

TRANSPORT SIMULATION OF STRIPED BASS EGGS IN THE  
CONGAREE, WATEREE, AND SANTEE RIVERS,  
SOUTH CAROLINA

By Noel M. Hurley, Jr.

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TRANSPORT SIMULATION OF STRIPED BASS EGGS IN THE  
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ABSTRACT

The transport of striped bass eggs in the Congaree, Wateree, and Santee Rivers was studied by using a one-dimensional unsteady-flow model and a Lagrangian-type transport model. Simulated streamflows from the flow model were used with channel geometry information as input to the transport model. The results of a dye study were used to calibrate the transport model. The dispersion coefficients determined by the calibration were used to simulate movement of striped bass eggs spawned in 1988.

Striped bass eggs were collected every 8 hours at 4 sites over a period of 6 weeks during 1988. The density and average age of the eggs at the time of sampling were then determined by South Carolina Wildlife and Marine Resources personnel. Water temperature, monitored at five locations, was used to identify critical periods for egg sampling and to predict egg development time.

Egg survival and striped-bass recruitment depend on four physical factors: spawning location, water temperature, streamflow, and flow velocity. Laboratory tests indicate that the eggs, which have a specific gravity of 1.001, will settle to the streambed if flow velocity falls below about 0.2 foot per second. The eggs that settle in the river channel or in Lake Marion might not survive because they could be covered with silt and smother. Eggs that hatch near the lake may have a greater probability of survival than eggs that hatch in the upstream riverine habitat, because the lake habitat produces greater quantities of food (zooplankton) required by striped bass larvae during feeding stages.

The transport simulation results indicate that the eggs were spawned from river mile 5.8 to river mile 44.0 on the Congaree River and from River mile 14.5 to upstream of the study limit, river mile 66.3, on the Wateree River. Additionally, the eggs hatched from the upper reaches of Lake Marion to river mile 16.7 on the Congaree River and from river mile 0.0 to river mile 46.5 on the Wateree River. For the 1988 spawning period, the modeled results indicate that nearly all of the striped bass eggs hatched in the Santee River near Lake Marion.

Model results were used to develop equations to predict distance to hatching point and distance to spawning point from the sample sites. The equations are site specific but provide an easy method for estimating travel distance of the eggs.

## INTRODUCTION

Shortly after the impoundment of Lakes Marion and Moultrie in 1941, the reservoirs, also known as the Santee-Cooper lakes, became nationally famous for their land-locked fishery of striped bass. The fishery is responsible for a significant part of the \$399 million that were spent on freshwater fishing trips in South Carolina in 1985 (U.S. Fish and Wildlife Service, 1985).

The striped bass spawn each spring in the Congaree and Wateree Rivers upstream from Lake Marion (fig. 1), and the eggs develop as they drift downstream, suspended in the water column. For many years, the natural reproduction of striped bass in these rivers was sufficient to maintain a large population in the lakes. In recent years, however, the success of natural reproduction has declined, and fingerling striped bass have been stocked to supplement natural reproduction.

Striped bass spawning location affects the success of the hatch in that the spawning location, in conjunction with water temperature and flow velocity, determine the location in which the eggs will hatch. Temperature affects the length of time it takes eggs to hatch (Hassler and others, 1981), and stream velocities determine the distance eggs will travel before hatching. If flow velocities are too low, the eggs will settle to the bottom, significantly reducing survival probabilities (Bayless, 1967).

Hatching location can affect survival probabilities of striped bass larvae. Higher survival rates generally are associated with areas of high food density such as the upper reaches of the Santee River and Lake Marion. Lake habitats generally produce greater quantities of the food (zooplankton) required by first-feeding striped bass.

Management of the striped bass fishery in Lake Marion and its tributaries requires a knowledge of the spawning and hatching locations and their relation to streamflow. To provide the responsible State agencies with the data needed to properly manage the fisheries resource, the U.S. Geological Survey, in cooperation with a number of state and local agencies, undertook a study in 1988 to simulate the transport of striped bass eggs in this stream system using existing flow and transport models. The State and local agencies that cooperated in this study were the South Carolina Wildlife and Marine Resources Department (SCWMRD), South Carolina Electric and Gas Company, South Carolina Public Service Authority, South Carolina Department of Health and Environmental Control, Duke Power Company, and South Carolina Water Resources Commission.

### Purpose and Scope

This report presents the results of a study to predict the spawning and hatching locations of striped bass eggs sampled during the 1988 spawning period in the Congaree, Wateree, and Santee Rivers using the BRANCH one-dimensional flow model and the BLTM transport model. Predictive relations were developed from the simulated transport results to estimate

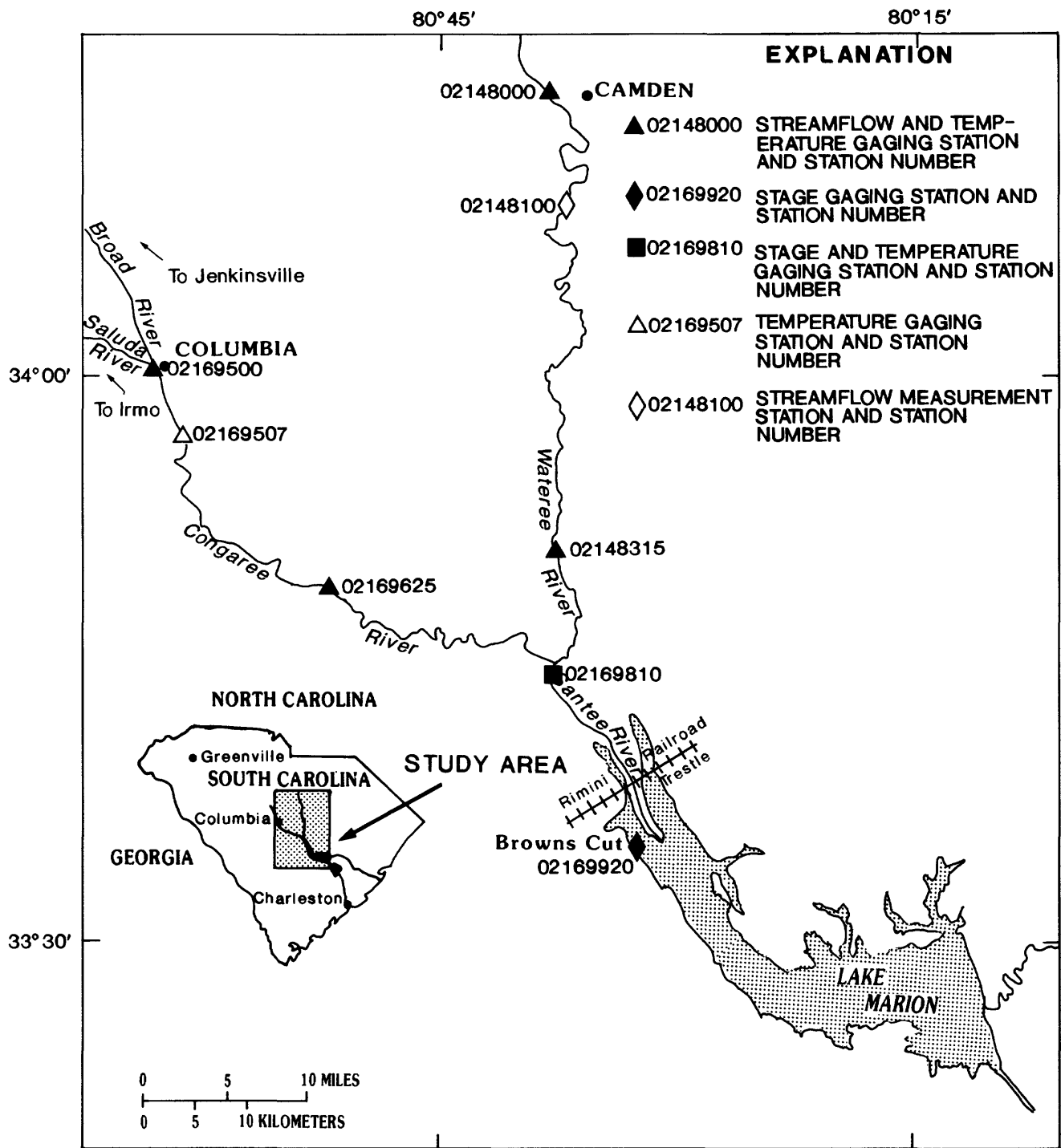


Figure 1.--Study area and data collection sites.

spawning and hatching location from specific egg sample sites. These relations were developed using multiple regression analyses of the independent variables of discharge, egg age, egg development time, and water temperature.

### Study Area

The study area includes the Congaree River, the Wateree River downstream of the U.S. Highway 601 bridges near Camden, S.C., and the Santee River to its confluence with Lake Marion at Browns Cut (fig. 1). Approximately 51.1, 67.5, and 16.2 river miles of the Congaree, Wateree, and Santee Rivers, respectively, were studied. The 7.3-mile section of the Wateree River from the Lake Wateree Dam to the U.S. Highway 601 bridge was not included in the study.

Flow in the study area is regulated by a series of dams. Flow in the Congaree River, formed by the confluence of the Saluda and Broad Rivers at Columbia, S.C., is controlled by the release of water from Lake Murray Dam on the Saluda River near Irmo, S.C., and from Parr Shoals Dam on the Broad River near Jenkinsville, S.C., during low and medium flows.

Flow in the Wateree River is controlled by the release of water from Lake Wateree Dam on the Wateree River upstream of Camden. The rapid fluctuations in stage and discharge, common to regulated streams, are more pronounced on the Wateree River than the Congaree River.

The Santee River is formed by the confluence of the Congaree and Wateree Rivers. Backwater from Lake Marion affects flow in portions of the Santee River. The location and magnitude of these effects are dependent on lake elevation and streamflow.

Lake Marion surrounds, but does not inundate, the river channel in the lower reaches of the Santee River. This is because the natural levees formed by the Santee River separate the river from the lake in the approximately 5-mile reach from the Rimini railroad trestle to Browns Cut where the natural levees are completely inundated. Numerous cuts, man made and natural, are present in these levees, and under a combination of low-reservoir level and a higher river stage allow some flow and striped bass eggs to escape the river channel.

### Acknowledgments

The author is grateful to personnel of the SCWMRD for sampling and determining the age of the striped bass eggs and providing technical suggestions and support. The striped bass eggs were sampled at 8-hour intervals during the 1988 spawning period by James Bulak, John Crane, Donald Gates, Drew Robb, and Gerrit Jöbis of the SCWMRD. Dr. Earl Hayter, Civil Engineering Department of Clemson University, is acknowledged for providing the use of a sand-channel flume for the suspended velocity experiments. Special thanks is extended to James Bulak, SCWMRD, whose insight and perseverance made this study possible.



## STREAMFLOW, STAGE, AND TEMPERATURE DATA

Discharge, stage, or temperature data were collected at eight stations during this study: three on the Wateree River, three on the Congaree River, one on the Santee River, and one on Lake Marion. Continuous records of discharge and stage were available at four of the eight sites and continuous records of stage were obtained at the Lake Marion site. Additionally, continuous records of temperature were obtained at six sites (table 1).

Discharge and (or) stage data from stations 02148000, 02169500, and 02169920 were used to provide boundary input data to the flow model. Discharge and stage data from stations 02148100, 02148315, 02169625, and 02169810 were used in model calibrations and validations. Temperature data were used to determine the development time necessary for the sampled striped bass eggs to hatch.

### Dye Study Data

The study area was divided into five reaches for the dye studies (fig. 2). Injection and sampling locations for the five reaches are summarized in table 2.

Several dye injections were made in the study area during August 1987. Measurements of dye concentration were used to determine travel times and dispersion coefficients, and to provide transport data for calibration of BLTM.

Procedures for the dye studies, which generally follow those described by Hubbard and others (1982), were as follows: A measured amount of rhodamine dye was instantaneously released near the center of the channel. Samples were collected at preselected locations along each study reach, and dye concentrations were determined by a fluorometer. The dye concentrations were usually determined at the observation sites prior to, during, and after the passage of the dye cloud. When possible the fluorescence of the river water was monitored until it had returned to background fluorescence. When time or manpower restrictions existed, the dye concentrations after the peak had passed were monitored only long enough to determine the rate of decrease in concentrations and the time at which concentrations returned to background levels was estimated. Automatic samplers were employed during the night and when the dye cloud became dispersed over many river miles.

### Cross-Sectional Data

Cross-sectional data were obtained in the study area by USGS personnel and from the U.S. Army Corps of Engineers (USACOE). Bed Profiles at selected locations along the Wateree and Santee Rivers were measured by USGS personnel. Forty-three cross sections were surveyed along the Wateree River and its tributaries from the Wateree-Congaree confluence to just downstream of Lake Wateree Dam. Eight cross sections were surveyed along the Santee River from its headwaters to Browns Cut, the downstream study limit. The USACOE provided maps and data for 272 cross sections at approximately 1,000-ft intervals along the Congaree River.

Table 1.--Stream gaging stations used in striped bass egg study

[Striped bass egg data collected by South Carolina Wildlife and Marine Resources Department]

| Station number | Station name   | River mile        | Type of record   | Period of record                          |
|----------------|--|-------------------|--|---|
| 02148000       | Wateree River at Camden  | <sup>1</sup> 67.5 | Stage, discharge, temperature  | 1935 - 1989<br>1988 - 1989                |
| 02148100       | Wateree River near Boykin                                      | <sup>1</sup> 54.7 | Stage, discharge, striped bass egg collection (site S3)              | 1987 - 1989<br>Spring 1988                |
| 02148315       | Wateree River below Eastover                                   | <sup>1</sup> 11.3 | Stage, discharge, temperature, striped bass egg collection (site S2) | 1968 - 1989<br>1970 - 1989<br>Spring 1988 |
| 02169500       | Congaree River at Columbia                                     | <sup>2</sup> 51.1 | Stage, discharge temperature   | 1939 - 1989<br>1988 - 1989                |
| 021695070      | Congaree River at Cayce Landing near Cayce                     | <sup>2</sup> 47.8 | Temperature  | 1988 - 1989                               |
| 02169625       | Congaree River west of Wise Lake near Gadsden                  | <sup>2</sup> 27.5 | Stage, discharge temperature, striped bass egg collection (site S4)  | 1981 - 1989<br>1988 - 1989<br>Spring 1988 |
| 02169710       | Congaree River at the Southern railway trestle near Fort Motte | <sup>2</sup> 4.7  | Striped bass egg collection (site S1)                                | Spring 1988                               |
| 02169810       | Santee River at Trezvants Landing near Fort Motte              | <sup>3</sup> 15.3 | Stage, miscellaneous measurements of discharge, temperature          | 1986 - 1989<br>1988 - 1989                |
| 02169920       | Lake Marion near Browns Cut near Lone Star                     | <sup>3</sup> 0.0  | Stage  | 1987 - 1989                               |

1. Wateree River Mile; mile 0.0 is the confluence with the Congaree River.
2. Congaree River Mile; mile 0.0 is the confluence with the Wateree River.
3. Santee River Mile; mile 0.0 is the Santee River at Browns Cut.

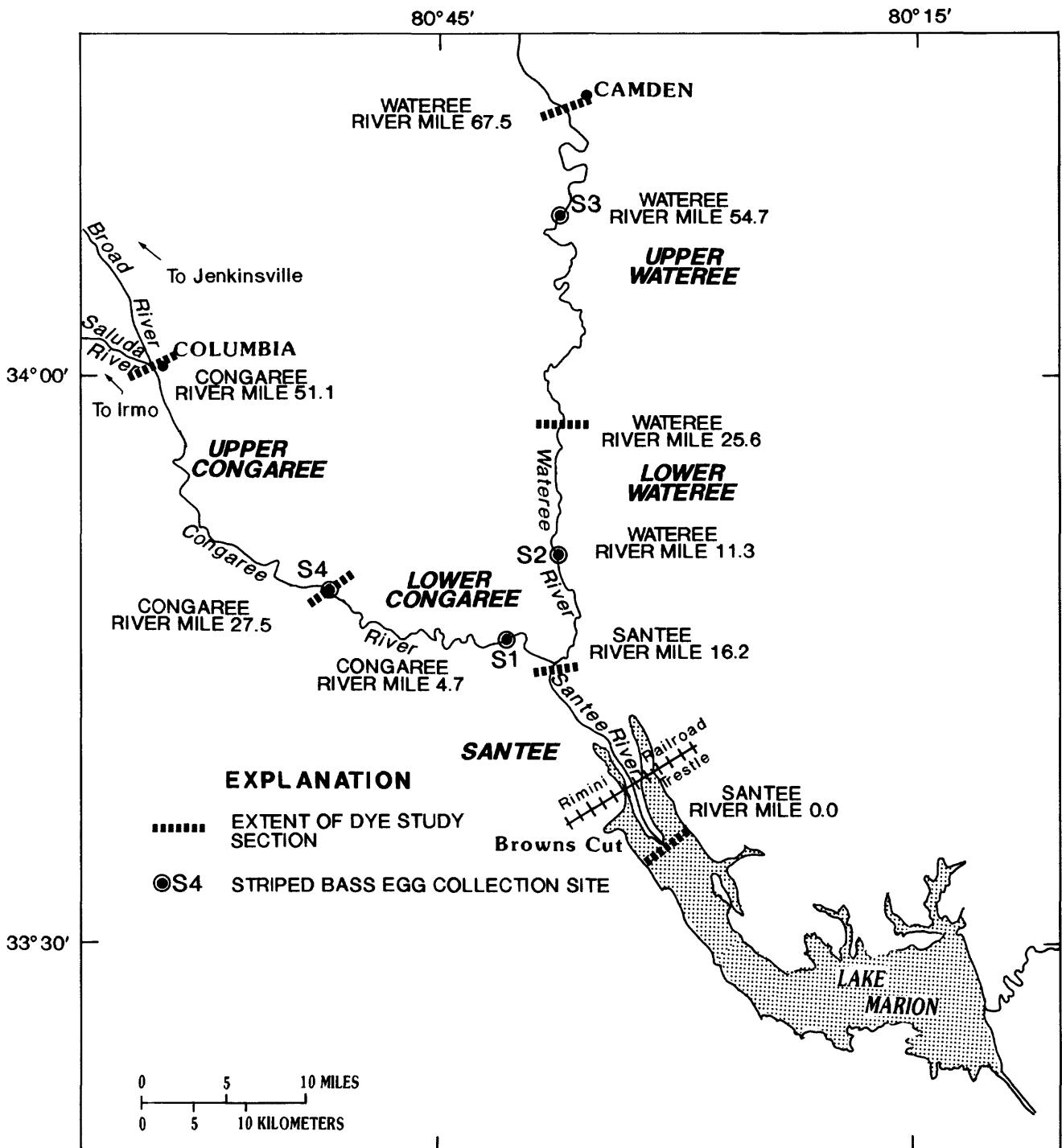


Figure 2.--Dye study reaches and striped bass egg collection sites.

