	AGRR	17,772	2.002	8,111	45.2
7	Brush Creek	AGRR	26,747	0.375	684	9.9
8	E Br Paw Paw River	AGRR	21,801	0.361	772	11.7
9	S Br Paw Paw River	AGRR	10,433	0.229	278	4.8
10	Paw Paw Lake	FRSD	8,998	0.002	40	0.7
11	Paw Paw River	AGRR	12,006	1.629	2,785	23.6
12	Mill Creek	AGRR	18,620	1.649	2,981	23.2
13	Nottawa Creek	AGRR	24,639	0.181	982	9.0
14	Alder Creek	AGRR	10,311	0.449	1,860	15.1
15	St. Joseph River	URLD	5,987	0.007	2,926	13.5
16	Tekonsha Creek	AGRR	13,899	0.103	548	6.3
17	Flowerfield Creek	AGRR	15,798	0.410	2,371	17.5
18	St. Joseph River	AGRR	12,226	0.271	967	8.8
19	Coldwater River	AGRR	7,246	0.156	836	7.7
20	Portage Creek	AGRR	17,482	0.288	1,560	12.8
21	Portage River	AGRR	3,085	0.199	548	5.8
22	St. Joseph River	PAST	15,564	0.005	1,990	9.7
23	Pipestone Creek	PAST	7,779	0.005	2,004	9.8
24	Dowagiac River	AGRR	32,884	0.303	393	7.2
25	S Br Hog Creek	AGRR	14,923	0.074	454	5.6
26	Bear Creek	AGRR	12,730	0.463	1,772	15.4
27	Hog Creek	AGRR	14,225	0.566	281	3.8
28	Coldwater River	AGRR	19,305	0.108	257	2.9
29	Silver Creek	AGRR	11,360	0.273	346	6.9
30	Rocky River	AGRR	25,284	1.684	5,415	34.3
31	Dowagiac River	AGRR	22,407	0.233	284	4.8
32	Nottawa Creek	AGRR	4,496	0.083	236	4.0
33	St. Joseph River	AGRR	14,953	0.090	387	5.4
34	Little Portage Creek	AGRR	10,287	0.370	1,156	11.3
35	St. Joseph River	AGRR	4,055	0.296	997	10.8
36	Dowagiac River	AGRR	11,162	1.140	1,729	15.7
37	Dowagiac Creek	AGRR	9,833	1.361	2,401	20.7
38	Swan Creek	AGRR	3,844	0.069	287	4.7
39	Beebe Creek	AGRR	11,811	0.302	1,944	15.6
40	St. Joseph River	AGRR	8,313	0.638	1,323	11.6
41	Portage River	AGRR	23,578	0.059	226	3.0
42	Swan Creek	AGRR	12,820	0.252	896	8.3
43	Little Swan Creek	AGRR	20,904	0.154	828	7.6
44	Spring Creek	AGRR	21,481	0.095	284	4.4
45	Prairie River	AGRR	12,345	0.147	475	8.3
46	Prairie River	AGRR	16,393	0.105	318	5.0
47	Pokagon Creek	AGRR	21,284	1.166	2,917	21.6
48	Mill Creek	FRSD	15,838	0.001	17	1.4
49	Fawn River	AGRR	17,746	0.081	342	4.9
50	Dowagiac River	AGRR	13,110	0.811	2,424	18.1
51	McCoy Creek	AGRR	14,992	0.449	3,213	20.5
52	St. Joseph River	AGRR	23,977	0.452	3,141	20.6
53	Fawn River	AGRR	14,195	0.094	455	5.6
54	Sherman Mill Creek	AGRR	15,248	0.225	731	10.7
55	Mill Creek	AGRR	12,114	1.576	2,671	23.1
56	Unnamed Tributary	AGRR	8,848	0.357	568	5.5
57	St. Joseph River	FRSD	4,812	0.001	11	0.8
58	Brandywine Creek	AGRR	15,157	0.239	295	6.3

Table A: SWAT annual subwatershed loadings (annual average 2000-2004) (Continued).

