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GEOLOGICAL SURVEY

DYE-DISPERSION STUDY AT PROPOSED PUMPED-STORAGE PROJECT ON HUDSON RIVER AT CORNWALL-ON-THE-HUDSON, NEW YORK

by Bernard Dunn and George C. Gravlee, Jr.

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FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS TO

INTERNATIONAL SYSTEM (SI) UNITS

Multiply U.S. Customary Units	By	To obtain SI units
miles (mi)	1.609	kilometers (km)
feet (ft)	.3048	meters (m)
inches (in)	2.54	millimeters (mm)
pounds (lb)	.4536	kilograms (kg)
parts per billion	--	micrograms per liter
cubic feet per second (ft^3/s)	2.832×10^{-2}	cubic meters per second (m^3/s)
degrees Fahrenheit (°F)	(°F-32) 5/9	degrees Celsius (°C)

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ABSTRACT

Data collected during a dye-dispersion study on a 6-mile, tide-affected reach of the Hudson River near the proposed Cornwall Pumped Storage Project on September 21-22, 1977 indicated that complete mixing did not occur during the first tidal cycle but was complete after two or more cycles.

The fluorometric dye-tracing procedure was used to determine the dispersion characteristics of the water mass. Rhodamine WT dye, 20-percent solution, was continuously injected on the west side of the river throughout an ebb tide, and its movement was monitored during a 30-hour period. Samples were collected both individually and continuously. Automatic dye samplers were used at selected cross sections near each bank.

Bathymetric measurements were made at eight cross sections between Newburgh and West Point to determine the depths.

INTRODUCTION

The U.S. Geological Survey made a dye-dispersion study on the Hudson River in the vicinity of the proposed Cornwall Pumped Storage Project at Cornwall-on-the-Hudson, N.Y. on September 21-22, 1977, to define the water movement in this reach of the river and to determine if the combination of freshwater inflow and tide-induced flows would cause mixing in the reach. The study was done in cooperation with the Federal Power Commission (FPC)[1/], Bureau of Power, River Basins Division. Location and major features of the study area are shown in figure 1.

On July 27, 1977, the U.S. Geological Survey discussed with the Federal Power Commission the design of the data-collection project. The reach of the river on which detailed information was needed extended 1.5 miles upstream and 1.5 miles downstream from the pumped-storage project tailrace, or from near Plum Point to near Little Stony Point. The principal question to be addressed was whether mixing of river water would occur naturally across the width of the river from tide-induced flows in both the upstream and downstream directions.

A fluorescent dye solution of rhodamine WT was injected continuously into the Hudson River estuary near the site of the proposed Cornwall Pumped Storage Project tailrace throughout an ebb flow period. Movement of the dye was monitored through an 11-mile reach of the river from Newburgh to 2.2 miles below Highland Falls during a 30-hour period.

River-stage observations were recorded at the breakwater of the Cornwall Yacht Club during the entire period. Bathymetric measurements were recorded at eight cross sections between Newburgh and West Point. All references to time in this report are referenced to a 24-hour clock on Eastern Daylight Saving Time (EDST).

Acknowledgments

The authors gratefully acknowledge the assistance rendered by the Federal Power Commission, especially by John A. Evans and Carl N. Shuster, who participated in the planning and execution of the study.

1/ The Federal Power Commission became a part of the Department of Energy (DOE) on October 1, 1977 (Public Law 95-91). The functions of the FPC in licensing of non-Federal hydroelectric projects is now handled by the Federal Energy Regulation Commission (FERC).

