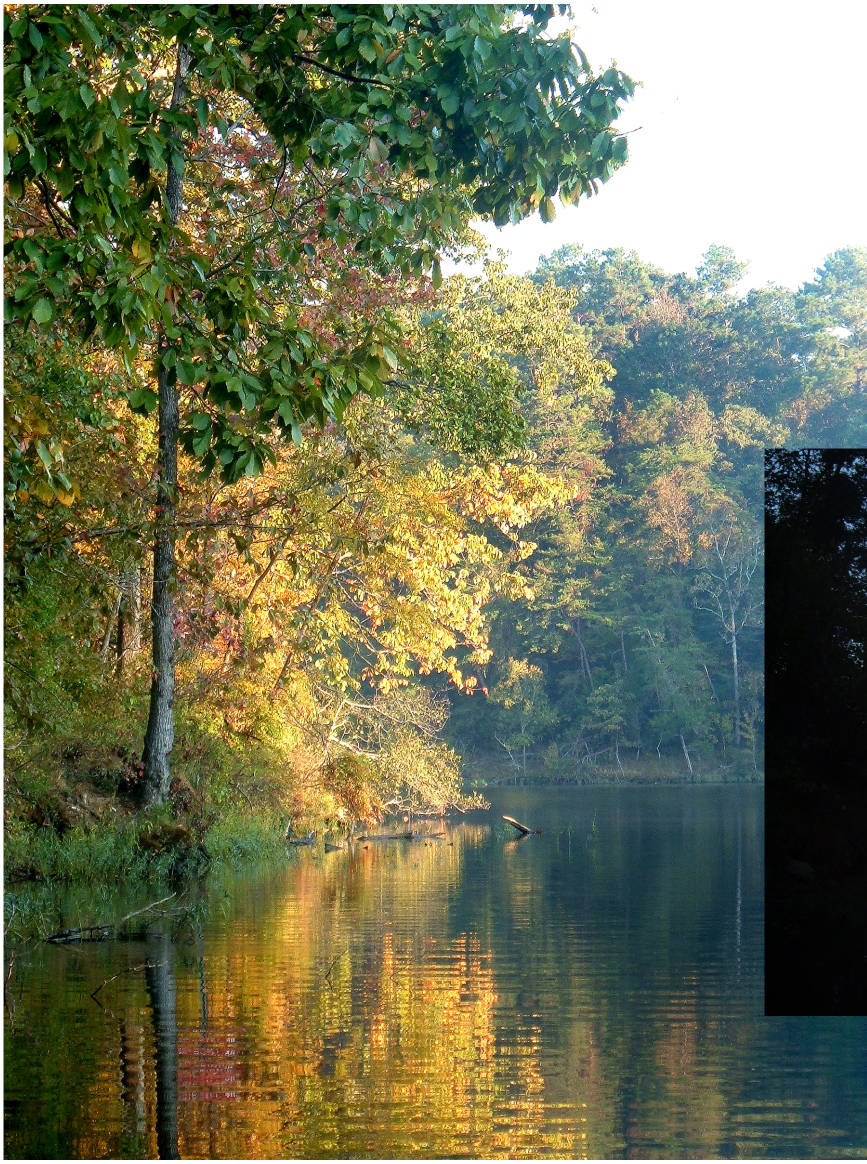

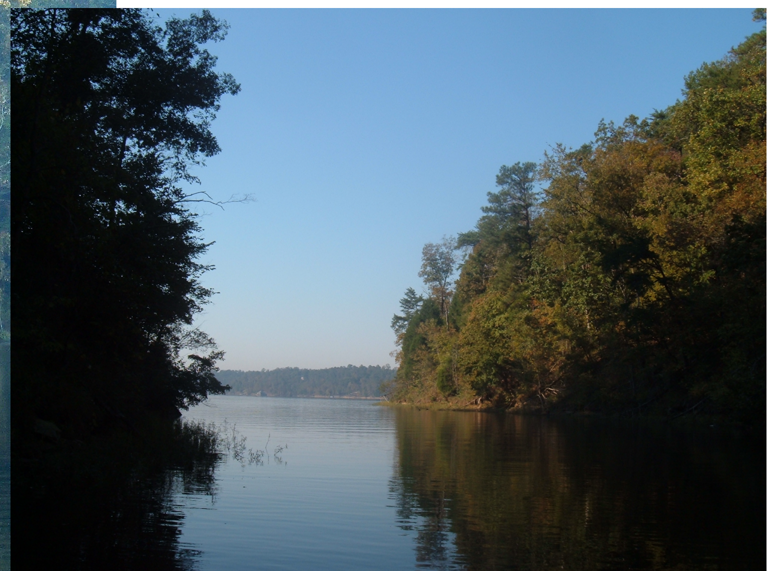

Distribution and Concentration of Total Coliform and *Escherichia coli* Bacteria in the North River/Lake Tuscaloosa Watershed, 2005

GEOLOGICAL SURVEY OF ALABAMA

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WATER INVESTIGATIONS PROGRAM

DISTRIBUTION AND CONCENTRATION OF TOTAL COLIFORM AND *ESCHERICHIA COLI* BACTERIA IN THE NORTH RIVER/LAKE TUSCALOOSA WATERSHED, 2005

OPEN-FILE REPORT 0604

by

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Tuscaloosa, Alabama
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INTRODUCTION

Created in 1970, Lake Tuscaloosa is one of the largest water supply reservoirs in Alabama. Unlike many other areas of the state that have suffered from insufficient water supplies during recent drought or are likely to do so in the near future, Tuscaloosa and the surrounding areas should enjoy a reliable, excellent water supply source thanks to proactive city leaders who took the long view of the area's water supply needs. Sustained economic growth requires adequate infrastructure, and water supply is one of the critical infrastructure components. Lake Tuscaloosa fills an infrastructure role in the region and is a major component of the economy in West Alabama.

The challenge of maintaining acceptable water quality in Lake Tuscaloosa will increase with the expanding commercial and residential development around the lake and the associated septic tank and sewer service requirements. The lake is also an excellent recreational resource and is heavily used for boating, swimming, and fishing; agricultural activity occurs adjacent to tributaries to the lake and further upstream in the watershed; large tracts of forest land are managed for timber and pulp wood; tracts of land are mined for coal and coalbed methane; and small communities use North River for disposal of wastewater. All of these activities have significant potential to negatively impact water quality in the North River watershed in general and Lake Tuscaloosa in particular. The large water storage volume of Lake Tuscaloosa can attenuation the effects of pollution to a degree and largely did so during the 1970s and 1980s. The cumulative impacts of population growth and watershed development are, however, now being expressed in lake water quality.

Recent studies by the city have shown that approximately 11 percent of the lake's original surface and volume have been lost to sedimentation and that high bacteria levels are consistently occurring in the lake under hydrologic conditions of high stream flow. The Alabama Department of Environmental Management (ADEM) examined the nutrient status of Lake Tuscaloosa in 1998 and 2002 (ADEM, 2004). Their data indicate that average total nitrogen and chlorophyl *a* were similar between 1998 and 2002, while average total phosphorus and total suspended solids increased over the same period. Their data also show that the lower lake was oligotrophic (unproductive) to mesotrophic (moderately productive) during 2002 while the mid and upper parts of the lake lake were mesotrophic to eutrophic (very productive) in late summer. North River upstream of Lake Tuscaloosa consistently rated eutrophic for several months in late summer and early fall (ADEM, 2004). The trophic status of a lake is related to its level of fertility, with oligotrophic lakes infertile and unproductive of algae (generally a desirable condition for water supply) and eutrophic lakes very fertile and very productive of algae (an undesirable condition for water supply and water quality).

Unless measures are taken to manage, monitor, and reduce increased pollutant loads associated with development, water quality in surrounding streams, rivers, and reservoirs will deteriorate. Based on current water-quality monitoring data, Lake Tuscaloosa now appears to be at this point in its history and is becoming an "urban" reservoir with associated pollution problems of excessive sediment runoff, high bacteria problems, and increased rates of productivity (cultural eutrophication). Water-quality sampling in Lake Tuscaloosa by city personnel the last few years has documented high bacteria concentrations, particularly after significant rainfall events. Storm water runoff during these events washes nonpoint-source pollutants into North River and into tributaries draining directly into Lake Tuscaloosa. This runoff may contain a variety of undesirable substances such as excessive sediment, nutrients, toxics, and bacteria. The concentrations of these pollutants are determined, to a large degree, by site-specific land cover and land uses within the watershed. Storm water runoff in agricultural areas can be elevated in sediment, nutrients such as nitrogen and phosphorus, and bacteria if animal operations are in the watershed. Storm water runoff in urban areas can contain elevated sediment from construction activities, nutrients from fertilized turf and lawns, toxics from paved surfaces, and bacteria from poorly functioning septic systems or leaking sanitary sewer systems.

The city of Tuscaloosa contacted the Geological Survey of Alabama (GSA) in 2004 to discuss the recurring bacteria problem in Lake Tuscaloosa and to design a plan to assist the city in understanding the geographic extent and concentrations of bacteria in the watershed. GSA's recommended plan included two key concepts. First, the study area should include the entire North River watershed. The quality of water in Lake Tuscaloosa is a direct result of the quality of source water entering the lake from all parts of the watershed. The second concept is that water resources of the North River area encompass both surface water and ground water, and that these sources should be investigated as integral parts of the same hydrogeologic unit.

ACKNOWLEDGMENTS

Several individuals with the city of Tuscaloosa contributed to the completion of this study. Maurice Sledge, Travis Leslie, Jimmy Junkin, Perry Acklin, Joe Robinson, and Bill Snowdon were instrumental in the initial discussions and design of this project. Travis Leslie, City Lakes Manager, provided technical assistance for many aspects of the investigation related to Lake Tuscaloosa. Harriet Mattox and Bernard Cassidy, with the Ed Love Treatment Plant, conducted an initial training workshop for GSA laboratory staff about the IDEXX bacteria analysis method and analyzed replicate samples to ensure quality control during sampling runs. Phillip Guin of Almon and Associates has discussed several aspects of the study and helped guide sampling design. Maurice Mettee, Tom Shepard, Stuart McGregor, Blakeney Gillett, and Bob Baker with the GSA provided field sampling assistance and contributed to various aspects of the study.

