GEOLOGICAL SURVEY OF ALABAMA

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WATER QUALITY AND BIOLOGICAL MONITORING IN BOBCAT AND MATTHEWS CAVES, REDSTONE ARSENAL, ALABAMA, 1990-2007

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By

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with field investigations and geochemical analyses by
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WATER QUALITY AND BIOLOGICAL MONITORING IN BOBCAT AND MATTHEWS CAVES, REDSTONE ARSENAL, ALABAMA, 1990-2007

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ABSTRACT

Basic water chemistry from October 2006 through September 2007 remained relatively unchanged in Bobcat Cave compared to previous years. Concentrations of chloride and sulfate, parameters typically associated with increased urbanization in a watershed, remained elevated over previous years in both caves. The maximum concentrations of cadmium, chromium, and lead remained low in 2006 and 2007 from higher levels observed in earlier years. The yearly rate of detection for these three trace metals also declined or were level with detection rates from previous years. Additional water-quality sampling in Muddy Cave, which supports a population of Alabama cave shrimp, indicated possible contamination from urban and(or) agricultural sources. Water levels in bobcat Cave cave permitted access for biological monitoring on eight occasions and cave shrimp were observed during six visits. Only 1 of 15 shrimp observed had oocytes or attached ova. The highest number of shrimp observed was 7 on June 28, 2007. Only 2 shrimp were observed in August, when the most sightings generally occur. This low shrimp count was likely related to the effects of a record drought which prompted shrimp migration to lower levels as they escaped the loss of pool habitat.

INTRODUCTION

The Alabama cave shrimp, *Palaemonias alabamae* Smalley, 1961, is a rare, troglobitic shrimp protected since 1988 by the U.S. Fish and Wildlife Service (USFWS) under the Endangered Species Act (USFWS, 1988). It was last observed at the type locality, Shelta Cave in northwest Huntsville, in 1973. Subsequent sightings were at Bobcat Cave on the U.S. Army's Redstone Arsenal (RSA) in southwest Madison County, in a series of three hydrologically connected caves in southeast Madison County (Rheams and others, 1994), and in another cave in Colbert County near the Tennessee River (B. Kuhajda, personal communication).

The Endangered Species Act and the Recovery Plan (USFWS, 1996) for the Alabama cave shrimp provide for protection and study of the species on federal property, and to that end numerous studies have been conducted to monitor the population and its habitat in Bobcat Cave and vicinity (Moser and Rheams, 1992; Rheams and others, 1994; Campbell and others, 1996; McGregor and O'Neil, 1996, 2000, 2001, 2002, 2003, 2004, 2006; McGregor, O'Neil, and Campbell, 1997, 1999; McGregor, O'Neil, Rheams, and others, 1997; McGregor, O'Neil, and Gillett, 2005). These studies increased our knowledge of the recharge area of Bobcat Cave, long-term trends in water quality in Bobcat and Matthews Caves, seasonal water levels in Bobcat Cave, the quality and relationships of local surface and ground waters, and the life history and population trends of the Alabama cave shrimp. Results have been summarized in two publications (Burnett and others, 2003; McGregor and others, 2003). Two other cave shrimp populations are known: one was recently discovered in Muddy Cave south of Huntsville near the Tennessee River and the other is from Colbert County, approximately 70 miles to the west of RSA. Morphological differences between specimens from the Colbert County population and the Alabama cave shrimp suggest the need for a systematic revision of the genus.

In 2006, the Geological Survey of Alabama (GSA) was contracted by RSA to continue monitoring the Alabama cave shrimp population in Bobcat Cave, to report on its life history and population trends, and to monitor water-quality trends in Bobcat, Matthews, and Muddy Caves. This report summarizes the results of these studies.

ACKNOWLEDGMENTS

Many individuals assisted with field work, provided valuable technical assistance, and otherwise contributed to the completion of this project. Danny Dunn of the Cultural and Environmental Resources Directorate coordinated access to Bobcat Cave. Bill Longgrear of RSA provided rainfall data for the Bobcat Cave vicinity. Dan Augenbaugh of RSA and his staff provided information regarding laser testing in the area near Bobcat Cave. Brett Smith of GSA assisted with field work. TTL, Inc. was contracted for volatile organic carbon analyses.

STUDY AREA

The study area is located near the western boundary of Redstone Arsenal, a U.S. Army facility in west-central Madison County, Alabama. Land in the immediate vicinity of the cave was formerly used as a cattle pasture. Implementation of a management plan for the cave shrimp within the past few years has resulted in retirement of the pasture as graze, and hardwood saplings have been planted throughout the area around Bobcat Cave. Urbanization is rapidly encroaching along Zeirdt Road from the west. Redstone Arsenal is located within the Tennessee Valley district of the Highland Rim section of the Interior Low Plateaus physiographic province.

This district is characterized by a plateau of moderate relief, composed of a chert belt to the north and a limestone plain along the Tennessee River with elevations ranging from approximately 600 to 800 feet above mean sea level (ft-msl) (Sapp and Emplaincourt, 1975). Some isolated hills or mountains up to 1,000 feet in elevation occur in this district in Madison County. Bobcat Cave is located within the limestone plain near the Tennessee River at an elevation of about 590 ft-msl.

Muddy Cave is located south of Huntsville just west of U.S. Hwy. 431 near the Tennessee River. The entrance is low and narrow on the side of a small sinkhole on the southwest side of a small knoll. The passageway transitions from walking to crawling to several static pools after passing through several narrow passages. Mud near the pooled water was plastic and deep and water surfaces typically had a thin layer of silt and clay on the surface (Rheams and others, 1992).

The study area is underlain predominantly by thick sequences of carbonate rocks that generally dip to the south at approximately 20 feet per mile. Ground-water movement is generally from north to south throughout the area, although localized and often complex disruptions of this southerly flow pattern may occur. The Tennessee River ultimately controls the direction of ground-water flow in the study area. The Tennessee River, which forms the southern boundary of Madison County, is the dominant surface-water feature in the area. Throughout Madison County, all surface-water systems flow in a general southerly direction and eventually discharge into the Tennessee River.

METHODS

Water samples were collected monthly in Bobcat and Matthews Caves beginning in October 2006 and ending in September 2007. Samples were also collected monthly in Muddy Cave but sampling was terminated after the July sample because the water table receded below the sample collection point. Chemical analyses of water samples were conducted in accordance with U.S. Environmental Protection Agency (USEPA 1973, 1983, 1988, 1990, 1991), Fishman and Friedman (1989), Greenberg and others (1992), and Wershaw and others (1987). Water samples were collected in accordance with the Standard Operating Procedures and Quality Assurance Manual of Alabama Department of Environmental Management (December 1986) and the Quality Assurance-Quality Control Plan for GSA (O'Neil and Meintzer, 1995).

The following parameters were measured *in situ* for each sample. Dissolved oxygen was measured in milligrams per liter (mg/L) using a Yellow Springs Instruments

(YSI) Model 55 dissolved-oxygen meter. Hydrogen-ion concentration, specific conductance (measured in micro Siemens per centimeter (µS/cm)), and temperature were measured with a Horiba Water Checker Model U-10. Total residual chlorine was measured colorimetrically with a HACH Pocket Colorimeter II chlorine test kit. A collected sample was inoculated with a standard reagent powder pillow, allowed to stand for 3 to 5 minutes for the reaction to occur, then compared against a stream blank in the standardized color-comparison wheel. All meters were regularly checked against similar instruments in the GSA geochemical laboratory or against standard calibration solutions.

An integrated grab sample of water was collected monthly at each cave, and the following raw and filtered (0.45µm) individual samples were transported in Nasco whirl-pak sterilized bags, polyethylene bottles, or glass bottles to the GSA geochemical laboratory for analysis: one 18-ounce (oz) raw water bag, one 4-oz filtered-untreated bag, two 4-oz filtered-chilled bags (4˚C), one 4-oz filtered-acidified (pH <2.0 with sulfuric acid) bag, one filtered-acidified (pH <2.0 with nitric acid) sample in a white polyethylene bottle, one raw-basic (pH >10 with NaOH) sample in a brown polyethylene bottle, one acidified (pH < 2.0 with sulfuric acid) raw sample in a small amber glass bottle, one raw sample in a 1-liter white polyethylene bottle, two disposable BOD (biochemical oxygen demand) bottles, one small amber glass bottle for GSA pesticides, and three small clear glass VOC (volatile organic compounds) bottles. These samples were analyzed for the parameters listed in table 1. In addition to standard inorganic constituents, samples were also analyzed for a suite of VOC's by an ADEM approved private laboratory for the constituents listed in table 1.

Biological monitoring consisted of monthly visual observations of the aquatic environment in Bobcat Cave when existing water levels permitted access and the recording of information regarding cave shrimp, such as number observed on each visit, seasonality of reproduction, and fecundity. Each visit involved walking along the margins of subterranean pools when water levels were low, or wading through pools when necessary, and recording each shrimp observed. Information such as observer, time, date, unit of effort expended, and ambient condition was recorded in addition to life history notes such as relative size (if appreciably different from an average cave shrimp) and presence or absence and number of oocytes or attached ova, if possible. Observations usually took 15 minutes to 1 hour to accomplish per trip, with a mean observation time of 45 minutes. No shrimp were handled due to their diminutive size

Table 1. Water-quality parameters, lower limits of detection, and analytical methods.

Parameter	Units	Lower limit of detection	Method [1]
Temperature	°C	--	Electrometric, field
Dissolved oxygen	mg/L	0.1	Electrometric, field
BOD 5-day	mg/L	0.1	Incubation, electrometric, EPA 405.1
Total residual chlorine	mg/L	0.02	Colorimetric, APHA 4500-Cl G
pH	units	--	Electrometric, field
Carbon dioxide-free	mg/L	1	Calculated, APHA 4500-CO2 D
Alkalinity	mg/L as $CaCO_3$	3	Colorimetric, EPA 310.2
Hardness	mg/L as $CaCO_3$	1	Calculated, USGS I-1340-85
Specific conductance	$\mu S/cm^2$	1	Electrometric, field
Total dissolved solids	mg/L	10	Gravimetric, USGS I-1750-85
Silica	mg/L	0.05	ICP, EPA 200.7
Calcium	mg/L	0.01	ICP, EPA 200.7
Magnesium	mg/L	0.04	ICP, EPA 200.7
Sodium	mg/L	0.05	ICP, EPA 200.7
Potassium	mg/L	0.5	ICP, EPA 200.7
Sulfate	mg/L	0.06	Ion chromatography, EPA 300.0
Chloride	mg/L	0.05	Ion chromatography, EPA 300.0
Fluoride	mg/L	0.02	Ion chromatography, USGS I-2057-85
Bicarbonate	mg/L	1	Calculated, APHA 4500-CO2 D
Carbonate	mg/L	1	Calculated, APHA 4500-CO2 D
Ammonia as N	mg/L	0.02	Colorimetric, USGS I-2522-85
Total Kjeldahl nitrogen	mg/L	0.1	Colorimetric, EPA 351.2
Nitrite as N	mg/L	0.01	Ion chromatography, EPA 300.0
Nitrite as NO_2	mg/L	0.03	Ion chromatography, EPA 300.0
Nitrate as N	mg/L	0.020	Ion chromatography, EPA 300.0
Nitrate as NO_3	mg/L	0.09	Ion chromatography, EPA 300.0
Total nitrate-nitrite as N	mg/L	0.020	Ion chromatography, EPA 300.0
Total nitrate-nitrite as NO_3	mg/L	0.09	Ion chromatography, EPA 300.0
Total phosphorus as P	mg/L	0.020	Colorimetric, EPA 365.1
Orthophosphate as PO_4	mg/L	0.02	Ion chromatography, EPA 300.0
Total suspended solids	mg/L	4	Gravimetric, USGS I-3765-85
Aluminum	$\mu g/L$	60	ICP, EPA 200.7
Antimony	$\mu g/L$	3.0	Graphite-furnace atomic absorption, EPA 200.9
Arsenic	$\mu g/L$	2	Graphite-furnace atomic absorption, EPA 200.9
Barium	$\mu g/L$	2.0	ICP, EPA 200.7
Beryllium	$\mu g/L$	1	ICP, EPA 200.7
Boron	$\mu g/L$	10	ICP, EPA 200.7
Bromide	mg/L	0.05	Ion chromatography, EPA 300.0
Cadmium	$\mu g/L$	4.0	ICP, EPA 200.7
Chromium	$\mu g/L$	8	ICP, EPA 200.7
Cobalt	$\mu g/L$	7	ICP, EPA 200.7
Copper	$\mu g/L$	8	ICP, EPA 200.7
Iron	$\mu g/L$	3	ICP, EPA 200.7
Lead	$\mu g/L$	2	Graphite-furnace atomic absorption, EPA 200.9
Lithium	$\mu g/L$	5	ICP, EPA 200.7
Manganese	$\mu g/L$	2	ICP, EPA 200.7
Mercury	$\mu g/L$	0.06	Cold vapor atomic absorption, USGS I-2462-85
Molybdenum	$\mu g/L$	20	ICP, EPA 200.7

1-APHA-American Public Health Association; EPA-Environmental Protection Agency: USGS-U.S. Geological Survey;
GF-graphite funace; GCMS-gas chromatography-mass spectrometry; ICP-inductively coupled plasma spectrometry

Table 1. Water-quality parameters, lower limits of detection, and analytical methods--continued.