Sub.†	Water Course	LU‡	Area (ac)	TP (lbs/ac/yr)	Sediment (lbs/ac/yr)	TN (lbs/ac/yr)
59	Himebaugh Drain	AGRR	7,751	0.268	410	4.2
60	Fawn River	AGRR	15,062	0.138	344	3.6
61	Nye Drain	AGRR	8,021	0.074	327	4.2
62	Fawn River	AGRR	6,874	0.104	515	8.7
63	Fawn River	AGRR	10,769	0.560	1,890	17.1
64	Fawn River	AGRR	8,359	0.107	568	9.4
65	St. Joseph River	AGRR	4,272	0.356	441	8.4
66	Pigeon River	AGRR	22,452	0.104	319	5.1
67	Pigeon River	AGRR	6,974	0.086	363	5.1
68	Lake Shipshewana	AGRR	12,599	0.217	1,428	10.6
69	Crooked Creek	AGRR	10,908	0.888	966	10.7
70	St. Joseph River	AGRR	10,632	0.192	762	9.9
71	Little Elkhart River	AGRR	12,757	1.123	6,305	37.1
72	St. Joseph River	AGRR	11,967	0.198	333	5.7
73	Juday Creek	AGRR	22,862	0.159	252	4.3
74	Pigeon River	AGRR	17,209	0.057	372	3.9
75	Fly Creek	AGRR	16,213	0.321	1,993	13.0
76	St. Joseph River	AGRR	5,576	0.425	2,912	20.9
77	Pine Creek	AGRR	19,759	0.574	4,008	25.7
78	Petersbaugh Creek	AGRR	10,530	0.056	201	3.2
79	St. Joseph River	AGRR	3,958	0.296	1,141	10.1
80	St. Joseph River	AGRR	7,923	0.061	230	3.7
81	St. Joseph River	URLD	196	0.004	1,087	7.4
82	Christiana Creek	AGRR	4,100	0.062	229	3.9
83	St. Joseph River	WATR	121	0.047	22,097	64.2
84	Christiana Creek	WATR	52	0.062	54,155	85.4
85	Elkhart River	AGRR	8,909	0.303	1,838	14.2
86	Little Elkhart Creek	AGRR	3,548	0.825	4,591	30.6
87	Little Elkhart Creek	AGRR	9,123	0.141	1,369	15.5
88	Fly Creek	AGRR	11,086	0.273	1,592	10.9
89	Cobus Creek	AGRR	22,614	0.178	292	4.9
90	St. Joseph River	AGRR	12,148	0.057	204	3.2
91	Little Elkhart Creek	AGRR	6,918	0.113	831	10.9
92	Rowe Eden Ditch	AGRR	20,765	0.102	539	7.9
93	Emma Creek	AGRR	12,121	0.159	931	7.5
94	Little Elkhorn River	AGRR	12,079	0.106	335	5.4
95	Rock Run Creek	AGRR	14,469	0.651	2,871	21.5
96	Elkhart River	AGRR	4,941	0.366	1,497	12.8
97	Grimes Ditch	AGRR	12,554	1.193	2,436	19.1
98	Baugo Creek	AGRR	14,569	0.775	4,443	29.5
99	Little Elkhart Creek	AGRR	9,416	0.137	870	7.6
100	Little Elkhart Creek	AGRR	13,964	0.136	868	7.8
101	Stony Creek	AGRR	12,411	0.613	2,467	18.6
102	Elkhart River	AGRR	15,681	0.186	1,107	8.7
103	N Br Elkhart River	AGRR	9,426	0.251	1,571	10.8
104	Mid. Branch Elkhart R.	AGRR	10,958	0.358	2,324	14.6
105	Dausman Ditch	AGRR	7,994	0.338	1,937	14.9
106	Turkey Creek	AGRR	10,918	0.434	2,991	21.2
107	N Br Elkhart River	AGRR	19,224	0.107	738	6.7
108	S Br Elkhart River	AGRR	17,083	0.338	1,802	13.3
109	Berlin Court Ditch	AGRR	11,559	1.008	4,796	31.6
110	Turkey Creek	AGRR	9,635	0.557	2,966	21.9
111	Turkey Creek	AGRR	686	0.266	1,554	12.7
112	Turkey Creek	AGRR	12,009	0.297	1,257	11.6
113	Wabee Lake	AGRR	9,152	0.499	3,298	22.3
114	Turkey Creek	AGRR	13,340	0.555	3,821	24.8
115	Croft Ditch	AGRR	15,852	0.357	4,718	22.9
116	S Br Elkhart River	AGRR	11,008	0.391	5,433	25.0

Table A: SWAT annual subwatershed loadings (annual average 2000-2004) (Continued).