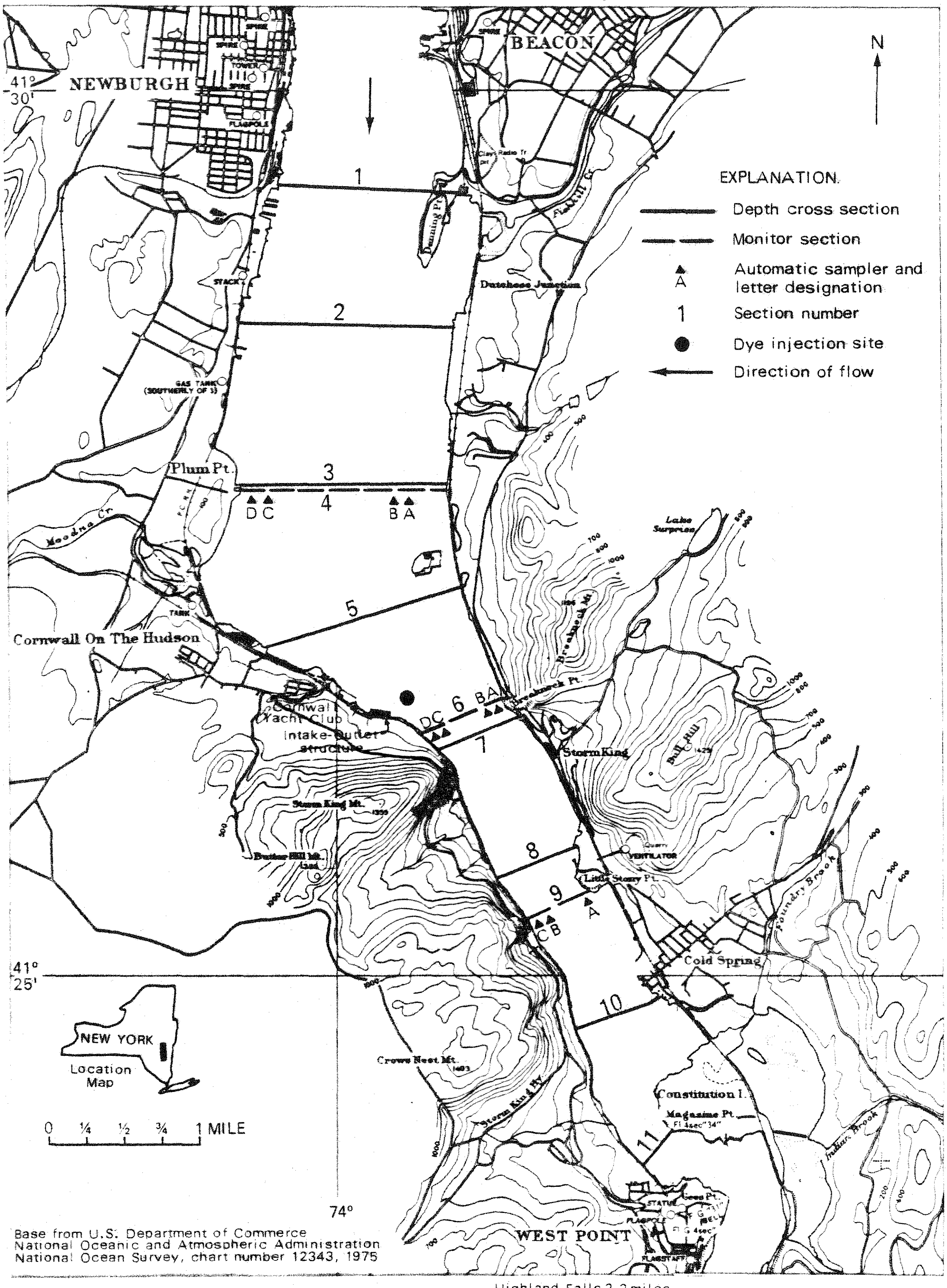

Figure 1.--Location and major features of study area.

LOCATION, DESCRIPTION, AND FLOW CONDITIONS OF STUDY REACH

The study reach embraces the site of the proposed Cornwall Pumped Storage Project near Storm King Mountain. The project site is on the west bank between Cornwall-on-the-Hudson and West Point, about 57 miles upstream from the mouth of the river at New York (fig. 1). Downstream from Cornwall-on-the-Hudson, the river narrows from a width of about 9,000 feet at the Cornwall Yacht Club to about 3,000 feet at Breakneck Point. Depth in the thalweg is less than 50 feet above the constriction but is considerably greater from the constriction south to West Point. The deepest section of the reach is between West Point and Constitution Island, where the depth is over 140 feet.

The study reach is within the Hudson River estuary, which extends 154 miles from New York City to Troy. The reach therefore experiences tide-induced variations in discharge. Monthly average discharges have been computed at Poughkeepsie (upstream from the study site) since October 1947 by adding to the measured flows of the Hudson River near Troy the measured and estimated flows from the drainage areas between Troy and Poughkeepsie. The average annual discharge at Poughkeepsie for the water years 1947 to 1965 was 17,700 ft^3/s (Giese and Barr, 1967), and the average discharge for September 1977 was estimated as 17,400 ft^3/s. At the gaging station near Troy (Hudson River at Green Island), the average discharge for water years 1947 to 1976 was 13,580 ft^3/s, and the average discharge for September 1977 was 14,400 ft^3/s. Discharge at Green Island during September 1977 ranged from 3,220 ft^3/s on September 12 to 43,400 ft^3/s on September 21.

Plan of Study

The study plan, designed by the U.S. Geological Survey and the Federal Energy Regulatory Commission (formerly FPC) on July 27, 1977, was as follows:

1. Rhodamine WT dye would be injected into the river during an ebb-flow period at a point 200 to 500 feet offshore (fig. 1) at a depth and location near the center of the proposed outflow from the proposed pumped-storage plant. The dye would be released continuously for about a 6-hour period from flood slack water to ebb slack water.

2. The dye cloud in the river would be monitored during the next two tidal cycles to determine its movement and the extent of its dispersion throughout the reach. Sampling was to be done at a series of fixed monitoring stations at river cross sections 4, 6, and 9 (fig. 1), both upstream and downstream from the dye-injection point. In addition to the fixed monitors, two boats equipped with dye-sensing devices would operate continuously in the reach to track the dye clouds' position and the extent of vertical and horizontal dispersion (vertically below the surface and horizontally across the river).

During the first 6 hours, one crew would monitor dye concentrations at section 9, and one crew would determine how far downstream the dye had traveled. During the second 6 hours, one crew would monitor dye concentration at sections 4, 6, and 9 while the other crew would define the upstream movement of the dye cloud. After the first 12 hours, the data-collection program would be redesigned on the basis of field observations.

