RETENTION TIME AND FLOW PATTERNS IN LAKE MARION, SOUTH CAROLINA, 1984

By Glenn G. Patterson and Richard M. Harvey

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BRUCE BABBITT, ***Secretary***

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, ***Director***

For additional information write to:

District Chief
U.S. Geological Survey
Stephenson Center- Suite 129
720 Gracern Road
Columbia, SC 29210-7651

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CONVERSION FACTORS

Multiply	By	To obtain
acre	0.4047	hectare
acre-foot	1,233	cubic meter
acre-foot per day (acre-ft/d)	1,233	cubic meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
mile	1.609	kilometer
pound (1b)	0.4356	kilogram
square foot (ft^2)	0.09294	square meter

In this report, chemical concentrations in water are expressed in micrograms per liter (µg/L), volume measurements in milliliter (mL), and density in kilogram per liter (kg/L).

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By Glenn G. Patterson[1] and Richard M. Harvey[2]

ABSTRACT

In 1984, six dye tracer tests were made on Lake Marion to determine flow patterns and retention times under conditions of high and low flow. During the high-flow tests, with an average inflow of about 29,000 cubic feet per second, the approximate travel time through the lake for the peak tracer concentration was 14 days. The retention time was about 20 days. During the low-flow tests, with an average inflow of about 9,000 cubic feet per second, the approximate travel time was 41 days, and the retention time was about 60 days.

The primary factors controlling movement of water in the lake are lake inflow and outflow. The tracer cloud moved consistently downstream, slowing as the lake widened. Flow patterns in most of the coves, and in some areas along the northeastern shore, are influenced more by tributary inflow than by factors attributable to water from the main body of the lake.

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[1]Hydrologist, U.S. Geological Survey

2Hydrologist, Division Director, Water Facilities, Florida Department of Environmental Protection

INTRODUCTION

Lake Marion, in the South Carolina Coastal Plain, has the largest surface area of any lake in the State (fig. 1). It is connected to another large reservoir, Lake Moultrie, by a 4-mile-long Diversion Canal. The two reservoirs were formed in 1941 as part of the Santee-Cooper diversion project. The major purpose for the diversion was to generate hydroelectric power at Pinopolis Dam at the outlet of Lake Moultrie. The lakes are also an important recreational resource, and are popular with fishing and boating enthusiasts.

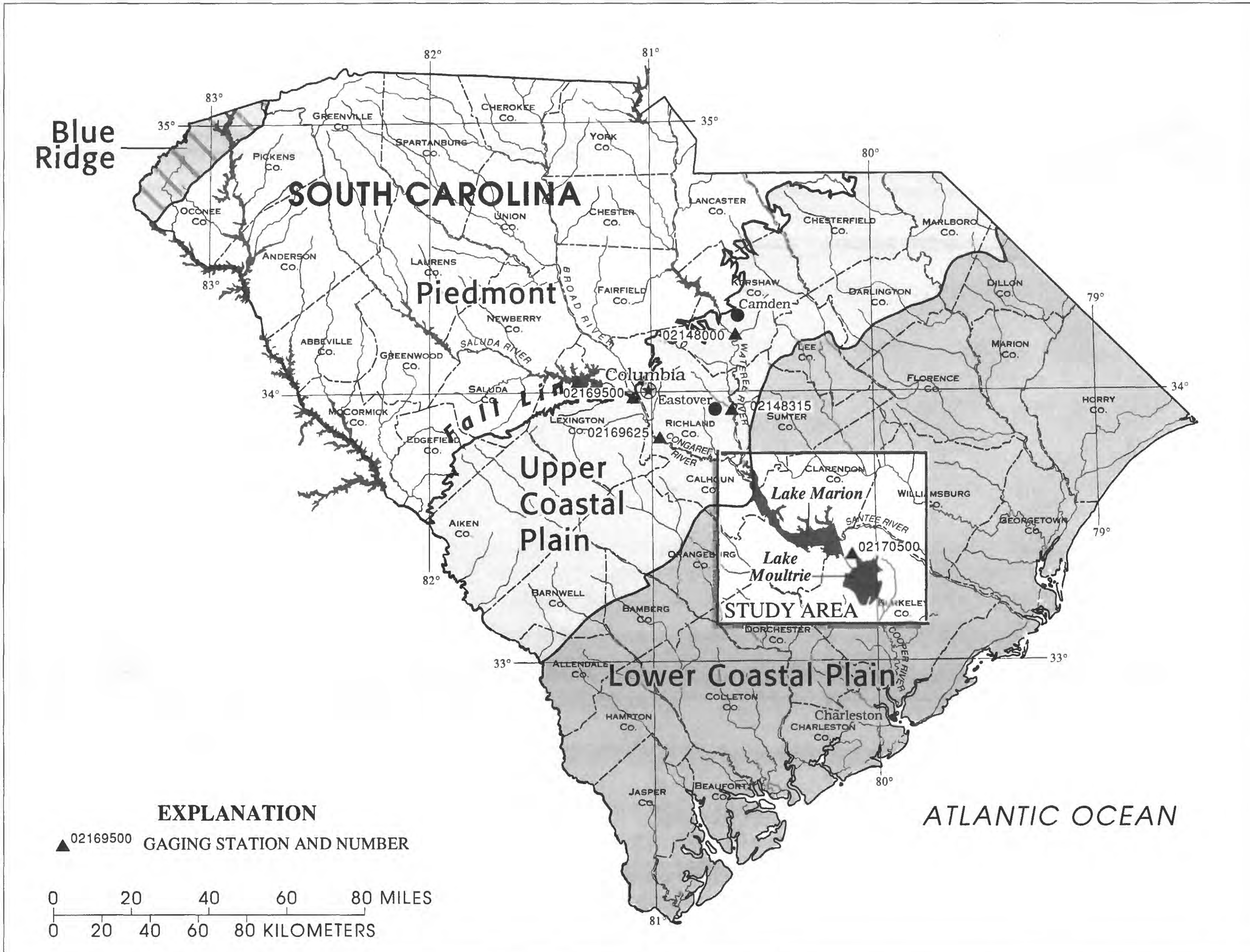
Concern has arisen over several issues pertaining to the quality of water in Lake Marion. Among these issues are transport and deposition of sediment, transport and accumulation of nutrients, growth of aquatic macrophytes and algae, dilution and assimilation of wastes, and viability of striped bass eggs and larvae as they are carried into the lake by the Wateree, Congaree, and Santee Rivers. All of these processes involve transport, mixing, or dilution of dissolved or suspended materials, which in turn depend on retention time and flow patterns. In response to the need for quantitative information on retention time and flow patterns in Lake Marion, a study was made by the U.S. Geological Survey (USGS) in cooperation with the South Carolina Department of Health and Environmental Control (SCDHEC). This study was part of SCDHEC's 10-year Santee-Cooper River Basin Water Quality Study (Harvey and Pickett, 1993).

Purpose and Scope

This report describes the results of a study of retention time and flow patterns in Lake Marion, South Carolina, by using fluorescent dye. The dye was used as a conservative solute tracer; this provided information on dilution and dispersion of constituents as well as on flow patterns and retention time of water. The results of a similar study on Lake Moultrie were presented in a publication by Patterson and Harvey (1986).

Description of Study Area

Lake Marion was formed in 1941 by the construction of Wilson Dam across the Santee River, the second largest river on the east coast of the United States. The lake is located in the Coastal Plain of South Carolina midway between Columbia and Charleston (fig. 1). Lake Marion is the primary storage reservoir in the Santee-Cooper diversion project supplying water to Lake Moultrie in the headwaters of the Cooper River Basin through a diversion canal that crosses a low drainage divide (fig. 2).



Base from U.S. Geological Survey 1:2,000,000 DIGITAL LINE GRAPHS

Figure 1.--Study area in South Carolina.

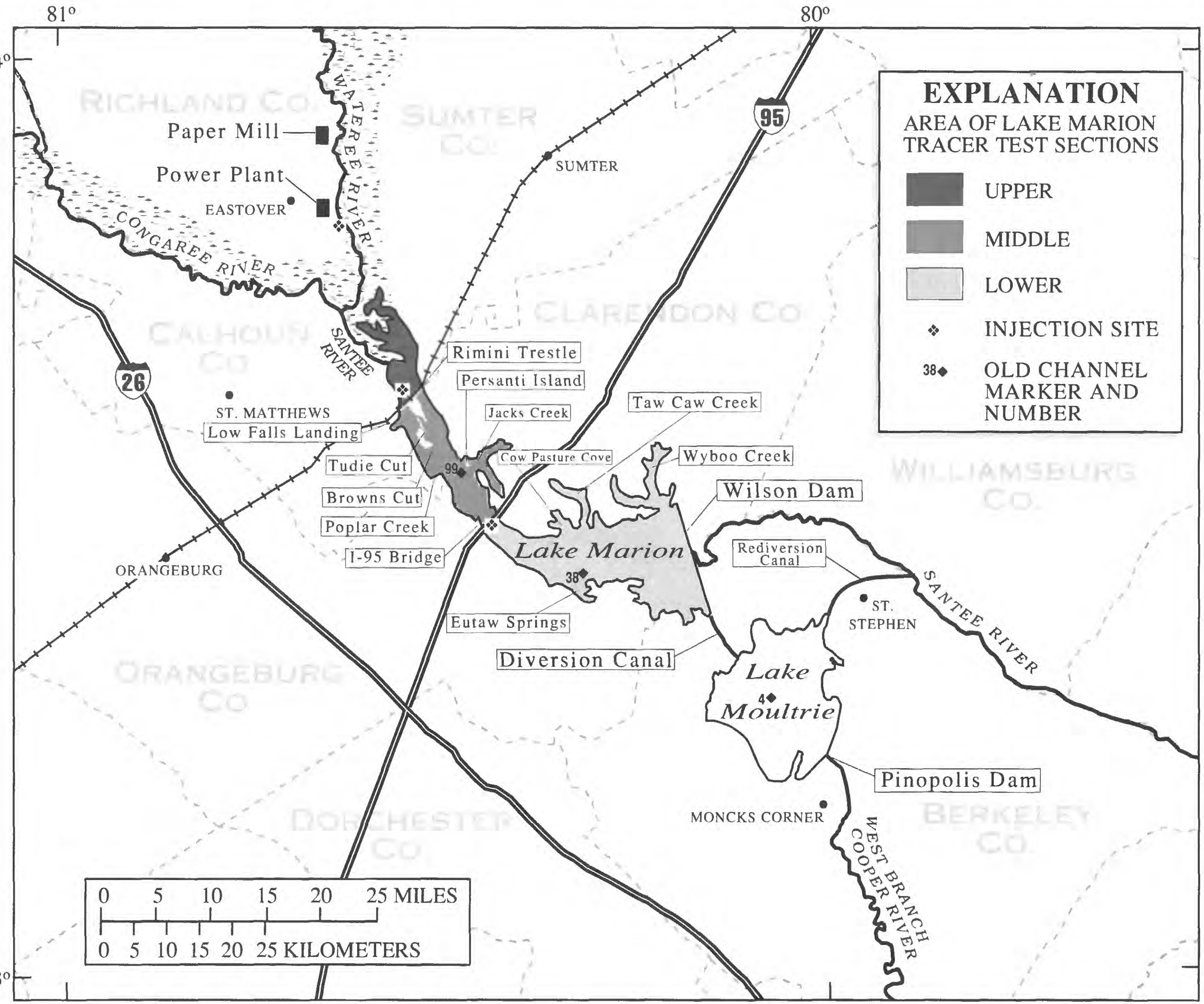


Figure 2.--Study area.

Tributary inflows to Lake Marion are measured at gaging stations 02169500 (Congaree River at Columbia), 02169625 (Congaree River west of Wise Lake near Gadsden), 02148000 (Wateree River near Camden), and 02148315 (Wateree River below Eastover) (fig. 1). The average streamflow at station 02169500 is 9,392 ft^3/s, and the average streamflow at station 02148000 is 6,451 ft^3/s (Bennett and others, 1984, p. 58, 126). The average outflow from Lake Marion measured at station 02170500 (Lakes Marion-Moultrie Diversion Canal near Pineville) is about 15,000 ft^3/s (Bennett and others, 1984, p. 129). When lake outflow exceeds about 30,000 ft^3/s, the excess flow is discharged through a spillway at Wilson Dam into the Santee River. Normal discharge through Wilson Dam is 500 ft^3/s. Most of Lake Marion occupies the relatively flat, 2- to 4-mile-wide flood plain of the Santee River (fig. 2). The lake is about 36 miles long and has a maximum width of about 14 miles. The surface area is approximately 96,000 acres.

The gentle topography of the Coastal Plain and the characteristic physiography of the inundated flood plain give Lake Marion some unique features. The meandering channel of the inundated Santee River dominates the topography of the lake bed. Although the lake has a maximum depth of 60 ft in the channel just upstream of the dam, the depth in the flood plain adjacent to the channel is about 35 ft near the dam; and the average depth of the lake is about 13 ft. Thousands of dead cypress trees standing on the inundated flood plain protrude above the water surface throughout the length of the lake. The lower part of the lake inundates tributary creek valleys, forming several deep coves exhibiting typical dendritic configuration. The rest of the lake occupies the flood plain. Dominant topographic features are the river channel, the natural levees along the channel, narrow, sinuous flood-plain channels, and a few oxbow lakes. At the upper end of the lake, only the river channel and the deeper depressions of the flood plain are inundated. Five miles downstream, only the natural levees protrude from the water, and these are inundated after another 5 miles. In the upper 10 miles of Lake Marion, therefore, the Santee River channel is separated from the adjacent lake water by natural levees that are breached by infrequent cuts. The lake is crossed at relatively narrow areas by the Rimini trestle of the Atlantic Coast Line Railroad and by Interstate Highway 95.

METHODS OF STUDY

Six dye tracer tests were made in 1984 to investigate dilution, dispersion, flow patterns, and retention times for Lake Marion. The lake was divided into three sections (fig. 2) for this study, because the tracer from a single injection at the upstream end of the lake would have become too diffused to monitor at the downstream end. The boundaries for the sections were selected so that a slug injection at the upstream end of each section would affect virtually the entire inflow to that section. The upper section extended 23 miles from a power plant on the Wateree River near Eastover to the Rimini railroad trestle across Lake Marion. The lower 11 miles of the Wateree River and the upper 12 miles of the Santee River were included in the upper section, because these river reaches contain several side-branching channels that divert some of the flow to the submerged Santee River flood plain in upper Lake Marion.

The middle section extended 15 miles from the Rimini trestle to the Interstate Highway 95 bridge, where flow is constricted by a causeway. The lower section extended 21 miles from Interstate Highway 95 to the entrance to the diversion canal. Tracer tests were made in each section under high-flow and low-flow conditions (table 1).

Table 1.--*Descriptions of the six dye tracer tests on Lake Marion*

[ft^3/s, cubic feet per second]

Lake section (fig. 2)	High or low flow	Average lake inflow (ft^3/s)	Location of injection (fig. 2)	Date of injection	Quantity of 20 percent dye injected (pounds)
Upper	High	18,000	Wateree River near Eastover	02/06/84	125
Upper	Low	6,000	Wateree River near Eastover	10/02/84	100
Middle	High	35,400	Santee River above Rimini trestle	03/26/84	375
Middle	Low	11,900	Santee River above Rimini trestle	11/27/84	250
Lower	High	32,400	Interstate Highway 95 bridge	03/07/84	750
Lower	Low	8,200	Interstate Highway 95 bridge	11/06/84	700

The same general method was used for all six tracer tests. Prior to each test, a network of sampling stations was established in the test section. The stations were located near existing channel markers or were identified by ribbons tied to trees, and were in the same general locations for the high-flow and low-flow tests. The network of sampling stations was designed to include: (a) sites where substantial velocities were expected, (b) sites fairly evenly spaced along parallel transects of the lake, and (c) sites in selected coves. Prior to each tracer injection, water samples were collected at all sampling sites in that study section to determine background fluorescence.

To initiate each test, a 20-percent solution of rhodamine WT liquid dye was injected as a slug at the upstream end of the test reach. The quantity of dye to be used in each injection was calculated to insure that a measurable amount of dye would arrive at the downstream end of the section. For the upper section, which was dominated by river flow, the volume of dye was estimated by using the following equation by Kilpatrick and Cobb (1984):

$$V_s = 3.79 \times 10^{-5}\ QL/v\ C_p, \qquad (1)$$

where the variables had the values in the following table:

Variable	Definition	High-flow test	Low-flow test
V_s	Volume of 20-percent dye	47,700 mL	38,200 mL
Q	Streamflow	18,000 ft^3/s	6,000 ft^3/s
L	Reach length	124,000 ft	124,000 ft
v	Mean velocity	2.0 ft/s	1.4 ft/s
C_p	Peak concentration at downstream end	1.1 µg/L	1.9 µg/L

The mass of the dye solution in pounds was computed using the following equation (Kilpatrick and Cobb, 1984):

$$M = V_s \times 10^{-3}\ L/ml \times 1.19\ kg/L \times 2.2\ lb/kg, \qquad (2)$$

where M is the mass in pounds and 1.19 kg/L is the density of the dye solution. The required amounts for the upper section were 125 pounds for the high-flow test and 100 pounds for the low-flow test.

The quantities of dye for tests in the middle and lower sections were calculated to produce fluorescence of the same order of magnitude, or slightly greater than, background fluorescence, assuming the dye was evenly mixed throughout the section. It was anticipated, therefore, that if complete mixing were to occur, the background fluorescence plus the fluorescence from the dye would produce fluorescence of at least two times the background level.

The amount of dye necessary for these two sections was dependent on the mass of water present. The mass of water in each section was estimated by multiplying the surface area of the section, obtained from digitized maps, by the average depth and the density of water.

For the middle section,

$$36{,}000 \text{ acres} \times 43{,}560 \text{ ft}^2/\text{acre} \times 9.5 \text{ ft} \times 62.4 \text{ lb}/\text{ft}^3 = 9.30 \times 10^{11} \text{ lb of water.}$$

For the lower section,

$$60{,}000 \text{ acres} \times 43{,}560 \text{ ft}^2/\text{acre} \times 18 \text{ ft} \times 62.4 \text{ lb}/\text{ft}^3 = 2.93 \times 10^{12} \text{ lb of water.}$$

The background fluorescence was equivalent to about 0.04 μg/L of dye, therefore, a target concentration of at least 0.05 μg/L greater than the background fluorescence was chosen. The required mass of pure dye was computed by multiplying the target concentration by the mass of water. For the middle section,

$$0.05 \times 10^{-9} \times 9.30 \times 10^{11} \text{ lb} = 46.5 \text{ lb of pure dye.}$$

The required mass of 20-percent dye solution was 46.5 lb x (100/20) = 232.5 lb, which was rounded up to 250 pounds for the low-flow test. For the high-flow test, the quantity was increased to 375 pounds.

For the lower section, the required mass of pure dye was

$$0.05 \times 10^{-9} \times 2.93 \times 10^{12} \text{ lb} = 146.5 \text{ lb of pure dye.}$$

The required mass of 20-percent dye solution was 147 lb x (100/20) = 732.5 lb. For the low-flow test 700 lb were used, and for the high-flow test 750 lb were used.

