FINAL REPORT to
U.S. FISH and WILDLIFE SERVICES

Potential Nonpoint-source Contamination of the Spring Mill Lake Drainage Basin with Emphasis on the Donaldson/Bronson/Twin Cave System

Compiled by
Nancy R. Hasenmueller and Mark A. Buehler

INDIANA GEOLOGICAL SURVEY OPEN-FILE STUDY 00-13
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September 2000

The cover photograph of Donaldson Cave Spring in Spring Mill State Park is from Harding, S. B., ed., 1904, Indiana University--1820-1904: Historical Sketch, Development of the Course of Instruction, Bibliography: Bloomington, Indiana University, 348 p.

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Potential Nonpoint-source Contamination of the Spring Mill Lake Drainage Basin with Emphasis on the Donaldson/Bronson/Twin Cave System

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INTRODUCTION

Background

The Spring Mill Lake drainage basin is located in Lawrence and Orange Counties in south central Indiana (figure 1). The drainage basin is developed on the Mitchell Plateau physiographic section, which is a low limestone plateau dissected by entrenched major stream systems (Gray, 2000). This plateau is an area of relatively low relief and is formed on a moderately thick sequence of Mississippian carbonate rocks of the Sanders and Blue River Groups (figure 2). The Mitchell Plateau exhibits some of the best examples of karst topography in the world and extends from just north of Bloomington in the central part of Monroe County to the Ohio River in southernmost Indiana. The Mitchell Plateau extends into central Kentucky where it is known as the Pennyroyal Plain.

The Spring Mill Lake drainage basin is characterized by thousands of sinkholes and a sinking stream, Mosquito Creek, as is typical of the Mitchell Plateau. The two main tributaries to the lake are Mill Creek, which flows from Hamer Cave, and Hamer Creek, which discharges from Donaldson Cave. The watershed is approximately 21 square miles.

Most precipitation falling in the basin travels underground into solution-enlarged conduits that discharge as springs in Spring Mill State Park. The water then flows a short distance in surface streams to recharge the lake. The chemical composition, biologic condition, and sediment load of the ground water flowing within the conduits determine the water quality and sedimentation characteristics of both the cave systems and the lake.

Nitrogen enrichment and siltation of the cave systems and the lake have been recognized as problems, and past complications indicated the excessive presence of pesticides. Two highways, a railroad line, and numerous county roads lie within the drainage area of Spring Mill Lake, so that chemical spills and roadway de-icing substances may quickly and drastically degrade the quality of ground water and the water that reaches the lake. Failed or inadequate septic systems in an area of expanding population and agricultural practices affect water quality, and erosion from tillage and construction have the potential to increase sedimentation rates in the lake.

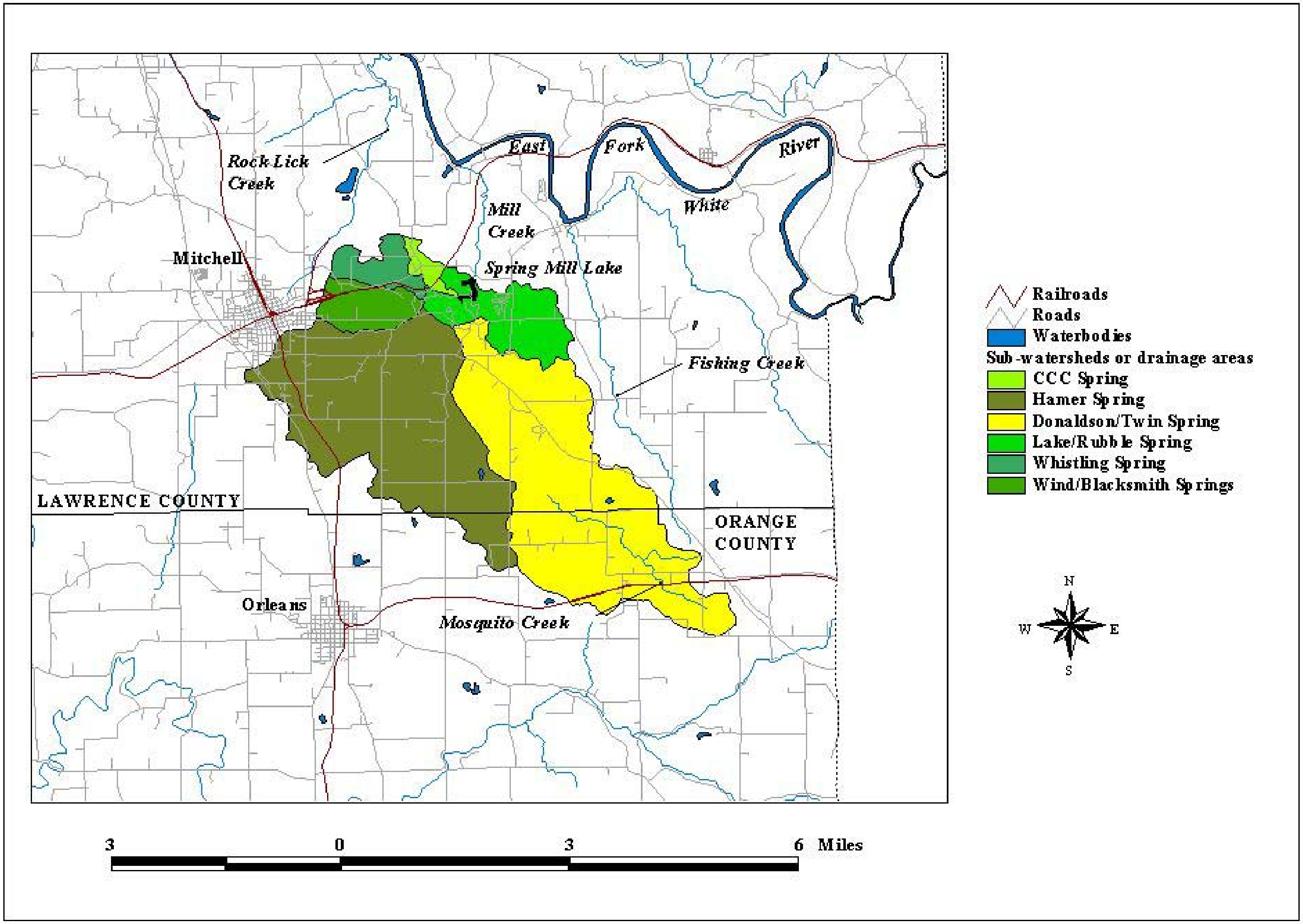


Figure 1. Map showing the Spring Mill Lake watershed in Lawrence and Orange Counties in south central Indiana (from Buehler and Hasenmueller, 2000).

CHRONOSTRATIGRAPHIC UNITS		LITHOSTRATIGRAPHIC UNITS	
SYSTEM	SERIES	GROUP	FORMATION
MISSISSIPPIAN	CHESTERIAN	BUFFALO WALLOW	(13 FORMATIONS)
		STEPHENSPORT	
		WEST BADEN	
		BLUE RIVER	PAOLI LS.
	VALMEYERAN		STE. GENEVIEVE LS.
			ST. LOUIS LS.
		SANDERS	SALEM LS. HARRODSBURG LS. RAMP CREEK FM.
		BORDEN	EDWARDSVILLE FM.
			SPICKERT KNOB FM.
			NEW PROVIDENCE SHALE
			ROCKFORD LS.
	KINDERHOOKIAN		NEW ALBANY SH.

Figure 2. Chart showing the classification of the Mississippian strata in Indiana (from Hasenmueller and others, 2000).

Approach to Solving the Problem

In order to determine best land management practices and to recognize danger to the ground water and the lake from chemical spills and highway construction, it is necessary to precisely define the drainage area of Spring Mill Lake. Through a series of earlier dye traces, the southern and western limits are known in general but need to be more accurately defined; information on the northern and eastern limits is lacking. During the current project, organic dyes were used at very low concentrations to delimit the drainage boundaries and to learn the general direction of flow of subsurface water in the cavernous bedrock.

To formulate a plan to provide information on best management practices to landowners, the water flowing from the springs was analyzed to determine any chemical and biologic contaminants and the volume of sediment entering the lake was measured. Variations in water quality were noted between low-flow regimes and storm events and with seasonal events such as tillage, application of fertilizers to cropland and of pesticides to highway and railroad right of way as well as to cropland. For the overall project, multiple data collecting sites were selected within the several subbasins of Spring Mill Lake including the springs discharging from Donaldson Cave, Hamer Cave, Upper Twin Cave, Whistling Cave, Wind Cave, and the Rubble site. In this particular phase of the project, efforts were concentrated on the Donaldson/Bronson/Twin (Shawnee) Cave System. Imagery and digital topography were used to illustrate land use and to estimate input of chemicals by subbasins.

DELINEATION OF THE SPRING MILL LAKE DRAINAGE BASIN

Introduction

The fluorescent dyes that were selected for use in determining the ground-water flow in the Spring Mill Lake watershed were Eosine OJ, Fluorescein (Uranine C), and Rhodamine WT. These dyes were selected because they are (1) easy to detect, (2) inexpensive to measure at high dilutions, (3) readily available and inexpensive, and (4) low in toxicity (Field and others, unpublished manuscript). Multiple dyes were needed because several traces were conducted concurrently using dyes released at different sites. Eosine, Fluorescein, and Rhodamine WT are recovered by adsorption on charcoal and are detected by scanning spectrofluorophotometric analysis.

The presence of any existing background dyes in the Spring Mill Lake drainage basin area was determined by placing charcoal dye detectors at Donaldson, Hamer, Whistling, Wind, and Rubble Springs and immediately below the dam at Spring Mill Lake in the summer of 1998. The charcoal detectors were recovered from all the sites except the site near the dam. The organic dyes, Direct Yellow, Eosine, Fluorescein, and Rhodamine WT were all below the detection limit. Optical brighteners were detected; the source of the brighteners is probably laundry detergent.

The recommended protocols for ground-water monitoring in karst terrains as outlined by Quinlan (1989) were followed during the dye tracing. The use of fluorescent dyes for the study of ground-water flow in karst is appropriate if thought is given to both human health and environmental effects (Field and others, unpublished manuscript).

Dye Detection Sites

Activated charcoal detectors were placed at a total of 22 locations during the project. Detectors were placed at Blacksmith Spring, CCC Spring, Clamshell Spring, Donaldson Cave Spring, East Farm Creek, Hamer Cave Spring, Lower Donaldson Cave, Lower Fishing Creek, Lower Rock Lick Creek, Middle Rock Lick Creek, Mill Creek Dam outflow, Orangeville Rise A, Orangeville Rise B, Rubble Spring, Stinky Creek, Twin Cave, Upper Fishing Creek, Upper Rock Lick Creek, Wind Cave downstream, Wind Cave Spring, Whistling Cave downstream, and Whistling Cave Spring. The background sampling at these 22 sites continued from the summer of 1998 until the end of May 2000 to ensure that no late-stage arrivals from previous injections occurred at other sites.