3. Bathymetryic data were to be collected with a fathometer at cross sections 1-3, 5, 7, 8, 10, and 11. (These observations were not critical to the dye study and no effort would be made to reference them to mean sea level.) Traversing the sections at a uniform velocity between physical features identifiable on a topographic map would provide adequate longitudinal and transverse control for the location being surveyed.

Equipment and Methods

Fluorometric Technique

The fluorometric dye-tracing procedure has been used for many years by the U.S. Geological Survey to determine the dispersion characteristics of water bodies. One advantage of this method is that the dye injected into the water behaves almost in the same manner as the water particles themselves.

In the past, floats, chemical salts, and radioisotopes have been used for water tracing. Radioisotopes, which proved to be the most effective and have greater versatility than floats or chemical salts, have been used by the Geological Survey only occasionally because of the safety precautions necessary, the special training required for their use, and a general fear by the public of radioactive substances. These limitations on the use of radioisotopes led to a search for a suitable substitute, and fluorescent dyes were found to be acceptable (Wilson, 1968).

The most common fluorescent dye now in use for water tracing is a 20-percent solution of rhodamine WT[1]. This dye has the essential properties for water tracing--it is water soluble, highly detectable, harmless in low concentrations, inexpensive, and reasonably stable in a normal stream environment. When a sample containing this dye is illuminated by an external light source, it emits radiation (light) that can be detected by a fluorometer.

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[1] Product of E. I. Du Pont de Nemours Co., Wilmington, Del. Use of brand names throughout this report is for identification only and does not imply endorsement by the U.S. Geological Survey.

A fluorometer gives a relative measure of the intensity of light emitted by the fluorescent substance in a sample. The fluorometer reading by itself has restricted meaning until it is compared with readings from samples of known concentrations or standards. All fluorometers used in this study were calibrated to standard samples before and after the test.

Fluorescence tracing can be done by collecting individual (or grab) samples at selected points or by continuous sampling. With the continuous-sampling technique, water is drawn through the fluorometer, and dial readings are recorded either manually or on an attached recorder. Also, grab samples from the discharge hose are taken periodically and tested in the laboratory under controlled conditions to verify the calibration of the instrument.

When the fluorometer is used under field conditions, a constant-voltage transformer is placed between the gasoline-driven generator and the fluorometer to reduce variations in electrical voltage that might affect flourometer readings. A schematic diagram of the system is presented in figure 2.

Accuracy of Fluorometer.--Turner Model III fluorometers were used for all fluorometric measurements in this study. The fluorometers used for laboratory analyses were equipped with a high-sensitivity conversion kit that enables a sixfold to tenfold increase in sensitivity above normal operating conditions. Under ideal conditions, these fluorometers can determine concentrations as low as 0.001 ppb (parts per billion) of dye. Because of variations in natural background readings and variations in instrument performance observed during calibration tests, the dye concentrations reported herein are considered valid within ±0.02 ppb. All fluorometers used in the laboratory and field to analyze samples were calibrated before and after the study from standards prepared with Hudson River estuary water obtained at the project site prior to the study. All calibration and study samples were analyzed at a laboratory temperature of 23°C.

Automatic samplers.--Automatic dye samplers were anchored at 11 locations in the study reach before or during the test and collected samples at approximately 25-minute intervals. Each sampler contains 24 spring-loaded syringes in a rectangular, metal box. The sampler unit is placed in a fiberglass float for bouyancy (fig. 3). Inside the sampler, a waterproofed, battery-operated motor drives a tripping mechanism that releases the syringes in sequence at predetermined intervals so that they fill with water. The intake nozzle of each syringe is about 2 inches below water surface. The samplers, which can run unattended for approximately 12 hours at the sampling rate used, were serviced on the average of once every 6 hours during the test.

Other equipment.--Bathymetric (depth) measurements were recorded with a Raytheon DE 119-D portable fathometer, which has a range of 0 to 240 feet. Recorded depths were verified at several points, and no instrument error was observed.

A vertical staff gage was temporarily installed on a piling near the breakwater of the Cornwall Yacht Club and was read several times an hour throughout the test. The variations in water level are shown in figure 4.

