# RETENTION TIME AND FLOW PATTERNS IN LAKE MOULTRIE, SOUTH CAROLINA

by Glenn G. Patterson and Richard M. Harvey

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DONALD PAUL HODEL, Secretary

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Dallas L. Peck, Director

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For additional information
write to:

District Chief
U.S. Geological Survey, WRD
1835 Assembly Street, Rm 658
Columbia, SC 29201

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## CONVERSION FACTORS AND ABBREVIATIONS OF UNITS

The following factors may be used to convert the inch-pound units published herein to the International System of units (SI).

| Multiply inch-pound units | By | To obtain SI units |
|---|---|---|
| foot (ft) | 0.3048 | meter (m) |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| mile (mi) | 1.609 | kilometer (km) |
| acre | 4,047 | square meter ($m^2$) |
| acre | 0.4047 | hectare |
| pound (lb) | 0.4536 | kilogram (kg) |

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## ABSTRACT

A liquid dye tracer was injected into the inflow to Lake Moultrie during high-flow conditions and again during low-flow conditions. Tracer concentrations were monitored at a network of fixed sampling stations in the lake to determine dispersion and transport characteristics in and through the lake. Wind-generated currents were the major factor in dispersing the tracer and controlling the flow patterns, with the advective flow of water through the lake a secondary contributing factor. During the high-flow test, most of the tracer was flushed through the lake in 12 days, which did not allow time for the tracer to fully disperse throughout the lake. During the low-flow test, most of the tracer remained in the lake for in excess of a month. After 16 days it was dispersed throughout the lake. Concentrations of tracer decreased by a factor of about 500 as the dye clouds passed through the lake.

## INTRODUCTION

Lake Moultrie is one of two large reservoirs in the Coastal Plain of South Carolina (fig. 1). The reservoirs were formed in 1941 as part of the Santee-Cooper diversion project. The major purpose for the diversion project was generation of power at Pinopolis Dam at the outlet of Lake Moultrie. The lake has become an important recreational resource because of its opportunities for fishing and boating.

Recently, concern has arisen over several issues pertaining to water quality in Lake Moultrie. Among these issues are transport and deposition of sediment, transport and accumulation of nutrients, growth of algae and aquatic macrophytes, and dilution and assimilation of wastes. All of these processes involve transport, mixing, or dilution of dissolved or suspended materials. These processes can be conveniently simulated using fluorescent dye as a tracer. The dye tracer behaves as a conservative solute and can be detected at very low concentrations, thereby providing information on dilution and dispersion of constituents as well as on flow patterns and general behavior of solutes entering the lake. Two tracer tests were conducted in 1983: the first test was conducted in May under high-flow conditions, and the second during September and October under low-flow conditions. During each test, tracer was injected at the point of inflow to the lake. Periodic water samples were taken at fixed sampling stations located throughout the lake and analyzed for concentration.

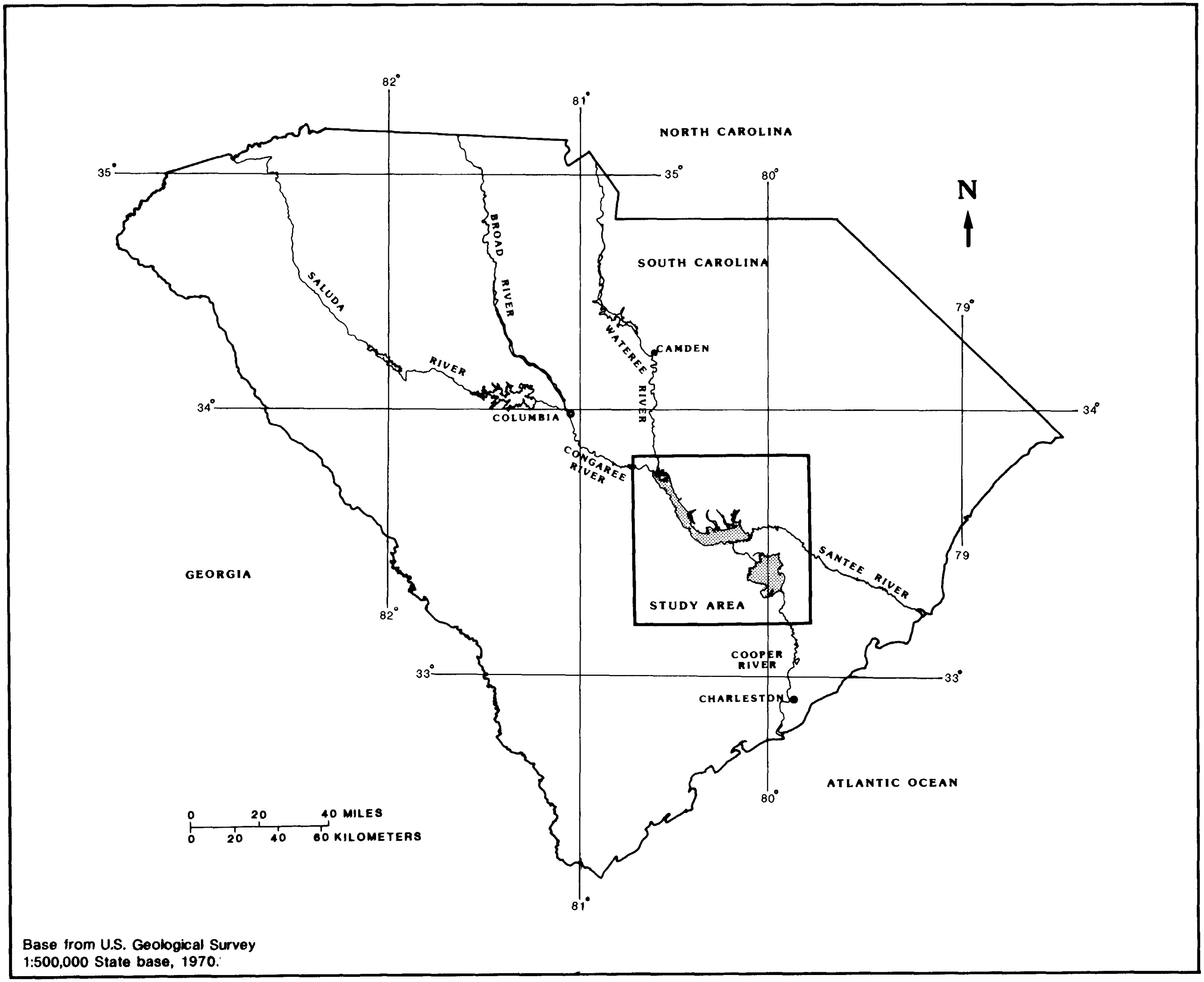


Figure 1.--Location of study area.

This study was undertaken in cooperation with the South Carolina Department of Health and Environmental Control (DHEC) as part of a comprehensive environmental assessment of Lakes Marion and Moultrie. The goals of the comprehensive assessment are to develop a better understanding of the physical, chemical, and biological processes occurring in the lakes and to develop a management strategy to maintain water-quality standards. Lake Moultrie was studied first because it would soon have a new outlet as a result of the Cooper River rediversion project, and the effect of the new outlet on flow patterns may need to be determined in the future.

## DESCRIPTION OF STUDY AREA

Lake Moultrie was formed by building a system of dikes and dams around an area of low-lying ground in the headwaters of the Cooper River basin (fig. 2). The lake has a surface area of 64,000 acres, an average depth of about 20 feet, and a maximum depth of about 60 feet (fig. 3). The lake is sub-circular in shape, with the inflow and outflow on opposite sides. On the southwestern side of the lake a system of dikes nearly encloses a shallow portion of the lake that was formerly used as a fish hatchery and is now a bird and wildlife area. Because this area is isolated, shallow, and nearly non-navigable because of stumps, it was excluded from the study. At the time of the study water flowed out of Lake Moultrie through the powerhouse of Pinopolis Dam, into a tailrace canal, and then, via the Cooper River, to Charleston Harbor and the Atlantic Ocean. The major source of inflow to Lake Moultrie is a diversion canal from Lake Marion that crosses the low drainage divide between the Santee and Cooper River basins. Lake Marion was formed by the construction of Wilson Dam across the Santee River, the second-largest river on the east coast of the United States.

In 1985, a new major outlet for Lake Moultrie was formed by completion of the Cooper River rediversion project. The rediversion canal created a new outlet closer to the diversion canal than the old outlet, and carries about 80 percent of the lake outflow back across the low drainage divide to the Santee River (fig. 2). Hydroelectric power is generated at a new powerhouse on the rediversion canal near St. Stephen (fig. 2). The purpose of the rediversion project is to alleviate a sedimentation problem that developed in Charleston Harbor following the original diversion project.

## METHODS

The methods used for both the high-flow and the low-flow tests were basically the same. Prior to each test, a network of fixed sampling stations was set up throughout the lake. The sampling stations were marked with special buoys or existing channel markers. Thirty-three stations were used for the high-flow test and 27 for the low-flow test (fig. 3). Locations of the stations were determined in the field with a microwave positioning system. Prior to injection of the dye tracer, water samples were taken at each station to determine background fluorescence.

To initiate each test a 20 percent solution of rhodamine WT liquid dye was injected as a slug in the lower 1/4 mile of the diversion canal just

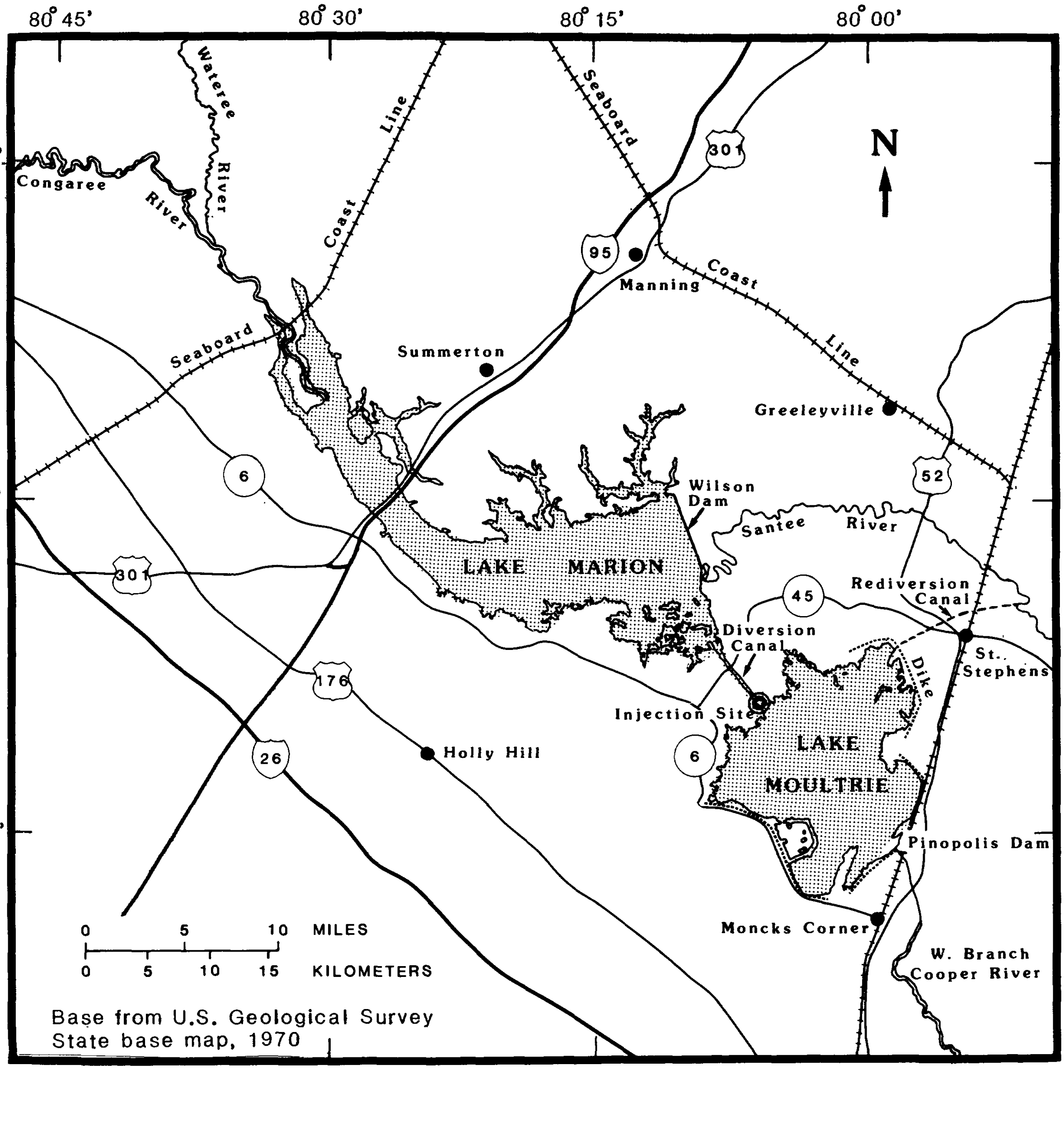


Figure 2.--Lakes Marion and Moultrie.