Parameter	Units	Lower limit of detection	Method [1]
Nickel	µg/L	10	ICP, EPA 200.7
Selenium	µg/L	3	Graphite-furnace atomic absorption, EPA 200.9
Silver	µg/L	10	ICP, EPA 200.7 (GF, EPA 200.9)
Strontium	µg/L	1	ICP, EPA 200.7
Thallium	µg/L	2	Graphite-furnace atomic absorption, EPA 200.9
Tin	µg/L	1	Graphite-furnace atomic absorption, EPA 200.9
Titanium	µg/L	4	ICP, EPA 200.7
Vanadium	µg/L	4	ICP, EPA 200.7
Zinc	µg/L	4	ICP, EPA 200.7
Cyanide, total recoverable	µg/L	0.003	Colorimetric, USGS I-4302-85
Anionic surfactants as MBAS	mg/L	0.025	Colorimetric, APHA 5540 C
Total Petroleum Hydrocarbons	mg/L	0.1	Spectrophotometric, Infrared, EPA 418.1
Chemical oxygen demand	mg/L	30	Colorimetric, EPA 410.4
2,4-D	mg/L	0.7	Immunoassay, EPA 4015
Recoverable phenolics	µg/L	3	Colorimetric, EPA 420.2
Total organic carbon	mg/L	0.4	Combustion, EPA 415.1
1,1,1-Trichloroethane	µg/L	0.5	GCMS, E524.2
1,1,2-Trichloroethane	µg/L	0.5	GCMS, E524.2
1,1-Dichloroethene	µg/L	0.5	GCMS, E524.2
1,2,4-Trichlorobenzene	µg/L	0.5	GCMS, E524.2
1,2-Dichloroethane	µg/L	0.5	GCMS, E524.2
1,2-Dichloropropane	µg/L	0.5	GCMS, E524.2
Benzene	µg/L	0.5	GCMS, E524.2
Carbon tetrachloride	µg/L	0.5	GCMS, E524.2
cis-1,2-Dichloroethene	µg/L	0.5	GCMS, E524.2
Ethylbenzene	µg/L	0.5	GCMS, E524.2
Methylene chloride	µg/L	0.5	GCMS, E524.2
Chlorobenzene	µg/L	0.5	GCMS, E524.2
1,2-Dichlorobenzene	µg/L	0.5	GCMS, E524.2
1,4-Dichlorobenzene	µg/L	0.5	GCMS, E524.2
Styrene	µg/L	0.5	GCMS, E524.2
Trichloroethene	µg/L	0.5	GCMS, E524.2
Tetrachloroethene	µg/L	0.5	GCMS, E524.2
Toluene	µg/L	0.5	GCMS, E524.2
trans-1,2-Dichloroethene	µg/L	0.5	GCMS, E524.2
Vinyl chloride	µg/L	0.5	GCMS, E524.2
Xylenes	µg/L	0.5	GCMS, E524.2
1,1-Dichloropropene	µg/L	0.5	GCMS, E524.2
1,1,1,2-Tetrachloroethane	µg/L	0.5	GCMS, E524.2
1,1,2,2-Tetrachloroethane	µg/L	0.5	GCMS, E524.2
1,1-Dichloroethane	µg/L	0.5	GCMS, E524.2
1,2,3-Trichlorobenzene	µg/L	0.5	GCMS, E524.2
1,2,3-Trichloropropane	µg/L	0.5	GCMS, E524.2
1,2,4-Trimethylbenzene	µg/L	0.5	GCMS, E524.2
1,3-Dichloropropane	µg/L	0.5	GCMS, E524.2
1,3-Dichloropropene	µg/L	0.5	GCMS, E524.2

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GF-graphite funace; GCMS-gas chromatography-mass spectrometry; ICP-inductively coupled plasma spectrometry

Table 1. Water-quality parameters, lower limits of detection, and analytical methods--continued.

Parameter	Units	Lower limit of detection	Method [1]
1,3,5-Trimethylbenzene	µg/L	0.5	GCMS, E524.2
2,2-Dichloropropane	µg/L	0.5	GCMS, E524.2
Bromobenzene	µg/L	0.5	GCMS, E524.2
Bromochloromethane	µg/L	0.5	GCMS, E524.2
Bromodichloromethane	µg/L	0.5	GCMS, E524.2
Bromoform	µg/L	0.5	GCMS, E524.2
Bromomethane	µg/L	0.5	GCMS, E524.2
Chloroethane	µg/L	0.5	GCMS, E524.2
Chloroform	µg/L	0.5	GCMS, E524.2
Chloromethane	µg/L	0.5	GCMS, E524.2
Dibromochloromethane	µg/L	0.5	GCMS, E524.2
Dibromomethane	µg/L	0.5	GCMS, E524.2
Dichlorodifluoromethane	µg/L	0.5	GCMS, E524.2
Hexachlorobutadiene	µg/L	0.5	GCMS, E524.2
Isopropylbenzene	µg/L	0.5	GCMS, E524.2
1,3-Dichlorobenzene	µg/L	0.5	GCMS, E524.2
Methyl tert-butyl ether	µg/L	2	GCMS, E524.2
n-Butylbenzene	µg/L	0.5	GCMS, E524.2
Naphthalene	µg/L	0.5	GCMS, E524.2
n-Propylbenzene	µg/L	0.5	GCMS, E524.2
2-Chlorotoluene	µg/L	0.5	GCMS, E524.2
4-Chlorotoluene	µg/L	0.5	GCMS, E524.2
4-Isopropyltoluene	µg/L	0.5	GCMS, E524.2
sec-Butylbenzene	µg/L	0.5	GCMS, E524.2
tert-Butyl benzene	µg/L	0.5	GCMS, E524.2
Trichlorofluoromethane	µg/L	0.5	GCMS, E524.2

1-APHA-American Public Health Association; EPA-Environmental Protection Agency: USGS-U.S. Geological Survey;
GF-graphite funace; GCMS-gas chromatography-mass spectrometry; ICP-inductively coupled plasma spectrometry

and to avoid physically damaging or unnecessarily stressing individuals. Similar observations have resulted from many sampling efforts varying in intensity and frequency since November 1990. The current sampling effort is intended to provide a tool for the determination of the relative health of the population over time when compared to information gathered during previous studies. Any marked change in the number of cave shrimp observations or observations of gravid females during periods of time when they historically have been observed could then be compared to water-quality or water-level monitoring data taken during the same period to see if a relationship exists.

RESULTS AND DISCUSSION

WATER QUALITY

Twelve sets of water samples each were collected from Bobcat and Matthews Caves from October 2006 through September 2007 (appendix). Water in Bobcat Cave generally has had slightly higher specific conductance, and hence higher dissolved solids content, over the years compared to Matthews Cave (fig. 1), but during 2006 and 2007 conductance was higher in Matthews Cave. The higher dissolved solids content is due to the presence of greater amounts of bicarbonate and calcium dissolved from the surrounding limestone. Other water-quality constituents and/or indicators of contamination, such as chloride, nitrate, and some trace metals, enter the ground water in both caves either through surface runoff directly into the cave or from deeper ground-water sources which eventually also supply water to the caves.

The alkalinity of a solution is defined as its capacity to react with and neutralize acid. The principal components of alkalinity are the dissolved carbon dioxide species carbonic acid, bicarbonate, and carbonate. At the pH values encountered in Bobcat and Matthews Caves, bicarbonate is the dominant form contributing to alkalinity. Contact with limestone, as in Bobcat and Matthews Caves, will generally saturate ground water for both bicarbonate and calcium. Bicarbonate in 2006-07 ranged from 130 to 180 mg/L with a median of 159 mg/L, which was higher than the preceding year in Bobcat Cave, while the median bicarbonate in Matthews at 149 mg/L, and ranging from 137 to 167 mg/L, was also slightly higher than the preceding year (table 2; fig. 1). Yearly median bicarbonate in Bobcat has ranged from a low of 128 mg/L in 2004 to a high of 179 mg/L in 1998, while this parameter in Matthews Cave has ranged from a low of 116 mg/L in

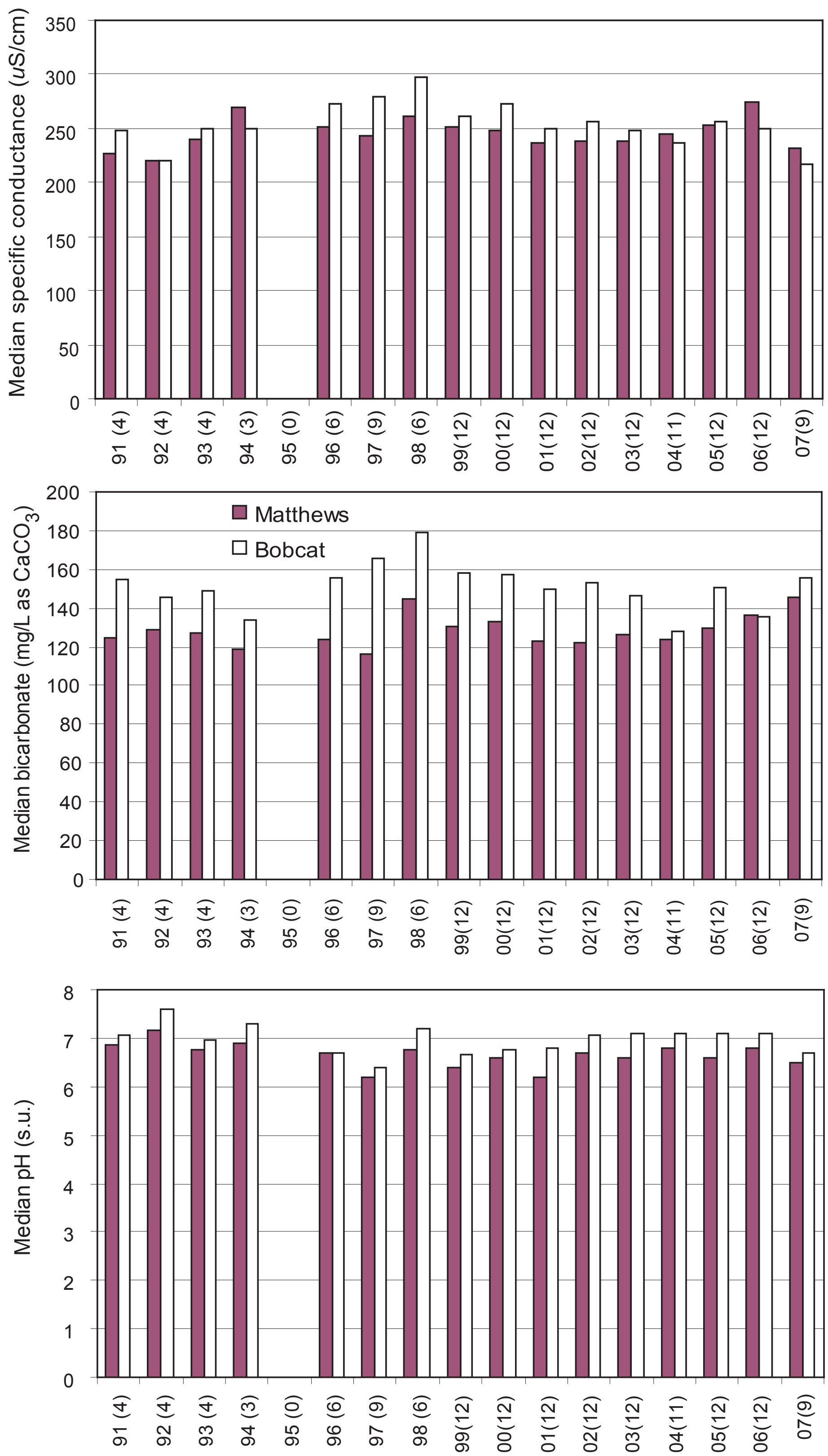

Figure 1. Plots of yearly median specific conductance, bicarbonate, and pH in Bobcat and Matthews Caves, 1991-2007. The number of samples collected each year is shown in parentheses.

Table 2. Summary water-quality data for Bobcat, Matthews, and Muddy Caves, October 2006 through September 2007.