STUDY AREA

The study area (fig. 1) included the entire 425-square-mile North River watershed upstream of the Lake Tuscaloosa dam. Lake Tuscaloosa flows through two physiographic sections, the Cumberland Plateau and the East Gulf Coastal Plain. The northern and eastern parts of Lake Tuscaloosa drain land in the Warrior Basin District (underlain by the Pottsville Formation) of the Cumberland Plateau while the western lake region drains land in the Fall Line Hills District (underlain by the Coker Formation) of the East Gulf Coastal Plain (Fig. 1).

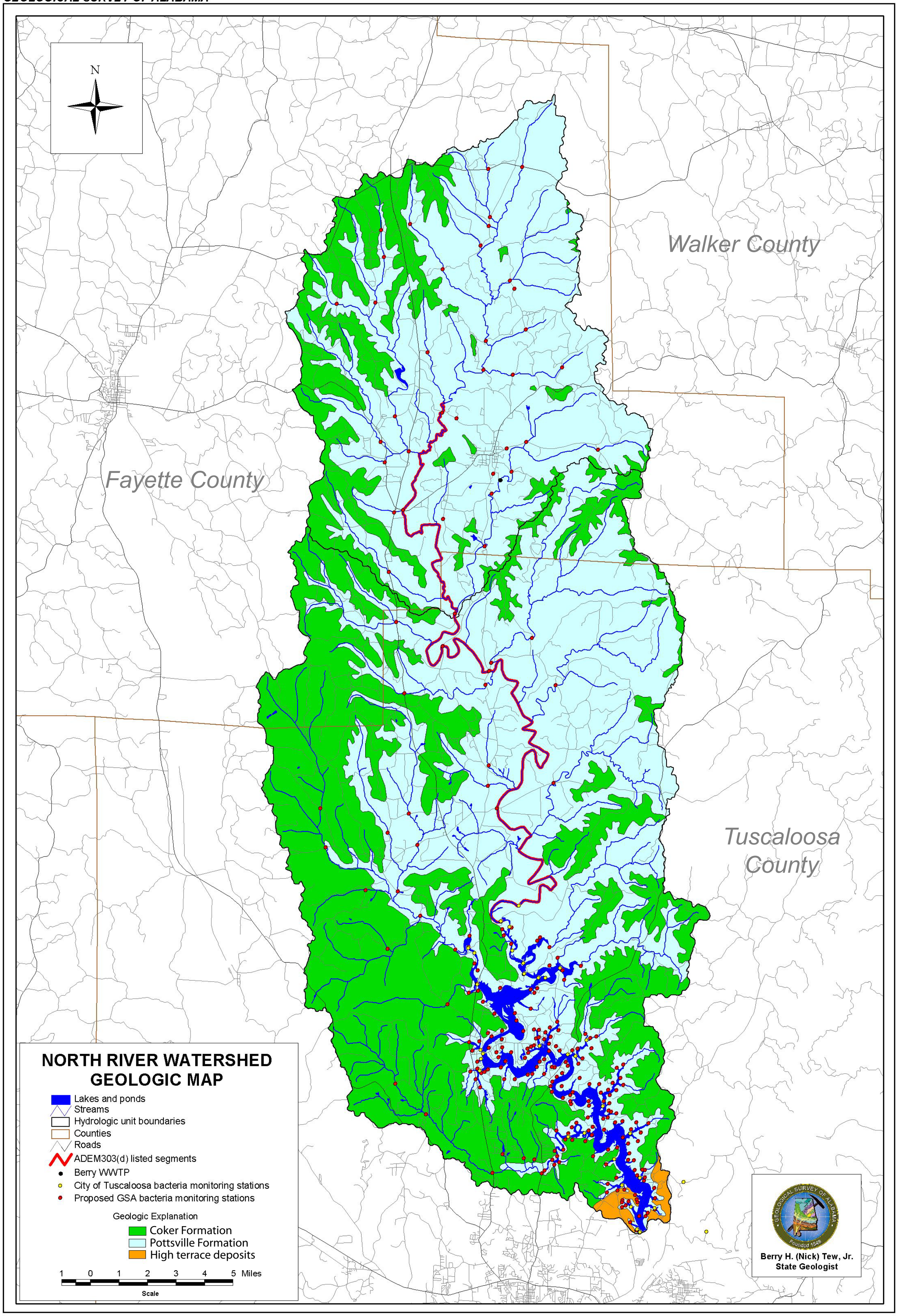

Figure 1. Study area in the North River/Lake Tuscaloosa watershed.

The Warrior Basin is a broad, dissected plateau about 80 miles wide underlain primarily by sandstone and shale and lying mainly in Winston, Cullman, Walker, Jefferson, and Tuscaloosa Counties. Flow in larger streams draining the Warrior Basin is usually sustained during summer months, but many headwater tributaries go dry because of low recharge from ground-water aquifers. The upper Black Warrior River and its tributaries–the Locust Fork, Mulberry Fork, Sipsey Fork, and North River–are dominant drainage features in the district with streams occurring in steep-sided valleys, many of which are gorge-like.

The Fall Line Hills District is a wide crescent-shaped band extending from the Tennessee River in northwest Alabama through the middle portion of the Mobile River basin, and the Chattahoochee River drainage in east Alabama. The Fall Line Hills district forms the southwestern and southern boundary to the Highland Rim, Cumberland Plateau, Alabama Valley and Ridge, and the Piedmont Upland. Streams draining the Fall Line Hills are well sustained, even in the driest years, because of extensive sand and gravel aquifers. Topography can be fairly rugged with steep slopes occurring near streams. In the western portion of the district around Lake Tuscaloosa the Fall Line exists as an irregularly shaped transition belt about 15 miles wide where rocks of the Warrior Basin (Pottsville Formation) dip below the land surface and are overlain by the sands and gravels of the Coker Formation in the Fall Line Hills (fig. 1).

METHODS

Sampling stations were established in four areas: (1) stations near the mouths of most tributaries draining into the North River upstream of Lake Tuscaloosa; (2) stations in the main channel of North River upstream of Lake Tuscaloosa; (3) stations in Lake Tuscaloosa proper; and (4) stations in tributaries draining directly into Lake Tuscaloosa. Multiple stations were established in the larger tributaries and in tributaries with suspected polluted runoff. The sampling regime was designed to collect water samples during the two extremes of the hydrologic cycle, low flows and high flows. Samples collected during low flow periods represent source water originating from shallow ground-water aquifers. If bacteria from poorly maintained septic tanks, damaged sanitary sewer systems, or infiltration of animal wastes were in contact with shallow ground water, then sampling during low flow periods should detect these problems. Samples collected during high flow periods represent source water from overland runoff of rainfall. Bacterial contamination originating from livestock or poultry operations or from poorly managed treatment facilities, would be detected during high flow periods.

Water samples were collected at 232 stations (table 1) in the North River/Lake Tuscaloosa watershed. Nine of the 232 stations were added after the high flow samples were collected in late spring and early summer, and 33 stations were not sampled during the low flow period in the fall because of dry stream channels. Each site was georeferenced to latitude and longitude with a global positioning system unit, and data were compiled into a Geographic Information System (GIS) project. For analytical purposes, Lake Tuscaloosa proper was divided into three sections (lower, middle, and upper). The lower section extended from the Lake Tuscaloosa dam (station 35) upstream to the mouth of Carrolls Creek (station 91); the middle section extended from

Table 1. Bacteria sampling stations in the North River/Lake Tuscaloosa watershed.

Tributary system	Station number	Number of stations
Lake Tuscaloosa Proper		
Lower lake	35, 37-47, 49-68, 70-74, 76-79, 81-91	52
Middle lake	92-98, 100-115, 117-136, 138-139, 141, 143-163,	90
Upper lake	1, 2, 4, 7-8, 10-14, 17-17, 19-21, 23-25, 28-32, 34	24
Binion Creek and tribs	BC1-BC3, BT1-BT6	9
Pole Bridge Creek	PBC	1
Carrolls Creek and tribs	CC1-CC4, CT1-CT3	7
North River		
North River proper	NR1-NR0	10
North River unnamed tribs	NT1-NT3	3
Cripple Creek	CP1	1
Gin Branch	GB1	1
Bear Creek	BE1	1
Tyro Creek	TC1-TC2	2
Boone Creek	BO1-BO2	2
Freeman Creek	FC1	1
Sandy Point Creek	SPC	1
Cedar Creek and tribs	CE1-CE4, BY1-BY2, LC1	7
Rocky Branch	RB1	1
Clear Creek	CL1-CL4	4
Boles Creek	BS1	1
Deadwater Creek	DC1, DCT	2
Ellis Creek	EC1	1
Cane Creek	CA1-CA2	2
Laney Branch	LB1	1
George Creek	GC1, GCT	2
Beaver Creek	BR1-BR2	2
Lowery Branch	LY1	1
Hendon Creek	HC1	1
Tanyard Creek	TD1	1
Lick Creek	LK1	1
TOTAL STATIONS		232

Carrolls Creek mouth upstream to station 163; and the upper section extended from station 163 upstream to station 34 (plate 1).

Bacteria samples were collected at each site during high flow periods in April and June and during low flow periods in September and October. Samples were collected in sterile containers and returned within a 5-hour period to the GSA laboratory where they were prepared, incubated, and quantified for total coliform bacteria (colony forming units per 100 milliliter of sample) (cfu/100 mL), and for *Escherichia coli (E. coli)* bacteria (cfu/100 mL). GSA and the city of Tuscaloosa used the same methodology – the IDEXX defined-substrate Colilert technology – to assay for bacteria. This technology is capable of simultaneously detecting total coliforms and *E. coli* bacteria within a 24-hour period. To ensure quality control, duplicate samples were processed by both the GSA laboratory and the city laboratory. During the low flow sampling period, additional water-quality measurements were made. including temperature (°C), specific conductance (*µ*S/cm), pH (standard units), and turbidity (NTU). Physical water quality measurements were made with a Horiba U-10 multiparameter water-quality meter.

Total coliform, fecal coliform, and *E. coli* are all indicators and measures of bacteria contamination in drinking water supplies and waters in contact with humans. The total coliform group is a large collection of different kinds of bacteria, the fecal coliform group is a sub-group of total coliform, and *E. coli* is a sub-group of fecal coliform. Generally, when a water sample is sent to a laboratory for analysis, it is tested for total coliform. If total coliform is present, the sample will also be tested for either fecal coliform or *E. coli*, depending on the lab testing method.