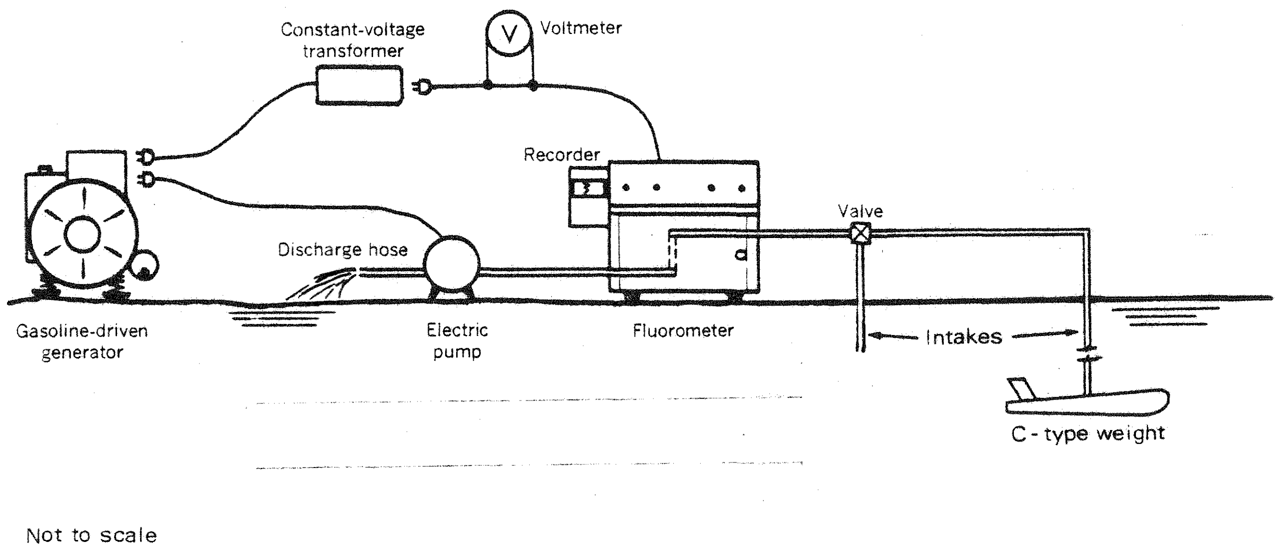


Figure 2.--Schematic diagram of continuous-sampling system.

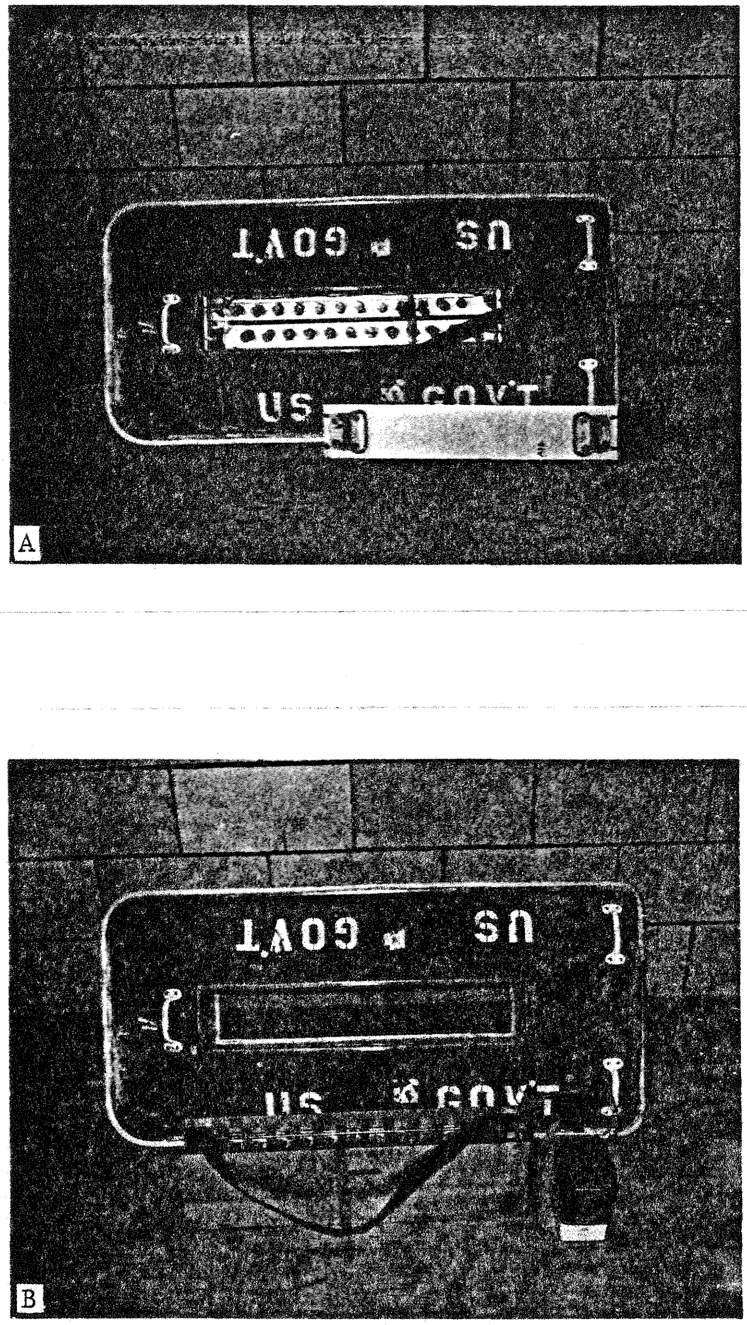


Figure 3.--Automatic dye sampler and fiberglass float:

