IMPACT OF DISCHARGES FROM POINT AND NONPOINT SOURCES ON WATER QUALITY OF THE UPPER REEDY RIVER NEAR GREENVILLE, SOUTH CAROLINA

By Donald I. Cahal and Gary K. Speiran

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4054

Prepared in cooperation with

APPALACHIAN REGIONAL COUNCIL OF GOVERNMENTS,

GREENVILLE, SOUTH CAROLINA

Columbia, South Carolina

1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey, WRD
1835 Assembly Street, Suite 658
Columbia, South Carolina 29201

Copies of this report can be
purchased from:

Open-File Services Section
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
(Telephone: 303/234-5888)

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS AND ABBREVIATIONS OF UNITS

The inch-pound units used in this report can be converted to equivalent International System of Units (SI) as follows:

Multiply inch-pound units	By	To obtain SI units
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	3785.0	cubic meter per day (m^3/d)
ton per day (ton/d)	0.9072	megagram per day (Mg/d)

National Geodetic Vertical Datum of 1929 (NGVD of 1929).--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

IMPACT OF DISCHARGES FROM POINT AND NONPOINT SOURCES ON WATER QUALITY OF THE UPPER REEDY RIVER NEAR GREENVILLE, SOUTH CAROLINA

By Donald I. Cahal and Gary K. Speiran

ABSTRACT

A study of the impacts of discharges from point and nonpoint sources in the Greenville, South Carolina urban area on water quality of the Reedy River was conducted from October 1979 through September 1980. Streamflow and water-quality data were collected at 17 stations before and during 2 storms, October 4-6, 1979 and September 28-30, 1980.

Discharges from the point source, the Mauldin Road Wastewater Treatment Plant, resulted in daily average concentrations of dissolved oxygen less than 5 milligrams per liter in the Reedy River on 34 days during low streamflow in the summer of 1980. With the combined effects of discharges from nonpoint sources from the urban area of Greenville and the discharge from the point source, concentrations of dissolved oxygen remained greater than 5 milligrams per liter in the Reedy River during periods of high streamflow, even though discharges from the urban nonpoint sources increased during the two rain storms monitored. Although instantaneous loads of oxygen-demanding material from the urban nonpoint sources increased from 0.5 tons per day to 9.9 tons per day during high streamflow, increased dilution reduced the impacts of these loads on the water quality of the Reedy River.

Although average instantaneous loads of constituents in the discharge from the point source varied between the two storms, they remained relatively constant in comparison to discharges from the nonpoint source. Average instantaneous loads from the point source during the October 1979 storm were 11.6 tons per day of organic nitrogen, 8.6 tons per day of ammonium nitrogen, 8.4 tons per day of nitrite plus nitrate nitrogen, 22 tons per day of ultimate carbonaceous biochemical oxygen demand, and 17 tons per day of orthophosphate phosphorus.

Near peak flood flows, discharge from nonpoint sources in the urban Greenville area contributed instantaneous loads as great as 9.9 tons per day of ultimate carbonaceous biochemical oxygen demand, 0.62 tons per day of organic nitrogen, and 0.51 tons per day of nitrite plus nitrate nitrogen. Instantaneous loads of orthophosphate and ammonium in these discharges remained low during periods of high streamflow.

INTRODUCTION

The original approach to improving stream water quality has been to identify discharges from point sources and require that these discharges meet specified quality standards. This approach has been modified by passage of the Federal Water Pollution Control Amendments of 1972 (Public Law 92-500) which requires the implementation of Wastewater Treatment Plans for the control of constituent loads in discharges from both point and nonpoint sources on an area-wide basis.

Studies have indicated that storm runoff from nonpoint sources may contain organic wastes, nitrogen, phosphorus, and heavy metals in sufficient concentrations to be a significant contributor to the degradation of water quality in receiving streams (Bryan, 1970). Bryan (1970) indicated that the load of BOD (biochemical oxygen demand) from urban runoff in a North Carolina basin was equal to the load of BOD from the wastewater treatment plants in the basin. Whipple (1970) in a study of three New Jersey river basins indicated that less than 39 percent of the total organic load as measured by BOD was from known point sources.

The South Carolina Department of Health and Environmental Control (1974) established dissolved oxygen standards that will not permit a daily average concentration of less than 5 mg/L (milligrams per liter) or an instantaneous concentration of dissolved oxygen less than 4 mg/L, when the streamflow is equal to or greater than $7Q_{10}$ (the discharge that, with a frequency of once in 10 years, is not exceeded during a 7-day period). An earlier assessment of water quality in the Reedy River basin indicated that concentrations of dissolved oxygen less than 5 mg/L could occur in the river as a result of discharge from nonpoint sources, primarily in the urban area during the storms (J. E. Sirrine Company, 1978).

The South Carolina Appalachian Council of Governments is considering means of reducing nonpoint loads from the urban area of Greenville that could contribute to the low concentrations of dissolved oxygen in the river. Before such costly means of reducing nonpoint loads to the river are implemented, the Council of Governments, the U.S. Environmental Protection Agency, and the U.S. Geological Survey conducted a study of concentrations of dissolved oxygen and the loads of parameters that affect concentrations of dissolved oxygen in the Reedy River.

Objective and Scope

The objective of the study was to determine if discharges from nonpoint sources in the urban Greenville area result in concentrations of dissolved oxgen less than 5 mg/L in the Reedy River downstream from Greenville. To determine this, the effects of discharges from nonpoint sources and the MRWTP (Mauldin Road Wastewater Treatment Plant) point source on water quality of the Reedy River were studied. Streamflow and water-quality data were collected at 17 stations on the Reedy River during two storms, October 4-6, 1979 and September 28-30, 1980. The pH and concentrations of total organic nitrogen, total ammonium, total nitrite plus nitrate, ultimate carbonaceous biochemical oxygen demand, dissolved oxygen, and dissolved orthophosphate were determined. Streamflow, water temperature, and concentrations of dissolved oxygen were measured continuously at three of the stations from May through September 1980.

Description of Study Area

The Reedy River rises about 8 miles north of the city of Greenville. The study area, 168 square miles, is within the Piedmont Province of South Carolina. The length of the river in the study area is about 40 river miles. The topography is characterized by rolling hills sloping gently from the upper Piedmont to the lower Piedmont. The elevation of the stream bed ranges from 1,060 feet above sea level in the headwaters to 568 feet above sea level at the downstream end of the study area. There are numerous shoals, one waterfall (in the city of Greenville), and two run-of-the-river dams on the river in the study area. One of the dams forms Lake Conestee on the Reedy River between the discharge from the MRWTP and station 02164040. The other dam forms a small lake on the Reedy River in the lower end of the study area between station 02164120 and station 02164180.

The locations of the sampling, streamflow, and rain gage stations; minor point sources; and the dams are shown in figure 1. Sampling and streamflow stations were located on the Reedy River and major tributaries. Station numbers, descriptions, and distances downstream from State Highway 250 are listed in table 1 for the sampling and streamflow stations. Latitudes and longitudes of the rain gage stations are listed in table 2.

Land use in the Reedy River basin is about 4 percent urban residential, 7 percent suburban residential, 47 percent agricultural, 25 percent forest, 3 percent suburban residential and commercial, 13 percent commercial and industrial, and 1 percent suburban residential and industrial (J. E. Sirrine Company, 1978). The area upstream of station 02163900 is predominately forested. The area between station 02163900 and station 02164000 is predominately urban. The area downstream from station 02164000 is predominately forested and agricultural.

METHODS OF DATA COLLECTION AND ANALYSIS

Streamflow and water quality were monitored during 2 storms at 17 stations. These stations include the MRWTP, the Lower Reedy River Wastewater Treatment Plant, nine stations on the Reedy River, and six stations on tributaries of the Reedy River. Data from the Lower Reedy River Wastewater Treatment Plant and the tributary stations are not included in this report, as analysis showed that flow from these sources had minimal impact on the main stem of the Reedy River. The data are available from the South Carolina District office of the U.S. Geological Survey in Columbia, S.C. Data were collected during low streamflow, during increasing streamflow, near peak streamflow, and during decreasing streamflow. The storms occurred during October 4-6, 1979 and September 28-30, 1980.

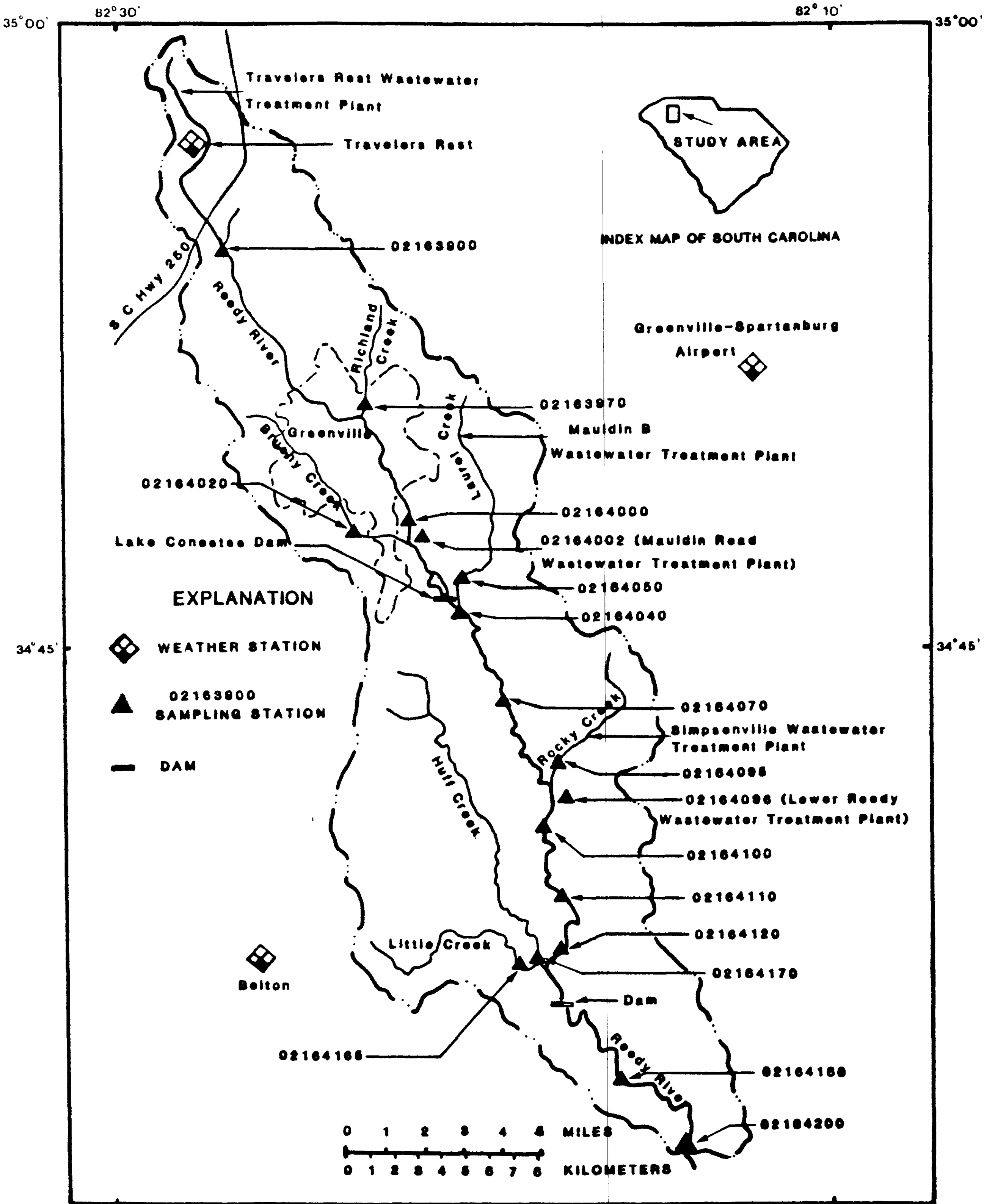

Figure 1.--Location of study area and locations of stations, point sources, and dams in the upper Reedy River Basin.

Table 1.--Station numbers, descriptions, and distances downstream from State Highway 250

Station number	Description	Miles downstream from State Highway 250, in miles
02163900	Reedy River at road S23-133	1.01
02163970	Richland Creek at Cleveland Park	--
02164020	Brushy Creek at Jacobs Road	--
02164000*	Reedy River at road S23-186	11.68
02164002**	Mauldin Road Wastewater Treatment Plant	11.78
02164040	Reedy River at road S23-107	14.45
02164050	Laurel Creek at road S23-107	--
02164070	Reedy River at road S23-316	18.49
02164095	Rocky Creek at road S23-453	--
02164099**	Lower Reedy Wastewater Treatment Plant	--
02164100	Reedy River at road S23-542	23.71
02164110*	Reedy River above State Highway 418	26.84
02164120	Reedy River at road S23-154	30.01
02164165	Little Creek at road S23-565	--
02164170	Huff Creek at road S23-154	--
02164180	Reedy River at road S23-377	35.44
02164200*	Reedy River at road S23-68	39.99

* Continuous stage, temperature, and dissolved oxygen stations.
** Wastewater treatment plant.

Table 2.--Latitude and longitude of rain gage stations

Rain gage stations	Latitude	Longitude
Travelers Rest	34°58'	82°27'
Greenville-Spartanburg Airport	34°54'	82°13'
Belton	34°36'	82°26'

Data collection during the storm of October 4-6, 1979 began at 1400 hours on October 4 and ended at 0235 hours on October 6. Data collection during the storm of September 28-30, 1980 began at 1000 hours on September 28 and ended at 1300 hours on September 30.

In addition to the data collected during the storms, stage, temperature, and concentrations of dissolved oxygen were continuously measured at three stations during the period May to October 1980.