Parameter	Units	Bobcat			Matthews			Muddy		
		min	max	med	min	max	med	min	max	med
Temperature	°C	10	20	17	13	21	18	11	21	17
Dissolved oxygen	mg/L	7.3	9.9	8.6	8.1	9.5	9.0	5.4	9.4	7.0
TRC	mg/L	<.02	0.35	<.02	<.02	1.5	0.06	0.02	0.54	0.08
pH	units	6.2	7.9	6.9	5.7	7.4	6.6	6.6	8.0	7.4
Alkalinity as $CaCO_3$	mg/L	107	148	130	112	137	122	148	192	182
Conductance	μS/cm	192	274	219	221	310	242	275	368	336
TDS	mg/L	92	188	150	149	217	172	193	270	232
Hardness as $CaCO_3$	mg/L	108	150	134	125	151	137	163	236	207
Sulfate	mg/L	0.82	3.15	1.63	3.07	5.31	3.85	7.02	11.70	8.75
Chloride	mg/L	2.28	3.38	2.62	5.28	8.05	6.06	3.82	9.99	6.33
Bromide	mg/L	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02	0.03	0.09	0.05
Silica	mg/L	6.92	8.09	7.51	7.74	8.76	8.12	5.18	6.74	5.79
Bicarbonate	mg/L	130	180	159	137	167	149	180	234	220
Carbonate	mg/L	<1	1	<1	<1	<1	<1	<1	1	<1
Ammonia as N	mg/L	<.02	0.040	0.024	<.02	0.058	0.036	<.02	0.060	0.038
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006	<.006
TKN	mg/L	<.07	0.37	0.21	<.07	0.43	0.13	<.07	0.72	0.23
Nitrate as N	mg/L	0.36	1.04	0.72	2.16	2.78	2.44	0.85	2.19	1.40
Total NOx as N	mg/L	0.36	1.04	0.72	2.16	2.78	2.44	0.85	2.19	1.40
Total phosphorus	mg/L	0.02	0.17	0.07	0.02	0.48	0.07	0.05	0.52	0.12
Orthophosphate as P	mg/L	<.05	0.08	<.05	<.05	<.05	<.05	<.05	0.09	<.05
Arsenic	μg/L	<2	2.2	<2	<2	<2	<2	<2	<2	<2
Barium	μg/L	12.6	45.1	18.6	15.0	50.0	17.1	23.7	61.5	31.1
Cadmium	μg/L	<.09	0.68	<.09	<.09	0.17	<.09	<.09	0.22	<.09
Chromium	μg/L	<.8	2.7	1.6	<.8	1.1	<.8	<.8	1.3	<.8
Copper	μg/L	<5	<5	<5	<5	<5	<5	<5	<5	<5
Iron	μg/L	<4	63.6	2.2	<4	29.8	3.5	<4	63.9	2.1
Lead	μg/L	<.9	2.4	<.9	<.9	2.3	<.9	<.9	1.4	<.9
Lithium	μg/L	<8	<8	<8	<8	<8	<8	<8	<8	<8
Manganese	μg/L	<.8	16.2	<.8	<.8	36.3	1.7	<.8	12.8	1.9
Mercury	μg/L	<.08	0.23	<.08	<.08	0.08	<.08	<.08	4.08	<.08
Molybdenum	μg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20
Nickel	μg/L	<20	23	<20	<20	27	<20	<20	112	<20
Selenium	μg/L	<3	3.6	<3	<3	<3	<3	<3	4.1	<3
Silver	μg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10
Strontium	μg/L	0.5	61.3	51.1	50.4	62.2	55.3	97.8	150	126
Zinc	μg/L	<4	18.2	<4	<4	24.0	6.3	<4	23.2	5.7
TSS	mg/L	<4	5	<4	<4	29	<4	<4	24	<4
Total organic carbon	mg/L	<.4	1.3	<.4	<.4	0.8	<.4	<.4	1.9	<.4
BOD	mg/L	0.1	0.7	0.3	<.1	0.8	0.2	0.2	1.8	0.4
COD	mg/L	33	145	73	<30	181	73	<30	248	71.5
Surfactants (MBAS)	mg/L	<.025	0.034	<.025	<.025	0.038	<.025	<.025	0.050	0.014
Atrazine	μg/L	<.046	<.046	<.046	<.046	0.121	<.046	<.046	0.057	<.046
2,4-D	μg/L	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7	<.7
Phenolics	mg/L	<3	<3	<3	<3	<3	<3	<3	<3	<3
Chloroform	μg/L	<.5	<.5	<.5	<.5	2.66	1.63	<.5	9.56	0.97
Trichloroethene	μg/L	<.5	<.5	<.5	<.5	<.5	<.5	<.5	1.21	<.5
Tetrachloroethene	μg/L	<.5	<.5	<.5	<.5	<.5	<.5	<.5	0.64	<.5

1997 to a high of 144 mg/L in 1998 (fig. 1). The pH of Bobcat Cave waters in 2006-07 ranged from 6.2 to 7.9 (median, 6.9), while pH of Matthews Cave ranged from 5.7 to 7.4 (median, 6.6) for the same period (table 2). Long-term trends of pH in both caves indicate that Matthews Cave waters are slightly more acidic than Bobcat Cave waters, with the median pH varying generally between 6.0 and 7.5 in both caves (fig. 1).

Chlorine is the most abundant of the halogens, and its compounds, which consist of chlorine and the common metallic elements, alkali metals, and alkaline earth metals, are readily soluble in water (Hem, 1989). The chloride form of chlorine is the only oxidation state of significance in water exposed to the atmosphere. The other oxidation states of chlorine are not found in significant quantities in natural waters, and their presence would be the result of contamination from a chlorinated water source. Chloride is present in rock types in concentrations lower than the other major constituents of natural water. As such, chloride concentrations are generally very low in natural fresh waters, and their presence in quantity may indicate contamination. Chloride ranged from 2.28 to 3.38 mg/L (median, 2.62 mg/L) in Bobcat Cave and from 5.28 to 8.05 mg/L (median, 6.06 mg/L) in Matthews Cave (table 2) in 2006-07. The median concentrations of chloride in Matthews Cave have consistently varied in the range of about one and a half to two times the median chloride concentrations in Bobcat Cave over the period 1991 through 2007 (fig. 2), indicating that water in Matthews Cave likely has a greater connectivity to contaminated surface runoff and ground water. Yearly median chloride in Matthews Cave shows a long-term increasing trend, particularly in 2006 and 2007 perhaps related to increasing urbanization in the recharge area.

Sulfate concentrations ranged from 0.82 to 3.15 mg/L (median, 1.63 mg/L) in Bobcat and from 3.07 to 5.31 mg/L (median, 3.85 mg/L) in Matthews (table 2) in 2006-07. Over the period 1991 through 2005, median sulfate concentrations in Bobcat were greater than Matthews (fig. 2), except 1998 when median sulfate was slightly greater in Matthews and in 2006 and 2007 when median sulfate was substantially greater in Matthews. Like chloride, the long-term trend for median sulfate is increasing in Matthews Cave.

The cycling of nitrogen through the atmosphere, hydrosphere, and lithosphere involves complex biological and chemical processes. Nitrogen in water occurs as nitrite

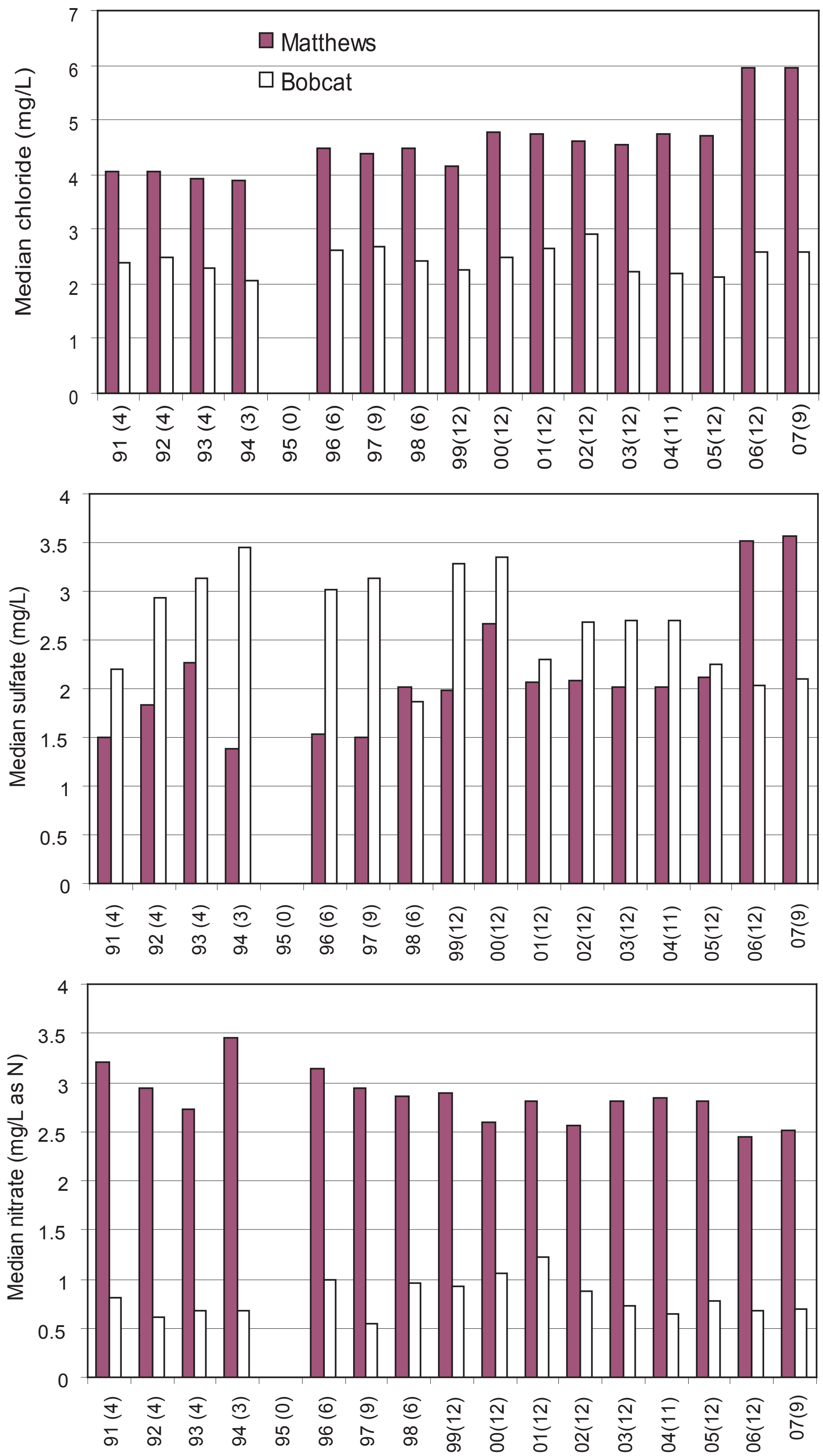

Figure 2. Plots of yearly median chloride, sulfate, and nitrate in Bobcat and Matthews Caves, 1991-2007. The number of samples collected is shown in parentheses.

(NO_2^-) and nitrate (NO_3^-) anions, as ammonium (NH_4^+) cations, and as organic solutes. Nitrate is stable in water over a variety of conditions, particularly in ground water, and is readily transported over long distances. Excessive nitrate concentrations (>10 mg/L NO_3 as N) may cause a condition known as methemoglobinemia in small children. Upon contact with sunlight, excess nitrate can contribute to nuisance algal blooms in surface waters. Nitrate ranged from 0.36 to 1.04 mg/L (median, 0.72 mg/L) in Bobcat and from 2.16 to 2.78 mg/L (median, 2.44 mg/L) in Matthews from 2006-07 (table 2). From 1991-2007, the median nitrate concentrations in Bobcat Cave have averaged from about 0.5 to just over 1.0 mg/L, whereas the median concentrations in Matthews Cave have averaged from around 2.5 to 3.0 mg/L (fig. 2). Ammonia was detected in eight samples from Bobcat Cave in 2006-07 compared to four samples in 2005-06, while ammonia was detected in ten samples from Matthews Cave in 2006-07 (appendix) compared to seven detections in 2005-06. Phosphorus concentrations during 2006-07 were low in each cave with total dissolved phosphorus ranging from 0.02 to 0.17 mg/L in Bobcat Cave and from 0.02 to 0.48 mg/L in Matthews Cave. Median total phosphorus was 0.07 mg/L in both Bobcat and Matthews Caves (table 2).

In natural waters unaffected by pollution, trace metals occur most of the time in low concentrations, generally <1.0 µg/L or undetectable. Elevated trace metal concentrations may indicate the presence of a contaminant source or a nearby ore deposit. Cadmium was detected in 4 of 12 samples taken from Bobcat and Matthews Caves during 2006-07 (appendix). Cadmium concentrations in samples from Bobcat ranged from <0.09 to 0.68 µg/L with a median of <0.09 µg/L, while samples from Matthews Cave ranged from <0.09 to 0.17 µg/L with a median of <0.09 µg/L (table 2) in 2006-07. The drinking water maximum contaminant level (MCL) for cadmium is 5.0 µg/L, the MCL for leachate from sanitary landfills is 10 µg/L, whereas the chronic and acute criteria for protection of aquatic life are 1.13 µg/L and 3.92 µg/L, respectively, calculated using a hardness of 100 mg/L. Data from 1996-2007 indicate the continued presence of cadmium in both Bobcat and Matthews Caves (fig. 3) with cadmium detections averaging 65.5 percent for Bobcat Cave and 64.6 percent for Matthews Cave over this period (table 3). However, the long term trend is decreasing cadmium detections and concentrations in both caves (figs. 3, 4). All samples from Matthews in