Dye Injection Sites

The results of previous dye traces performed in the vicinity of the watershed by Bayless and others (1994) and Keith and others (1997) were reviewed and field reconnaissance was performed to determine potential injection sites. Ten dye injection sites were selected within the Spring Mill Lake drainage area (figure 3 and table 1). Dyes were injected at low concentrations and flushed with approximately 2,000 gallons of water at the ten sites. Traces if the dyes were recovered for all of the injection sites except the Drive-Inn Sink (table 1).

Table 1. Summary of dye injections sites and recoveries in the project area

Injection Location	Date	Time	Dye	Vol. (Lbs)	Recovery	Date	Time	Grab	Bug	Visual
Burnt Stump Sink	3/31/00	1130	Fl	3	HAM	4/03/00	1055	X	X	?
Drive-Inn Sink	4/09/99	1130	Rwt	4	N/A	-	-	N/A	-	-
Entrance Sink	3/01/00	1115	Fl	2	HAM	3/02/00	1106	X	X	?
Gaping Maw Sink	3/01/00	1220	Rwt	2	WIA/BLK	3/02/00	1112	X	X	?
Law Sink	1/18/00	1000	Rwt	5	HAM	1/20/00	1045	N/A	X	?
Northside Sink	1/18/00	1130	Fl	1	WHA/BLK	1/20/00	1055	N/A	X	?
Old Gatehouse Sink	3/01/00	1000	Eo	2	WIA/BLK	3/01/00	1400	X	X	Yes
Rocking Chair Sink	3/31/00	1020	Rwt	6	TWIN/DONB	4/03/00	1033	X	X	?
Rusty Car Sink	3/31/00	1225	Eo	2	CCC	4/03/00	1048	X	X	Yes
Trashpile Sink	4/09/99	1018	Fl	2	LFC	4/10/00		N/A	X	?

HAM = Hamer Cave
WIA = Wind Cave
BLK = Blacksmith Spring
WHA = Whistling Cave
TWIN = Twin Cave
DONB = Donaldson Cave
CCC = CCC Spring
LFC = Lower Fishing Creek

Fl = Fluorescein Dye
Rwt = Rhodamine WT Dye
Eo = Eosine Dye

Sample Analysis for Dyes

The samples were analyzed on a Shimadzu RF5000U Spectrofluorophotometer. The wavelengths ranged 577 +/- 5 nm for Rhodamine WT to 435 +/- 5 & 410 +/- 5 nm for the optical brighteners (table 2).

Table 2. Wavelength ranges for peak detection classifications

Potential Substance	Range of fluorescence wavelength (nm)
Rhodamine WT	577 +/- 5
Eosine	535 +/- 5
Fluorescein	510-518
Direct Yellow	452 +/- 5
Optical Brighteners	435 +/- 5 & 410 +/- 5

Results

The boundaries of the Spring Mill Lake drainage basin and its six subbasins were better defined using organic dyes at low concentrations (figure 3). The Donaldson Cave System is fed by a sinking stream, Mosquito Creek, and drains the southeastern part of the watershed. The Hamer Cave System drains the southwestern part of the watershed. The Donaldson/Bronson/Twin Cave sub-watershed drains 42 percent of the total Spring Mill Lake watershed and Hamer Cave sub-watershed drains 39 percent of the total watershed.

MONITORING

Introduction

The subbasins of Spring Mill Lake, including those of Donaldson/Twin, Hamer, Whistling, Wind, and Rubble Springs, were monitored during low flow to establish background data. Samples from the Donaldson/Twin Cave System and the confluence of Hamer/Whistling/Wind Cave Systems were collected and analyzed during one storm event prior to the seasonal application of pesticides. The initial water monitoring included measurement of precipitation, stream flow, turbidity, sediment volume, specific conductance, temperature, pH, coliform bacteria, pesticides, major cations and anions, trace elements, and nitrogen isotopes.

Precipitation Monitoring

Rainfall data were collected from four sites within the Spring Mill Lake watershed. A continuous recording Davis "Rain Collector II" rain monitor was installed and recorded rainfall at Spring Mill State Park in the Service Area (figures 4 and 5). The continuous monitoring at this site began on July 24, 1998. The tipping bucket rain gage has 1/100-inch accuracy.

Two property owners living within the Spring Mill Lake drainage basin monitored and recorded daily rainfall totals using manual rain gauges installed on their property. This monitoring began on October 1, 1998.

The staff at the Mitchell Waste Water Treatment Facility provided copies of the daily rainfall totals that are recorded at the facility. Rainfall data is available for previous 10 years or more.

Stream-flow Monitoring

Pressure transducers to monitor the stage level and thermometers to monitor temperature were installed at the confluence of the streams from Hamer, Whistling, and Wind Caves (continuous monitoring began on August 7, 1998) and at the mouth of Donaldson Cave (continuous monitoring began on August 19, 1998). The pressure transducers and thermometers continue to monitor stage level and temperature at ½-hour intervals (figures 4 and 5).

Rating staffs were installed and rating curves were completed for Hamer combined outflow and for Wind, Whistling, and Donaldson Caves outflow (figure 6). The rating curves were developed using a Marsh-McBirney "Flo-Mate" model 2000 electromagnetic water-flow meter. The single point method (6/10 depth) for weighted average velocities over channel cross section was used.

Rating staffs were installed at Rubble Spring outflow and the dam outflow; however, the rating curves for these two sites were incomplete. Due to logistical problems, the rating curves for Rubble Spring and the dam outflow were discontinued. Real-time measurements of discharge will be completed during quarterly sampling. Lack of continuous monitoring equipment excludes the possibility of discharge variation recording and calculation.

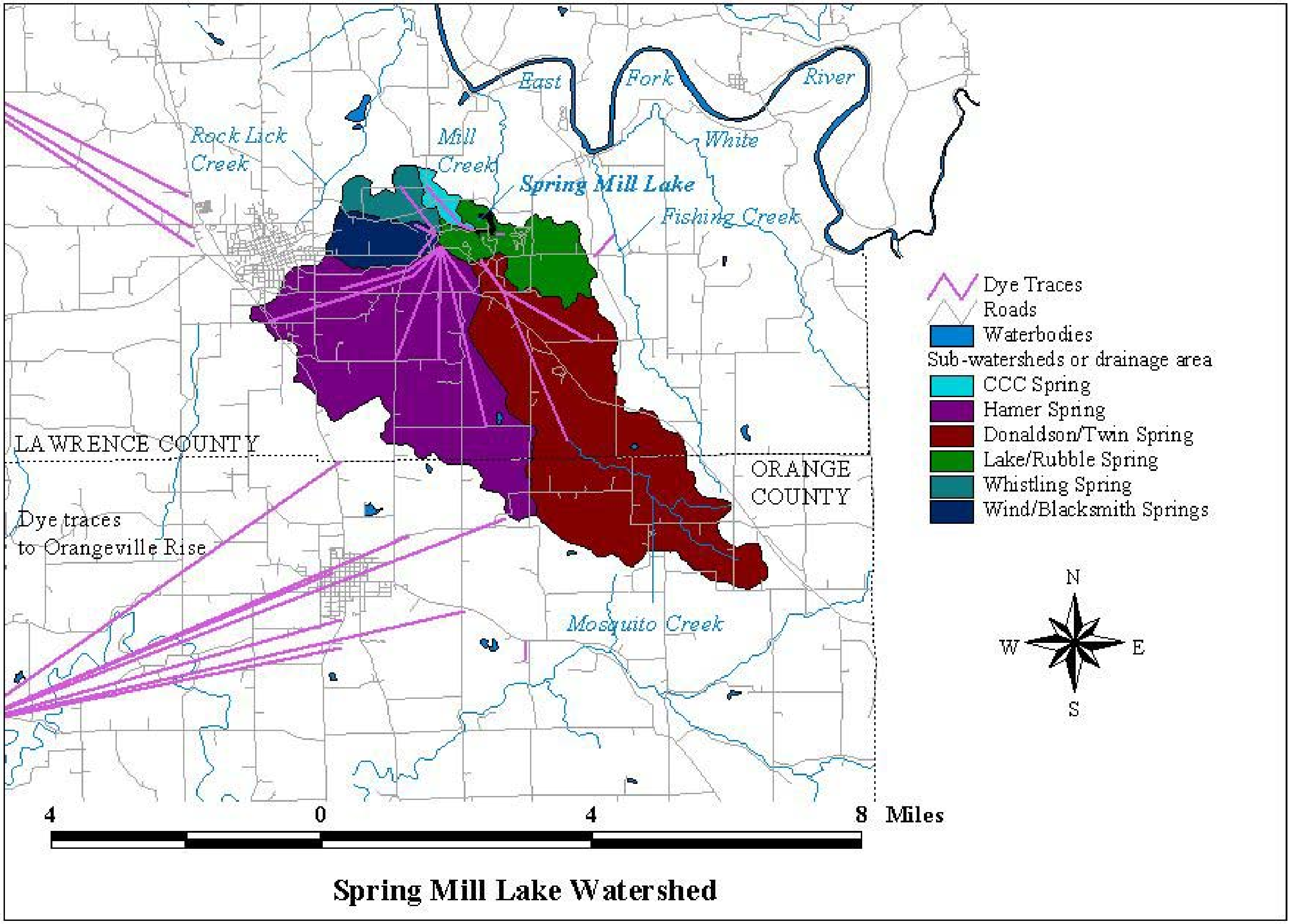


Figure 3. **Map showing the dye traces and the present delineation of the Spring Mill Lake watershed and its sub-watersheds.**

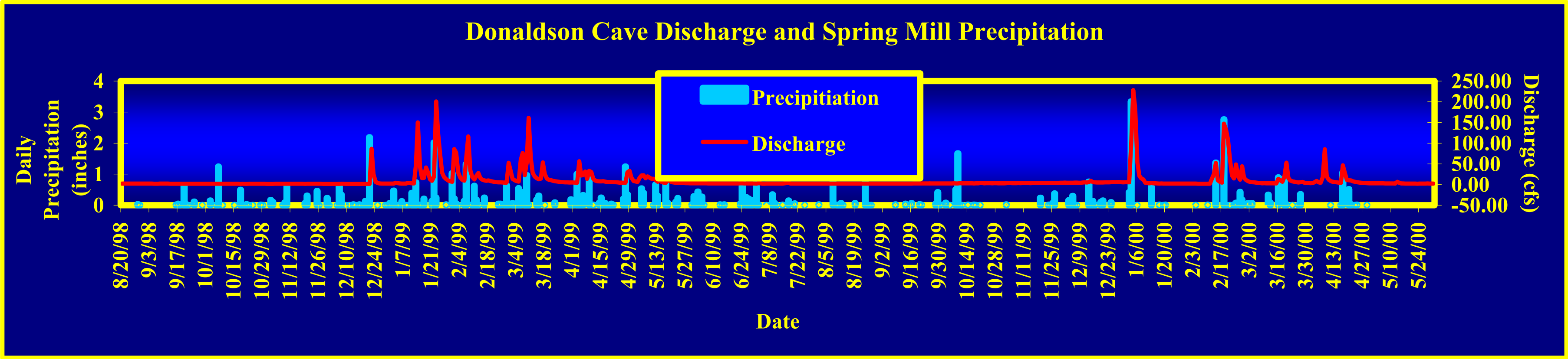


Figure 4. Graph showing the average daily discharge records from Donaldson Cave at Spring Mill State Park (from Buehler and Hasenmueller, 2000).