Total coliform bacteria are commonly found throughout the environment in soil and vegetation and are generally harmless. If only total coliform bacteria are detected in drinking water, the source is probably environmental and fecal contamination is not likely. Fecal coliform bacteria appear in great quantities in the intestines and feces of people and animals. The presence of fecal coliform in a water sample often indicates recent fecal contamination of the water resulting in a greater risk that pathogens are present. Most *E. coli* are harmless and are also found in great quantities in the intestines of people and warm-blooded animals. Some strains, however, may cause illness and the presence of *E. coli* in a drinking water sample almost always indicates recent fecal contamination and a greater risk that pathogens are present. Most *E. coli* outbreaks reported in the media have been related to food contamination, caused by a specific strain of *E. coli* known as *E. coli* O157:H7. When a water sample is reported as containing *E. coli* it does not mean that this specific strain is present and in fact, it is probably not present. It does, however, indicate recent fecal contamination.

Bacteria data sets can be highly variable, or skewed, with some samples measuring several orders of magnitude higher, or lower, than the majority of samples. Highly skewed data can unduly influence calculation of the arithmetic average by “pulling” the average value in one direction. Calculation of median values avoids this problem and was used in some instances to compare bacteria samples from different regions of Lake Tuscaloosa and North River tributaries.

RESULTS

During the course of this investigation, a total of 422 samples were collected, 223 during high flow periods and 199 during low flow periods (appendix A). Total coliform bacteria ranged from 273 to 241,960 cfu (median 4,870) for the low flow period, and from 1,046 to 242,000 cfu (median 15,000) for the high flow period. The concentration of *E. coli* bacteria ranged from 1 to 14,670 cfu (median 100) for the low flow period, and from 22 to 17,980 (median 488) for the high flow period (table 2, figs. 2, 3). These results indicate that bacteria associated with storm water runoff during high stream flow periods caused the high concentrations observed in Lake Tuscaloosa. During high stream flows within the lake proper, including small direct tributaries, the upper section had higher median and average bacteria concentrations compared to the middle and lower sections (table 2). During low flows, the median bacteria concentrations were similar throughout the lake, with median *E. coli* counts less than 200 cfu in the three sections (table 2). Another piece of evidence relating storm water flows with high bacteria counts is the observation that during high stream flows approximately 30.5 percent of the samples collected and analyzed for *E. coli* were less than 200 cfu and 69.5 percent were greater than or equal to 200 cfu. During low flows approximately 71 percent of the samples were less than 200 cfu and 29 percent were greater than or equal to 200 cfu.

The bacteria data set was stratified into smaller watersheds for *E. coli* in table 3 and total coliforms in table 4. A majority of the watershed units, 83 percent, had at least one *E. coli* count that exceeded 200 cfu during high flows. For low stream flows, 16 of the smaller watershed units (55 percent) listed in table 3 had at least one *E. coli* count greater than or equal to 200 cfu, indicating that, although storm water runoff appears to be a major source of bacteria, *E. coli* bacteria contamination also occurs in the watershed during low flow periods unrelated to storm water events.

Data were further explored within the GIS environment by color coding bacteria concentration for all the stations sampled within the larger North River/Lake Tuscaloosa watershed. This analysis is presented in plates 1 through 4, which depict *E. coli* and total coliform bacteria concentrations for both high and low stream flow periods. Total coliform bacteria results (plates 1 and 3) essentially mirror the patterns observed for *E. coli* bacteria relative to the distribution and occurrence of high and low concentrations. For *E. coli* concentrations during low flows (plate 4) excluding the lake proper, a large part of the eastern watershed was less than 200 cfu, while about one third to one half of the western watershed was greater than 200 cfu (plate 4). Two *E. coli* samples collected during this period were between 1,000 and 10,000 cfu (stations 030 and 146) and one station (035), a small drainage at Rock Quarry landing, had an *E. coli* concentration of 14,670 cfu, the highest measured during low flows. Many stations around the lake proper had *E. coli* less than 200 cfu during low flow periods, but there were a few stations with *E. coli* between 200 and 1,000 cfu. Both Carrolls and Binion Creeks, major tributaries to Lake Tuscaloosa proper, had several stations with *E. coli* bacteria ranging between 200 and 1,000 cfu during low flow periods.

Table 2. Summary total coliform and *E. coli* bacteria concentrations for samples collected in the North River/Lake Tuscaloosa watershed, 2005.

	Total coliforms				*E. coli*			
	Min [1]	Max	Med	Avg	Min	Max	Med	Avg
Low stream flows (September-October)								
Lake Tuscaloosa								
Upper lake	1,986	11,120	6,200	6,632	6	1,414	120	262
Middle lake	273	23,820	3,320	5,513	1	1,120	61	161
Lower lake	435	173,290	4,140	9,290	2	14,670	133	519
Tributaries	4,960	18,500	8,230	9,320	2	613	228	257
North River								
Main channel	1,300	7,480	2,425	3,329	8	145	83	82
Tributaries	1,414	241,960	7,195	13,476	3	921	91	185
ALL STATIONS	273	241,960	4,870	8,242	1	14,670	100	263
High stream flows (April-June)								
Lake Tuscaloosa								
Upper lake	2,420	242,000	135,665	128,983	32	6,450	980	1,542
Middle lake	1,553	242,000	11,180	31,178	33	17,980	203	998
Lower lake	3,010	242,000	26,130	47,139	22	4,260	579	844
Tributaries	6,700	242,000	34,480	62,907	613	17,250	3,050	4,028
North River								
Main channel	1,046	26,030	11,980	10,927	41	2,040	1,378	1,088
Tributaries	1,986	129,970	7,650	23,181	47	12,360	435	1,407
ALL STATIONS	1,046	242,000	15,000	44,446	22	17,980	488	1,324

[1] min-minimum; max-maximum; med-median; avg-average.

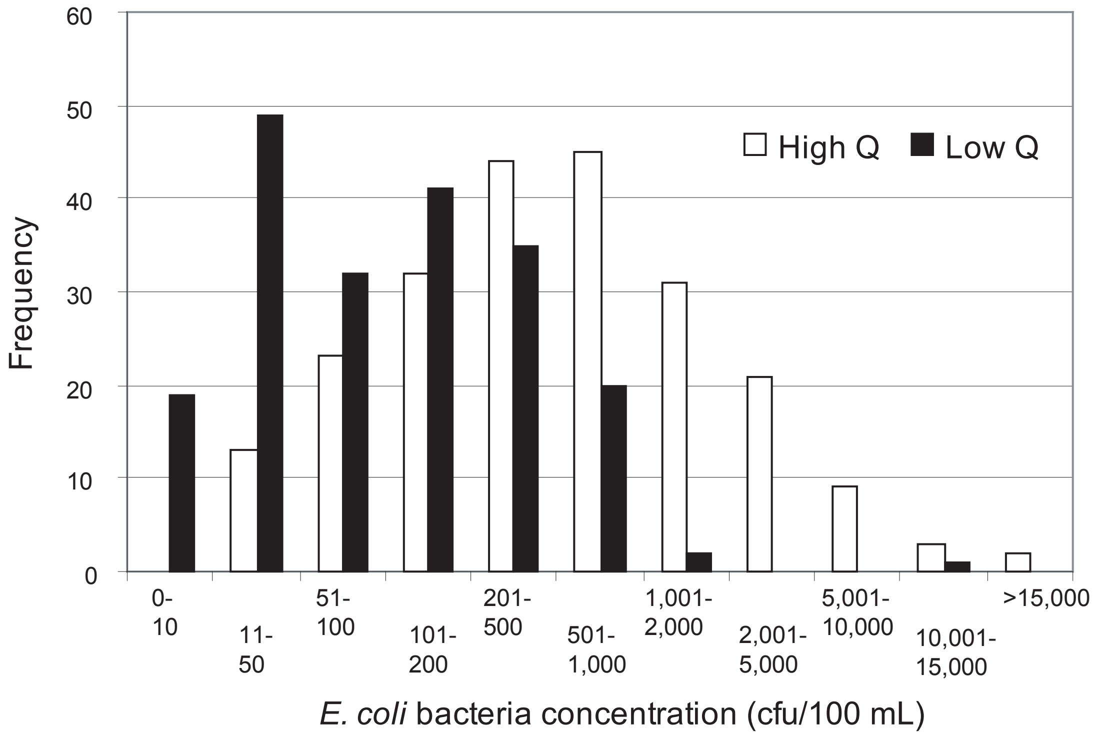

Figure 2. Frequency distribution of *E. coli* bacteria concentrations measured in the North River/Lake Tuscaloosa watershed, 2005.

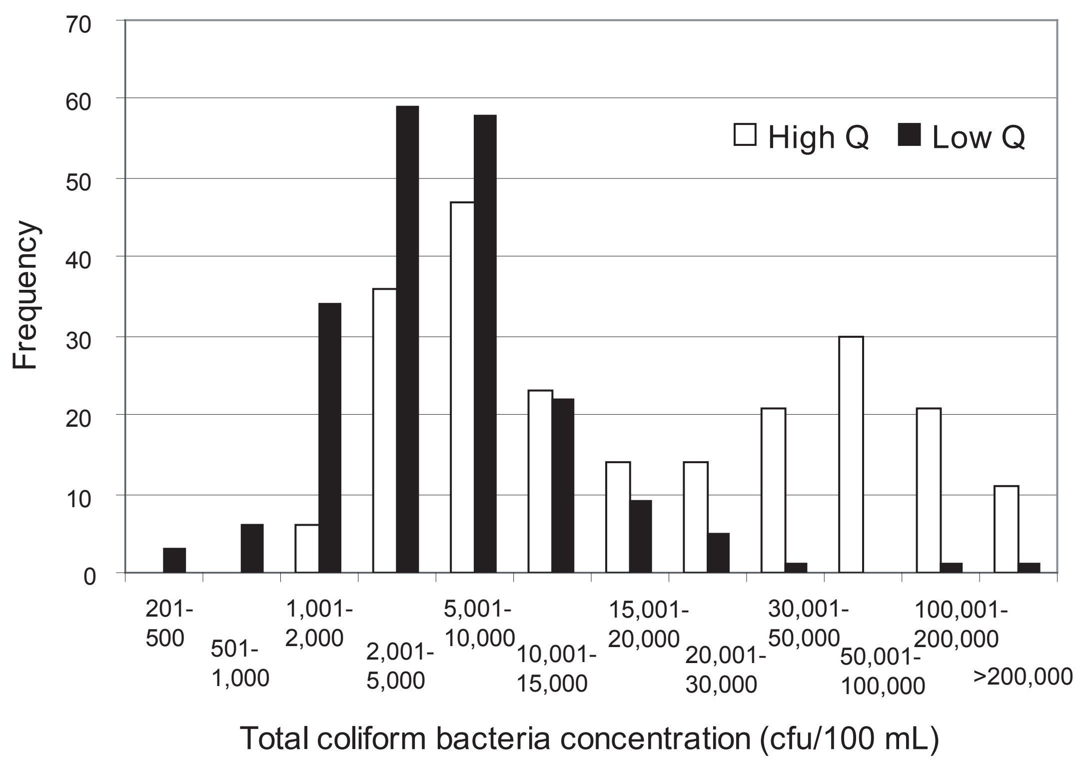

Figure 3. Frequency distribution of total coliform bacteria concentrations measured in the North River/Lake Tuscaloosa watershed, 2005.