Slug injections of tracer for the six tests were made at the location of greatest flow in the cross section as determined visually from the surface (table 1). The 100-lb injection for low-flow test in the upper section was made by pouring dye from a container over the side of a boat at a point in the center of flow. The other five injections were made by siphoning dye from drums as the boat was driven back and forth across the main part of the flow. The boat's propeller was used to help mix the dye and water.

The movement of the tracer through the network of sampling sites was monitored by taking water samples periodically at each site, and analyzing them in a field laboratory by using a Turner Designs model 10 fluorometer. Established procedures were used for calibrating the fluorometer to read directly in μg/L of dye (Wilson and others, 1984, p. 34). Water samples were taken just below the surface by using two methods: (1) dipping a sample bottle into the water by hand, and (2) automatic sampling with spring-loaded syringes mounted in unattended floating samplers. Previous work on nearby Lake Moultrie has shown that in shallow reservoirs, vertical mixing of the dye takes place rapidly enough so that surface samples are representative of the entire water column (Patterson and Harvey, 1986).

The sampling schedule varied according to the rate of change in concentration of dye. Samples were collected as often as every 5 minutes at sites near the point of injection, and as infrequently as once per week near the end of tests made in the lower section.

The relation of tracer concentration as a function of time was determined for each sampling site. The spatial distribution of the tracer cloud at various times also was determined.

RETENTION TIME AND FLOW PATTERNS

During the tracer tests under high-flow and low-flow conditions, 35 to 50 percent of the flow of the Santee River was derived from the Wateree River, with the remainder from Congaree River. Streamflow entering Lake Marion from the Santee River averaged three to four times higher during the high-flow tests than during the low-flow tests (table 1). At high and low flows, about 10 percent of the streamflow was diverted from the Santee River through each of two artificial cuts in the natural levee in upper Lake Marion, as determined by streamflow measurements in and upstream of the cuts. These cuts are at the Rimini Trestle and at Low Falls Landing (fig. 2).

In all six tests, the primary movement of the tracer was downstream, indicating a predominance of lake inflow and outflow over wind in controlling water movements. The movement and dispersion of the tracer clouds are summarized in table 2 for Lakes Marion and Moultrie. Travel times represent the time required for the peak tracer concentration to reach a station. Retention times represent the time required for all the measurable tracer to be flushed from the reach.

Table 2.--*Travel times and dilution data for tracer tests in Lakes Marion and Moultrie, 1984*

[Site locations are shown in figures 2, 3, and 4; µg/L, micrograms per liter; --, not applicable]

			High flow					
Station	River miles below Eastover	Intervening miles	Travel time from Eastover (days)	Intervening travel time (days)	Miles per day	Pounds of pure dye injected	Peak concentration (µg/L)	Dilution factor[a] (µg/L)/lb
Wateree River near Eastover[b]	0	--	0	--	--	25	--	--
Wateree/Congaree River confluence	11	11	.38	0.38	29	--	9.9	4.0×10^{-1}
Santee River at Rimini Trestle[b]	23	12	.64	.26	46	75	2.5	1.0×10^{-1}
Santee River below Low Falls Landing (fig. 3)	25	2	.69[d]	.05[d]	40[d]	--	56	7.5×10^{-1}
Santee River at Tudic Cut (fig. 4)	27	2	.75	.06	33	--	53	7.1×10^{-1}
Santee River at Browns Cut (fig. 4)	29	2	.90	.15	13	--	30	4.0×10^{-1}
Channel Marker 99[c] (fig. 4)	33	4	1.6	.70	5.7	--	13	1.7×10^{-1}
Interstate Highway 95 bridge[b] (fig. 4)	38	5	3.9	2.3	2.2	150	.5	6.7×10^{-3}
Channel Marker 38[c] (fig. 2)	49	11	7.1	3.2	3.4	--	1.9	1.3×10^{-2}

Table 2.--*Travel times and dilution data for tracer tests in Lakes Marion and Moultrie, 1984--Continued*

[Site locations are shown in figures 2, 3, and 4; µg/L, micrograms per liter; --, not applicable]

			High flow					
Station	River miles below Eastover	Intervening miles	Travel time from Eastover (days)	Intervening travel time (days)	Miles per day	Pounds of pure dye injected	Peak concentration (µg/L)	Dilution factor[a] (µg/L)/lb
Diversion Canal (Lake Marion end) (fig. 2)	59	10	14	6.9	1.4	--	0.21	1.4×10^{-3}
Diversion Canal[b] (Lake Moultrie end) (fig. 2)	64	5	14	.10[d]	48[d]	100	--	--
Channel Marker 4[c,e] (fig. 2)	68	4	17	3.1	1.2	--	.46	4.6×10^{-3}
Pinopolis Dam[e] (fig. 2)	74	6	23	6	1.0	--	.11	1.1×10^{-3}

Table 2.--*Travel times and dilution data for tracer tests in Lakes Marion and Moultrie--Continued*

[Site locations are shown in figures 2, 3, and 4; µg/L, micrograms per liter; --, not applicable]

Station	River miles below Eastover	Intervening miles	Low flow					
			Travel time from Eastover (days)	Intervening travel time (days)	Miles per day	Pounds of pure dye injected	Peak concentration (µg/L)	Dilution factor[a] (µg/L)/lb
Wateree River near Eastover[b] (fig.2)	0	--	0	--	--	20	--	--
Wateree/Congaree River confluence (fig.2)	11	11	.53[d]	0.53[d]	21[d]	--	11[d]	$5.5x10^{-1}$
Santee River at Rimini Trestle[b] (fig. 3)	23	12	1.0	.47	26[d]	50	2.8	$1.4x10^{-1}$
Santee River below Low Falls Landing (fig. 3)	25	2	1.1	.10	20	--	67	1.3
Santee River at Tudic Cut (fig. 4)	27	2	1.2[d]	.12[d]	17[d]	--	60[d]	1.2
Santee River at Browns Cut (fig. 4)	29	2	1.3	.12	17	--	22	$4.4x10^{-1}$

Table 2.--*Travel times and dilution data for tracer tests in Lakes Marion and Moultrie--Continued*

[Site locations are shown in figures 2, 3, and 4; µg/L, micrograms per liter; --, not applicable]

Station	River miles below Eastover	Intervening miles	Low flow					
			Travel time from Eastover (days)	Intervening travel time (days)	Miles per day	Pounds of pure dye injected	Peak concentration (µg/L)	Dilution factor[a] (µg/L)/lb
Channel Marker 99[c] (fig. 4)	33	4	3.8	2.5	1.6	--	4	8.0×10^{-1}
Interstate Highway 95 bridge[b] (fig. 4)	38	5	8.5	4.7	1.1	140	.12	2.4×10^{-3}
Channel Marker 38[c] (fig. 2)	49	11	22	13	.8	--	.18	1.3×10^{-3}
Diversion Canal (Lake Marion end) (fig. 2)	59	10	41	19	.5	--	.15	1.1×10^{-3}
Diversion Canal[b] (Lake Moultrie end) (fig. 2)	64	5	41	.31[d]	16[d]	150	--	--
Channel Marker 4[c,e] (fig. 2)	68	4	44	2.9	1.4	--	.32	2.1×10^{-3}
Pinopolis Dam[e] (fig. 2)	74	6	58	14	.4	--	.17	1.1×10^{-3}

[a]Dilution factor is defined as the concentration of tracer at the indicated location, resulting from each pound of tracer injected at corresponding location.
[b]Denotes tracer injection site.
[c]Channel markers referenced in this report and shown on figure 2 were placed and renumbered in 1990.
[d]Denotes estimated value.
[e]Data from Patterson and Harvey (1986).

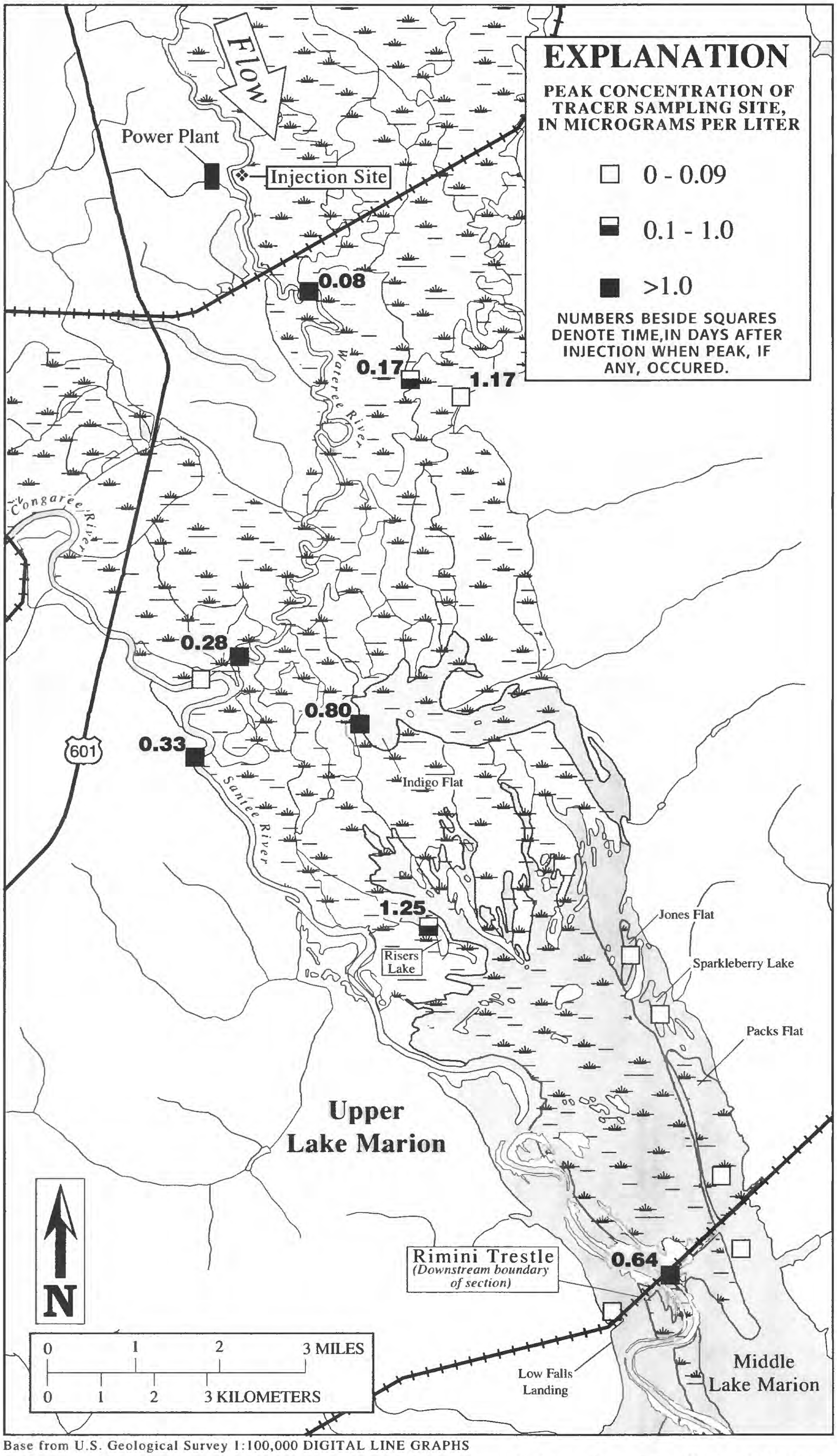
High-Flow Tests

The high-flow tracer injection, in the upper section of Lake Marion, was made on February 6, 1984, in the Wateree River at the power plant near Eastover. The tracer moved downstream as a coherent cloud in the Wateree and Santee Rivers without entering the Congaree River. The peak tracer concentration moved downstream at an average of about 29 miles per day (1.21 miles per hour) in the tightly meandering Wateree River. The velocity increased to an average of 46 miles per day in the Santee River because of the slightly steeper gradient, but gradually decreased again as the backwater from Lake Marion was encountered (table 2). Significant amounts of tracer were diverted from the rivers into flood-plain channels, producing tracer peaks at Indigo Flat and Risers Lake (fig. 3). Tracer was not detected, however, at the eastern edge of the flood plain (Jones Flat, Sparkleberry Lake). In this area, flow entering the lake from small eastern tributaries prevents water derived from the Wateree and Santee Rivers from reaching the shore.

The high-flow tracer injection, in the middle section of Lake Marion, was made on March 26, 1984, just upstream from Rimini Trestle. The cloud separated into three parts as river water was diverted through cuts in the natural levees at Rimini Trestle and Low Falls Landing (fig. 4, at end of report). The transition from river channel to open lake in the vicinity of Browns Cut was evidenced by a marked reduction in speed of the tracer (table 2), and in the magnitude of the peak concentration as the cloud dispersed in the lake. The bulk of the tracer cloud followed a flow path generally along the southwestern side of the lake. By the second day, the tracer cloud emanating from the cut at Low Falls Landing coalesced with the main tracer cloud emanating from Browns Cut (fig. 4 and 5, at end of report). A smaller tracer cloud emanated from the cut along Rimini Trestle, and moved down the northeastern side of the lake and back toward the main tracer cloud on the southwestern side. Little or no tracer was detected to the east of Persanti Island. In this part of Lake Marion, near the mouth of Jacks Creek, flow entering the lake from small eastern tributaries prevents water derived from the Santee River from reaching the shore. On the southwestern side of the lake, however, closer to the submerged river channel, tracer was detected in Poplar Creek (figs. 6-9, at end of report).

By the fourth day, most of the tracer had passed under the Interstate Highway 95 bridge (fig. 8). By the seventh day, little dye was detectable upstream from the Interstate Highway 95 bridge (fig. 9).

The high-flow tracer injection, in the lower section of Lake Marion, was made on March 7, 1984, at the Interstate Highway 95 bridge. The injection was made under the wider, western-most opening of the bridge in the vicinity of the submerged Santee River channel. The tracer cloud remained relatively intact as it gradually spread down the southwestern shore of the lake during the first day (fig. 10, at end of report). On the second day, the expanding tracer cloud extended from the southwestern shore to the northeastern shore. The most rapid downstream movement was slightly to the southwest of the centerline of the lake (fig. 11, at end of report). Toward the shores, especially the northeastern shore, the tracer spread into water that moved downstream



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 3.--Peak tracer concentrations and travel times in upper Lake Marion during high-flow test, February 6-7, 1984.

more slowly. This accounts for the "U"-shaped configuration of the tracer cloud in figure 11. On the third day, the relatively shallow, wooded area along the centerline of the lake retarded the downstream movement of the tracer cloud in the middle of the lake, while the relatively deep channels on either side allowed more rapid movement (fig. 12, at end of report). This trend continued through the seventh day when the leading edge of the tracer cloud approached Wilson Dam and the entrance to the diversion canal (fig. 13, at end of report). The tracer cloud had a longer residence time in the slower water in the northeastern corner of this section of the lake than in the faster water along the southeastern shore (figs. 13-15, at end of report). After the twelfth day, no concentrations of tracer significantly higher than background levels were found at any of the sampling sites in this section of the lake.

During the high-flow test in lower Lake Marion, tracer was detected at every station monitored, with the exception of those in the large cove near Eutaw Springs and at the mouth of Taw Caw Creek. Water in the larger coves and creeks appeared to be primarily from tributary inflow, and underwent little mixing with water from the main part of the lake.

The approximate high-flow travel time between Eastover and the diversion canal entrance, as calculated from the travel times for the three high-flow injection tests, was 14 days. Based on data from the Lake Moultrie Study (Patterson and Harvey, 1986), travel time through Lakes Marion and Moultrie was 23 days. Travel times for intermediate locations are given in table 2.

Based on the retention times for the three high-flow tests, the approximate high-flow retention time in Lake Marion is about 20 days. This compares favorably with a theoretical high-flow retention time of about 23 days, which is approximated as the lake volume (about 1,350,000 acre-ft) (Patterson and Logan, 1988) divided by the average inflow during the high-flow tests (about 29,000 ft^3/s or 57,500 acre-ft/d).

Low-Flow Tests

As in the high-flow tests, the tracer moved downstream through the upper section as a coherent cloud following a low-flow injection in the Wateree River near Eastover on October 2, 1984. The tracer cloud traveled more slowly than during the high-flow test, requiring 1 day rather than 0.64 day to reach the Rimini Trestle in upper Lake Marion. Concentrations of tracer in the flood plain of the Wateree River were lower than during the high-flow study, because the water level in the river was low enough to prevent flow into the side-branching channels that lead to the submerged Santee River flood plain in upper Lake Marion (fig. 16).

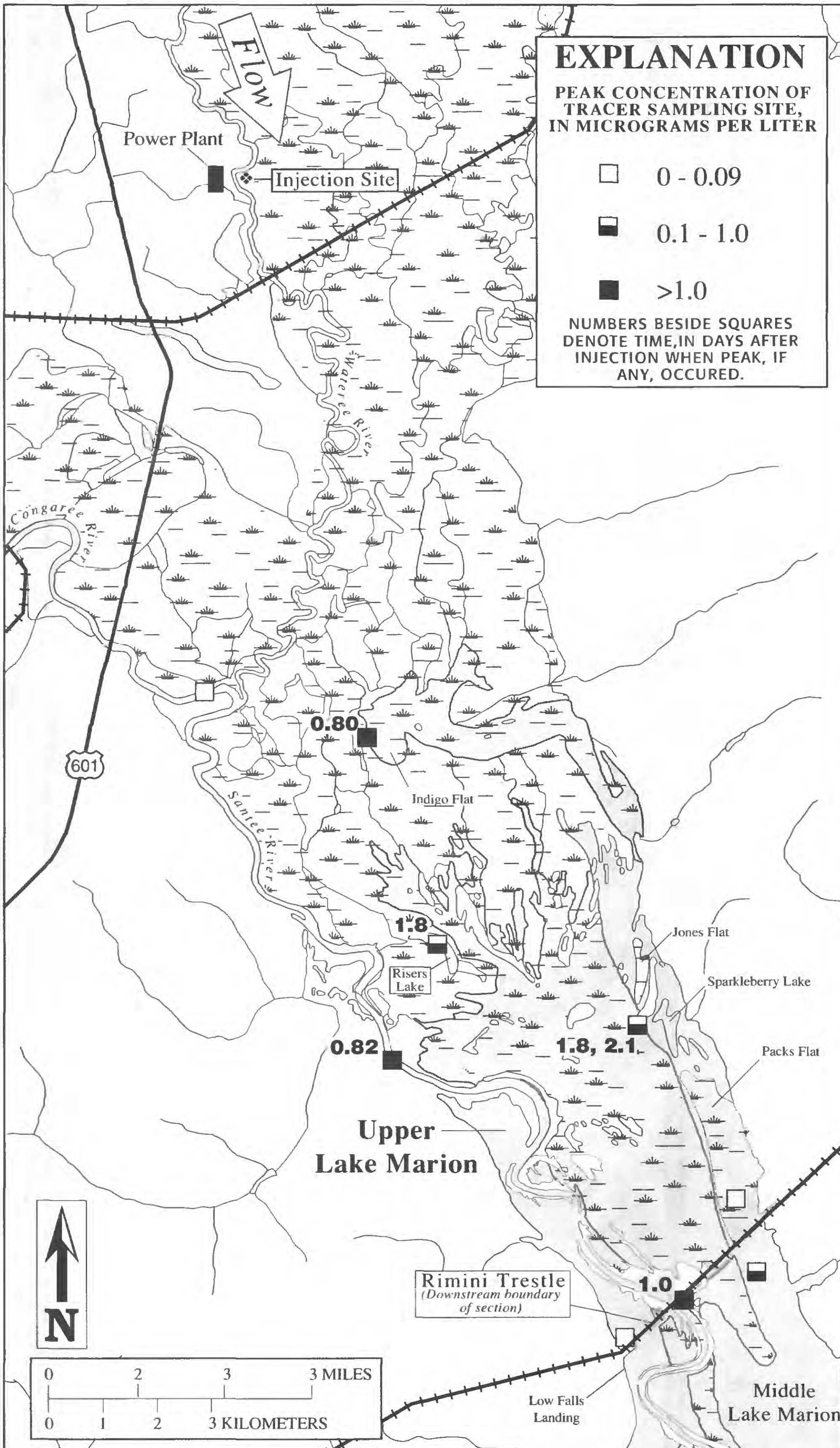


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Figure 16.--Peak tracer concentrations and travel times in upper Lake Marion during low-flow test, October 2-3, 1984.