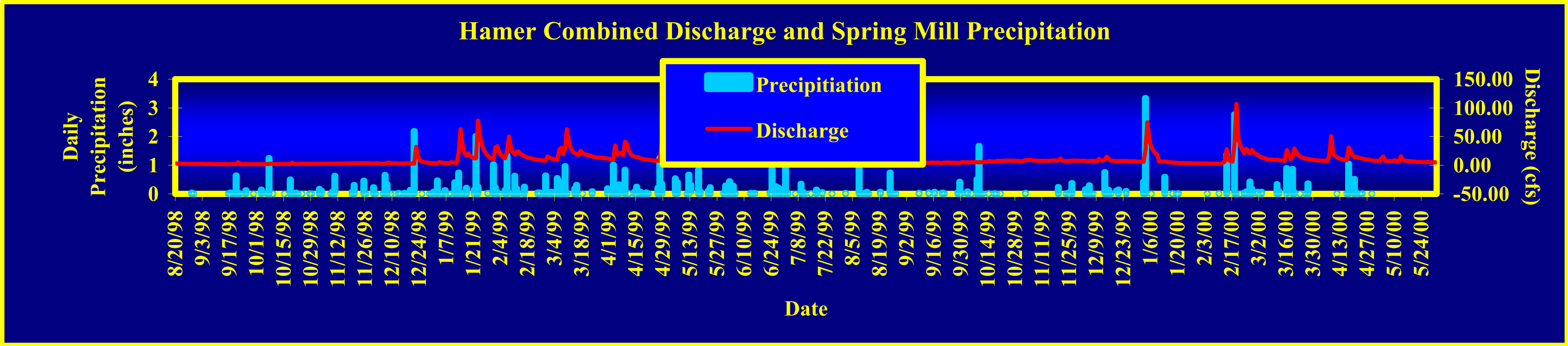


Figure 5. Graph showing the average daily discharge records from the confluence of the streams discharging from Hamer, Wind, and Whistling Caves located in the Pioneer Village at Spring Mill State Park (from Buehler and Hasenmueller, 2000).

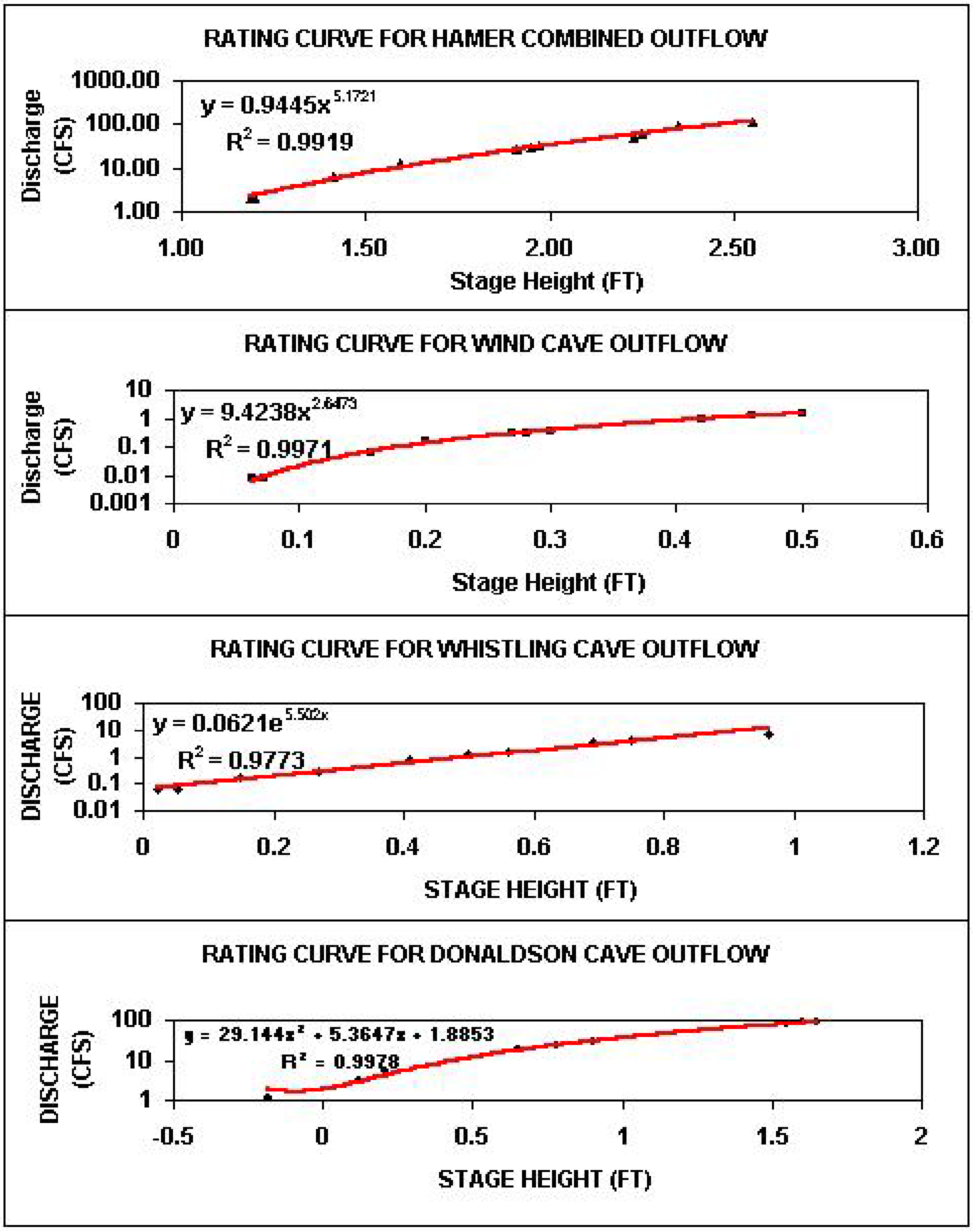


Figure 6. **Rating curves developed for Hamer combined outflow, Wind Cave outflow, Whistling Cave outflow, and Donaldson Cave outflow.**

Water-Quality Monitoring

Introduction--A Quality Assurance Project Plan (QAPP) was prepared and submitted to the Indiana Department of Environmental Management prior to conducting sampling activities (Comer and others, 1999). Water-quality sampling for *Escherichia coli* and pesticide analyses were conducted on a quarterly basis. Quarterly field measurements were also taken at the water-quality sampling sites. Major ion chemistry and trace element analyses were conducted on water samples collected annually from the monitoring sites. Water sampling was conducted during one storm event in February 2000. During the storm event, water samples were collected for pesticide, nitrogen isotope, and major ion analyses.

Quarterly water monitoring--Quarterly water samples were collected at the following monitoring sites: (1) Hamer Cave Spring, (2) Wind Cave Spring, (3) Whistling Cave Spring, (4) Donaldson Cave Spring, (5) Rubble Spring, (6) Spring Mill Lake immediately above the dam, (7) Upper Twin Cave Spring, and (8) the confluence of Hamer, Whistling, and Wind Cave Springs. Field measurements were taken quarterly at each monitoring site by members of the Indiana Geological Survey Geochemistry Section and include temperature, specific conductance, pH, oxidation-reduction potential, and dissolved oxygen (DO) (table 3). The quarterly samples were analyzed for *E. coli* and pesticide content.

The Indiana State Department of Health analyzed the water samples for concentrations of *E. coli*. *E. coli* levels are used as an indicator of the overall level of fecal bacteria pollution in water and are currently receiving attention because of the new Total Maximum Daily Load (TMDL) program (Turco and others, 2000). The presence of *E. coli* is usually due to animal manure (wildlife or livestock) and/or raw sewage entering a stream; however, identifying the specific source of *E. coli* is very difficult (Faulkenburg and others, 2000). The EPA (1986) recommended *E. coli* level for a designated beach area is 235 most probable number (MPN) per 100 mL. The *E. coli* levels from the springs within the park were variable. From August 1998 to May 2000, the levels in quarterly water samples from the Upper Twin Cave Spring varied from 27 to 276 MPN per 100 mL and the levels in samples from Donaldson Cave Spring varied from 53 to 166 MPN per mL (table 4).

The Office of the Indiana State Chemist analyzed water samples for the presence of 29 pesticides. Samples were analyzed quarterly and during a February 2000 storm event prior to pesticide application. None of the samples contained pesticide concentrations above the minimum levels for detection (table 5). The results of pesticide analyses from November 1999 through May 2000 are not yet available.

Annual water monitoring--Major ion chemistry and trace element analyses were conducted by members of the Indiana Geological Survey Geochemistry Section on water samples collected from the monitoring sites in August of 1998 and 1999 to represent seasonal low-flow conditions (table 6). Samples were also collected during a storm event to represent high-flow conditions (table 7). Triangular Piper diagrams display the relative concentrations of major ion chemistry (figure 7). The waters are calcium bicarbonate waters that are typical of karst regions in Indiana. The concentrations of major cation and anions and trace metals in the water samples do not exceed the EPA drinking water standards.

Nitrate concentrations in water samples from Donaldson Cave were 11.0 mg/L in August 1998 and 32.8 mg/L in August 1999. The nitrate concentration in the water sample from Upper Twin Cave was 7.8 mg/L in August 1999. Bolton (1980) noted that the nitrate concentrations in the discharge from Donaldson Cave Spring were lowest in the late fall and winter. He reported that the nitrate values for Donaldson and Twin Cave Springs peaked at about 22 ppm in late July 1979 and were about 20 ppm in late August 1979. Bolton (1980) indicated that the increases in May are probably associated with agricultural activity to the south. The natural decomposition of organic matter, i.e., the breakdown of amino acids, in the drainage area would cause only a minor increase the amounts of nitrates in the waters.