A. Float with automatic dye sampler installed.

B. Float with automatic dye sampler removed.

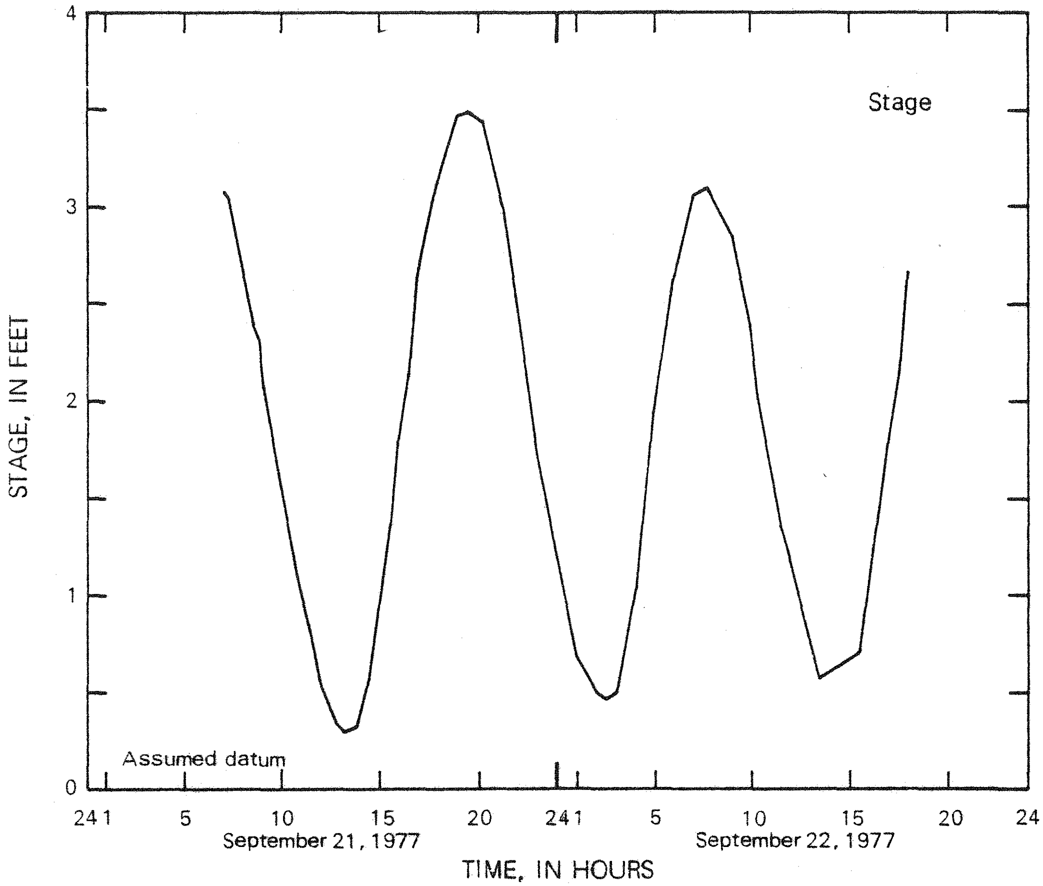


Figure 4.--River stage, Hudson River at Cornwall Yacht Club, Cornwall-on-the-Hudson, N.Y., September 21-22, 1977.

DYE-DISPERSION STUDY

The dye-dispersion study was scheduled to start on the morning of September 20, 1977. However, rain, fog, and strong southerly winds, which caused high waves on the river, forced the postponement of dye injection until the following day.

Natural background fluorescence is detectable in most waters. It is generally caused either by natural materials, pollutants, or a combination of these. Samples of river water were collected with floating automatic dye samples from about 0900 to 1600 hours on September 20, 1977 to determine background fluorescence. The samplers were positioned near the west banks of cross sections 6 and 9; the observed variation in background fluorescence is shown in figures 5B and 6C. At section 4, no background-fluorescence samples were obtained. (See fig. 7.)

On September 21, eleven automatic samplers were placed in operation-- two near each bank of cross sections 4 and 6, two near the west bank of cross section 9, and one near the east bank at cross section 9. (See fig. 1.) The general locations of the monitoring cross sections were selected in cooperation with FPC representatives.

Dye injection was started from a boat about 500 feet from the west shore off the north side of the base of Storm King Mountain at 0845 hours, at slack water before an ebb tide. (See fig. 1). The dye was injected 10 feet below water surface, which was considered the centroid of the expected outflow of the proposed pumped-storage project. The slack-water time was obtained from the National Oceanic and Atmospheric Administration. The dye, a 20-percent solution of rhodamine WT, was pumped into the river with a Horizon Ecology Co. Model 7570 portable sampling pump.

At 1335 hours, it was found that the pump was injecting the dye at a lower-than-planned rate. A second pump was added, and the injection rate was approximately doubled during the latter part of the injection period to release the total planned volume of dye. The injection rate was 49.5 pounds of dye solution per hour from 0845 to 1335 and 99.0 pounds per hour until 1545, at which time the injection was terminated. A total of about 450 pounds of dye solution was injected.

Dye concentrations were measured along cross section 9 with a boat-mounted fluorometer equipped with a Mosley Autograf Model 680 recorder, principally during ebb tide, but with some measurements during flood tide. Concentrations at cross sections 6 and 4 were monitored during flood tide. Measurements were made at several depths by lowering the intake hose to the desired depth and traversing a cross section. Grab samples were taken from the discharge line and tested later under controlled conditions. Data collected at these sections are presented in figures 8-10.

Another fluorometer-equipped boat, hereafter called the chase boat, measured dye concentrations at selected points and depths as shown in figures 11 and 12. The chase boat was to have collected data along longitudinal and transverse lines at various depths to define the limits of the dye plume. However, the fluorometer failed to operate properly; therefore only the information obtained from grab samples is available for this analysis. The locations at which these samples were taken were referenced to topographic features on the shore and field plotted on navigation charts. Locations and results are shown in figure 11 and 12, additional information is given in table 1.