In the middle section, following the low-flow injection just upstream from the Rimini Trestle on November 27, 1984, the tracer followed a pattern similar to that of the high-flow test for this section, but again the velocity was less (figs. 17-22, at end of report). The travel time from the Rimini Trestle to Browns Cut, the downstream limit of protruding natural levees, was 0.3 day, as opposed to 0.26 day for the high-flow test. The travel time for movement of the peak tracer concentration to the Interstate Highway 95 bridge was 7.5 days as opposed to 3.2 days during the high-flow test (table 2). As in the high-flow test, some of the tracer was diverted through cuts at Rimini Trestle and at Low Falls Landing forming three main separate clouds (fig. 17). The middle and western clouds subsequently merged (figs. 18,19). As in the high-flow test, tracer was detected in Poplar Creek but not in the Jacks Creek area behind Persanti Island.

Following the low-flow injection for the lower section at the Interstate Highway 95 bridge on October 6, 1984, the tracer cloud moved slowly down the southwestern shore as it gradually dispersed (figs. 23-27, at end of report). Ten days were required for the tracer to spread across the lake, as opposed to 2 days during the high-flow test (fig. 28, at end of report). The tracer moved about 5 miles down the lake during the next 10 days (figs. 29, 30, at end of report). By the 43d day, the tracer had been partially flushed out of the lake (fig. 31, at end of report). On the 51st day, the only sampling site with a tracer concentration as high as 0.1 μg/L was at the Lake Marion end to the diversion canal (fig. 32, at end of report).

As in the high-flow test, tracer was not detected at the mouth of Taw Caw Creek. In contrast to the high-flow test, however, the tracer was not detected in or at the mouth of Polly Cantey Cove on the northeastern shore near the Interstate Highway 95 bridge. Tracer was detected at station 5A in the large cove near Eutaw Springs. Tracer remained in this cove for several days after the main part of the cloud had passed beyond the mouth of the cove.

The total low-flow travel time for movement of the peak tracer concentration from Eastover to the diversion canal entrance was approximately 41 days (table 2). Based on travel times from the Lake Moultrie study (Patterson and Harvey, 1986), an approximate low-flow travel time through Lakes Marion and Moultrie would be about 58 days.

The total retention time for Lake Marion under low-flow conditions was about 60 days. This compares with a theoretical low-flow retention time of about 73 days, which is approximated as the lake volume (about 1,350,000 acre-ft) divided by the average inflow during the low-flow tests (about 9,400 ft^3/s or 18,600 acre-ft/d).

SUMMARY

Dye tracer tests were made on Lake Marion in 1984 to determine flow patterns and retention times under conditions of high and low flow (approximately 29,000 and 9,000 ft^3/s, respectively). These tests indicated that the primary factors controlling movement of water in Lake Marion were lake inflow and outflow in that the tracer moved consistently downstream. In this respect, Lake Marion differs from Lake Moultrie, where wind-driven currents are the primary factor controlling water movement. The reason for the difference is probably the elongated shape of Lake Marion and the presence of many protruding trees that shelter some areas from the wind. Movement of the tracer through Lake Marion gradually slowed as the lake widened. The tracer was not detected in some of the more isolated coves and along the shoreline of the northeastern part of the lake near the mouth of Taw Caw Creek.

Travel times for the peak tracer concentration through the lake were approximately 14 days during high flow and approximately 41 days during low flow. Retention times obtained from the dye tests were about 20 days during high flow and about 60 days during low flow.

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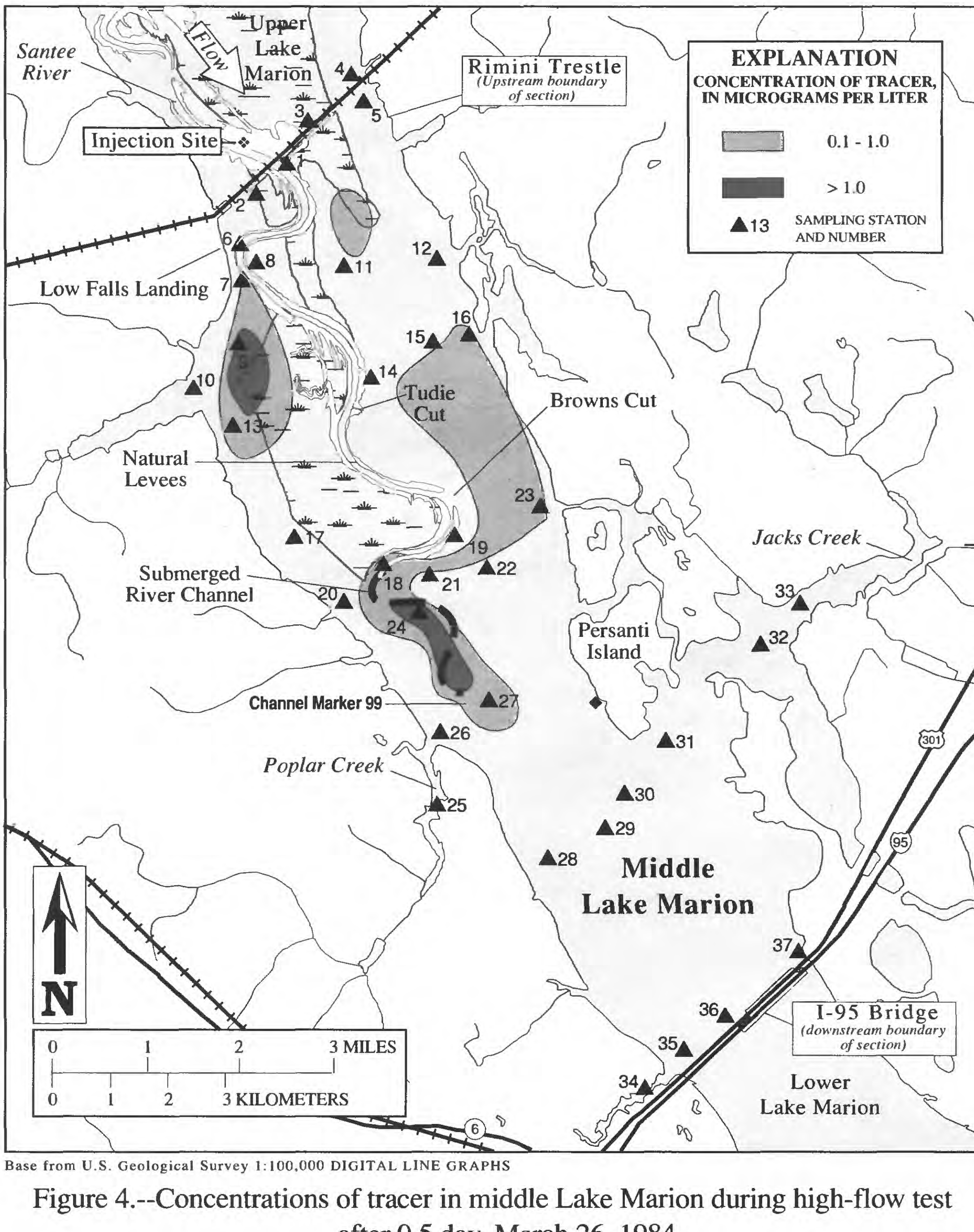
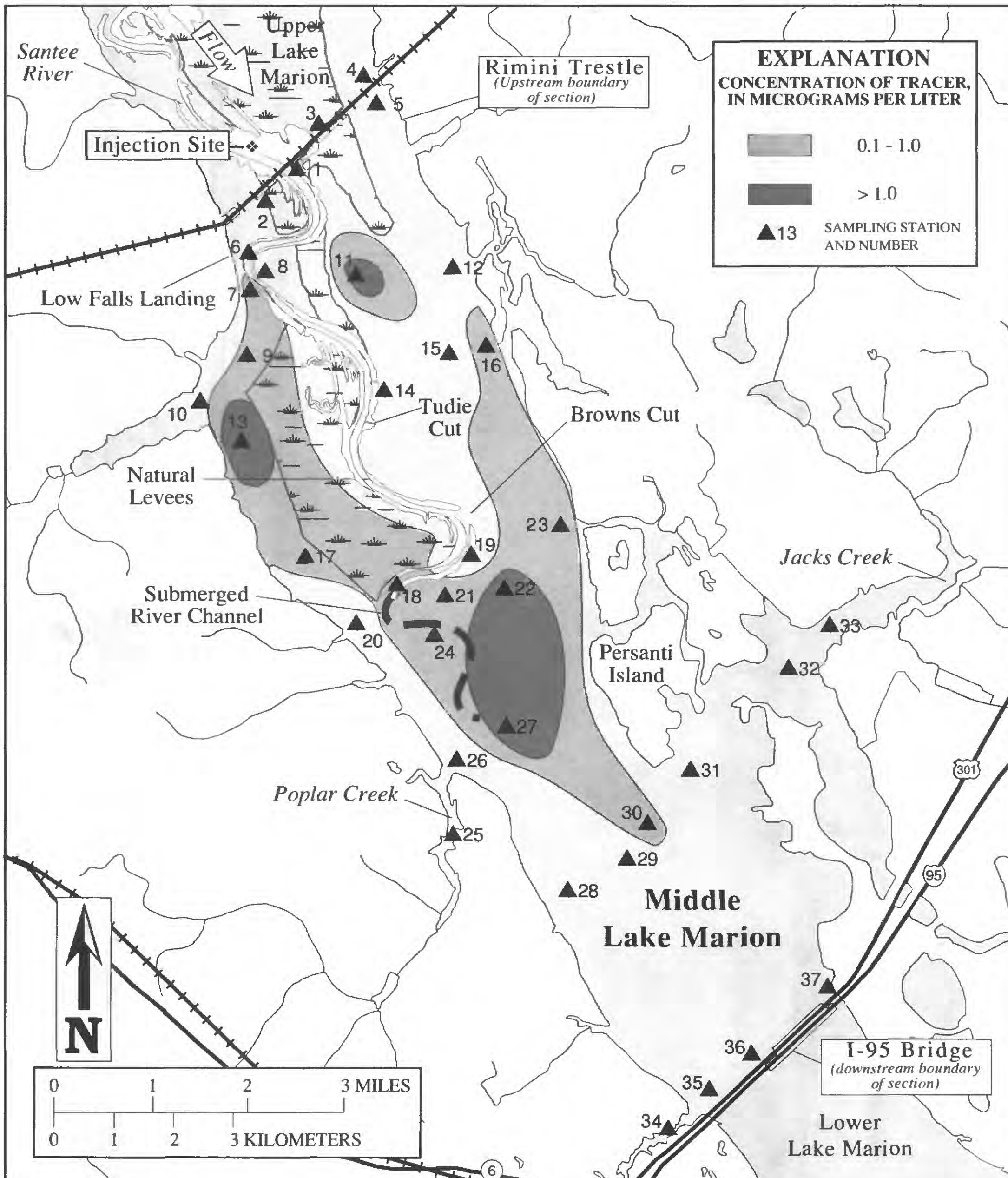
FIGURES 4-9

High-flow test in middle Lake Marion, March 26 - April 2, 1984.



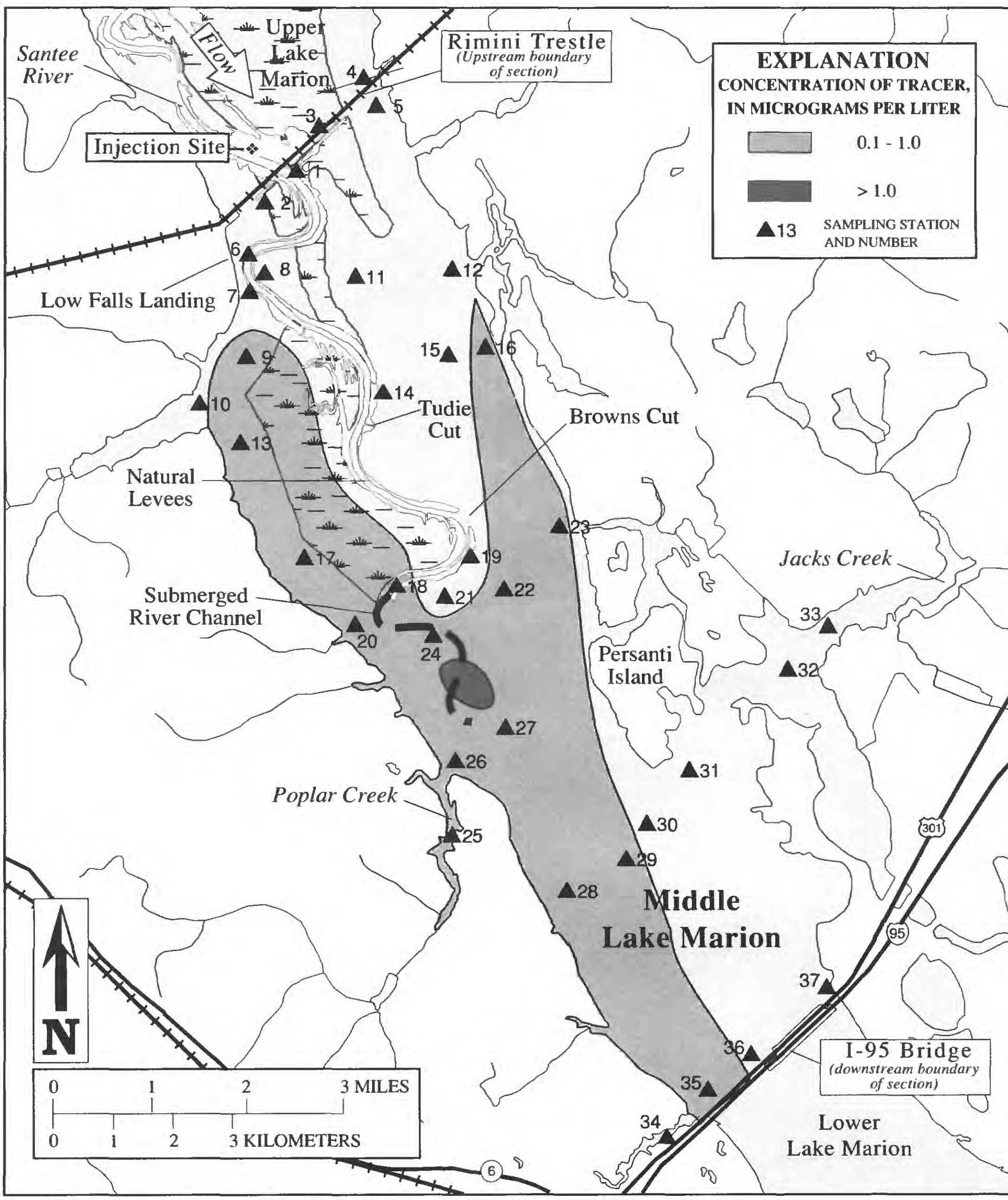
Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 4.--Concentrations of tracer in middle Lake Marion during high-flow test after 0.5 day, March 26, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 5.--Concentrations of tracer in middle Lake Marion during high-flow test after 1 day, March 26-27, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 6.--Concentrations of tracer in middle Lake Marion during high-flow test after 2 days, March 26-28, 1984.