Table 3. Concentrations of *E. coli* bacteria at sampling stations in the North River/Lake Tuscaloosa watershed, 2005.

Tributary system	Number of stations	*E. coli* concentration (cfu)	
		Low stream flow	High stream flow
Lake Tuscaloosa Proper			
Lower lake	52	2 - 14,670	22 - 4,260
Middle lake	90	1 - 1,120	33 - 17,980
Upper lake	24	6 - 1,414	32 - 6,450
Binion Creek and tribs	9	75 - 517	613 - 3,640
Pole Bridge Creek	1	613	8,360
Carrolls Creek and tribs	7	2 - 488	1,986 - 17,250
North River			
North River proper	10	8 - 145	41 - 2,040
North River unnamed tribs	3	84 - 770	866 - 12,360
Cripple Creek	1	107	411
Gin Branch	1	345	921
Bear Creek	1	93	308
Tyro Creek	2	91 - 210	144 - 2,430
Boone Creek	2	91 - 687	1,414 - 6,630
Freeman Creek	1	285	11,620
Sandy Point Creek	1	517	2,660
Cedar Creek and tribs	7	8 - 86	199 - 4,140
Rocky Branch	1	29	461
Clear Creek	4	86 - 236	74 - 435
Boles Creek	1	91	172
Deadwater Creek	2	119 - 488	122 - 548
Ellis Creek	1	34	125
Cane Creek	2	36 - 59	58 - 866
Laney Branch	1	23	47
George Creek	2	12 - 33	73 - 980
Beaver Creek	2	147 - 157	101 - 206
Lowery Branch	1	3	866
Hendon Creek	1	548	72
Tanyard Creek	1	921	276
Lick Creek	1	8	184

Table 4. Concentrations of total coliform bacteria at sampling stations in the North River/Lake Tuscaloosa watershed, 2005.

Tributary system	Number of stations	Total coliform concentration (cfu)	
		Low stream flow	High stream flow
Lake Tuscaloosa Proper			
Lower lake	52	435 - 173,290	3,010 - 242,000
Middle lake	90	273 - 23,820	1,553 - 242,000
Upper lake	24	1,986 - 11,120	2,420 - 242,000
Binion Creek and tribs	9	4,960 - 15,150	6,700 - 68,670
Pole Bridge Creek	1	5,560	51,720
Carrolls Creek and tribs	7	7,030 - 18,500	26,030 - 242,000
North River			
North River proper	10	1,300 - 7,480	1,300 - 7,480
North River unnamed tribs	3	7,120 - 7,800	7,280 - 129,970
Cripple Creek	1	7,330	12,740
Gin Branch	1	241,960	43,600
Bear Creek	1	2,420	8,160
Tyro Creek	2	2,420 - 2,620	2,420 - 7,650
Boone Creek	2	21,870 - 29,090	46,110 - 92,080
Freeman Creek	1	9,600	86,640
Sandy Point Creek	1	9,880	29,090
Cedar Creek and tribs	7	1,986 - 11,450	4,890 - 129,970
Rocky Branch	1	1,986	20,980
Clear Creek	4	1,414 - 6,440	2,280 - 7,760
Boles Creek	1	3,970	3,590
Deadwater Creek	2	6,500 - 8,800	8,650 - 46,110
Ellis Creek	1	2,420	4,640
Cane Creek	2	8,390 - 9,080	3,270 - 9,840
Laney Branch	1	10,100	2,460
George Creek	2	7,540 - 13,540	1,986 - 8,230
Beaver Creek	2	4,410 - 9,320	2,880 - 3,270
Lowery Branch	1	2,420	3,730
Hendon Creek	1	7,380	1,986
Tanyard Creek	1	6,760	2,430
Lick Creek	1	7,540	3,590

Elevated *E. coli* concentrations were more widespread during high stream flows (plate 2). A few headwater streams, and a few small watersheds draining directly into Lake Tuscaloosa were less than 200 cfu. Several stations in main channel North River (NR1-NR6), and tributaries to North River in this area (Sandy Point Creek, Boones Creek, and lower Tyro Creek), had *E. coli* concentrations in the 1,000 to 10,000 cfu range. Headwater tributaries to Binion Creek (BC2, BC3, BT2, BT4 to BT6) and stations in the embayment of Binion Creek (004 and 007) were also in this range. All samples taken in the Carrolls Creek watershed were between 1,000 and 10,000 cfu for *E. coli* including stations CC1 to CC4, CT3 and stations 077 and 086 in the embayment of Carrolls Creek. Many small direct tributaries to Lake Tuscaloosa (plate 2) were in the 1,000 to 10,000 cfu range and included stations 011 to 013, 016, 021, 030, 032, 037, 039, 040, 041, 042, 045, 050, 061, 064, 133, 154, 179, 180, 182, 183, and 185. A few stations sampled during high stream flows had *E. coli* concentrations greater than 10,000 cfu including FC1 and NT1 in North River, CT1 and CT2 in the Carrolls Creek watershed, and station 106 in Lake Tuscaloosa.

DISCUSSION

The sampling strategy of this study was designed to incorporate both surface-water (high stream flows) and ground-water (low stream flows) sources to the North River/Lake Tuscaloosa watershed in the examination of recently observed high bacteria concentrations. This approach was desirable because the North River/Lake Tuscaloosa area is hydrogeologically diverse, with source water originating from geologic units of the Pottsville and Coker Formations and modified by runoff from multiple land use activities, discharged effluents, and any ground-water contamination that may be in the watershed. Elevated bacteria concentrations can be caused by many factors including storm water runoff over agricultural and urban areas, leaking and(or) improperly functioning septic tanks, and(or) discharge from poorly operated waste treatment facilities. Shallow ground water overlying the Pottsville Formation in the eastern part of the watershed travels relatively quickly, and directly, to the nearest stream outlet, while shallow ground water in soils overlying the more sandy and gravelly Coker Formation in the western part of the watershed tends to percolate longer, thus providing a longer period for natural treatment before it enters a stream channel.

Samples collected during low stream flows represent predominantly ground-water contributions to the watershed. Overall, bacteria concentrations were low with regard to *E. coli* during this period with 71 percent of the samples less than 200 cfu/100 mL. In general, the area immediately around Lake Tuscaloosa was in good condition with regard to bacteria concentration with the exception of a few samples. The city should consider this as an acceptable baseline condition relative to *E. coli* bacteria and should strive to maintain these levels through its regulatory and management activities. Sampling during the high stream flow period revealed the widespread occurrence of elevated *E. coli* bacteria concentrations with 69.5 percent of samples greater than 200 cfu/100 mL. In particular, the areas around the central North River watershed upstream of Lake Tuscaloosa, upper Binion Creek, and practically all of the sites in Carrolls Creek had *E. coli* bacteria concentrations that exceeded 1,000 cfu/100 mL.

Data collected during this investigation were used for a specific purpose, to evaluate the geographic extent and concentration of bacteria contamination in the North River/Lake Tuscaloosa watershed. From a regulatory perspective, these data are insufficient for direct comparison to water-quality criteria for stream classifications as established by the Alabama Department of Environmental Management (ADEM). The current ADEM water-quality criteria for bacteria are based on the fecal coliform membrane filter protocol (U.S. EPA, 1986). The U.S. EPA and ADEM will soon adopt the *E. coli* standard, for which the defined-substrate Colilert method used in this study will be acceptable, but at present the ADEM fecal coliform standard still applies to all water-use classifications in the State of Alabama. The fecal coliform criterion for the Swimming water-use classification states that the geometric mean of fecal coliform organism density shall not exceed 200 colonies/100 mL of sample, while the geometric mean concentration is calculated from no less than 5 samples collected at a given station over a 30-day period at intervals not less than 24 hours. The Public Water Supply water-use classification states that the geometric mean of fecal coliform organism density shall not exceed 1,000 colonies/100 mL of sample, nor exceed a single sample maximum of 2,000 colonies/100 mL, while the geometric mean concentration is calculated from no less than 5 samples collected at a given station over a 30-day period at intervals not less than 24 hours. The geometric mean is calculated by taking the n^{th} root of the product of n measurements. For example, the geometric mean of the numbers 150, 345, and 2,350 is 495...[$\sqrt[3]{(150*345*2350)}$]. The geometric mean is preferable to the arithmetic mean when summarizing a series of numbers that can vary substantially, such as bacteria concentrations.

The U.S. EPA (1986, 2002) has recommended a geometric mean density of *E. coli,* for an illness rate of 8 per 1,000 individuals, should not exceed 126 cfu/100 mL. Further, they recommended that for designated beach areas the geometric mean *E. coli* concentration should not exceed 235 cfu/100 mL (75^{th} percentile); for moderate full body contact it should not exceed 298 cfu/100 mL (82^{nd} percentile); for lightly used, full body contact it should not exceed 410 cfu/100 mL (90^{th} percentile); and for infrequently used full body contact it should not exceed 576 cfu/100 mL (95^{th} percentile) (U.S. EPA, 2002).

The 200 cfu/100 mL *E. coli* bacteria concentration that was used as a benchmark in this report was derived by the City of Tuscaloosa in consultation with the Tuscaloosa County Board of Health and the Alabama Department of Public Health. This “action level” is used by the Board of Health and Health Department to determine whether the lake is safe for bodily contact. For water-quality management purposes this limit also provides a useful comparison to the regulatory fecal coliform limit for the Swimming water-use classification which is applicable to Lake Tuscaloosa with its high recreational use in warmer months.