Sub.†	Water Course	LU‡	Area (ac)	TP (lbs/ac/yr)	Sediment (lbs/ac/yr)	TN (lbs/ac/yr)
117	Carrol Creek	AGRR	11,421	0.835	5,148	28.7
118	Beebe Creek	AGRR	15,016	0.485	1,937	16.2
119	S Br Hog Creek	AGRR	8,950	0.354	1,382	12.4
120	St. Joseph River	AGRR	2,344	0.223	1,275	11.1
121	St. Joseph River	AGRR	16,348	0.294	1,138	10.3
122	St. Joseph River	PAST	13,483	0.005	2,434	11.2
123	St. Joseph River	PAST	15,924	0.006	3,022	13.0
124	Paw Paw River	PAST	9,963	0.002	301	4.6
125	St. Joseph River	AGRR	13,701	0.271	366	7.7
126	St. Joseph River	AGRR	20,938	1.274	2,109	17.2
127	Baugo Creek	AGRR	11,590	0.547	2,246	17.8
128	Turkey Creek	AGRR	9,611	0.097	1,167	8.6
129	Turkey Creek	AGRR	19,458	0.424	1,968	17.4
130	Elkhart River	AGRR	4,136	0.283	1,853	12.3
131	S Br Elkhart River	AGRR	5,068	1.315	10,401	45.1
132	Forker Creek	AGRR	11,759	1.508	11,380	48.2
133	Henderson Lake	AGRR	12,621	0.161	1,248	10.0
134	Little Elkhart Creek	AGRR	12,187	0.373	2,463	15.2
135	Turkey Creek	AGRR	11,492	0.774	3,176	23.7
136	Turkey Creek	AGRR	10,955	0.938	4,206	28.9
137	Little Turkey Lake	AGRR	12,432	0.411	2,826	16.8
138	Pigeon Creek	AGRR	7,961	0.391	738	5.8
139	Pigeon Creek	AGRR	14,004	1.378	6,868	40.6
140	Mud Lake	AGRR	6,450	0.573	2,080	17.3
141	Pigeon Creek	AGRR	12,837	0.927	1,026	11.2
142	Pigeon Creek	AGRR	11,322	0.269	1,832	13.4
143	Buck Creek	AGRR	19,567	0.211	1,241	9.5
144	Pigeon River	AGRR	10,432	0.139	779	6.4
145	S Br Paw Paw River	AGRR	13,281	0.349	629	9.5
146	Eagle Lake Drain	AGRR	10,184	0.794	2,354	17.7
147	Dowagiac Creek	AGRR	23,182	1.531	2,524	21.4
148	Dowagiac Creek	AGRR	14,912	1.000	2,700	20.7
149	Dowagiac River	AGRR	17,497	1.137	1,724	15.7
150	Diamond Lake	AGRR	9,386	0.905	2,054	16.4
151	Christiana Creek	AGRR	15,313	1.209	4,203	27.5
152	Paradise lake	AGRR	8,928	1.753	5,992	36.7
153	Christiana Creek	AGRR	25,569	1.158	1,952	17.4
154	Christiana Creek	AGRR	13,650	0.944	1,526	13.9
155	Flowerfield Creek	AGRR	3,224	0.426	1,474	14.2
156	Flowerfield Creek	AGRR	10,315	0.330	1,041	9.8
157	St. Joseph River	AGRR	7,626	0.092	270	4.4
158	Portage River	AGRR	8,906	0.078	218	3.6
159	St. Joseph River	AGRR	5,782	0.082	345	5.1
160	Bear Creek	AGRR	11,550	0.374	1,173	11.4
161	Portage River	AGRR	19,353	0.450	1,576	14.2
162	Portage River	AGRR	20,075	0.448	1,290	14.2
163	Little Portage Creek	AGRR	17,967	0.336	1,758	14.6
164	Nottawa Creek	AGRR	16,602	0.422	1,707	14.1
165	St. Joseph River	AGRR	14,217	0.158	848	7.8
166	St. Joseph River	AGRR	28,073	0.239	1,394	11.6
167	St. Joseph River	AGRR	3,238	0.354	393	4.9
168	Nottawa Creek	AGRR	15,868	0.258	1,560	12.8
169	St. Joseph River	AGRR	10,393	0.173	936	8.4
170	Soap Creek	AGRR	8,169	0.363	1,403	12.3
171	Prairie River	AGRR	12,179	0.163	542	9.7
172	Prairie River	AGRR	4,733	0.072	289	4.3
173	Prairie River	AGRR	19,225	0.135	395	5.5
174	Prairie River	AGRR	17,925	0.172	232	2.7
175	Fawn River	AGRR	7,435	0.306	454	4.6

Table A: SWAT annual subwatershed loadings (annual average 2000-2004) (Continued).