The locations of the automatic samplers and the boat that was traversing cross sections 4, 6, and 9 were determined by visual observations. The location of sampling points along a cross section was determined by traversing the section at a steady speed between the anchored dye boats.

During the study, the automatic dye sampler at point C on cross section 6, 300 feet from the west bank, did not function between 1246 and 1331 hours. The sampler at point D at cross section 6, 150 feet from west bank, was found adrift and provided no record from 1200 to 1500 hours. Sampler B at cross section 4 did not operate from 1125 to 2207 hours; however, grab samples were taken at 1655 and 1710 hours. All other samplers operated satisfactorily throughout the study period. All automatic dye samplers were removed by 1432 hours on September 22. Concentration-versus-time graphs for the 11 automatic samplers are shown in figures 5-7.

Table 1.-- Dye concentrations at selected traverses on Hudson River at Cornwall-on-the-Hudson, September 21, 1977

[Locations of traverses are given in figures 12 and 13]

Traverse	Time[1/]	Bank	Depth (ft)	Concentration (ppb)
AA	1045	East	2	0.02
	1047	--	2	.00
	1050	West	2	.06
	1053	West	15	.02
	1055	--	15	.02
	1056	--	15	.02
	1057	--	15	.00
	1057	East	15	.04
	1102	East	30	.00
	1108	--	30	.00
	1111	West	30	.02
BB	1217	West	5	.00
	1220	--	5	.04
	1422	East	5	.06
	1424	--	5	.10
	1425	West	5	.16
CC	1139	West	5	0.02
	1142	--	5	.02
	1145	East	5	.04
	1147	East	20	.02
	1151	--	20	.02
	1159	West	20	.04
	1408	East	5	.08
	1410	West	5	.04
DD	1307	East	5	.04
	1311	--	5	.12
	1315	West	5	.04
	1315	West	20	.02
	1318	East	20	.08
EE	1338	East	5	.02
	1342	West	5	.02
	1422	East	5	.06
	1424	--	5	.10
	1425	West	5	.16

1/ Eastern Daylight Savings Time.

The sampling operations conducted from the two manned dye-sampling boats were discontinued at 2200 hours on September 21 and were resumed at 0800 hours on September 22. On September 22, between 0800 and 1100 hours, dye concentrations were measured at 5-foot, 13-foot, and 15-foot depths in the area between sections 4 and 9. These results are shown in figure 13.

On September 22, between 1100 and 1230 hours during an ebb-tide period, samples were collected between sections 1 and 5 at 5-foot and 15-foot depths. At three sampling points the dye concentration was monitored at three depths ranging from 5 feet to 25 feet. Results are shown in figure 14.

During the afternoon of September 22, depth profiles were recorded at cross sections 1, 2, 3, 5, 7, 8, and 10 with a portable fathometer. The location of these sections was determined visually from physical landmarks. Bathymetric profiles are presented in figure 15.

EVALUATION OF DATA

The results of this study can best be understood by examining the sampling data in chronological order and referring to figures 1, 6-14, and 16.

The injection of dye began at 0845 hours on September 21. The first measurable concentration of dye was observed in the samples collected at sites 6C and 6D between 1000 and 1100 hours; from about 1100 until about 1600 hours the samplers recorded only background fluorescence. (See fig. 6.). The dye was probably confined during this time to a width of the river between samplers at sites 6B and 6C.

The progress of the dye plume was observed visually between 0935 and 0950 hours from a shore vantage point several hundred feet above the river between sections 7 and 8. Those observations are illustrated in figure 16 (Carl N. Shuster, Jr., written commun., December 1977).

The dye cloud reached section 9 at about 1030 hours, 1.75 hours after the start of injection. Between 1030 and 1200 hours, 6 traverses were made at section 9. (See figs. 8A-8F.) Figures 8A, 8C, 8E, 8F (showing dye concentrations at the 2-ft depth) show the maximum dye concentration moving from the east side of the river to the west side. This is also indicated by the automatic-sampler record at sites 9B and 9C, where no significant concentration of dye was observed until about 1130 hours. Figures 8B and 8D (15-ft depth) show the dye uniformly spread across the section but in significantly lower concentrations than those observed near the surface at the same time.

From 1300 to 1500 hours, 10 more traverses were made at cross section 9. (See figs. 8G-8P). Four of these traverses were made at a 2-ft depth, two at 10 ft, two at 15 ft, one at 20 ft, and one at 25 ft. All these figures show the dye plume remaining within 400 to 900 ft of the west shore. The maximum dye concentrations observed in cross section 9 were of about the same magnitude at all depths sampled--0.2 to 0.35 ppb. During this time (1300 to 1500 hours), the samples collected by the automatic sampler site 9A showed no significant dye concentration, whereas those at sites 9B and 9C showed dye concentrations ranging from about 0.1 to 0.5 ppb.

Between 1600 and 1700 hours, four traverses were made at cross section 9 (figs. 8Q-8T) at depths of 2, 10, 25, and 30 ft. During this time the water was flowing upstream. At all depths sampled between 1600 and 1700 hours at cross section 9 (except 30 ft, where no data had been previously collected), maximum dye concentrations were lower than when the section was previously sampled between 1300 and 1500 hours. The dye was still confined to the west side of the river, but the plume extended several hundred feet farther east. The concentration of dye in the samples collected at samplers 9B and 9C between 1600 and 1700 hours decreased from about 0.4 ppb at 1600 to 0.2 ppb at 1700 hours.