CONCLUSIONS

Completion of this study has resulted in a better understanding of the geographic extent and concentration of total coliform and *E. coli* bacteria in the North River/Lake Tuscaloosa watershed as related to surface- and ground-water hydrogeology in the system. Upon further study and consideration, the data may yield additional answers and insight into questions about bacteria and water quality in the watershed. Our initial conclusions are listed below:

- Water quality in the North River/Lake Tuscaloosa watershed is controlled by interaction of the surface-and ground-water hydrogeologic system. Shale and sandstone in the Pottsville Formation and sand and gravel in the Coker Formation have different controlling influences on surface- and ground-water flow, which affect the transport of pollutants into Lake Tuscaloosa.

- Low-flow sampling revealed that ground water is generally of good quality relative to bacteria content in much of the watershed and of fair quality in some areas. Around 71 percent of the collected samples were less than 200 cfu/100 mL, 28 percent of the samples were between 200 and 1,000 cfu/100 mL, and one percent of the samples exceeded 1,000 cfu/100 mL. One was collected that exceeded 10,000 cfu/100 mL.

- High-flow sampling revealed that storm-water runoff during rain events is a substantial source of bacteria, particularly in the middle North River region, in upper Binion Creek, and in most of the Carrolls Creek watershed. Around 30 percent of the collected samples were less than 200 cfu/100 mL, 40 percent were between 200 and 1,000 cfu/100 mL, and 30 percent exceeded 1,000 cfu/100 mL. Five samples were collected with *E. coli* bacteria concentrations exceeding 10,000 cfu/100 mL.

- Bacteria levels in the watershed can eventually be reduced by adopting a basin-wide process and plan by which agricultural runoff, animal waste runoff, sediment runoff (both urban and agricultural), and other waste-related activities and threats are identified, monitored, and managed through public education and application of best management practices suitable to the terrain and conditions of the region. From this larger basin-wide plan the City should consider selecting one or two smaller watersheds in the basin and implement a hands-on demonstrating of how to manage water quality through best management practices, monitoring, and citizen education.

- Understanding how the North River/Lake Tuscaloosa watershed functions hydrogeologically and how pollutants from human activities are transported by the hydrogeologic system will be key to managing water quality in Lake Tuscaloosa. Because potential water-quality threats to Lake Tuscaloosa are watershed in extent and are many times located well beyond political and jurisdictional boundaries, cooperation between landowners, local and county governments, industries and businesses, and the general public to identify and manage water-quality threats is crucial for the future protection of this resource.

The observation that the source(s) of bacteria contamination, as observed over the recent past, has not been located or remedied illustrates the absence of a comprehensive understanding of the Lake Tuscaloosa-North River watershed and that there are few effective region-wide landowner/stakeholder/government relationships and a watershed plan to collectively solve problems of this scope. National experience in watershed assessment, protection, and management has led to a common understanding that a regional or watershed perspective is the best way to maintain water quality for the widest group of users and to provide protection for all other resource components including wildlife, habitat, and water supply. Landowners, lake users, and all local and city governments must begin thinking about Lake Tuscaloosa and the North River watershed as a single, functioning system and developing a comprehensive environmental understanding of the system and regional watershed approach for use in protecting, managing, and developing this resource.

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Appendix

Total coliform and *E. coli* bacteria concentrations measured in the North River/Lake Tuscaloosa watershed, 2005

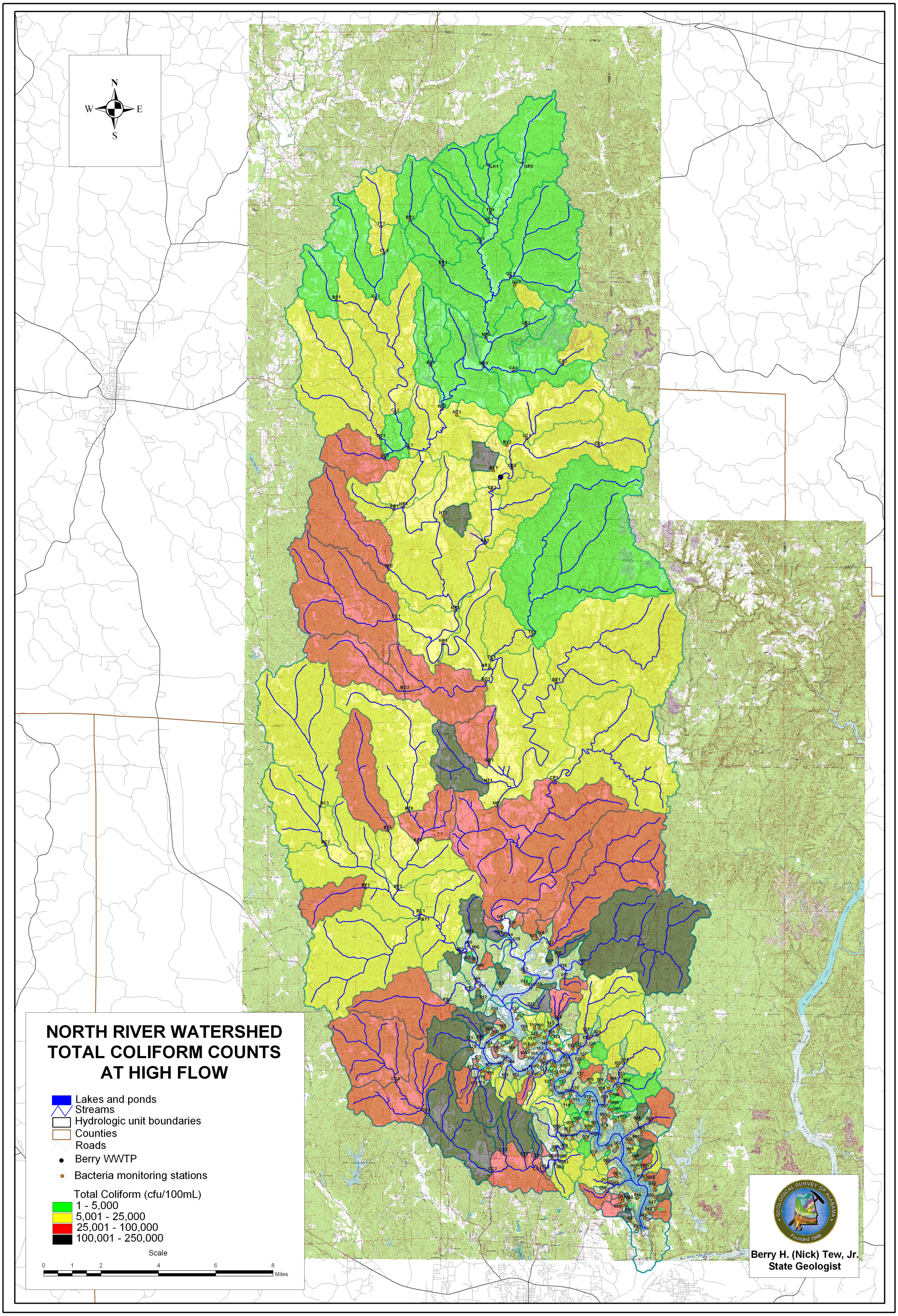
Station	Date	Total coliforms	*E. coli*	Date	Total coliforms	*E. coli*	Specific cond. (µS/cm)	Temp. (°C)	pH (s.u.)	Turbidity (NTU)
001	8-Apr-05	8,800	816	19-Sep-05	10,430	42	50	27	6	10
002	11-Jun-05	155,310	365	26-Oct-05	6,020	387	21	10	7	1
004	11-Jun-05	241,960	5,040	19-Sep-05	10,170	326	25	24	7	1
007	11-Jun-05	141,360	1,553	19-Sep-05	10,460	727	57	25	7	0
008	11-Jun-05	92,080	727	26-Oct-05	6,380	649	21	10	7	2
010	–	–	–	26-Oct-05	5,380	140	19	12	7	7
011	11-Jun-05	242,000	1,300	–	–	–	–	–	–	–
012	11-Jun-05	242,000	1,203	19-Sep-05	9,880	214	27	25	7	0
013	11-Jun-05	141,360	4,410	–	–	–	–	–	–	–
014	11-Jun-05	2,420	32	–	–	–	–	–	–	–
016	11-Jun-05	241,960	1,046	19-Sep-05	10,430	99	86	26	7	15
017	11-Jun-05	51,720	980	–	–	–	–	–	–	–
019	11-Jun-05	155,310	816	26-Oct-05	4,410	161	35	12	7	16
020	11-Jun-05	120,330	866	26-Oct-05	1,986	249	41	11	7	21
021	11-Jun-05	141,360	1,300	26-Oct-05	2,990	86	35	13	7	5
023	11-Jun-05	41,060	488	–	–	–	–	–	–	–
024	11-Jun-05	86,640	727	–	–	–	–	–	–	–
025	11-Jun-05	68,670	579	26-Oct-05	2,880	31	41	11	6	9
028	–	–	–	26-Oct-05	2,420	6	107	12	6	100
029	11-Jun-05	41,060	270	26-Oct-05	2,420	11	30	9	6	11
030	11-Jun-05	129,970	1,986	19-Sep-05	9,080	1,414	56	26	7	1
031	11-Jun-05	77,010	980	26-Oct-05	10,500	91	51	11	6	7
032	11-Jun-05	241,960	6,450	20-Sep-05	11,120	55	74	22	7	5
034	11-Jun-05	173,290	1,986	20-Sep-05	2,420	29	58	22	7	2
035	–	–	–	20-Oct-05	17,930	14,670	609	19	8	0
037	1-Jun-05	104,620	1,203	19-Sep-05	8,390	345	277	24	8	1
038	1-Jun-05	120,330	4,260	19-Sep-05	173,290	110	166	24	6	1
039	1-Jun-05	98,040	1,414	21-Sep-05	22,820	154	33	26	7	10
040	1-Jun-05	38,730	1,733	20-Oct-05	4,200	816	85	18	7	0
041	1-Jun-05	77,010	1,203	20-Oct-05	11,980	48	130	19	8	1
042	1-Jun-05	173,290	2,420	20-Sep-05	5,040	26	158	26	7	20
043	1-Jun-05	32,550	2,420	19-Sep-05	1,986	30	30	25	8	17
044	1-Jun-05	51,720	308	–	–	–	–	–	–	–
045	1-Jun-05	77,010	1,203	19-Sep-05	8,200	83	116	24	7	1
046	1-Jun-05	16,070	78	20-Oct-05	5,370	261	52	19	7	17
047	1-Jun-05	111,990	1,300	19-Sep-05	5,730	365	277	24	8	4
049	1-Jun-05	98,040	613	19-Sep-05	10,460	649	86	24	7	11
050	–	–	–	20-Oct-05	3,840	548	79	19	8	8
051	1-Jun-05	54,750	816	19-Sep-05	5,830	13	68	25	7	53
052	1-Jun-05	31,690	770	20-Oct-05	770	2	91	21	7	3
053	1-Jun-05	9,340	210	20-Oct-05	1,553	48	162	19	8	2
054	1-Jun-05	32,550	980	19-Sep-05	4,870	148	64	26	8	5
055	1-Jun-05	15,850	613	21-Sep-05	1,986	126	162	27	7	1
056	1-Jun-05	43,520	2,420	19-Sep-05	6,830	613	23	25	7	10
057	1-Jun-05	21,420	435	20-Oct-05	5,760	770	41	21	7	0
058	–	–	–	20-Oct-05	1,046	9	39	20	7	13
059	1-Jun-05	41,060	687	20-Oct-05	3,230	291	77	21	8	2
060	1-Jun-05	242,000	548	19-Sep-05	5,730	148	162	27	8	22
061	1-Jun-05	20,640	1,553	19-Sep-05	2,430	43	311	25	8	32
062	1-Jun-05	34,480	411	–	–	–	–	–	–	–