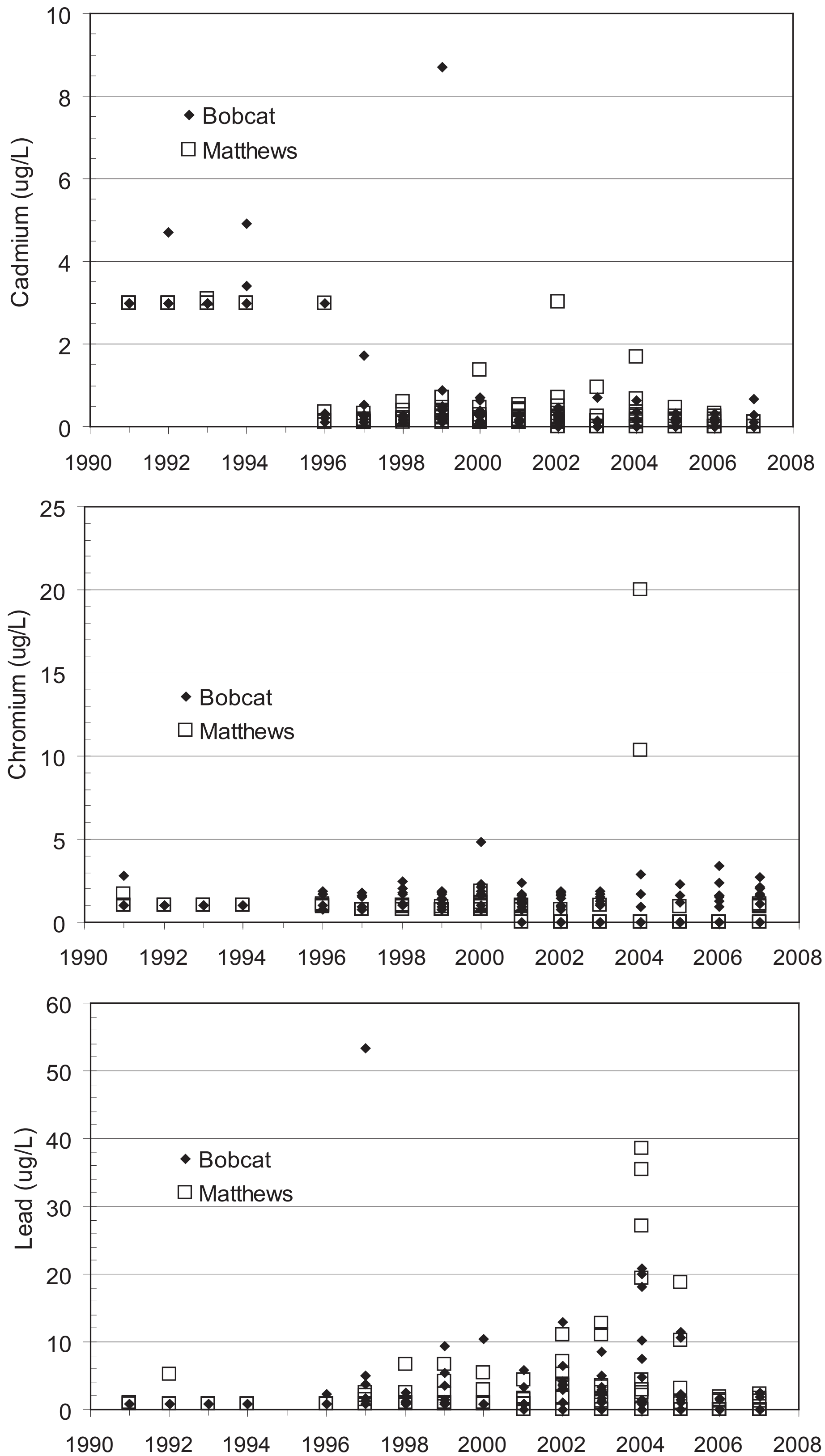

Figure 3. Selected trace metal concentrations of water in Bobcat and Matthews Caves, 1991-2007.

Table 3. Yearly detection rate (percent of samples collected) of selected trace metals in water collected from Bobcat and Matthews Caves, 1996-2007

Year	Sample size	Cadmium		Chromium		Lead	
		Bobcat	Matthews	Bobcat	Matthews	Bobcat	Matthews
1996	6	80	60	60	60	20	0
1997	9	67	67	56	0	89	44
1998	6	100	100	100	67	67	67
1999	12	100	100	75	25	50	42
2000	12	58	58	67	42	8	42
2001	12	75	67	75	25	25	25
2002	12	75	83	67	8	75	75
2003	12	42	42	58	8	83	58
2004	11	64	73	36	18	73	82
2005	12	58	58	25	8	58	42
2006	12	42	50	58	0	17	25
2007	9	25	17	50	33	17	25
Average		65.5	64.6	60.6	24.5	48.5	43.9

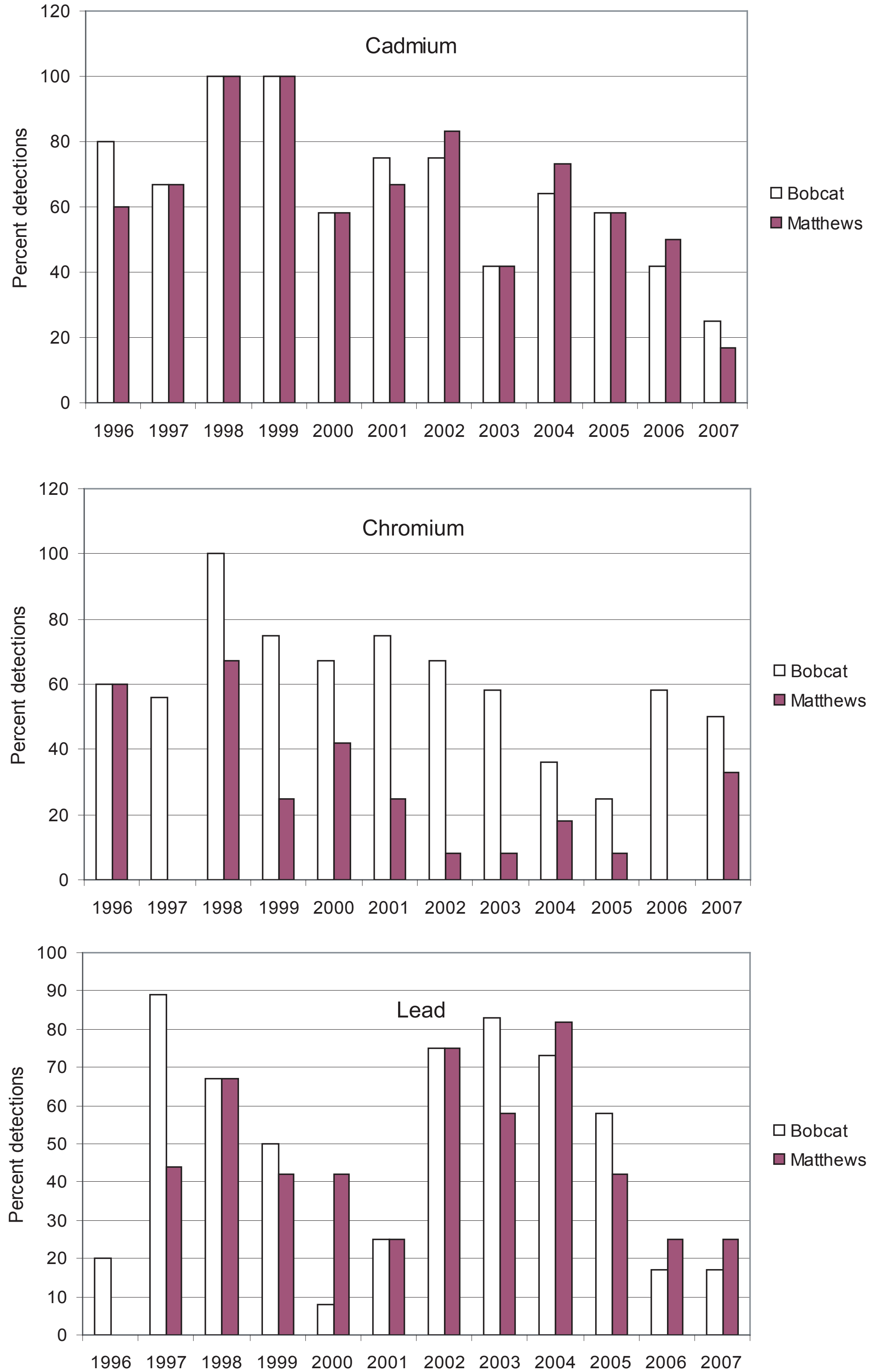

Figure 4. Yearly detection rates of cadmium, chromium, and lead in Bobcat and Matthews Caves, 1996-2007.

the period 1991-1994 were near or below detection limits, while a few detections were made in Bobcat Cave in 1992 and 1994 (fig. 3).

Chromium was detected in 9 of 12 samples from Bobcat Cave in 2006-07 (appendix) and ranged from <0.8 to 2.7 µg/L with a median of <1.6 µg/L (table 2). Chromium was detected in 4 of 12 samples from Matthews Cave. The drinking water MCL for chromium (III) is 100 µg/L, the landfill leachate MCL is 50 µg/L, while the chronic and acute aquatic-life criteria are 207 µg/L and 1,736 µg/L, respectively, for a hardness of 100 mg/L. The number of chromium detections decreased in Bobcat Cave from 1998-2000, rose to 75 percent in 2001, declined steadily to 25 percent in 2005, and has increased in 2006 and 2007 (table 3). Chromium detections in Matthews Cave declined from a high of 67 percent in 1998 to lows of 8 percent in 2002, 2003, and 2005 and 0 percent in 2006 and have recently increased to 33 percent in 2007 (table 3, fig 4). Chromium detections averaged 60.6 percent for Bobcat Cave and 24.5 percent for Matthews Cave during the period 1996-2007 (table 3, fig. 4).

Lead was detected in 2 of 12 samples from Bobcat Cave in 2006-07 (appendix), ranging from <0.9 to 2.4 µg/L with a median of <0.9 µg/L. Lead was detected in 3 of 12 samples from Matthews Cave (appendix), ranging from <0.9 to 2.3 µg/L with a median of <0.9 µg/L (table 2). The drinking water MCL for lead is 15 µg/L, the landfill leachate criterion is 15 µg/L, while the chronic and acute aquatic-life criteria are 3.18 µg/L and 81.6 µg/L, respectively, for a hardness of 100 mg/L. The percentage of lead detections in Bobcat Cave steadily declined from a high of 89 percent in 1997 to 8 percent in 2000 before increasing to 25 percent in 2001, 75 percent in 2002, and 83 percent in 2003 (table 3, fig. 4). Lead detections have since declined progressively in each succeeding year to 73 percent in 2004, 58 percent in 2005, 17 percent in 2006, and 17 percent for nine samples in 2007. The maximum lead values for the past ten years in Bobcat Cave are elevated well above the detection limit: 53 µg/L-1997, 2.5 µg/L-1998, 9.4 µg/L-1999,10.5 µg/L-2000, 5.8 µg/L-2001, 13.0 µg/L-2002, 8.6 µg/L-2003, 20.9 µg/L in 2004, 11.4 µg/L in 2005, 1.6 µg/L in 2006, and 2.4 µg/L through September in 2007. Similarly, the maximum lead values for Matthews Cave the past ten years have also been well above detection limits: 2.5 µg/L-1997, 6.7 µg/L-1998, 6.6 µg/L-1999, 5.4 µg/L-2000, 4.3 µg/L-2001, 11.1 µg/L-2002, 12.7 µg/L-2003, 38.6 µg/L in 2004, 18.7 µg/L in 2005, 1.8

μg/L in 2006, and 2.3 μg/L through September in 2007. Average lead detection between the years 1996 and 2007 is slightly less than 50 percent of all samples collected in each cave (table 3). Maximum lead concentrations have declined steadily since the peak observed in 2004 (fig. 3).

Median levels of several other toxic trace metals measured this year were less than detection limits in both caves and included arsenic, copper, lithium, mercury, molybdenum, nickel, selenium, and silver (table 2). Median zinc in Bobcat Cave was less than the detection limit and was 6.3 μg/L in Matthews Cave. Median manganese was less than detection limit in Bobcat and 1.7 μg/L in Matthews Cave. Median chemical oxygen demand (COD) was the same for both caves, 73 mg/L, while median total phenolics and total organic carbon were both less than detection limits (<3 mg/L and <0.4 mg/L, respectively) in both caves.

Inclusion of Muddy Cave in the water-quality sampling program this year provided additional insight into cave water-quality as affected by urban environments and environments in transition from rural to urban. Figure 5 shows percentile distributions of six water-quality parameters determined for monthly samples collected from October 2006 through September 2007. Dissolved oxygen was markedly lower in Muddy Cave (median-7.0 mg/L) compared to medians of 8.6 mg/L in Bobcat and 9.0 mg/L in Matthews. Chloroform was not detected in Bobcat Cave but was detected in most of the samples from Matthews and Muddy Caves. Chloroform ranged from <0.5 to 2.66 μg/L with a median of 1.63 μg/L in Matthews Cave and from <0.5 to 9.56 μg/L with a median of 0.97 μg/L in Muddy Cave (table 2). Median total dissolved solids was significantly greater in Muddy at 232 mg/L compared to 150 and 172 mg/L for Bobcat and Matthews. Median nitrate was greatest in Matthews Cave at 2.44 mg/L, lower in Muddy Cave at 1.40 mg/L, and least in Bobcat Cave at 0.72 mg/L. Median total phosphorus was similar among all three caves ranging from 0.07 mg/L in Bobcat to 0.12 mg/L in Muddy. Median chloride was significantly greater in Matthews (6.1 mg/L) and Muddy (6.3 mg/L) Caves compared to Bobcat Cave (2.6 mg/L)(table 2).