Table 2.--Dye peak travel times in the Congaree, Wateree, and Santee Rivers

| Injection location (river mile) | Injection date | Sample location                                    | River mile | Distance from injection (miles) | Dye peak travel time (hours) |
|---------------------------------|----------------|--|------------|---------------------------------|------------------------------|
| Upper Congaree River Section    |                |  |            |                                 |                              |
| 49.9                            | 8/24/87        | Interstate 326 bridge                              | 46.6       | 3.3                             | 4.6                          |
| 49.9                            | 8/24/87        | Station 02169625                                   | 27.5       | 25.4                            | 24.5                         |
| Lower Congaree River Section    |                |  |            |                                 |                              |
| 27.5                            | 8/17/87        | Big Beaver Creek                                   | 24.5       | 3.0                             | 2.6                          |
| 27.5                            | 8/17/87        | River mile 19.4                                    | 19.4       | 8.1                             | 8.2                          |
| 27.5                            | 8/17/87        | Southern Railway trestle                           | 4.7        | 22.7                            | 23.8                         |
| 27.5                            | 8/17/87        | 0.25 mile, upstream of Wateree-Congaree confluence | .25        | 27.3                            | 27.8                         |
| Upper Wateree River Section     |                |  |            |                                 |                              |
| 67.5                            | 8/19/87        | Interstate 20 bridge                               | 66.4       | 1.1                             | 2.2                          |
| 67.5                            | 8/19/87        | River mile 61.0                                    | 61.0       | 6.5                             | 5.8                          |
| 67.5                            | 8/19/87        | Station 02148100                                   | 54.7       | 12.8                            | 11.8                         |
| 67.5                            | 8/19/87        | Spears Creek                                       | 32.7       | 34.8                            | 30.4                         |
| 67.5                            | 8/19/87        | U.S. Hwy 378 bridge                                | 25.6       | 41.9                            | 38.2                         |

Table 2.--Dye peak travel times--Continued

| Injection location (river mile) | Injection date | Sample location   | River mile | Distance from injection (miles) | Dye peak travel time (hours) |
|---------------------------------|----------------|---|------------|---------------------------------|------------------------------|
| Lower Wateree River Section     |                |   |            |                                 |                              |
| 25.6                            | 8/12/87        | Cove Lake   | 22.5       | 3.1                             | 3.1                          |
| 25.6                            | 8/12/87        | Station 02148312<br>Wateree River<br>at Union Camp              | 17.7       | 7.9                             | 7.7                          |
| 25.6                            | 8/12/87        | 0.25 mile,<br>upstream of<br>Wateree-<br>Congaree<br>confluence | .25        | 25.3                            | 28.1                         |
| Santee River Section            |                |   |            |                                 |                              |
| 16.2                            | 8/10/87        | Station 02169810  | 15.3       | 0.8                             | 1.4                          |
| 16.2                            | 8/10/87        | Rimini trestle  | 5.0        | 11.1                            | 12.5                         |
| 16.2                            | 8/10/87        | Browns Cut  | 0.0        | 16.2                            | 20.9                         |

The cross sections on the Wateree and Santee Rivers were determined by using a graphic fathometer attached to the gunwale of a boat. The trace of the channel bottom was recorded as the boat crossed the river at a constant speed. The width of the main channel and cross-sectional geometry for approximately 150 ft on either side of the channel were determined with conventional surveying equipment. Additionally, USGS 7.5-minute topographic maps (U.S. Geological Survey, 1953, 1982, 1987, and 1988) were used to extrapolate cross sections beyond the surveyed portion to delineate the flood plain.

## STRIPED BASS EGGS IN THE CONGAREE, WATEREE, AND SANTEE RIVERS

The majority of the adult striped bass in the study area winter in Lakes Marion and Moultrie. Some striped bass, however, remain in the Congaree, Wateree, and Santee Rivers throughout the year. In early spring the striped bass migrate upstream from Lakes Marion and Moultrie to spawn in the Congaree and Wateree Rivers.

### Spawning and Development Characteristics

Spawning begins when the water temperature reaches approximately 18 °C and continues intermittently for 6 to 8 weeks. Spawning begins as early as April 1 and terminates by June 1 and generally includes one to three "spawning peaks" in which a majority of the eggs are spawned. For example, in 1984 seventy-four percent of all Congaree River eggs were spawned during a 2-day period (Bulak and others, 1985).

The eggs are suspended in the water as they drift downstream. Sampling by SCWRD in 1983 indicated that the eggs are uniformly distributed vertically throughout the water column. The development time of the striped bass eggs is inversely proportional to temperature and ranges from 63 hours at 15 °C to 23 hours at 26 °C (Hassler and others, 1981).

### Sampling Procedures

Striped bass egg production was sampled by SCWRD with anchored, 1.64 ft plankton nets at four sites; two on the Congaree River and two on the Wateree River. The egg-sampling locations are shown in figure 2 and listed below:

- Collection Site, S1: Station 02169710, Congaree River at the Southern Railway Trestle, near Fort Motte
- Collection Site, S2: Station 02148315, Wateree River below Eastover
- Collection Site, S3: Station 02148100, Wateree River near Boykin
- Collection Site, S4: Station 02169625, Congaree River west of Wise Lake, near Gadsden

Egg sampling began at each site in 1988 when the water temperature reached 17 °C. Initially, samples were collected twice each day until more than two eggs per 35.3 cubic feet of water were observed at sites S1, S3, or S4, or if more than five eggs were observed at site S2. Sampling was conducted at 8-hour intervals at each site after the egg concentration reached these threshold levels. When the number of eggs collected on each sampling event was less than the threshold levels on three successive samples, the sampling was reduced to daytime activity only. The sampling net was lowered into the river at midstream for 5 minutes at each site (fig. 3). The net used to collect the eggs was a 1.64 ft diameter, 0.02 in. mesh size plankton net. Discharges were estimated from USGS gaging station records, and the number of eggs passing the sample site was estimated by multiplying the density of eggs per sample by the estimated volume of water passing the sample site during a sample interval.



Figure 3.--Striped bass egg collection, Congaree River.

Ages of the sampled eggs were determined by SCWMRD personnel. A subsample of eggs from each sample was analyzed with a microscope and assigned an age. The mean age for the eggs sampled each day was computed by averaging the ages of the eggs in all samples collected that day. The results of the 1988 striped bass egg sampling effort furnished by the SCWMRD are listed in table 3. The data in this table indicates that the mean age of eggs in individual samples ranged from about 3 to 36 hours, and the peak spawning period was in late April at most sites.

Table 3.--Estimated total number of eggs, mean number of eggs per hour, mean temperature, mean flow rate, number of eggs aged, and mean age of eggs by site and day for the 1988 South Carolina striped bass spawning study

(page 1)

[ft<sup>3</sup>/s, cubic foot per second; dashes indicate no data]

| Date 1988  | Total eggs  | Mean eggs per hour | Mean temperature (degrees Celsius) | Mean flow (ft <sup>3</sup> /s) | Number aged | Mean age of sample (hours) | Development time, sample to hatch (hours) |
|--|-------------|--------------------|------------------------------------|--------------------------------|-------------|----------------------------|---|
| Site S1 -- Station 02169710, Congaree River at the Southern Railway Trestle, near Fort Motte |             |                    |                                    |                                |             |                            |   |
| March 30   | 1,100,041   | 45,835             | 17.4                               | 5,930                          | 2           | 16.70                      | 31  |
| March 31   | 6,293,467   | 262,228            | 17.6                               | 6,030                          | 5           | 17.02                      | 31  |
| April 1  | 3,290,524   | 137,105            | 17.6                               | 5,100                          | 5           | 13.70                      | 34  |
| April 2  | 9,640,858   | 401,702            | 18.2                               | 4,880                          | 15          | 10.85                      | 37  |
| April 3  | 9,315,511   | 388,146            | 18.2                               | 4,880                          | 13          | 17.36                      | 28  |
| April 4  | 20,128,714  | 838,696            | 18.7                               | 3,800                          | 43          | 8.92                       | 32  |
| April 5  | 80,459,799  | 3,352,492          | 19.6                               | 2,510                          | 127         | 8.10                       | 33  |
| April 6  | 183,005,593 | 7,625,233          | 20.0                               | 2,570                          | 288         | 12.27                      | 31  |
| April 7  | 268,750,311 | 11,197,930         | 18.8                               | 4,490                          | 313         | 10.70                      | 37  |
| April 8  | 2,754,284   | 114,761            | 17.1                               | 4,900                          | 3           | 31.67                      | 22  |
| April 9  | 146,292     | 6,096              | 16.6                               | --                             | --          | --                         | --  |
| April 10   | 0           | 0                  | 17.1                               | --                             | --          | --                         | --  |
| April 11   | 6,945,829   | 289,410            | 18.5                               | 5,080                          | 12          | 10.74                      | 37  |
| April 12   | 22,737,173  | 947,382            | 18.6                               | 3,760                          | 35          | 9.37                       | 42  |
| April 13   | 13,533,891  | 563,912            | 17.7                               | 4,610                          | 17          | 10.53                      | 44  |
| April 14   | 1,366,702   | 56,946             | 17.4                               | 9,680                          | 1           | 15.20                      | 39  |
| April 15   | 0           | 0                  | 17.5                               | --                             | --          | --                         | --  |
| April 16   | 12,352      | 515                | 18.5                               | --                             | --          | --                         | --  |
| April 17   | 1,047,933   | 43,664             | 18.5                               | --                             | --          | --                         | --  |
| April 18   | 16,465,717  | 686,072            | 18.8                               | 7,520                          | 18          | 9.28                       | 36  |



Table 3.--Estimated total number of eggs, mean number of eggs per hour, mean temperature, mean flow rate, number of eggs aged, and mean age of eggs by site and day for the 1988 South Carolina striped bass spawning study--Continued

[ft<sup>3</sup>/s, cubic foot per second; dashes indicate no data]

| Date 1988 | Total eggs    | Mean eggs per hour | Mean temperature (degrees Celsius) | Mean flow (ft <sup>3</sup> /s) | Number aged | Mean age of sample (hours) | Development time, sample to hatch (hours) |
|-----------|---------------|--------------------|------------------------------------|--------------------------------|-------------|----------------------------|---|
| April 19  | 6,150,192     | 256,258            | 19.1                               | 6,150                          | 8           | 12.07                      | 31  |
| April 20  | 6,010,789     | 250,450            | 19.8                               | 5,320                          | 7           | 19.69                      | 23  |
| April 21  | 19,677,943    | 819,914            | 19.8                               | 5,480                          | 27          | 11.37                      | 30  |
| April 22  | 108,533,567   | 4,522,232          | 20.6                               | 5,210                          | 175         | 7.44                       | 30  |
| April 23  | 655,440,419   | 27,310,017         | 21.4                               | 5,090                          | 644         | 16.66                      | 19  |
| April 24  | 1,518,262,601 | 63,260,942         | 21.7                               | 5,130                          | 907         | 19.80                      | 16  |
| April 25  | 426,577,392   | 17,774,058         | 21.7                               | 5,220                          | 255         | 18.17                      | 19  |
| April 26  | 108,500,433   | 4,520,851          | 20.9                               | 5,160                          | 103         | 12.36                      | 25  |
| April 27  | 25,610,008    | 1,067,084          | 21.1                               | 5,280                          | 30          | 10.92                      | 27  |
| April 28  | 36,683,424    | 1,528,476          | 21.0                               | 5,120                          | 59          | 10.78                      | 28  |
| April 29  | 114,273,804   | 4,761,408          | 20.8                               | 4,170                          | 151         | 12.45                      | 27  |
| April 30  | 113,923,326   | 4,746,805          | 20.8                               | 4,040                          | 142         | 14.18                      | 25  |
| May 1     | 54,250,240    | 2,260,427          | 20.3                               | 4,320                          | 68          | 12.63                      | 26  |
| May 2     | 14,195,652    | 591,485            | 20.9                               | 4,220                          | 18          | 12.00                      | 24  |
| May 3     | 143,999,293   | 5,999,971          | 21.3                               | 3,140                          | 288         | 5.06                       | 30  |
| May 4     | 220,251,541   | 9,177,148          | 21.6                               | 3,150                          | 215         | 10.80                      | 25  |
| May 5     | 27,301,061    | 1,137,544          | 21.7                               | 3,160                          | 21          | 15.37                      | 20  |
| May 6     | 1,976,085     | 82,337             | 21.9                               | 3,850                          | 4           | 16.30                      | 21  |
| May 7     | 8,917,501     | 371,563            | 21.2                               | 4,990                          | 15          | 14.78                      | 21  |
| May 8     | 3,565,916     | 148,580            | 21.6                               | 4,180                          | 5           | 22.02                      | 14  |

Table 3.--Estimated total number of eggs, mean number of eggs per hour, mean temperature, mean flow rate, number of eggs aged, and mean age of eggs by site and day for the 1988 South Carolina striped bass spawning study--Continued

[ft<sup>3</sup>/s, cubic foot per second; dashes indicate no data]

| Date 1988   | Total eggs | Mean eggs per hour | Mean temperature (degrees Celsius) | Mean flow (ft <sup>3</sup> /s) | Number aged | Mean age of sample (hours) | Development time, sample to hatch (hours) |
|---|------------|--------------------|------------------------------------|--------------------------------|-------------|----------------------------|---|
| May 9   | 4,490,069  | 187,086            | 21.9                               | 4,410                          | 4           | 7.70                       | 27  |
| May 10  | 6,945,967  | 289,415            | 22.2                               | 5,300                          | 11          | 8.90                       | 24  |
| May 11  | 6,272,037  | 261,335            | 22.3                               | 3,840                          | 9           | 12.39                      | 20  |
| May 12  | 96,357,075 | 4,014,878          | 23.4                               | 3,810                          | 215         | .92                        | 30  |
| May 13  | 73,128,933 | 3,047,039          | 23.7                               | 2,960                          | 28          | 9.38                       | 1 23                                      |
| May 14  | 5,792,158  | 241,340            | 23.5                               | 3,270                          | 6           | 14.23                      | 17  |
| May 15  | 103,471    | 4,311              | 24.2                               | 3,360                          | 1           | 24.90                      | 3   |
| May 16  | 3,204,750  | 133,531            | 25.4                               | 3,000                          | 8           | 8.71                       | 18  |
| May 17  | 2,489,337  | 103,722            | 25.6                               | 2,720                          | 2           | 9.00                       | 18  |
| May 18  | 0          | 0                  | 25.3                               | --                             | --          | --                         | --  |
| Site S2 -- Station 02148315, Wateree River below Eastover |            |                    |                                    |                                |             |                            |   |
| March 30  | 0          | 0                  | 16.2                               | --                             | --          | --                         | --  |
| March 31  | 312,964    | 13,040             | 16.4                               | --                             | --          | --                         | --  |
| April 1   | 0          | 0                  | 16.3                               | --                             | --          | --                         | --  |
| April 2   | 363,269    | 15,136             | 16.5                               | --                             | --          | --                         | --  |
| April 3   | 563,962    | 23,498             | 17.0                               | 1,130                          | 1           | 11.30                      | 34  |
| April 4   | 11,204,719 | 466,863            | 18.4                               | 990                            | 26          | 9.53                       | 32  |
| April 5   | 4,196,741  | 174,864            | 18.8                               | 2,630                          | 11          | 16.20                      | 27  |
| April 6   | 18,304,484 | 762,687            | 17.3                               | 1,930                          | 14          | 8.60                       | 39  |
| April 7   | 1,629,071  | 67,878             | 16.8                               | 1,820                          | 5           | 20.56                      | 33  |
| April 8   | 200,523    | 8,355              | 16.0                               | 2,930                          | 1           | 22.60                      | 35  |

Table 3.--Estimated total number of eggs, mean number of eggs per hour, mean temperature, mean flow rate, number of eggs aged, and mean age of eggs by site and day for the 1988 South Carolina striped bass spawning study--Continued