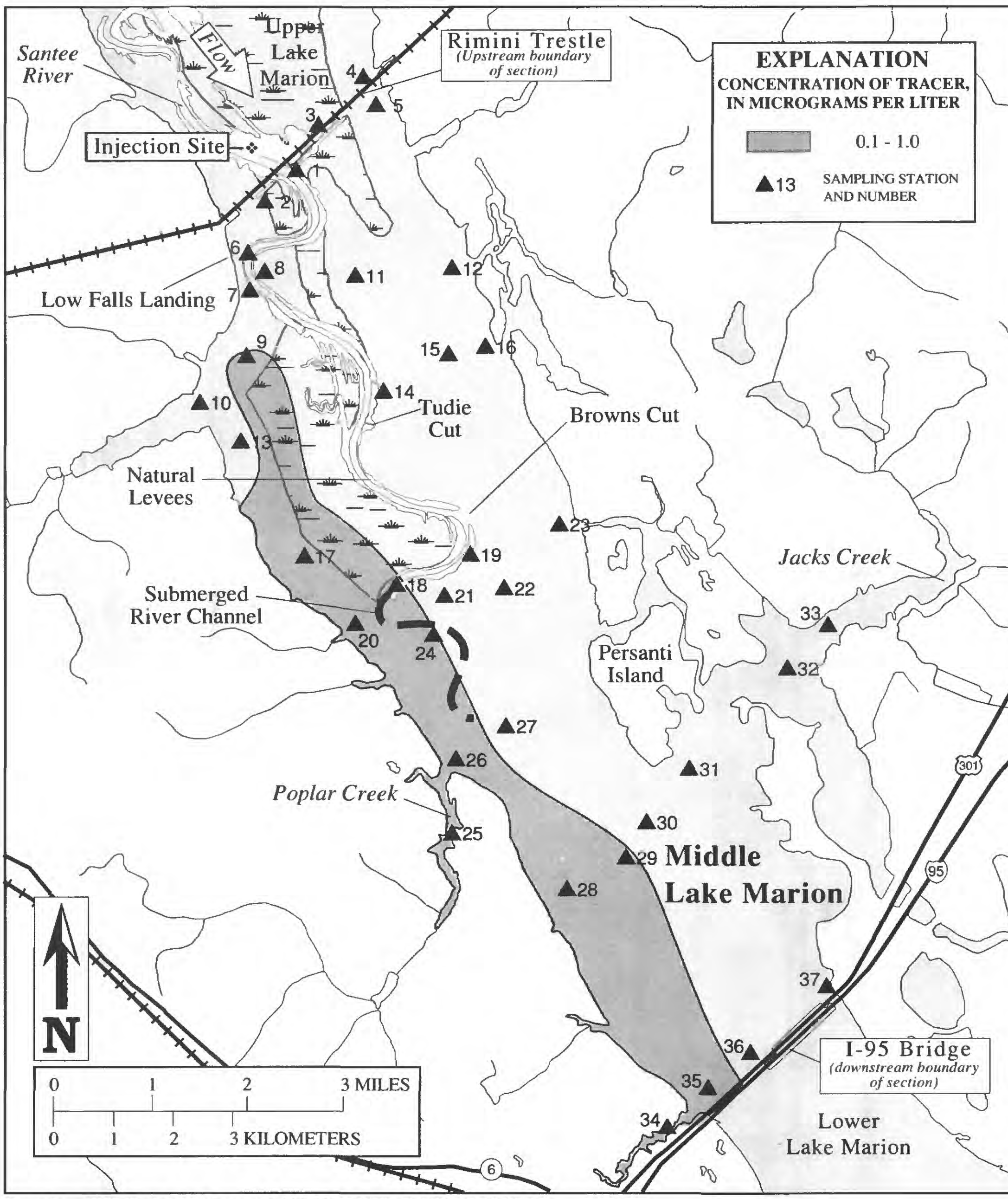
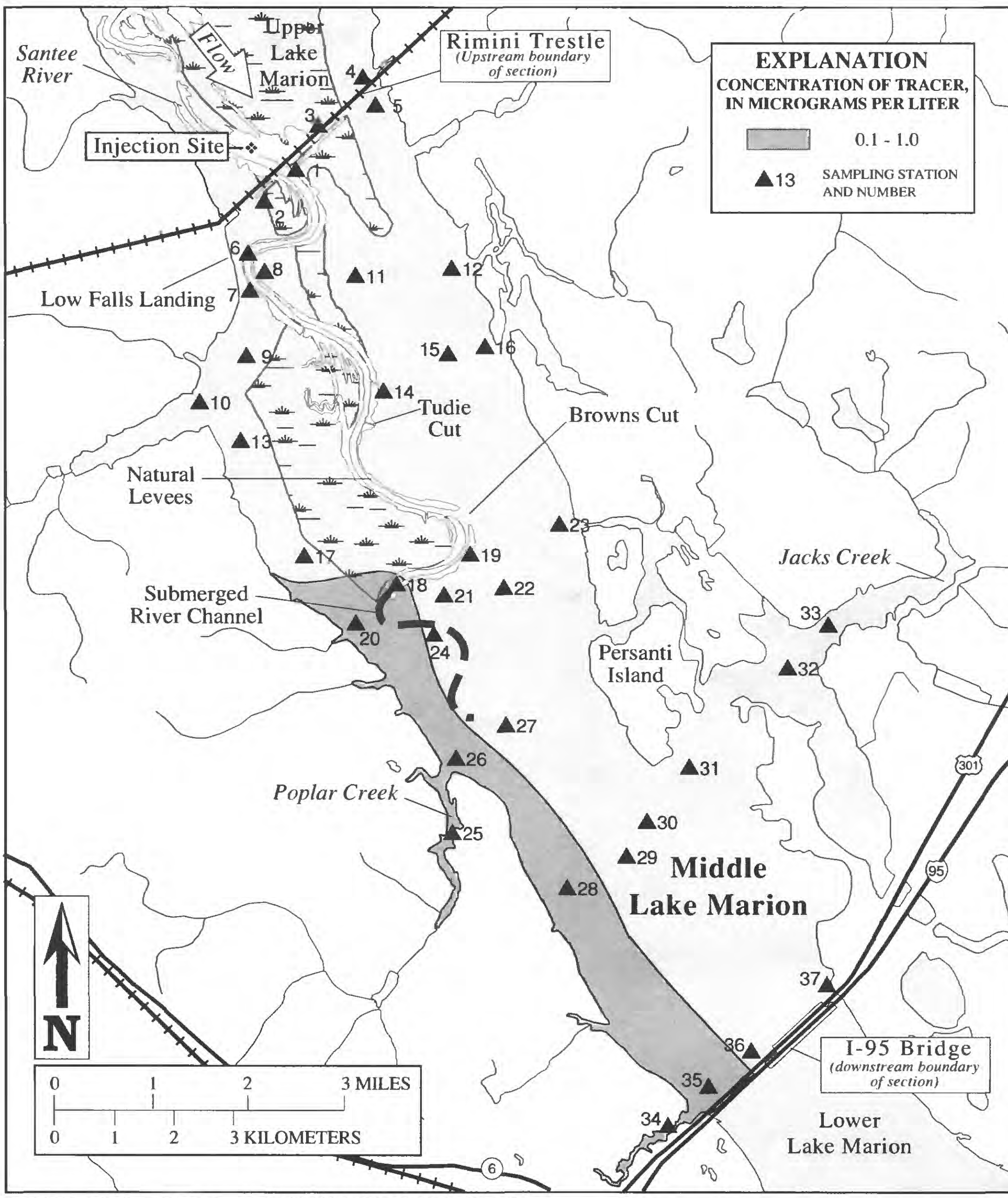
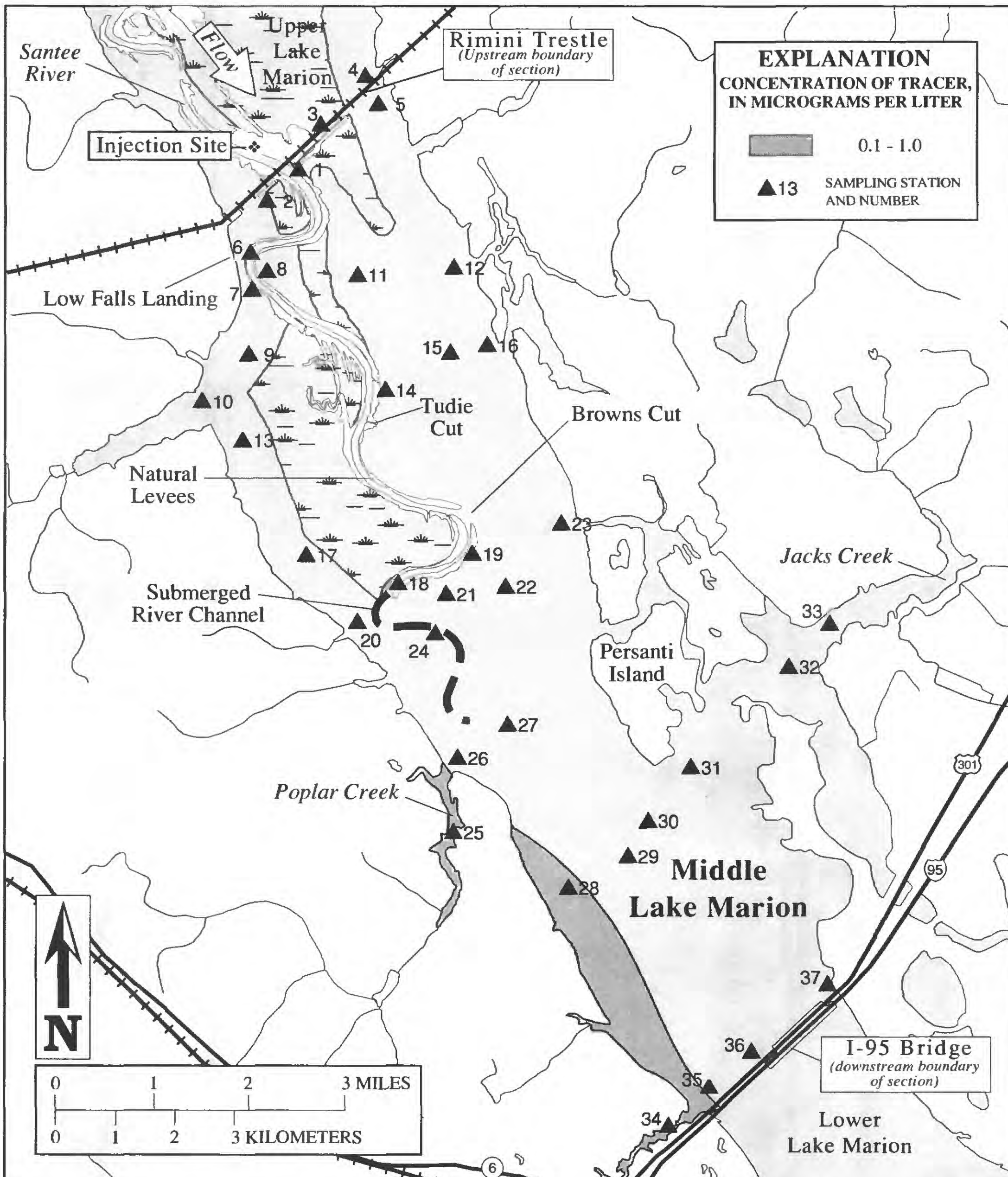


Figure 7.--Concentrations of tracer in middle Lake Marion during high-flow test after 3 days, March 26-29, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 8.--Concentrations of tracer in middle Lake Marion during high-flow test after 4 days, March 26-30, 1984.

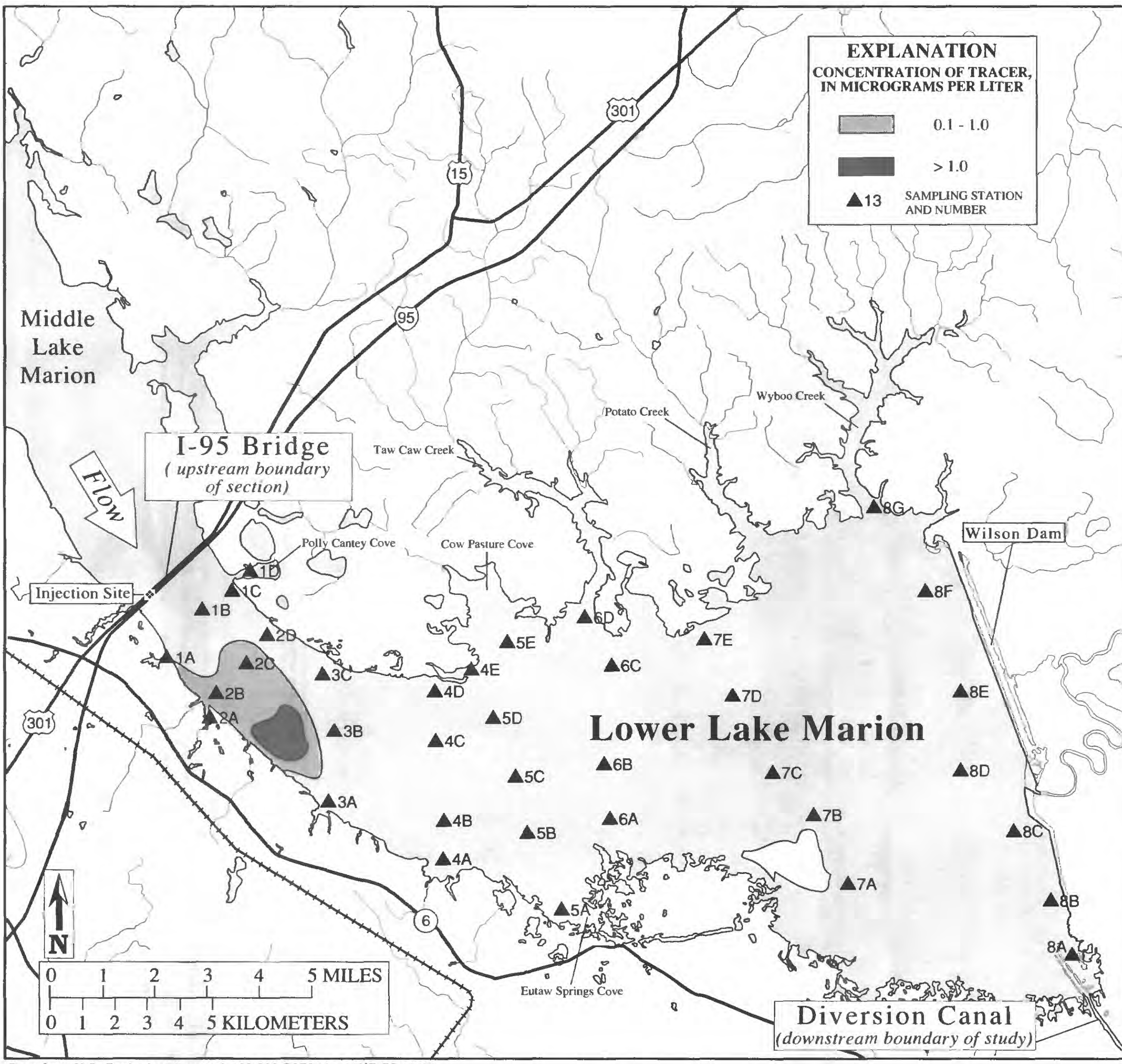


Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 9.--Concentrations of tracer in middle Lake Marion during high-flow test after 7 days, March 26-April 2, 1984.

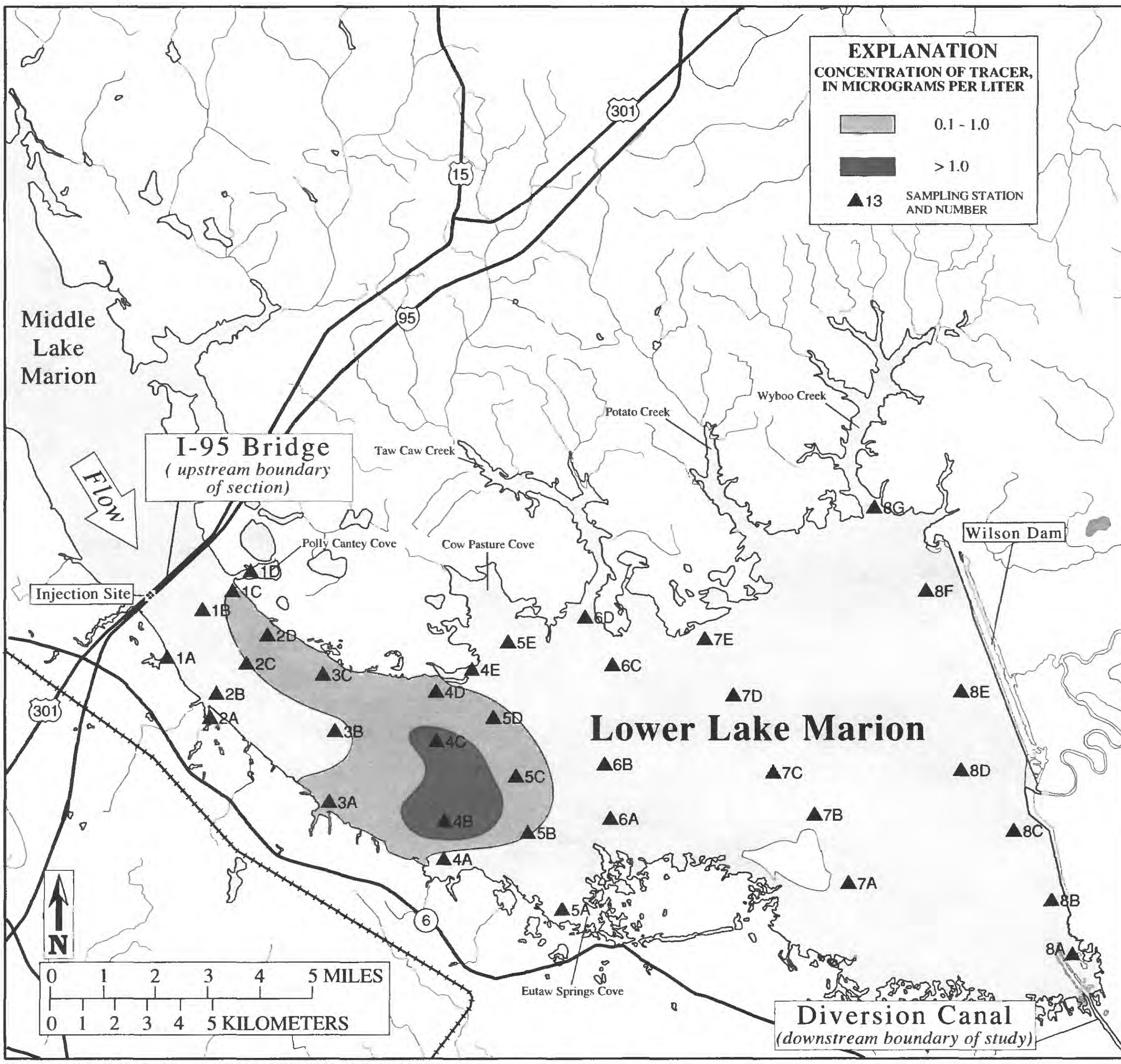
FIGURES 10-15

High-flow test in lower Lake Marion, March 7-19, 1984.



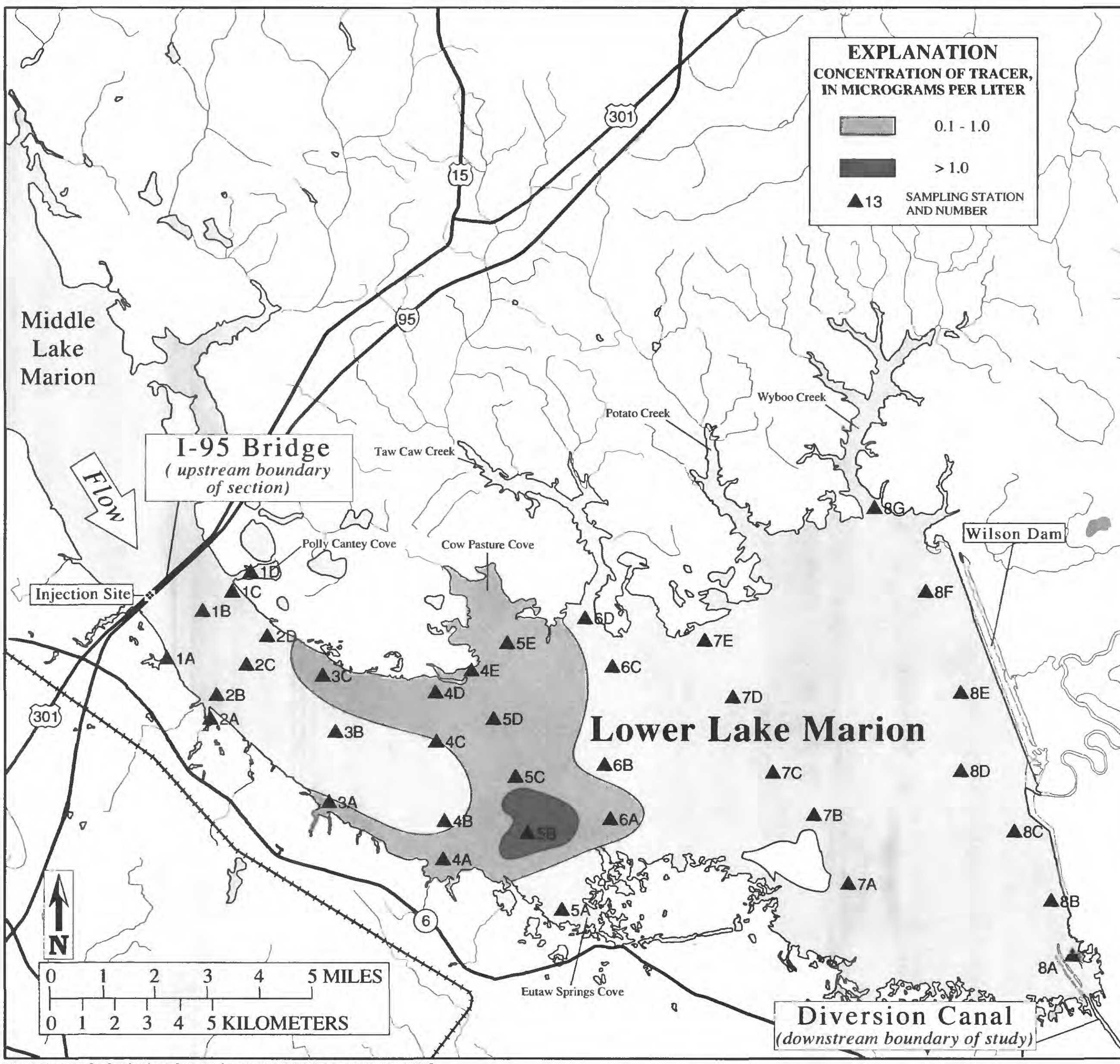
Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 10.--Concentrations of tracer in lower Lake Marion during high-flow test after 1 day, March 7-8, 1984.