Storm-event water monitoring--Storm-event samples were collected from February 18 to 23, 2000, at Donaldson Cave Spring, and the confluence of the streams from Hamer, Whistling, and Wind Caves after a rain event dropped 3.1 inches of precipitation in less than 24 hours (figures 8 and 9). A storm occurring on February 13 had saturated the soil with 1.36 inches of precipitation in approximately 9 hours, providing high antecedent moisture conditions. Total precipitation for the month of February was over twice the historical average. According to statistical return periods for storms lasting 12 to 24 hours, this was a 2- to 5-year storm.

Major ion chemistry analyses were conducted by members of the Indiana Geological Survey Geochemistry Section on water samples collected during a storm event to represent high-flow conditions (table 7). Triangular Piper diagrams display the relative concentrations of major ion chemistry (figure 7). Buehler and Hasenmueller (2000) reported that the results of the storm-event sampling indicate that there is very little change in the ratio of ions from low flow to high flow. Storm events merely dilute the total concentration (tables 6 and 7).

Nitrate concentrations in the water samples collected from Donaldson Cave Spring during the storm event in February 2000 ranged from a low of 5.45 mg/L immediately after the beginning of the storm on February 18 to a high of 14.13 mg/L on February 22. Nitrate concentrations in background samples collected from Donaldson Cave Spring on January 10, 2000, and January 20, 2000, were 13.77 and 13.14 mg/L, respectively.

Nitrogen isotope analyses of the storm-event samples were conducted by the Water Sciences Laboratory at the University of Nebraska. The range was from –0.15 to +2.83 per mil (‰) for the water samples collected during and immediately after the storm event (table 8). Nitrogen isotope concentrations in background samples collected from Donaldson Cave Spring on January 10, 2000, and January 20, 2000 were 3.00 and 3.14‰ respectively. These nitrogen isotope concentrations indicate an inorganic source. The range of nitrate produced from animal waste is +9.6 to 17.6‰ (Wells and Krothe, 1989).

The storm-event samples were analyzed by the Office of the Indiana State Chemist for concentrations of pesticides. Because of the amount of clay/sediment in the samples, the Office of the Indiana State Chemist was unable to use the normal extraction method on the water samples. They performed the extraction by a liquid-liquid method. These extractions are being analyzed for concentrations of pesticides.

Table 3. Chart showing quarterly field measurements† of ground water discharging from Donaldson (SM04) and Upper Twin (SM07) Caves within the Spring Mill Lake watershed

Site ID	Sampling Date‡	Field Temp °C	SpC @25°C µmhos/cm	pH @25°C	(SHE) calc.	Dissolved Oxygen mg/L
SM04	08/18/98	14.0	458	8.1	394	7.8
SM04	10/05/98	13.0	541	7.8	437	11.2
SM04	11/18/98	11.7	558	8.1	434	10.6
SM07	11/18/98	12.2	594	8.1	411	9.6
SM04	03/02/99	10.8	373	7.3	399	16.3
SM07	03/02/99	10.9	378	7.0	409	10.6
SM04	05/11/99	12.7	477	7.8	402	10.4
SM07	05/11/99	12.7	475	7.3	367	9.9
SM04	08/10/99	13.1	571	8.0	345	10.0
SM07	08/10/99	12.5	591	7.3	359	8.6
SM04	11/08/99	12.0	575	8.0	316	11.0
SM07	11/08/99	12.3	614	7.9	321	10.7
SM04	02/09/00	10.9	487	7.9	371	11.1
SM07	02/09/00	11.8	493	7.7	396	10.6
SM04	05/16/00	12.6	407	8.1	284	10.4
SM07	05/16/00	12.8	414	7.4	2999	9.9

†The field measurements were taken quarterly at each monitoring site by members of the Indiana Geological Survey Geochemistry Section.

‡Quarterly field measurements were not initiated at Upper Twin Cave until November 1998.

Table 4. Chart showing concentrations of *Escherichia coli* in water samples from monitoring sites at Donaldson (SM04) and Upper Twin (SM07) Cave Springs within the Spring Mill Lake watershed

Site ID	Sampling Date†	*E. coli* MPN/100ml‡
SM04	08/18/98	111
SM04	11/18/98	166
SM04	03/02/99	127
SM04	05/11/99	53
SM04	08/10/99	64
SM04	11/08/99	61
SM04	02/09/00	+§
SM04	05/16/00	120
SM07	11/18/98	276
SM07	03/02/99	115
SM07	05/11/99	111
SM07	08/10/99	27
SM07	11/08/99	35
SM07	02/09/00	+
SM07	05/16/00	155

†Collection of water samples for *E. coli* analysis was not initiated at Upper Twin Cave until November 1998.
‡MPN = Most probable number.
§+ = *E. coli* was detected in the water sample; however, a quantitative measurement for *E. coli* content was not performed.

Table 5. Chart showing concentrations of pesticides in ground water discharging from Donaldson (SM04) and Upper Twin (SM07) Caves within the Spring Mill Lake watershed

Site ID	Sampling Date†	Acetachlor *ppb*	Alachlor *ppb*	Atrazine *ppb*	Bromacil *ppb*	Cyanazine *ppb*	Diazinon *ppb*	Endosulfan *ppb*	Fenamiphos *ppb*	Metolachlor *ppb*
SM04	08/18/98	<0.0069	<0.011	<0.0047	<0.013	<0.0091	<0.0037	<0.00089	<0.0060	<0.032
SM04	11/18/98	<0.31	<0.28	<0.30	<0.50	<0.50	<0.44	<0.50	<2.1	<0.47
SM04	03/02/99	<0.31	<0.28	<0.30	<0.50	<0.50	<0.44	<0.50	<2.1	<0.47
SM04	05/11/99	<0.31	<0.28	<0.30	<0.50	<0.50	<0.44	<0.50	<2.1	<0.47
SM07	11/18/98	<0.31	<0.28	<0.30	<0.50	<0.50	<0.44	<0.50	<2.1	<0.47
SM07	03/02/99	<0.31	<0.28	<0.30	<0.50	<0.50	<0.44	<0.50	<2.1	<0.47
SM07	05/11/99	<0.31	<0.28	<0.30	<0.50	<0.50	<0.44	<0.50	<2.1	<0.47

Site ID	Sampling Date	Metribuzin *ppb*	Pendimethalin *ppb*	Prometon *ppb*	Propachlor *ppb*	Simazine *ppb*	Terbufos *ppb*	Trifluralin *ppb*	2,4-D *ppb*	2,4-DP *ppb*
SM04	08/18/98	<0.018	<0.0077	<0.0074	<0.025	<0.0074	<0.0015	<0.0066	<0.11	<0.16
SM04	11/18/98	<0.54	<0.57	<0.15	<0.38	<0.48	<0.50	<0.35	<0.11	<0.16
SM04	03/02/99	<0.54	<0.57	<0.15	<0.38	<0.48	<0.50	<0.35	<0.11	<0.16
SM04	05/11/99	<0.54	<0.57	<0.15	<0.38	<0.48	<0.50	<0.35	<0.11	<0.16
SM07	11/18/98	<0.54	<0.57	<0.15	<0.38	<0.48	<0.50	<0.35	<0.11	<0.16
SM07	03/02/99	<0.54	<0.57	<0.15	<0.38	<0.48	<0.50	<0.35	<0.11	<0.16
SM07	05/11/99	<0.54	<0.57	<0.15	<0.38	<0.48	<0.50	<0.35	<0.11	<0.16

†The collection of water samples for pesticide analyses was not initiated at Upper Twin Cave until November 1998.

Table 6. Chart showing the field measurements, major cations and anions, and selected trace elements† for water samples from the Donaldson (SM04) and Upper Twin Cave Springs (SM07) within the Spring Mill Lake watershed

Site ID	Sampling Date‡	Field Temp. °C	SpC @25°C *µmhos/cm*	PH @25°C	Eh (SHE) calc.	Dissolved Oxygen mg/L	Alkal. mg/L	HCO_3- mg/L	CO_3= mg/L	F- mg/L	Cl- mg/L	NO_3- mg/L	SO_4- mg/L	PO_4 mg/L	Ca++ mg/L
SM04	08/18/98	14.0	458	8.1	394	7.8	208	250	1	0.14	6.7	11.0	15.7	<1	76
SM04	08/10/99	13.1	571	8.0	345	10.0	234	280	1	0.10	9.5	32.8	23.6	<0.5	106
SM07	08/10/99	12.5	591	7.3	359	8.6	250	300	0	0.20	14.0	7.8	24.4	<0.5	107

Site ID	Sampling Date	Mg++ mg/L	K+ mg/L	Na+ mg/L	Fe (tot) mg/L	Mn (tot) mg/L	Zn++ mg/L	Ba++ mg/L	Sr++ mg/L	Al+++ mg/L	Si° mg/L	Cd++ µg/L	Se µg/L	As µg/L	Ni++ µg/L
SM04	08/18/98	11	5	5	<0.1	0.1	<0.05	0.1	0.3	<0.1	4.5	0.1	<1	<1	<1
SM04	08/10/99	26	7	25	0.9	0.9	0.4	0.5	1.1	1.2	5.6	<0.2	<1		<1
SM07	08/10/99	26	5	25	0.9	0.9	0.4	0.5	1.1	1.4	5.6	<0.2	<1		<1

Site ID	Sampling Date	Cu (tot) *µg/L*	Pb *µg/L*	Sb *µg/L*	Ag *µg/L*	Cr *µg/L*	Mo *µg/L*	B mg/L	Hg ppb	H+ mg/L	Anion Sum meq/L	Cation Sum meq/L	EPM Balance ± % dev	TDS mg/L	TDS/SpC Ratio	TSS mg/L
SM04	08/18/98	11	12.8	<2	<0.2	<1	<1	0.13	<0.3	0.0	4.8	5.1	3.0	411	0.9	<3
SM04	08/10/99	<1	<1	<2	<1	<1		0.14	<0.3	0.0	5.9	8.9	20.3	521	0.9	8
SM07	08/10/99	<1	<1	<2	<1	<1		0.25	<0.3	0.0	6.0	9.0	20.0	520	0.9	3

†The field measurements, major cations and anions analyses, and selected trace element analyses were conducted by members of the Indiana Geological Survey Geochemistry Section.
‡The collection of water samples for major cations and anions and selected trace elements analyses was not initiated at Upper Twin Cave until August 1999.