Sub.†	Water Course	LU‡	Area (ac)	TP (lbs/ac/yr)	Sediment (lbs/ac/yr)	TN (lbs/ac/yr)
176	Snow Lake	AGRR	17,556	0.658	4,577	28.5
177	Crooked Creek	AGRR	8,010	2.847	6,389	40.7
178	Sand Creek	AGRR	13,485	0.703	940	9.6
179	St. Joseph River	AGRR	19,896	0.473	868	8.4
180	Swan Creek	AGRR	34,602	0.261	937	8.5
181	St. Joseph River	AGRR	4,548	0.341	1,918	14.3
182	St. Joseph River	AGRR	11,311	0.119	119	2.1
183	St. Joseph River	AGRR	9,409	0.432	728	6.9
184	Baugo Creek	AGRR	10,609	0.367	2,153	16.1
185	Elkhart River	AGRR	3,815	0.470	2,070	16.6
186	Solomon Creek	AGRR	8,664	0.222	1,228	10.2
187	Waldron Lake	AGRR	16,867	0.334	2,107	13.6
188	Pigeon Creek	AGRR	12,398	0.958	8,323	43.0
189	Rock Run Creek	AGRR	13,049	0.725	3,348	24.0
190	Coldwater Lake	AGRR	12,443	0.169	200	2.1
191	Fisher Creek	AGRR	9,999	0.719	1,146	11.1
192	Marble Lake	AGRR	12,367	0.077	385	4.4
193	Tallahassee Drain	AGRR	18,682	0.444	296	3.7
194	E Br Sauk River	AGRR	10,532	0.147	793	6.5
195	Mud Creek	AGRR	12,642	0.749	1,099	10.7
196	Coldwater River	AGRR	3,083	0.229	309	3.7
197	Coldwater River	AGRR	14,016	0.361	700	7.1
198	Prairie River	AGRR	11,351	0.355	1,982	15.1
199	Rocky River	AGRR	17,753	0.718	2,727	22.7
200	Pine Creek	AGRR	9,706	0.319	2,047	16.5
201	Gourdneck Creek	AGRR	12,696	0.300	948	9.2
202	Gourdneck Creek	AGRR	8,489	0.372	1,239	11.7
203	Flowerfield Creek	AGRR	7,466	0.341	1,870	14.6
204	Rocky River	AGRR	27,607	0.517	3,383	23.8
205	St. Joseph River	AGRR	16,999	0.094	277	4.3
206	Trout Creek	AGRR	19,589	0.801	1,234	17.3
207	St. Joseph River	AGRR	14,866	0.219	500	7.9
208	Elkhart River	AGRR	14,517	0.615	2,641	20.1
209	Paw Paw River	AGRR	20,796	0.092	481	9.8
210	Paw Paw River	AGRR	16,131	0.130	382	7.3
211	Hickory Creek	AGRR	32,180	0.247	1,456	13.5
212	Big Meadow Drain	AGRR	9,897	0.445	1,682	13.3
213	S Br Hog Creek	AGRR	12,952	0.329	2,169	17.0
214	S Br Hog Creek	AGRR	18,005	0.427	1,650	13.9
215	Pine Creek	AGRR	18,928	0.299	1,881	15.3
216	Emma Lake	PAST	8,835	0.003	680	5.0
217	Pigeon Creek	AGRR	10,253	0.472	858	7.9
218	Tamarack Lake Outlet	AGRR	15,304	0.505	944	8.5
219	St. Joseph River	AGRR	8,298	1.029	1,376	12.5
220	Yellow Creek	AGRR	15,991	0.683	3,076	22.6
221	Elkhart River	AGRR	13,718	0.453	1,964	15.8
222	Turkey Creek	AGRR	11,543	0.434	2,720	19.4
223	Solomon Creek	AGRR	15,408	0.078	689	7.4
224	Pigeon Creek	AGRR	10,619	0.993	4,570	30.5
225	Pigeon Creek	AGRR	13,910	0.045	192	7.4
226	N Br Paw Paw River	FRSD	18,618	0.001	1	2.3
227	Pipestone Creek	PAST	24,022	0.008	3,552	15.4
228	Mudd Lake Exit Drain	AGRR	8,674	0.361	487	9.9
229	St. Joseph River	AGRR	12,559	0.123	566	8.8

† Subwatershed number (see Figures 3-5).
‡ Landuse types: AGRR: (Agricultural) Row Crop; FRSD: Deciduous Forest; URLD: (Urban) Low Density Residential; PAST: Pasture.