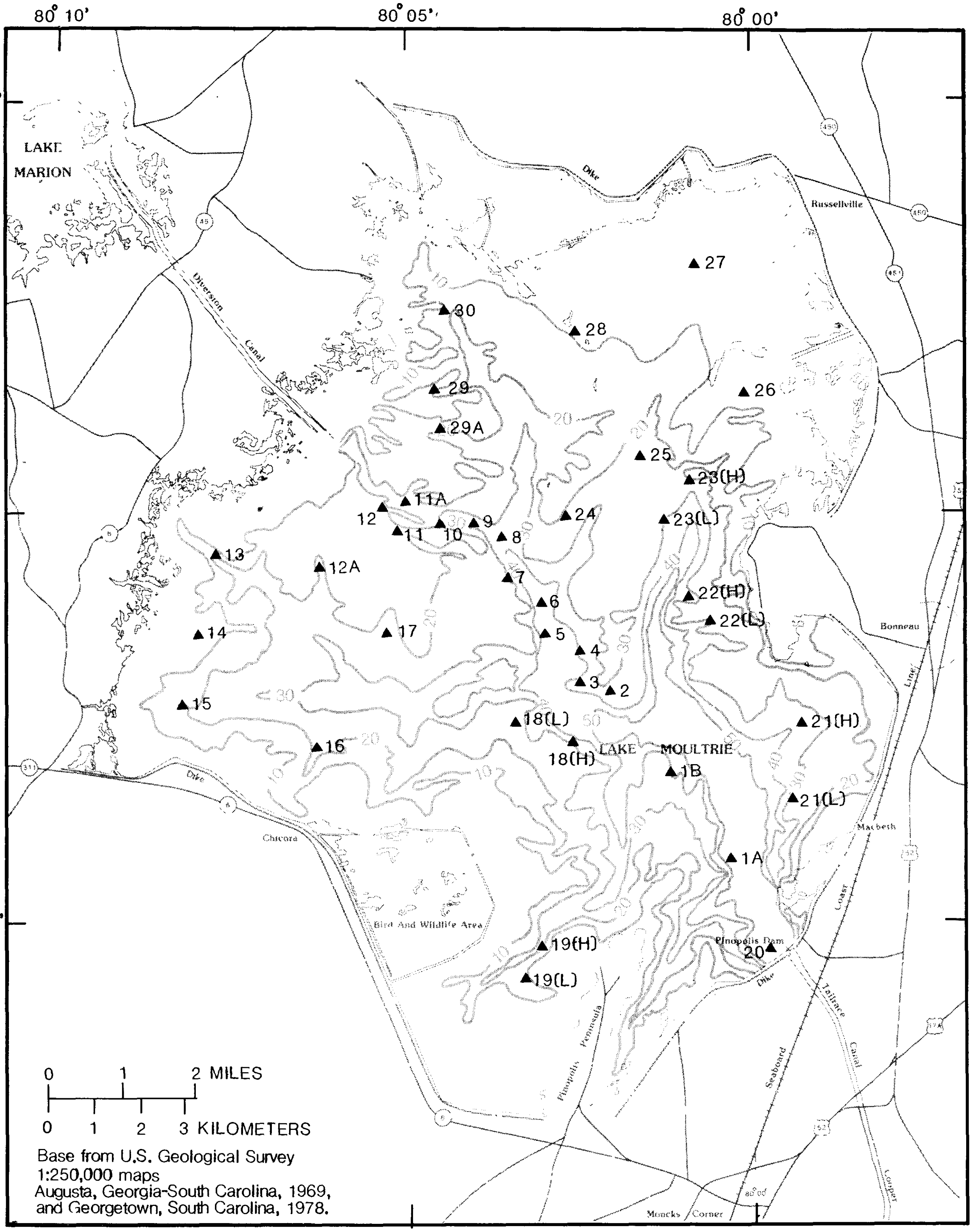


Figure 3.--Bottom contours and location of sampling stations in Lake Moultrie.

upstream from Lake Moultrie. The quantity of dye to be used in the first injection was determined by estimating the mass of dye needed to produce fluorescence of the same order of magnitude as background fluorescence if the dye were evenly mixed throughout the lake. As a result of these computations, 500 lb (pounds) of 20 percent solution were injected for the first test.

A similar process was used to determine the quantity of dye for the second injection; accordingly, 750 lb of 20 percent dye solution were injected for the second test. The low-flow test involved a longer period of time during which the dye was present in the lake at relatively dilute concentrations, and the extra dye improved the reliability of the data during this period.

Each injection was made by siphoning dye into the water from barrels aboard a boat as the boat was driven back and forth across the diversion canal. Because the dye solution had a specific gravity of 1.19, the discharge from the siphon hose was directed toward the propeller to help mix the dye with the water and minimize any density effects. The injections took about 15 minutes to complete.

The movement of the dye cloud through the lake was monitored by taking periodic water samples at the network of sampling stations and analyzing them for fluorescence which can be related to concentration. Basic procedures for mixing dye standards and calibrating the fluorometer were used (Hubbard and others, 1982). Initially the sampling frequency was twice per day at each station, with additional samples from three to five automatic floating samplers which were set to obtain samples at 24-hour intervals. As the change in dye concentration became more gradual with time, the sampling frequency was reduced, eventually to once per week. Sampling continued until fluorescence decreased to background levels.

Both surface and depth-integrated samples were taken. Surface samples were taken by hand or by the automatic samplers, and several hundred depth-integrated samples were taken with a DH-59 suspended-sediment sampler (U.S. Geological Survey, 1977, p. 3-20). Concentrations from the surface and the depth-integrated samples were compared to determine whether dye concentrations were vertically homogeneous.

For each sampling station, a graph of tracer concentration versus time was prepared. The data were also plotted on maps showing concentrations of tracer throughout the lake at selected intervals.

Records of lake level, mean daily discharge at the outflow of Lake Moultrie, and wind direction and wind speed every 4 hours at Wilson Dam were obtained from the South Carolina Public Service Authority, which manages the reservoirs.

## RESULTS

The tracer cloud remained visible for about 1 to 2 days following each dye injection, permitting visual observations of initial flow patterns. Upon entering the lake, the path of each dye cloud turned abruptly in the direction of the prevailing wind, providing ample evidence that the wind was a major influence on the movement of water in the lake. A resultant wind vector appears on each of the tracer concentration maps (figs. 5-10 and 12-19). The vectors are based on six daily readings at Wilson Dam and represent the net movement of a particle of air during the period since the time of the previous map. To obtain the resultant vector, the product of wind speed in miles per hour times wind duration in hours during the period was computed for each of eight compass points and then combined (fig. 4).

The advective transport of water through the lake was a contributing factor in the movement of the tracer. During the high-flow test, which covered the period May 16 through 27, 1983, discharge at the outflow from Lake Moultrie averaged 13,800 $ft^3/s$. During the low-flow test, which covered the period September 27 through November 1, 1983, discharge at the outflow averaged 3,310 $ft^3/s$. Daily lake level, change in storage, outflow, and inflow are listed in tables 1 and 2. For the purpose of these tabulations, inflow is computed as outflow plus change in storage.

## High-Flow Test

On the day of the injection, the lake current and the prevailing wind were from the southwest. Immediately upon entering the lake at the mouth of the diversion canal, the tracer was swept in a northeasterly direction along the shore by lake currents. One day after the injection, an arm of the dye cloud was visible in the vicinity of the mouth of Angel's Cove, about 2 miles northeast of the diversion canal (fig. 5). On the second day after the injection, the wind shifted so that it was blowing from the northeast, and the tracer cloud could be seen moving back toward the southwest (fig. 6). Some tracer began to spread down the middle of the lake toward the dam. Lake outflows were decreasing during this period (table 1).

During days 3 and 4, the wind continued to blow from the northeast (figs. 7 and 8). Most of the tracer cloud continued to spread in two directions from Angel's Cove: toward the southwestern corner of the lake and down the middle of the lake toward the dam. Apparently the wind was responsible for the southwesterly movement while the normal flow of water from the inlet to the dam was responsible for the southeasterly movement. Some of the tracer remained in Angel's Cove. As the tracer cloud spread out, concentrations decreased. Lake outflows began to increase during this period (table 1).

On the third day following the high-flow injection, three stations near the deepest part of the lake had significantly higher concentrations in the depth-integrated samples than in the surface samples (table 3). This was the only day on which there was significant evidence of vertical differences in concentrations. Apparently the tracer advanced more rapidly toward the dam at depth than it did near the surface. One possible explanation for this southeasterly movement of dye at depth is that the wind blowing from the northeast dragged the surface water toward the southwest and this created a return flow of water toward the northeast at depth (Liv and Perez, 1971, p. 923).

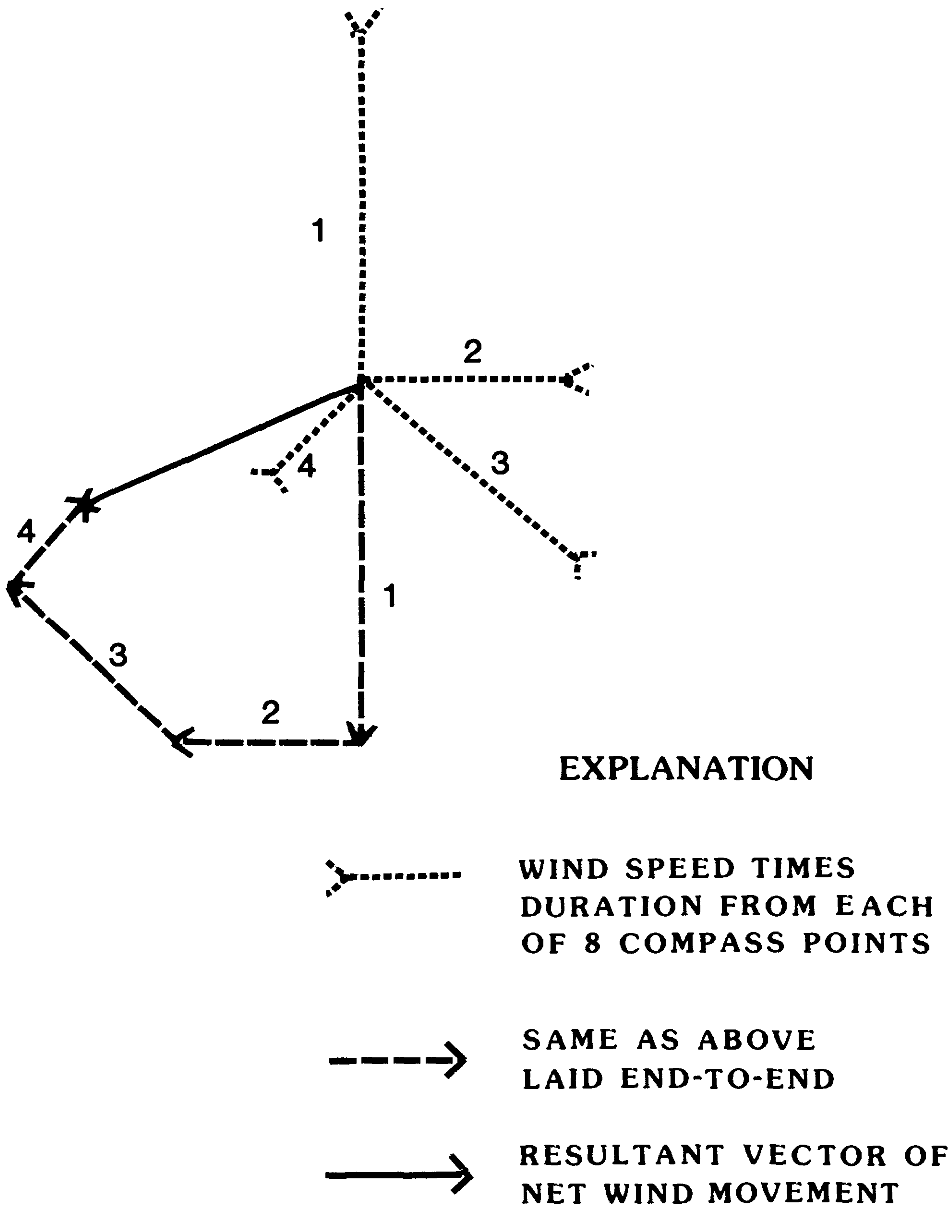


Figure 4.--Determination of resultant wind vector.