Table 7. Chart showing the field measurements and major cations and anions† for water samples from Donaldson Cave Spring (SM04) within the Spring Mill Lake watershed during the February storm event

Sample ID	Sampling Date	Time	Field Temp °C	CFS	PH @25°C	Alkal. mg/L	HCO_3- (calc.) mg/L	CO_3= (calc.) mg/L	Cl- mg/L	NO_3- mg/L	SO_4- mg/L	Ca++	Mg++ mg/L	K+ mg/L
SM4-18-830	02/18/00	08:30	9.28	237.2	7.5	114	140	0	12	8.4	17	48	8	<5
SM4-18-1030	02/18/00	10:30	9.18	220.6	7.3	87	110	0	6.4	6.8	15	37	6	<5
SM4-18-1330	02/18/00	13:30	9.08	193.7	7.2	67	82	0	5.7	8.3	15	30	5	<5
SM4-18-1730	02/18/00	17:30	8.79	232.1	7.2	56	68	0	4.3	5.1	14	25	4	<5
SM4-19-0030	02/19/00	00:30	8.89	153.3	7.2	66	80	0	3.7	5.8	15	27	4	<5
SM4-19-0730	02/19/00	07:30	8.79	136.1	6.9	64	77	0	3.9	5.7	14	26	4	<5
SM4-19-1230	02/19/00	12:30	8.59	128.6	6.5	61	75	0	3.7	6.1	14	25	4	<5
SM4-19-1830	02/19/00	18:00	8.59	122.5	6.8	61	74	0	3.5	6.4	14	24	4	<5
SM4-20-0030	02/20/00	00:30	8.50	134.9	7.2	60	73	0	3.4	6.4	14	25	4	<5
SM4-20-0830	02/20/00	08:30	8.20	111.8	7.3	62	75	0	3.6	6.9	14	23	3	<5
SM4-20-2030	02/20/00	20:30	7.81	101.6	7.4	65	79	0	3.7	7.8	14	27	4	<5
SM4-21-1230	02/21/00	12:30	8.11	51.7	7.4	88	110	0	5.5	11	16	33	5	<5
SM4-22-1230	02/22/00	12:30	10.55	19.9	7.6	151	180	0	6.5	16	17	61	8	<5
SM4-23-1230	02/23/00	12:30	10.84	12.5	7.7	161	190	0	6.9	16	17	62	9	<5

†The field measurements and major cation and anion analyses were conducted by members of the Indiana Geological Survey Geochemistry Section.

Table 7 (cont.). **Chart showing the field measurements and major cations and anions for water samples from Donaldson Cave Spring (SM04) within the Spring Mill Lake watershed during the February storm event**

Sample ID	Sampling Date	Na+ mg/L	Fe (tot) mg/L	Mn (tot) mg/L	Zn++ mg/L	Ba++ mg/L	Sr++ mg/L	Al+++ mg/L	Si° mg/L	H+ mg/L	Anion Sum meq/L	Cation Sum Sum	EPM Balance ± % dev	TDS (calc.) mg/L
SM4-18-830	02/18/00	7	<0.1	0.10	<0.05	<0.05	0.2	<0.1	3.3	0.0	3.1	3.3	3.1	177
SM4-18-1030	02/18/00	4	<0.1	0.07	<0.05	<0.05	0.1	<0.1	2.7	0.0	2.4	2.5	2.0	135
SM4-18-1330	02/18/00	3	<0.1	0.09	<0.05	<0.05	0.1	0.1	2.5	0.0	2.0	2.0	0.0	112
SM4-18-1730	02/18/00	2	0.1	<0.05	<0.05	<0.05	0.1	<0.1	2.5	0.0	1.6	1.6	0.0	93
SM4-19-0030	02/19/00	2	<0.1	0.09	<0.05	<0.05	0.1	<0.1	2.4	0.0	1.8	1.7	-2.9	101
SM4-19-0730	02/19/00	2	<0.1	<0.05	<0.05	0.31	0.1	<0.1	2.2	0.0	1.8	1.7	-2.9	98
SM4-19-1230	02/19/00	2	0.2	0.05	<0.05	0.23	0.1	0.2	2.6	0.0	1.7	1.7	0.0	98
SM4-19-1830	02/19/00	1	<0.1	<0.05	<0.05	<0.05	0.1	<0.1	2.2	0.0	1.7	1.6	-3.0	94
SM4-20-0030	02/20/00	1	<0.1	<0.05	<0.05	<0.05	0.1	<0.1	2.2	0.0	1.7	1.6	-3.0	94
SM4-20-0830	02/20/00	2	<0.1	<0.05	<0.05	0.06	0.1	0.1	2.1	0.0	1.7	1.5	-6.3	94
SM4-20-2030	02/20/00	1	<0.1	0.06	<0.05	0.05	0.1	<0.1	2.4	0.0	1.8	1.8	0.0	102
SM4-21-1230	02/21/00	3	<0.1	<0.05	<0.05	<0.05	0.1	0.4	2.9	0.0	2.5	2.2	-6.4	133
SM4-22-1230	02/22/00	3	<0.1	<0.05	<0.05	<0.05	0.1	<0.1	3.5	0.0	3.7	3.9	2.6	208
SM4-23-1230	02/23/00	3	<0.1	<0.05	<0.05	<0.05	0.2	0.5	3.6	0.0	3.9	4.0	1.3	216

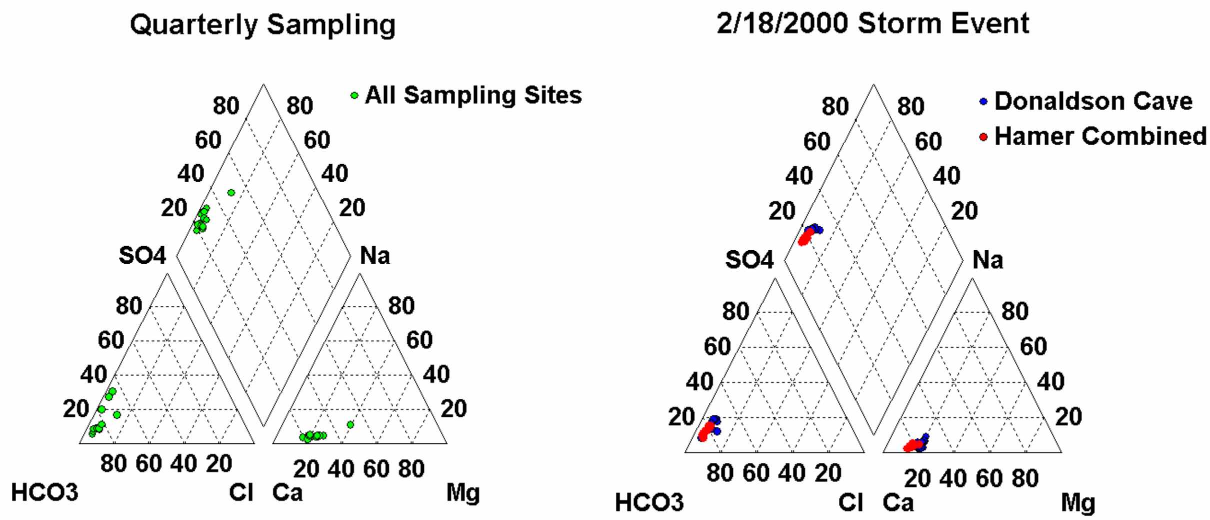


Figure 7. Piper diagrams showing the relative concentrations of major ion chemistry (from Buehler and Hasenmueller, 2000).

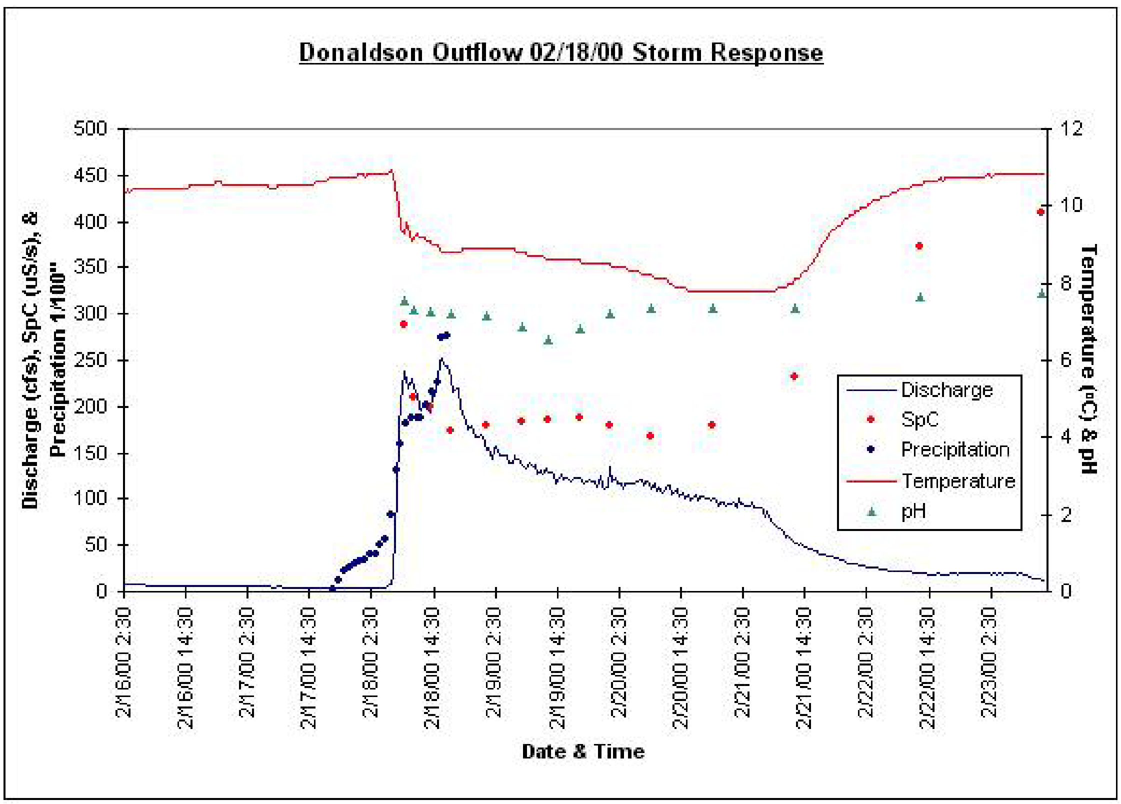


Figure 8. Graph showing the discharge, specific conductance, temperature, and pH of the water at Donaldson Cave Spring in relation to the February 18, 2000 storm event.