Between 1915 and 1930 hours on September 21, traverses were again made at 5-ft and 15-ft depths at cross section 9. (See figs. 8U-8V). These samplings showed dye concentrations of less than 0.05 ppb, as did the samples taken by the automatic samplers at sites 9A, 9B, and 9C between 1900 and 2000 hours.

No additional traverses were made at section 9 until 1035 hours on September 22. Dye concentrations were low in samples collected at sites 9B and 9C from 2000 hours to about 2200 hours on September 21, then began to increase and peaked at about 0.8 to 0.9 ppb between 0200 and 0300 hours on September 22. The concentrations at both sites declined to about 0.05 ppb at about 0430 hours, when they again began to increase to another peak of about 0.4 ppb between 0630 and 0800 hours. They then began another gradual decline.

The dye concentration in samples collected by sampler 9A, near the east shore of section 9, between 2000 hours on September 21 and 1000 hours on September 22, increased and decreased at about the same times as those at sites 9B and 9C. The peak concentration of about 0.25 ppb observed at sampler 9A was, however, significantly lower than those recorded at sites 9B and 9C. The increase in concentration near midnight on September 21 at sampler 9A was the first indication of dye at this site.

At section 6, a traverse made at 1720 hours at a 2-ft depth on September 21 showed the dye to be concentrated within 800 feet of the west bank. (See fig. 9A.) Between 1800 and 1900 hours, three more traverses made at section 6 at 5-, 15-, and 30-ft depths found dye only near the west shore and maximum concentrations of less than 0.15 ppb. (See figs. 9B-9D.) Two more traverses were made, at 2-ft and 15-ft depths, between 1950 and 2020 hours (see figs. 9E and 9F); both showed maximum dye concentrations of less than 0.08 ppb. No additional traverses were made until 0922 hours on September 22.

From 1700 to 2030 hours, no dye was observed in samples from automatic sampler 6B. (See fig. 6B.) Samples from site 6A had higher readings than those collected at site 6B before 1900 hours, but these readings probably did represent dye. From 1700 to 2030 hours, the dye concentration in samples collected by samplers at sites 6C and 6D decreased from about 1.0 ppb to less than 0.1 ppb. Dye concentrations began to rise at about 2100 hours at sites 6C and 6D to a concentration between 0.5 and 1.5 ppb until about 0200 hours on September 22. (See fig. 6C and 6D.) Dye concentrations then decreased to less than 0.1 ppb. Moderately high concentrations of dye, about 0.25 ppb, were observed at sections 6C and 6D from 0600 hours until about 1200 hours. On the east side of the river, dye was first found in samples collected automatically at sites 6A and 6B at about 0300 hours on September 22. Concentrations at sites 6A and 6B then decreased to insignificant levels until about 0600 hours, when they began to rise and reached peaks of 0.1 and 0.2 ppb, respectively, at about 0900 hours.

At section 4, only one traverse was made. This traverse, made at about 2100 hours on September 21, found very low dye concentrations except near the west shore. (See figs. 7A–7D and 10A.) Between 1720 hours and 1823 hours, the chase boat searched for the main dye cloud between sections 4 and 6. Dye concentrations determined from grab samples during this time are shown in figure 11.

Figure 12 shows the location, depth, and apparent concentration of dye in grab samples collected downstream from Little Stony Point. Downstream from cross section 11 are two sewage-disposal plants whose effluents could contain substances that would produce a fluorescence reading similar to that of the dye. Because background readings here were not obtained before the start of the study, it can not be determined whether the values reported are the result of dye or other substances. Upstream from section 11, near West Point, the values reflect dye concentrations present during the study.

On September 22, between 0817 and 1040 hours, traverses were made at 15-ft depths, and grab samples were obtained at 5-ft depths at cross sections 4, 6, and 9 and along lines between these cross sections. The results of these investigations are shown in figures 8W, 9G, 10B, and 13. At cross section 4, between 0815 and 0830 hours, dye concentrations ranged from 0 to 0.12 ppb and averaged 0.05 ppb. Dye concentrations of 0.05 ppb were found in samples collected by automatic samplers 4A and 4B as well as at depths of 5 and 15 ft near these samplers at about 0830.

Dye concentration was found to increase at both depths (5 and 15 ft) to about 0.25 ppb as the boats traveled from cross section 4 to cross section 6 between 0830 and 0920 hours. Between 0915 and 0930, the dye concentration at cross section 6 was found to range from about 0.15 to 0.30 ppb. No significant variation in dye concentration was found across the width of section 6, and concentrations were similar at both depths. At 0930, samples from automatic samplers 6B, 6C, and 6D indicated concentrations ranging from 0.20 to 0.25 ppb. Samples collected at sampler 6A were somewhat lower at about 0.10 ppb.