Station	Date	Total coliforms	*E. coli*	Date	Total coliforms	*E. coli*	Specific cond. (µS/cm)	Temp. (°C)	pH (s.u.)	Turbidity (NTU)
063	1-Jun-05	26,130	276	20-Oct-05	4,140	921	11	20	7	4
064	1-Jun-05	104,620	2,420	20-Sep-05	19,890	194	21	25	7	28
065	1-Jun-05	46,110	866	20-Oct-05	1,203	81	18	20	7	4
066	1-Jun-05	242,000	517	20-Sep-05	7,760	91	196	24	8	62
067	1-Jun-05	54,750	980	–	–	–	–	–	–	–
068	1-Jun-05	19,180	261	19-Sep-05	5,040	179	28	25	7	17
070	12-Jun-05	3,770	36	20-Oct-05	1,203	4	30	20	7	4
071	12-Jun-05	6,500	55	20-Oct-05	3,640	186	42	20	7	0
072	12-Jun-05	3,180	350	24-Oct-05	435	24	98	12	6	0
073	12-Jun-05	9,590	142	24-Oct-05	1,733	133	12	12	7	1
074	12-Jun-05	7,540	326	20-Oct-05	3,180	46	99	22	8	5
076	12-Jun-05	4,740	26	24-Oct-05	2,950	108	11	13	7	2
077	12-Jun-05	6,200	1,120	20-Sep-05	4,410	161	13	25	7	8
078	12-Jun-05	11,530	435	24-Oct-05	1,046	18	44	13	7	7
079	12-Jun-05	5,200	42	24-Oct-05	727	548	14	13	7	1
081	12-Jun-05	6,160	210	24-Oct-05	2,410	548	11	13	7	1
082	12-Jun-05	11,530	579	24-Oct-05	4,040	272	12	13	7	0
083	12-Jun-05	68,670	1,553	–	–	–	–	–	–	–
084	12-Jun-05	54,750	411	21-Sep-05	7,850	133	65	26	7	11
085	12-Jun-05	15,000	921	–	–	–	–	–	–	–
086	12-Jun-05	20,140	1,203	20-Sep-05	5,710	108	23	27	7	1
087	12-Jun-05	7,840	32	24-Oct-05	34,360	100	14	15	7	8
088	12-Jun-05	6,630	22	24-Oct-05	1,986	13	25	14	7	0
089	12-Jun-05	3,010	57	24-Oct-05	1,046	5	23	15	7	1
090	12-Jun-05	6,310	387	24-Oct-05	1,203	179	38	14	7	2
091	12-Jun-05	12,010	517	24-Oct-05	1,414	7	113	13	8	0
092	12-Jun-05	2,420	166	24-Oct-05	1,300	61	35	14	7	6
093	12-Jun-05	54,750	1,553	21-Sep-05	16,160	14	124	26	8	32
094	12-Jun-05	5,280	133	24-Oct-05	1,300	61	30	13	6	1
095	12-Jun-05	4,960	132	21-Sep-05	9,090	411	17	22	8	1
096	12-Jun-05	4,080	54	24-Oct-05	2,790	18	23	12	6	3
097	12-Jun-05	3,640	62	24-Oct-05	6,160	148	18	11	6	11
098	12-Jun-05	4,140	54	24-Oct-05	1,210	43	14	11	6	0
100	12-Jun-05	2,420	179	24-Oct-05	816	8	23	11	6	0
101	12-Jun-05	47,100	73	24-Oct-05	2,210	1	22	13	7	2
102	12-Jun-05	4,570	47	24-Oct-05	1,553	88	9	12	7	1
103	12-Jun-05	3,450	70	24-Oct-05	1,986	365	14	11	7	0
104	12-Jun-05	15,530	150	21-Sep-05	10,710	228	11	24	7	1
105	12-Jun-05	5,450	127	24-Oct-05	2,260	179	6	13	7	3
106	12-Jun-05	72,700	17,980	21-Sep-05	1,414	12	55	25	7	0
107	12-Jun-05	6,440	225	24-Oct-05	488	4	61	12	6	0
108	12-Jun-05	5,120	70	–	–	–	–	–	–	–
109	–	–	–	24-Oct-05	816	16	39	12	7	0
110	12-Jun-05	5,630	119	24-Oct-05	2,420	8	10	13	7	0
111	12-Jun-05	1,553	58	24-Oct-05	1,203	54	29	14	7	3
112	12-Jun-05	3,410	110	–	–	–	–	–	–	–
113	12-Jun-05	4,430	102	24-Oct-05	2,420	109	12	14	7	5
114	12-Jun-05	16,740	111	21-Sep-05	15,150	140	28	25	7	2
115	12-Jun-05	3,840	147	24-Oct-05	1,553	9	46	16	7	4
117	12-Jun-05	27,550	579	24-Oct-05	1,553	21	25	12	7	0

Station	Date	Total coliforms	*E. coli*	Date	Total coliforms	*E. coli*	Specific cond. (µS/cm)	Temp. (°C)	pH (s.u.)	Turbidity (NTU)
118	12-Jun-05	12,500	99	24-Oct-05	1,414	22	22	13	7	4
119	12-Jun-05	2,420	72	24-Oct-05	4,430	53	19	15	7	90
120	12-Jun-05	13,960	122	25-Oct-05	273	2	30	15	7	6
121	12-Jun-05	3,410	131	25-Oct-05	4,500	47	41	16	7	35
122	12-Jun-05	6,450	980	21-Sep-05	20,980	37	102	24	7	45
123	12-Jun-05	7,330	356	25-Oct-05	16,070	168	0	0	0	0
124	12-Jun-05	12,590	179	25-Oct-05	1,733	81	28	13	7	0
125	12-Jun-05	11,240	91	–	–	–	–	–	–	–
126	12-Jun-05	2,420	64	25-Oct-05	1,203	1	23	13	6	5
127	12-Jun-05	8,620	249	25-Oct-05	1,300	37	30	11	6	2
128	12-Jun-05	2,590	47	25-Oct-05	1,300	46	18	11	6	3
129	12-Jun-05	7,120	72	25-Oct-00	2,420	172	9	11	6	4
130	–	–	–	25-Oct-05	980	17	12	11	6	3
131	12-Jun-05	8,160	461	21-Sep-05	12,230	192	53	24	7	2
132	12-Jun-05	3,830	115	–	–	–	–	–	–	–
133	12-Jun-05	28,510	7,120	–	–	–	–	–	–	–
134	12-Jun-05	14,700	206	–	–	–	–	–	–	–
135	12-Jun-05	10,140	222	25-Oct-05	1,414	8	68	13	7	1
136	12-Jun-05	4,310	148	–	–	–	–	–	–	–
138	12-Jun-05	15,150	435	25-Oct-05	3,410	72	144	12	7	5
139	12-Jun-05	6,690	111	25-Oct-05	2,010	310	29	11	7	5
141	12-Jun-05	17,260	2,420	–	–	–	–	–	–	–
143	–	–	–	25-Oct-05	6,970	56	69	15	6	4
144	12-Jun-05	68,670	285	25-Oct-05	2,420	31	120	14	7	8
145	12-Jun-05	10,170	411	25-Oct-05	4,870	921	108	13	6	100
146	12-Jun-05	6,440	345	25-Oct-05	19,350	1,120	57	15	6	21
147	12-Jun-05	16,070	980	–	–	–	–	–	–	–
148	12-Jun-05	7,490	87	–	–	–	–	–	–	–
149	12-Jun-05	10,810	66	25-Oct-05	921	16	85	14	7	5
150	12-Jun-05	9,870	387	25-Oct-05	3,680	38	47	14	7	5
151	12-Jun-05	20,460	613	–	–	–	–	–	–	–
152	12-Jun-05	19,350	88	–	–	–	–	–	–	–
153	12-Jun-05	8,330	210	25-Oct-05	5,560	179	46	17	7	28
154	12-Jun-05	9,050	649	25-Oct-05	2,420	23	54	14	7	6
155	12-Jun-05	11,370	155	25-Oct-05	3,550	238	37	15	7	4
156	12-Jun-05	27,550	5,460	21-Sep-05	11,870	99	60	24	7	3
157	12-Jun-05	72,700	579	–	–	–	–	–	–	–
158	12-Jun-05	51,720	1,414	–	–	–	–	–	–	–
159	12-Jun-05	8,010	36	–	–	–	–	–	–	–
160	12-Jun-05	54,750	199	25-Oct-05	5,940	345	20	12	7	2
161	12-Jun-05	22,470	179	25-Oct-05	1,553	488	41	12	7	0
162	12-Jun-05	9,090	179	25-Oct-05	1,553	45	12	13	7	10
163	12-Jun-05	19,180	172	25-Oct-05	4,640	201	36	12	7	6
165	12-Jun-05	13,010	115	25-Oct-05	2,110	93	21	12	7	0
166	12-Jun-05	30,760	687	20-Sep-05	7,890	33	60	25	7	40
167	–	–	–	26-Oct-05	3,550	26	31	15	7	4
168	12-Jun-05	32,820	727	26-Oct-05	23,820	488	148	15	7	4
169	12-Jun-05	57,940	921	–	–	–	–	–	–	–
170	12-Jun-05	15,290	276	25-Oct-05	2,620	23	53	13	7	13
171	12-Jun-05	51,720	488	25-Oct-05	3,320	145	102	12	7	2