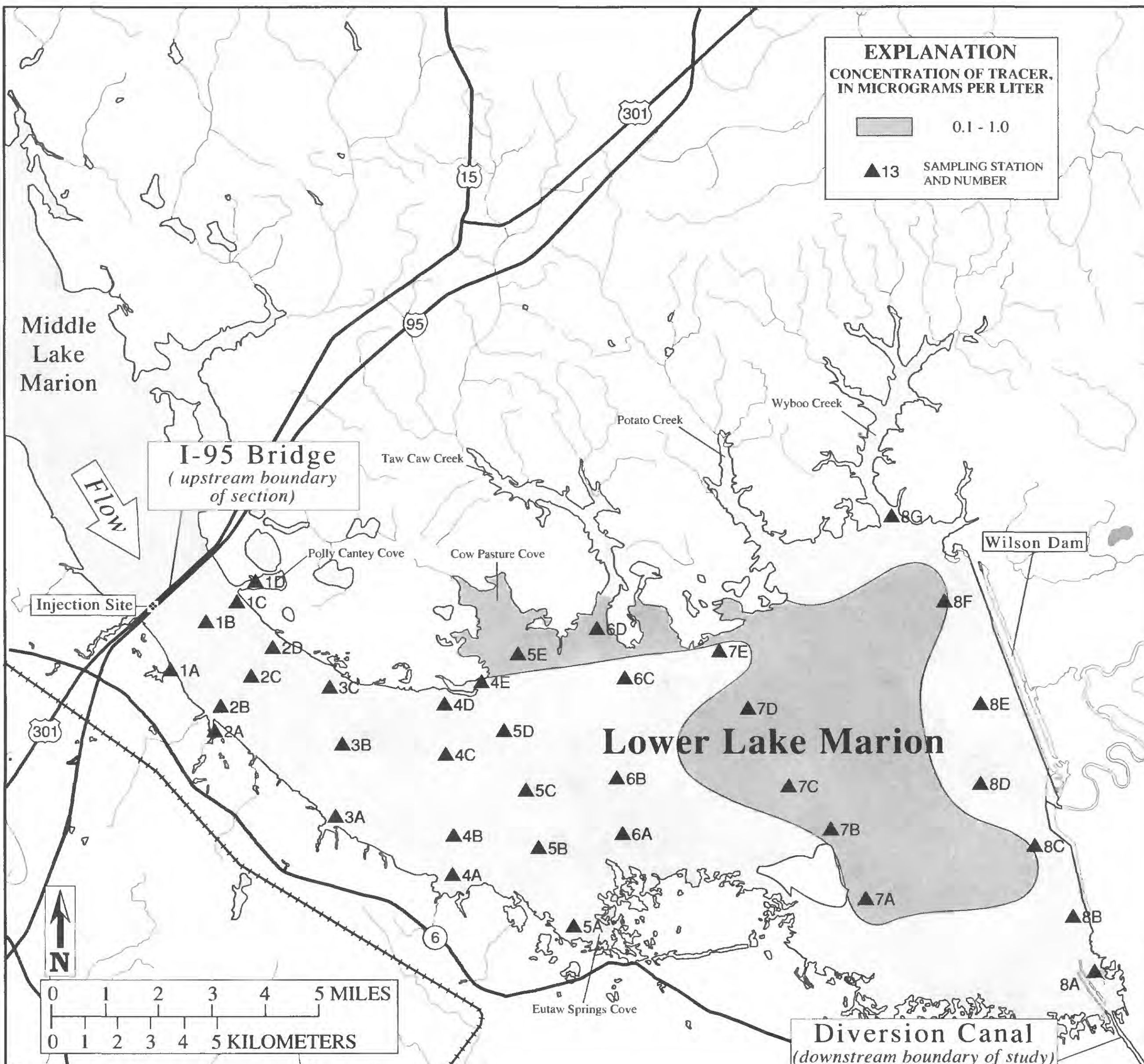
Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 11.--Concentrations of tracer in lower Lake Marion during high-flow test after 2 days, March 7-9, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 12.--Concentrations of tracer in lower Lake Marion during high-flow test after 3 days, March 7-10, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 13.--Concentrations of tracer in lower Lake Marion during high-flow test after 7 days, March 7-14, 1984.

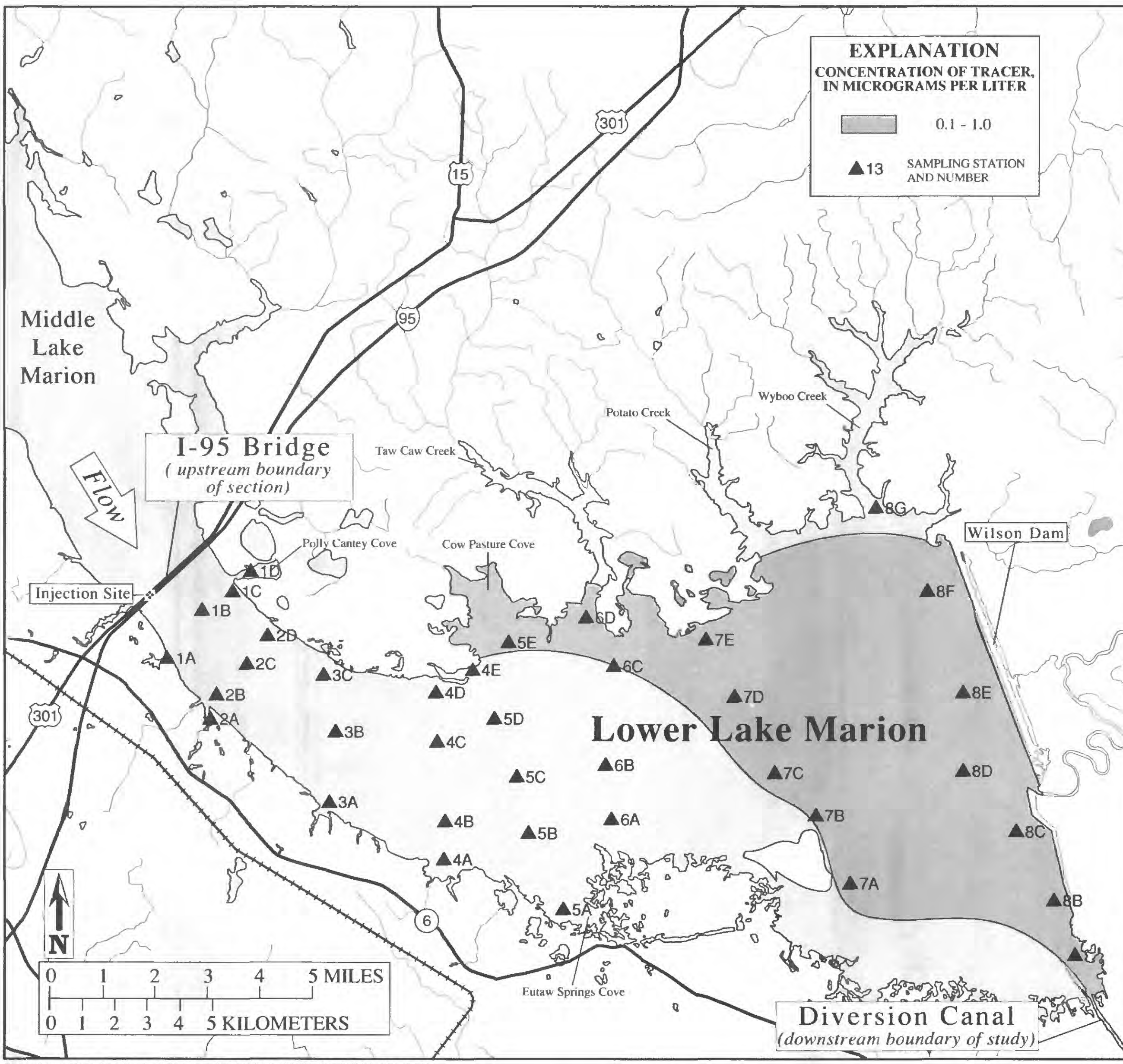
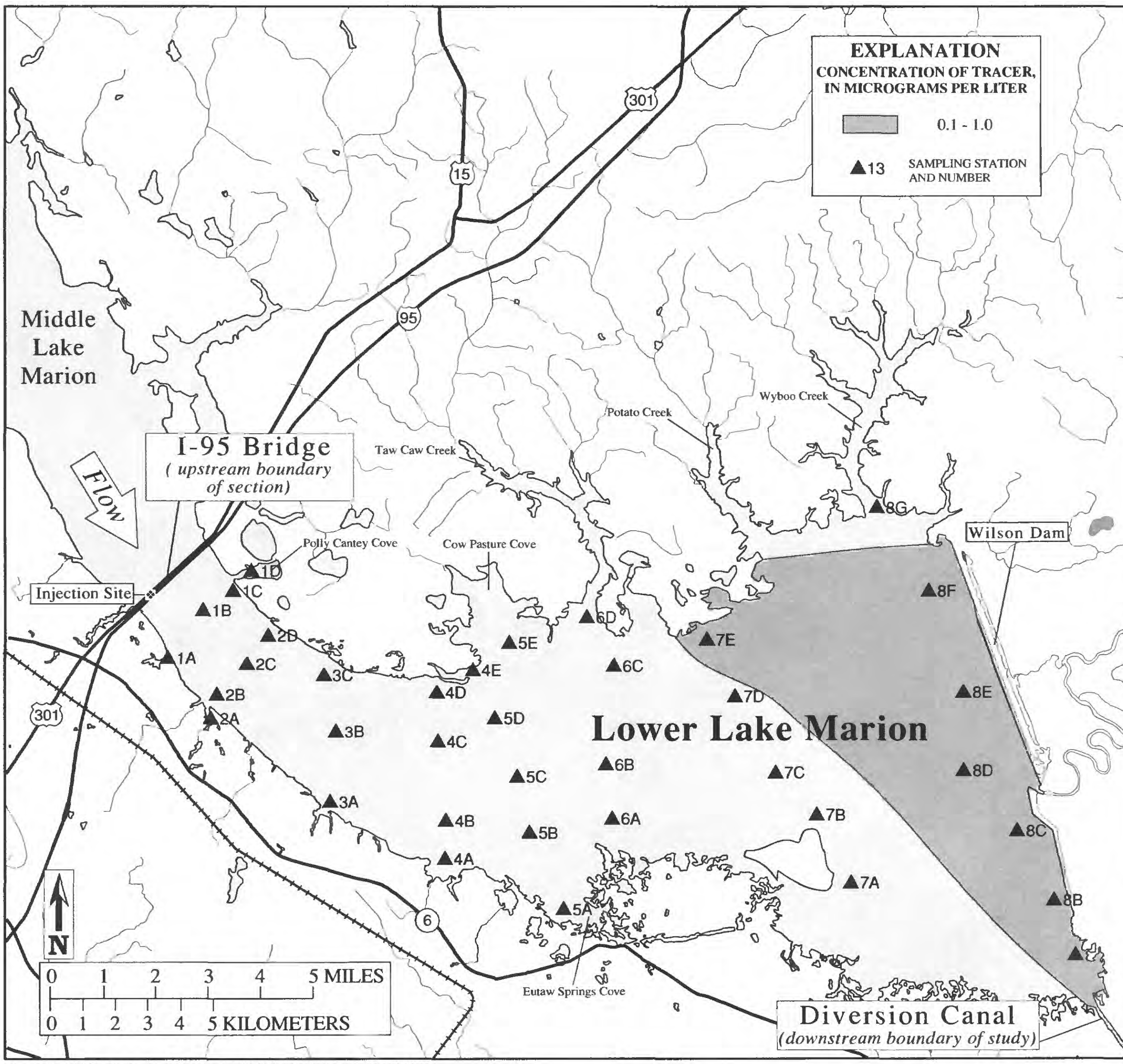


Figure 14.--Concentrations of tracer in lower Lake Marion during high-flow test after 8 days, March 7-15, 1984.

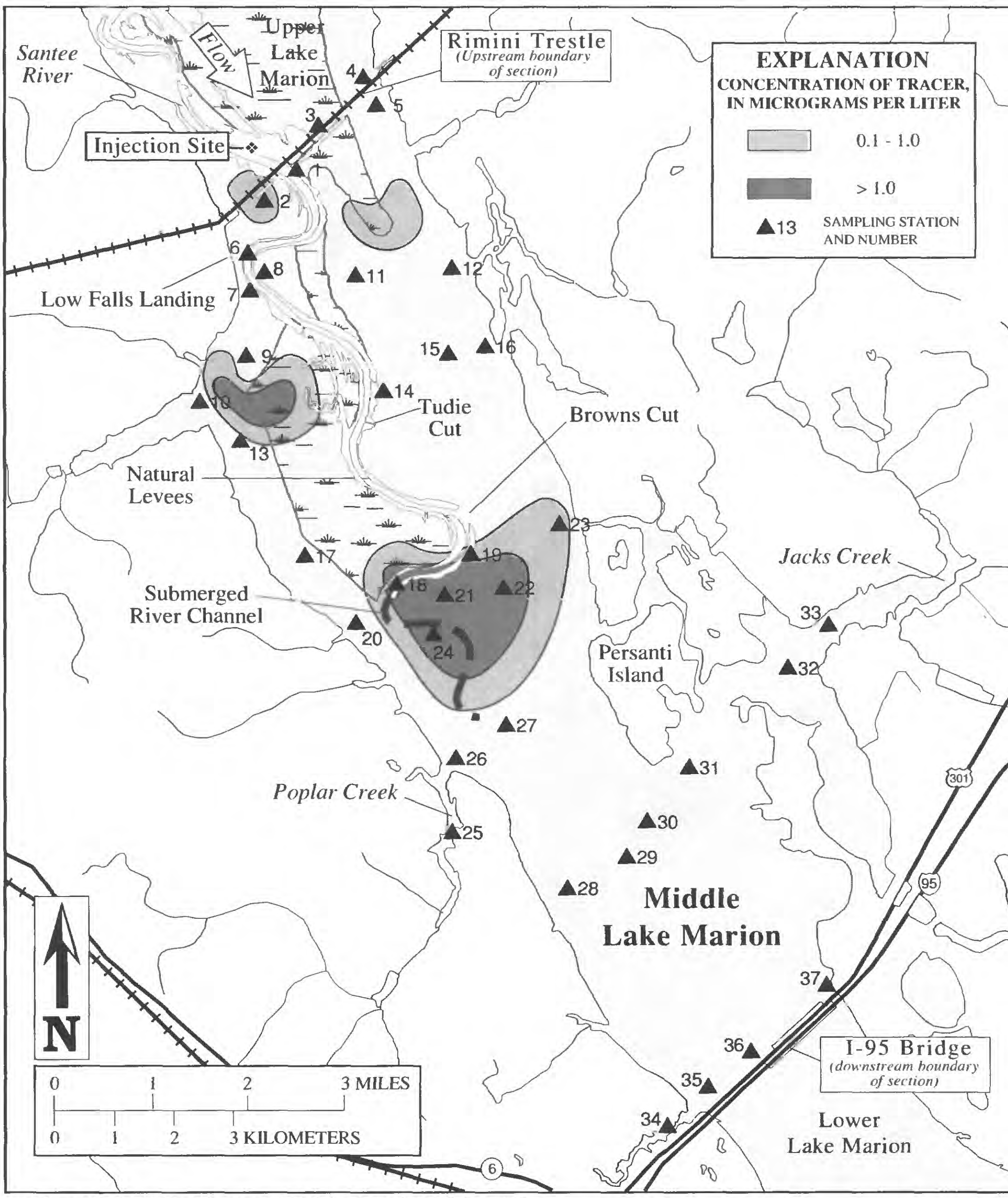


Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 15.--Concentrations of tracer in lower Lake Marion during high-flow test after 12 days, March 7-19, 1984.