Water samples were collected using methods described by the U.S. Geological Survey (1977). Streamflow was determined from a stage-streamflow relation developed for each station. Water temperature, pH, and concentrations of dissolved oxygen were measured in the field.

Concentrations of total organic nitrogen as nitrogen, total ammonium as nitrogen, total nitrite plus nitrate as nitrogen, and total and dissolved orthophosphate as phosphorus were determined in the laboratory using methods described by Skougstad and others (1978).

Concentrations of $CBOD_u$ (ultimate carbonaceous biochemical oxygen demand) were determined using a laboratory procedure described by Stamer and others (1979) and a computational procedure described by Jennings and Bauer (1976).

The instantaneous load for each constituent was determined by the equation:

$$Q_c = 0.002698\ C\ Q$$

where:

Q_c = Instantaneous load of constituent, in tons per day;

C = Concentration of constituent, in milligrams per liter; and

Q = Instantaneous discharge, in cubic feet per second.

The effects of discharges from point and nonpoint sources were determined by (1) comparing instantaneous loads and concentrations from the point source with instantaneous loads and concentrations from urban nonpoint sources during the two storms and (2) comparing the water quality of the river when the point source had a large effect with the water quality of the river when the point source had little effect.

DISCHARGES FROM POINT AND NONPOINT SOURCES

The streamflow of the Reedy River consists of discharges from point and nonpoint sources.

The major point source in the study area is the MRWTP (Mauldin Road Wastewater Treatment Plant) which discharges about 25 Mgal/d or 39 ft^3/s of secondary effluent into the Reedy River just downstream from the urban area of Greenville. Smaller point sources of discharge include the Abney Mills Renfew bleachery, Travelers Rest Wastewater Treatment Plant, Mauldin B plant, Simpsonville plant, and Lower Reedy River Wastewater Treatment Plant, which have a combined discharge of about 3 Mgal/d or 5 ft^3/s. Abney Mills Renfrew bleachery and Travelers Rest Wastewater Treatment Plant discharge into the Reedy River near Travelers Rest, upstream of Greenville. The Mauldin B plant discharges into Laurel Creek. The Simpsonville plant discharges into Rocky Creek. Laurel Creek, Rocky Creek, and the Lower Reedy River Wastewater Treatment Plant discharge into the Reedy River downstream from the urban area of Greenville. In this report the MRWTP will be referred to as the point source.

Nonpoint sources are all sources of discharge other than the point source. Discharge from nonpoint sources includes runoff from urban, rural, and forested areas and discharge from the smaller point sources.

Discharge from nonpoint sources increases as a result of runoff resulting from rainfall and decreases during dry periods. Because discharge from the point source remains relatively constant, increased discharge from nonpoint sources results in greater dilution of the discharge from the point source. Discharge from nonpoint sources increases in a downstream direction; therefore, dilution of the discharge from the point source increases downstream.

Discharge from the point source (station 02164002) is equal to or greater than discharge from urban nonpoint sources (station 02164000) about 25 percent of the time. The 30-year average streamflow in the Reedy River near Greenville is 83.0 ft^3/s and the $7Q_{10}$ is 16 ft^3/s (Bloxham, 1979).

Discharge from the point source to the Reedy River was about 32 ft^3/s during the October 4-6, 1979 storm and ranged from 38-49 ft^3/s during the September 28-30, 1980 storm (fig. 2).

During the October 4-6, 1979 storm, discharge from urban nonpoint sources to the Reedy River just upstream from the point source (station 02164000) ranged from 63 ft^3/s during low flow prior to the storm to 267 ft^3/s near peak flow for the storm (fig. 2). The combined discharges from point and nonpoint sources near the downstream end of the study reach (station 02164180) ranged from 202 ft^3/s during low flow to 496 ft^3/s near peak flow. During the September 28-30, 1980 storm, discharge at station 02164000 ranged from 38 ft^3/s during low flow prior to the storm to 501 ft^3/s near peak flow. Discharge at station 02164180 ranged from 147 ft^3/s during low flow to 1,189 ft^3/s near peak flow. Streamflow was greater during the second storm because rainfall was greater.

Rainfall at the Travelers Rest station was 0.9 inch during the October 4-6, 1979 storm and 3.1 inches on September 28 and 29, 1980 (table 3). Rainfall during the two storms was about evenly distributed over the basin.

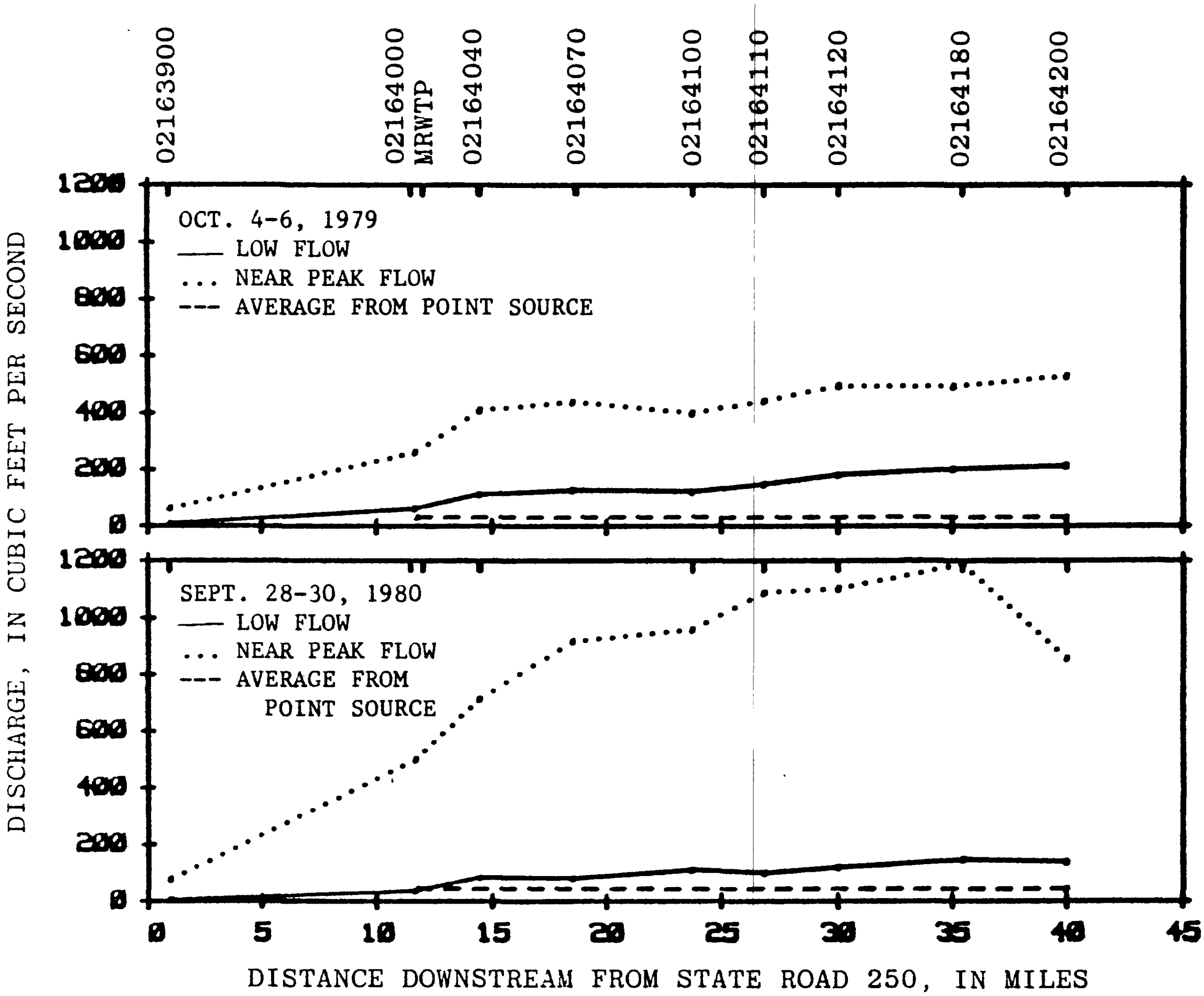

Figure 2.--Discharge during low flow and near peak flow in the Reedy River, October 4-6, 1979 and September 28-30, 1980.

Table 3.--Observed rainfall during the two storms, in inches

Date	Travelers Rest	Greenville-Spartanburg Airport	Belton
1979:			
October 4	0.9	0.64	1.0
October 5	--	--	--
October 6	--	--	--
Total	0.9	0.64	1.0
1980:			
September 28	2.1	1.95	1.7
September 29	1.0	1.03	1.3
Total	3.1	2.98	3.0

EFFECTS OF DISCHARGES FROM POINT AND NONPOINT SOURCES ON WATER QUALITY

The water-quality parameters discussed in this report are organic nitrogen, ammonium, nitrite, nitrate, $CBOD_u$, dissolved oxygen, orthophosphate, and pH. Emphasis is placed on the concentration of dissolved oxygen. The parameters that affect concentrations of dissolved oxygen are organic nitrogen, ammonium, nitrite, and $CBOD_u$.

Sources of organic nitrogen include wastewater effluents and organic debris from urban areas, farms, and forests. Organic nitrogen is decomposed into ammonium, a form of inorganic nitrogen, by bacteria. Ammonium is oxidized to nitrite, and nitrite is oxidized to nitrate by bacteria in a process called nitrification. The nitrification process requires 4.3 mg of oxygen for each milligram of nitrate produced (Wezernak and Gannon, 1967). Nitrification creates an oxygen demand that can significantly reduce concentrations of dissolved oxygen in the river. In addition to decomposition of organic nitrogen and the nitrification process, sources of ammonium and nitrite plus nitrate in the river include wastewater effluents; fertilizers; and discharges from urban areas, farms, and forests.

Nitrification of ammonium to nitrate in the river results in downstream changes in instantaneous loads of ammonium and nitrite plus nitrate. However, if only nitrification affects loads of these constituents, the downstream loads of inorganic nitrogen, composed of ammonium, nitrite, and nitrate nitrogen, remain unchanged.

Downstream increases in loads of inorganic nitrogen result from increased loads of ammonium and/or nitrite plus nitrate from nonpoint sources. Downstream decreases in inorganic nitrogen result from loss of ammonium and/or nitrite plus nitrate from the system.

$CBOD_u$ is a measure of the total amount of dissolved oxygen required for the aerobic breakdown of decomposable organic matter by microorganisms.

Dissolved oxygen is required by all aerobic aquatic organisms for respiration. Each type of organism requires its own minimum concentration of dissolved oxygen to function properly. Whenever the concentration of dissolved oxygen decreases significantly below this level for an organism, the organism dies. Dissolved oxygen standards are based on the oxygen requirements for certain organisms.

The concentration of dissolved oxygen in a stream is controlled by numerous physical, chemical, and biological processes. Sources of oxygen in a stream include discharges from point sources and nonpoint sources, production of oxygen during photosynthesis by aquatic plants, and the atmosphere. Concentrations of dissolved oxygen in a stream are decreased by chemical oxidation of reduced compounds, by respiration of aerobic aquatic organisms, and by release to the atmosphere.

Sources of orthophosphate include the point source and nonpoint sources such as organic debris, fertilizers, and automobile exhausts.

The pH of water has significant effects on reactions involving both hydrogen ions and hydroxide ions. Many of these reactions are part of the metabolic processes of all organisms. Thus, changes in pH can have a significant impact on aquatic organisms.

The pH of water is defined as the negative logarithm of the hydrogen ion activity. In dilute solutions, activity is approximately equal to concentration. For a hydrogen ion activity of $3.16X10^{-5}$ mg/L,

$$\begin{aligned} pH &= -\log\ [3.16X10^{-5}] \\ &= -\log\ [1X10^{-4.5}] \\ &= 4.5. \end{aligned}$$

Because pH is a logarithmic function, small changes in pH represent significant changes in the hydrogen ion activity. A change of 1 pH unit represents a change of an order of magnitude in the hydrogen ion activity.

The following is a discussion by parameter of the results of the study. Instantaneous loads are used to compare contributions of each parameter from urban nonpoint sources, the point source, and rural nonpoint sources. Concentrations are used to determine the water quality that resulted from these loads.

Figure 3 presents a comparison of data from urban nonpoint sources with data from the point source. The data compared include discharge and parameter loads during both storms. This figure is the key to the discussion of the relative effects of urban nonpoint sources and the point source on water quality of the Reedy River. Profiles of instantaneous loads of parameters in the river assist in the comparison of loads to the river from urban nonpoint sources, the point source, and rural nonpoint sources. However, changes in loads of parameters within the stream also affect the profiles.

The sequence for this discussion for each parameter is a comparison of:

1. Instantaneous loads from urban nonpoint sources and the point source.
2. Profiles of instantaneous loads in the river.
3. Profiles of concentrations in the river.

Organic Nitrogen

The instantaneous load of organic nitrogen from the point source was generally greater than that from urban nonpoint sources both prior to and during both storms (fig. 3).

During low flow of both storms and near peak flow for the October 1979 storm, the load from the point source was not apparent at the next station downstream from the point source (02164040) (fig. 4). Farther downstream the instantaneous loads of organic nitrogen gradually increased during low flows, but were still less than the combined instantaneous loads from the point source and from urban nonpoint sources. Only near peak flow of the greater storm (September 1980) was the instantaneous load in the Reedy River at the station immediately downstream from the point source equal to the combined loads from the point source and from urban nonpoint sources.

Organic nitrogen was apparently removed from the stream at low flow and at the lesser of the two storm peak flows, in the reach between the point source and station 02164040. There may have been some decomposition of organic nitrogen to ammonium, but this was not a major factor, as the load of ammonium did not increase significantly in this reach. It is more likely that suspended organic nitrogen settled out of the stream in Lake Conestee and other slow-moving water. Such settling is more likely to occur during low flow and lesser peak flows than during greater peak flows. The gradual increase in loads of organic nitrogen downstream from station 02164040 was probably caused by inflow of organic nitrogen from rural nonpoint sources and by production of organic nitrogen by algae.