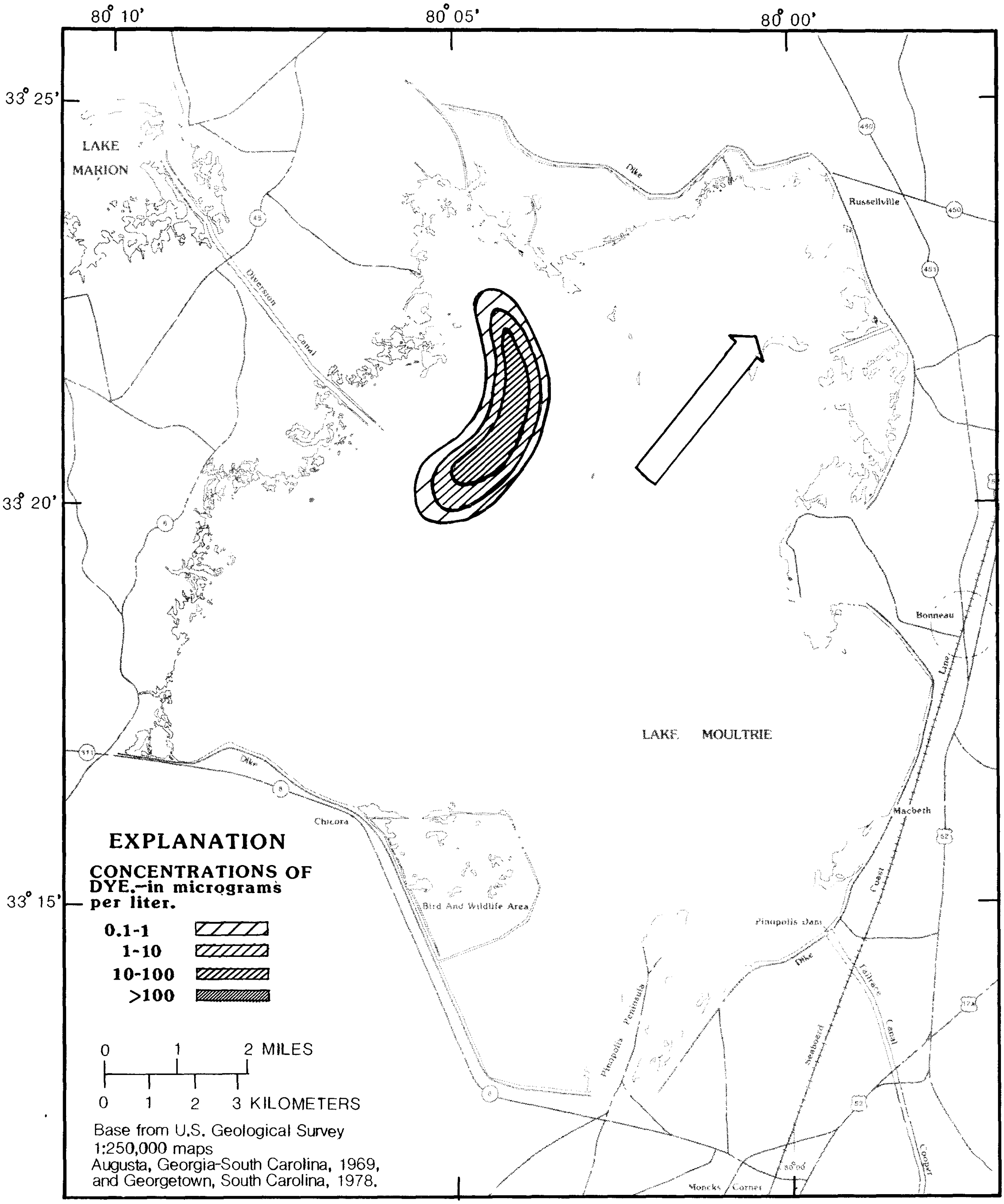


Figure 5.--Concentrations of dye in Lake Moultrie 1 day following the high-flow injection.

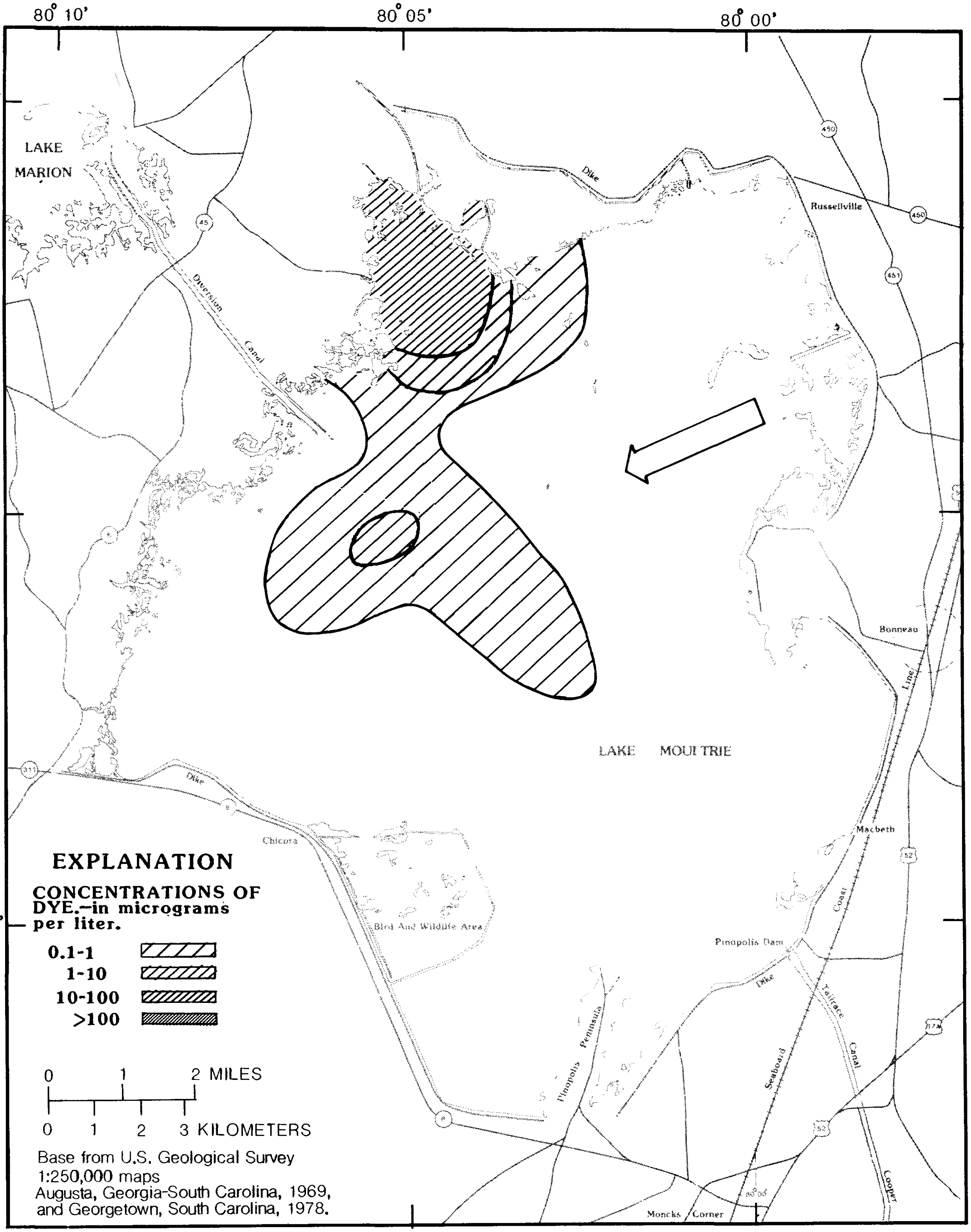


Figure 6.--Concentrations of dye in Lake Moultrie 2 days following the high-flow injection.

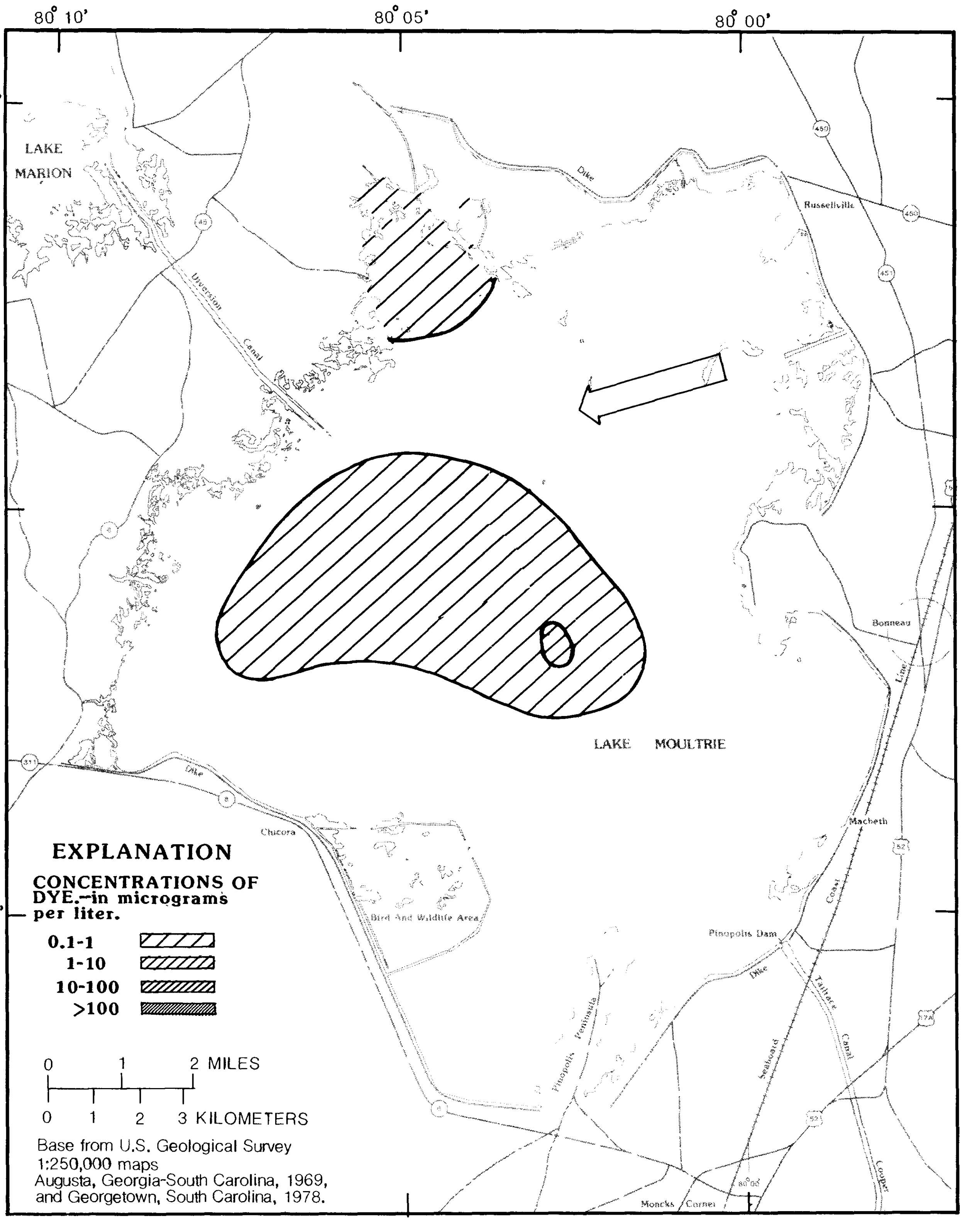


Figure 7.--Concentrations of dye in Lake Moultrie 3 days following the high-flow injection.