[ft<sup>3</sup>/s, cubic foot per second; dashes indicate no data]

| Date 1988 | Total eggs | Mean eggs per hour | Mean temperature (degrees Celsius) | Mean flow (ft <sup>3</sup> /s) | Number aged | Mean age of sample (hours) | Development time, sample to hatch (hours) |
|-----------|------------|--------------------|------------------------------------|--------------------------------|-------------|----------------------------|---|
| April 9   | 226,947    | 9,456              | 15.9                               | 1,830                          | 1           | 33.20                      | 21  |
| April 10  | 472,626    | 19,693             | 17.2                               | 1,440                          | 1           | 2.80                       | 45  |
| April 11  | 7,530,940  | 313,789            | 18.2                               | 1,500                          | 20          | 9.62                       | 38  |
| April 12  | 1,341,342  | 55,889             | 17.8                               | 1,440                          | 1           | 12.40                      | 39  |
| April 13  | 77,966     | 3,249              | 16.7                               | --                             | --          | --                         | --  |
| April 14  | 0          | 0                  | 16.6                               | --                             | --          | --                         | --  |
| April 15  | 0          | 0                  | 17.2                               | --                             | --          | --                         | --  |
| April 16  | 264,370    | 11,015             | 17.3                               | --                             | --          | --                         | --  |
| April 17  | 3,172,735  | 132,197            | 18.4                               | 2,440                          | 4           | 9.82                       | 36  |
| April 18  | 2,791,428  | 116,309            | 18.2                               | 2,880                          | 6           | 17.82                      | 28  |
| April 19  | 1,916,700  | 79,862             | 18.4                               | 2,580                          | 3           | 29.60                      | 13  |
| April 20  | 289,218    | 12,051             | 18.4                               | 2,980                          | 1           | 36.40                      | 7   |
| April 21  | 2,686,619  | 111,942            | 18.6                               | 1,930                          | 7           | 4.29                       | 37  |
| April 22  | 32,698,750 | 1,362,448          | 20.1                               | 2,460                          | 69          | 7.76                       | 30  |
| April 23  | 91,674,498 | 3,819,771          | 20.4                               | 2,720                          | 149         | 13.47                      | 24  |
| April 24  | 52,445,877 | 2,185,245          | 20.6                               | 1,950                          | 83          | 24.21                      | 11  |
| April 25  | 21,060,148 | 877,506            | 20.5                               | 1,830                          | 47          | 22.79                      | 15  |
| April 26  | 10,758,356 | 448,265            | 20.5                               | 4,230                          | 17          | 15.02                      | 24  |
| April 27  | 2,455,708  | 102,321            | 19.4                               | 3,520                          | 3           | 23.07                      | 16  |
| April 28  | 2,053,215  | 85,551             | 17.5                               | 2,140                          | 5           | 9.98                       | 29  |

Table 3.--Estimated total number of eggs, mean number of eggs per hour, mean temperature, mean flow rate, mean flow rate, mean age of eggs by site and day for the 1988 South Carolina striped bass spawning study--Continued (page 5)

| Date 1988 | Total eggs | Mean eggs per hour | Mean temperature (degrees Celsius) | Mean flow (ft <sup>3</sup> /s) | Number aged | Mean age of sample (hours) | Development time, sample to hatch (hours) |
|-----------|------------|--------------------|------------------------------------|--------------------------------|-------------|----------------------------|---|
| April 29  | 11,576,681 | 482,362            | 19.4                               | 1,630                          | 31          | 7.59                       | 31  |
| April 30  | 25,014,798 | 1,042,283          | 19.6                               | 1,670                          | 53          | 8.65                       | 32  |
| May 1     | 12,038,823 | 501,618            | 19.7                               | 1,550                          | 34          | 7.02                       | 34  |
| May 2     | 6,594,980  | 274,791            | 19.7                               | 1,200                          | 18          | 4.66                       | 33  |
| May 3     | 2,955,604  | 123,150            | 20.4                               | 1,330                          | 5           | 11.76                      | 24  |
| May 4     | 800,228    | 33,343             | 20.8                               | 1,330                          | 4           | 8.62                       | 27  |
| May 5     | 386,169    | 16,090             | 21.1                               | 1,460                          | 2           | 18.75                      | 17  |
| May 6     | 29,387     | 1,224              | 20.6                               | --                             | --          | --                         | --  |
| May 7     | 50,409     | 2,100              | 20.3                               | --                             | --          | --                         | --  |
| May 8     | 185,037    | 7,710              | 20.7                               | 2,090                          | 1           | 5.60                       | 30  |
| May 9     | 244,413    | 10,184             | 21.8                               | 2,130                          | 3           | 16.23                      | 18  |
| May 10    | 658,096    | 27,421             | 22.3                               | 2,010                          | 2           | 10.25                      | 23  |
| May 11    | 544,196    | 22,675             | 22.6                               | 1,190                          | 2           | 11.15                      | 31  |
| May 12    | 0          | 0                  | 22.8                               | --                             | --          | --                         | --  |
| May 13    | 48,403     | 2,017              | 23.1                               | --                             | --          | --                         | --  |
| May 14    | 0          | 0                  | 23.5                               | --                             | --          | --                         | --  |
| May 15    | 0          | 0                  | 23.8                               | --                             | --          | --                         | --  |
| May 16    | 0          | 0                  | 24.5                               | --                             | --          | --                         | --  |
| May 17    | 0          | 0                  | 24.5                               | --                             | --          | --                         | --  |
| May 18    | 47,910     | 1,996              | 23.4                               | --                             | --          | --                         | --  |

Table 3.--Estimated total number of eggs, mean number of eggs per hour, mean temperature, mean flow rate, number of eggs aged, and mean age of eggs by site and day for the 1988 South Carolina striped bass spawning study--Continued

[ft<sup>3</sup>/s, cubic foot per second; dashes indicate no data]

| Date 1988 | Total eggs | Mean eggs per hour | Mean temperature (degrees Celsius) | Mean flow (ft <sup>3</sup> /s) | Number aged | Mean age of sample (hours) | Development time, sample to hatch (hours) |
|-----------|------------|--------------------|------------------------------------|--------------------------------|-------------|----------------------------|---|
| March 30  | 0          | 0                  | 14.0                               | --                             | --          | --                         | --  |
| March 31  | 0          | 0                  | 15.0                               | --                             | --          | --                         | --  |
| April 1   | 0          | 0                  | 14.3                               | --                             | --          | --                         | --  |
| April 2   | 0          | 0                  | 16.1                               | --                             | --          | --                         | --  |
| April 4   | 0          | 0                  | 15.1                               | --                             | --          | --                         | --  |
| April 5   | 0          | 0                  | 14.9                               | --                             | --          | --                         | --  |
| April 6   | 6,265,008  | 261,042            | 16.6                               | 1,560                          | 9           | 8.60                       | 53  |
| April 7   | 2,387,388  | 99,475             | 14.8                               | 3,280                          | 1           | 11.30                      | 50  |
| April 8   | 559,101    | 23,296             | 15.5                               | --                             | --          | --                         | --  |
| April 9   | 0          | 0                  | 16.7                               | --                             | --          | --                         | --  |
| April 10  | 0          | 0                  | 16.8                               | --                             | --          | --                         | --  |
| April 11  | 0          | 0                  | 17.2                               | --                             | --          | --                         | --  |
| April 12  | 0          | 0                  | 16.1                               | --                             | --          | --                         | --  |
| April 13  | 0          | 0                  | 15.3                               | --                             | --          | --                         | --  |
| April 14  | 0          | 0                  | 15.8                               | --                             | --          | --                         | --  |
| April 15  | 1,75,968   | 7,332              | 16.5                               | --                             | --          | --                         | --  |
| April 16  | 472,347    | 19,681             | 16.8                               | 2,490                          | 1           | 8.60                       | 42  |
| April 17  | 1,043,008  | 43,459             | 16.9                               | 2,770                          | 1           | 1.70                       | 49  |
| April 18  | 23,565,052 | 981,877            | 16.7                               | 2,560                          | 21          | 8.66                       | 42  |

Site S3 -- Station 02148100, Wateree River near Boykin

Table 3.--Estimated total number of eggs, mean number of eggs per hour, mean temperature, mean flow rate, number of eggs aged, and mean age of eggs by site and day for the 1988 South Carolina striped bass spawning study--Continued

[ft<sup>3</sup>/s, cubic foot per second; dashes indicate no data]

| Date 1988 | Total eggs  | Mean eggs per hour | Mean temperature (degrees Celsius) | Mean flow (ft <sup>3</sup> /s) | Number aged | Mean age of sample (hours) | Development time, sample to hatch (hours) |
|-----------|-------------|--------------------|------------------------------------|--------------------------------|-------------|----------------------------|---|
| April 19  | 16,931,639  | 705,485            | 16.7                               | 3,210                          | 12          | 8.57                       | 42  |
| April 20  | 2,076,956   | 86,540             | 16.8                               | 1,820                          | 2           | 11.60                      | 36  |
| April 21  | 0           | 0                  | 17.5                               | --                             | --          | --                         | --  |
| April 22  | 36,562,731  | 1,523,447          | 18.4                               | 2,720                          | 53          | 3.99                       | 39  |
| April 23  | 289,243,183 | 12,051,799         | 18.6                               | 1,940                          | 371         | 6.31                       | 35  |
| April 24  | 197,041,162 | 8210,048           | 18.5                               | 1,730                          | 191         | 8.62                       | 32  |
| April 25  | 6,581,991   | 274,250            | 19.2                               | 3,920                          | 4           | 12.25                      | 31  |
| April 26  | 53,733,773  | 2238,907           | 19.3                               | 4,070                          | 40          | 7.88                       | 38  |
| April 27  | 233,606     | 9,734              | 19.1                               | 2,060                          | 1           | 27.40                      | 18  |
| April 28  | 654,384     | 27,266             | 19.1                               | 1,520                          | 1           | 10.00                      | 33  |
| April 29  | 4,042,784   | 168,449            | 18.7                               | 1,670                          | 6           | 7.60                       | 38  |
| April 30  | 5,048,157   | 210,340            | 18.8                               | 1,530                          | 12          | 4.69                       | 38  |
| May 1     | 2,217,823   | 92,409             | 18.8                               | 1,100                          | 1           | 12.80                      | 28  |
| May 2     | 154,687     | 6,445              | 19.1                               | 1,480                          | 1           | 11.60                      | 29  |
| May 3     | 702,625     | 29,276             | 20.2                               | 1,240                          | 1           | 1.80                       | 37  |
| May 4     | 3,188,376   | 132,849            | 19.6                               | 1,540                          | 6           | 9.33                       | 30  |
| May 5     | 1,714,829   | 71,451             | 19.7                               | 1,570                          | 3           | 9.73                       | 31  |
| May 6     | 1,163,658   | 48,486             | 19.3                               | 1,600                          | 2           | 6.10                       | 33  |
| May 7     | 4,771,140   | 198,797            | 19.8                               | 2,060                          | 8           | 8.65                       | 29  |
| May 8     | 1,127,753   | 46,990             | 21.0                               | 2,130                          | 3           | 5.60                       | 32  |

Table 3.--Estimated total number of eggs, mean number of eggs per hour, mean temperature, mean flow rate, number of eggs aged, and mean age of eggs by site and day for the 1988 South Carolina striped bass spawning study--Continued  
 [ft<sup>3</sup>/s, cubic foot per second; dashes indicate no data]

| Date 1988  | Total eggs  | Mean eggs per hour | Mean temperature (degrees Celsius) | Mean flow (ft <sup>3</sup> /s) | Number aged | Mean age of sample (hours) | Development time, sample to hatch (hours) |
|--|-------------|--------------------|------------------------------------|--------------------------------|-------------|----------------------------|---|
| May 9  | 12,513,584  | 521,399            | 21.0                               | 2,100                          | 19          | 7.91                       | 27  |
| May 10   | 6,038,147   | 251,589            | 21.1                               | 875                            | 8           | 9.55                       | 25  |
| May 11   | 113,334     | 4,722              | 22.0                               | 722                            | 1           | 5.80                       | 27  |
| May 12   | 55,757      | 2,323              | 22.6                               | 1,530                          | 10          | 12.00                      | 21  |
| May 13   | 60,271,681  | 2,511,320          | 21.8                               | 1,220                          | 169         | .73                        | 32  |
| May 14   | 35,848,639  | 1,493,693          | 21.2                               | 1,570                          | 1           | 8.60                       | 23  |
| May 15   | 451,446     | 18,810             | 22.3                               | --                             | --          | --                         | --  |
| May 16   | 0           | 0                  | 23.3                               | --                             | --          | --                         | --  |
| May 17   | 0           | 0                  | 22.0                               | --                             | --          | --                         | --  |
| May 18   | 55,823      | 2,326              | 21.8                               | 1,960                          | 1           | 15.50                      | 16  |
| <u>Site S4 -- Station 02169625, Congaree River west of Wise Lake, near Gadsden</u> |             |                    |                                    |                                |             |                            |   |
| March 30   | 5,722,528   | 238,439            | 16.7                               | 6,140                          | 3           | 8.60                       | 42  |
| March 31   | 7,824,761   | 326,032            | 16.7                               | --                             | --          | --                         | --  |
| April 1  | 15,856,973  | 660,707            | 17.3                               | 4,710                          | 10          | 8.22                       | 40  |
| April 2  | 12,280,949  | 511,706            | 17.7                               | 4,870                          | 7           | 7.31                       | 41  |
| April 3  | 15,731,147  | 655,464            | 17.5                               | 4,250                          | 16          | 10.32                      | 38  |
| April 4  | 93,256,021  | 3,885,668          | 19.0                               | 2,590                          | 177         | 7.09                       | 36  |
| April 5  | 346,895,221 | 14,453,968         | 19.9                               | 2,190                          | 313         | 4.64                       | 38  |
| April 6  | 185,588,979 | 7,732,874          | 19.6                               | 4,270                          | 94          | 12.46                      | 33  |
| April 7  | 38,379,757  | 1,599,157          | 17.5                               | 4,960                          | 29          | 14.16                      | 37  |
| April 8  | 512,472     | 21,353             | 16.1                               | --                             | --          | --                         | --  |

Table 3.--Estimated total number of eggs, mean number of eggs per hour, mean temperature, mean flow rate, number of eggs aged, and mean age of eggs by site and day for the 1988 South Carolina striped bass spawning study--Continued

[ft<sup>3</sup>/s, cubic foot per second; dashes indicate no data]

| Date 1988 | Total eggs    | Mean eggs per hour | Mean temperature (degrees Celsius) | Mean flow (ft <sup>3</sup> /s) | Number aged | Mean age of sample (hours) | Development time, sample to hatch (hours) |
|-----------|---------------|--------------------|------------------------------------|--------------------------------|-------------|----------------------------|---|
| April 9   | 0             | 0                  | 16.8                               | --                             | --          | --                         | --  |
| April 10  | 0             | 0                  | 17.0                               | --                             | --          | --                         | --  |
| April 11  | 0             | 0                  | 17.7                               | --                             | --          | --                         | --  |
| April 12  | 8,688,280     | 362,012            | 17.0                               | 3,500                          | 11          | 9.42                       | 45  |
| April 13  | 283,749       | 11,823             | 15.8                               | --                             | --          | --                         | --  |
| April 14  | 160,871       | 6,703              | 15.9                               | --                             | --          | --                         | --  |
| April 15  | 1,769,584     | 73,733             | 16.5                               | 7,860                          | 1           | 9.80                       | 38  |
| April 16  | 0             | 0                  | 17.0                               | --                             | --          | --                         | --  |
| April 17  | 214,458       | 8,936              | 17.0                               | --                             | --          | --                         | --  |
| April 18  | 3,255,266     | 135,636            | 17.7                               | 6,660                          | 2           | 7.60                       | 35  |
| April 19  | 14,405,685    | 600,237            | 18.4                               | 5,260                          | 15          | 8.57                       | 34  |
| April 20  | 4264,475      | 177,686            | 18.4                               | 5,450                          | 8           | 8.10                       | 35  |
| April 21  | 21,401,904    | 891,746            | 18.3                               | 5,270                          | 29          | 8.56                       | 32  |
| April 22  | 686,409,721   | 28,600,405         | 19.4                               | 5,130                          | 328         | 4.96                       | 34  |
| April 23  | 2,513,513,853 | 104,729,744        | 20.1                               | 5,060                          | 900         | 7.64                       | 30  |
| April 24  | 2,515,772,673 | 104,823,861        | 20.2                               | 5,190                          | 399         | 13.02                      | 24  |
| April 25  | 12,564,956    | 523,540            | 20.1                               | 5,260                          | 24          | 7.87                       | 31  |
| April 26  | 22,369,998    | 932,083            | 19.7                               | 5,290                          | 19          | 11.61                      | 27  |
| April 27  | 21,026,486    | 876,104            | 19.6                               | 5,170                          | 25          | 10.23                      | 29  |
| April 28  | 61,060,667    | 2,544,194          | 19.4                               | 4,340                          | 98          | 6.95                       | 32  |



Table 3.--Estimated total number of eggs, mean number of eggs per hour, mean temperature, mean flow rate, number of eggs aged, and mean age of eggs by site and day for the 1988 South Carolina striped bass spawning study--Continued