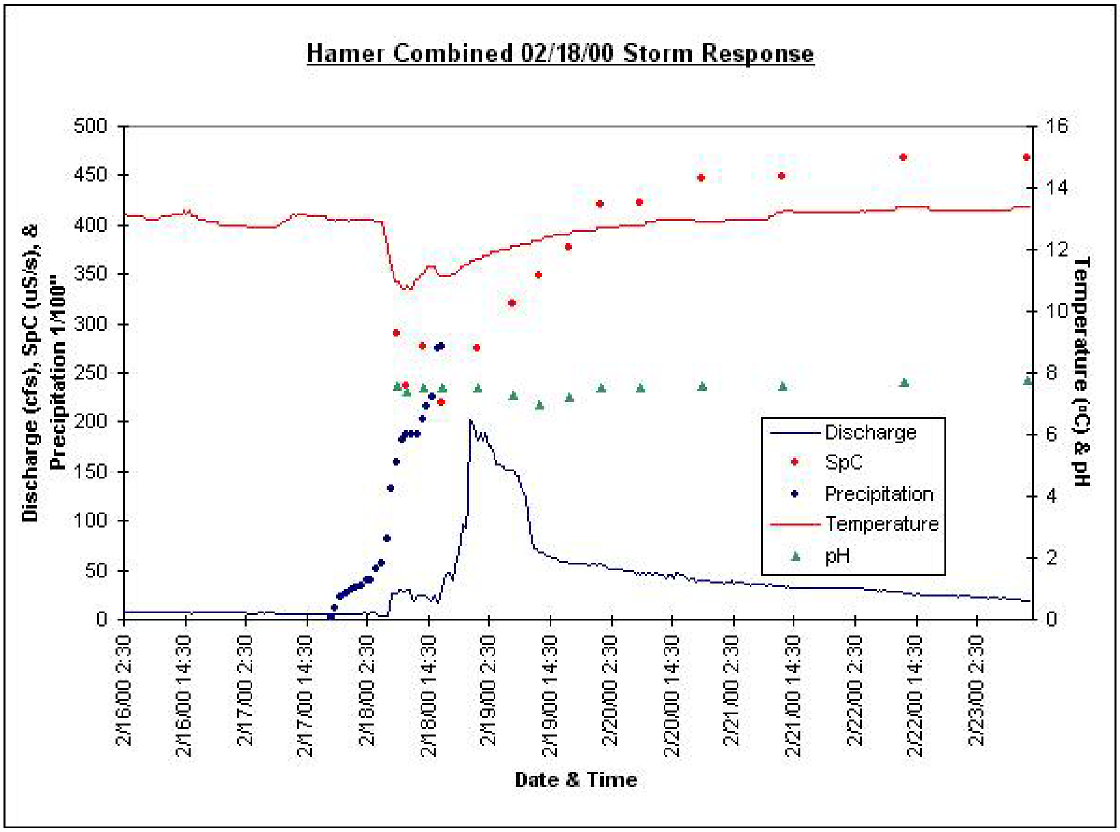


Figure 9. Graph showing the discharge, specific conductance, temperature, and pH of the water at the confluence of the streams from Hamer, Wind, and Whistling Caves in relation to the February 18, 2000 storm event.

Table 8. Chart showing the nitrogen isotope analyses for water samples collected at Donaldson Cave Spring prior to and during the February 2000 storm event

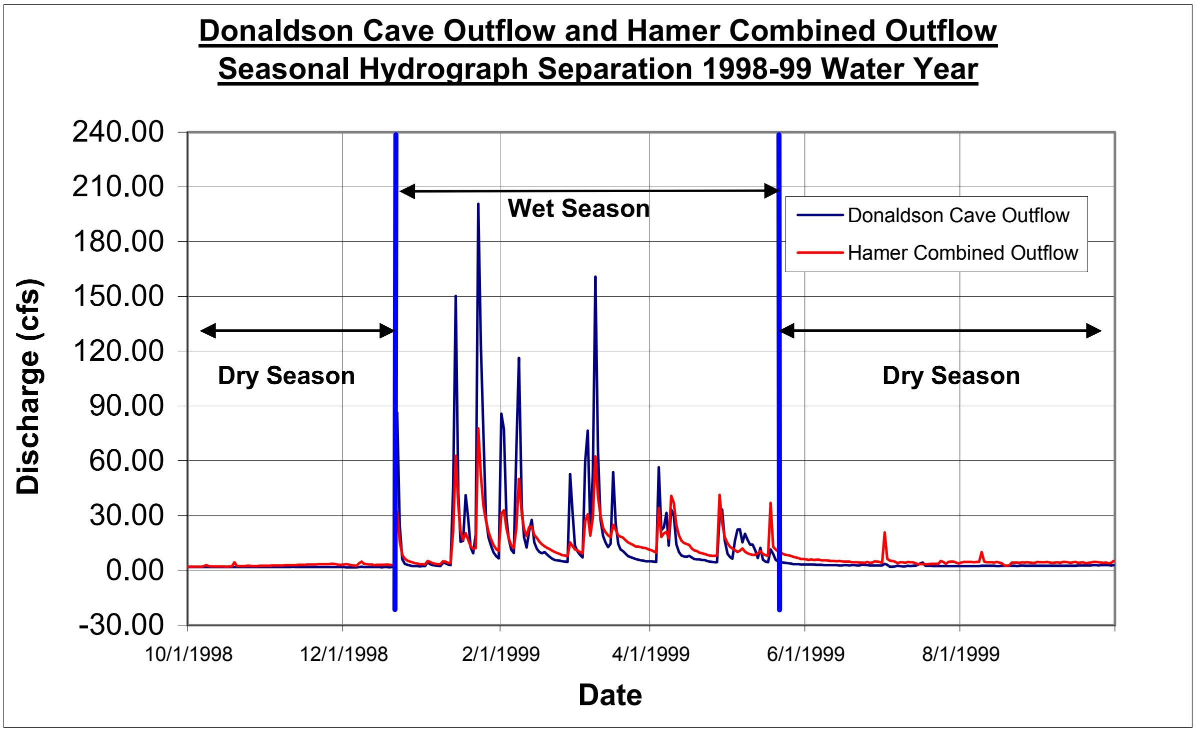
Lab ID #	Sample ID	Collection Date	NO_3 - N (mg/L)	NO_3 (mg/L)	$\delta^{15}N - NO_3$ ‰	NH_4-N (mg/L)	$\delta^{15}N - NH_4$ ‰	Analyzed
00-714	04-0830	02/18/2000	1.21	5.45	1.93	<0.10	NM†	06/29/2000
00-715	04-1030	02/18/2000	1.36	6.12	0.98	0.17	NM	06/29/2000
00-716	04-1330	02/18/2000	1.67	7.52	2.16	0.17	NM	06/29/2000
00-717	04-1730	02/18/2000	1.08	4.86	-0.15	<0.10	NM	07/18/2000
00-718	04-0030	02/19/2000	1.20	5.40	2.01	0.20	NM	06/29/2000
00-719	04-0730	02/19/2000	1.25	5.63	0.34	0.14	NM	07/18/2000
00-720	04-1230	02/19/2000	1.28	5.76	1.76	0.20	NM	07/18/2000
00-721	04-1830	02/19/2000	1.31	5.90	2.16	0.22	NM	07/18/2000
00-722	04-0030	02/20/2000	1.31	5.90	0.59	0.22	NM	07/19/2000
00-723	04-0830	02/20/2000	1.36	6.12	2.21	0.14	NM	07/19/2000
00-724	04-0830	02/20/2000	1.53	6.89	0.02	0.11	NM	07/10/2000
00-725	04-1230	02/21/2000	2.20	9.90	0.79	0.14	NM	07/19/2000
00-726	04-1230	02/22/2000	3.14	14.13	1.61	0.17	NM	07/19/2000
00-727	04-1230	02/23/2000	2.86	12.87	2.83	0.14	NM	07/19/2000
00-728	Donaldson Background	01/10/2000	3.06	13.77	3.00	<0.10	NM	07/19/2000
00-729	Donaldson Background	01/20/2000	2.92	13.14	3.14	<0.10	NM	07/19/2000

†NM = Not Measured.

FLOW REGIMES DURING WET AND DRY SEASONS OF THE 1998-99 WATER YEARS

During the summer and fall of 1999, much of Indiana experienced a severe drought. Water sampling during the drought period may not be indicative of water quality during more typical flow periods. Owing to the drought-induced low-flow conditions during 1999-2000 (figures 10 and 11), it was not possible to complete the proposed storm-event pesticide sampling in the Spring Mill Lake drainage basin. Water from a pre-pesticide application storm event was sampled and analyzed in February 2000; however, it was not possible to sample water from a post-pesticide application storm event during the spring/early summer of 2000.

Surface-water samples for the Indiana Department of Environmental Management's ongoing Pesticide Monitoring Program were analyzed from April through July because this time period represents the season when pesticide application is most likely to occur (McDuffee, 2000). Reports and publications from the U.S. Geological Survey describing the pesticide levels in surface-water samples collected in Indiana on a weekly to monthly basis indicate that the highest concentrations occur from May through July (Crawford, 1997). Therefore, collecting additional water samples for analyses in the Spring Mill Lake drainage basin after the application of pesticides in the spring is deemed important. Because of the nature of the surface-water/ground-water flow within this karst terrain, the window within which post-pesticide application storm-event waters can be sampled is rather narrow. After late May, the ground-water flow discharge rates from the major springs do not always increase in response to rain/storm events during the "dry season." It is advisable to also collect water samples from selected spring systems (Donaldson and Hamer Cave Spring Systems) within the basin after the spring pesticide applications. These water samples will be collected on a weekly or biweekly basis from mid- to late April through mid-July 2001 in lieu of collecting water samples from a single post-pesticide application storm event.



Donaldson Cave Outflow Seasonal Hydrograph Separation 1998-1999 Water Year				
Season	**≅ Avg Daily cfs**	**ft^3/yr**	**gal/yr**	**% Distribution**
Dry Season	453	4.78E+07	3.57E+08	12%
Wet Season	3215	2.68E+08	2.01E+09	88%
DCO Total	3668	3.16E+08	2.36E+09	100%

Hamer Combined Outflow Seasonal Hydrograph Separation				
Season	**≅ Avg Daily cfs**	**ft^3/yr**	**gal/yr**	**% Distribution**
Dry Season	769	6.64E+07	4.97E+08	23%
Wet Season	2608	2.25E+08	1.69E+09	77%
HCO Total	3377	3.15E+08	2.36E+09	100%

Combined Total	7045	6.31E+08	4.72E+09	100%

Outflow	**Avg Daily cfs**	**ft^3/day**	**gal/day**	**% Distribution**
Donaldson Cave	10.05	8.66E+05	6.48E+06	52%
Hamer Combined	9.25	8.63E+05	6.46E+06	48%
Total Avg Daily cfs	19.30	1.73E+06	1.29E+07	100%

Flow component	**Avg Daily cfs**	**cfs/mi2***
Total Flow	19.30	0.932
Baseflow Only	4.10	0.198

*Assuming contributing basin area of 20.61 $mi^{2.}$

Figure 10. Graph illustrating the marked difference between the flow regimes during the wet and dry seasons of the 1998-99 water years. Although there is not an absolute time scale for yearly wet and dry seasons, during this particular year the wet season occurred from December 22, 1998, to June 4, 1999. This marks a period of 164 days; the remaining 201 days represent the dry season. The length of the wet season is a function of rainfall totals, rainfall intensities, and evapotranspiration.