Elevated nitrate, chloride, and chloroform and, in the case of Muddy Cave, lower dissolved oxygen, demonstrate that Matthews and Muddy Caves are both affected by contaminated runoff entering these two caves. However, the sources of contaminants to these systems appear different. Matthews Cave receives runoff from a mixed residential/commercial urban area between Madison and Huntsville, while runoff into

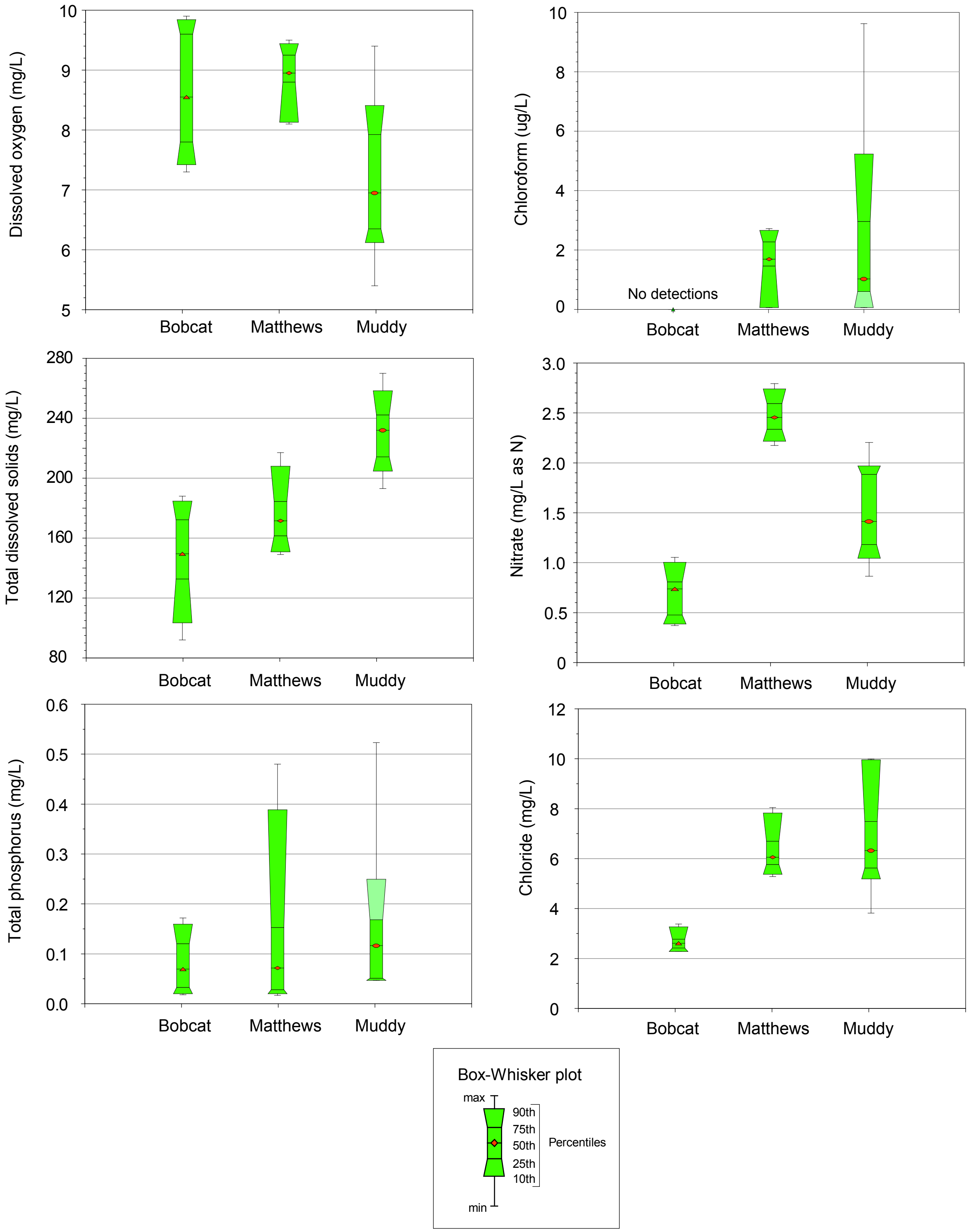

Figure 5. Percentile distributions of selected water-quality constituents in Bobcat, Matthews, and Muddy Caves, October 2006-September 2007.

Muddy Cave is much more localized from pasture, agricultural fields, and a small horse ranch located on the east slope of the knoll covering the Muddy Cave cavity. Cave hydrology in Muddy is likely similar to Bobcat in that water moves in response to increasing ground-water level primarily in the vertical axis while moving much more slowly in the horizontal axis in response to the local ground-water gradient. Water in Matthews Cave moves primarily in the horizontal axis, much like a surface stream, while vertical movements appear restricted to surface flooding events.

Volatile organic compounds, which are used in plastics, cleaning solvents, gasoline, and industrial operations, occur widely in shallow urban ground water. Some of the most frequently detected of the 60 compounds analyzed as part of the U.S. Geological Survey National Water-Quality Assessment (NAWQA) program were the commercial and industrial solvents trichloroethene (TCE), tetrachloroethene (PCE), and methylene chloride; the gasoline additive methyl tert-butyl ether (MTBE); and the solvent and disinfection by-product of water treatment, trichloromethane (also known as chloroform). The presence of chloroform in Matthews and Muddy Caves is a reflection of this national trend and is not unexpected given the urban and urban/agricultural nature of land use in the watersheds surrounding the recharge areas of these caves.

Rowe and others (1997) summarized published toxicity data for chloroform and several other VOC's and reported a *Ceriodaphnia dubia* 48-hr LC_{50} of 290,000 µg/L. They also reported a 7-10 day chronic toxicity, no-observable-effect-concentration (NOEC) of 3,400 µg/L for a chronic reproduction endpoint and 200,000 µg/L for a chronic mortality endpoint for this same species. These authors also reported toxicity studies using *Daphnia magna* as the test organism. The acute 48-hr LC_{50} was 29,000 µg/L and a 7-10 day NOEC value of 6,300 µg/L for a reproduction endpoint and 120,000 µg/L for a mortality endpoint. The U.S. EPA has established 80 µg/L of total trihalomethanes (THM's, which include chloroform, dichlorobromomethane, chlorodibromomethane, and bromoform) as a human health maximum contaminant level (USEPA, 2002).

Chloroform was detected in 80+ percent of the samples collected from both Matthews and Muddy Caves, which indicates it is a persistent contaminant in both systems and occurs in Muddy Cave at elevated concentrations (appendix). Jones (2005) reported that chloroform was detected 47 times out of 111 samples (42 percent) collected in streams receiving treated effluent from part of Atlanta. The maximum chloroform concentration measured was 1.6 µg/L. The aquatic toxicological effects of chloroform to Alabama Cave shrimp cannot be predicted from these data but concentrations do appear much lower than human consumption MCL's and published aquatic toxicity values as well.

CONTINUAL WATER-QUALITY AND WATER-LEVEL MONITORING

An automated water surface elevation, temperature, and specific conductance monitor has operated in Bobcat Cave from November 1992 through September 2007. Results of previous water-level investigations in and around Bobcat Cave (McGregor, O'Neil, and Campbell, 1997) indicate that the hydrology of Bobcat Cave is likely controlled by two distinct factors: (1) ground water originating in the soils and karst terrane around the cave, and (2) the degree to which Bobcat Cave is connected to the land surface by direct conduits through which surface runoff enters the cave during storm events.

Plots of daily parameter measurements for specific conductance, temperature, and surface water elevation are depicted in figure 6, along with daily rainfall records provided by RSA. The rainfall station is located about 5 miles to the southeast of Bobcat Cave. Some of the rainfall events, particularly isolated summer storms, cannot be directly correlated with rising water level in Bobcat Cave. However, widespread rains, as occur from fall through spring months, do correlate with rising water levels in the cave.

Average water level in Bobcat Cave is highest from January through May and lowest from August through October (fig. 6). Rising ground water during winter months increases the base level of Bobcat Cave by approximately 6 feet, from 575 ft-msl to around 581 ft-msl. Runoff associated with storm fronts can temporarily raise the surface elevation another 5 feet to the maximum level of 586 feet (fig. 6). Water exits through fissures and cracks generally to the east of Bobcat Cave at 585 to 586 feet. Monthly variation of water level is highest from November through April, when Bobcat receives greater quantities of surface runoff. Water is present only in isolated pools and windows at 575 feet. Water level in Bobcat Cave averaged 578.8 ft-msl over the period 1993 through 2007.

Bobcat Cave has a very stable water temperature regime throughout the year, averaging 14.2˚C from 1993-2007. Temperature generally varies 2˚C throughout the

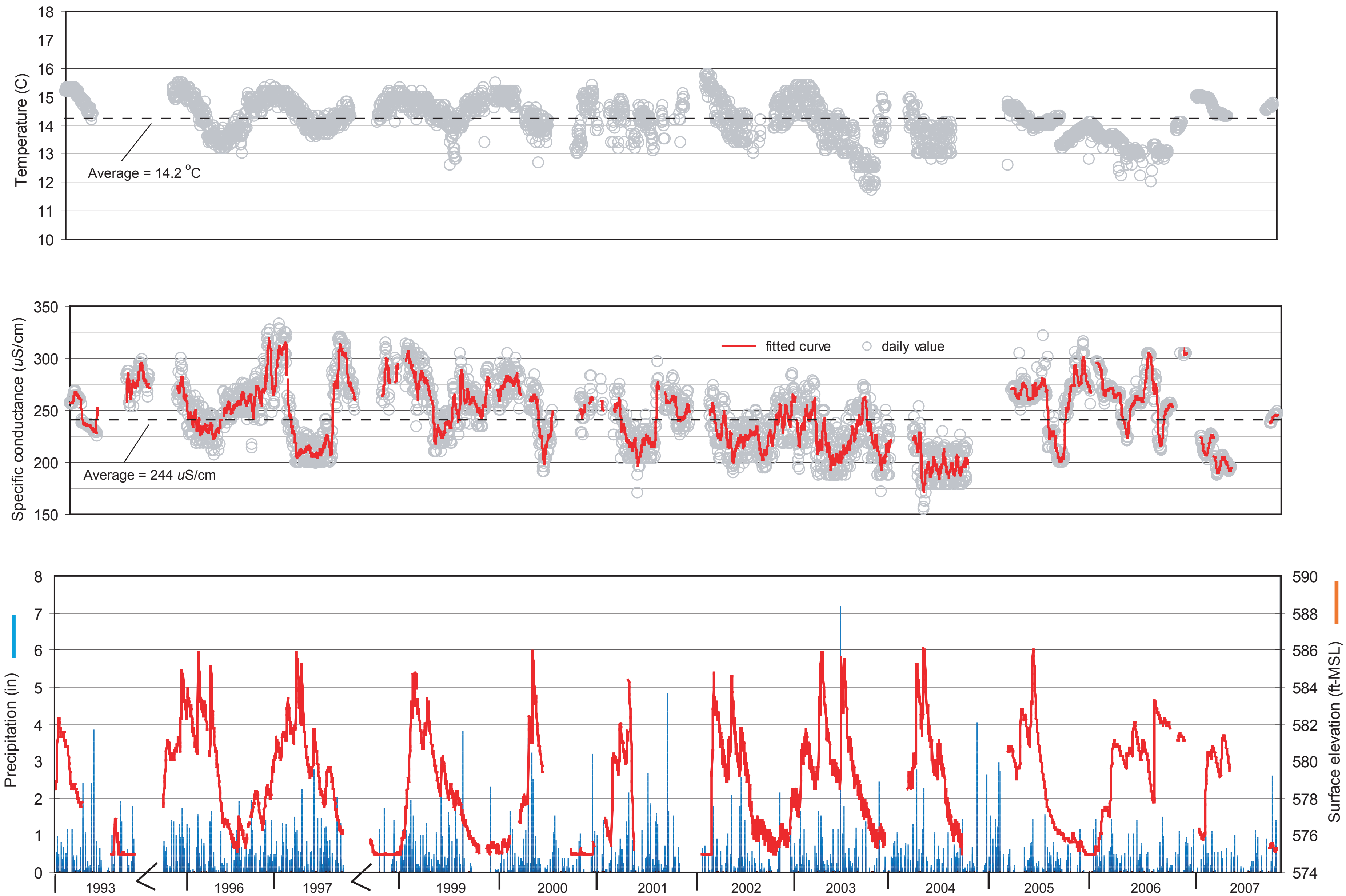

Figure 6. Daily water-quality monitoring data for Bobcat Cave, 1993-2007.

year, ranging from around 13˚C to around 15˚C (fig. 6). The highest average monthly water temperature occurs in November and December, while the lowest occurs in May. The water temperature regime in Bobcat Cave appeared to be vulnerable to flooding effects of surface-water runoff. Several storm events (July 1996, May 1999, April 2000 and 2001, May 2002, September 2003) briefly lowered temperature by 0.5 to 1.0˚C below the average for that time of year with rapid recovery to ambient water temperature.

The quality of ground water in Bobcat Cave is controlled by several mechanisms including surface runoff into the cave, solubility conditions between the surrounding limestone and water, and quality of ground water from deep aquifers that contribute to the cave's water supply. Average specific conductance from 1993 through 2007 was 244 µS/cm, ranging from 155 to 333 µS/cm (fig. 6). Specific conductance spikes occurred when cave waters were low and rapidly received surface runoff from summer and fall storms. A significant jump in average specific conductance from May to June may indicate a transitional period during the annual hydrologic cycle when deeper ground water with a higher mineral content begins to dominate Bobcat Cave's water supply.

BIOLOGICAL MONITORING

Bobcat Cave was visited monthly from October 2006 to September 2007 (table 4). On four occasions (January to April) the cave was filled by high ground-water levels, and no observations of cave shrimp were possible beyond the foot of the entrance slope. Cave shrimp were observed during six of eight visits when the cave was accessible and a total of 15 shrimp were observed. The highest number of shrimp observed was seven on June 28, 2007, including the only shrimp with what appeared to be oocytes or attached ova (table 4, fig. 7). August generally produces the most sightings of cave shrimp in Bobcat Cave, but this year only two were observed during that month, likely due to extremely low water levels due to a continuing severe drought.

Information concerning long-term trends in the shrimp population in Bobcat Cave (1990 to present) is found in figure 7. June, July, and August are the months when shrimp observations are most prevalent, each month having yielded 40 or more shrimp in one or more visits. The upper graph provides a comparison of monthly shrimp

Table 4.-- Chronological list of recent Alabama cave shrimp observations in Bobcat Cave, November 1990-September 2007.