[ft<sup>3</sup>/s, cubic foot per second; dashes indicate no data]

| Date 1988 | Total eggs  | Mean eggs per hour | Mean temperature (degrees Celsius) | Mean flow (ft <sup>3</sup> /s) | Number aged | Mean age of sample (hours) | Development time, sample to hatch (hours) |
|-----------|-------------|--------------------|------------------------------------|--------------------------------|-------------|----------------------------|---|
| April 29  | 135,783,335 | 5,657,639          | 19.3                               | 4,080                          | 124         | 12.39                      | 27  |
| April 30  | 43,661,002  | 1,819,208          | 19.5                               | 4,190                          | 61          | 8.98                       | 30  |
| May 1     | 42,788,303  | 1,782,846          | 18.6                               | 4,400                          | 39          | 9.89                       | 28  |
| May 2     | 21,940,631  | 914,193            | 19.2                               | 3,180                          | 32          | 7.56                       | 28  |
| May 3     | 115,715,633 | 4,821,485          | 20.0                               | 3,150                          | 210         | 7.67                       | 28  |
| May 4     | 160,282,636 | 6,678,443          | 20.1                               | 3,130                          | 162         | 12.85                      | 23  |
| May 5     | 35,339,286  | 1,472,470          | 20.7                               | 3,450                          | 45          | 12.02                      | 24  |
| May 6     | 11,222,189  | 467,591            | 19.9                               | 5,110                          | 16          | 8.01                       | 30  |
| May 7     | 27,326,879  | 1,138,620          | 19.7                               | 4,420                          | 27          | 12.04                      | 24  |
| May 8     | 2,815,007   | 117,292            | 19.7                               | 3,870                          | 3           | 13.27                      | 22  |
| May 9     | 3,319,303   | 141,304            | 20.0                               | 5,660                          | 6           | 10.30                      | 24  |
| May 10    | 33,073,590  | 1,378,066          | 20.5                               | 4,110                          | 36          | 12.21                      | 21  |
| May 11    | 38,975,382  | 1,623,974          | 21.0                               | 3,000                          | 46          | 14.08                      | 18  |
| May 12    | 37,534,854  | 1,563,952          | 22.2                               | 2,850                          | 67          | 5.13                       | 27  |
| May 13    | 32,264,054  | 1,344,336          | 22.2                               | 3,350                          | 22          | 12.63                      | 19  |
| May 14    | 16,028,788  | 667,866            | 22.0                               | 3,440                          | 19          | 12.24                      | 18  |
| May 15    | 4,558,922   | 189,955            | 23.5                               | 2,980                          | 10          | 7.94                       | 20  |
| May 16    | 4,139,444   | 172,477            | 24.5                               | 2,830                          | 4           | 8.25                       | 19  |
| May 17    | 3,467,134   | 144,464            | 24.2                               | 2,410                          | 5           | 15.36                      | 13  |
| May 18    | 152,812     | 6,367              | 23.9                               | 2,980                          | 1           | 15.00                      | 14  |

### Physical Characteristics of Eggs

Striped bass eggs are relatively large in diameter, 0.118 to 0.157 in., and are spherical and non-adhesive. A large oil globule is attached to the top of the yolk mass. The yolk sphere is greenish or golden green in living eggs, but amber colored or pale yellow in a preserved state (Mansueti, 1958) (fig. 4).

The specific gravity, settling velocities, and minimum velocity at which striped bass eggs will stay in suspension were determined for use in implementing the water-quality model. The specific gravity of striped bass eggs, which is the ratio of the weight of an egg to the weight of an equal volume of water, was determined at collection sites S3 and S4 stations 02148100 and 02169625, respectively.

The specific gravity of the eggs was determined by inserting the eggs into solutions of known specific gravities. The specific gravity of the egg was determined to be the specific gravity of the solution at which the eggs were neutrally bouyant (tables 4 and 5).

The specific-gravity solutions were made by mixing sodium chloride with distilled water. Solutions varied in specific gravity from 1.00025 to 1.00140 and were mixed in increments of 0.00005. Special care was taken to avoid contamination of the solutions while transferring the egg samples.

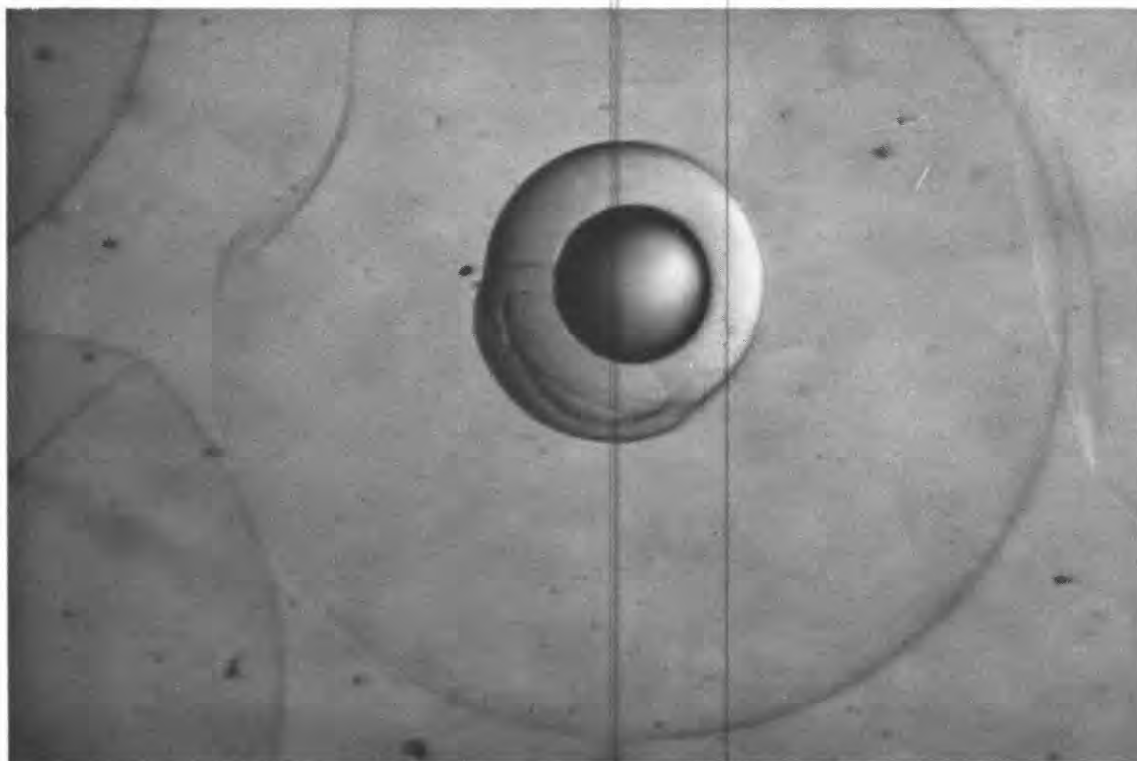


Figure 4.--Viable striped bass egg.

Table 4.--Striped bass egg specific gravities for site S4, station 02169625, Congaree River west of Wise Lake near Gadsden, sample date, April 7, 1988

| Egg number | Specific gravity |
|------------|------------------|
| 1          | 1.00125          |
| 2          | 1.00120          |
| 3          | 1.00120          |
| 4          | 1.00125          |
| 5          | 1.00120          |
| 6          | 1.00110          |
| 7          | 1.00110          |
| 8          | 1.00125          |
| 9          | 1.00110          |
| 10         | 1.00105          |
| 11         | 1.00110          |
| 12         | 1.00110          |
| 13         | <u>1.00105</u>   |
| Mean       | 1.00115          |

Table 5.--Striped bass egg specific gravities for site S3, station 02148100, Wateree River near Boykin, sample date, May 10, 1988

| Egg Number | Specific gravity |
|------------|------------------|
| 1          | 1.00105          |
| 2          | 1.00105          |
| 3          | 1.00100          |
| 4          | 1.00090          |
| 5          | 1.00090          |
| 6          | 1.00105          |
| 7          | 1.00100          |
| 8          | 1.00105          |
| 9          | 1.00110          |
| 10         | <u>1.00100</u>   |
| Mean       | 1.00101          |

The specific gravity of striped bass eggs tested at site S4 ranged from 1.00105 to 1.00125 with an average specific gravity of 1.00115, while the specific gravity of the striped bass eggs tested at site S3 ranged from 1.00090 to 1.00110 with an average specific gravity of 1.00101. These specific gravities were slightly greater than the mean specific gravity of 1.0005 determined for a 1962-63 California striped bass egg study (Albrecht, 1964), but were small enough for the striped bass eggs to be almost neutrally buoyant. For purpose of this study, the eggs were assumed to be well mixed vertically and act as a "dissolved" substance in the water-quality model.

Viable (live) striped bass eggs were also tested to determine settling velocities in still water. The eggs were allowed to settle in a graduated cylinder filled with water from the sample site. The eggs were inspected at the sample site to insure viability.

The eggs were allowed to settle from the top of the cylinder to the 16.9 oz graduation line to allow the settling velocities to stabilize; then the time required for the eggs to settle a distance of 0.58 ft (from the 16.9 oz line to the 6.8 oz line) was recorded. Settling velocity was determined by dividing the distance traveled by time (seconds) (tables 6-8). Eggs collected on May 12, 1987, at site S1 had an average settling velocity of 0.011 ft/s. The average settling velocity of eggs collected April 6, 1988, at site S4 was 0.009 ft/s, while eggs collected at site S3 on May 10, 1988, had an average settling velocity of 0.009 ft/s.

Determination of the minimum velocity at which striped bass eggs will remain in suspension (the suspended velocity) was one of the more important aspects of this study, because there is a possibility that the eggs that settle to the river bed could be covered by sediment and die. Consequently, to determine the velocity required to maintain the eggs in suspension experiments were conducted in 1988 and 1989. On the morning of April 29, 1988, approximately 150 viable eggs were collected at site S4 for testing. They were transported to Clemson University in an insulated water cooler equipped with an aerator pump used to replenish oxygen for the eggs during transport.

The eggs were reexamined before testing at Clemson University, and approximately 70 percent of the eggs had survived the 3.5-hour transport. Viable eggs were injected into a 30-ft long by 1-ft wide by 1-ft high sand-channel flume to determine the velocity at which these eggs would remain suspended. The velocity was measured with an electromagnetic flow meter set at 80 percent of the total depth. The eggs were kept in suspension by velocities exceeding 0.10 ft/s and traveled in an elliptical pattern along the flume reach.

This test was repeated on May 1, 1989. Eggs were collected at site S4, during a spawning peak. The SCWRD personnel stated that more than 25,000 eggs were retrieved in a 5-minute sampling. Approximately 2,000 eggs were collected and transported to Clemson University in the same manner as was done in the 1988 experiment.

Table 6.--Striped bass egg settling velocities for site S1, station 02169710, Congaree River at the Southern Railway Trestle near Fort Motte, sample date, May 12, 1987

| Egg number | Settling velocity<br>(feet per second) |
|------------|--|
| 1          | 0.014                                  |
| 2          | .008                                   |
| 3          | .008                                   |
| 4          | .017                                   |
| 5          | .010                                   |
| 6          | .007                                   |
| 7          | .014                                   |
| 8          | .008                                   |
| 9          | .013                                   |
| 10         | .009                                   |
| 11         | .010                                   |
| 12         | .010                                   |
| 13         | .010                                   |
| 14         | .012                                   |
| 15         | .016                                   |
| 16         | .010                                   |
| 17         | .010                                   |
| 18         | .014                                   |
| 19         | .012                                   |
| 20         | .011                                   |
| 21         | .008                                   |
| 22         | .013                                   |
| 23         | .009                                   |
| 24         | .013                                   |
| 25         | .016                                   |
| 26         | .013                                   |
| 27         | .012                                   |
| 28         | <u>.010</u>                            |
| Mean       | 0.011                                  |

Table 7.--Striped bass egg settling velocities for site S4, station 02169625, Congaree River west of Wise Lake near Gadsden, sample date, April 6, 1988

| Egg number | Settling velocity<br>(feet per second) |
|------------|--|
| 1          | 0.011                                  |
| 2          | .009                                   |
| 3          | .012                                   |
| 4          | .009                                   |
| 5          | .008                                   |
| 6          | .007                                   |
| 7          | .010                                   |
| 8          | .008                                   |
| 9          | .009                                   |
| 10         | .010                                   |
| 11         | .010                                   |
| 12         | .011                                   |
| 13         | .008                                   |
| 14         | .009                                   |
| 15         | .011                                   |
| 16         | .008                                   |
| 17         | .009                                   |
| 18         | .010                                   |
| 19         | .010                                   |
| 20         | .008                                   |
| Mean       | <u>0.009</u>                           |

Table 8.--Striped bass egg settling velocities for site S3, station 02148100, Wateree River near Boykin, sample date, May 10, 1988

| Egg number | Settling velocity<br>(feet per second) |
|------------|--|
| 1          | 0.012                                  |
| 2          | .009                                   |
| 3          | .010                                   |
| 4          | .008                                   |
| 5          | .009                                   |
| 6          | .008                                   |
| 7          | .009                                   |
| 8          | .010                                   |
| 9          | .008                                   |
| 10         | .008                                   |
| Mean       | <u>0.009</u>                           |

Water flowing at a depth of 0.9 ft through a sand channel flume 30 ft by 1 ft was again used to carry the eggs. Velocities were monitored with an electromagnetic flow meter.

The eggs were inserted in the middle of the water column and observed as they were transported down the flume. The results were as follows:

| Velocity<br>(feet per<br>second) | Total<br>depth<br>(feet) | Flow meter<br>position<br>(percent of<br>total depth) | Observations  |
|----------------------------------|--------------------------|---|---|
| 0.05 ± 0.01                      | 0.9                      | 60<br>80  | All eggs sampled (6 of 6) settled to bottom and stopped before traversing the length of the flume.  |
| .1 ± .01                         | .9                       | 80  | Sixty percent (6 of 10) of the eggs remained in suspension for the length of the flume.   |
| .2 ± .02                         | .9                       | 60  | Eighty percent (8 of 10) of the eggs sampled remained in suspension for the length of the flume, and the two eggs that settled were bounced along the bottom for the length of the flume. |
| .17 ± .01                        | .9                       | 80  |   |

The eggs did not appear to move in an elliptical pattern as they did on the similar test conducted on April 29, 1988. The elliptical pattern noted in the previous test probably could be attributed to more sand in the flume bottom, which may have caused more turbulent flow and increased movement of the eggs. The 1989 observations indicated that the minimum velocity required to keep the eggs suspended was approximately 0.2 ft/s. This velocity was substantially lower than the previously reported value of 1.0 ft/s (Albrecht, 1964).

#### FLOW AND TRANSPORT MODEL FORMULATION

Streamflow was modeled by using the BRANCH Model (Schaffranek and others, 1981), a one-dimensional numerical model for simulation of flow in singular and interconnected channels. The one-dimensional flow model, BRANCH, was developed in 1981 and has been extensively used by the USGS in riverine and estuarine environments. Transport of the eggs was modeled by using the Branched Lagrangian Transport model, or BLTM (Jobson and Schoellhamer, 1987). The BLTM is commonly used as a transport model for dissolved water-quality constituents. Because of the small specific gravity of the eggs, they were assumed to act as a "dissolved" substance in the

water-quality model. The BLTM uses a Lagrangian reference frame instead of Eulerian. The Lagrangian reference frame follows the water parcel as it moves through the system much like floating along a river in a boat. The Eulerian reference frame differs from Lagrangian theory in that it tracks a parcel of water from a fixed point, much like observing stream-flow from a bridge.

### BRANCH Model

The branch-network flow model, BRANCH, is a tool for simulating one-dimensional, unsteady flows and water-surface elevations occurring in a single reach of river channel or a system of multi-connected channels. The branch-network model applies two one-dimensional partial-differential equations, which govern transient flow in open channels. The equations are:

$$\frac{1}{gA} \frac{\partial Q}{\partial t} + \frac{2BQ}{gA^2} \frac{\partial Q}{\partial x} - \frac{\beta Q^2}{gA^3} \frac{\partial A}{\partial x} \Big|_z + \frac{\partial z}{\partial x} + \frac{k}{A^{2R^{4/3}}} Q |Q| = 0 \quad (1)$$

and

$$B \frac{\partial z}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad (2)$$

where equation (1) is the equation of motion and equation (2) is the equation of continuity; and the dependent variables are  $z$ , the water-surface elevation, and  $Q$ , the channel discharge. The distance,  $x$ , in the longitudinal direction and elapsed time,  $t$ , are the independent variables. Other terms in the equations are  $B$ , the channel top width;  $g$ , the acceleration of gravity;  $A$ , the cross-sectional area;  $R$ , the hydraulic radius;  $k$ , a function of the flow-resistance of coefficient  $\eta$  (similar to Manning's  $n$ ); and  $\beta$  is the momentum coefficient.

A weighted, 4-point, implicit-finite-difference-solution technique is used to solve the governing equations for a given open-channel network. This implicit technique has computational efficiency, stability, and versatility with respect to the application of boundary conditions. This model was selected because of its appropriateness to assess flows in regulated rivers where backwater is prevalent.

The BRANCH model requires specification of a simulation time increment and a finite difference weighting factor. As with all finite difference solutions for (1) and (2), these two parameters can affect the accuracy, stability, and convergence of the computations.

The BRANCH model uses stage or discharge at the boundaries to compute stage and discharge throughout the modeled reach. For this study, BRANCH used stage data at the upstream study limits, stations 02148000 and 02169500, and at the downstream study limit, station 02169920, and computed discharge, area, and top width at various cross sections in the model.