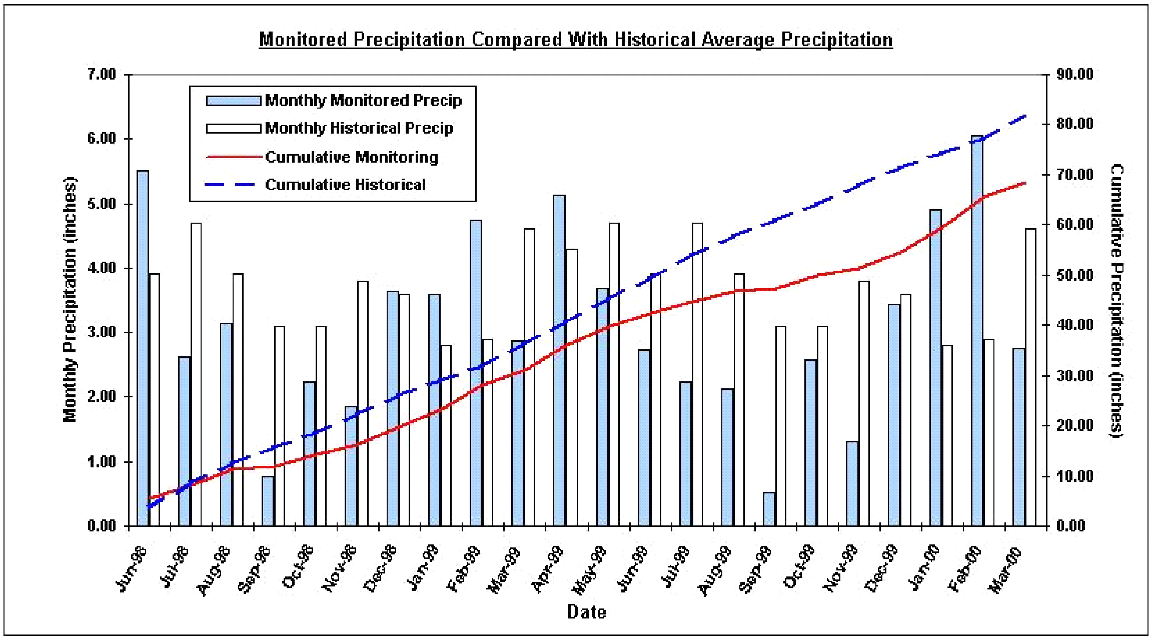


Figure 11. Graph comparing the precipitation measured at the Service Area site in Spring Mill State Park from June 1998 to March 2000 to the historical average precipitation in the area. Note the deficit of the measured precipitation compared to historical data, especially during the summer months of 1999.

GIS LAND-COVER/LAND-USE DATABASE

Farmland-use data received from Agricultural Stabilization and Conservation Service (ASCS) office in Bedford and Paoli were used to classify land use on a farm-by-farm basis (figure 12). Graphical coverages were digitized and georeferenced using Arc/Info software. The current land use in the area is as follows: 31.3 percent corn, soybeans, wheat, and other crops; 21.3 percent forest; 15.9 percent Crop Reserve Program (CRP); 14.1 percent forest/pasture, pasture/forest, orchard, and pasture; 7.2 percent grass; 6 percent residential; 2 percent golf course; 0.8 percent urban; 0.8 percent water; and 0.6 percent industrial (figure 13).

Thus, nearly 60 percent of the land use should be characterized by low pesticide application. In order to maintain water quality within the area, it would be advantageous to continue programs such as the CRP and to limit residential/urban construction and the installation of septic systems.

On the basis of land use, an estimate of the input of chemicals by subbasins was determined. Standard application rates for commonly used pesticides and fertilizers were obtained in part from the White River Co-Op and in part from product labels. A pesticide and inorganic fertilizer loading estimate was compiled using this information.

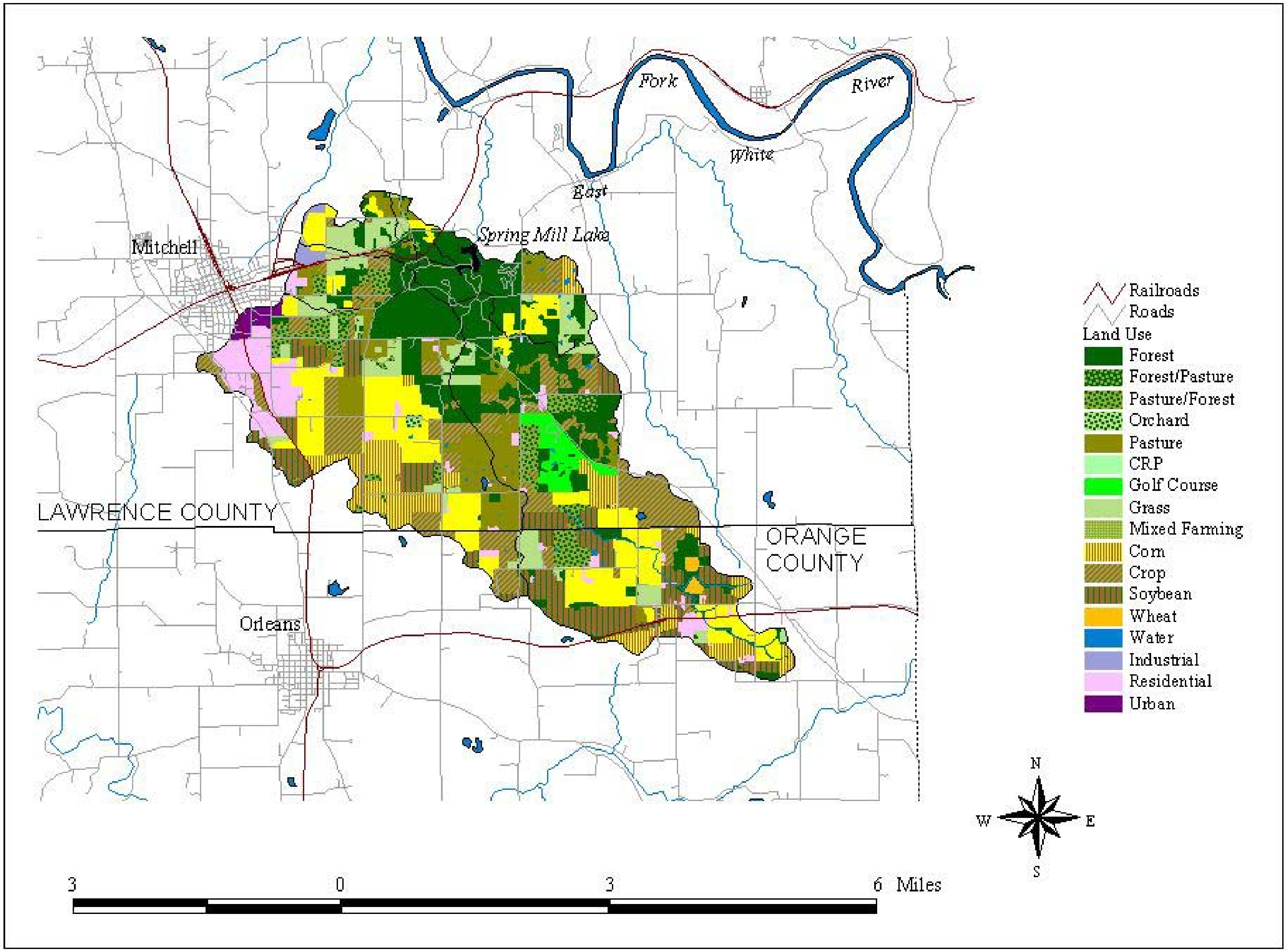


Figure 12. Map showing land use in the Spring Mill Lake watershed in Lawrence and Orange Counties (modified from Buehler and Hasenmueller, 2000).

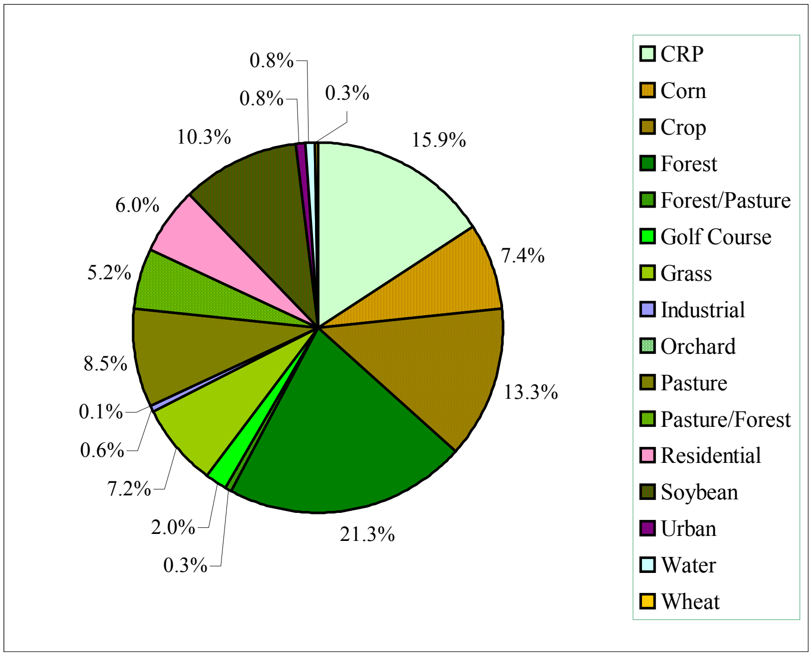


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Figure 13. Chart showing the land use in the Spring Mill Lake watershed by percentage of the total land.

EDUCATIONAL ASPECTS

Internet site

Because the Internet is becoming such an effective means of disseminating information quickly and is widely used as an educational tool in classrooms across the state, a web page was established for the project. The site is used to update progress and to provide a final information summary for future reference to the project site. The URL for the site is http://adamite.igs.indiana.edu/indsurv/research/index.htm.