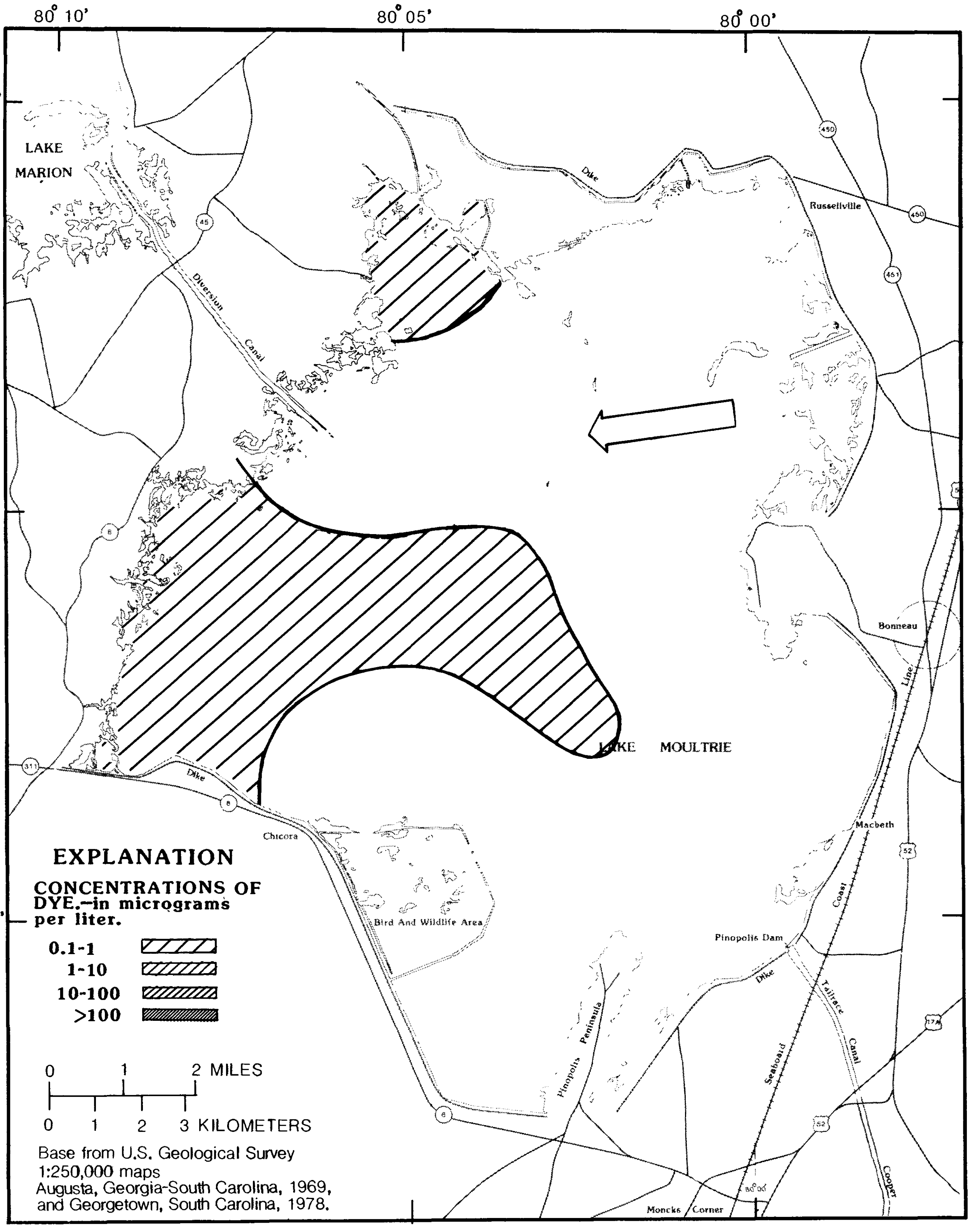


Figure 8.--Concentrations of dye in Lake Moultrie 4 days following the high-flow injection.

Table 1.--Water budget for Lake Moultrie during high-flow test

| Date | Days after injection | Lake level, feet | Change in storage, $ft^3/s$ | Outflow, $ft^3/s$ | Inflow, $ft^3/s$ |
|---|---|---|---|---|---|
| 05/15/83 | -1 | 74.97 | -- | 14447 | -- |
| 05/16 | 0 | 75.01 | 1325 | 14548 | 15873 |
| 05/17 | 1 | 75.03 | 664 | 9171 | 9835 |
| 05/18 | 2 | 75.08 | 1662 | 7331 | 8993 |
| 05/19 | 3 | 75.16 | 2667 | 7302 | 9969 |
| 05/20 | 4 | 75.12 | -1335 | 11984 | 10649 |
| 05/21 | 5 | 74.95 | -5644 | 16213 | 10569 |
| 05/22 | 6 | 74.96 | 331 | 14876 | 15207 |
| 05/23 | 7 | 74.95 | -331 | 16987 | 16656 |
| 05/24 | 8 | 74.96 | 331 | 17021 | 17352 |
| 05/25 | 9 | 75.00 | 1325 | 16710 | 18035 |
| 05/26 | 10 | 75.06 | 1992 | 17151 | 19143 |
| 05/27 | 11 | 75.12 | 1997 | 15910 | 17907 |
| 05/28 | 12 | 75.05 | -2329 | 18912 | 16653 |
| 05/29 | 13 | 75.03 | -664 | 18730 | 18066 |
| 05/30 | 14 | 75.03 | 0 | 16824 | 16824 |
| 05/31 | 15 | 74.98 | -1658 | 18327 | 16669 |

Table 2.--Water budget for Lake Moultrie during low-flow test

| Date | Days after injection | Lake level, feet | Change in storage, ft$^3$/s | Outflow, ft$^3$/s | Inflow, ft$^3$/s |
|---|---|---|---|---|---|
| 09/26/83 | -1 | 74.16 | -- | 2996 | -- |
| 09/27 | 0 | 74.13 | -957 | 3047 | 2090 |
| 09/28 | 1 | 74.09 | -1274 | 3796 | 2522 |
| 09/29 | 2 | 74.13 | 1274 | 3107 | 4381 |
| 09/30 | 3 | 74.17 | 1276 | 3300 | 4576 |
| 10/01 | 4 | 74.22 | 1598 | 3345 | 4943 |
| 10/02 | 5 | 74.23 | 320 | 3194 | 3514 |
| 10/03 | 6 | 74.22 | -320 | 3226 | 2906 |
| 10/04 | 7 | 74.19 | -959 | 4095 | 3136 |
| 10/05 | 8 | 74.25 | 1920 | 3510 | 5430 |
| 10/06 | 9 | 74.37 | 3855 | 3725 | 7580 |
| 10/07 | 10 | 74.42 | 1613 | 3462 | 5075 |
| 10/08 | 11 | 74.49 | 2264 | 4198 | 6462 |
| 10/09 | 12 | 74.50 | 324 | 4183 | 4507 |
| 10/10 | 13 | 74.51 | 324 | 3782 | 4106 |
| 10/11 | 14 | 74.47 | -1296 | 3975 | 2679 |
| 10/12 | 15 | 74.30 | -5480 | 6323 | 843 |
| 10/13 | 16 | 74.37 | 2251 | 6869 | 9120 |
| 10/14 | 17 | 74.38 | 323 | 7111 | 7434 |
| 10/15 | 18 | 74.40 | 645 | 3255 | 3900 |
| 10/16 | 19 | 74.39 | -322 | 3613 | 3291 |
| 10/17 | 20 | 74.38 | -302 | 3629 | 3327 |
| 10/18 | 21 | 74.33 | -1614 | 3160 | 1646 |
| 10/19 | 22 | 74.41 | 2577 | 3510 | 6087 |
| 10/20 | 23 | 74.23 | -5786 | 10869 | 5083 |
| 10/21 | 24 | 74.21 | -640 | 8976 | 8336 |
| 10/22 | 25 | 74.20 | -320 | 5657 | 5337 |
| 10/23 | 26 | 74.27 | 2242 | 3688 | 5930 |
| 10/24 | 27 | 74.37 | 3214 | 3451 | 6665 |
| 10/25 | 28 | 74.40 | 967 | 3153 | 4120 |
| 10/26 | 29 | 74.44 | 1292 | 3044 | 4336 |
| 10/27 | 30 | 74.45 | 323 | 4566 | 4889 |
| 10/28 | 31 | 74.43 | -646 | 5059 | 4413 |
| 10/29 | 32 | 74.46 | 970 | 4904 | 5874 |
| 10/30 | 33 | 74.46 | 0 | 4841 | 4841 |
| 10/31 | 34 | 74.38 | -2583 | 7208 | 4625 |

Table 3.--Concentrations of tracer in surface and in depth-integrated samples from the deepest part of Lake Moultrie 3 days following the high-flow injection

| Station | Days from injection | Concentration of tracer, microgram per liter | |
|---|---|---|---|
| | | Surface | Depth-integrated |
| 1A | 2.86 | 0.04 | 0.13 |
| 1A | 3.04 | .05 | .04 |
| 1B | 2.87 | .05 | .05 |
| 2 | 2.87 | .10 | .17 |
| 4 | 2.87 | .15 | .32 |
| 4 | 3.03 | .05 | .13 |
| 6 | 2.87 | .04 | .05 |

During days 5, 6, and 7, the net wind was from the south (fig. 9). Lake outflow generally continued to increase. The wind may have been a factor in keeping some of the tracer in Angel's Cove. The rest of the dye cloud appeared to move from west to east across the middle of the lake. The concentrations in the surface samples and the depth-integrated samples were similar.

During days 8 and 9, the net wind was again from the northeast (fig. 10) and lake outflow was about 17,000 $ft^3/s$. The primary movement of the dye was toward the dam and out of the lake. Concentrations of dye in the range of 0.08 to 0.09 ug/L (microgram per liter) in most of the southeastern half of the lake indicate that some tracer was being spread away from the heart of the tracer cloud. However, little or no tracer dye traveled to the extreme northern or southern parts of the lake.

By the 12th day after the injection, most of the tracer had been flushed from the lake.

Graphs of tracer concentration versus time for four sampling stations are shown in figure 11. The first and highest peak concentration measured was at station 33 in Angel's Cove on the second day. Station 33 had a second peak on the fourth day, resulting probably from a wind reversal. Three sharp peaks occurred on the third and fourth days station 3 in the middle of the lake. This station was equipped with a floating automatic sampler that provided a detailed record of concentration versus time. The three peaks, separated by intervals of about 12 hours, could have been caused by oscillating currents or by wind reversal.

The peak concentration at station 17, in the southwestern corner of the lake, occurred on the fourth day (fig. 11). At station 29, in the northeastern corner of the lake, little or no tracer was detected.

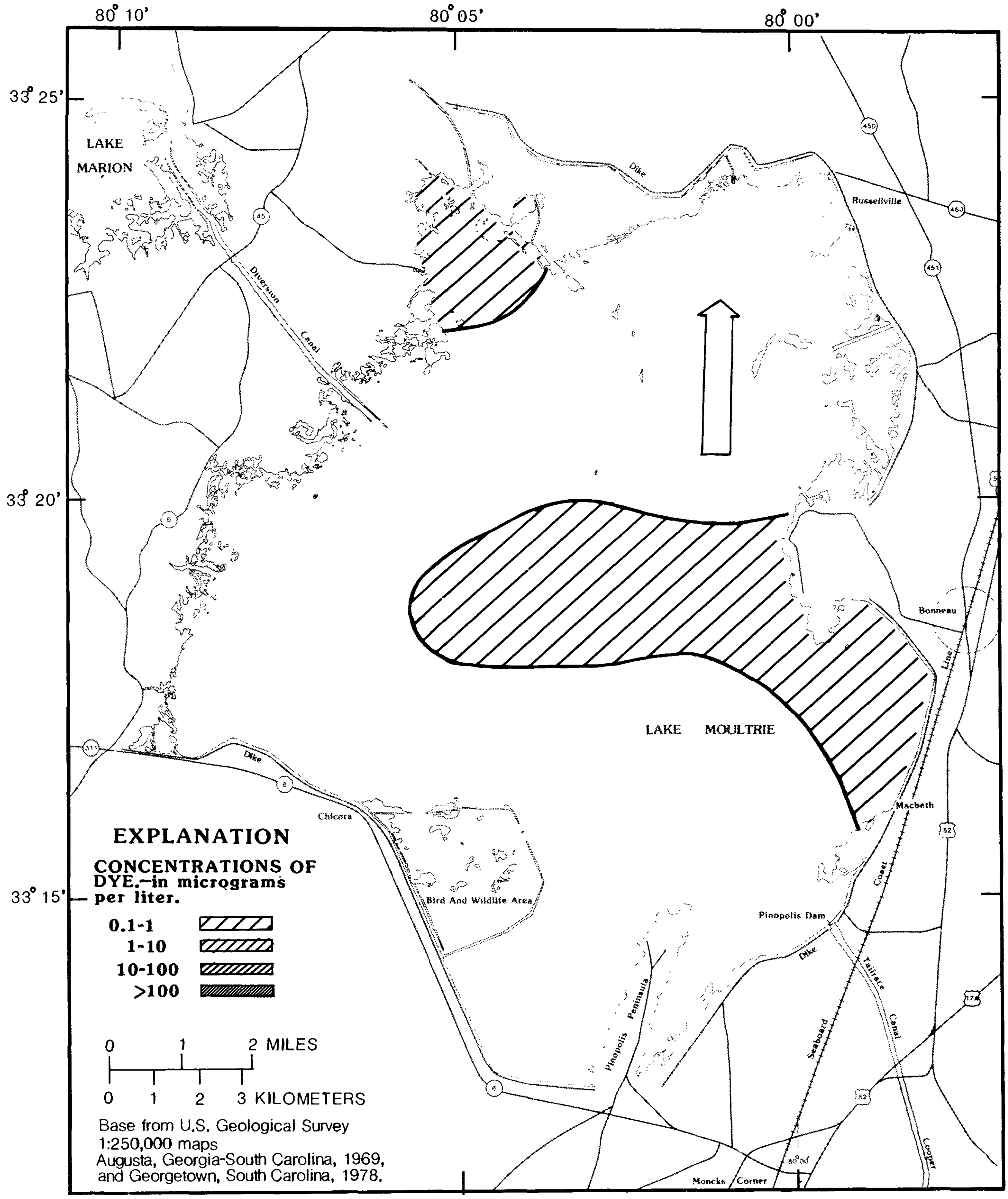


Figure 9.--Concentrations of dye in Lake Moultrie 7 days following the high-flow injection.