Date	Number observed	Notes[1]
November, 10, 1990	0	
November 11, 1990	0	
December 12, 1990	3	
December 16, 1990	18	
July 22, 1991	51	Unknown number females with oocytes or attached ova
July 24, 1991	0	
August 16, 1991	40	At least 15 females with oocytes or attached ova
August 17, 1991	0	
August 21, 1991	16	Three females with oocytes or attached ova
September 11, 1991	2	
September 16, 1991	2	
September 18, 1991	4	
September 20, 1991	1	
October 4, 1991	0	
October 28, 1991	30	Four females with oocytes or attached ova
November 14, 1991	1	
November 29, 1991	2	
December 9, 1991	0	
March 11, 1992	0	
May 6, 1992	0	
May 7, 1992	0	
May 15, 1992	1	Reportedly 44 mm long with “black spot” on back
May 25, 1992	1	Female with large oocytes or attached ova, 44-48 mm long
June 8, 1992	0	
June 12, 1992	0	
July 21, 1992	0	
October 8, 1992	12	One female with about 15 oocytes or attached ova
October 14, 1992	7	Lengths range from 22-29 mm
October 21, 1992	13	Lengths range from 22.7-29.4 mm

Table 4.-- Chronological list of recent Alabama cave shrimp observations in Bobcat Cave, November 1990-September 2007—continued.

Date	Number observed	Notes[1]
October 21, 1992	13	Lengths range from 22.7-29.4 mm
October 26, 1992	9	One female with oocytes or attached ova; one juvenile?
November 4, 1992	7	Lengths range from 22-27.2 mm
November 10, 1992	0	
November 17, 1992	0	
March 3, 1993	0	
April 13, 1993	0	
June 8, 1993	0	
June 23, 1993	8	
June 30, 1993	2	
July 9, 1993	5	One female with oocytes or attached ova and one juvenile(?) not measured; others range 20-25 mm
July 14, 1993	11	Three females with oocytes or attached ova not measured; remainder range 16-28 mm
July 23, 1993	0	
August 5, 1993	0	
August 10, 1993	0	
August 20, 1993	0	
August 25, 1993	5	Three measured ranged 12 to 14 mm, two measured were about 25 mm
September 3, 1993	8	
September 12, 1993	10	Eight measured were <13 mm; two measured were about 25 mm
September 13, 1993	10	
September 23, 1993	4	Lengths range 17-24 mm
September 30, 1993	11	No gravid females
October 8, 1993	1	
October 13, 1993	2	Each was <13 mm
October 22, 1993	1	
October 28, 1993	3	One of the three measured 22 mm
November 2, 1993	2	Lengths range 20-22 mm
November 11, 1993	1	

Table 4.-- Chronological list of recent Alabama cave shrimp observations in Bobcat Cave, November 1990-September 2007—continued.

Date	Number observed	Notes[1]
November 22, 1993	0	
November 24, 1993	1	15 mm
November 30, 1993	2	Each measured 23 mm
December 10, 1993	2	One measured 18 mm
December 15, 1993	2	
February 14, 1994	0	
July 21, 1994	0	
June 4, 1996	5	In window where water monitoring probes are located
July 12, 1996	5	Observed from foot of entrance slope to window where water monitoring probes are located
July, 1996	14	One shrimp had “at least three eggs” according to Warren Campbell and students from University of Alabama, Huntsville
November 11, 1996	1	At foot of entrance slope; unknown sex
June 12, 1997	1	Unknown sex
July 14, 1997	0	
July 31, 1997	12	Three females with oocytes or attached ova
August 7, 1997	20	Three females with oocytes or attached ova
July 21, 1998	0	Water very low, restricted to isolated pools
August 14, 1998	0	
August 18, 1998	80	Observed throughout the cave during low water; 18 shrimp had oocytes or attached ova; 85 minutes collecting time
October 15, 1998	17	Observed throughout the cave; three had oocytes or attached ova and one was small enough to be considered a juvenile.
November 10, 1998	0	
December 16, 1998	9	Water level up from November sample but not sumped-no gravid females observed.
January 11, 1999	0	No shrimp observed; cave passage sumped
February 17, 1999	0	No shrimp observed; cave passage sumped
March 10, 1999	0	No shrimp observed; cave passage sumped
April 27, 1999	0	No shrimp observed; cave passage sumped
May 7, 1999	0	No shrimp observed; cave passage sumped; 2.5-inch rain caused turbid conditions in cave
May 24, 1999	0	

Table 4.-- Chronological list of recent Alabama cave shrimp observations in Bobcat Cave, November 1990-September 2007—continued.

Date	Number observed	Notes[1]
June 16, 1999	0	
July 8, 1999	20	Observed throughout the cave, though effort was hampered by presence of cold water up to 4 feet deep in the shrimp room. No gravid females observed.
August 17, 1999	112	Observed throughout cave-10 females with oocytes or attached ova.
September 23, 1999	14	Two gravid females observed; water level very low.
October 26, 1999	4	Restricted to shrimp window.
November 15, 1999	3	Very low water.
December 15, 1999	4	All in shrimp window, 1 with unknown number of oocytes or attached ova.
January 18, 2000	3	Water unseasonably low; no gravid females observed.
February 15, 2000	0	
March 21, 2000	0	
April 15, 2000	0	
May 11, 2000	0	
June 12, 2000	40	No shrimp with oocytes or attached ova.
July 19, 2000	40	One shrimp with unknown number of oocytes or attached ova.
August 22, 2000	26	Five shrimp with unknown number of oocytes or attached ova; very low water level; one deceased raccoon (*Procyon lotor*).
September 26, 2000	2	Water levels still exceedingly low; both shrimp observed had oocytes or attached ova.
October 31, 2000	27	Eight with oocytes or attached ova.
November 14, 2000	9	One with oocytes or attached ova.
December 20, 2000	0	About 2' airspace, cave not searched past entrance slope.
January 18, 2001	5	Five shrimp observed; water level down drastically from December.
February 14, 2001	0	No shrimp; cave sumped
March 20, 2001	0	High water; no shrimp observed
April 12, 2001	0	High water; no shrimp observed
May 17, 2001	1	Cave near sumped; one cave shrimp observed at foot of entrance slope
June 11, 2001	0	No counts made due to high water

Table 4.-- Chronological list of recent Alabama cave shrimp observations in Bobcat Cave, November 1990-September 2007—continued.

Date	Number observed	Notes[1]
July 24, 2001	10	10 shrimp observed, though water level relatively high; observed by R. Blackwood, K. Roe, and B. Kuhajda; no shrimp with oocytes or attached ova; four collected for DNA study
August 23, 2001	13	13 shrimp observed, one with about 10 oocytes or attached ova; water relatively high for the season
September 27, 2001	27	Two shrimp with oocytes or attached ova; 46 crayfish and 42 southern cavefish observed in one-hour sample
October 30, 2001	0	No shrimp observed
November 28, 2001	1	No ova observed, 2/3 of cave observed
December 20, 2001	0	Cave sumped; no shrimp observed at foot of entrance slope
January 17, 2002	0	Cave sumped; no shrimp observed at foot of entrance slope
February 13, 2002	0	Cave sumped; no shrimp observed at foot of entrance slope
March 25, 2002	0	Cave sumped; no shrimp observed at foot of entrance slope
April 15, 2002	0	Cave sumped; no shrimp observed at foot of entrance slope
May 21, 2002	0	Cave sumped; no shrimp observed at foot of entrance slope
June 14, 2002	6	Observed from foot of entrance slope to opening to shrimp room; all with oocytes or attached ova
July 25, 2002	7	Seven shrimp observed, none with oocytes or attached ova; water lower than June visit
August 21, 2002	5	Five shrimp observed
September 18, 2002	5	Five shrimp observed, none with oocytes or attached ova; water low, and generally covered in a fine film of flocculents
October 28, 2002	11	Eleven shrimp observed in about 20 minutes; about half with oocytes or attached ova
November 20, 2002	0	Water level higher than October; observed 15 minutes at foot of entrance slope
December 18, 2002	0	Cave sumped
January 23, 2003	0	Cave sumped
February 26, 2003	0	Cave sumped
March 25, 2003	0	Cave sumped
April 24, 2003	0	Cave sumped
May 28, 2003	0	Cave sumped
June 24, 2003	0	Cave sumped

Table 4.-- Chronological list of recent Alabama cave shrimp observations in Bobcat Cave, November 1990-September 2007—continued.

July 24, 2003	0	Water level near ceiling of cave at entrance to shrimp room
August 8, 2003	0	Water level only slightly lower than July
September 24, 2003	3	Water level low enough to access rear of cave; no shrimp with oocytes or attached ova observed
October 15, 2003	1	One cave shrimp observed, also 19 crayfish and 10 cave fish; no oocytes or attached ova
November 20, 2003	0	No shrimp observed; isolated pools
December 23, 2003	0	No shrimp observed; cave passage nearly sumped
January 22, 2004	0	No shrimp observed; cave passage nearly sumped
February 19, 2004	0	No shrimp observed; cave passage sumped
March 19, 2004	0	No shrimp observed; cave passage sumped
April 22, 2004	0	No shrimp observed
May 22, 2004	0	No shrimp observed
June 16, 2004	1	One cave shrimp observed along with three crayfish
July 27, 2004	10	Ten shrimp observed along with 15 southern cavefish and 34 crayfish
August 2004	0	No observation
September 21, 2004	0	No shrimp observed; cave passage sumped
October 27, 2004	0	No shrimp observed; cave passage sumped
November 23, 2004	0	No shrimp observed; cave passage sumped
December 21, 2004	0	No shrimp observed; cave passage sumped
January 21, 2005	0	No shrimp observed; cave passage sumped
February 24, 2005	0	No shrimp observed; cave passage sumped
March 24, 2005	0	No shrimp observed; cave passage sumped
April 26, 2005	0	No shrimp observed; cave passage sumped
May 2005	0	Water level much lower, but no shrimp observed
June 21, 2005	30	Six with oocytes or attached ova
July 21, 2005	0	Water low; crayfish observed
August 17, 2005	10	One with oocytes or attached ova; water reduced to isolated pools
September 20, 2005	15	Five with oocytes or attached ova; water reduced to isolated pools; sampled with Bryan Phillips of RSA
October 12, 2005	12	Four with oocytes or attached ova in 30 minutes sampling time; low water level
November 16, 2005	1	Tiny, perhaps newly hatched; 15 minutes sampling time

Table 4.-- Chronological list of recent Alabama cave shrimp observations in Bobcat Cave, November 1990-September 2007—continued.

Date	Number observed	Notes[1]
December 15, 2005	0	Cave sumped
January 18, 2006	0	Cave sumped
February 16, 2006	0	Cave sumped
March 2006	0	Cave sumped
April 19, 2006	0	Water level almost to cave roof
May 11, 2006	0	Cave sumped
June 28, 2006	19	Three with oocytes or attached ova; 45 minutes sampling time; sampled with Bryan Phillips of Redstone Arsenal
July 18, 2006	22	None with visible oocytes or attached ova; 45 minutes sampling time; sampled with Sydney DeJarnette
August 23, 2006	5	Possibly one with oocytes or attached ova; 20 minutes sampling time; water extremely low due to drought
September 20, 2006	1	Very low water due to drought; 15 minutes of sampling time; no shrimp with oocytes or attached ova
October 16, 2006	1	Very low water due to drought, 15 minutes of sampling time; no shrimp with oocytes or attached ova
November 14, 2006	1	Very low water due to drought, 30 minutes of sampling time; no shrimp with oocytes or attached ova
December 19, 2006	2	Water level still low but higher than November; 30 minutes sampling time; no shrimp with oocytes or attached ova
January 25, 2007	0	Water level too high for access; no observations of shrimp attempted
February 14, 2007	0	Water level too high for access; no observations of shrimp attempted
March 12, 2007	0	Water level too high for access; no observations of shrimp attempted
April 16, 2007	0	Water level too high for access; no observations of shrimp attempted
May 10, 2007	2	Water level still higher than optimum but accessible; 15 minutes of sampling time; no shrimp with oocytes or attached ova
June 28, 2007	7	Water level low; 15 minutes sampling time; 1 shrimp with oocytes or attached ova
July 26, 2007	0	Water level low; 15 minutes sampling time
August 23, 2007	2	Water level low; 20 minutes sampling time; no shrimp with oocytes or attached ova
September 18, 2007	0	Water level extremely low with only a few extremely isolated pools 1-3 inches in depth; 25 minutes sampling time

[1]- measurements=total length including rostrum

observations and the total number of observation trips into the cave, as well as the average monthly surface water elevation. The reason that relatively large numbers of shrimp are observed during June through August is likely related to low water levels during those months. However, the lowest average monthly water elevation occurs in September, when counts have never risen above 27 individuals observed in one visit. We suspect a behavioral trait such as migration to deeper ground water with receding water level to prevent individuals from becoming stranded in isolated pools. As shown in the upper graph of figure 7, shrimp have been observed in almost every visit in September, probably a result of some shrimp that didn't escape to the lower level and became stranded. As stated before, shrimp have never been observed in Bobcat Cave during the months of February through April, due to the fact that the cave is inaccessible during that period. Shrimp have only been observed on four occasions during the collective months of May probably due to restricted access. The inverse may be true for the fall and winter months, when the water level begins rising with seasonal rainfall. Conditions for observations are generally good at this time, but the shrimp are still inaccessible and therefore relatively few are observed.