Field Trips and Demonstrations

A field trip guidebook describing the karst features in the Spring Mill Lake and Lost River areas was written. Copies of the guidebook are available as Indiana Geological Survey Open-file Study 99-10 by Hasenmueller and others (2000). A field trip to the Spring Mill Lake and Lost River areas was conducted on Saturday, April 8, 2000 as part of the North Central Section Meeting of the Geological Society of America.

As part of Earth Science Week in October 1999, geologists from the Indiana Geological Survey and Indiana University hosted field demonstrations and presentations relating to the project. The presentations were at four different stops within the park and related to (1) karst geology and the formation of caves, (2) dye tracing to better delineate the drainage area of Spring Mill Lake, (3) sediment accumulation in the lake, and (4) water sampling and field measurements to determine the chemistry of the waters entering the lake.

SUMMARY

- The boundaries of the Spring Mill Lake drainage basin and its six subbasins were better defined using organic dyes at low concentrations. The Donaldson/Bronson/Twin Cave and Hamer Cave subbasins drain much of the watershed. The Donaldson Cave System is fed by a sinking stream, Mosquito Creek, and drains the southeastern part of the watershed. The Hamer Cave System drains the southwestern part of the watershed.

- The initial water monitoring included measurement of precipitation, stream flow, turbidity, sediment volume, specific conductance, temperature, pH, coliform bacteria, pesticides, major cations and anions, trace elements, and nitrogen isotopes.

- Quarterly water samples were collected at the following monitoring sites within Spring Mill State Park: (1) Hamer Cave Spring, (2) Wind Cave Spring, (3) Whistling Cave Spring, (4) Donaldson Cave Spring, (5) Rubble Spring, (6) Spring Mill Lake immediately above the dam, (7) Upper Twin Cave Spring, and (8) the confluence of Hamer, Whistling, and Wind Cave Springs. The quarterly samples were analyzed for *E. coli* and pesticide content.

- The *E. coli* levels from the springs within the park were variable. From August 1998 to May 2000, the levels in water samples from the Upper Twin Cave Spring varied from 27 to 276 most probable number (MPN) per 100 mL and the levels in samples from Donaldson Cave Spring varied from 53 to 166 MPN per mL. The level of *E. coli* for whole body contact recreation is 235 MPN per 100 mL.

- Water samples were analyzed by the Office of the Indiana State Chemist for the presence of 29 pesticides. Samples were analyzed quarterly and during a February 2000 storm event prior to pesticide application. None of the samples contained pesticide concentrations above the minimum levels for detection. The results of pesticide analyses from November 1999 through May 2000 are not yet available.

- Major ion chemistry and trace element analyses were conducted on water samples collected from the monitoring sites in August of 1998 and 1999 to represent seasonal low-flow conditions. Samples were also collected during a February 2000 storm event to establish high-flow conditions. The results of the storm-event sampling indicate that there is very little change in the ratio of ions from low to high flow. Storm events merely dilute the total concentration. The concentrations of major cation and anions and trace metals in the water samples do not exceed the EPA drinking water standards.

- Nitrate concentrations in water samples from Donaldson Cave were 11.0 mg/L in August 1998 and 32.8 mg/L in August 1999. The nitrate concentration in the water sample from Upper Twin Cave was 7.8 mg/L in August 1999. Nitrate concentrations in the water samples collected from Donaldson Cave Spring during the storm event in February 2000 ranged from a low of 5.45 mg/L immediately after the beginning of the storm on February 18 to a high of 14.13 mg/L on February 22. Nitrate concentrations in background samples collected from Donaldson Cave Spring on January 10, 2000, and January 20, 2000, were 13.77 and 13.14 mg/L, respectively.

- Nitrogen isotope analyses of the storm-event samples were conducted by the Water Sciences Laboratory at the University of Nebraska. The range was from -0.15 to +2.83 per mil (‰) for the water samples collected during and immediately after the storm event. Nitrogen isotopes concentrations in background samples collected from Donaldson Cave Spring on January 10, 2000, and January 20, 2000 were 3.00 and 3.14‰ respectively. These concentrations are well below the range of nitrate (+9.6 to 17.6‰) produced from animal waste and indicate possible inorganic source.

- The waters are calcium bicarbonate waters that are typical of karst regions in Indiana.

- During the summer and fall of 1999, much of Indiana experienced a severe drought. Water sampling over the drought period may not be indicative of water quality during more typical flow periods. Owing to the drought-induced low-flow conditions during 1999-2000, it was not possible to complete the proposed storm-event pesticide sampling in the Spring Mill Lake drainage basin. Waters from a pre-pesticide application storm event were sampled and analyzed in February 2000; however, it was not possible to sample waters from a post-pesticide application storm event during the spring/early summer of 2000.

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- The current land use in the area is as follows: 31.3 percent corn, soybeans, wheat, and other crops; 21.3 percent forest; 15.9 percent Crop Reserve Program (CRP); 14.1 percent forest/pasture, pasture/forest, orchard, and pasture; 7.2 percent grass; 6 percent residential; 2 percent golf course; 0.8 percent urban; 0.8 percent water; and 0.6 percent industrial. Thus, up to nearly 60 percent of the land use should be characterized by low pesticide application. In order to maintain water quality within the area, it would be advantageous to continue programs such as the CRP and to limit residential/urban construction and the installation of septic systems.

- On the basis of land use, an estimate of the input of chemicals by subbasins was determined. Standard application rates for commonly used pesticides and fertilizers were obtained in part from the White River Co-Op and in part from product labels. A pesticide and inorganic fertilizer loading estimate was compiled using this information.

ACKNOWLEDGMENTS

This work, conducted by the personnel of the Indiana Geological Survey and the Department of Geological Sciences at Indiana University, was funded in part by the U.S. Fish and Wildlife Services and the Indiana Department of Environmental Management. In addition to these two agencies, the project participants worked cooperatively with the Division of State Parks (especially personnel at Spring Mill State Park), Division of Fish and Wildlife, Division of Nature Preserves, and Soil Conservation (Lakes and Rivers), all divisions of the Department of Natural Resources; the State Chemist; the Water Quality Survey and Standards Branch, Environmental Health Laboratory, Indiana Department of Health; the Natural Resources Conservation Service (U.S.D.A.) in Lawrence and Orange Counties; Indiana Karst Conservancy; the Hoosier Environmental Council; and of course, with the landowners.

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REFERENCES CITED

Bayless, E.R., Taylor, C.J., and Hopkins, M.S., 1994, Directions of ground-water flow and locations of ground-water divides in the Lost River watershed near Orleans, Indiana: U.S. Geological Survey Water-Resources Investigations Report 94-4195, 25 p.

Bolton, D.W., 1980, Water chemistry of springs in the St. Louis Limestone, Lawrence County, Indiana: Bloomington, Indiana University, A.M. thesis, 100 p.

Buehler, M.A. and Hasenmueller, N.R., 2000, Water quality and karst hydrogeology of the Spring Mill Lake drainage basin *in* Improving and Protecting Water Quality: Assessment, Regulation, and Policy: Proceedings of the 21st Annual Water Resources Symposium of the Indiana Water Resources Association convened June 14-16, 2000 at Spring Mill State Park, Mitchell, Indiana, p. 36.

Comer, J.B., Ennis, M.V., Branam, T.D., Smith, R.T., Hahn, L., and Beebe, R., 1999, Quality Assurance Project Plan for potential nonpoint source contamination of the Spring Mill Lake drainage basin: ARN-176: Indiana Geological Survey Open-file Study 99-11, unnumbered.

Crawford, C.G., 1997, Trends in acetochlor concentrations in surface waters of the White River Basin, Indiana, 1994-96: U.S. Geological Survey Fact Sheet 058-97, 4 p.

Faulkenburg, A., Frankenberger, J., and Dickey, M., 2000, Development and validation of a watershed inventory tool *in* Improving and Protecting Water Quality: Assessment, Regulation, and Policy: Proceedings of the 21st Annual Water Resources Symposium of the Indiana Water Resources Association convened June 14-16, 2000 at Spring Mill State Park, Mitchell, Indiana, 11 p.

Field, M.S., Wilhelm, R.G., and Quinlan, J.F., unpublished manuscript circa 1992, Selection, toxicity, and use of fluorescent dyes for tracing ground ware in karst and fractured rock aquifers: 1. What is safe, why, where, and when: Unpublished report to the U.S. Environmental Protection Agency, 45 p.

Gray, H.H., 2000, Physiographic divisions of Indiana: Indiana Geological Survey Special Report 61, 15 p.

Harding, S.B., ed., 1904, Indiana University--1820-1904: Historical Sketch, Development of the Course of Instruction, Bibliography: Bloomington, Indiana University, 348 p.

Hasenmueller, N.R., Rexroad, J.B., Powell, R.L., Buehler, M.A., and Bassett, J.L., 2000, Karst geology, hydrology, and water quality in the Spring Mill Lake and Lost River drainage basins in southern Indiana: Indiana Geological Survey Open-file Study 99-10, 33 p.

Keith, J.H., Bassett, J.L., and Duwelius, J.A., 1997, Findings from MOU-related karst studies for Indiana State Road 37, Lawrence County, Indiana, *in* Beck, B.F., and Stephenson, J.B., eds., The Engineering Geology and Hydrogeology of Karst Terranes: Proceedings of the Sixth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Springfield, Missouri, p. 157-171.

McDuffee, R., 2000, An assessment of pesticide concentrations in the Upper Wabash River Basin *in* Improving and Protecting Water Quality: Assessment, Regulation, and Policy: Proceedings of the 21st Annual Water Resources Symposium of the Indiana Water Resources Association convened June 14-16, 2000 at Spring Mill State Park, Mitchell, Indiana, p. 7.

Quinlan, J.F., 1989, Ground-water monitoring in karst terranes: Recommended protocols and implicit assumptions: U.S. Environmental Protection Agency, Environmental Monitoring Laboratory, Las Vegas, Nevada, EPA/600/X-89/050, 79 p. [Draft: Final version to be released in 1992.]

Turco, R. Brouder, S., Nakatsu, C., Frankenberger, J., Harbor, J., Thomas, G., and Oliver, L., 2000, *Escherichia coli* in the Indiana environment *in* Improving and Protecting Water Quality: Assessment, Regulation, and Policy: Proceedings of the 21st Annual Water Resources Symposium of the Indiana Water Resources Association convened June 14-16, 2000 at Spring Mill State Park, Mitchell, Indiana, p. 9.

U.S. Environmental Protection Agency, 1986, Ambient water quality criteria for bacteria-1986: U.S. Environmental Protection Agency 440-5-86-007.

Wells, E.R. and Krothe, N.C., 1989, Seasonal fluctuation in $\delta^{15}N$ of groundwater nitrate in a mantled karst aquifer due to macropore transport of fertilizer-derived nitrate: Journal of Hydrology, v. 112, p. 191-201.