The concentration of total organic nitrogen decreased from the most upstream station (02163900) to the station just upstream of the point source (02164000), then generally increased, both during low flow and near peak flow (fig. 5). Sharp increases in concentration that occurred downstream from station 02164040 near peak flow of the October 1979 storm resulted from discharge from rural nonpoint sources.

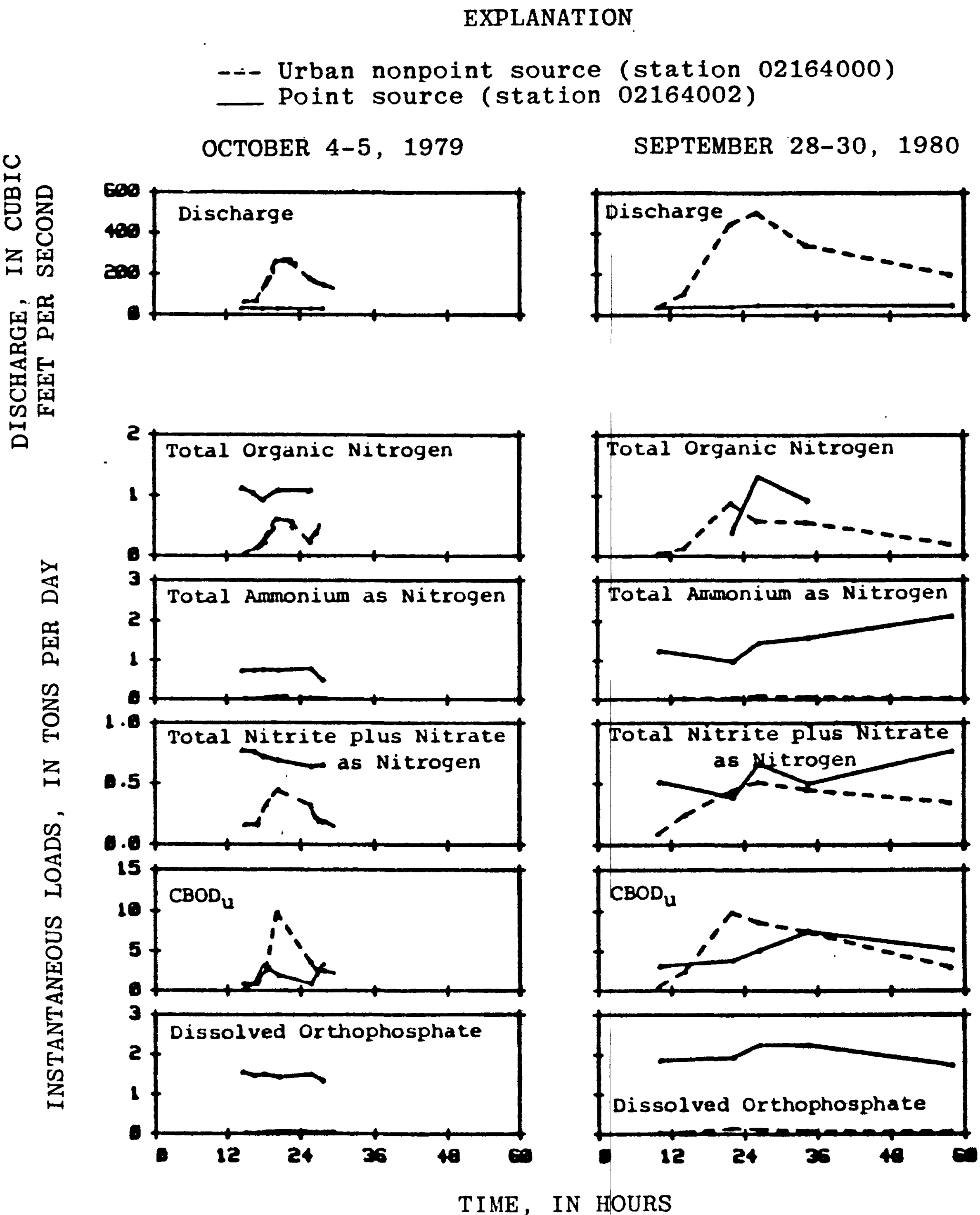

Figure 3.--Discharges and instantaneous loads of water-quality parameters from urban nonpoint sources (station 02164000) and the point source (station 02164002) October 4-6, 1979 and September 28-30, 1980.

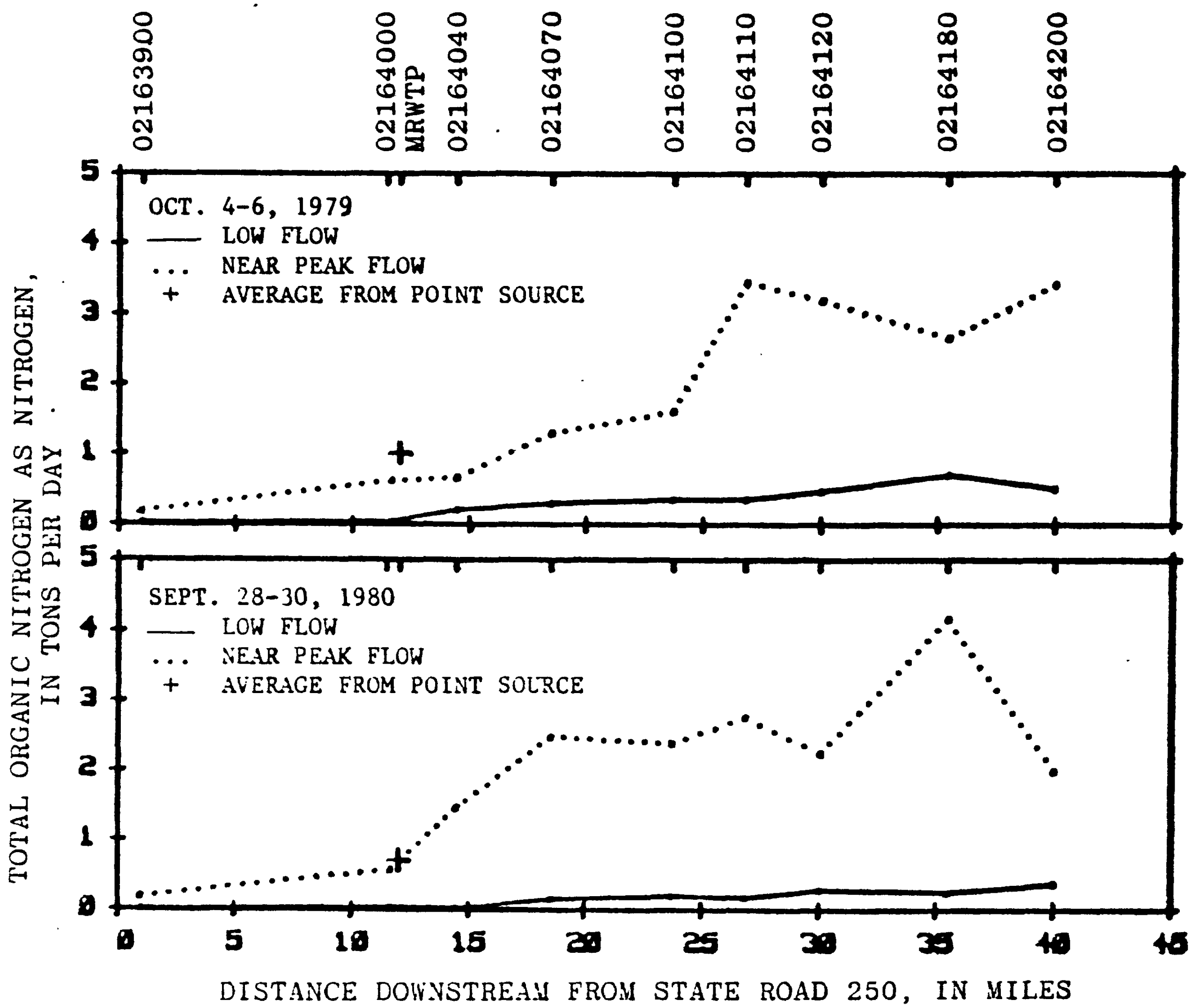

Figure 4.--Instantaneous load of total organic nitrogen as nitrogen, during low flow and near peak flow in the Reedy River, October 4-6, 1979 and September 28-30, 1980.

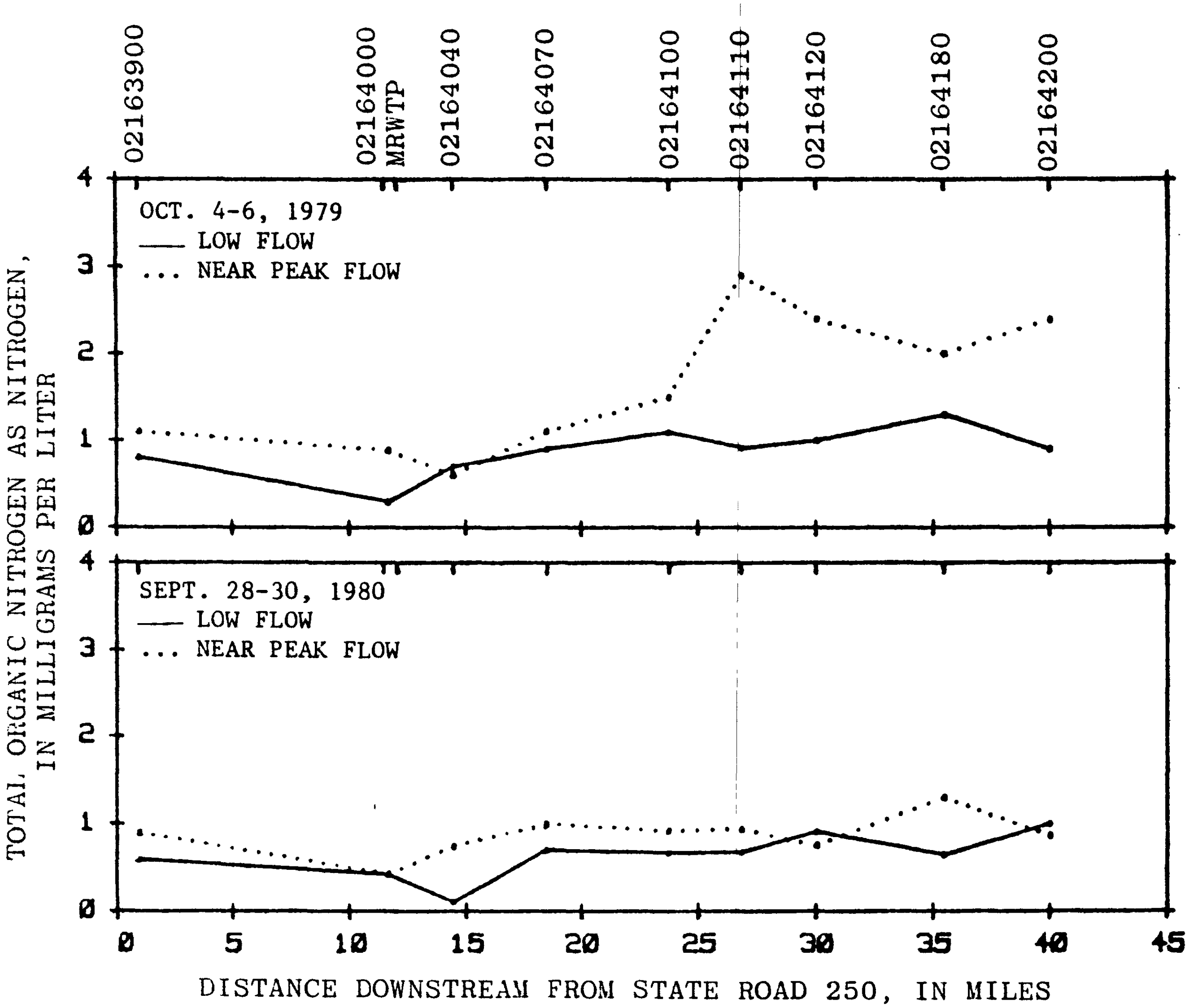

Figure 5.--Concentrations of total organic nitrogen as nitrogen during low flow and near peak flow in the Reedy River, October 4-6, 1979 and September 28-30, 1980.

Ammonium Nitrogen

The instantaneous load of ammonium nitrogen in the discharge from urban nonpoint sources (station 02164000) changed little throughout both storms (fig. 3). The instantaneous load from the point source (station 02164002) showed only slight changes and was substantially greater than that from urban nonpoint sources. The effects of the point source and subsequent nitrification of ammonia are also evident in stream profiles of instantaneous loads of ammonium nitrogen (fig. 6). During low flow the load at the station immediately downstream from the point source was less than that contributed by the point source. Loads decreased downstream from that station. This was probably the result of nitrification in the river.

Near peak flow in October 1979, the load of ammonium at the station immediately downstream from the point source was greater than that of the point source and nonpoint sources combined. This may have resulted from the scour of ammonium from Lake Conestee as a result of the greater velocities. This ammonium could have resulted from the decomposition of organic nitrogen deposited in Lake Conestee during low flow. Loads of ammonium decreased downstream from station 02164040, but this decrease occurred farther downstream than during low flow. Instantaneous loads of total ammonium showed little change throughout the study reach during the September 1980 storm.