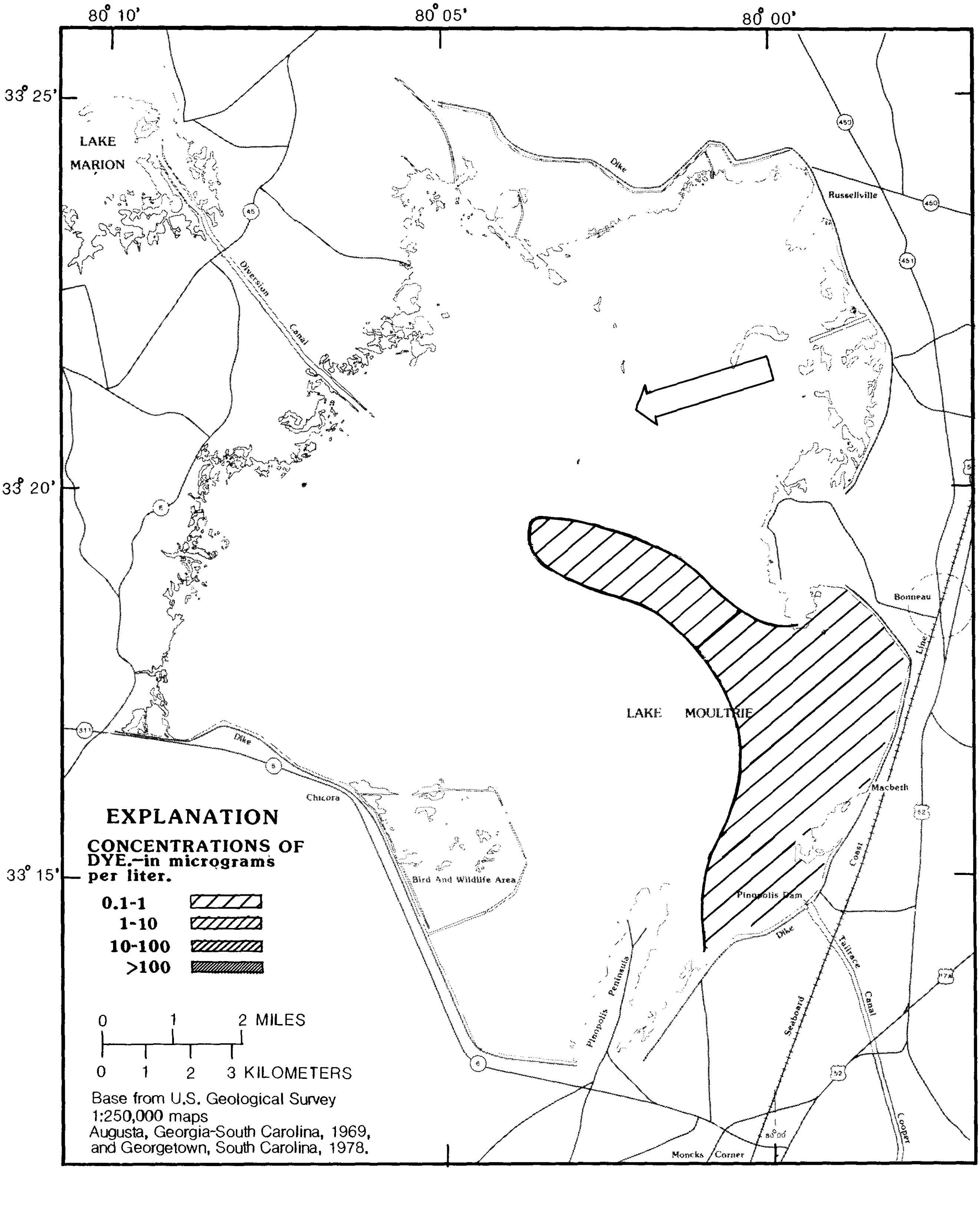


Figure 10.--Concentrations of dye in Lake Moultrie 9 days following the high-flow injection.

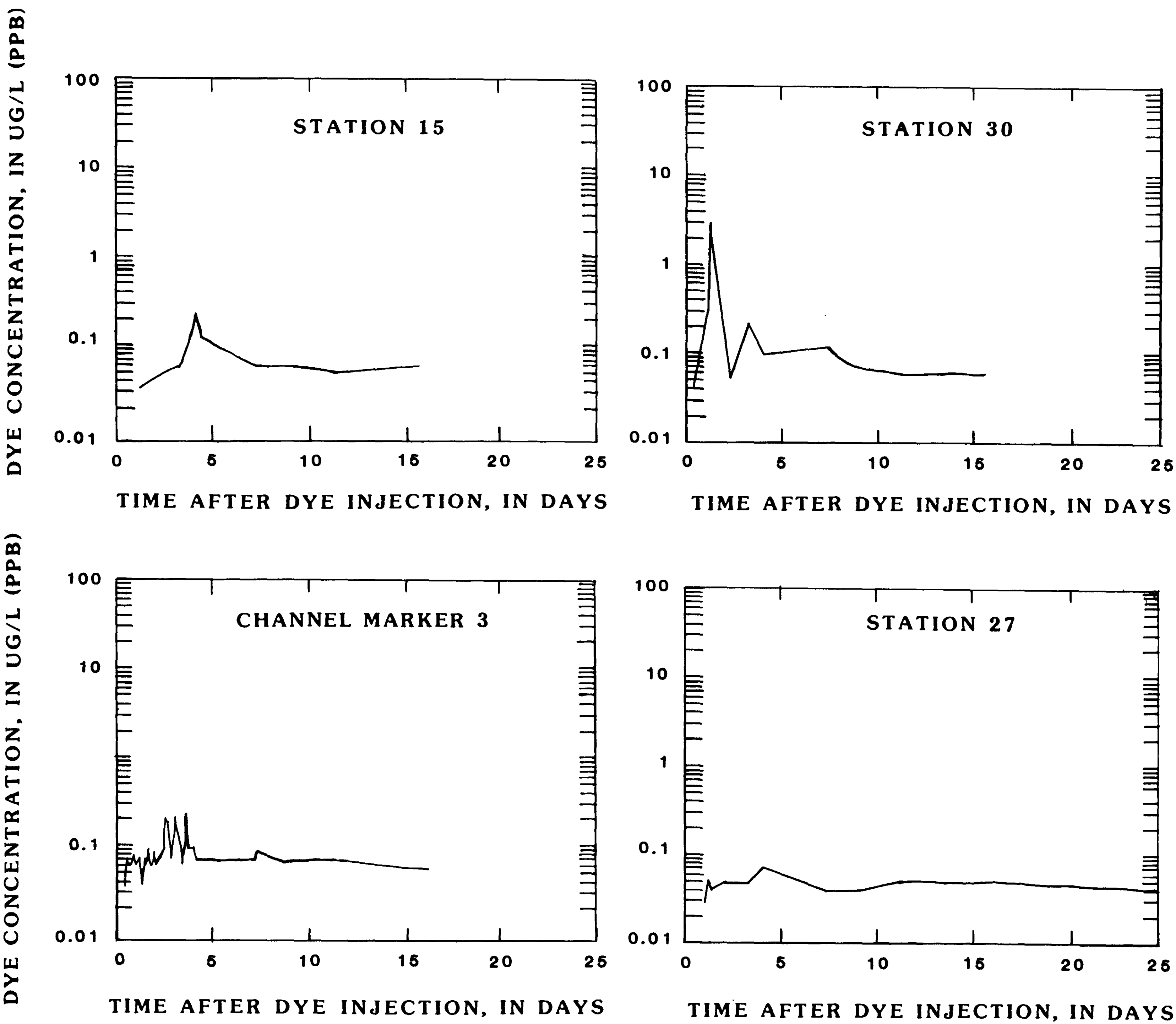


Figure 11.--Concentration of dye versus time at four stations for the high-flow test, Lake Moultrie.

The solid lines in figure 11 connect points representing samples taken from the surface of the lake while the large dots represent depth-integrated samples. Except for the third day following the high-flow injection, there was little difference in dye concentration between surface and depth-integrated samples at any of the four stations, and the small differences that did exist showed no bias toward higher concentrations at the surface or at depth. Results of a statistical test on samples from both the high-flow and low-flow tests are presented later.

## Low-Flow Test

During the low-flow test, lake inflow and outflow averaged about 24 percent of inflow and outflow during the high-flow test (table 2). Advection of water through the lake was therefore a less significant factor in dispersing the tracer during the low-flow test, and the tracer cloud appeared to move more slowly through the lake.

During the low-flow injection, the lake current near the mouth of the diversion canal and the prevailing wind were moving from the northeast. Most of the tracer was swept along the shore toward the southwest immediately after entering the lake. One day after the injection, the visible tracer cloud stretched from slightly north of the diversion canal about half way to the southwest corner of the lake (fig. 12). During the second day following the injection, the wind continued to blow from the northeast and the tracer continued to move toward the south and southwest, to the southwestern shore of the lake and toward the vicinity of the bird and wildlife area (fig. 13).

During day 3 following the low-flow injection, the wind continued to blow from the northeast. The tracer began to spread into the deep water in the middle of the lake (fig. 14). As in the high-flow study, there was some evidence of tracer spreading more rapidly against the wind in deep water than in shallow water (table 4). However, during the low-flow study the effect was still noticeable on day 6.

The wind direction varied during days 4 through 10 and the tracer remained in the same general area of the lake, moving slowly toward the dam (figs. 15, 16, and 17). During days 10 through 20, the net wind was from the northeast. By the end of day 13, the highest concentrations had moved to the east side of the lake and closer to the dam (fig. 18). Concentrations in the range of 0.08 to 0.09 ug/L over the southeastern half of the lake indicate that the tracer was dispersing away from the centroid of the tracer cloud. By the end of day 20, nearly all of the lake showed at least a slight trace of dye. The highest concentrations, however, were near the dam, indicating that much of the tracer had already left the lake (fig. 19).

By the 35th day, most of the tracer had been flushed from the lake, and the remaining tracer was well dispersed throughout the lake.

Graphs of concentration versus time for four sampling stations are shown in figure 20. Three separate peaks in concentration occurred at station 15 in the southwestern part of the lake. During the first peak, which occurred on the second day following the injection, the concentration rose to 4.7 ug/L for a brief time. The subsequent peaks recurred at intervals of about 7 days, and showed a trend toward decreasing concentration and increasing duration. The pattern appears to indicate a cyclical or reversing movement of water past the sampling station.

The concentration reached a peak of 0.32 ug/L at station 4, in the middle of the lake, on the third day following the injection (fig. 20). A second peak, lower and much broader, began on about the 10th day and continued until about the 35th day. This broad peak appears in the time-concentration graphs for all of the stations. Examples shown in figure 20 are for station 15, station 4, station 8 (about one-fourth of the way between the diversion canal and the dam) and station 28, in the northeastern corner of the lake. The appearance of this peak at all of the stations suggests that by the 20th day the tracer had become well-mixed throughout the lake.