Station	Date	Total coliforms	*E. coli*	Date	Total coliforms	*E. coli*	Specific cond. (µS/cm)	Temp. (°C)	pH (s.u.)	Turbidity (NTU)
172	12-Jun-05	7,030	261	20-Sep-05	3,890	225	24	24	7	3
173	12-Jun-05	198,630	1,986	22-Sep-05	12,670	30	32	27	6	22
174	12-Jun-05	36,540	649	26-Oct-05	4,480	161	22	13	7	7
175	12-Jun-05	41,060	250	26-Oct-05	7,120	238	23	13	7	6
176	12-Jun-05	18,600	219	–	–	–	–	–	–	–
177	12-Jun-05	54,750	921	–	–	–	–	–	–	–
178	11-Jun-05	198,630	5,650	20-Sep-05	12,740	770	38	25	7	5
179	11-Jun-05	242,000	2,420	20-Sep-05	6,270	488	22	25	7	2
180	11-Jun-05	242,000	3,090	20-Sep-05	19,350	980	28	25	7	10
181	12-Jun-05	11,120	214	20-Sep-05	13,140	137	109	27	6	7
182	11-Jun-05	242,000	8,570	20-Sep-05	10,760	125	63	25	7	2
183	11-Jun-05	98,040	6,130	–	–	–	–	–	–	–
184	12-Jun-05	20,640	488	26-Oct-05	4,140	34	171	13	7	34
185	11-Jun-05	86,640	3,170	20-Sep-05	6,970	57	68	24	7	6
186	12-Jun-05	5,980	46	–	–	–	–	–	–	–
187	12-Jun-05	7,940	33	–	–	–	–	–	–	–
BC1	26-Apr-05	6,700	687	22-Sep-05	6,890	236	30	23	7	10
BC2	26-Apr-05	8,010	1,046	22-Sep-05	7,230	260	14	24	7	7
BC3	26-Apr-05	12,810	1,119	22-Sep-05	6,630	130	14	23	7	3
BE1	26-Apr-05	8,160	308	19-Oct-05	2,420	93	52	15	7	1
BO1	26-Apr-05	46,110	1,414	19-Oct-05	29,090	91	180	16	8	10
BO2	26-Apr-05	92,080	6,630	22-Sep-05	21,870	687	36	23	7	30
BR1	26-Apr-05	2,880	101	19-Oct-05	4,410	147	10	15	6	4
BR2	26-Apr-05	3,270	206	19-Oct-05	9,320	157	7	15	6	3
BS1	26-Apr-05	3,590	172	19-Oct-05	3,970	91	21	16	6	14
BT1	26-Apr-05	10,460	613	22-Sep-05	11,060	517	17	22	7	6
BT2	26-Apr-05	32,550	3,050	22-Sep-05	4,960	75	22	21	6	16
BT3	26-Apr-05	9,840	727	22-Sep-05	7,840	291	59	24	7	8
BT4	26-Apr-05	61,310	3,640	22-Sep-05	15,150	143	98	23	7	14
BT5	26-Apr-05	68,670	2,420	22-Sep-05	11,370	228	13	22	6	6
BT6	26-Apr-05	9,340	1,733	22-Sep-05	8,230	162	81	24	7	3
BY1	26-Apr-05	129,970	4,140	22-Sep-05	9,320	36	155	24	7	1
BY2	26-Apr-05	4,890	613	20-Oct-05	7,270	8	41	18	7	4
CA1	26-Apr-05	3,270	58	22-Sep-05	8,390	36	317	23	7	2
CA2	26-Apr-05	9,840	866	22-Sep-05	9,080	59	312	23	7	6
CC1	7-Apr-05	43,520	1,986	22-Sep-05	9,580	285	64	24	6	13
CC2	26-Apr-05	111,990	3,990	22-Sep-05	7,030	488	62	24	7	8
CC3	26-Apr-05	34,480	3,640	18-Oct-05	10,460	161	18	15	6	24
CC4	26-Apr-05	26,030	4,320	18-Oct-05	7,330	186	12	15	6	23
CE1	7-Apr-05	11,980	649	19-Oct-05	2,820	49	129	16	7	0
CE2	26-Apr-05	6,970	517	22-Sep-05	11,450	29	113	25	7	2
CE3	26-Apr-05	8,300	199	20-Oct-05	1,986	44	100	17	7	20
CE4	26-Apr-05	10,760	1,553	20-Oct-05	3,270	26	55	18	7	50
CL1	26-Apr-05	2,280	74	19-Oct-05	1,414	86	23	18	7	14
CL2	26-Apr-05	5,940	285	19-Oct-05	6,020	214	21	18	7	3
CL3	26-Apr-05	4,730	435	19-Oct-05	5,560	222	10	16	6	3
CL4	26-Apr-05	7,760	214	19-Oct-05	6,440	236	8	16	6	4
CP1	26-Apr-05	12,740	411	22-Sep-05	7,330	107	698	23	7	18
CT1	26-Apr-05	242,000	10,170	22-Sep-05	18,500	196	71	22	7	6
CT2	26-Apr-05	141,360	17,250	18-Oct-05	12,230	387	20	16	6	7

Station	Date	Total coliforms	*E. coli*	Date	Total coliforms	*E. coli*	Specific cond. (μS/cm)	Temp. (°C)	pH (s.u.)	Turbidity (NTU)
CT3	26-Apr-05	198,630	3,730	18-Oct-05	8,390	2	114	18	6	15
DC1	26-Apr-05	8,650	122	19-Oct-05	6,500	119	24	17	7	23
DCT	26-Apr-05	46,110	548	19-Oct-05	8,800	488	16	17	7	11
EC1	26-Apr-05	4,640	125	19-Oct-05	2,420	34	111	16	6	7
FC1	26-Apr-05	86,640	11,620	22-Sep-05	9,600	285	30	24	7	4
GB1	26-Apr-05	43,600	921	22-Sep-05	241,960	345	6330	24	8	13
GC1	26-Apr-05	1,986	73	22-Sep-05	7,540	33	79	22	7	1
GCT	26-Apr-05	8,230	980	22-Sep-05	13,540	12	57	22	7	2
HC1	26-Apr-05	1,986	72	20-Oct-05	7,380	548	25	15	7	3
LB1	26-Apr-05	2,460	47	22-Sep-05	10,100	23	92	22	7	1
LC1	26-Apr-05	5,120	308	20-Oct-05	4,260	86	40	17	7	8
LK1	26-Apr-05	3,590	184	20-Oct-05	7,540	8	43	16	6	4
LY1	26-Apr-05	3,730	866	20-Oct-05	2,420	3	33	16	6	0
NR0	26-Apr-05	1,986	56	20-Oct-05	5,210	46	54	17	6	0
NR1	7-Apr-05	26,030	2,040	22-Sep-05	1,300	8	177	28	7	16
NR2	7-Apr-05	19,180	1,553	22-Sep-05	7,480	62	781	25	8	5
NR3	7-Apr-05	16,700	1,986	19-Oct-05	2,420	83	91	16	7	6
NR4	7-Apr-05	11,980	1,733	19-Oct-05	2,420	138	85	16	7	4
NR4	7-Apr-05	11,980	1,733	19-Oct-05	2,420	138	85	16	7	4
NR6	7-Apr-05	14,500	1,203	19-Oct-05	2,420	84	90	17	7	23
NR7	26-Apr-05	1,986	173	19-Oct-05	2,430	84	173	17	6	12
NR8	26-Apr-05	3,880	365	22-Sep-05	3,050	145	286	23	7	4
NR9	26-Apr-05	1,046	41	22-Sep-05	4,140	30	79	24	7	2
NT1	26-Apr-05	129,970	12,360	22-Sep-05	7,800	770	35	23	8	10
NT2	26-Apr-05	111,990	980	–	–	–	–	–	–	–
NT3	26-Apr-05	7,280	866	20-Oct-05	7,120	84	60	18	7	82
PBC	26-Apr-05	51,720	8,360	18-Oct-05	5,560	613	15	17	6	88
RB1	26-Apr-05	20,980	461	19-Oct-05	1,986	29	24	17	7	15
SPC	26-Apr-05	29,090	2,660	19-Oct-05	9,880	517	15	16	7	17
TC1	26-Apr-05	7,650	2,430	19-Oct-05	2,620	210	74	15	7	1
TC2	26-Apr-05	2,420	144	19-Oct-05	2,420	91	83	15	7	1
TD1	26-Apr-05	2,430	276	20-Oct-05	6,760	921	49	15	6	1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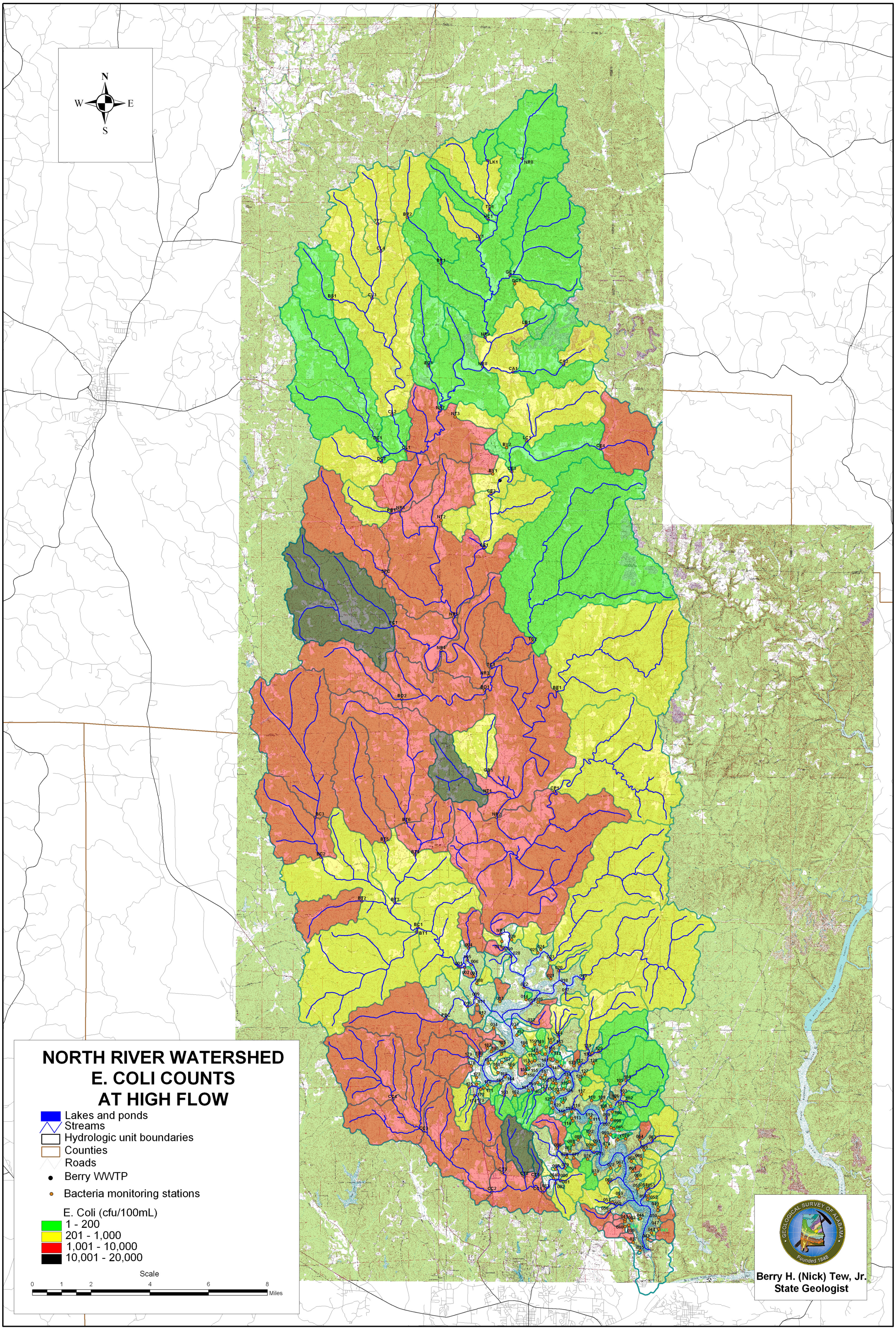
NORTH RIVER WATERSHED
TOTAL COLIFORM COUNTS
AT HIGH FLOW
Lakes and ponds
Streams
Hydrologic unit boundaries
Counties
Roads
Berry WWTP
Bacteria monitoring stations
Total Coliform (cfu/100mL)
1 - 5,000
5,001 - 25,000
25,001 - 100,000
100,001 - 250,000
Scale
0 1 2 4 6 8
Miles
GEOLOGICAL SURVEY OF ALABAMA
Founded 1848
Berry H. (Nick) Tew, Jr.
State Geologist