Sufficient data are not available to fully evaluate the effects of discharge, mean velocity, and time of travel on loads of ammonium. Velocities increased about fourfold at station 02164120 between low flow and near peak flow during the September 1980 storm. However, the changes in time of travel are unknown. Increased velocities and shorter time of travel would result in loads of ammonium remaining nearly unchanged farther downstream during high flow than during low flow before loads decreased because of nitrification. This would have been more of a factor during the September 1980 storm because peak streamflow during the September 1980 storm was greater than during the October 1979 storm. Increased discharge from rural nonpoint sources could also have contributed to the greater loads downstream.

Concentrations of ammonium at station 02164040 were less during near peak flow than during low flow because of the greater dilution of ammonium from the point source by discharges from urban nonpoint sources (fig. 7). Concentrations of ammonium showed much less change farther downstream during both storms than during low flow, possibly as a result of the impact of time of travel discussed previously.

Nitrite Plus Nitrate Nitrogen

The instantaneous load of nitrite plus nitrate nitrogen from the point source was greater than that from urban nonpoint sources during the October 1979 storm (fig. 3). During low flow prior to the September 1980 storm, the instantaneous load from the point source also was greater than that from nonpoint sources. However, near peak flow, the nonpoint load of nitrite plus nitrate increased to a level similar to that from the point source.

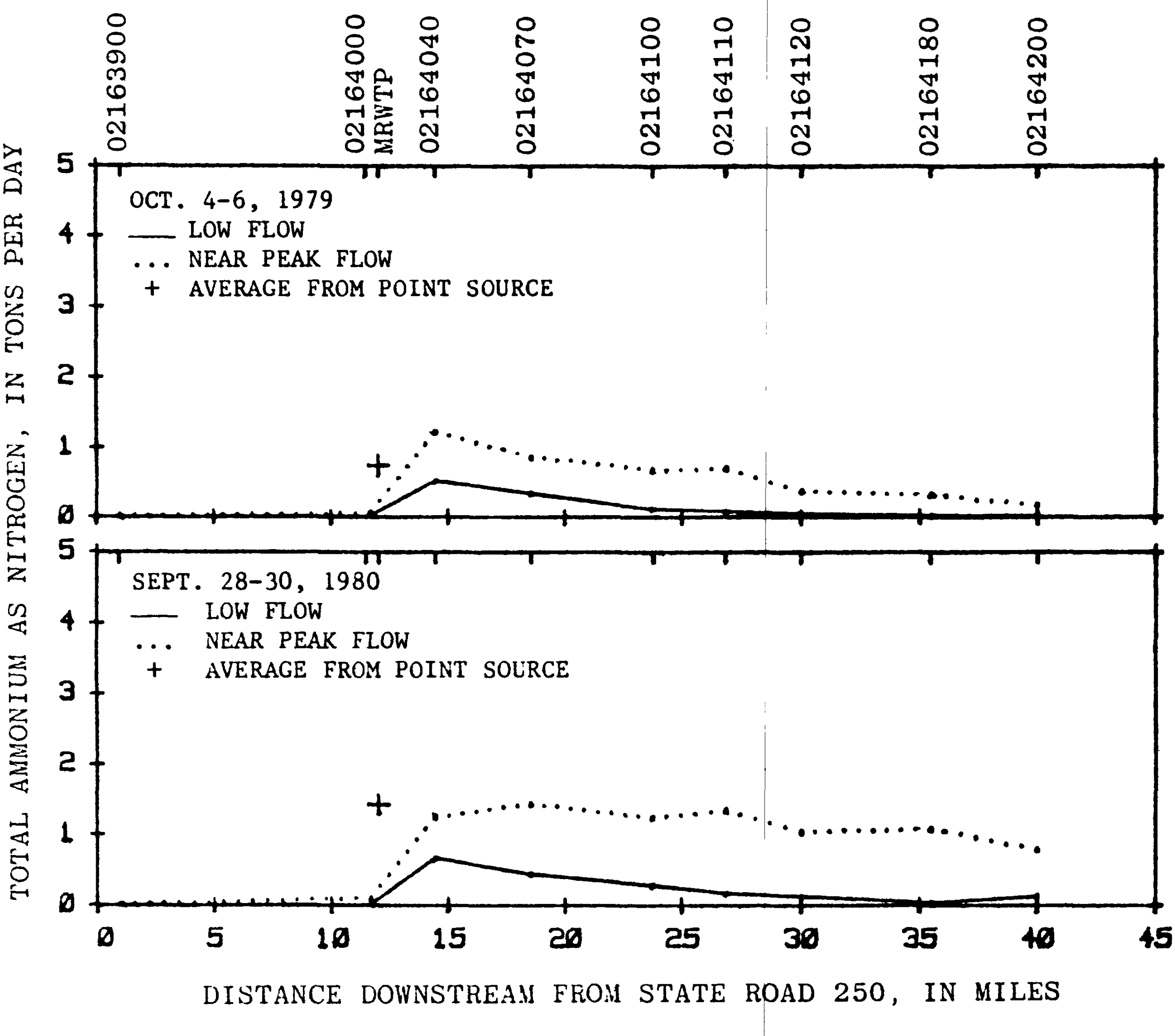

Figure 6.--Instantaneous loads of total ammonium as nitrogen during low flow and near peak flow in the Reedy River, October 4-6, 1979 and September 28-30, 1980.

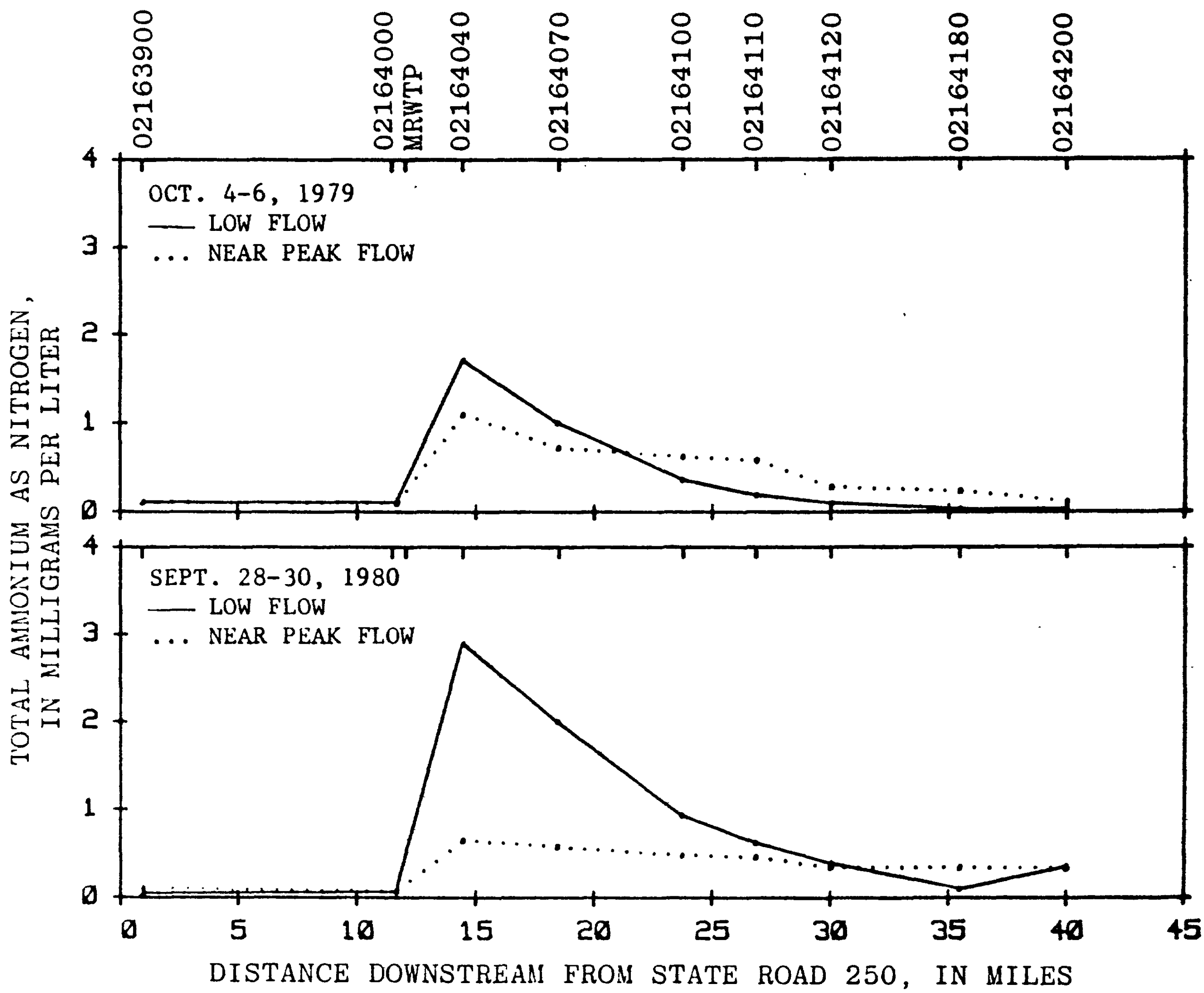

Figure 7.--Concentrations of total ammonium as nitrogen during low flow and near peak flow in the Reedy River, October 4-6, 1979 and September 28-30, 1980.

Profiles of instantaneous loads of nitrite plus nitrate during low flow indicate a greater load from the point source than from urban nonpoint sources (fig. 8). Loads of total inorganic nitrogen (ammonium, nitrite, and nitrate nitrogen) changed little downstream from the point source (fig. 9). Downstream decreases in loads of ammonium, downstream increases in loads of nitrite plus nitrate, and little change in loads of inorganic nitrogen reflect nitrification of ammonium.

Near peak flow, the instantaneous load of nitrite plus nitrate nitrogen from urban nonpoint sources was about equal to that from the point source. Near peak flow for both storms, the load of nitrite plus nitrate at the station immediately downstream from the point source was greater than the combined loads from urban nonpoint sources and the point source. This may have resulted from contributions of scour from Lake Conestee because of the greater velocities near peak flow. The nitrite and nitrate in Lake Conestee could have been derived from the decomposition and subsequent nitrification of organic nitrogen deposited in the lake during low flow. Increases in loads of inorganic nitrogen downstream from the point source (fig. 9) indicate that the continued increase in loads of nitrite and nitrate downstream from the point source was greater than can be accounted for by the nitrification of ammonium from the point source (fig. 8). Therefore, rural nonpoint sources probably contributed nitrite and nitrate nitrogen and/or ammonium nitrogen which was then nitrified.

Concentrations of nitrite plus nitrate nitrogen reflect the effects of the point source during low flow and the greater dilution of the discharge from the point source near peak flow (fig. 10). The contribution of rural nonpoint sources resulted in downstream increases in concentration, even with dilution, especially during the 1979 storm.

Ultimate Carbonaceous Biochemical Oxygen Demand

The instantaneous load of $CBOD_u$ from the point source was greater than the load from urban nonpoint sources during low flow (fig. 3). Near peak flow, the instantaneous loads of $CBOD_u$ from the point source and urban nonpoint sources were similar. However, the peak instantaneous load of $CBOD_u$ from urban nonpoint sources (more than twice that from the point source) occurred before peak discharge and resulted from an initial flush of carbonaceous materials from the urban area (fig. 3).

At near peak flow, the instantaneous load of $CBOD_u$ from urban nonpoint sources was less than the maximum load measured, but was still greater than the load from the point source (fig. 11). During low flow in September 1980 and near peak flow for both storms, the load of $CBOD_u$ at the station immediately downstream from the point source was less than combined loads from the point source and urban nonpoint sources. This may have resulted from deposition of carbonaceous materials in Lake Conestee. Such a change did not occur during low flow in October 1979. Near peak flow for the October 1979 storm, loads of $CBOD_u$ decreased downstream from the point source, possibly as a result of decomposition of carbonaceous materials. During the September 1980 storm, instantaneous loads of $CBOD_u$ were similar throughout the lower part of