Table 4.--Concentrations of tracer in surface and in depth-integrated samples from the deepest part of Lake Moultrie 3 to 6 days following the low-flow injection

| Station | Days from injection | Concentration of tracer, microgram per liter | |
|---|---|---|---|
| | | Surface | Depth-integrated |
| 1B | 2.87 | 0.05 | 0.05 |
| 1B | 6.02 | .07 | .15 |
| 2 | 2.87 | .10 | .17 |
| 2 | 6.02 | .06 | .06 |
| 4 | 2.87 | .15 | .32 |
| 4 | 3.03 | .05 | .13 |
| 4 | 5.93 | .10 | .11 |
| 20L | 2.85 | .85 | .85 |
| 20L | 3.03 | .24 | .48 |
| 20L | 5.99 | .15 | .15 |

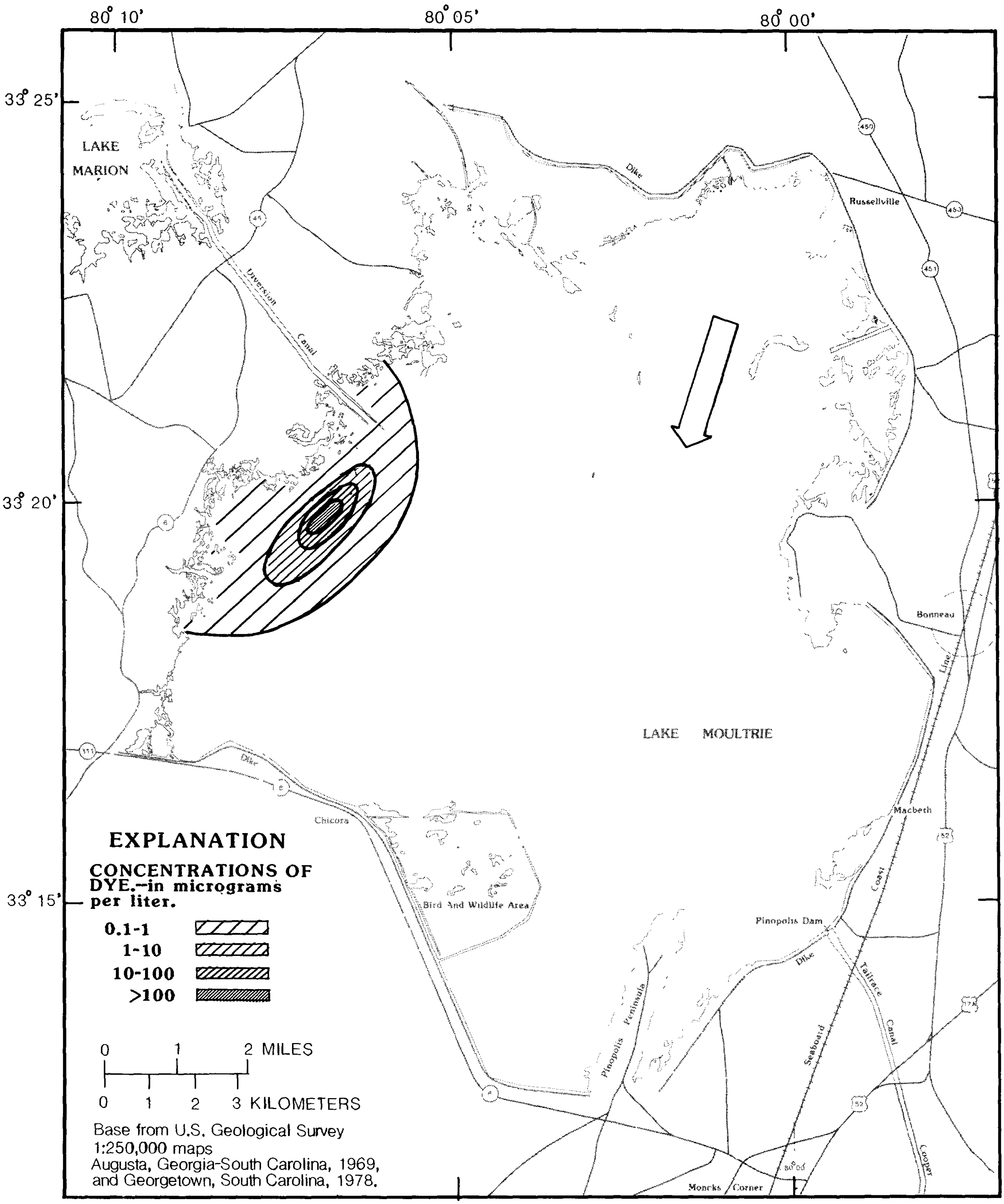


Figure 12.--Concentrations of dye in Lake Moultrie 1 day following the low-flow injection.

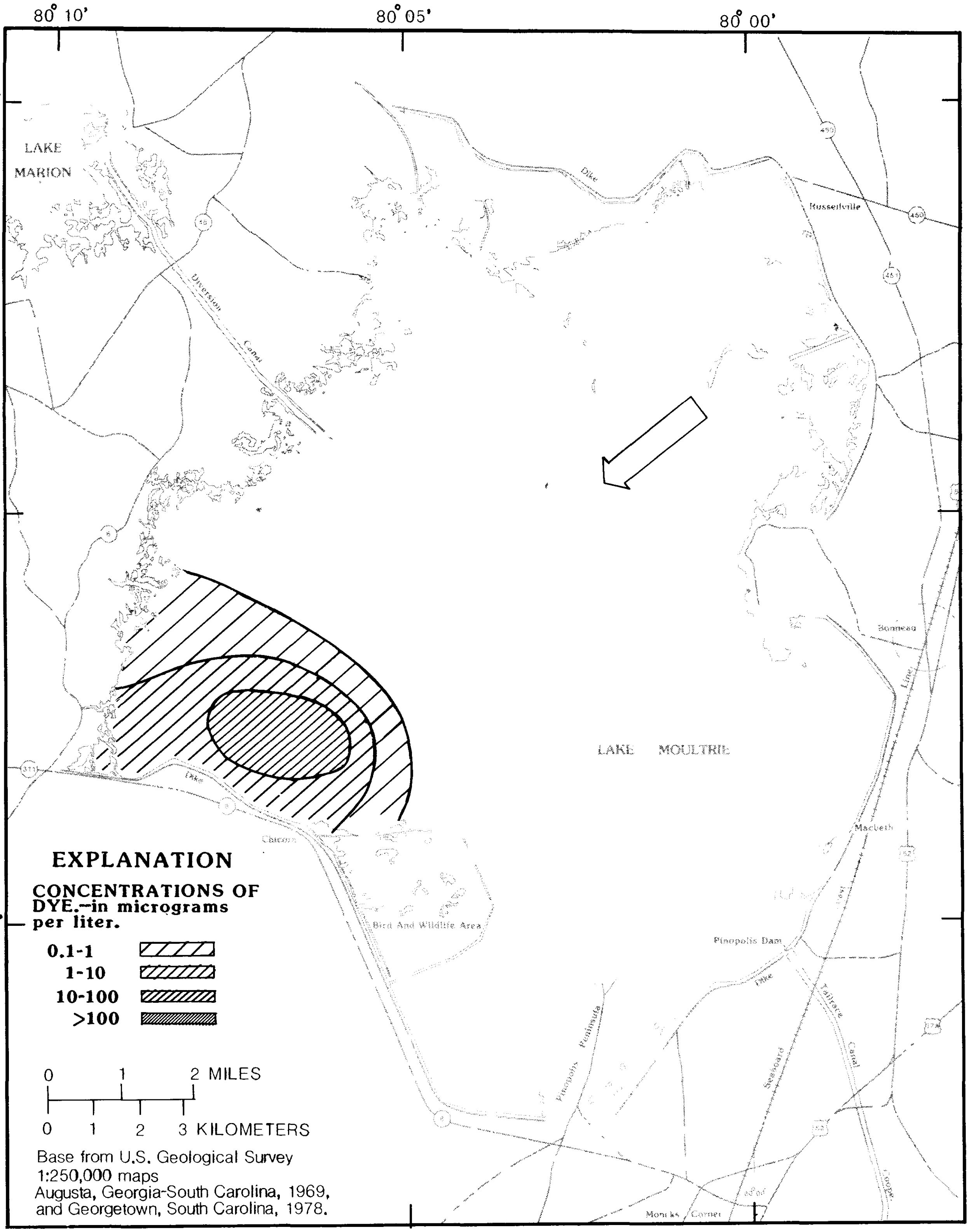


Figure 13.--Concentrations of dye in Lake Moultrie 2 days following the low-flow injection.

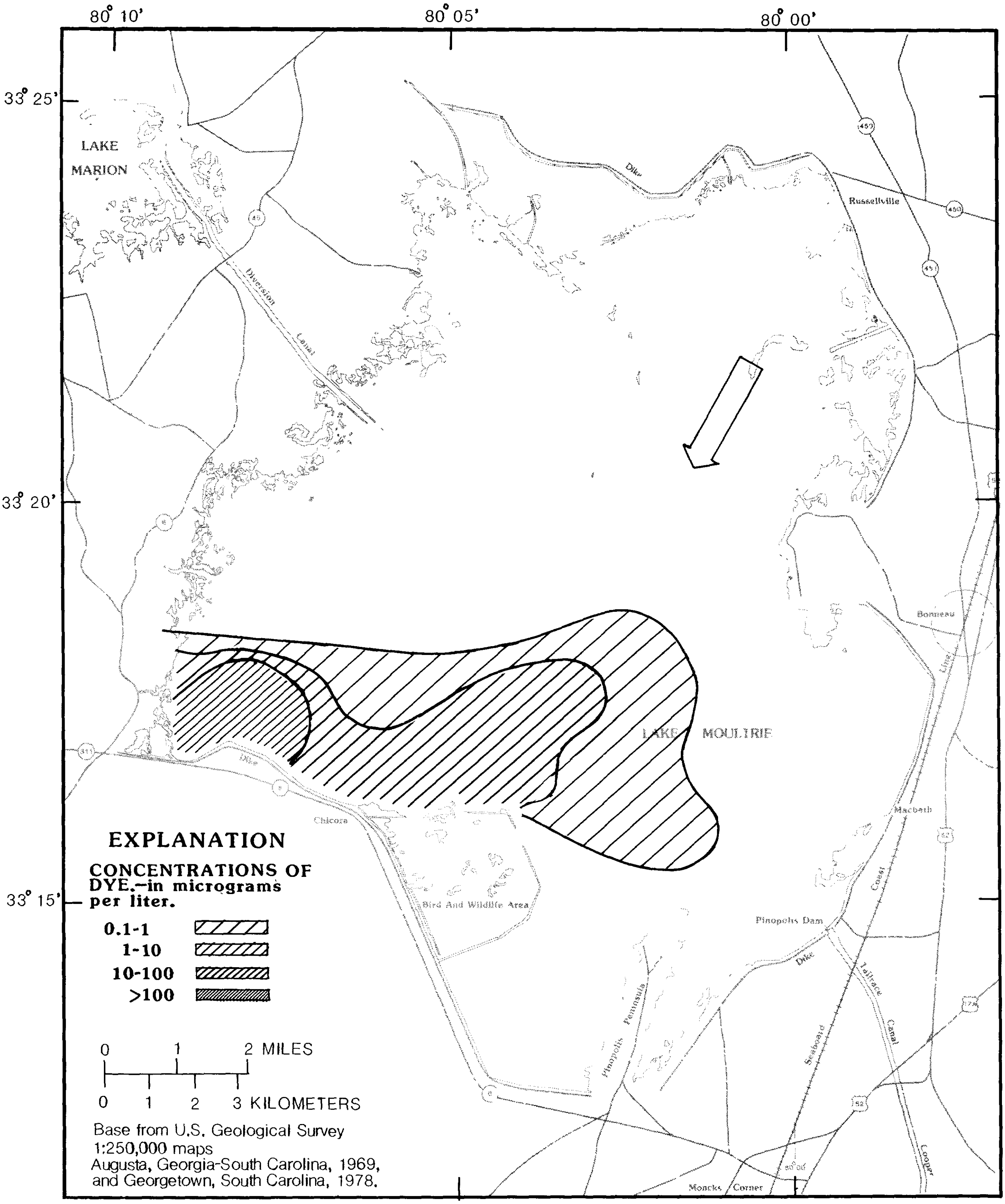


Figure 14.--Concentrations of dye in Lake Moultrie 3 days following the low-flow injection.