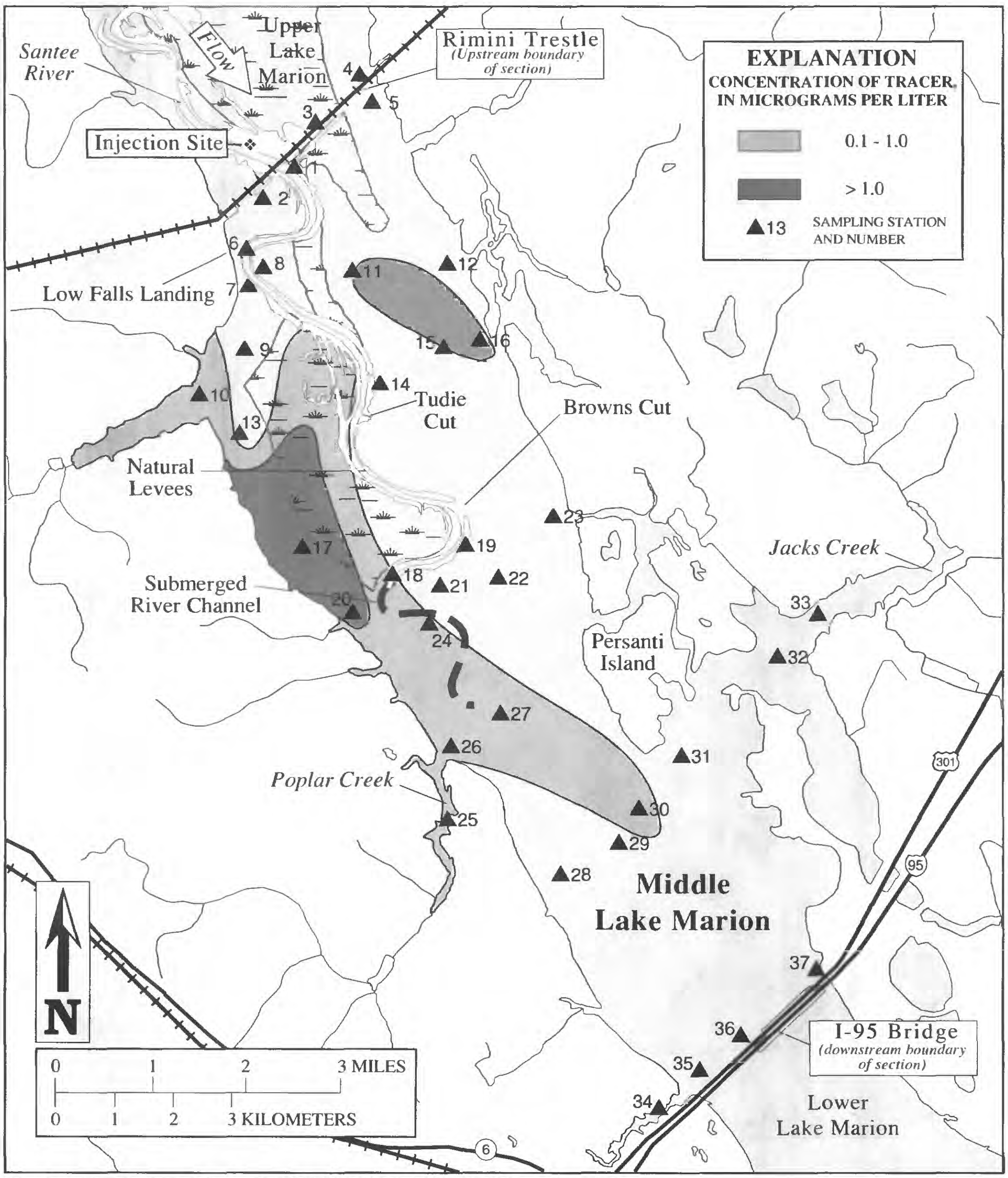
FIGURES 17-22

Low-flow test in middle Lake Marion, November 27 - December 5, 1984.



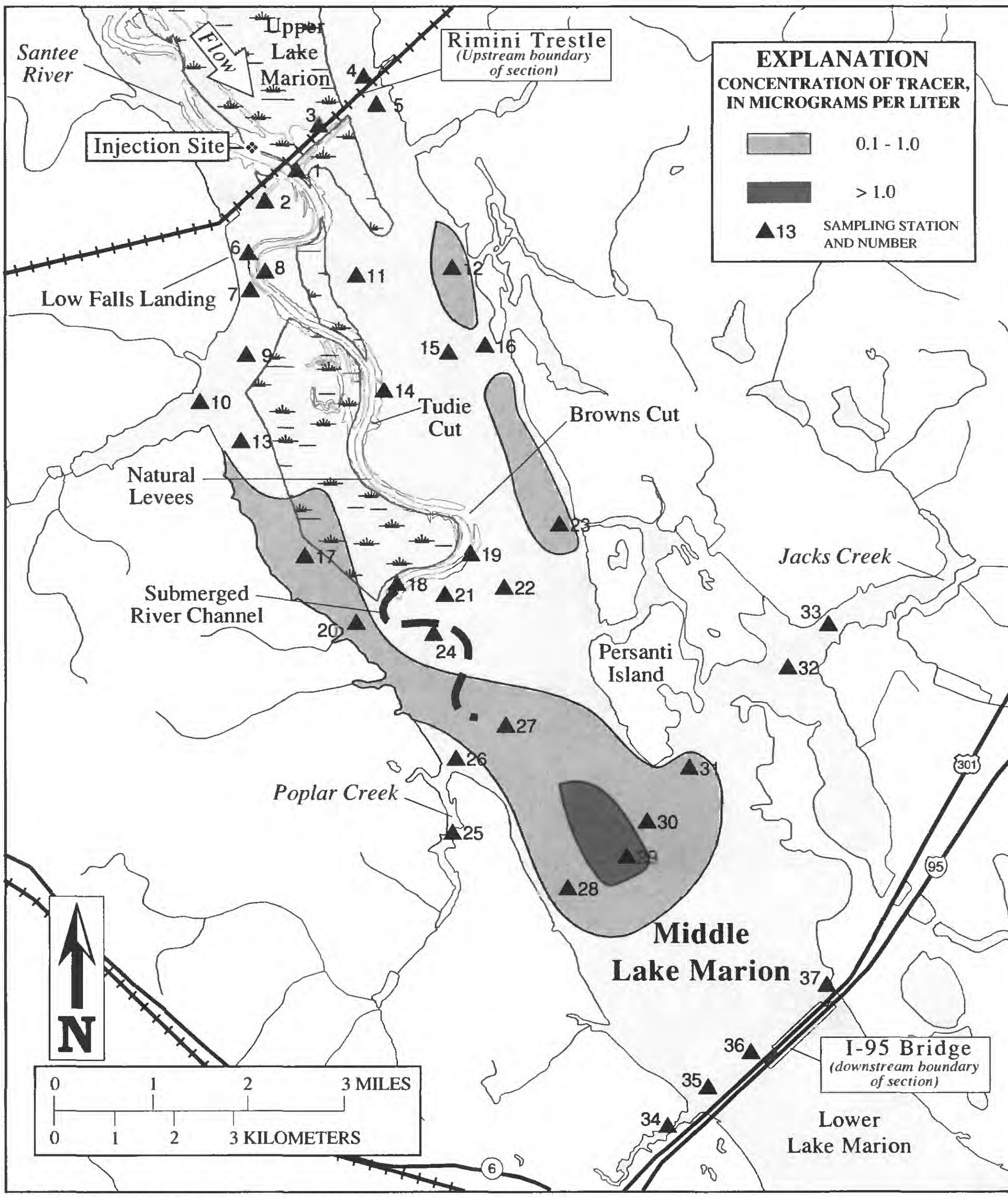
Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 17.--Concentrations of tracer in middle Lake Marion during high-flow test after 1 day, November 27-28, 1984.



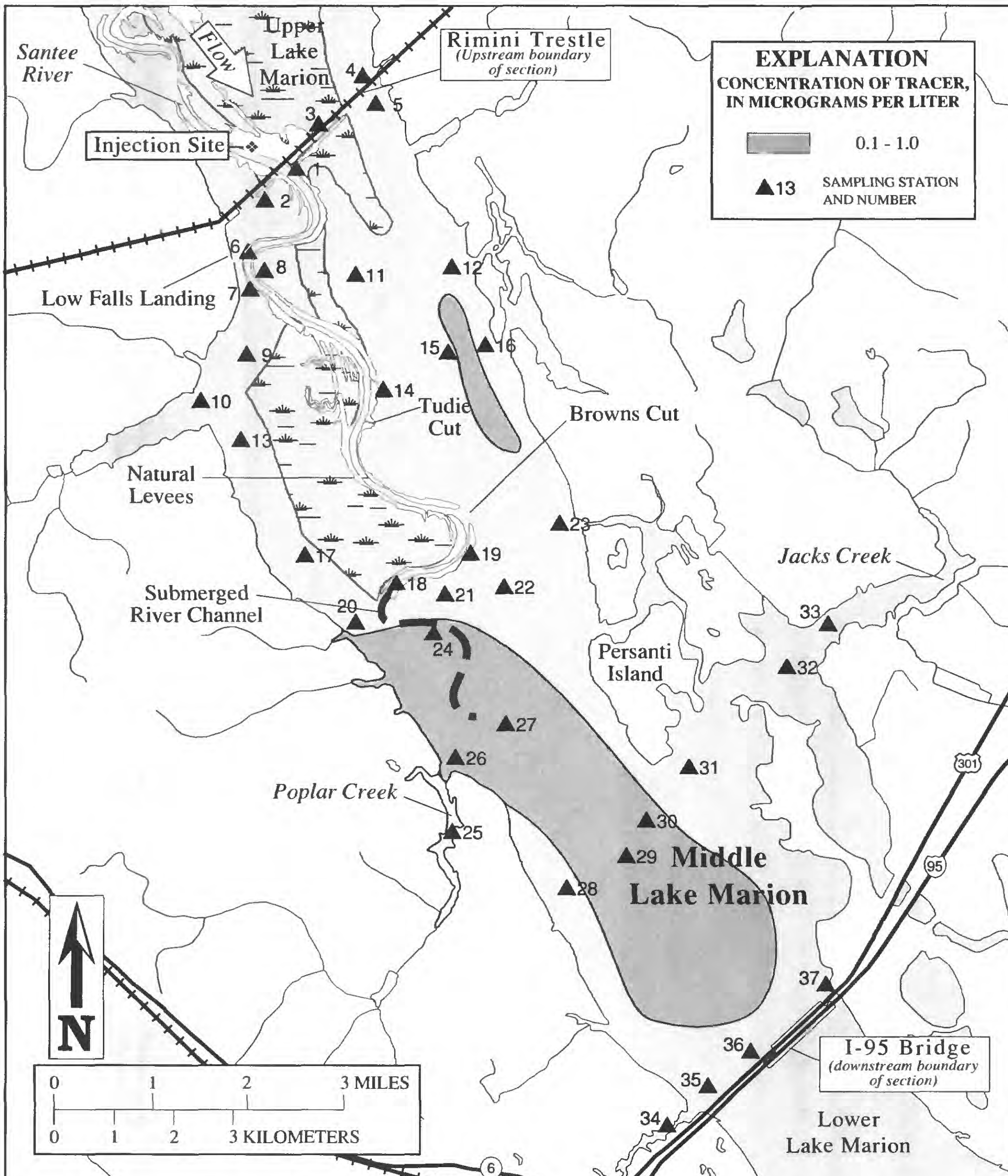
Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 18.--Concentrations of tracer in middle Lake Marion during high-flow test after 2 days, November 27-29, 1984.



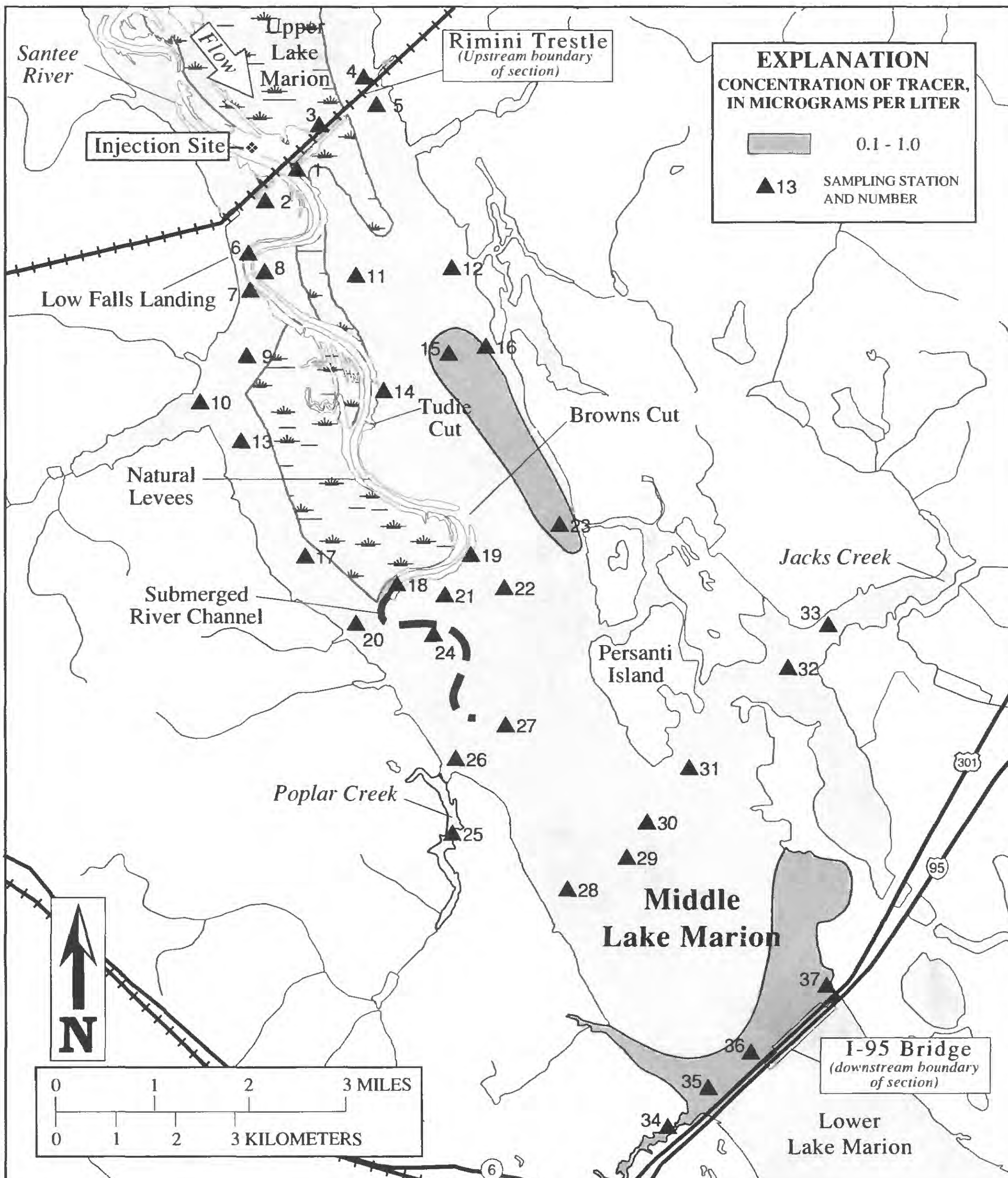
Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 19 .--Concentrations of tracer in middle Lake Marion during high-flow test after 3 days, November 27-30, 1984.



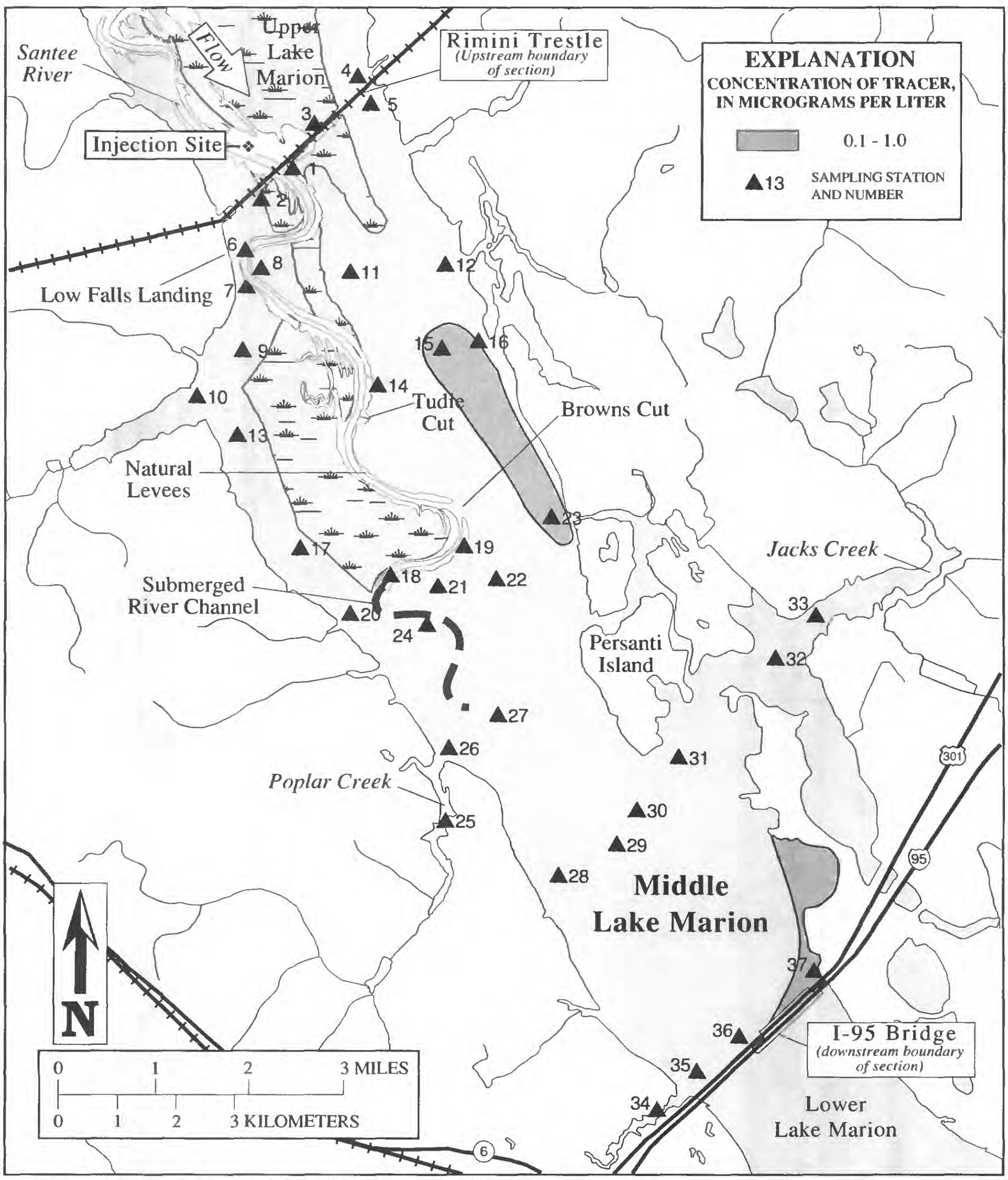
Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 20.--Concentrations of tracer in middle Lake Marion during high-flow test after 4 days, November 27-December 1, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 21.--Concentrations of tracer in middle Lake Marion during high-flow test after 6 days, November 27-December 3, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 22.--Concentrations of tracer in middle Lake Marion during high-flow test after 8 days, November 27-December 5, 1984.

FIGURES 23-32

Low-flow test in lower Lake Marion, November 6 - December 27, 1984.