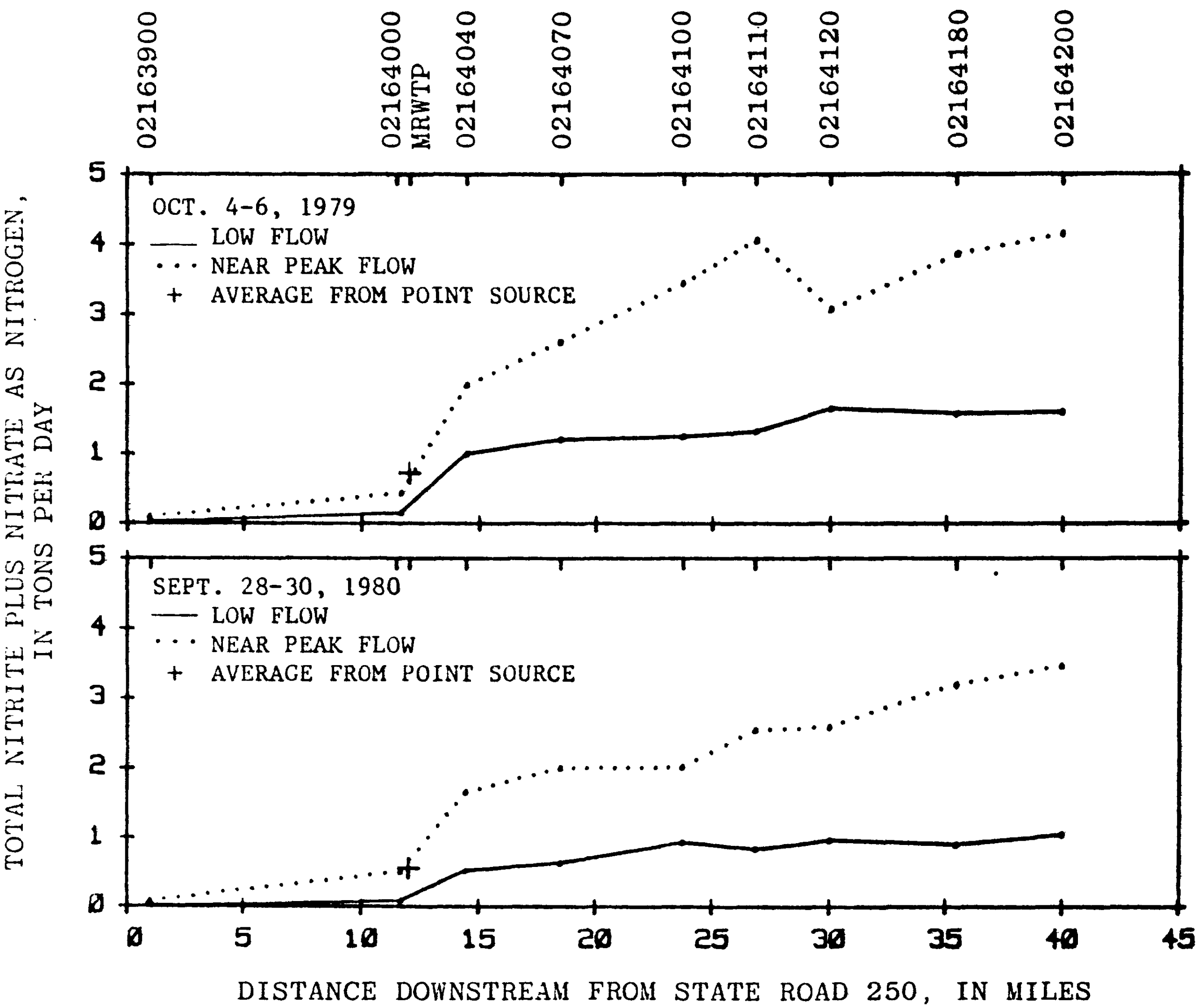

Figure 8.--Instantaneous load of total nitrite as nitrogen plus nitrate as nitrogen, during low flow and near peak flow in the Reedy River, October 4-6, 1979 and September 28-30, 1980.

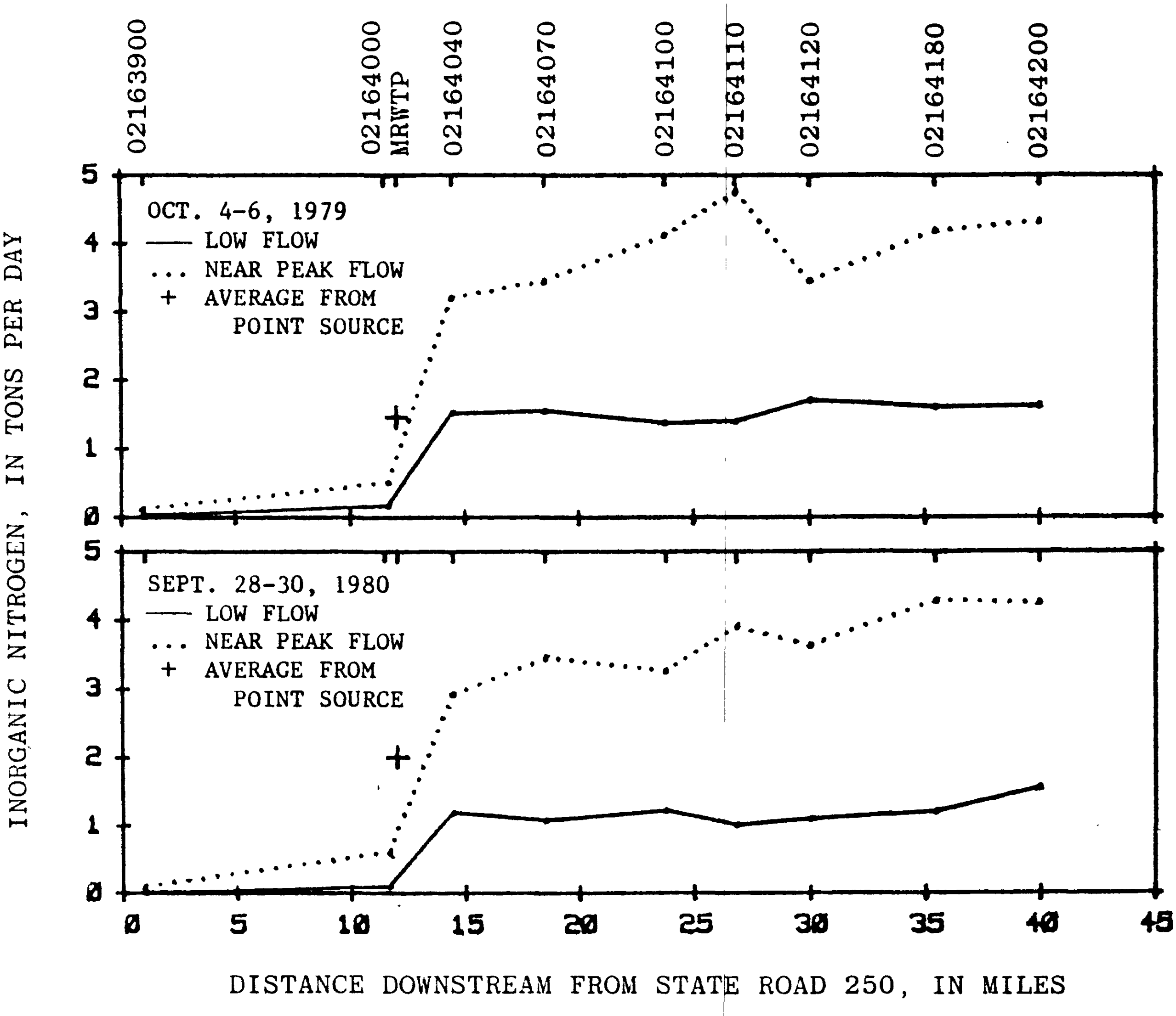

Figure 9.--Instantaneous loads of inorganic nitrogen during low flow and near peak flow, October 4-6, 1979 and September 28-30, 1980.

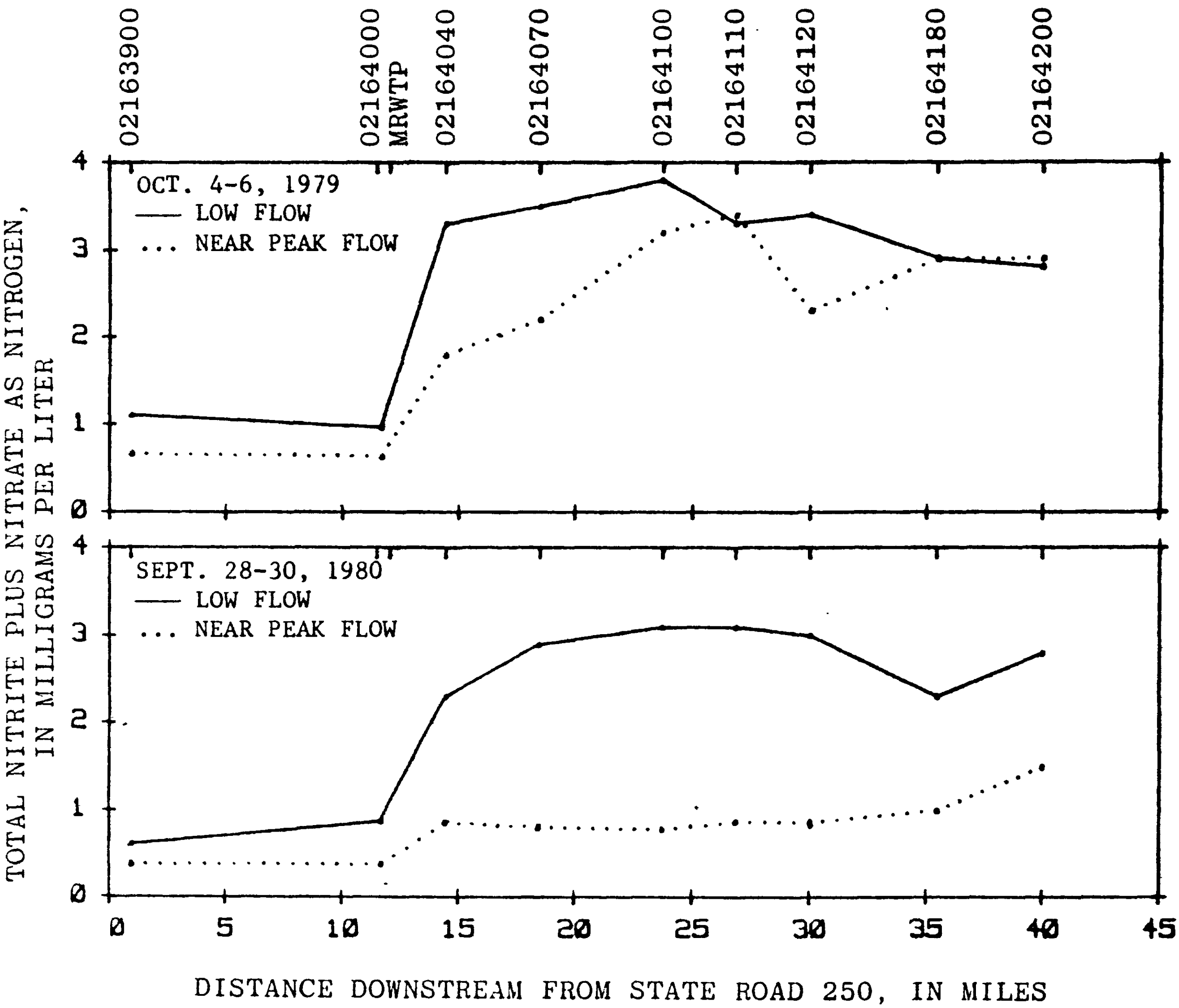

Figure 10.--Concentrations of total nitrite as nitrogen plus nitrate as nitrogen during low flow and near peak flow, October 4-6, 1979 and September 28-30, 1980.

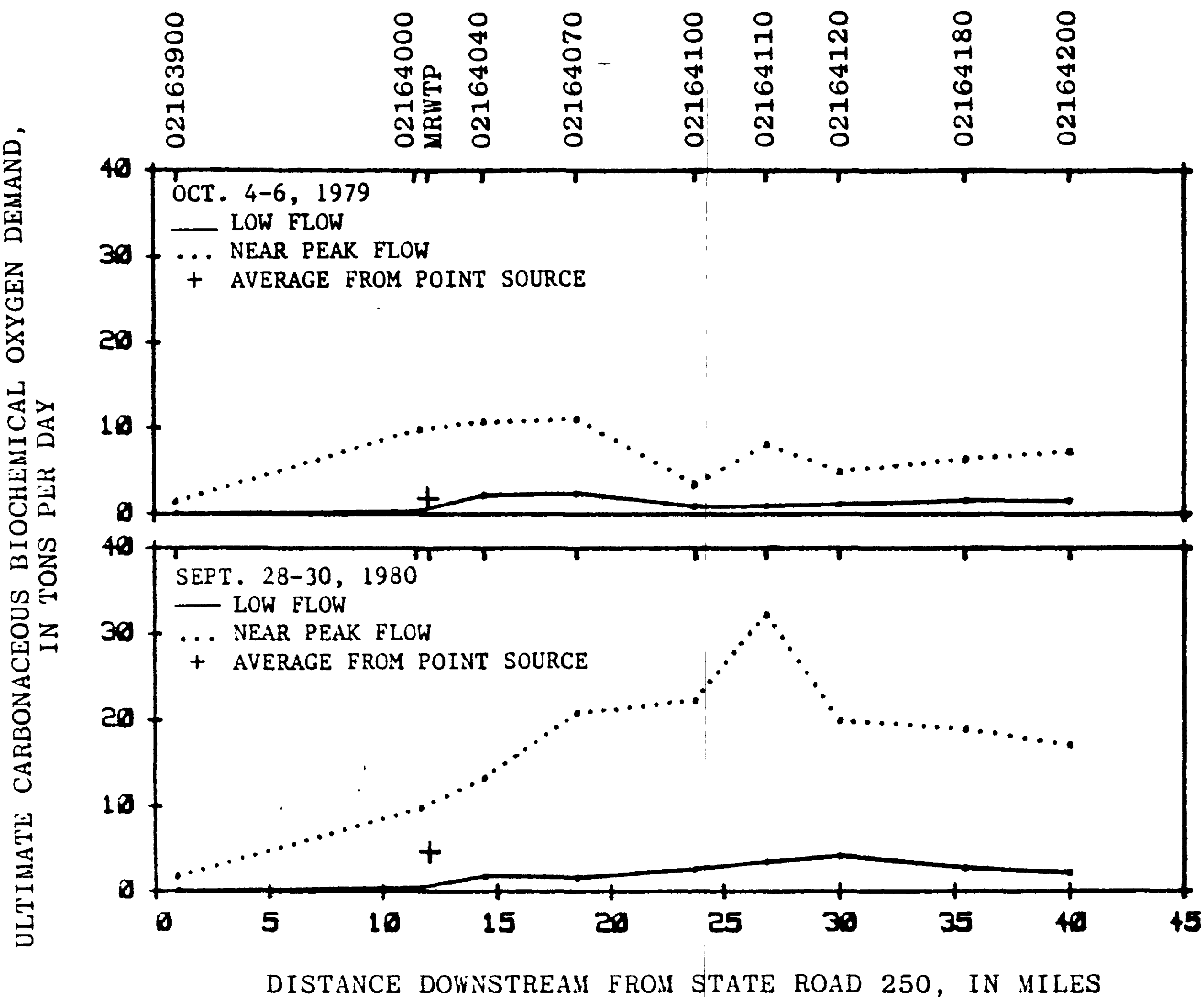

Figure 11.--Instantaneous load of ultimate carbonaceous biochemical oxygen demand during low flow and near peak flow, October 4-6, 1979 and September 28-30, 1980.

the study area except for the sharp increase at station 02164110. Although the load profiles are somewhat different near peak flow for both storms, a significant portion of the $CBOD_u$ near peak flow resulted from nonpoint sources.