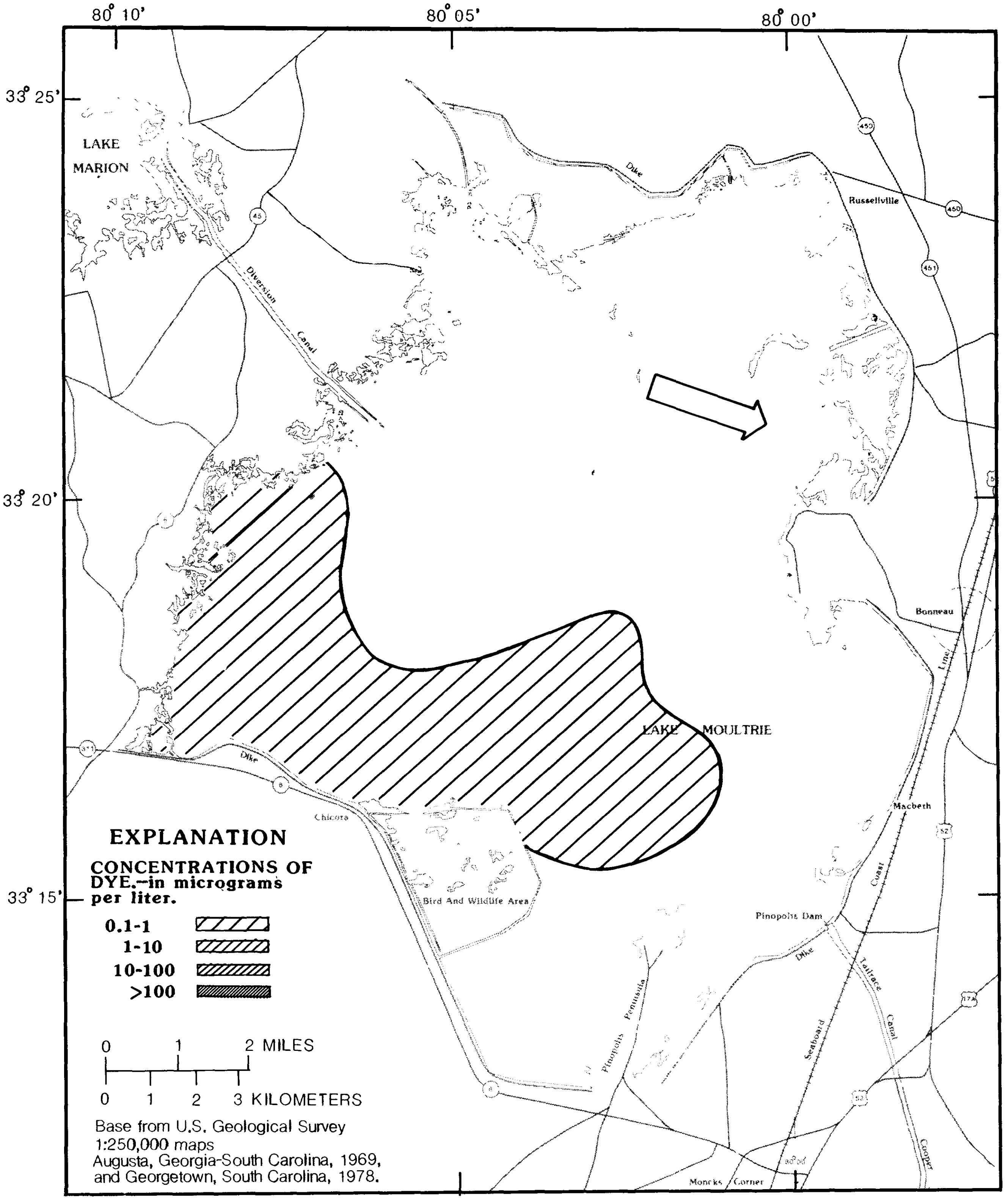


Figure 15.--Concentrations of dye in Lake Moultrie 6 days following the low-flow injection.

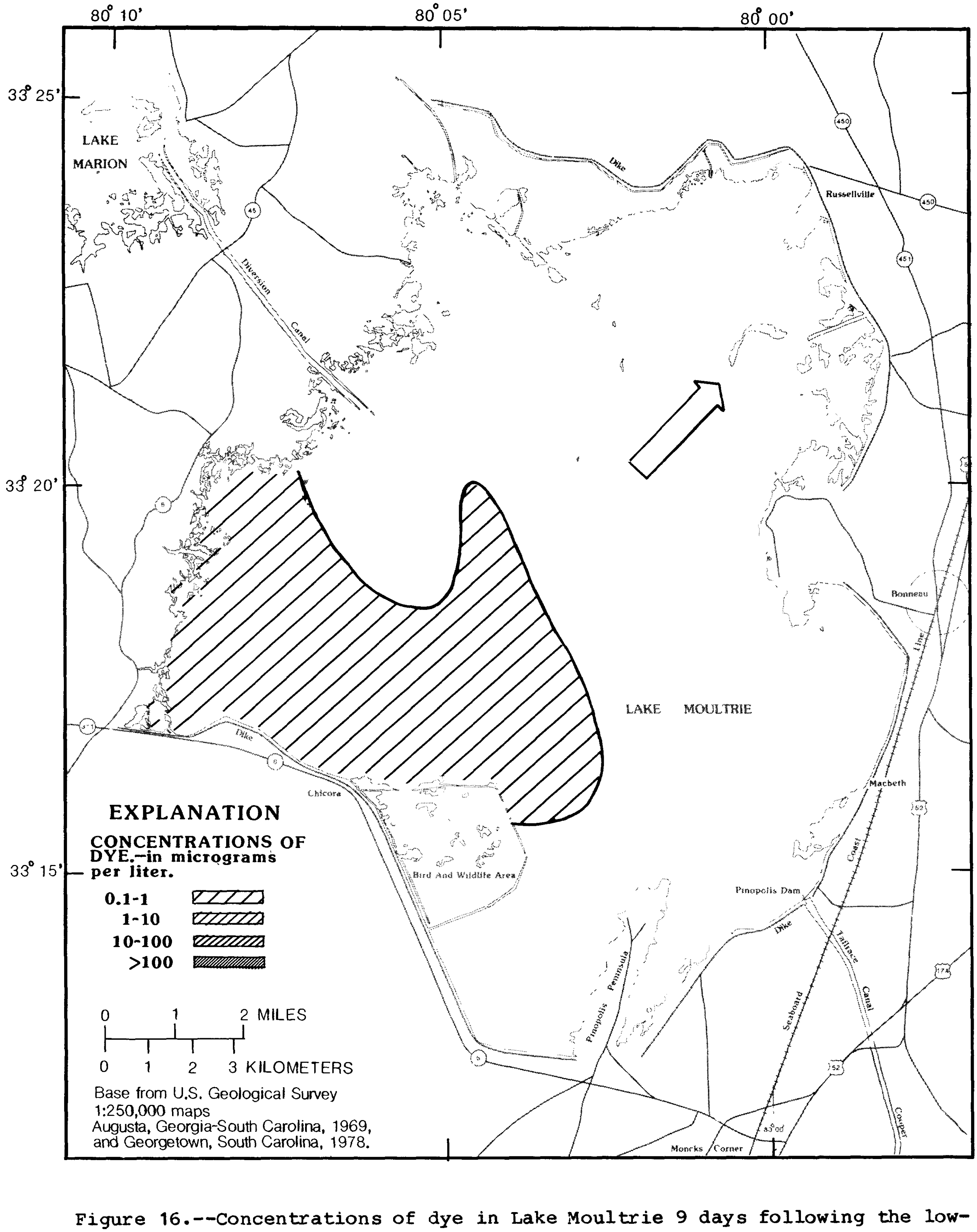


Figure 16.--Concentrations of dye in Lake Moultrie 9 days following the low-flow injection.

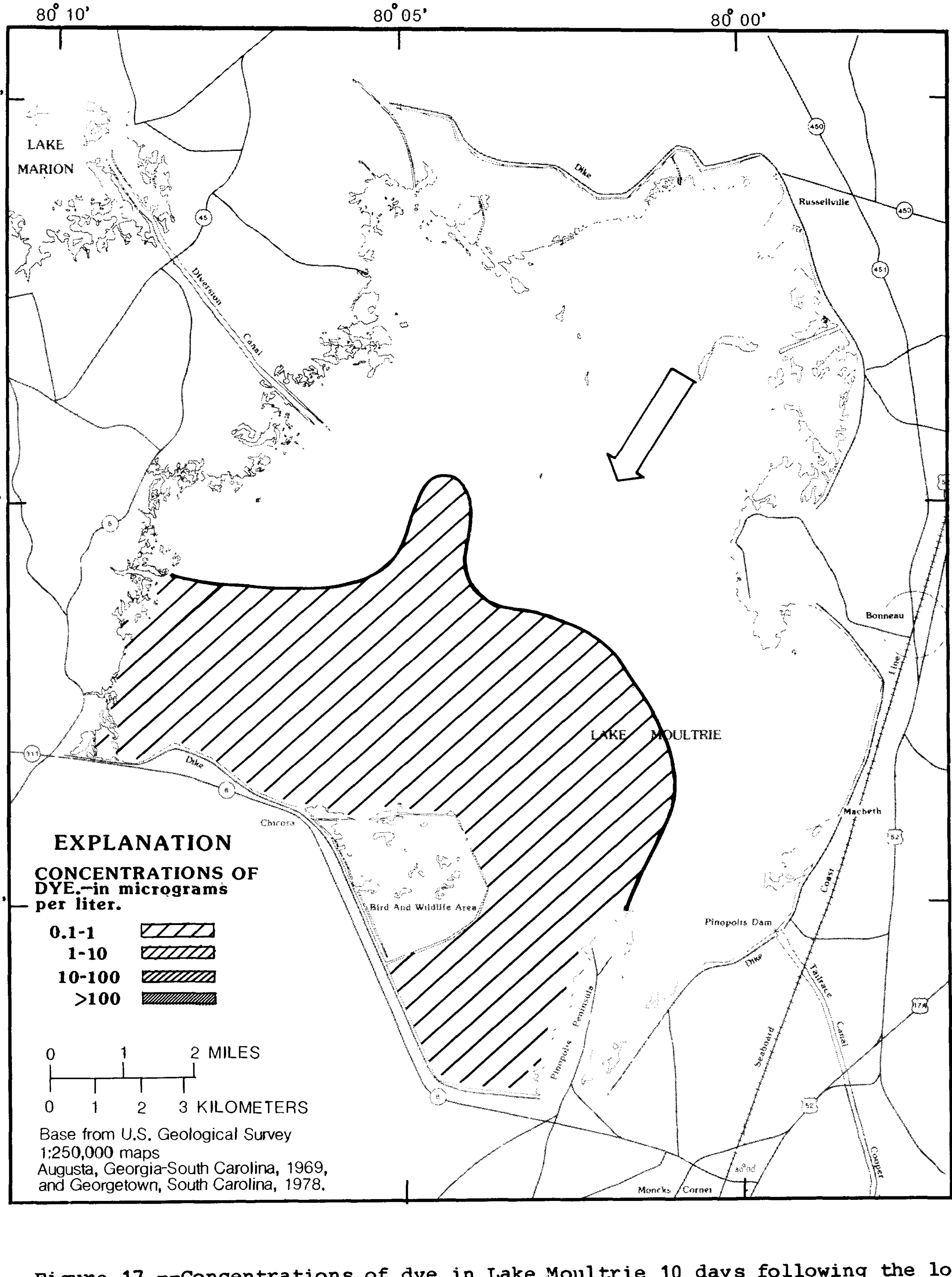


Figure 17.--Concentrations of dye in Lake Moultrie 10 days following the low-flow injection.

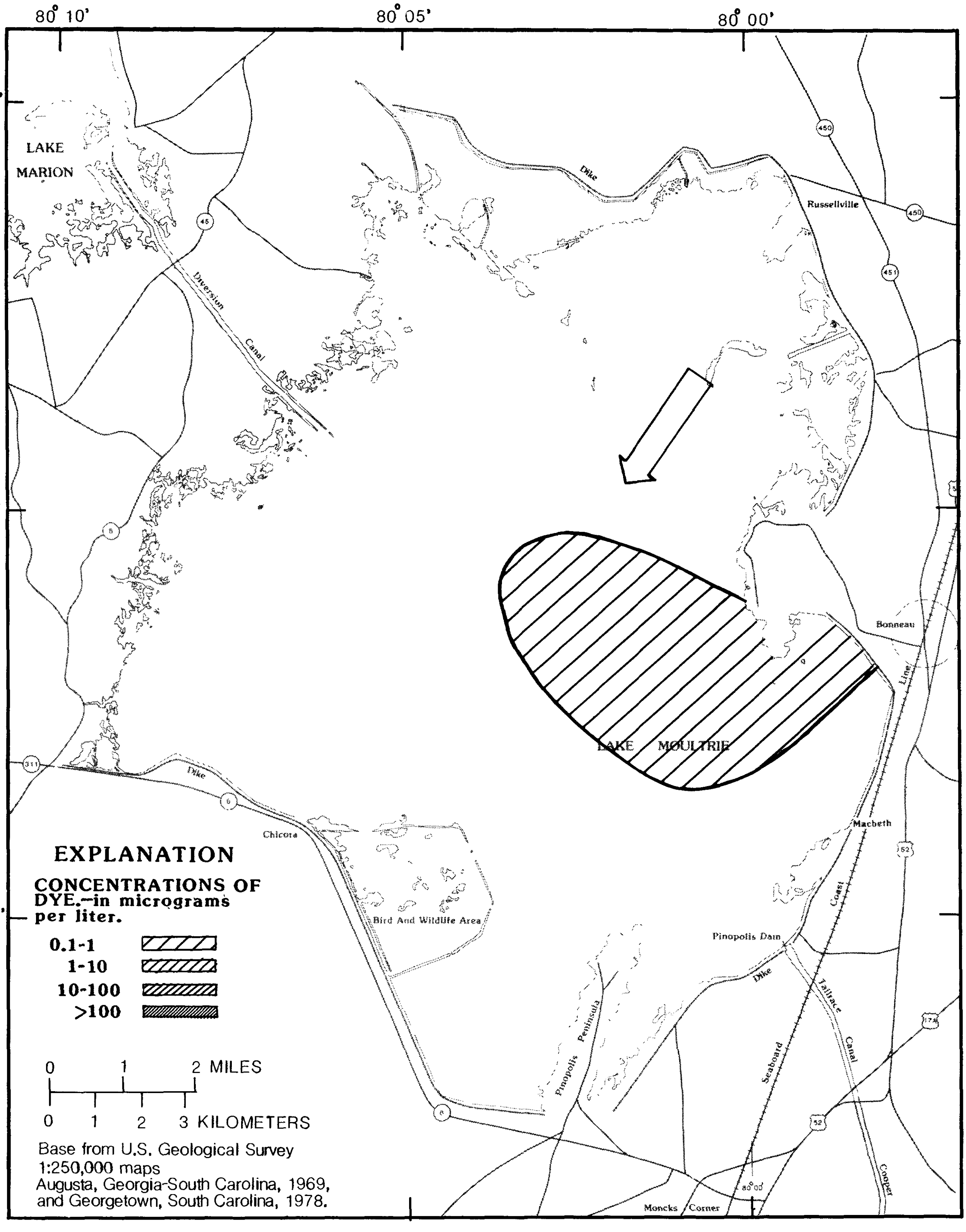


Figure 18.--Concentrations of dye in Lake Moultrie 13 days following the low-flow injection.