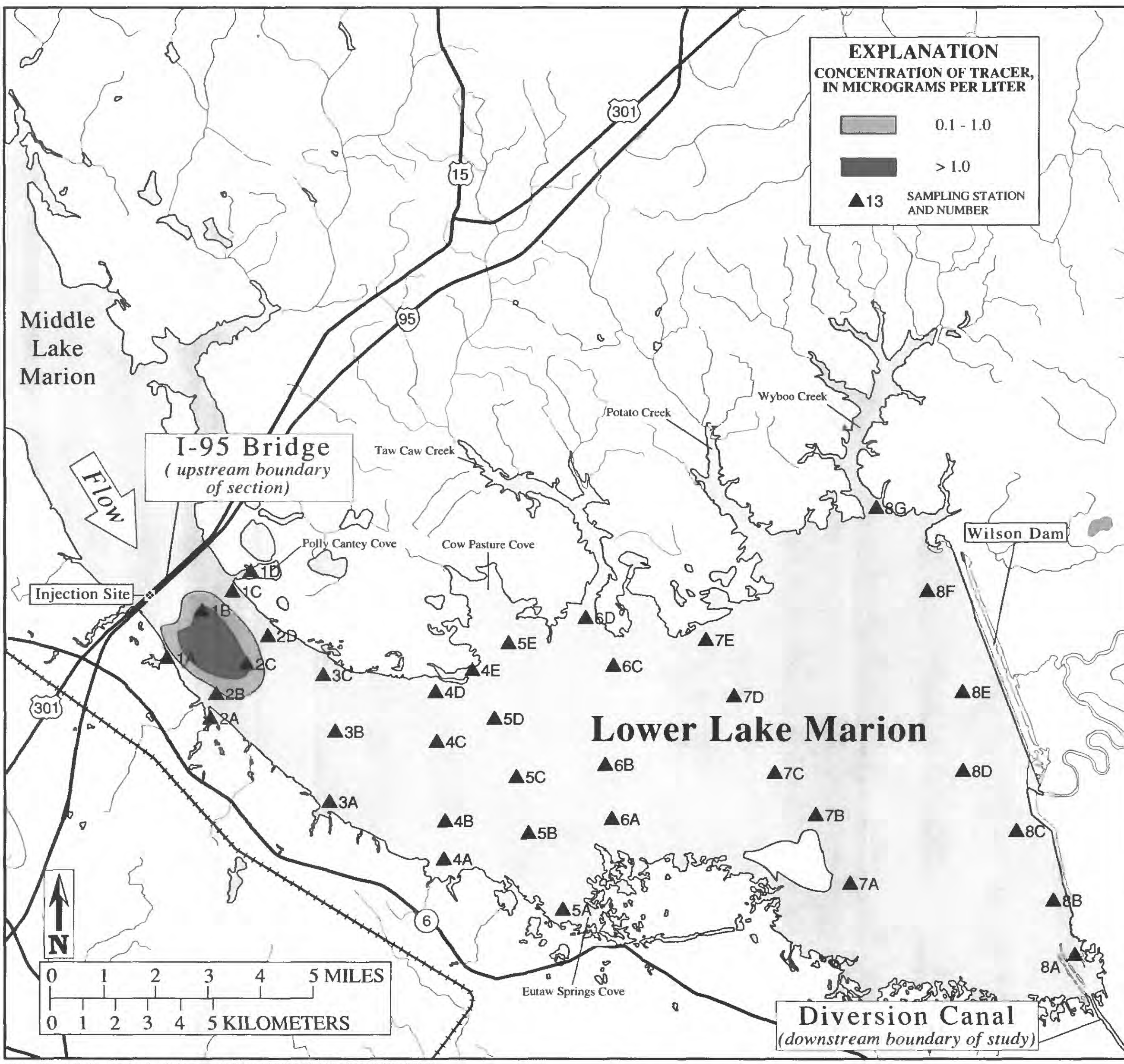


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Figure 23.--Concentrations of tracer in lower Lake Marion during high-flow test after 1 day, November 6-7, 1984.

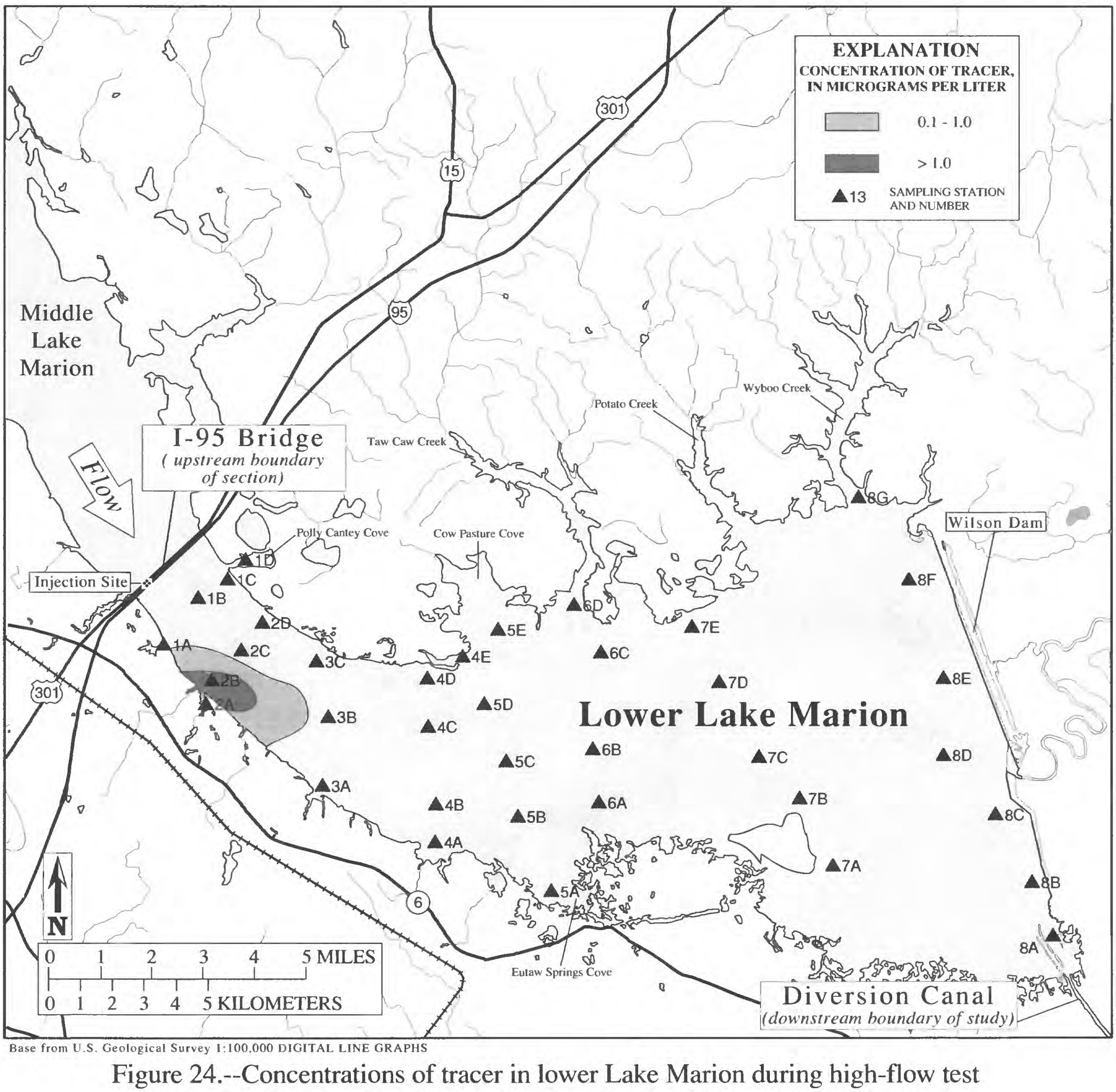
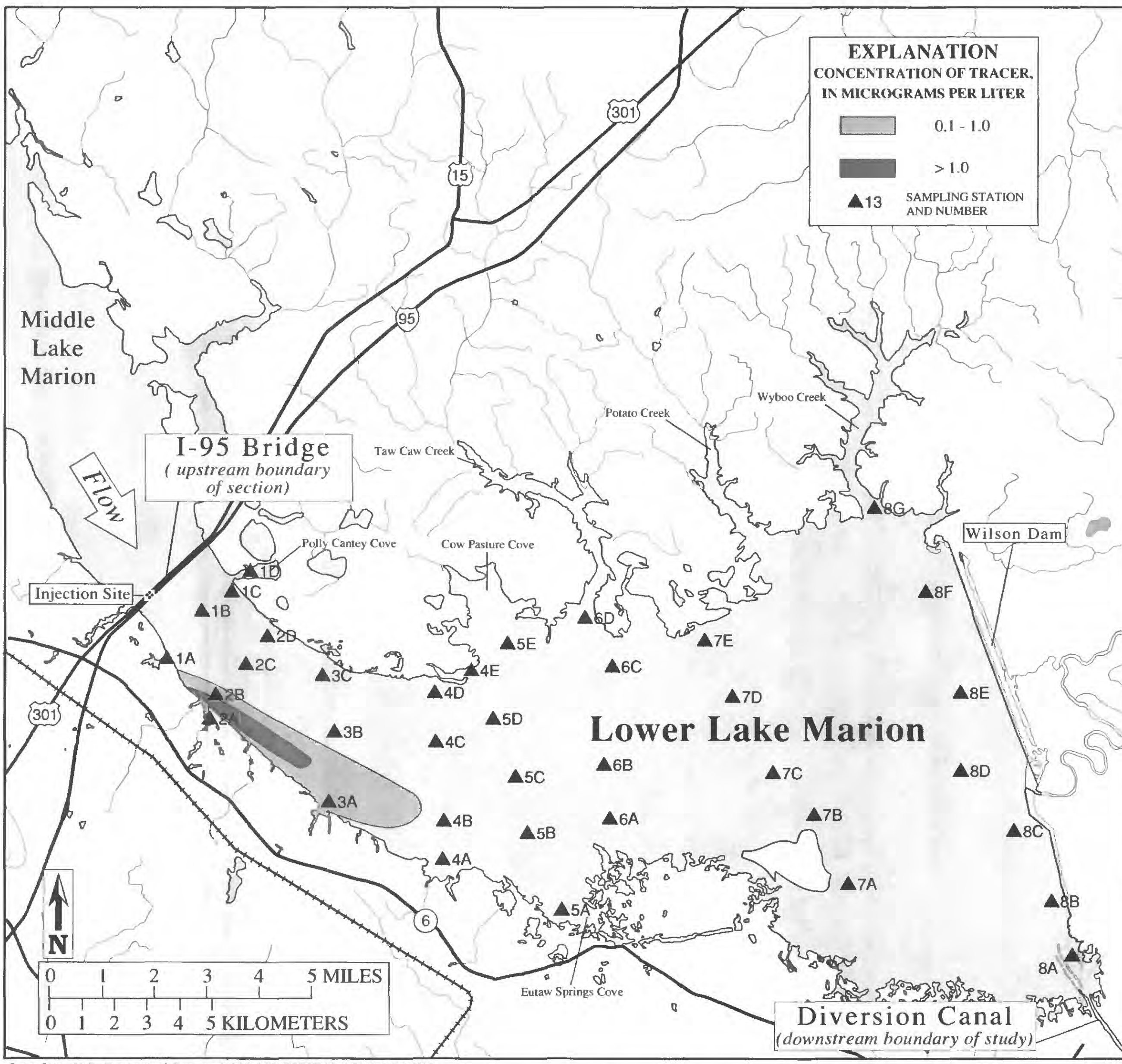
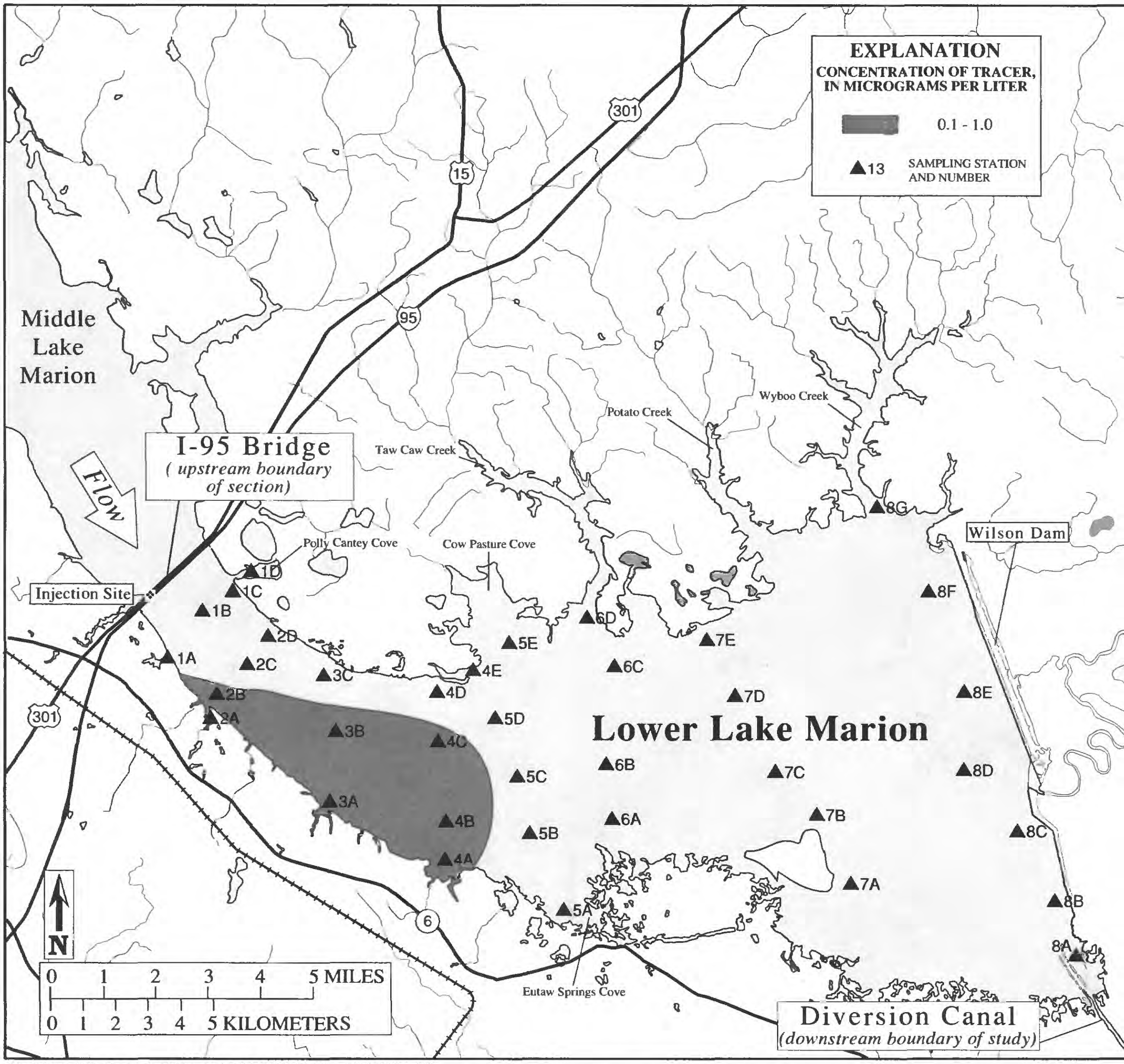


Figure 24.--Concentrations of tracer in lower Lake Marion during high-flow test after 2 days, November 6-8, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 25.--Concentrations of tracer in lower Lake Marion during high-flow test after 3 days, November 6-9, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 26.--Concentrations of tracer in lower Lake Marion during high-flow test after 6 days, November 6-12, 1984.