The study area was divided into 13 branches with 100 cross sections. Identical cross sections were used where branches connected. The Congaree River was subdivided into 5 branches with 40 cross sections, the Wateree River was subdivided into 7 branches with 51 cross sections, and the Santee River had 1 branch with 9 cross sections. Cross sections, where needed between measured cross sections, were interpolated from measured cross sections.

The cross-section data were put into a BRANCH usable format by the USGS Channel Geometry Analysis Program (Regan and Schaffranek, 1985). The USGS streamflow and stage unit-value data were stored in ANNIE, a data management and model preprocessor program that allows time-series data to be interactively read, stored, retrieved, listed, plotted, and checked. ANNIE was used not only as a data base for observed data, but also to check computed data generated by the BRANCH model. Also, ANNIE stored hydraulic conditions computed by the BRANCH model that were used as input to the BLTM.

The BRANCH Model was calibrated with a time step of 1 hour for the 1988 striped bass spawning period. The computed streamflow hydrographs were stored in ANNIE and compared to observed streamflows at stations 02169500 (Congaree river mile 51.1) (fig. 5), 02169625 (Congaree river mile 27.5), 02148000 (Wateree river mile 67.5) (fig. 6), and 02148315 (Wateree river mile 11.3). More than 200-discharge measurements have been made at station 02169500, Congaree River at Columbia, S.C., and more than 400-discharge measurements have been made at station 02148000, Wateree River at Camden, S.C. Consequently, excellent stage-discharge (rating curve) relations have been determined at these sites. The computed discharges were adjusted by modifying cross-sectional areas, varying flow resistance (Manning's  $n$ ) with stage, and by accounting for storage in the reach. The upstream limits of the study area are located at or near the fall line, the boundary of the Piedmont and Upper Coastal Plain Physiographic provinces. Rivers in this area are characterized by boulder and cobble bedrock beds with steep bed slopes. The study area is located in the upper and lower Coastal Plains of South Carolina; consequently, the channels are prone to meander and are bounded by swampland. Therefore, once the rivers leave their banks the storage area (area of little or no flow) increases dramatically. Discharge was originally calibrated for a 1-hour time step by varying the roughness coefficient with stage and varying the available cross-sectional area. The flow resistance values in the Fall Line were varied with stage from 0.025 to 0.120 on the Congaree River and from 0.025 to 0.050 on the Wateree River. Below the Fall Line flow resistance values varied from 0.025 to 0.050. Once the observed and computed discharges agreed within acceptable limits, the Branch model computed hydraulic parameters for the BLTM using a 30-minute time step. The 30-minute time step was used to calibrate the BLTM to more closely define observed dye transport conditions. When the hydraulic parameters of the original calibration were used in the BLTM, however, the observed and computed dye travel times did not correspond. Storage in cross sections was therefore altered, using data obtained from USGS 7.5-minute series topographic maps (1953, 1982, 1987, and 1988) in order to increase computed travel times to agree with the observed travel times. Additionally, the changes in storage did not significantly change the computed discharges. Computed and observed discharges at stations 02169500 and 02148000 are shown in figures 5 and 6, respectively. The 1-hour time step produces adequate results and even

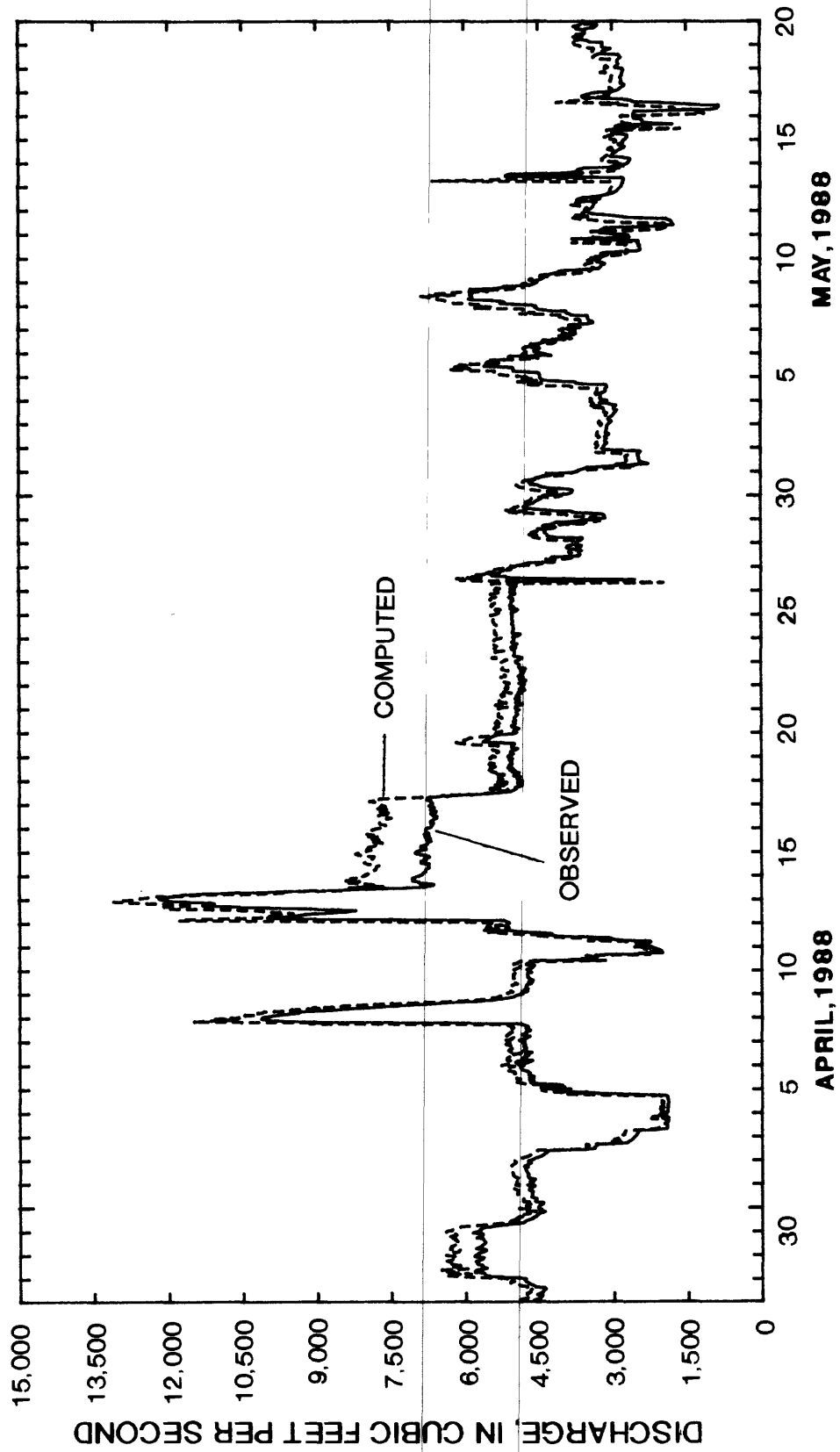


Figure 5.--Computed and observed discharges at station 02169500, Congaree River at Columbia.

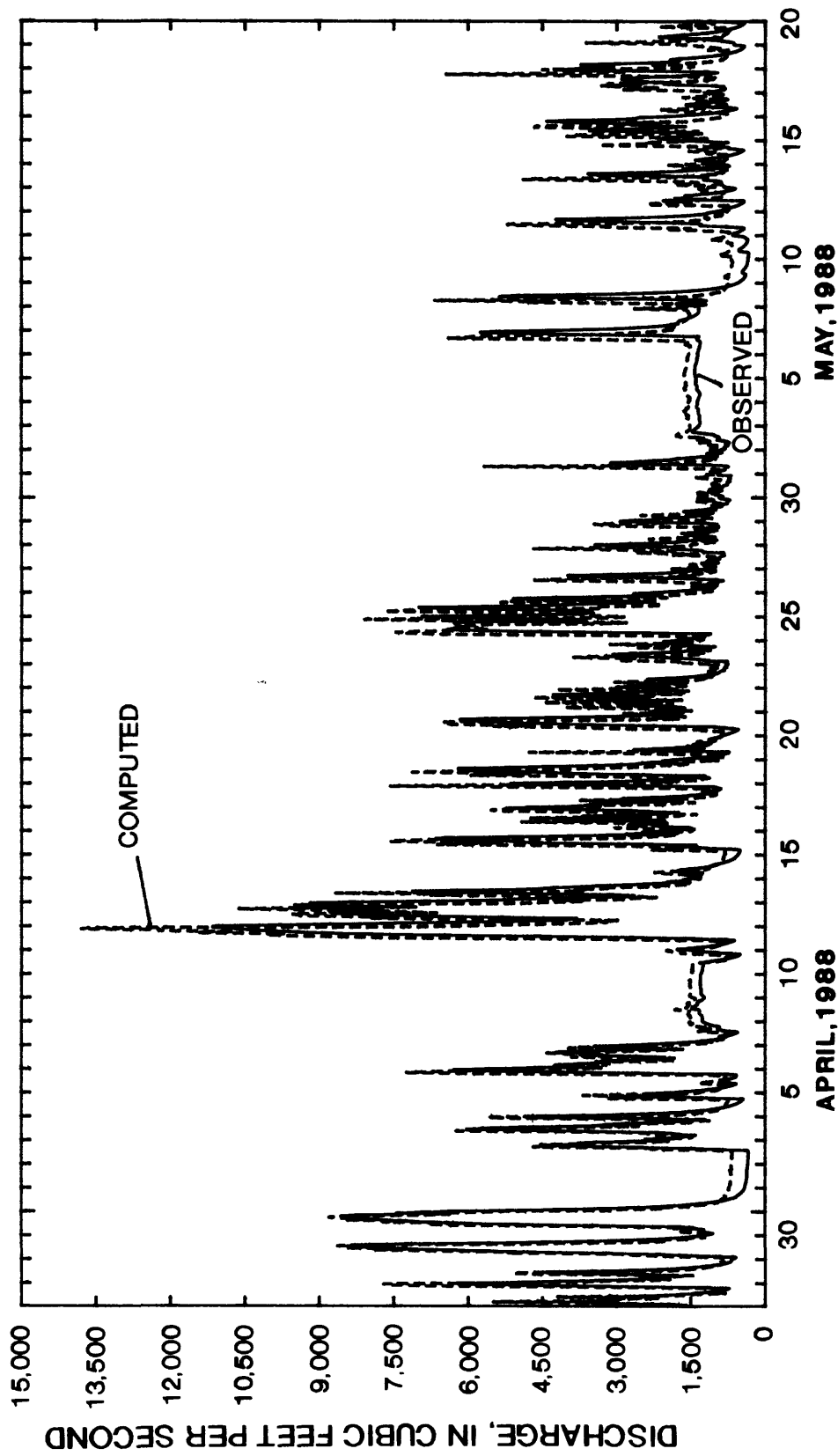


Figure 6.---Computed and observed discharges at station 02148000, Wateree River at Camden.

though there is a slight phase difference, the computed and observed travel times generally are in good agreement and the model is suitable for estimating the striped bass egg hatching locations.

### Branched Lagrangian Transport Model

The BRANCH model supplied instantaneous hydraulic conditions, discharge, area, and top width, at each cross section. The Branched Lagrangian Transport model or, BLTM requires average hydraulic conditions at a cross section for the time step. In this study, the instantaneous conditions were assumed to represent average conditions for the time step (30 minutes) and a short program was written to convert the instantaneous conditions, output from the BRANCH model, to the input format required to drive the BLTM model.

The BLTM solves the convective-dispersion equation by using a Lagrangian reference frame in which the computational nodes move with the flow.

In the Lagrangian reference frame, the continuity of mass equation is

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial \xi} \left| D \frac{\partial C}{\partial \xi} \right| + S + \Phi + K (C - CR), \quad (3)$$

in which C is concentration, t is time, D is longitudinal dispersion coefficient, K is rate of production of the constituent, CR is the equilibrium concentration (that is, the concentration at which the internal production ceases),  $\Phi$  is the rate of change in concentration due to tributary inflow, S is the rate of production of concentration, which is independent of the concentration (zero-order production rate), and  $\xi$  is the Lagrangian distance coordinate given by

$$\xi = x - x_0 - \int_{t_0}^{t_u} u dt', \quad (4)$$

in which x is the Eulerian (stationary) distance coordinate along the river, u is the cross-sectional mean stream velocity, and  $x_0$  is the location of the parcel of water at time  $t_0$ .

Parcels of water in the river are assumed to be completely mixed; their volumes are affected only by tributary flows. The variation of concentration in a river reach is approximated by solving equation 3 for a series of parcels spaced along the river at intervals of about  $u\Delta t$ . The concentration at any point is the concentration of the parcel at that point.

The assumption of completely mixed parcels may cause interpolation errors when determining the concentration at a given point. The major reason for the accuracy of a Lagrangian model, in comparison to an Eulerian model, is that this interpolation error applies only to the output computations; the grid concentration is not used in further computations

and therefore the error is not compounded. In an Eulerian model, similar interpolation errors are made for every time step and grid point but the interpolated values are used as the basis of all further computations.

The advantages of a Lagrangian approach, as outlined above, are: (1) the scheme is very accurate in modeling the convection and dispersion terms in comparison to the usual Eulerian approach (Jobson 1980, Thomson and others 1984), (2), the Lagrangian model is stable for any time step (Jobson 1981), (3) the computer code for the algorithms is short, (4) the conceptual model directly represents the actual transport processes, (5) the model is economical to run, and (6) the model output includes helpful calibration and interpretation information that is not usually available from an Eulerian model.

The BLTM was calibrated by using results of a dye study of the rivers conducted August 10-25, 1987, on the upper and lower Congaree River, upper and lower Wateree River, and the Santee River. For calibration, the BLTM was operated at a 30-minute time step. Observed dye concentrations were entered into the model at the most upstream cross section. Adjustments to the dispersion coefficient allowed calibration of peak dye concentrations and adjustments to storage area, discussed previously in the BRANCH model section allowed calibration of the travel times. The reaches modeled by the BLTM incorporated the Congaree River from the I-326 bridge to its mouth, the Wateree River from the I-20 bridge to its mouth, and the Santee River from its headwaters to Browns Cut. Computed and observed dye concentrations and travel times are compared in figures 7-10. Once calibrated, both models were used to simulate the transport of the striped bass eggs during the 1988 spawning period.

#### **PREDICTED SPAWNING AND HATCHING LOCATIONS FOR 1988**

As previously stated, because the striped-bass eggs are almost neutrally bouyant (specific gravity 1.001), they were modeled as though they were a dissolved substance in the BLTM. The age of the egg samples was determined by SCWMRD personnel. The mean daily temperature and egg age from the 1988 sampling data (table 3) were compared to the total development times supplied by SCWMRD (table 9) to determine the remaining development time required for hatching. Data simulating a slug of eggs were introduced to the BLTM at noon to simulate the striped bass eggs passing the sample site on a particular day. Then the BLTM was operated on a 1-hour time step for the development time of that set of eggs. The resulting concentration profile was plotted and the egg hatching location was predicted. The predicted spawning and hatching locations are given in tables 10-13.

The spawning locations of striped bass eggs were predicted in much the same manner. The age of the eggs was determined by SCWMRD personnel. Cross sections upstream of the sample sites were added to the BLTM. To facilitate tracking, the BLTM numbers each parcel as it enters each reach of the BLTM. The parcel of water passing the sample site at noon on the day in question was noted, and then the parcel was relocated in the system at the time step that corresponded to the age of the eggs.