Concentration profiles show considerable variability (fig. 12). The October 1979 concentrations appear to reflect decomposition of carbonaceous material downstream from the point source. However, during September 1980 concentrations increased downstream.

Dissolved Oxygen

The instantaneous load of dissolved oxygen is of questionable significance because of the more varied sources and sinks for dissolved oxygen compared with other constituents. However, the concentration of dissolved oxygen is of critical importance to biological processes in the river. This importance is reflected in stream water-quality standards established for dissolved oxygen.

When discharge from nonpoint sources is high, oxygen-demanding materials from the urban Greenville area enter the Reedy River just upstream of the point source. The minimum concentration of dissolved oxygen resulting from these materials is likely to occur downstream from the point source. The oxygen sag resulting from nonpoint sources is therefore superimposed on the sag resulting from the point source, and concentrations of dissolved oxygen observed in the stream are a composite of all factors affecting the oxygen. Attributing changes in concentrations of dissolved oxygen to point and nonpoint sources can best be done by evaluating loads of oxygen-demanding materials from point and nonpoint sources and concentrations of oxygen during low-flow periods.

During low flow prior to both storms, concentrations of dissolved oxygen decreased as a result of discharge from the point source (fig. 13). The lower concentrations of dissolved oxygen that occurred downstream from the point source were probably the result of decomposition of carbonaceous organic material and nitrification.

Near peak flow for the October 1979 storm, concentrations of dissolved oxygen also decreased downstream from the point source. However, the minimum concentration of dissolved oxygen occurred farther downstream near peak flow than during low flow, probably as a result of the increased velocities that accompany the higher discharges. Concentrations of ammonium and $CBOD_u$ remained high farther downstream during this storm (figs. 7 and 12).

From the profiles of concentrations and instantaneous loads of $CBOD_u$ (figs. 11 and 12) it appears that a significant portion of the decrease in concentrations of dissolved oxygen resulted from nonpoint contributions of carbonaceous oxygen-demanding materials from the urban area.

Near peak flow for the September 1980 storm, concentrations of dissolved oxygen remained high throughout the study area. Concentrations of dissolved

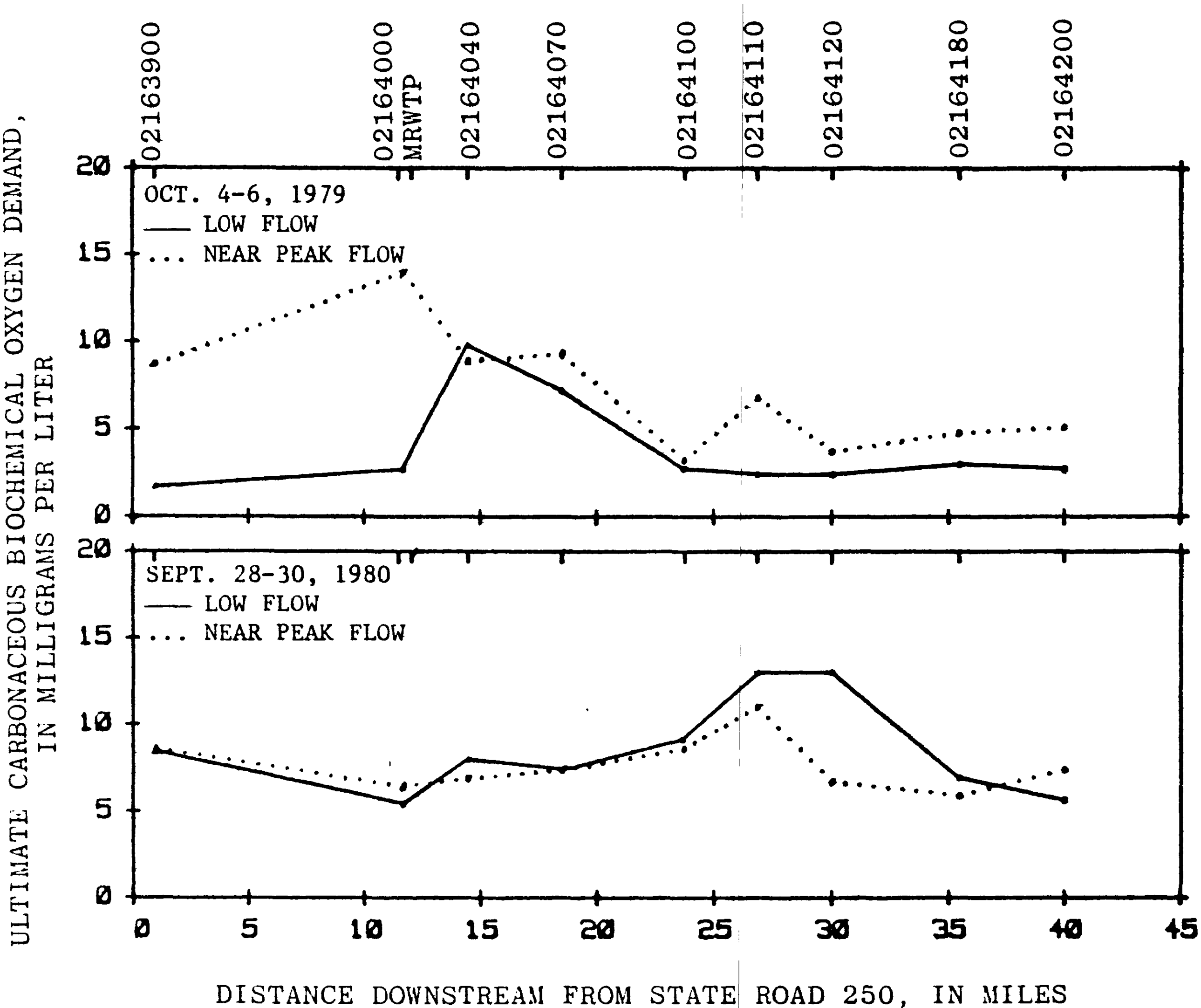

Figure 12.--Concentrations of ultimate carbonaceous biochemical oxygen demand during low flow and near peak flow in the Reedy River, October 4-6, 1979 and September 28-30, 1980.

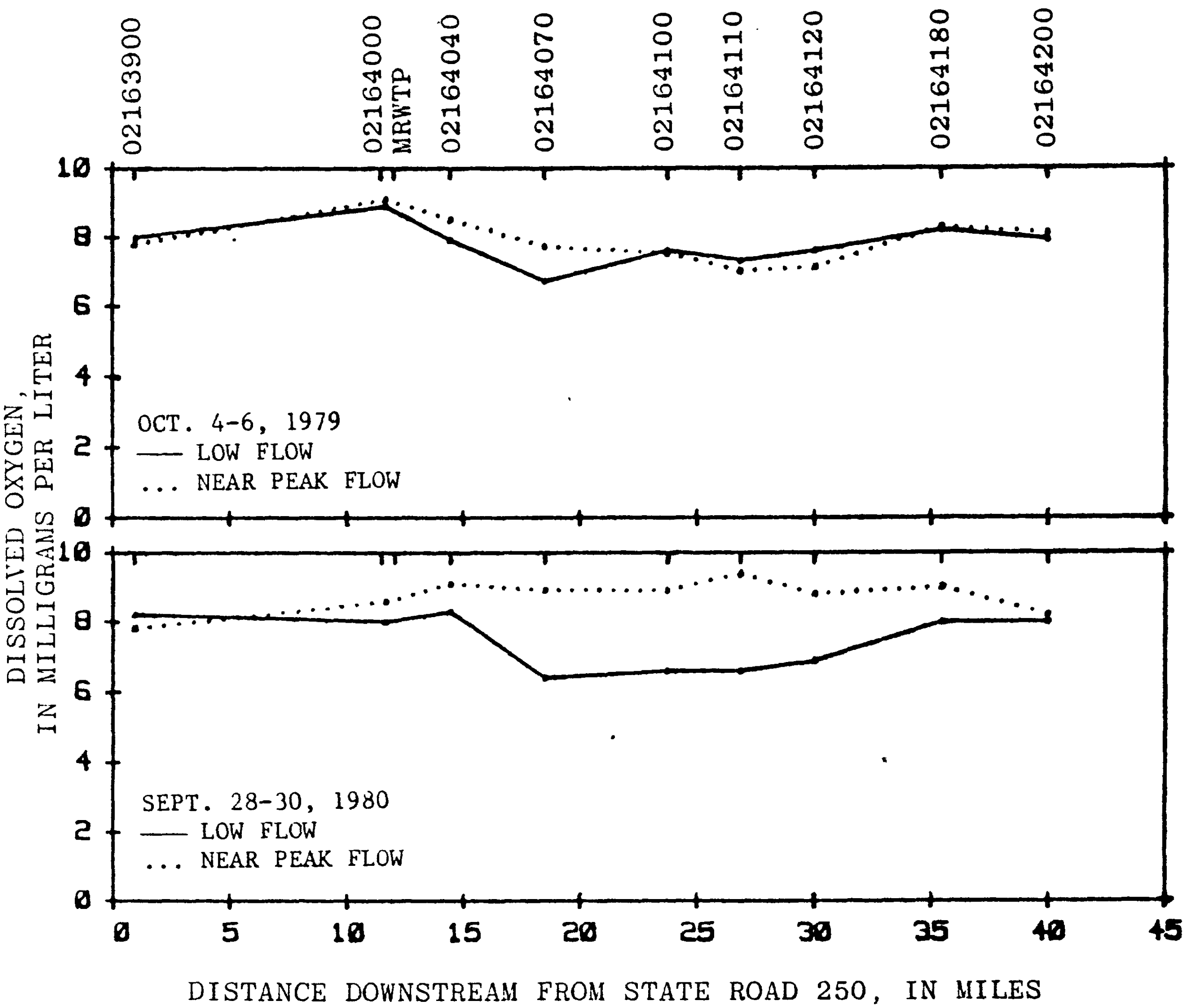

Figure 13.--Concentrations of dissolved oxygen during low flow and near peak flow in the Reedy River, October 4-6, 1979 and September 28-30, 1980.

oxygen were considerably higher near peak flow than during low flow throughout the study reach.

Although the characteristics of the profiles of concentrations of dissolved oxygen differed between the two storms, the concentrations of dissolved oxygen remained above 5 mg/L, even with the combined effects of the point and nonpoint sources.

Streamflow and concentrations of dissolved oxygen at three stations for the period May to October 1980 are presented in figures 14, 15, and 16. Concentrations of dissolved oxygen have a similar trend at the station upstream of the point source (02164000), the station in the vicinity of the lowest concentrations of dissolved oxygen (02164110), and the station at the downstream end of the study reach (02164200).

In general, concentrations of dissolved oxygen were greater during periods of high flow than during low flow. This may have occurred for several reasons. There may have been an increased dilution of the discharge from the point source by the greater discharge from nonpoint sources. During high flow, temperatures were often lower and saturation concentrations of dissolved oxygen higher.

The nature of the nonpoint source may also have affected concentrations of dissolved oxygen. During increased streamflow, surface runoff from rainfall contributes increased portions of the discharge from nonpoint sources. Concentrations of dissolved oxygen in rainfall are near saturation. During low flow, ground-water discharge contributes an increased portion of the discharge from nonpoint sources. Because concentrations of dissolved oxygen in ground water are generally less than saturation, concentrations of dissolved oxygen in headwater streams may be low during low flow. Although discharges from ground water occur all along a stream, aeration of water undersaturated with dissolved oxygen results in downstream increases in concentrations of dissolved oxygen.

During low flow prior to both storms, concentrations of dissolved oxygen increased between station 02163900, upstream of Greenville, and station 02164000 at Greenville. These increases may have resulted from aeration of water contributed by ground-water sources having undersaturated concentrations of dissolved oxygen.

The only daily average concentrations of dissolved oxygen less than 5 mg/L were observed at station 02164110 located at the point in the river where the minimum concentration of dissolved oxygen occurs. These concentrations occurred during periods of low flow when the point source contributed 30 percent or more of the streamflow of the Reedy River. Daily average concentrations less than 5 mg/L were observed during 34 days in the summer of 1980.