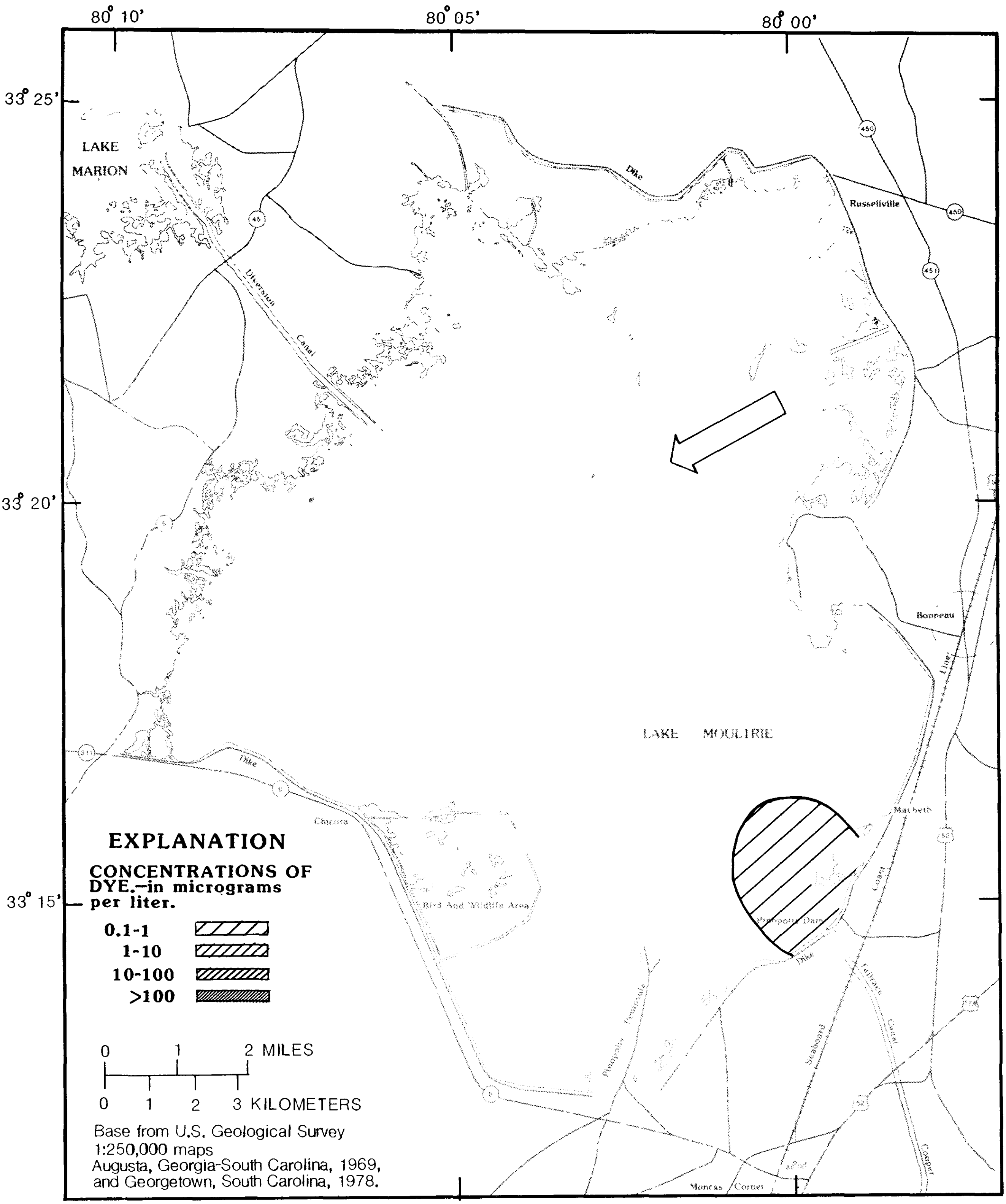


Figure 19.--Concentrations of dye in Lake Moultrie 20 days following the low-flow injection.

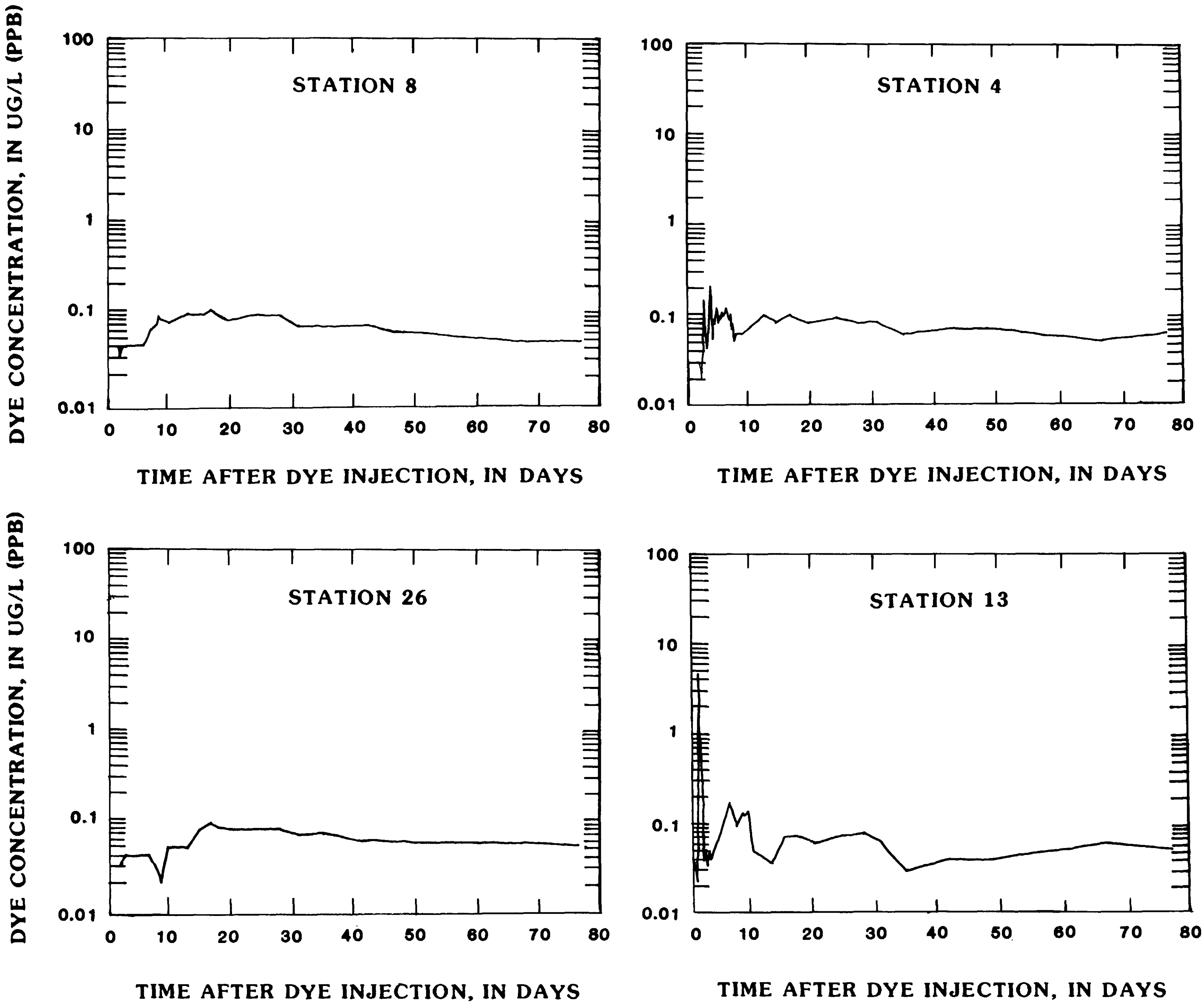


Figure 20.--Concentration of dye versus time at four stations for the low-flow test, Lake Moultrie.

## Results Common to Both Tests

A useful result of tracer tests such as these is a determination of the dilution of a conservative constituent as water flows through the study area. During both tests, concentrations that were in the range of 200-400 ug/L in the diversion canal were diluted by a factor of about 10 during the first 2 days in the lake, and by a factor of about 500 by the time the tracer reached Pinopolis Dam.

During both the high-flow and the low-flow tests, little difference was found between dye concentrations in surface versus depth-integrated samples. To compare surface versus depth-integrated sampling, all of the pairs of samples in which the concentration was greater than or equal to 0.10 ug/L in either or both samples were examined. The pairs of samples in which both concentrations were less than 0.10 ug/L were ignored to avoid unnecessary bias in favor of no difference in the data. The 158 pairs of samples examined had descriptive statistics as follows:

| Sample type | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Surface | 0.16 | 0.20 | 0.03 | 1.85 |
| Depth | 0.17 | 0.21 | 0.06 | 2.00 |
| Depth minus surface | 0.01 | 0.044 | -0.23 | 0.24 |

According to a paired T-test the difference of 0.01 ug/L is statistically significant at the 99 percent confidence level. However, the difference is within the range of error of the fluorometer. Therefore, surface samples that were taken without corresponding depth-integrated samples may be considered representative of the water column.

The only times when there appeared to be a consistent difference between surface and depth-integrated samples were day 3 of the high-flow test and days 3 through 6 of the low-flow test. During these periods, depth-integrated samples tended to have greater concentrations than surface samples in the deep part of the lake between station 6 and the dam.

Apparently the tracer entering the lake was mixed throughout the shallow water column in the upper end of the lake. As the dye spread toward the deep part of the lake on the third day, it could have encountered a two-layer circulation pattern in which surface water moved in the direction of the wind and deep water returned in the opposite direction (Liv and Perez, 1971, p. 923). However, the limited amount of deep water in Lake Moultrie and the turbulence caused by the wind and by advective currents were probably responsible for the rapid mixing of the dye throughout both deep and shallow water during the next day or so. An alternative explanation for the partial stratification of the tracer, involving the existence of a density current, is unlikely because the inflow to Lake Moultrie is the outflow from an even larger lake. Therefore, density differences due to sediment or temperature should be minimal.

The large size of Lake Moultrie created a problem with the limit of detection. It was physically and financially impractical to inject enough dye in a single slug to be easily detectable when evenly dispersed throughout the lake. The fluorescence of the samples after the initial peaks was generally of the same order of magnitude as the fluorescence of background materials. These background materials may include sediment, detergents, and other natural and artificial substances that exhibit fluorescence. During both tests, fluorescence due to background sources prior to the injections was equivalent to an average of 0.04 ug/L of dye. By the 75th day of the low-flow test, the winter rains had begun washing fresh sediment into the lakes, raising the background concentration slightly.

Of greatest value are the first week or so of each test when concentrations were high enough (greater than about 0.3 ug/L) to clearly indicate where the tracer was, and when the tracer cloud was still compact enough to be moving as a unit.

During this period, useful information was obtained on flow patterns near the diversion canal, on dilution, on vertical mixing, and on travel times. During the later phases of each test, general information was obtained that was of limited value in estimating retention time and dilution.

The retention of tracer in the lake during these tests can be compared with the theoretical retention time of water in the lake. The retention of detectable tracer ranged from about 2 weeks at an average outflow of 13,800 $ft^3/s$ to about 6 weeks at an average through flow of 3,310 $ft^3/s$. The theoretical hydraulic retention time, which is the lake volume divided by the average outflow, is 6 weeks for the high-flow condition and 24 weeks for the low-flow condition. The differences may be attributable to dilution below the limit of detection, and in addition, for the high-flow study, to incomplete mixing of tracer in the lake.

## CONCLUSIONS

Wind-generated currents are capable of dispersing incoming water throughout Lake Moultrie within about 16 days at low flow (3,310 $ft^3/s$). Tracer that was injected at high flow (13,800 $ft^3/s$) was not dispersed throughout the lake in the 12 days required for it to be flushed from the lake or reduced to nondetectable levels. Tracer that was injected at low flow remained detectable in the lake for about 35 days and was dispersed throughout the lake. Concentrations decreased by a factor of about 500 as the tracer clouds passed through the lake.

## REFERENCES

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