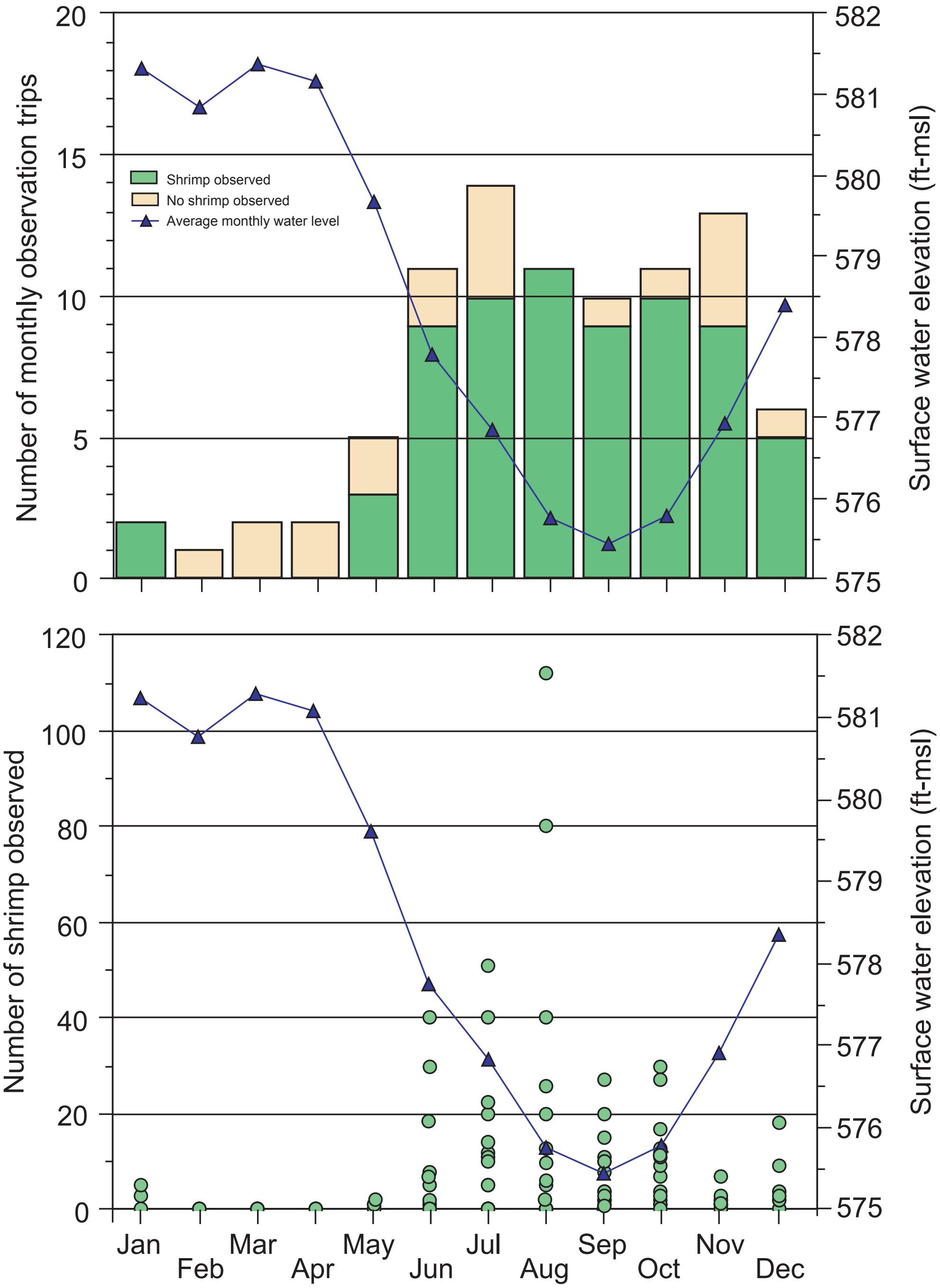

Figure 7. Shrimp observations and counts in Bobcat Cave, 1990-2007.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results found in this and previous studies of Bobcat and Matthews Caves, we make the following recommendations:

> Monitoring of the shrimp population within the cave should be continued, and information should be gathered and compiled into the existing database to monitor population trends.
>
> Monitoring of the physical and chemical properties of cave waters should continue with special attention placed on the levels and trends of potential toxins, such as lead, cadmium, and chloroform, and other parameters associated with urban runoff. Increasing urbanization around RSA will likely affect ground water, which may have consequences for Bobcat Cave and the resident Alabama cave shrimp population. The quality of surface runoff into Bobcat Cave from the local watershed should be monitored occasionally during storm events to document any changes in the quality of surface waters entering the cave.

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APPENDIX

Water-quality sampling data
2006-2007

Site Date	Units	Bobcat 16-Oct-06	Bobcat 14-Nov-06	Bobcat 19-Dec-06	Bobcat 25-Jan-07	Bobcat 14-Feb-07	Bobcat 12-Mar-07
Time	24-hr	12:35	13:35	11:10	11:00	10:30	11:15
Temperature	°C	15	17	16	14	10	16
Dissolved oxygen	mg/L	7.8	7.8	8.8	9.4	9.6	8.3
Total residual chlorine	mg/L	<.02	0.35	0.16	<.02	<.02	0.03
pH	units	6.3	7.9	7.7	6.4	6.6	7.0
Alkalinity as $CaCO_3$	mg/L	145	136	119	107	115	118
Specific conductance	µS/cm	274	234	203	192	211	205
Total dissolved solids	mg/L	145	155	92	131	130	144
Hardness as $CaCO_3$	mg/L	150	138	126	108	112	122
Sulfate	mg/L	0.82	1.95	1.31	2.1	2.5	3.15
Chloride	mg/L	3.38	2.65	3.01	2.41	2.46	2.28
Bromide	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Silica	mg/L	8.09	7.45	7.29	7.09	6.92	7.67
Bicarbonate	mg/L	177	165	144	130	140	144
Carbonate	mg/L	<1	1	<1	<1	<1	<1
Ammonia as N	mg/L	0.04	<.02	0.034	0.022	0.024	0.033
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Total Kjeldahl nitrogen	mg/L	0.22	0.25	0.24	0.2	0.09	0.24
Nitrate as N	mg/L	1.040	0.570	0.784	0.686	0.589	0.406
Total NOx as N	mg/L	1.040	0.570	0.784	0.686	0.589	0.406
Total phosphorus	mg/L	0.04	0.07	0.07	0.08	0.13	0.02
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Arsenic	µg/L	<2	<2	<2	<2	<2	2.2
Barium	µg/L	37.3	17.2	21.1	36.2	43.1	12.6
Cadmium	µg/L	<.09	<.09	0.11	<.09	<.09	<.09
Chromium	µg/L	2.4	1.3	1.6	<.8	1.1	<.8
Copper	µg/L	<5	<5	<5	<5	<5	<5
Iron	µg/L	5.8	4.7	<4	<4	4.3	<4
Lead	µg/L	<.9	<.9	<.9	<.9	<.9	<.9
Lithium	µg/L	<8	<8	<8	<8	<8	<8
Manganese	µg/L	<.8	<.8	<.8	<.8	<.8	<.8
Mercury	µg/L	<.08	<.08	<.08	0.23	<.08	<.08
Molybdenum	µg/L	<20	<20	<20	<20	<20	<20
Nickel	µg/L	23	<20	<20	<20	<20	<20
Selenium	µg/L	<3	<3	<3	<3	<3	<3
Silver	µg/L	<10	<10	<10	<10	<10	<10
Strontium	µg/L	59.3	55.6	47.8	<.5	44.7	46.1
Zinc	µg/L	<4	6.4	6.3	18.2	17.7	<4
Total suspended solids	mg/L	<4	<4	<4	<4	5	<4
Total organic carbon	mg/L	<.4	<.4	<.4	<.4	<.4	<.4
Biochemical oxygen demand	mg/L	0.4	0.5	0.1	0.3	0.1	0.1
Chemical oxygen demand	mg/L	59	74	74	132	72	45
Surfactants (MBAS)	mg/L	<.025	<.025	<.025	<.025	<.025	0.025
Atrazine	µg/L	<.046	<.046	<.046	<.046	<.046	<.046
2,4-D	µg/L	<.7	<.7	<.7	<.7	<.7	<.7
Phenolics	mg/L	<3	<3	<3	<3	<3	<3
Chloroform	µg/L	<.5	<.5	<.5	<.5	<.5	<.5
Trichloroethene	µg/L	<.5	<.5	<.5	<.5	<.5	<.5
Tetrachloroethene	µg/L	<.5	<.5	<.5	<.5	<.5	<.5

Site Date	Units	Bobcat 16-Apr-07	Bobcat 10-May-07	Bobcat 28-Jun-07	Bobcat 26-Jul-07	Bobcat 23-Aug-07	Bobcat 18-Sep-07
Time	24-hr	11:40	11:40	10:45	14:10	9:50	12:45
Temperature	°C	16	20	17	20	19	18
Dissolved oxygen	mg/L	9.6	9.9	9.7	7.32	7.7	7.9
Total residual chlorine	mg/L	0.02	0.101	<.02	<.02	0.02	<.02
pH	units	7.3	7.4	6.2	7.6	6.7	6.7
Alkalinity as $CaCO_3$	mg/L	120	132	128	133	141	148
Specific conductance	μS/cm	209	217	220	228	236	254
Total dissolved solids	mg/L	138	158	154	177	177	188
Hardness as $CaCO_3$	mg/L	122	136	133	140	136	146
Sulfate	mg/L	2.75	2.59	1.09	0.92	0.82	0.94
Chloride	mg/L	2.29	2.58	2.65	2.79	2.74	2.57
Bromide	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Silica	mg/L	7.35	7.56	7.39	8.07	7.82	7.82
Bicarbonate	mg/L	146	161	156	162	172	180
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.025	0.024	0.026	<.02	<.02	<.02
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Total Kjeldahl nitrogen	mg/L	0.37	0.31	<.07	0.07	<.07	<.07
Nitrate as N	mg/L	0.426	0.357	0.760	0.798	0.774	0.875
Total NOx as N	mg/L	0.426	0.357	0.760	0.798	0.774	0.875
Total phosphorus	mg/L	0.17	0.03	0.10	0.03	0.04	0.13
Orthophosphate as P	mg/L	<.05	0.08	<.05	<.05	<.05	<.05
Arsenic	μg/L	<2	<2	<2	<2	<2	<2
Barium	μg/L	13.2	45.1	18.2	19.0	15.8	16.7
Cadmium	μg/L	<.09	<.09	0.09	<.09	0.28	0.68
Chromium	μg/L	1.6	1.7	2.7	2	2.1	<.8
Copper	μg/L	<5	<5	<5	<5	<5	<5
Iron	μg/L	<4	<4	<4	63.6	10.7	17.6
Lead	μg/L	1.8	<.9	2.4	<.9	<.9	<.9
Lithium	μg/L	<8	<8	<8	<8	<8	<8
Manganese	μg/L	<.8	16.2	2.2	6.7	<.8	<.8
Mercury	μg/L	<.08	<.08	<.08	<.08	<.08	<.08
Molybdenum	μg/L	<20	<20	<20	<20	<20	<20
Nickel	μg/L	<20	<20	<20	<20	<20	<20
Selenium	μg/L	3.6	<3	<3	<3	<3	<3
Silver	μg/L	<10	<10	<10	<10	<10	<10
Strontium	μg/L	48.1	51.3	50.9	53.4	52.6	61.3
Zinc	μg/L	<4	16.4	<4	6	<4	<4
Total suspended solids	mg/L	<4	<4	<4	<4	4	<4
Total organic carbon	mg/L	<.4	<.4	<.4	<.4	1.34	0.75
Biochemical oxygen demand	mg/L	0.4	0.1	0.2	0.1	0.7	0.3
Chemical oxygen demand	mg/L	135	35	145	71	33	87
Surfactants (MBAS)	mg/L	0.027	<.025	0.034	0.034	<.025	0.029
Atrazine	μg/L	<.046	<.046	<.046	<.046	<.046	<.046
2,4-D	μg/L	<.7	<.7	<.7	<.7	<.7	<.7
Phenolics	mg/L	<3	<3	<3	<3	<3	<3
Chloroform	μg/L	<.5	<.5	<.5	<.5	<.5	<.5
Trichloroethene	μg/L	<.5	<.5	<.5	<.5	<.5	<.5
Tetrachloroethene	μg/L	<.5	<.5	<.5	<.5	<.5	<.5