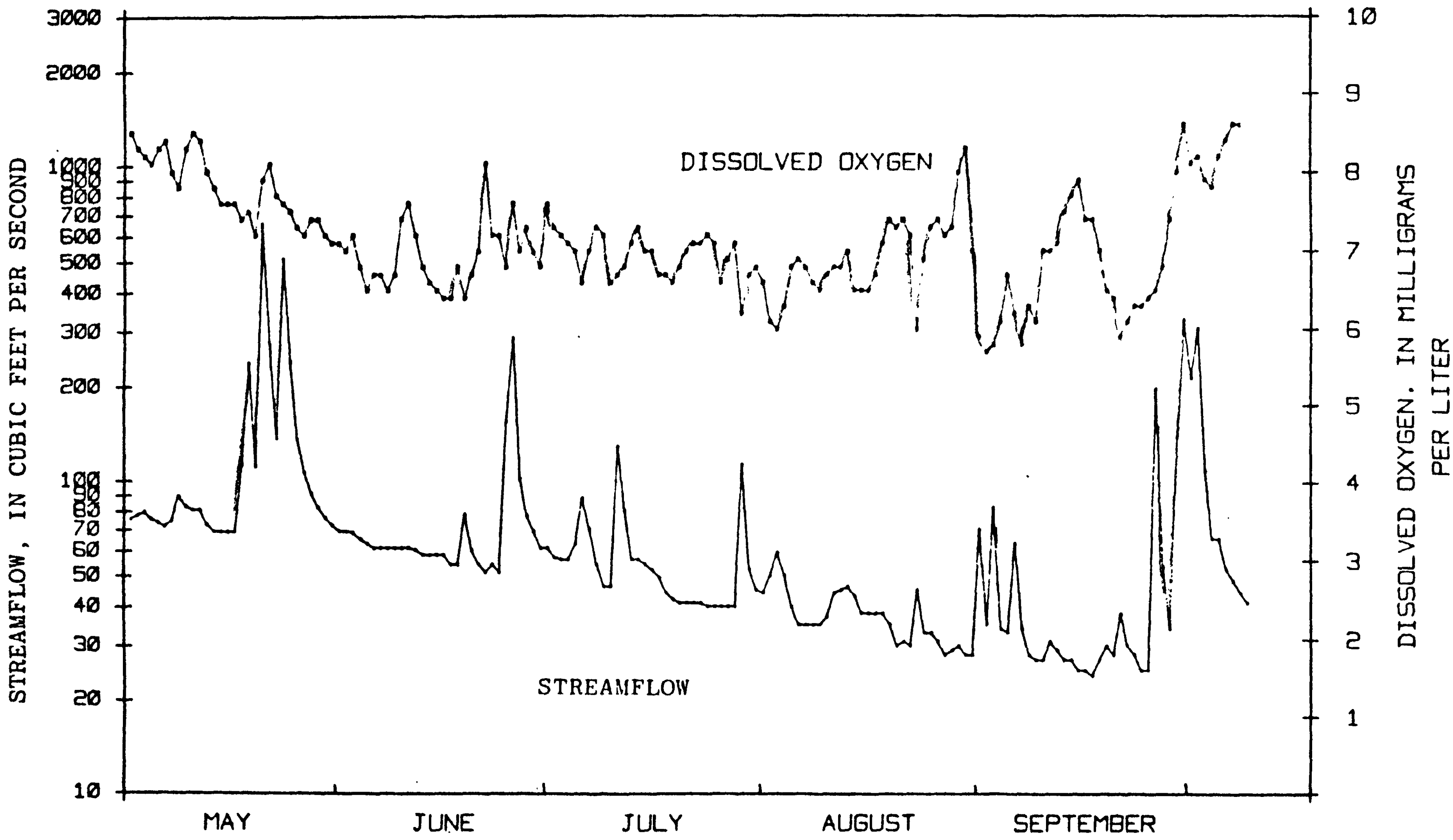

Figure 14.--Average daily concentrations of dissolved oxygen and streamflow for station 02164000 for the period May to October 1980.

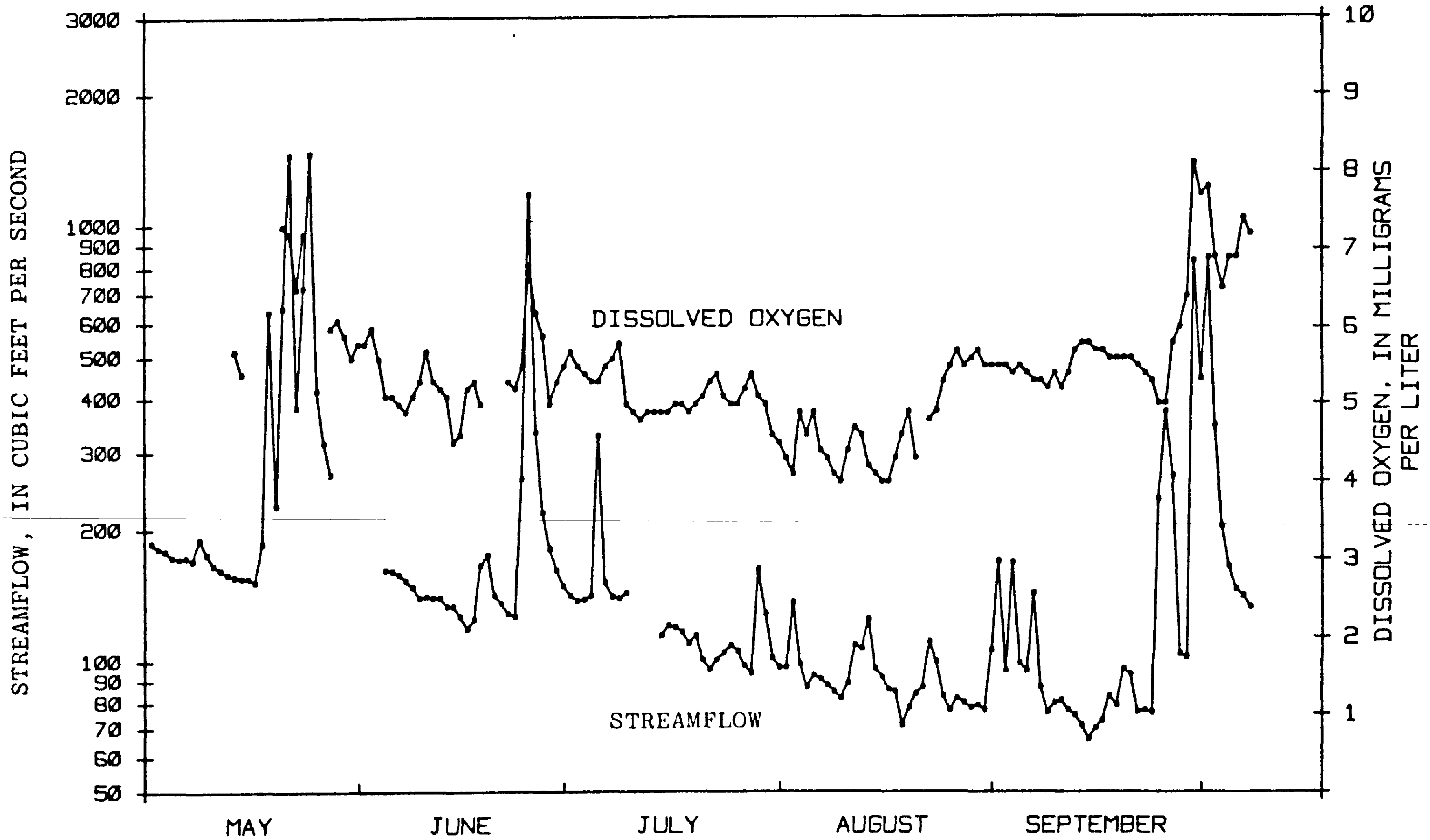

Figure 15.--Average daily concentrations of dissolved oxygen and streamflow for station 02164110 for the period May to October 1980.

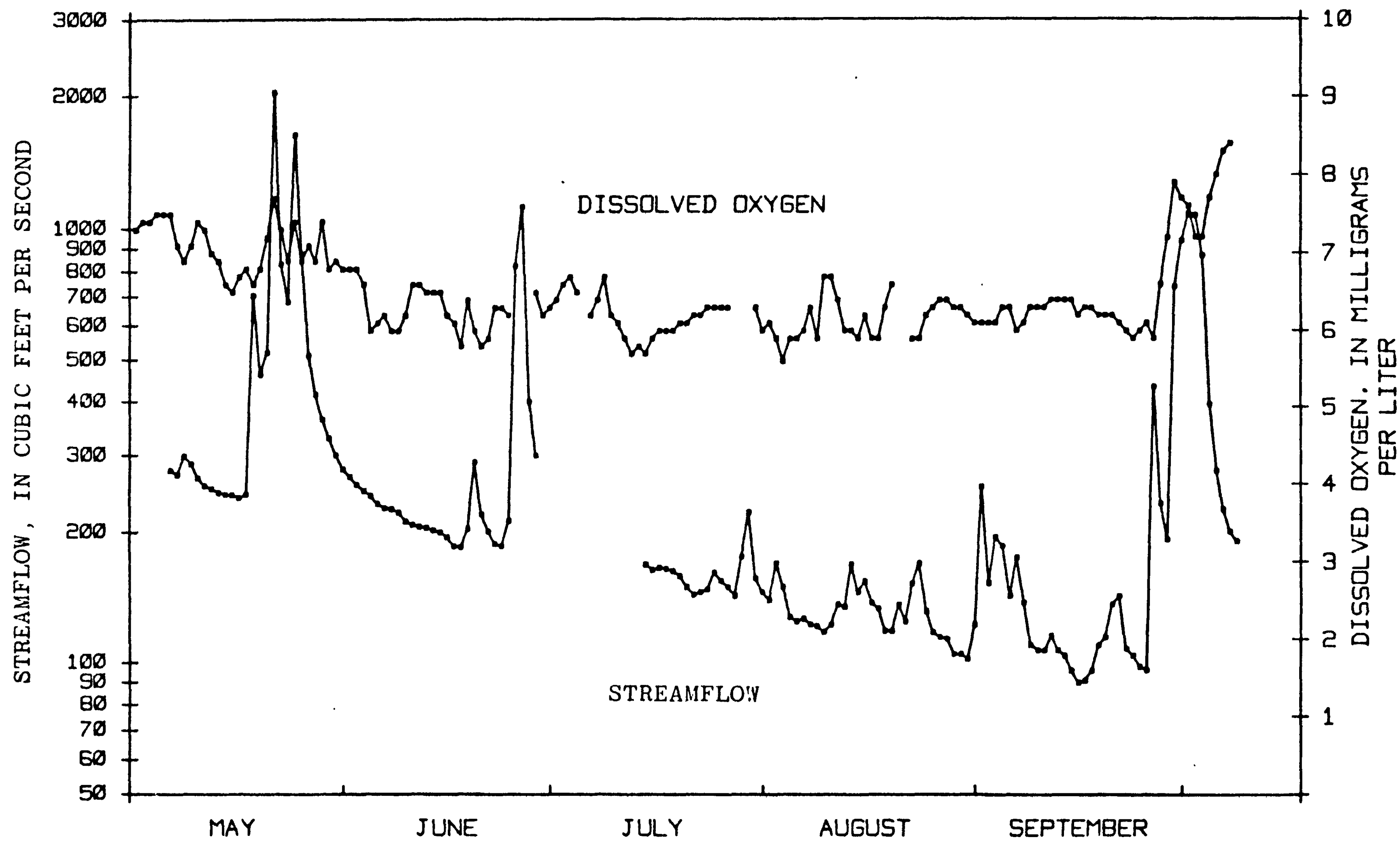

Figure 16.--Average daily concentrations of dissolved oxygen and streamflow for station 02164200 for the period May to October 1980.

Orthophosphate

The instantaneous load of dissolved orthophosphate from the point source was much greater than that from urban nonpoint sources throughout both storms (fig. 3). The effect of the point source on instantaneous loads of orthophosphate in the river is shown in the load profiles for both periods (fig. 17). During low flow, a substantial increase in load resulted from the point source. Loads decreased downstream from the point source, indicating a loss of dissolved orthophosphate from the system.

Near peak flow for both storms, the load of orthophosphate from urban nonpoint sources was small, but the point source caused an increased load at the station immediately downstream from the point source. Downstream from that station, rural nonpoint sources caused a gradual increase in loads. This increase in loads of orthophosphate near peak flow compared to loads during low flow was greater for the October 1979 storm than the September 1980 storm.

Throughout the study area concentrations of orthophosphate near peak flow were less than concentrations during low flow for the September 1980 storm (fig. 18). This resulted from increased dilution of the orthophosphate from the point source by discharge from urban nonpoint sources. During the October 1979 storm, effects of dilution of the orthophosphate from the point source were evident in the upstream part of the river affected by the point source, but were offset by increases in discharge from rural nonpoint sources in the downstream portion of the river.

pH

The pH of the Reedy River was near 7.0 during both storms (fig. 19). Near peak flow, pH was less than the pH during low flow at all stations during the September 1980 storm. During the October 1979 storm, pH near peak flow was less than or equal to the pH during low flow.

SUMMARY AND CONCLUSIONS

Concentrations of dissolved oxygen in the Reedy River remained above 5 mg/L during the storms. Even though combined loads of oxygen-demanding materials from point and nonpoint sources increased during the storms, dilution of these loads caused concentrations of dissolved oxygen to remain above 5 mg/L.

In the summer of 1980, daily average concentrations of dissolved oxygen in the Reedy River were less than 5 mg/L during 34 days. These low concentrations of dissolved oxygen occurred during periods of low flow and resulted from loads of oxygen-demanding materials, especially ammonium, in the discharge from the point source, the Mauldin Road Wastewater Treatment Plant.