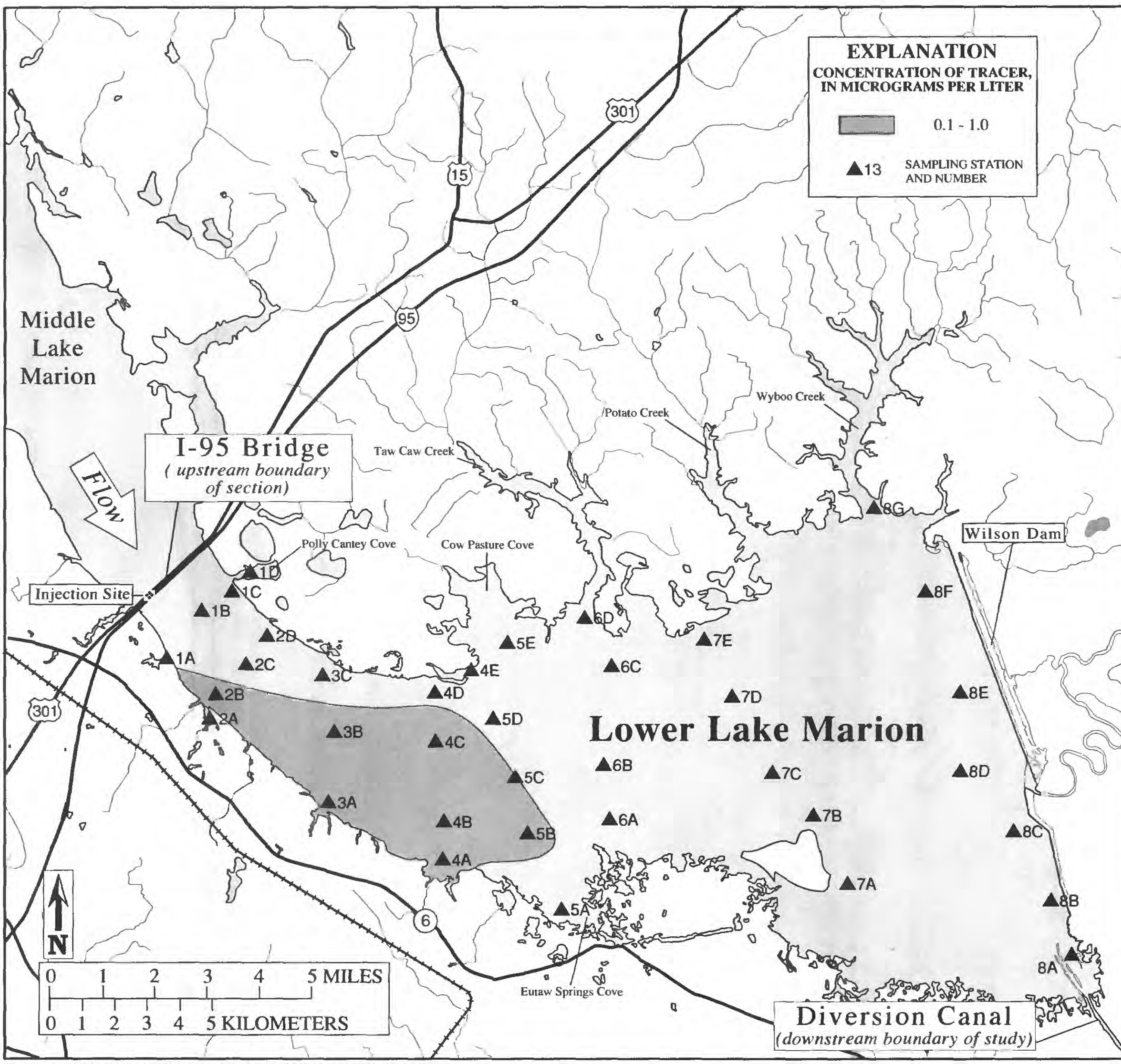
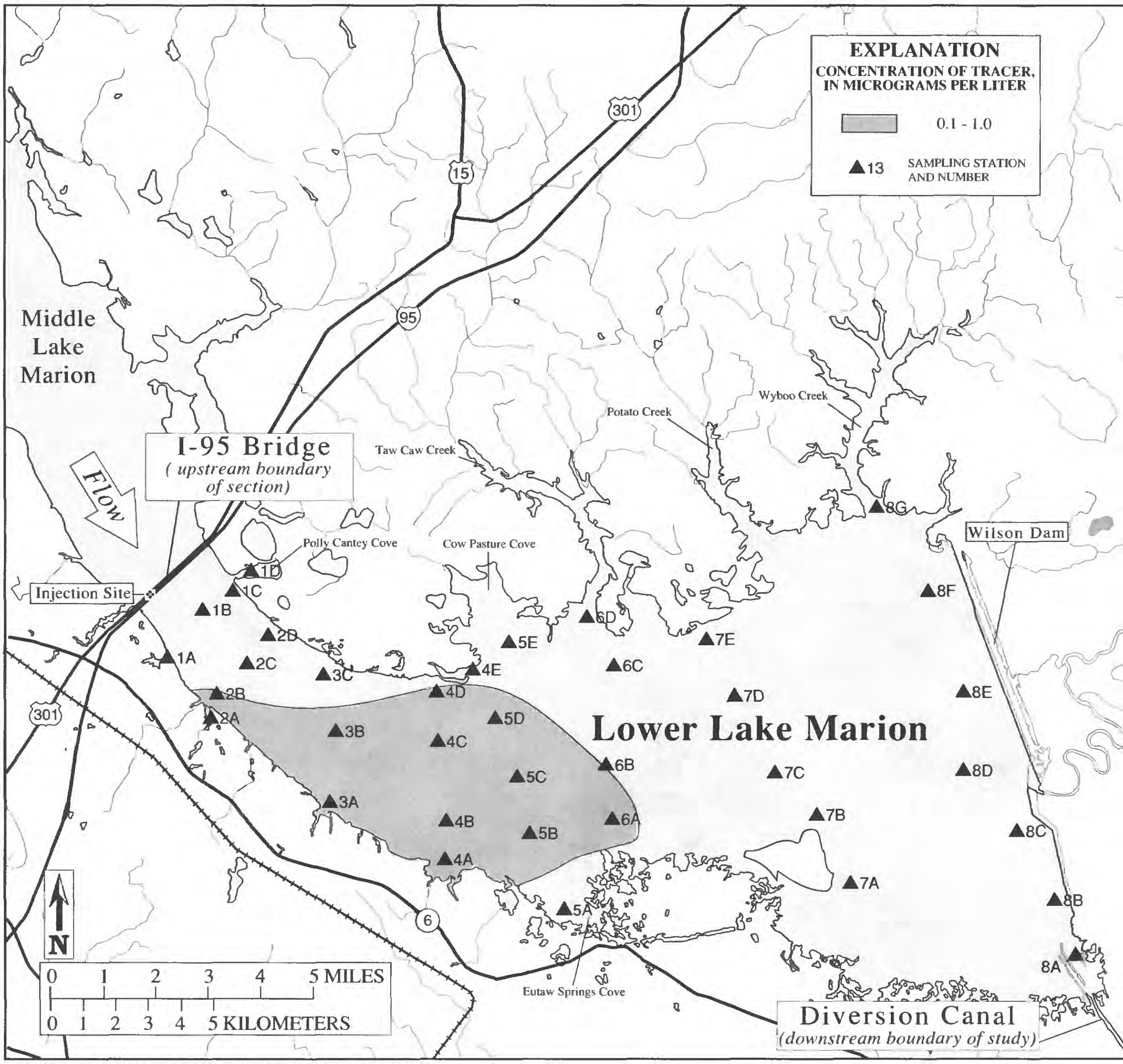
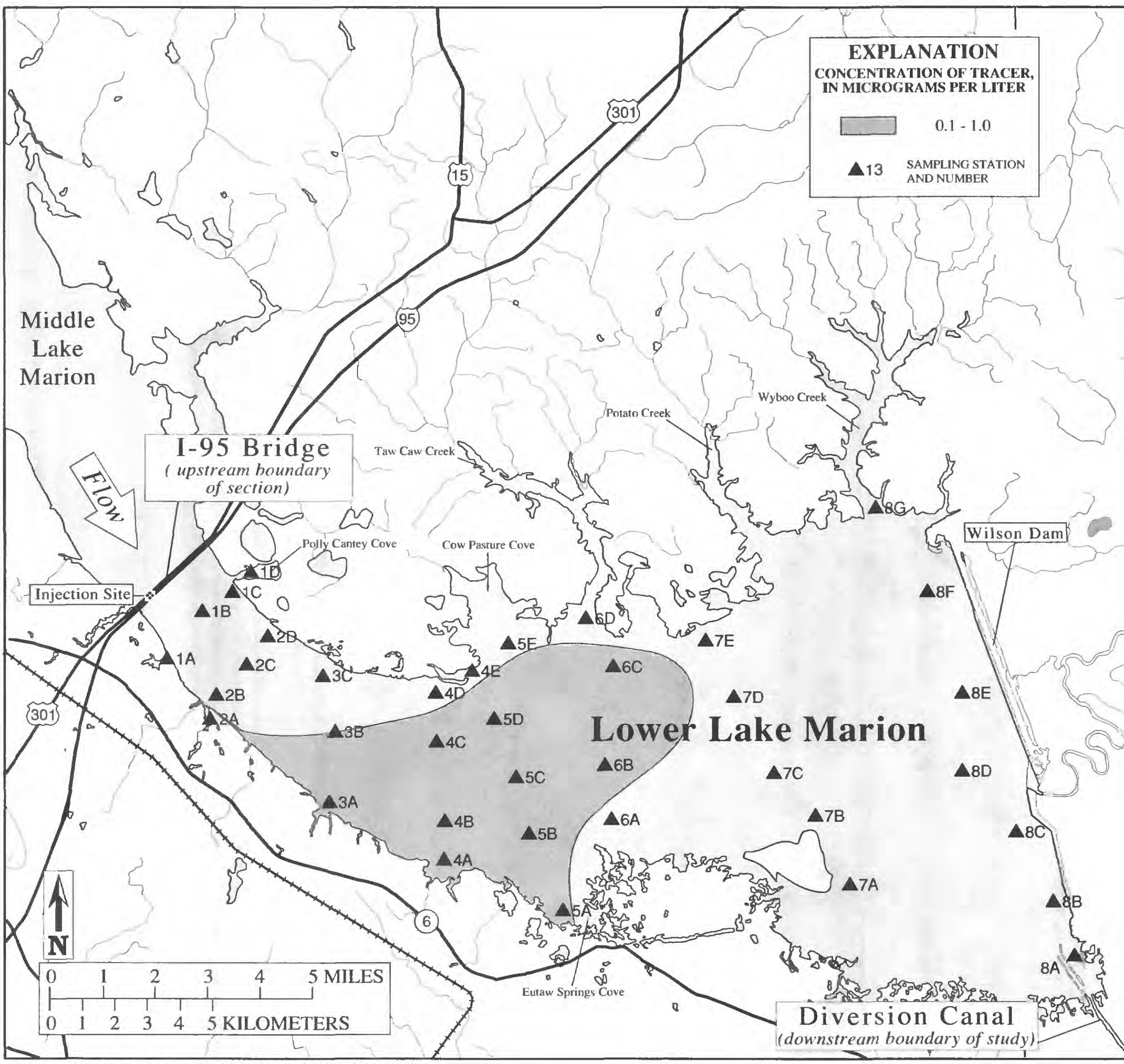


Figure 27.--Concentrations of tracer in lower Lake Marion during high-flow test after 8 days, November 6-14, 1984.



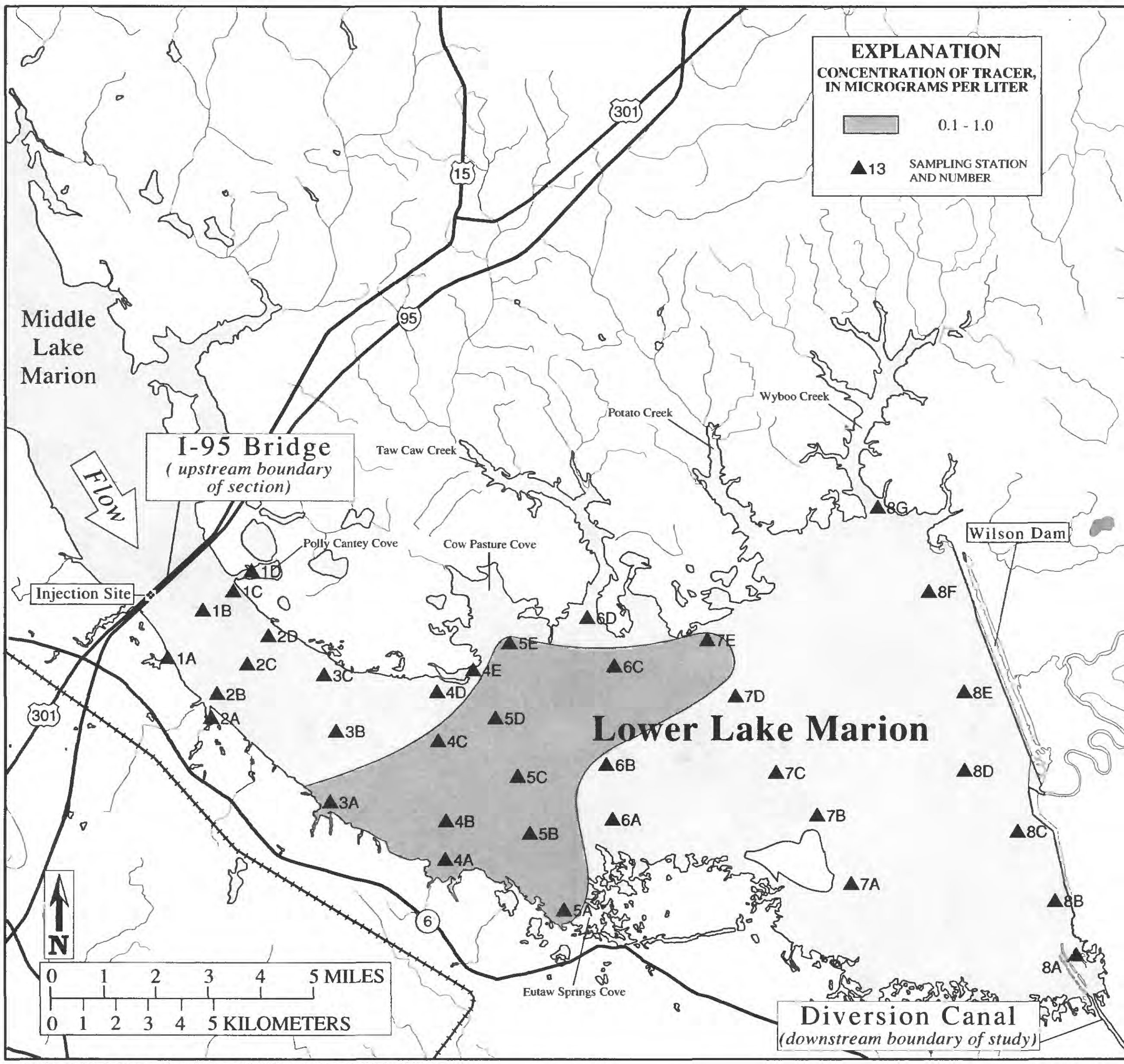
Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 28.--Concentrations of tracer in lower Lake Marion during high-flow test after 10 days, November 6-16, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 29.--Concentrations of tracer in lower Lake Marion during high-flow test after 15 days, November 6-21, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 30.--Concentrations of tracer in lower Lake Marion during high-flow test after 20 days, November 6-26, 1984.

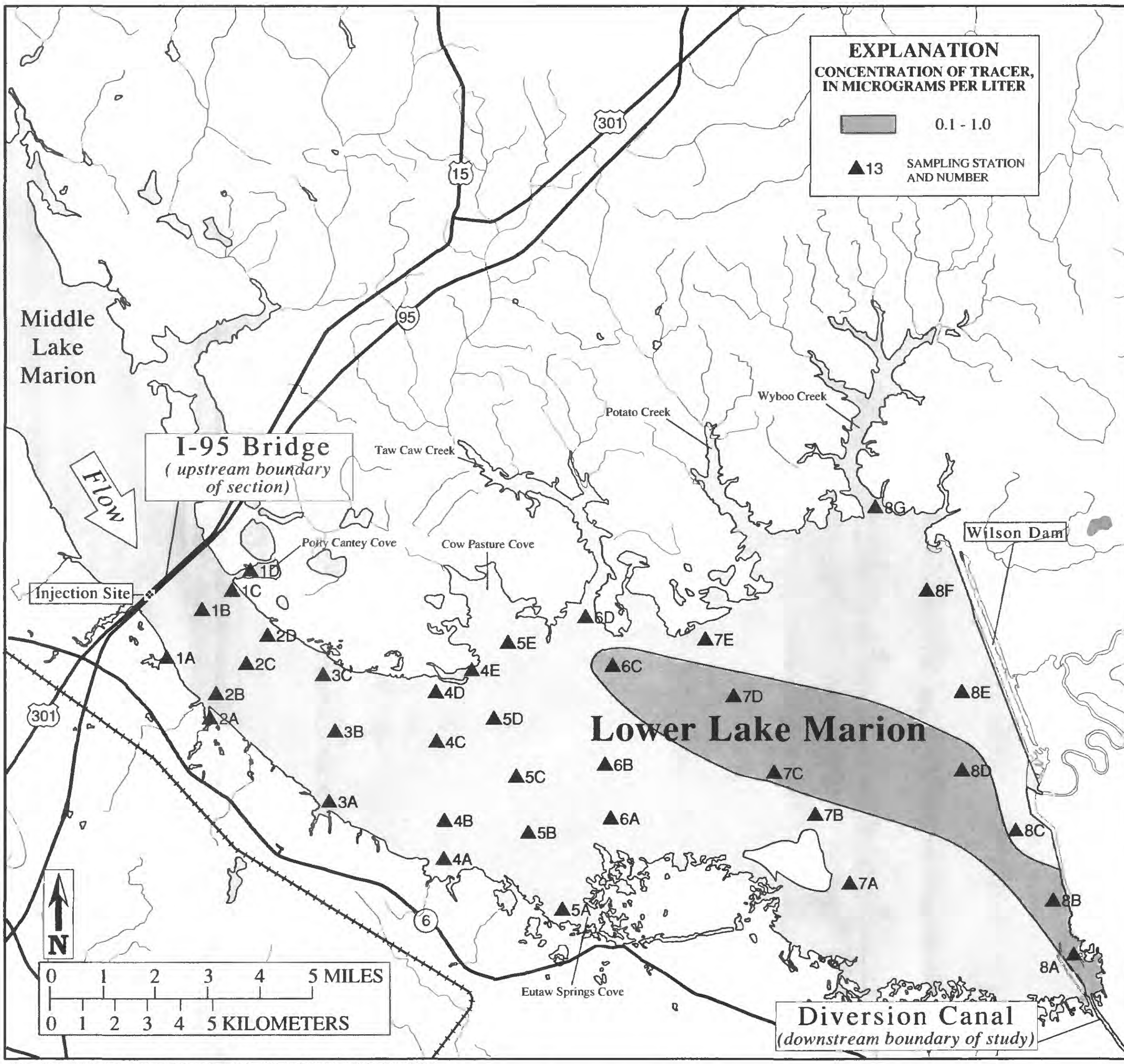
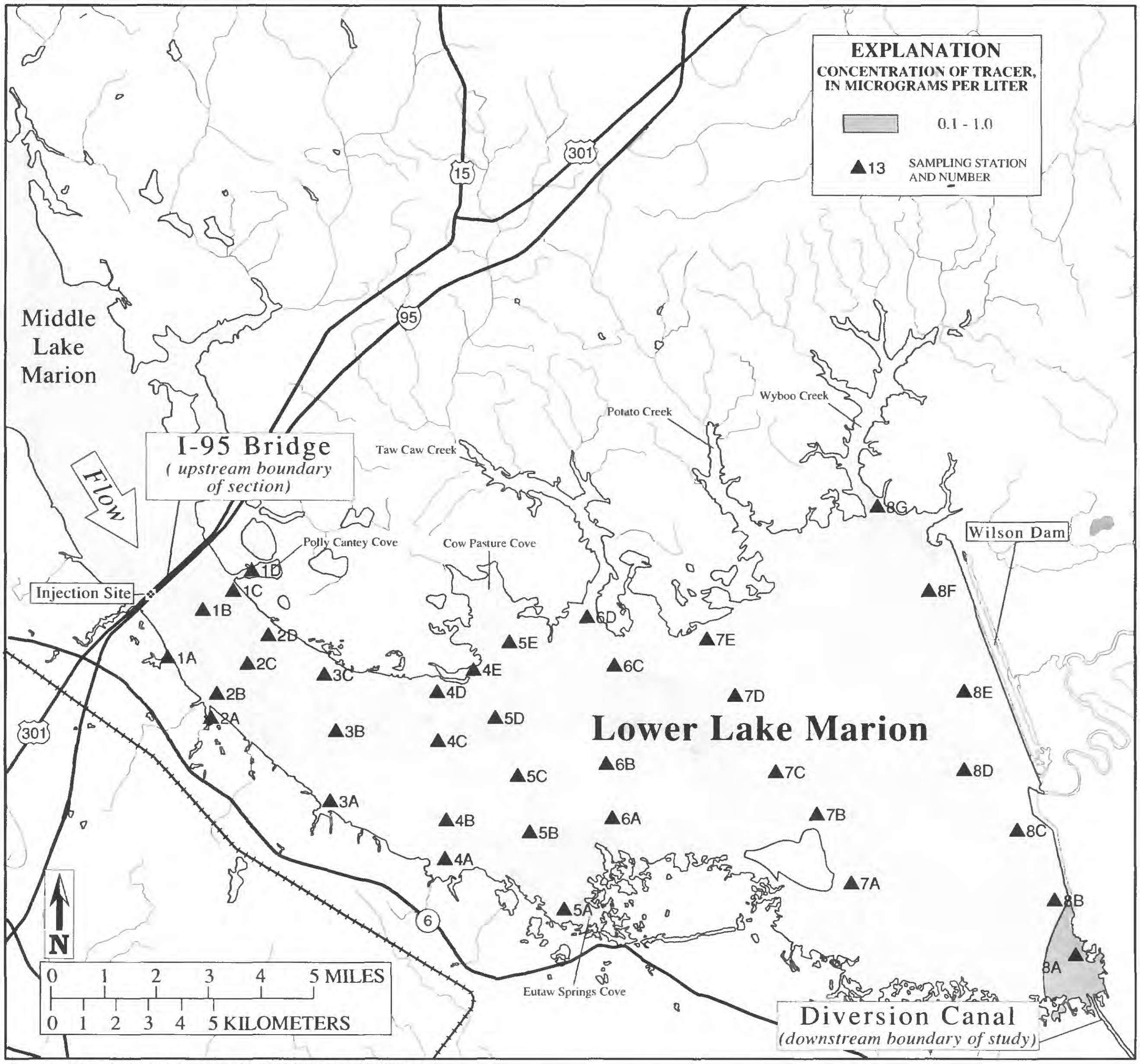


Figure 31.--Concentrations of tracer in lower Lake Marion during high-flow test after 43 days, November 6-December 19, 1984.



Base from U.S. Geological Survey 1:100,000 DIGITAL LINE GRAPHS

Figure 32.--Concentrations of tracer in lower Lake Marion during high-flow test after 51 days, November 6-December 27, 1984.

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