Site Date	Units	Matthews 16-Oct-06	Matthews 14-Nov-06	Matthews 19-Dec-06	Matthews 25-Jan-07	Matthews 14-Feb-07	Matthews 12-Mar-07
Time	24-hr	15:30	12:30	12:15	12:15	12:00	10:20
Temperature	°C	16	17	17	14	13	18
Dissolved oxygen	mg/L	9.3	8.9	8.8	9.5	9.14	8.2
Total residual chlorine	mg/L	1.5	0.06	<.02	0.05	0.06	0.03
pH	units	7.2	6.5	7.4	6.5	7.2	7.3
Alkalinity as $CaCO_3$	mg/L	131	120	124	114	124	120
Specific conductance	µS/cm	252	284	229	231	230	229
Total dissolved solids	mg/L	159	169	174	217	155	169
Hardness as $CaCO_3$	mg/L	151	133	144	125	137	131
Sulfate	mg/L	5.31	4.65	4.2	3.86	4.07	3.32
Chloride	mg/L	7.32	8.05	6.08	5.58	5.94	5.73
Bromide	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Silica	mg/L	8.16	8.02	8.04	7.74	7.92	8.06
Bicarbonate	mg/L	159	146	151	139	151	146
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.047	0.024	0.05	0.036	0.058	0.027
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Total Kjeldahl nitrogen	mg/L	0.26	0.08	0.3	0.4	0.07	<.07
Nitrate as N	mg/L	2.380	2.300	2.160	2.580	2.780	2.600
Total NOx as N	mg/L	2.380	2.300	2.160	2.580	2.780	2.600
Total phosphorus	mg/L	0.05	0.13	0.10	0.09	0.16	0.02
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Arsenic	µg/L	<2	<2	<2	<2	<2	<2
Barium	µg/L	37.4	16.7	22.1	36.2	16.0	15.0
Cadmium	µg/L	0.17	<.09	0.12	<.09	<.09	<.09
Chromium	µg/L	<.8	<.8	<.8	<.8	<.8	<.8
Copper	µg/L	<5	<5	<5	<5	<5	<5
Iron	µg/L	6.9	<4	<4	7.7	7.5	<4
Lead	µg/L	<.9	<.9	<.9	<.9	<.9	<.9
Lithium	µg/L	<8	<8	<8	<8	<8	<8
Manganese	µg/L	<.8	2.1	36.3	5.9	<.8	2
Mercury	µg/L	<.08	0.08	<.08	0.08	<.08	<.08
Molybdenum	µg/L	<20	<20	<20	<20	<20	<20
Nickel	µg/L	27	<20	<20	<20	<20	<20
Selenium	µg/L	<3	<3	<3	<3	<3	<3
Silver	µg/L	<10	<10	<10	<10	<10	<10
Strontium	µg/L	62.2	55.6	55	50.4	53.8	51.2
Zinc	µg/L	<4	9.2	6	15.5	9.4	<4
Total suspended solids	mg/L	<4	5	<4	<4	<4	<4
Total organic carbon	mg/L	<.4	<.4	<.4	<.4	<.4	<.4
Biochemical oxygen demand	mg/L	0.3	0.3	0.2	0.8	0.1	0.2
Chemical oxygen demand	mg/L	66	39	123	154	<30	89
Surfactants (MBAS)	mg/L	<.025	<.025	<.025	<.025	0.026	0.038
Atrazine	µg/L	<.046	<.046	<.046	<.046	<.046	<.046
2,4-D	µg/L	<.7	<.7	<.7	<.7	<.7	<.7
Phenolics	mg/L	<3	<3	<3	<3	<3	<3
Chloroform	µg/L	2.66	2.07	2.26	1.55	1.35	1.59
Trichloroethene	µg/L	<.5	<.5	<.5	<.5	<.5	<.5
Tetrachloroethene	µg/L	<.5	<.5	<.5	<.5	<.5	<.5

Site Date	Units	Matthews 16-Apr-07	Matthews 10-May-07	Matthews 28-Jun-07	Matthews 26-Jul-07	Matthews 23-Aug-07	Matthews 18-Sep-07
Time	24-hr	10:25	10:30	11:45	12:30	8:15	10:20
Temperature	°C	18	20	19	21	21	20
Dissolved oxygen	mg/L	9	9.1	9.3	8.9	8.8	8.1
Total residual chlorine	mg/L	0.09	0.11	<.02	0.1	0.04	0.07
pH	units	6.2	7.3	5.7	6.7	6.4	6.5
Alkalinity as $CaCO_3$	mg/L	112	118	127	114	137	127
Specific conductance	µS/cm	221	231	252	310	256	257
Total dissolved solids	mg/L	149	169	175	180	187	186
Hardness as $CaCO_3$	mg/L	126	133	148	143	147	137
Sulfate	mg/L	3.07	3.57	3.33	3.54	3.84	3.88
Chloride	mg/L	5.28	6.04	5.88	6.12	6.74	6.58
Bromide	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Silica	mg/L	8.22	8.22	8.11	8.74	8.12	8.76
Bicarbonate	mg/L	137	144	155	139	167	155
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.036	0.02	<.02	0.047	0.037	<.02
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Total Kjeldahl nitrogen	mg/L	0.43	0.2	0.17	<.07	0.09	<.07
Nitrate as N	mg/L	2.580	2.510	2.310	2.360	2.380	2.500
Total NOx as N	mg/L	2.580	2.510	2.310	2.360	2.380	2.500
Total phosphorus	mg/L	0.18	0.03	0.48	0.04	0.03	0.03
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Arsenic	µg/L	<2	<2	<2	<2	<2	<2
Barium	µg/L	15.4	50.0	16.4	19.3	17.5	16.4
Cadmium	µg/L	<.09	<.09	0.1	0.11	<.09	<.09
Chromium	µg/L	0.9	1.1	<.8	1	0.9	<.8
Copper	µg/L	<5	<5	<5	<5	<5	<5
Iron	µg/L	<4	7.1	<4	11.2	29.8	<4
Lead	µg/L	1.7	<.9	<.9	2.3	<.9	1.2
Lithium	µg/L	<8	<8	<8	<8	<8	<8
Manganese	µg/L	<.8	2.6	1.4	17.9	<.8	<.8
Mercury	µg/L	<.08	<.08	<.08	<.08	<.08	<.08
Molybdenum	µg/L	<20	<20	<20	<20	<20	<20
Nickel	µg/L	<20	<20	<20	<20	<20	<20
Selenium	µg/L	<3	<3	<3	<3	<3	<3
Silver	µg/L	<10	<10	<10	<10	<10	<10
Strontium	µg/L	51.2	53.1	58.4	57.5	58.3	61
Zinc	µg/L	<4	24	6.6	10.2	<4	<4
Total suspended solids	mg/L	7	<4	<4	29	<4	<4
Total organic carbon	mg/L	<.4	<.4	<.4	<.4	0.68	0.76
Biochemical oxygen demand	mg/L	0.4	0.1	0.2	0.4	0.1	<.1
Chemical oxygen demand	mg/L	181	53	59	130	73	73
Surfactants (MBAS)	mg/L	<.025	0.036	0.033	<.025	<.025	<.025
Atrazine	µg/L	<.046	<.046	<.046	<.046	0.121	<.046
2,4-D	µg/L	<.7	<.7	<.7	<.7	<.7	<.7
Phenolics	mg/L	<3	<3	<3	<3	<3	<3
Chloroform	µg/L	1.67	2.46	1.56	1.68	<.5	<.5
Trichloroethene	µg/L	<.5	<.5	<.5	<.5	<.5	<.5
Tetrachloroethene	µg/L	<.5	<.5	<.5	<.5	<.5	<.5

Site Date	Units	Muddy 16-Oct-06	Muddy 14-Nov-06	Muddy 19-Dec-06	Muddy 25-Jan-07	Muddy 14-Feb-07	Muddy 12-Mar-07
Time	24-hr	16:45	15:30	14:40	13:20	14:15	13:10
Temperature	°C	15	17	17	11	12	18
Dissolved oxygen	mg/L	8.3	8.1	7.2	9.4	7.43	6.2
Total residual chlorine	mg/L	nd	0.02	0.02	0.17	0.12	0.08
pH	units	7.3	7.9	7.6	6.6	7.5	8.0
Alkalinity as $CaCO_3$	mg/L	178	174	190	160	181	182
Specific conductance	µS/cm	317	324	353	310	330	342
Total dissolved solids	mg/L	211	231	270	206	224	233
Hardness as $CaCO_3$	mg/L	200	207	236	182	191	208
Sulfate	mg/L	8.56	8.96	10.8	7.91	8.79	8.57
Chloride	mg/L	5.34	6.02	9.96	5.62	7.36	7.53
Bromide	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	0.039	0.08	0.032	0.046	0.054	0.049
Silica	mg/L	5.62	5.29	6.51	5.18	5.95	6.43
Bicarbonate	mg/L	217	211	231	195	220	220
Carbonate	mg/L	<1	1	1	<1	<1	1
Ammonia as N	mg/L	0.032	<.02	0.055	0.021	0.047	0.043
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Total Kjeldahl nitrogen	mg/L	0.31	0.14	0.38	<.07	0.08	0.32
Nitrate as N	mg/L	1.160	1.190	1.840	1.930	2.190	1.880
Total NOx as N	mg/L	1.160	1.190	1.840	1.930	2.190	1.880
Total phosphorus	mg/L	0.05	0.13	0.11	0.13	0.18	0.05
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Arsenic	µg/L	<2	<2	<2	<2	<2	<2
Barium	µg/L	44.2	23.7	48.8	36.1	58.1	24.1
Cadmium	µg/L	<.09	<.09	0.14	<.09	<.09	<.09
Chromium	µg/L	<.8	<.8	<.8	<.8	<.8	<.8
Copper	µg/L	<5	<5	<5	<5	<5	<5
Iron	µg/L	4.7	<4	4.1	12.3	<4	<4
Lead	µg/L	<.9	<.9	<.9	<.9	<.9	<.9
Lithium	µg/L	<8	<8	<8	<8	<8	<8
Manganese	µg/L	<.8	1.4	4.3	8.8	<.8	<.8
Mercury	µg/L	4.08	0.46	<.08	<.08	<.08	<.08
Molybdenum	µg/L	<20	<20	<20	<20	<20	<20
Nickel	µg/L	23	112	<20	<20	<20	<20
Selenium	µg/L	<3	<3	<3	<3	<3	<3
Silver	µg/L	<10	<10	<10	<10	<10	<10
Strontium	µg/L	125	125	150	97.8	129	127
Zinc	µg/L	<4	<4	12.2	11.3	23.2	<4
Total suspended solids	mg/L	<4	<4	8	9	<4	24
Total organic carbon	mg/L	<.4	<.4	<.4	<.4	<.4	<.4
Biochemical oxygen demand	mg/L	0.2	0.4	0.7	0.4	0.3	0.2
Chemical oxygen demand	mg/L	77	66	134	248	<30	48
Surfactants (MBAS)	mg/L	<.025	<.025	<.025	<.025	0.05	0.034
Atrazine	µg/L	0.057	<.046	<.046	<.046	0.048	<.046
2,4-D	µg/L	<.7	<.7	<.7	<.7	<.7	<.7
Phenolics	mg/L	<3	<3	<3	<3	<3	<3
Chloroform	µg/L	1.58	0.65	4.68	0.52	1.28	0.61
Trichloroethene	µg/L	<.5	<.5	1.21	<.5	0.78	<.5
Tetrachloroethene	µg/L	<.5	<.5	0.64	<.5	<.5	<.5

Site Date	Units	Muddy 16-Apr-07	Muddy 10-May-07	Muddy 28-Jun-07	Muddy 26-Jul-07
Time	24-hr	13:25	14:30	13:45	16:30
Temperature	°C	15	19	21	20
Dissolved oxygen	mg/L	6.3	5.4	6.7	6.5
Total residual chlorine	mg/L	0.54	0.05	0.17	0.02
pH	units	6.9	7.2	7.1	7.4
Alkalinity as $CaCO_3$	mg/L	148	188	187	192
Specific conductance	µS/cm	275	357	362	368
Total dissolved solids	mg/L	193	234	245	257
Hardness as $CaCO_3$	mg/L	163	221	215	219
Sulfate	mg/L	7.02	10.2	8.71	11.7
Chloride	mg/L	3.82	5.64	6.63	9.99
Bromide	mg/L	<.05	<.05	<.05	<.05
Fluoride	mg/L	0.064	0.038	0.047	0.092
Silica	mg/L	5.25	5.33	6.06	6.74
Bicarbonate	mg/L	180	229	228	234
Carbonate	mg/L	<1	<1	<1	<1
Ammonia as N	mg/L	0.049	0.06	<.02	<.02
Nitrite as N	mg/L	<.006	<.006	<.006	<.006
Total Kjeldahl nitrogen	mg/L	0.72	0.37	<.07	<.07
Nitrate as N	mg/L	0.850	1.050	1.230	1.570
Total NOx as N	mg/L	0.850	1.050	1.230	1.570
Total phosphorus	mg/L	0.22	0.05	0.52	0.05
Orthophosphate as P	mg/L	<.05	<.05	<.05	0.09
Arsenic	µg/L	<2	<2	<2	<2
Barium	µg/L	23.7	61.5	24.7	26.1
Cadmium	µg/L	<.09	<.09	<.09	0.22
Chromium	µg/L	<.8	<.8	1.3	1
Copper	µg/L	<5	<5	<5	<5
Iron	µg/L	63.9	<4	<4	33.5
Lead	µg/L	1	<.9	1.4	1.1
Lithium	µg/L	<8	<8	<8	<8
Manganese	µg/L	12.8	2.3	1.3	2.5
Mercury	µg/L	<.08	<.08	<.08	<.08
Molybdenum	µg/L	<20	<20	<20	<20
Nickel	µg/L	<20	<20	<20	<20
Selenium	µg/L	4.1	<3	<3	<3
Silver	µg/L	<10	<10	<10	<10
Strontium	µg/L	98.1	119	131	131
Zinc	µg/L	<4	16	12	<4
Total suspended solids	mg/L	20	<4	<4	<4
Total organic carbon	mg/L	1.75	<.4	<.4	1.85
Biochemical oxygen demand	mg/L	1.8	0.4	0.2	0.2
Chemical oxygen demand	mg/L	200	64	61	81
Surfactants (MBAS)	mg/L	0.032	<.025	0.027	0.05
Atrazine	µg/L	<.046	<.046	<.046	<.046
2,4-D	µg/L	<.7	<.7	<.7	<.7
Phenolics	mg/L	<3	<3	<3	<3
Chloroform	µg/L	<.5	<.5	3.34	9.56
Trichloroethene	µg/L	<.5	<.5	<.5	<.5
Tetrachloroethene	µg/L	<.5	<.5	<.5	<.5

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