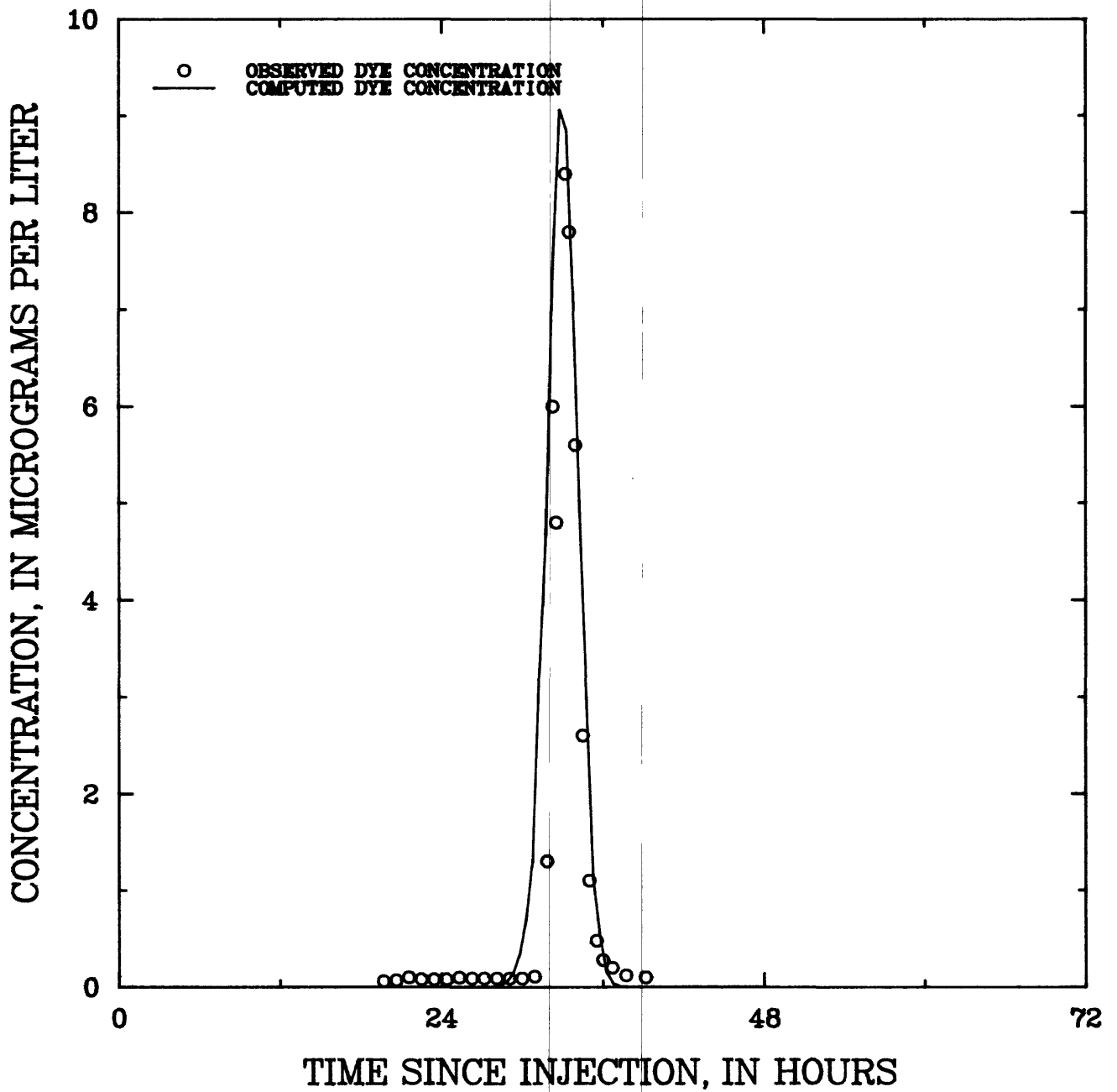


Figure 7.--Computed and observed dye concentrations in the Congaree River at the Southern Railway trestle, Congaree River mile 4.7.

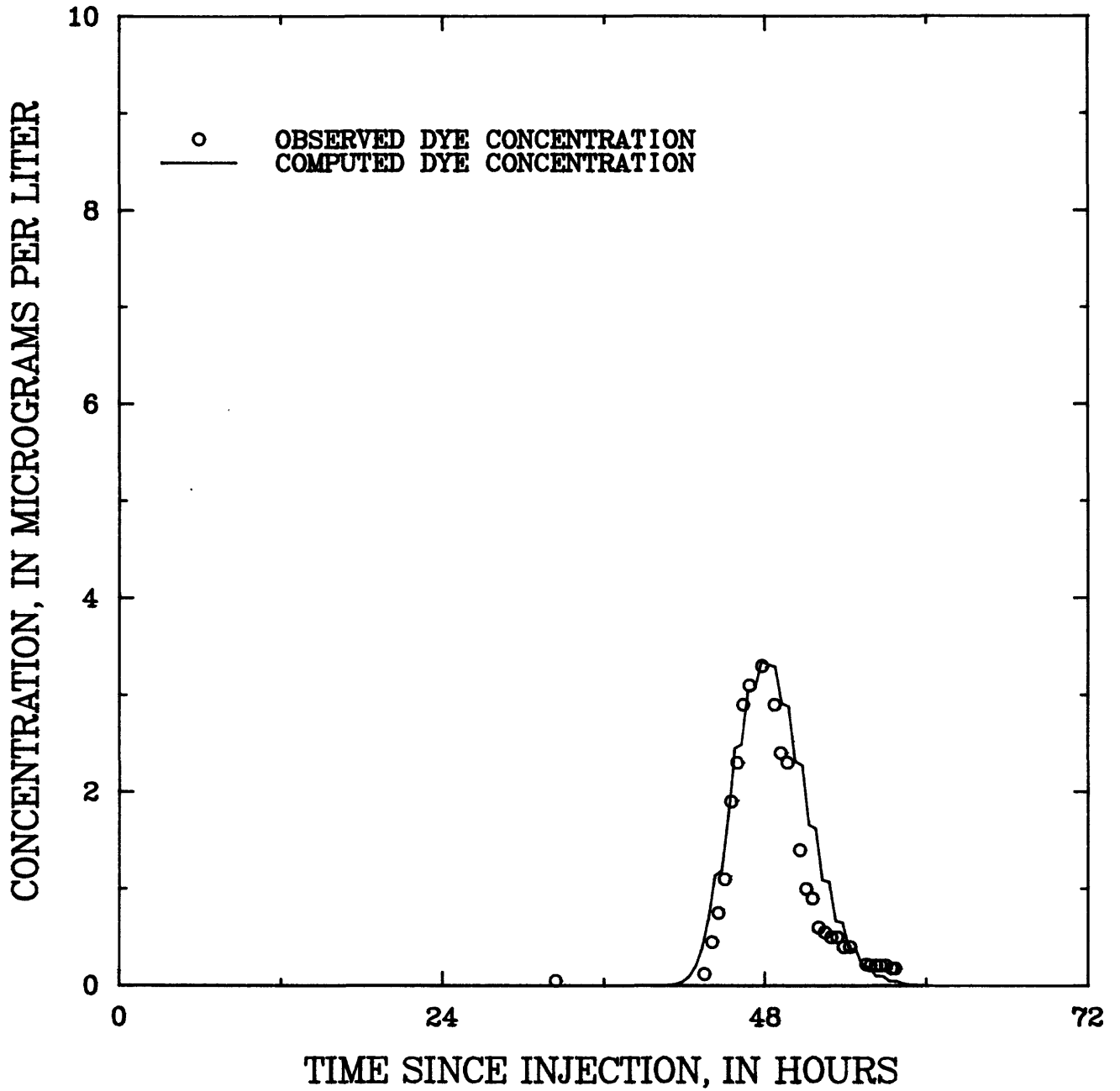


Figure 8.--Computed and observed dye concentrations in the Wateree River at the U.S. Highway 378 bridge, Wateree River mile 25.6.

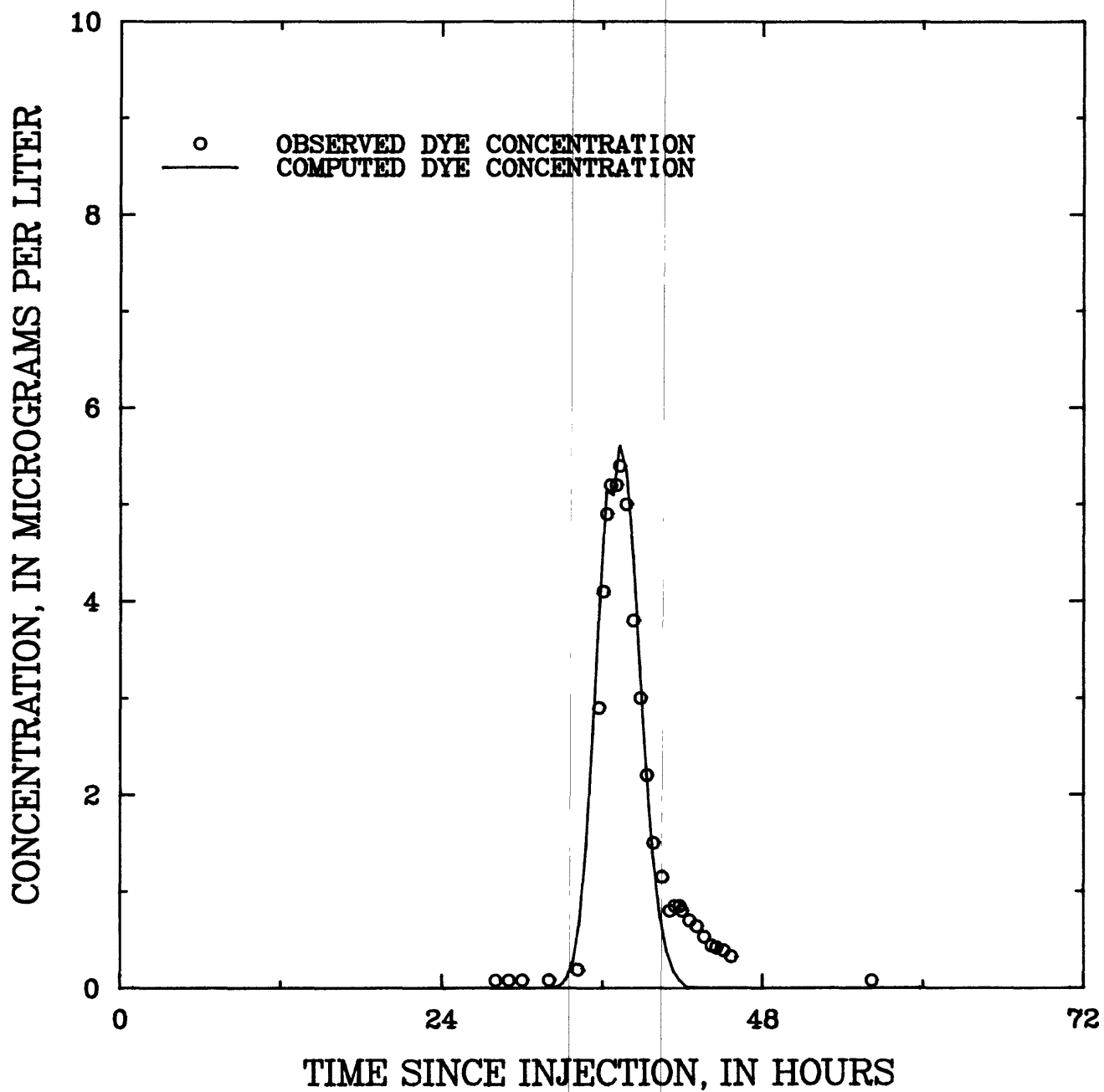


Figure 9.--Computed and observed dye concentrations in the Wateree River upstream of mouth, Wateree River mile 0.25.



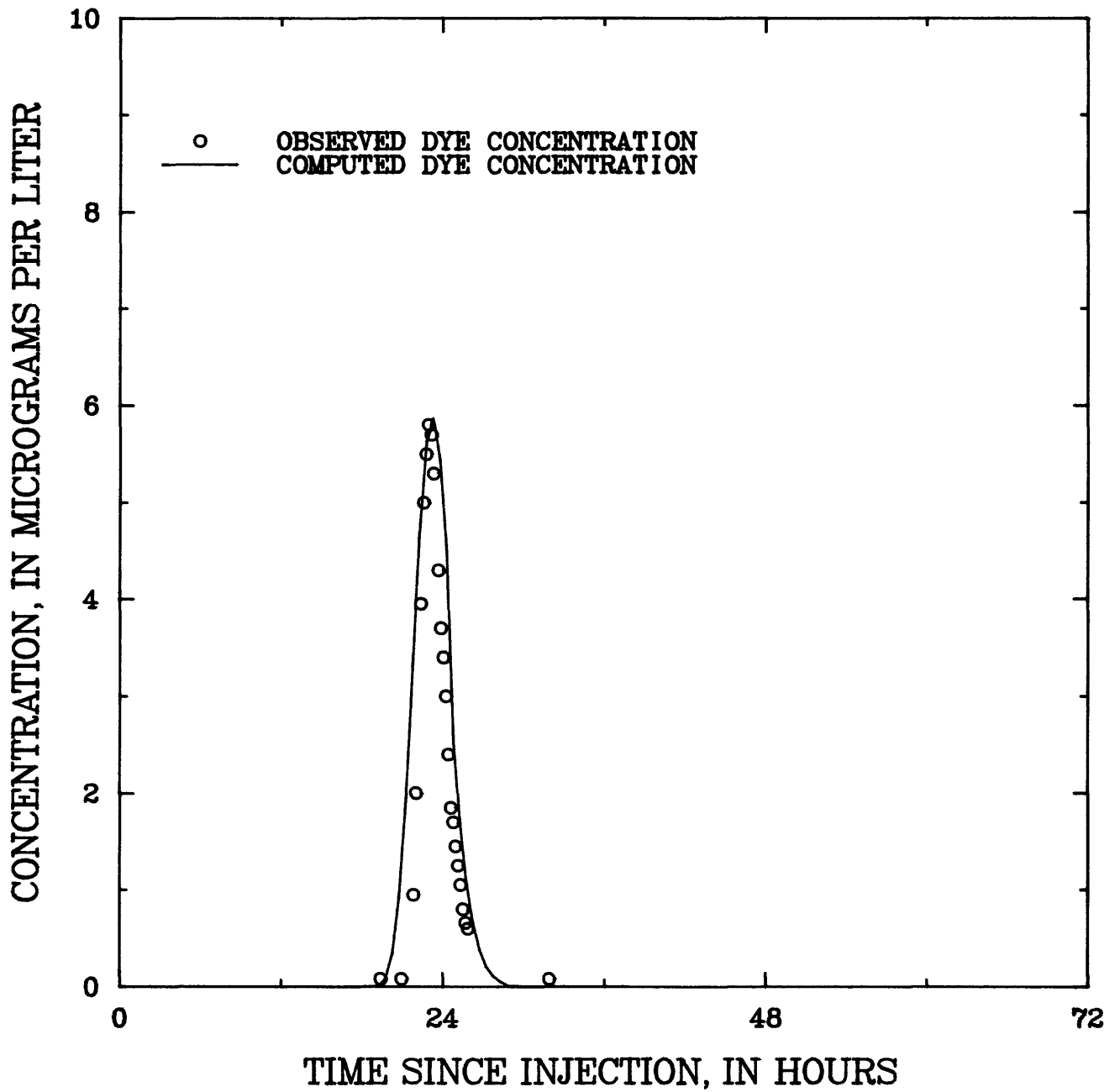


Figure 10.--Computed and observed dye concentrations in the Santee River at the Rimini Railway trestle, Santee River mile 5.3.

Table 9.--Striped bass egg development time

| Temperature<br>(degrees Celsius) | Spawn-to-hatch time<br>(hours) |
|----------------------------------|--------------------------------|
| 14.0                             | 78.5                           |
| 14.5                             | 74.0                           |
| 15.0                             | 70.0                           |
| 15.5                             | 66.0                           |
| 16.0                             | 61.5                           |
| 16.5                             | 58.0                           |
| 17.0                             | 54.0                           |
| 17.5                             | 51.0                           |
| 18.0                             | 48.0                           |
| 18.5                             | 45.5                           |
| 19.0                             | 43.0                           |
| 20.0                             | 39.0                           |
| 20.5                             | 37.5                           |
| 21.0                             | 35.5                           |
| 21.5                             | 34.5                           |
| 22.0                             | 33.0                           |
| 22.5                             | 32.0                           |
| 23.0                             | 31.0                           |
| 23.5                             | 30.0                           |
| 24.0                             | 29.0                           |
| 24.5                             | 28.0                           |
| 25.0                             | 27.5                           |
| 25.5                             | 27.0                           |
| 26.0                             | 26.0                           |
| 26.5                             | 25.5                           |
| 27.0                             | 25.0                           |

Table 10--Predicted spawning and hatching locations of striped bass eggs collected at site SL,  
 station 02169710, Congaree River at the Southern Railway Trestle near Fort Motte

[dashes indicate no sample obtained]

| Date<br>1988 | Sampled<br>egg age<br>(hours) | Development<br>time, sampled<br>age to hatch<br>(hours) | Spawn location<br>river mile <sup>1</sup> | Predicted range of hatch location        |                                 |   |
|--------------|-------------------------------|---|---|--|---------------------------------|---|
|              |                               |   |   | Trailing edge<br>river mile <sup>2</sup> | Peak<br>river mile <sup>2</sup> | Leading edge<br>river mile <sup>2</sup> |
| March 30     | 17                            | 31  | 28.5                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| March 31     | 17                            | 31  | 28.5                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 1      | 14                            | 34  | 23.8                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 2      | 11                            | 37  | 20.2                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 3      | 17                            | 28  | 28.1                                      | 2.6                                      | Lake Marion                     | Lake Marion                             |
| April 4      | 9                             | 32  | 16.3                                      | 3.2                                      | 0.0                             | Lake Marion                             |
| April 5      | 8                             | 33  | 13.9                                      | 2.7                                      | Lake Marion                     | Lake Marion                             |
| April 6      | 12                            | 31  | 16.3                                      | 2.3                                      | Lake Marion                     | Lake Marion                             |
| April 7      | 11                            | 37  | 18.5                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 8      | 32                            | 22  | 41.2                                      | 3.6                                      | Lake Marion                     | Lake Marion                             |
| April 9      | --                            | --  | --  | --                                       | --                              | --                                      |
| April 10     | --                            | --  | --  | --                                       | --                              | --                                      |
| April 11     | 11                            | 37  | 20.2                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 12     | 9                             | 42  | 16.3                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 13     | 11                            | 44  | 19.4                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 14     | 15                            | 39  | 32.1                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 15     | --                            | --  | --  | --                                       | --                              | --                                      |
| April 16     | --                            | --  | --  | --                                       | --                              | --                                      |
| April 17     | --                            | --  | --  | --                                       | --                              | --                                      |
| April 18     | 9                             | 36  | 20.2                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 19     | 12                            | 31  | 23.3                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 20     | 20                            | 23  | 34.8                                      | 4.1                                      | 0.0                             | Lake Marion                             |