NORTH RIVER WATERSHED
E. COLI COUNTS
AT HIGH FLOW
Lakes and ponds
Streams
Hydrologic unit boundaries
Counties
Roads
Berry WWTP
Bacteria monitoring stations
E. Coli (cfu/100mL)
1 - 200
201 - 1,000
1,001 - 10,000
10,001 - 20,000
Scale
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Miles
N
S
E
W
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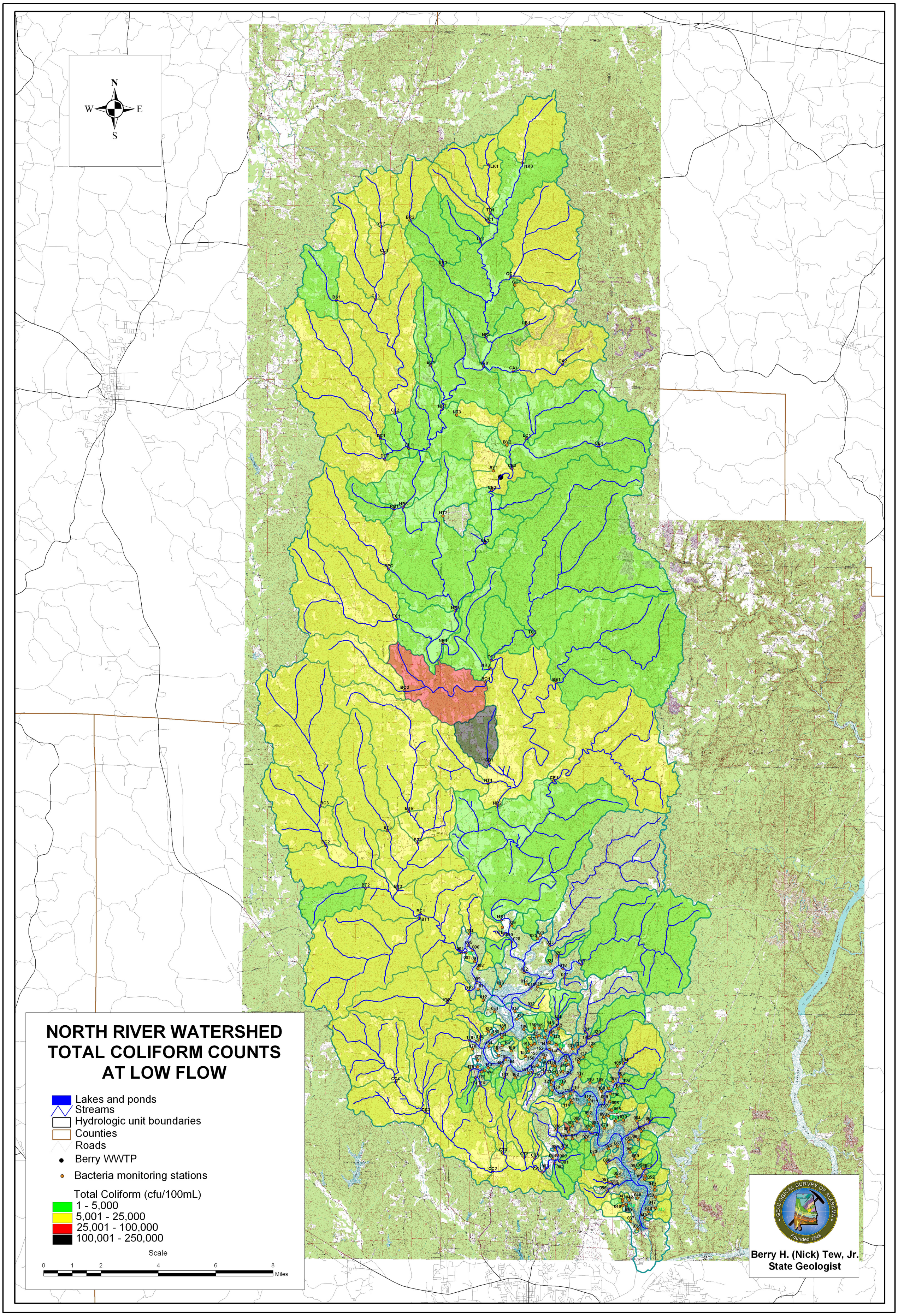
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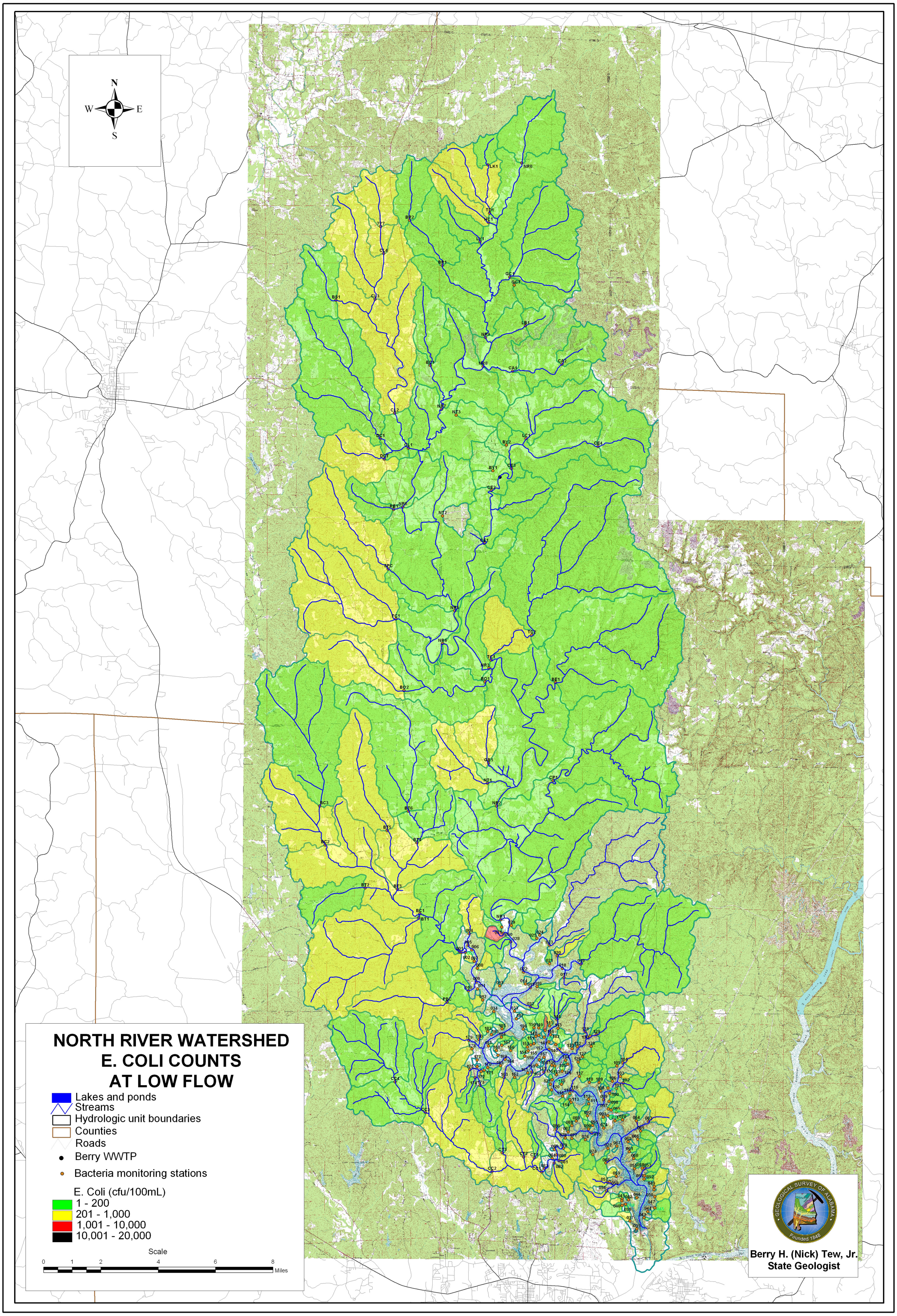
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