Discharge from the point source is equal to or greater than streamflow of the Reedy River near Greenville (station 02164000) about 25 percent of the

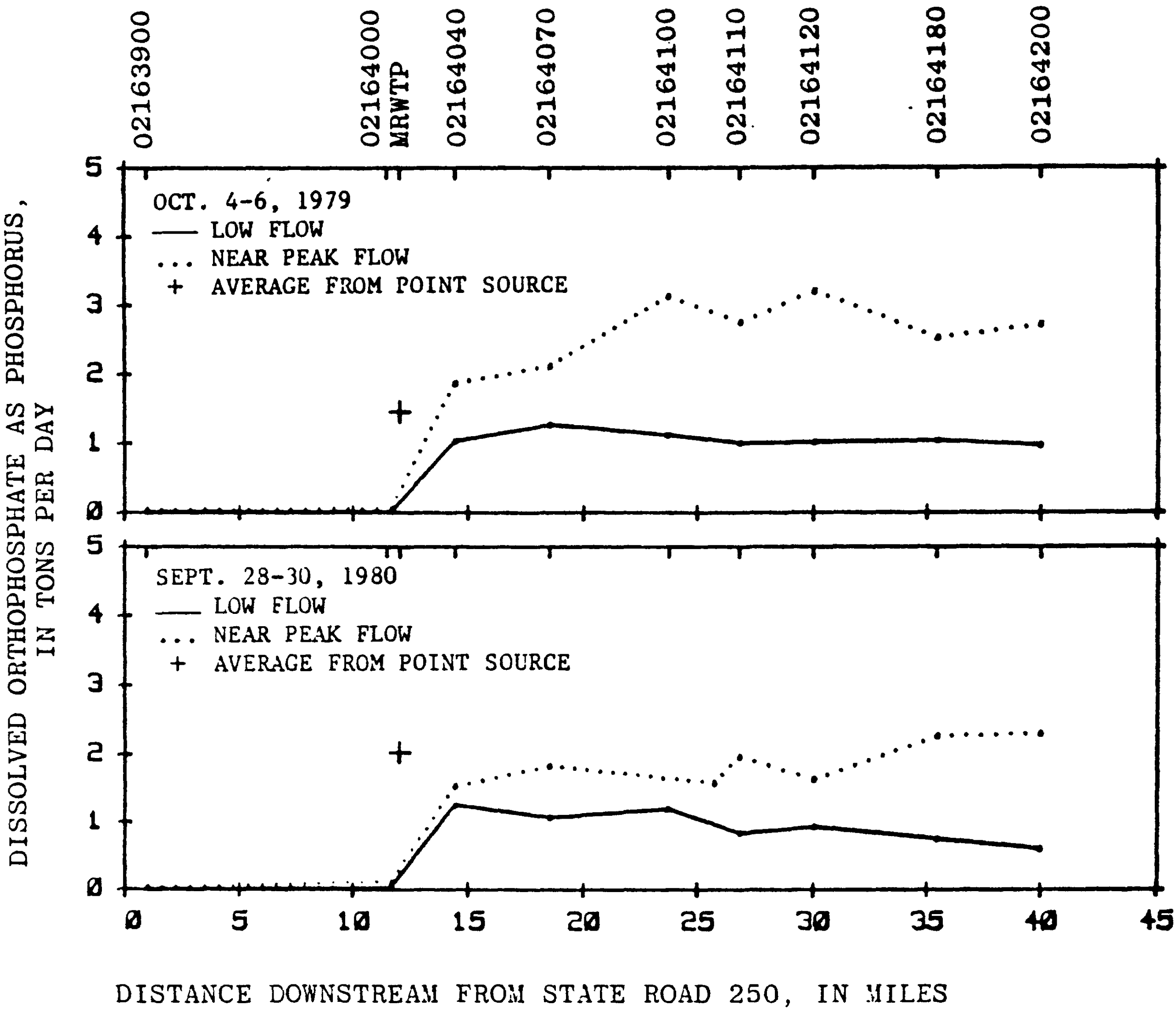

Figure 17.--Instantaneous load of dissolved orthophosphate as phosphorus, during low flow and near peak flow in the Reedy River, October 4-6, 1979 and September 28-30, 1980.

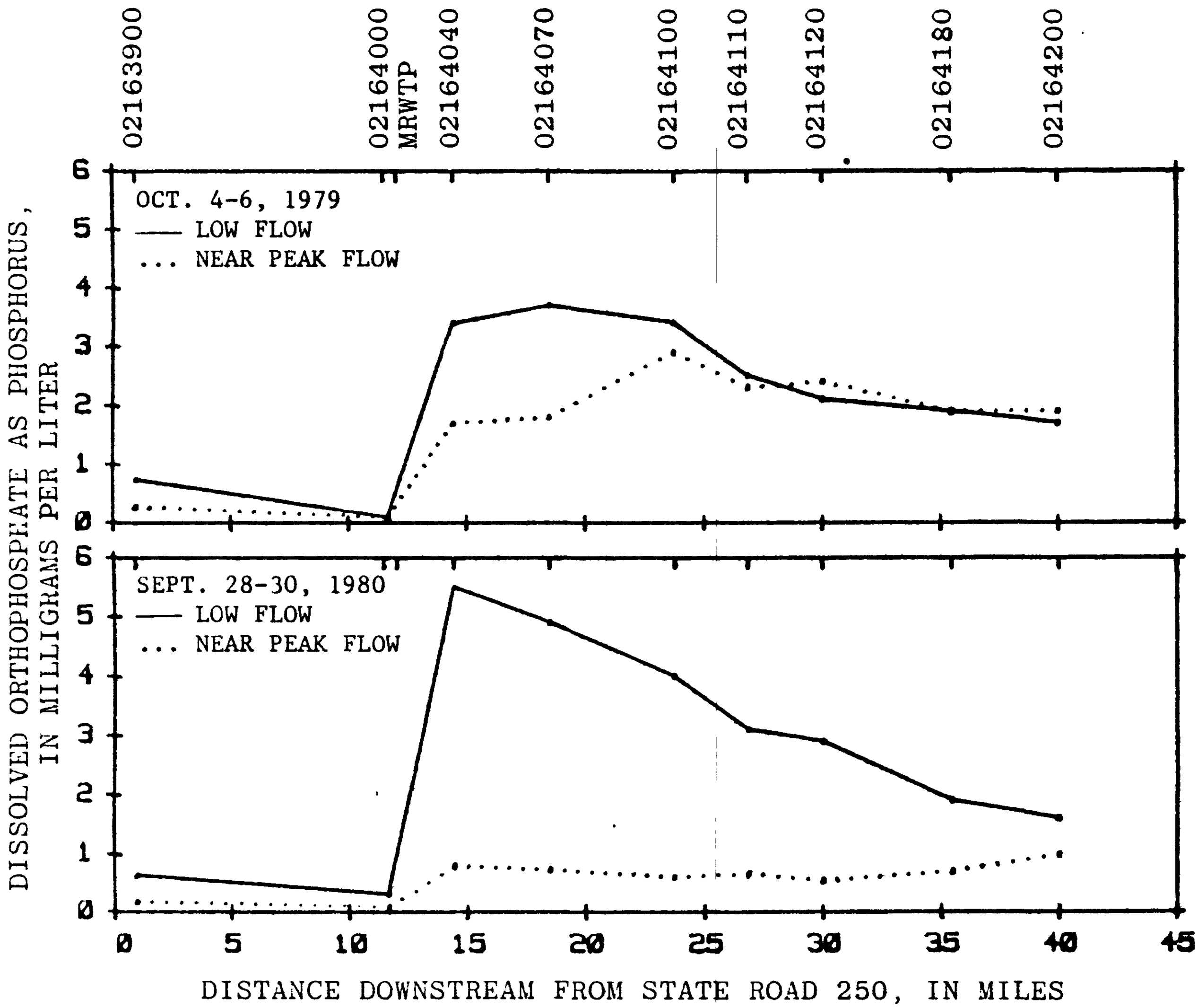

Figure 18.--Concentrations of dissolved orthophosphate as phosphorus during low flow and near peak flow, October 4-6, 1979 and September 28-30, 1980.

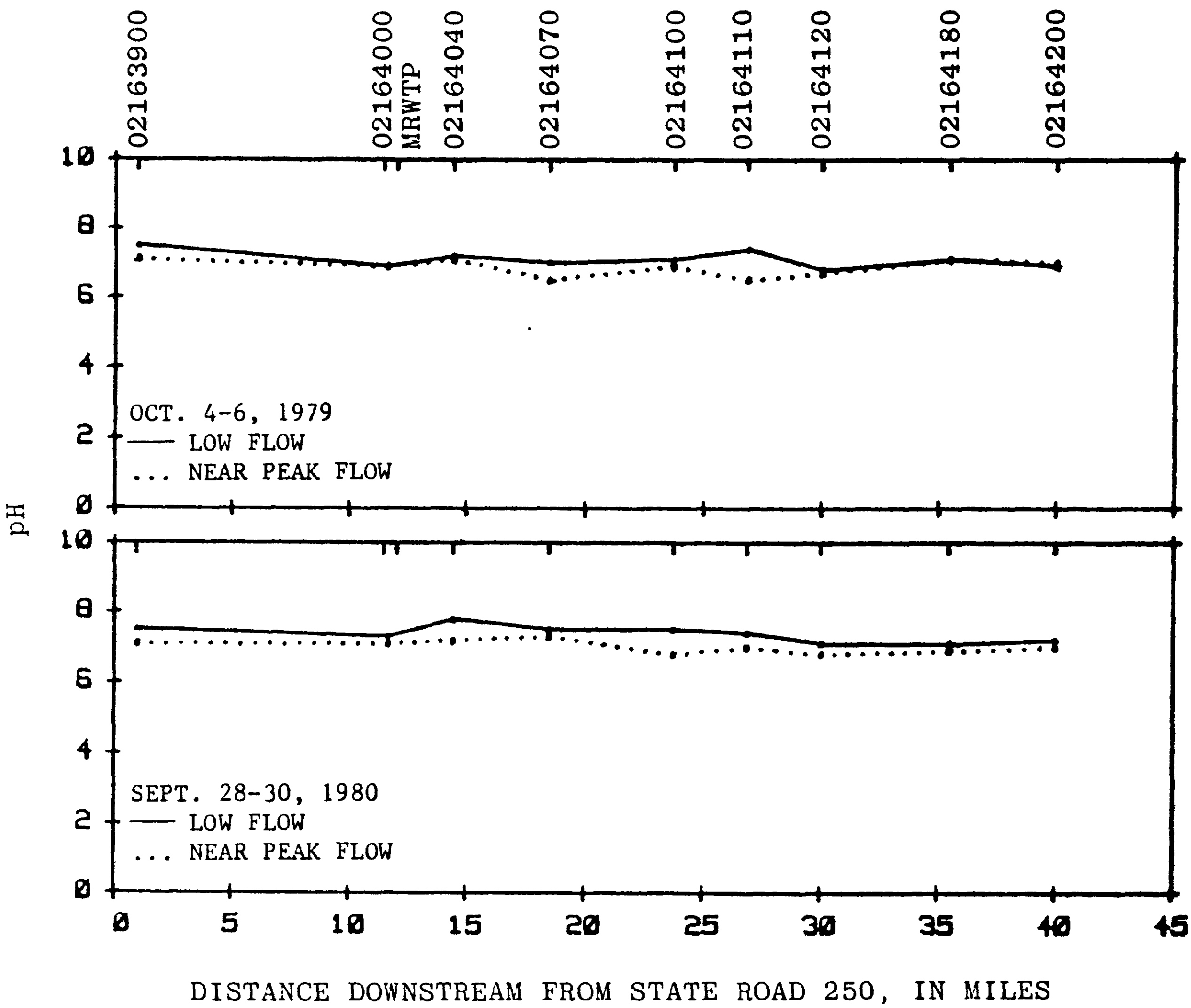

Figure 19.--Profiles of pH during low flow and near peak flow in the Reedy River, October 4-6, 1979 and September 28-30, 1980.

time. Low concentrations of dissolved oxygen occur frequently in the Reedy River because loads of constituents in the discharge from the point source are diluted less during lower streamflow than during higher streamflow. Because streamflow increases downstream, dilution of loads from the point source increases downstream.

Discharge from the point source contributed significant instantaneous loads of organic nitrogen, ammonium, nitrite plus nitrate, $CBOD_u$, and orthophosphate. During low flow, the load of total organic nitrogen at the station just downstream from the discharge from the point source was less than the load from the point source.

Discharge from nonpoint sources in the urban Greenville area had a much greater impact on water quality of the Reedy River near peak flow than during low flow. Discharge from these sources from the urban area contributed significant instantaneous loads of $CBOD_u$, organic nitrogen, and nitrite plus nitrate nitrogen near peak flow. Instantaneous loads of orthophosphate and ammonium in these discharges remained low during high flow.

During low flow, discharge from nonpoint sources in rural areas downstream from the point source had little impact on water quality of the Reedy River. Near peak flows, instantaneous loads of organic nitrogen, nitrite plus nitrate nitrogen, $CBOD_u$, and orthophosphate resulted from discharges from nonpoint sources in rural areas.

REFERENCES

Bloxham, W. M., 1979, Low-flow frequency and flow duration of South Carolina streams: South Carolina Water Resources Commission Report Number 11, 90 p.

Bryan, E. H., 1970, Quality of stormwater drainage from urban land areas in North Carolina: Water Resources Research Institute, University of North Carolina, Durham, N.C., Report No. 37, 44 p.

Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, 92nd Congress, S.2770, October 18, 1972, 89 p.

J. E. Sirrine Company, 1978, Appalachian 208 water quality study, Reedy River basin report: Sirrine Job No. S-1164.

Jennings, M. E., and Bauer, B. P., 1976, Determination of biochemical-oxygen-demand parameters: U.S. Geological Survey Computer Contribution, Program number G731.

South Carolina Department of Health and Environmental Control, 1974, Water Classification Standards System.

Skougstad, M. W., Fishman, M. S., Friedman, L. C., and Erdmann, D. E., 1978, Methods for the analysis of inorganic substances in water and fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, p. 1006.

Stamer, J. K., McKenzie, S. W., Cherry, R. N., and Scott, S. L., 1979, Methods of ultimate carbonaceous BOD determination: Journal Water Pollution Control Federation, v. 51, no. 5, p. 918-925.

U.S. Geological Survey, 1977, National Handbook of Recommended Methods for Water-Data Acquisition: Office of Water Data Coordination, Chapter 5.

Wezernak, C. T., and Gannon, J. J., 1967, Oxygen-nitrogen relationships in autotrophic nitrification: Applied Microbiology, v. 15, no. 5, p. 1211-1215.

Whipple, W., 1970, BOD mass balance and water quality standards: Water Resources Research, v. 6, no. 3, pp. 827-837.