Table 10--Predicted spawning and hatching locations of striped bass eggs collected at site S1, station 02169710, Congaree River at the Southern Railway Trestle near Fort Motte--Continued

[dashes indicate no sample obtained]

| Date<br>1988 | Sampled<br>egg age<br>(hours) | Development<br>time, sampled<br>age to hatch<br>(hours) | Spawn location<br>river mile <sup>1</sup> | Predicted range of hatch location        |                                 |   |
|--------------|-------------------------------|---|---|--|---------------------------------|---|
|              |                               |   |   | Trailing edge<br>river mile <sup>2</sup> | Peak<br>river mile <sup>2</sup> | Leading edge<br>river mile <sup>2</sup> |
| April 21     | 11                            | 30  | 21.0                                      | 0.1                                      | Lake Marion                     | Lake Marion                             |
| April 22     | 7                             | 30  | 15.0                                      | .1                                       | Lake Marion                     | Lake Marion                             |
| April 23     | 17                            | 19  | 30.4                                      | 7.4                                      | 2.5                             | Lake Marion                             |
| April 24     | 20                            | 16  | 32.3                                      | 10.1                                     | 4.6                             | 1.0                                     |
| April 25     | 18                            | 19  | 30.4                                      | 7.9                                      | 1.7                             | Lake Marion                             |
| April 26     | 12                            | 25  | 21.6                                      | 1.7                                      | Lake Marion                     | Lake Marion                             |
| April 27     | 11                            | 27  | 18.5                                      | 1.1                                      | Lake Marion                     | Lake Marion                             |
| April 28     | 11                            | 28  | 19.8                                      | 2.5                                      | Lake Marion                     | Lake Marion                             |
| April 29     | 12                            | 27  | 20.5                                      | 4.2                                      | .4                              | Lake Marion                             |
| April 30     | 14                            | 25  | 22.4                                      | 5.8                                      | 1.3                             | Lake Marion                             |
| May 1        | 13                            | 26  | 22.2                                      | 4.4                                      | 1.6                             | Lake Marion                             |
| May 2        | 12                            | 24  | 20.2                                      | 7.3                                      | 2.8                             | 0.0                                     |
| May 3        | 5                             | 30  | 9.3                                       | 5.8                                      | 1.9                             | Lake Marion                             |
| May 4        | 11                            | 25  | 16.7                                      | 8.4                                      | 3.4                             | .2                                      |
| May 5        | 15                            | 20  | 21.5                                      | 11.1                                     | 6.3                             | 2.2                                     |
| May 6        | 16                            | 21  | 21.9                                      | 7.8                                      | 3.2                             | 0.0                                     |
| May 7        | 15                            | 21  | 24.1                                      | 6.8                                      | 2.2                             | Lake Marion                             |
| May 8        | 22                            | 14  | 34.1                                      | 13.6                                     | 8.5                             | 4.1                                     |
| May 9        | 8                             | 27  | 13.9                                      | 2.6                                      | Lake Marion                     | Lake Marion                             |
| May 10       | 9                             | 24  | 16.7                                      | 4.5                                      | 1.5                             | Lake Marion                             |

Table 10.---Predicted spawning and hatching locations of striped bass eggs collected at site SL,  
station 02169710, Congaree River at the Southern Railway Trestle near Fort Motte--Continued

[dashes indicate no sample obtained]

| Date<br>1988 | Sampled<br>egg age<br>(hours) | Development<br>time, sampled<br>age to hatch<br>(hours) | Spawn location<br>river mile <sup>1</sup> | Predicted range of hatch location        |                                 |   |
|--------------|-------------------------------|---|---|--|---------------------------------|---|
|              |                               |   |   | Trailing edge<br>river mile <sup>2</sup> | Peak<br>river mile <sup>2</sup> | Leading edge<br>river mile <sup>2</sup> |
| May 11       | 12                            | 20  | 18.9                                      | 10.7                                     | 5.7                             | 2.6                                     |
| May 12       | 1                             | 30  | 5.8                                       | 6.8                                      | 2.7                             | Lake Marion                             |
| May 13       | 9                             | 23  | 13.9                                      | 9.7                                      | 5.1                             | 2.0                                     |
| May 14       | 14                            | 17  | 20.2                                      | 12.8                                     | 8.6                             | 4.4                                     |
| May 15       | 25                            | 3   | 33.6                                      | 13.8                                     | 12.4                            | 1.5                                     |
| May 16       | 9                             | 18  | 13.6                                      | 13.1                                     | 8.4                             | 4.4                                     |
| May 17       | 9                             | 18  | 13.6                                      | 13.5                                     | 8.3                             | 4.4                                     |

<sup>1</sup> - Congaree River mile; mile 0.0 is the confluence with Wateree River.

<sup>2</sup> - Santee River mile; mile 0.0 is the Santee River at the Browns Cut.

Table 11.--Predicted spawning and hatching locations of striped bass eggs collected at site S2, station 02148315, Wateree River below Eastover

[dashes indicate no sample obtained]

| Date 1988 | Sampled egg age (hours) | Development time, sampled age to hatch (hours) | Spawn location river mile <sup>1</sup> | Predicted range of hatch location     |                              |                                      |
|-----------|-------------------------|--|--|---------------------------------------|------------------------------|--------------------------------------|
|           |                         |  |  | Trailing edge river mile <sup>2</sup> | Peak river mile <sup>2</sup> | Leading edge river mile <sup>2</sup> |
| March 30  | --                      | --   | --                                     | --                                    | --                           | --                                   |
| March 31  | --                      | --   | --                                     | --                                    | --                           | --                                   |
| April 1   | --                      | --   | --                                     | --                                    | --                           | --                                   |
| April 2   | --                      | --   | --                                     | --                                    | --                           | --                                   |
| April 3   | 11                      | 34   | 19.5                                   | <sup>2</sup> 8.3                      | <sup>2</sup> 4.0             | <sup>2</sup> 1.3                     |
| April 4   | 10                      | 32   | 17.4                                   | <sup>2</sup> 10.0                     | <sup>2</sup> 5.3             | <sup>2</sup> 2.3                     |
| April 5   | 16                      | 27   | 31.1                                   | <sup>2</sup> 8.4                      | <sup>2</sup> 3.7             | Lake Marion                          |
| April 6   | 9                       | 39   | 20.0                                   | Lake Marion                           | Lake Marion                  | Lake Marion                          |
| April 7   | 21                      | 33   | 32.4                                   | <sup>2</sup> 3.7                      | Lake Marion                  | Lake Marion                          |
| April 8   | 23                      | 35   | 42.8                                   | <sup>2</sup> 2.2                      | Lake Marion                  | Lake Marion                          |
| April 9   | 33                      | 21   | 46.7                                   | <sup>1</sup> 1.2                      | <sup>2</sup> 11.8            | <sup>2</sup> 4.0                     |
| April 10  | 3                       | 45   | 14.5                                   | Lake Marion                           | Lake Marion                  | Lake Marion                          |
| April 11  | 10                      | 38   | 20.0                                   | Lake Marion                           | Lake Marion                  | Lake Marion                          |
| April 12  | 12                      | 39   | 21.6                                   | Lake Marion                           | Lake Marion                  | Lake Marion                          |
| April 13  | --                      | --   | --                                     | --                                    | --                           | --                                   |
| April 14  | --                      | --   | --                                     | --                                    | --                           | --                                   |
| April 15  | --                      | --   | --                                     | --                                    | --                           | --                                   |
| April 16  | --                      | --   | --                                     | --                                    | --                           | --                                   |
| April 17  | 10                      | 36   | 22.1                                   | Lake Marion                           | Lake Marion                  | Lake Marion                          |
| April 18  | 18                      | 28   | 32.4                                   | <sup>2</sup> 4.0                      | <sup>2</sup> 0.0             | Lake Marion                          |
| April 19  | 30                      | 13   | 45.8                                   | <sup>1</sup> 2.3                      | <sup>1</sup> 0.0             | <sup>2</sup> 11.6                    |
| April 20  | 36                      | 7  | 52.9                                   | <sup>1</sup> 6.7                      | <sup>1</sup> 4.1             | <sup>1</sup> 1.3                     |

Table 11.--Predicted spawning and hatching locations of striped bass eggs collected at site S2, station 02148315, Wateree River below Eastover--Continued

[dashes indicate no sample obtained]

| Date<br>1988 | Sampled<br>egg age<br>(hours) | Development<br>time, sampled<br>age to hatch<br>(hours) | Spawn location<br>river mile <sup>1</sup> | Predicted range of hatch location        |                                 |   |
|--------------|-------------------------------|---|---|--|---------------------------------|---|
|              |                               |   |   | Trailing edge<br>river mile <sup>2</sup> | Peak<br>river mile <sup>2</sup> | Leading edge<br>river mile <sup>2</sup> |
| April 21     | 4                             | 37  | 14.9                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 22     | 8                             | 30  | 20.0                                      | <sup>2</sup> 4.1                         | <sup>2</sup> 0.0                | Lake Marion                             |
| April 23     | 13                            | 24  | 26.4                                      | <sup>2</sup> 8.6                         | <sup>2</sup> 3.7                | Lake Marion                             |
| April 24     | 24                            | 11  | 55.9                                      | <sup>1</sup> 4.4                         | <sup>1</sup> 2.4                | <sup>1</sup> 0.2                        |
| April 25     | 23                            | 15  | 32.6                                      | <sup>1</sup> 2.7                         | <sup>1</sup> 0.0                | <sup>2</sup> 13.3                       |
| April 26     | 15                            | 24  | 46.7                                      | <sup>2</sup> 5.0                         | <sup>2</sup> .7                 | Lake Marion                             |
| April 27     | 23                            | 16  | 41.1                                      | <sup>2</sup> 14.0                        | <sup>2</sup> 9.6                | <sup>2</sup> 4.1                        |
| April 28     | 10                            | 29  | 20.7                                      | <sup>2</sup> 9.2                         | <sup>2</sup> 3.9                | <sup>2</sup> .7                         |
| April 29     | 8                             | 31  | 18.2                                      | <sup>2</sup> 7.4                         | <sup>2</sup> 3.2                | Lake Marion                             |
| April 30     | 9                             | 32  | 19.7                                      | <sup>2</sup> 7.3                         | <sup>2</sup> 2.6                | Lake Marion                             |
| May 1        | 7                             | 34  | 17.7                                      | <sup>2</sup> 6.9                         | <sup>2</sup> 2.9                | <sup>2</sup> 0.0                        |
| May 2        | 5                             | 33  | 14.5                                      | <sup>2</sup> 12.3                        | <sup>2</sup> 6.2                | <sup>2</sup> 2.2                        |
| May 3        | 12                            | 24  | 21.3                                      | <sup>2</sup> 14.2                        | <sup>2</sup> 10.3               | <sup>2</sup> 6.4                        |
| May 4        | 9                             | 27  | 18.8                                      | <sup>2</sup> 12.9                        | <sup>2</sup> 8.7                | <sup>2</sup> 4.3                        |
| May 5        | 19                            | 17  | 28.3                                      | <sup>1</sup> 1.6                         | <sup>2</sup> 15.1               | <sup>2</sup> 12.8                       |

Table 11.--Predicted spawning and hatching locations of striped bass eggs collected at site S2, station 02148315, Wateree River below Eastover--Continued

[dashes indicate no sample obtained]

| Date<br>1988 | Sampled<br>egg age<br>(hours) | Development<br>time, sampled<br>age to hatch<br>(hours) | Spawn location<br>river mile <sup>1</sup> | Predicted range of hatch location        |                                 |   |
|--------------|-------------------------------|---|---|--|---------------------------------|---|
|              |                               |   |   | Trailing edge<br>river mile <sup>2</sup> | Peak<br>river mile <sup>2</sup> | Leading edge<br>river mile <sup>2</sup> |
| May 6        | --                            | --  | --  | --                                       | --                              | --                                      |
| May 7        | --                            | --  | --  | --                                       | --                              | --                                      |
| May 8        | 6                             | 30  | 16.9                                      | <sup>2</sup> 6.0                         | <sup>2</sup> 1.0                | Lake Marion                             |
| May 9        | 16                            | 18  | 27.8                                      | 1.2                                      | <sup>2</sup> 11.6               | <sup>2</sup> 7.0                        |
| May 10       | 10                            | 23  | 21.6                                      | <sup>2</sup> 12.8                        | <sup>2</sup> 8.2                | <sup>2</sup> 3.5                        |
| May 11       | 11                            | 31  | 20.0                                      | 1.7                                      | <sup>2</sup> 14.6               | <sup>2</sup> 10.7                       |

<sup>1</sup> - Wateree River mile; mile 0.0 is the confluence with the Congaree River.

<sup>2</sup> - Santee River mile; mile 0.0 is the Santee River at Browns Cut.



Table 12.--Predicted spawning and hatching locations of striped bass eggs collected at site S3,  
station 02148100, Wateree River near Boykin

[dashes indicate no sample obtained]

| Date<br>1988 | Sampled<br>egg age<br>(hours) | Development<br>time, sampled<br>age to hatch<br>(hours) | Spawn location<br>river mile <sup>1</sup> | Predicted range of hatch location        |                                 |   |    |
|--------------|-------------------------------|---|---|--|---------------------------------|---|----|
|              |                               |   |   | Trailing edge<br>river mile <sup>1</sup> | Peak<br>river mile <sup>1</sup> | Leading edge<br>river mile <sup>2</sup> |    |
| March 30     | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| March 31     | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 1      | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 2      | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 3      | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 4      | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 5      | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 6      | 9                             | 53  | 61.1                                      | 7.9                                      | 2.2                             | <sup>2</sup> 9.1                        |    |
| April 7      | 11                            | 50  | upstream<br>of study area                 | 11.4                                     | 3.1                             | <sup>2</sup> 6.8                        |    |
| April 8      | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 9      | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 10     | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 11     | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 12     | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 13     | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 14     | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 15     | --                            | --  | --  | --                                       | --                              | --                                      | -- |
| April 16     | 9                             | 42  | 60.3                                      | 14.4                                     | 8.3                             | <sup>1</sup> 2.2                        |    |
| April 17     | 2                             | 49  | 55.9                                      | 9.2                                      | 2.2                             | <sup>2</sup> 7.5                        |    |
| April 18     | 9                             | 42  | 62.8                                      | 19.3                                     | 12.4                            | <sup>1</sup> 6.2                        |    |
| April 19     | 9                             | 42  | 62.9                                      | 17.2                                     | 7.3                             | <sup>1</sup> 0.0                        |    |
| April 20     | 12                            | 36  | 63.7                                      | 31.7                                     | 27.2                            | <sup>1</sup> 20.9                       |    |

Table 12.--Predicted spawning and hatching locations of striped bass eggs collected at site S3,  
station 02148100, Wateree River near Boykin--Continued

[dashes indicate no sample obtained]

| Date<br>1988 | Sampled<br>egg age<br>(hours) | Development<br>time, sampled<br>age to hatch<br>(hours) | Spawn location<br>river mile <sup>1</sup> | Predicted range of hatch location        |                                 |   |
|--------------|-------------------------------|---|---|--|---------------------------------|---|
|              |                               |   |   | Trailing edge<br>river mile <sup>1</sup> | Peak<br>river mile <sup>1</sup> | Leading edge<br>river mile <sup>2</sup> |
| April 21     | --                            | --  | --  | --                                       | --                              | --                                      |
| April 22     | 4                             | 39  | 58.9                                      | 21.1                                     | 14.0                            | <sup>1</sup> 7.1                        |
| April 23     | 6                             | 35  | 58.9                                      | 32.8                                     | 28.5                            | <sup>1</sup> 21.1                       |
| April 24     | 9                             | 32  | 62.5                                      | 31.9                                     | 27.6                            | <sup>1</sup> 22.2                       |
| April 25     | 12                            | 31  | upstream<br>of study area                 | 19.6                                     | 11.7                            | <sup>1</sup> 5.8                        |
| April 26     | 8                             | 38  | 65.6                                      | 20.1                                     | 11.5                            | <sup>1</sup> 2.6                        |
| April 27     | 27                            | 18  | upstream<br>of study area                 | 44.2                                     | 40.4                            | <sup>1</sup> 36.0                       |
| April 28     | 10                            | 33  | 60.7                                      | 32.6                                     | 30.5                            | <sup>1</sup> 24.5                       |
| April 29     | 8                             | 38  | 60.7                                      | 30.5                                     | 24.0                            | <sup>1</sup> 19.1                       |
| April 30     | 5                             | 38  | 58.9                                      | 33.2                                     | 28.9                            | <sup>1</sup> 22.1                       |
| May 1        | 13                            | 28  | 62.8                                      | 42.3                                     | 38.1                            | <sup>1</sup> 32.9                       |
| May 2        | 12                            | 29  | 62.8                                      | 38.3                                     | 32.2                            | <sup>1</sup> 28.5                       |
| May 3        | 2                             | 37  | 55.5                                      | 32.2                                     | 29.2                            | <sup>1</sup> 23.6                       |
| May 4        | 9                             | 30  | 61.2                                      | 36.1                                     | 31.9                            | <sup>1</sup> 27.2                       |
| May 5        | 10                            | 31  | 62.5                                      | 36.0                                     | 31.3                            | <sup>1</sup> 26.1                       |
| May 6        | 6                             | 33  | 58.9                                      | 33.9                                     | 30.9                            | <sup>1</sup> 23.6                       |
| May 7        | 9                             | 29  | 61.7                                      | 31.6                                     | 27.5                            | <sup>1</sup> 21.9                       |
| May 8        | 6                             | 32  | 58.9                                      | 32.0                                     | 27.5                            | <sup>1</sup> 20.5                       |
| May 9        | 8                             | 27  | 64.1                                      | 38.1                                     | 31.7                            | <sup>1</sup> 24.6                       |
| May 10       | 10                            | 25  | 59.8                                      | 47.2                                     | 43.9                            | <sup>1</sup> 32.9                       |

Table 12.--Predicted spawning and hatching locations of striped bass eggs collected at site S3, station 02148100, Wateree River near Boykin--Continued

[dashes indicate no sample obtained]

| Date<br>1988 | Sampled<br>egg age<br>(hours) | Development<br>time, sampled<br>age to hatch<br>(hours) | Spawn location<br>river mile <sup>1</sup> | Predicted range of hatch location        |                                 |   |
|--------------|-------------------------------|---|---|--|---------------------------------|---|
|              |                               |   |   | Trailing edge<br>river mile <sup>1</sup> | Peak<br>river mile <sup>1</sup> | Leading edge<br>river mile <sup>2</sup> |
| May 11       | 6                             | 27  | 56.3                                      | 45.9                                     | 42.6                            | 39.2                                    |
| May 12       | 12                            | 21  | 62.1                                      | 42.0                                     | 36.4                            | 32.8                                    |
| May 13       | 1                             | 32  | 55.1                                      | 37.2                                     | 32.7                            | 29.9                                    |
| May 14       | 9                             | 23  | 61.5                                      | 41.8                                     | 36.0                            | 31.7                                    |
| May 15       | --                            | --  | --  | --                                       | --                              | --                                      |
| May 16       | --                            | --  | --  | --                                       | --                              | --                                      |
| May 17       | --                            | --  | --  | --                                       | --                              | --                                      |
| May 18       | 16                            | 16  | upstream of study area                    | 45.9                                     | 41.5                            | 36.9                                    |

<sup>1</sup> - Wateree River mile; mile 0.0 is the confluence with the Congaree River.

<sup>2</sup> - Santee River mile; mile 0.0 is the Santee River at Browns Cut.

Table 13.--Predicted spawning and hatching locations of striped bass eggs collected at site S4, station 02169625, Congaree River west of Wise Lake near Gadsden

[dashes indicate no sample obtained]

| Date<br>1988 | Sampled<br>egg age<br>(hours) | Development<br>time, sampled<br>age to hatch<br>(hours) | Spawn location<br>river mile <sup>1</sup> | Predicted range of hatch location        |                                 |   |
|--------------|-------------------------------|---|---|--|---------------------------------|---|
|              |                               |   |   | Trailing edge<br>river mile <sup>2</sup> | Peak<br>river mile <sup>2</sup> | Leading edge<br>river mile <sup>2</sup> |
| March 30     | 9                             | 42  | 39.3                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| March 31     | --                            | --  | --  | --                                       | --                              | --                                      |
| April 1      | 8                             | 40  | 38.1                                      | 210.7                                    | 20.8                            | Lake Marion                             |
| April 2      | 7                             | 41  | 36.1                                      | 29.8                                     | 22.7                            | Lake Marion                             |
| April 3      | 10                            | 38  | 40.2                                      | 1.5                                      | 27.7                            | Lake Marion                             |
| April 4      | 7                             | 36  | 35.5                                      | 22.5                                     | 213.7                           | 2.6                                     |
| April 5      | 5                             | 38  | 32.0                                      | 211.4                                    | 23.6                            | 7.0                                     |
| April 6      | 12                            | 33  | 40.6                                      | 214.1                                    | 24.4                            | Lake Marion                             |
| April 7      | 14                            | 37  | 44.0                                      | 27.3                                     | 20.0                            | Lake Marion                             |
| April 8      | --                            | --  | --  | --                                       | --                              | --                                      |
| April 9      | --                            | --  | --  | --                                       | --                              | --                                      |
| April 10     | --                            | --  | --  | --                                       | --                              | --                                      |
| April 11     | --                            | --  | --  | --                                       | --                              | --                                      |
| April 12     | 9                             | 45  | 36.8                                      | Lake Marion                              | Lake Marion                     | Lake Marion                             |
| April 13     | --                            | --  | --  | --                                       | --                              | --                                      |
| April 14     | --                            | --  | --  | --                                       | --                              | --                                      |
| April 15     | 10                            | 38  | 41.2                                      | 22.1                                     | Lake Marion                     | Lake Marion                             |

Table 13.--Predicted spawning and hatching locations of striped bass eggs collected at site S4, station 02169625, Congaree River west of Wise Lake near Gadsden--Continued

[dashes indicate no sample obtained]

| Date<br>1988 | Sampled<br>egg age<br>(hours) | Development<br>time, sampled<br>age to hatch<br>(hours) | Spawn location<br>river mile <sup>1</sup> | Predicted range of hatch location        |                                 |   |             |
|--------------|-------------------------------|---|---|--|---------------------------------|---|-------------|
|              |                               |   |   | Trailing edge<br>river mile <sup>2</sup> | Peak<br>river mile <sup>2</sup> | Leading edge<br>river mile <sup>2</sup> |             |
| April 16     | --                            | --  | --  | --                                       | --                              | --                                      | --          |
| April 17     | --                            | --  | --  | --                                       | --                              | --                                      | --          |
| April 18     | 8                             | 35  | 39.7                                      | 29.1                                     | 20.8                            |   | Lake Marion |
| April 19     | 9                             | 34  | 39.7                                      | 212.1                                    | 22.9                            |   | Lake Marion |
| April 20     | 8                             | 35  | 39.7                                      | 210.8                                    | 22.3                            |   | Lake Marion |
| April 21     | 9                             | 32  | 40.2                                      | 213.2                                    | 24.6                            |   | Lake Marion |
| April 22     | 5                             | 34  | 34.6                                      | 213.3                                    | 23.7                            |   | Lake Marion |
| April 23     | 8                             | 30  | 39.0                                      | 1.2                                      | 27.1                            |   | 20.8        |
| April 24     | 13                            | 24  | 44.0                                      | 15.4                                     | 213.6                           |   | 25.6        |
| April 25     | 8                             | 31  | 40.2                                      | 10.0                                     | 25.6                            |   | Lake Marion |
| April 26     | 12                            | 27  | 43.0                                      | 12.9                                     | 210.0                           |   | 22.4        |
| April 27     | 10                            | 29  | 40.7                                      | 12.5                                     | 210.3                           |   | 23.0        |
| April 28     | 7                             | 32  | 36.5                                      | 1.2                                      | 28.8                            |   | 23.1        |
| April 29     | 12                            | 27  | 41.9                                      | 14.6                                     | 213.3                           |   | 7.4         |
| April 30     | 9                             | 30  | 39.0                                      | 11.8                                     | 210.7                           |   | 3.6         |
| May 1        | 10                            | 28  | 40.2                                      | 15.6                                     | 114.6                           |   | 28.4        |
| May 2        | 8                             | 28  | 36.8                                      | 15.1                                     | 10.0                            |   | 210.7       |
| May 3        | 8                             | 28  | 35.9                                      | 16.2                                     | 10.0                            |   | 210.5       |
| May 4        | 13                            | 23  | 41.5                                      | 214.0                                    | 12.9                            |   | 210.0       |
| May 5        | 12                            | 24  | 40.7                                      | 16.4                                     | 214.8                           |   | 28.5        |

Table 13.--Predicted spawning and hatching locations of striped bass eggs collected at site S4, station 02169625, west of Wise Lake near Gadsden--Continued

[dashes indicate no sample obtained]

| Date<br>1988 | Sampled<br>egg age<br>(hours) | Development<br>time, sampled<br>age to hatch<br>(hours) | Spawn location<br>river mile <sup>1</sup> | Predicted range of hatch location        |                                 |   |
|--------------|-------------------------------|---|---|--|---------------------------------|---|
|              |                               |   |   | Trailing edge<br>river mile <sup>2</sup> | Peak<br>river mile <sup>2</sup> | Leading edge<br>river mile <sup>2</sup> |
| May 6        | 8                             | 30  | 38.4                                      | <sup>1</sup> 1.8                         | <sup>2</sup> 9.5                | <sup>2</sup> 2.6                        |
| May 7        | 12                            | 24  | 42.1                                      | <sup>1</sup> 7.2                         | <sup>1</sup> 9                  | <sup>2</sup> 10.7                       |
| May 8        | 13                            | 22  | 42.6                                      | <sup>1</sup> 6.8                         | <sup>1</sup> 0.0                | <sup>2</sup> 8.7                        |
| May 9        | 10                            | 24  | 41.2                                      | <sup>1</sup> 6.6                         | <sup>2</sup> 15.0               | <sup>2</sup> 7.8                        |
| May 10       | 12                            | 21  | 42.2                                      | <sup>1</sup> 11.2                        | <sup>1</sup> 4.1                | <sup>2</sup> 14.9                       |
| May 11       | 14                            | 18  | 41.9                                      | <sup>1</sup> 15.7                        | <sup>1</sup> 8.3                | <sup>1</sup> 2.2                        |
| May 12       | 5                             | 27  | 32.6                                      | <sup>1</sup> 6.6                         | <sup>1</sup> 4                  | <sup>2</sup> 11.2                       |
| May 13       | 13                            | 19  | 41.2                                      | <sup>1</sup> 13.2                        | <sup>1</sup> 5.8                | <sup>1</sup> 2                          |
| May 14       | 12                            | 18  | 39.9                                      | <sup>1</sup> 14.8                        | <sup>1</sup> 7.4                | <sup>1</sup> 2.0                        |
| May 15       | 8                             | 20  | 36.1                                      | <sup>1</sup> 13.2                        | <sup>1</sup> 6.2                | <sup>1</sup> 1.2                        |
| May 16       | 8                             | 19  | 36.1                                      | <sup>1</sup> 15.2                        | <sup>1</sup> 8.5                | <sup>1</sup> 3.3                        |
| May 17       | 15                            | 13  | 41.9                                      | <sup>1</sup> 20.5                        | <sup>1</sup> 14.4               | <sup>1</sup> 8.1                        |
| May 18       | 15                            | 14  | 42.2                                      | <sup>1</sup> 18.6                        | <sup>1</sup> 12.6               | <sup>1</sup> 6.6                        |

<sup>1</sup> - Congaree River mile, river mile; mile 0.0 is the confluence with the Wateree River.

<sup>2</sup> - Santee River mile, river mile; mile 0.0 is the Santee River at Browns Cut.

The transport simulation results indicate that the striped bass eggs were spawned on the Congaree River from river mile 5.8 to river mile 44.0 and on the Wateree River from river mile 14.5 to upstream of the study limit, river mile 66.3. Additionally, a majority of the striped bass eggs sampled at sites S1, S2, and S4 hatched in the Santee River or Lake Marion. Nearly 100 percent of the eggs sampled at site S3 hatched in the lower Wateree River. The eggs hatched from the upper reaches of Lake Marion to river mile 16.7 on the Congaree River and to river mile 46.5 on the Wateree River. For the 1988 spawning period, the modeled results indicate that most of the striped bass eggs hatched in Santee River near Lake Marion. Eggs that hatched or were spawned outside the study area were noted.

### EQUATIONS TO PREDICT SPAWNING AND HATCHING LOCATIONS

Most results were used to compute site-specific regression equations for the four sample sites. These equations predict spawning and hatching locations using discharge, egg age, egg development time, and temperature as explanatory variables. Stepwise regression analyses were made by using P-STAT (P-STAT, Inc., 1986), a file management, data modification, and statistical analysis software system. All variables were transformed into logarithms and statistical testing was done before analysis to (1) obtain a linear regression model, and (2) achieve equal variance about the regression line throughout the range (Riggs, 1968, p. 10). A 95 percent confidence limit was specified to select the significant independent variables.

Accuracy of linear multiple-regression techniques can be expressed by two standard statistical measures: the coefficient of determination,  $R^2$ , and the standard error of regression (or estimate). The  $R^2$  statistic indicates the proportion of the total variation of the dependent variable that is explained by the independent variables. For instance, an  $R^2$  of 0.93 would indicate that 93 percent of the variation in the dependent variable is accounted for by the independent variables. The standard error of regression is, by definition, the standard deviation of the residuals of the regression equation and contains about two-thirds of the data in the range of the 95 percent confidence level. Conversely, about one-third of the data will fall outside the standard error of regression. The standard error presented represents the standard error between the BLTM computed results and the regression equations.

The equations developed by using multiple stepwise regression techniques for the indicated sample sites (fig. 2) are listed below:

Sample site 1:

$$HD = (0.031)(DT^{0.68})(Q^{0.51}) \quad (5)$$

$$R^2 = 0.932$$

$$SE = 4.6 \text{ percent} \quad \text{Maximum distance} = 20.9 \text{ mi}$$

$$SD = (0.0107)(Age^{1.05})(Q^{0.56}) \quad (6)$$

$$R^2 = 0.986$$

$$SE = 5.6 \text{ percent} \quad \text{Maximum distance} = 41.8 \text{ mi}$$

Sample site 2:

$$HD = (0.033)(DT^{1.02})(Q^{0.42}) \quad (7)$$

$$R^2 = 0.982$$

$$SE = 5.1 \text{ percent} \quad \text{Maximum distance} = 27.4 \text{ mi}$$

$$SD = (0.0447)(Age^{1.08})(Q^{0.38}) \quad (8)$$

$$R^2 = 0.996$$

$$SE = 5.1 \text{ percent} \quad \text{Maximum distance} = 55.0 \text{ mi}$$

Sample site 3:

$$HD = (0.009)(DT^{1.10})(Q^{0.56}) \quad (9)$$

$$R^2 = 0.939$$

$$SE = 10.0 \text{ percent} \quad \text{Maximum distance} = 65.8 \text{ mi}$$

$$SD = (0.00501)(Age^{1.09})(Q^{0.64}) \quad (10)$$

$$R^2 = 0.949$$

$$SE = 18.9 \text{ percent} \quad \text{Maximum distance} = 11.6 \text{ mi}$$

Sample site 4:

$$HD = (0.160)(DT^{0.87})(Q^{0.28}) \quad (11)$$

$$R^2 = 0.956$$

$$SE = 9.3 \text{ percent} \quad \text{Maximum distance} = 43.6 \text{ mi}$$

$$SD = (0.0417)(Age^{0.85})(Q^{0.45}) \quad (12)$$

$$R^2 = 0.967$$

$$SE = 5.9 \text{ percent} \quad \text{Maximum Distance} = 19.1 \text{ mi}$$



where

HD = Distance downstream to hatching point from sampling point, in miles.

SD = Distance upstream to spawning point from sampling point, in miles.

DT = Development time from time sampled to hatch, in hours.

Age = Age of sampled eggs, in hours.

Q = Discharge, in cubic feet per second.

R<sup>2</sup> = Coefficient of determination.

SE = Standard error of estimate, in percent.

The data for these equations were obtained from SCWMRD and from USGS computations. Development time is a function of egg age and water temperature and may be obtained by using tables 3 and 4, provided by SCWMRD. Conditions during the 1988 spawning period that caused the egg hatching distance or spawning distance to exceed the limits of the study were not used to determine the regression equations; therefore, these equations are accurate for predicted values less than the respective maximum distances listed for each equation.

Plots of residuals and the explanatory variables indicated that the regression models were not biased.

### SUMMARY

The spawning and hatching locations of striped bass eggs collected by South Carolina Wildlife and Marine Resources Department in 1988 in the Santee River system in South Carolina were predicted with flow and transport models. The two computer models used were a one-dimensional unsteady flow model, or BRANCH and the Branched Lagrangian Transport model, or BLTM.

Physical characteristics of the striped bass eggs were determined using laboratory experiments. These experiments indicated that the average specific gravity of the egg is 1.001 and the average settling velocity is 0.01 ft/s. Additional laboratory experiments indicated that the minimum velocity required to keep the striped bass eggs in suspension is approximately 0.2 ft/s.

The BRANCH model simulated the hydraulic conditions, discharge, area, and top width used to drive the transport model, BLTM. The results of a dye study were used to calibrate the BLTM. The BLTM simulated the transport and dispersion of the striped bass eggs as they traveled through the system suspended in the water column. Because of the results of the specific gravity experiments, the striped bass eggs were assumed to act as a dissolved substance. Output from the BLTM predicted the spawning and hatching location of the eggs.

The transport simulation results indicate that the eggs were spawned from river mile 5.8 to river mile 44.0 on the Congaree River and from River mile 14.5 to upstream of the study limit, river mile 66.3, on the Wateree River. Additionally, the eggs hatched from the upper reaches of Lake Marion to river mile 16.7 on the Congaree River and from river mile 0.0 to river mile 46.5 on the Wateree River. For the 1988 spawning period, the modeled results indicate that most of the striped bass eggs hatched in the Santee River near Lake Marion.

Egg age and development time, discharge, and temperature were used in multiple stepwise regression analyses to develop site-specific equations to estimate spawning and hatching locations. Temperature was not statistically significant; therefore, it was not included in the regression equations. Either the model or the equations can be used to predict spawning and hatching locations.

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## ERRATA SHEET

**In the list of cooperators on the cover and title page of this report, the South Carolina Wildlife and Marine Resources Division should be listed as South Carolina Wildlife and Marine Resources Department.**