As the boat traveled from section 6 to section 9, dye concentration decreased slightly. At cross section 9, dye concentrations of 0.02 to 0.09 ppb were measured along the east shore and 0.12 to 0.15 ppb near the west shore. No significant variation was observed by the boat traversing section 6 and sampling at a 15-ft depth between 1035 and 1040 hours. Between 1000 and 1100 hours, all automatically collected samples at cross section 9 showed dye concentration between 0.10 to 0.23 ppb. The highest reading was near the west shore.

Between 1050 and 1240 hours, during a period when the water was moving downstream, samples were collected between cross sections 1 and 5, as shown in figure 14. These samples showed that the dye front, which was near cross section 2 at 1130 hours, had moved downstream to near or below cross section 5 by 1230 hours. The lack of dye north of cross section 2 also provided documentation that there had been no change in the natural background levels of the river during the study. Samples collected at various depths at points A, B, and C between 1100 and 1300 hours showed no significant variations in dye concentration with depth. (See fig. 14.)

CONCLUSIONS

From the data collected it can be concluded that, in the area studied, Hudson River water is mixed naturally. Complete mixing does not occur rapidly but, during flow conditions similar to those at the time of this study, it will occur during two or more tidal cycles and before the water mass had moved out of the area. Dye-concentration data collected early in the study, at cross section 9, show that the flow path of the water will vary with time and tidal discharge rate.

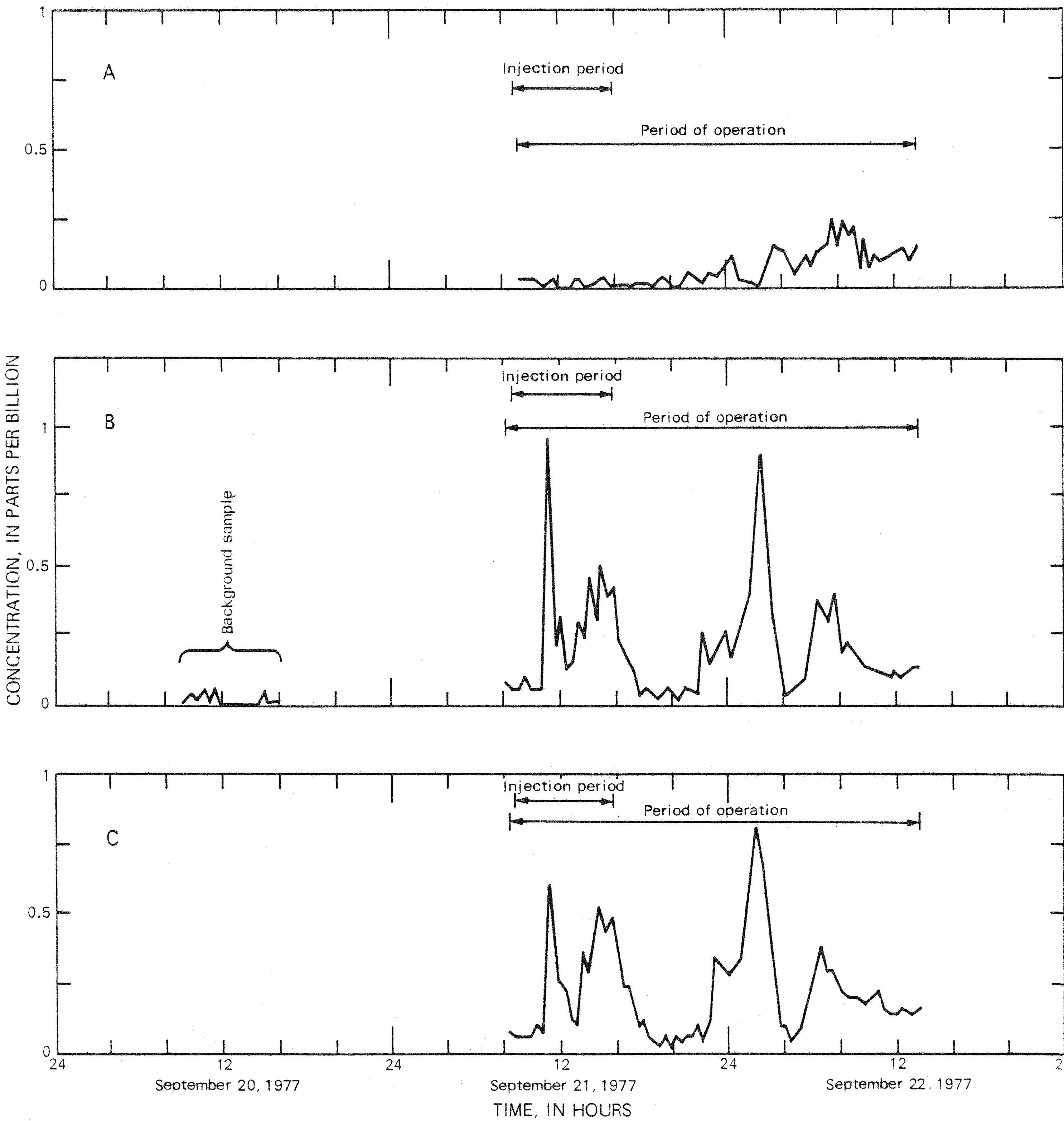


Figure 5.--Dye concentrations in samples collected by automatic samplers A, B, and C at section 9.

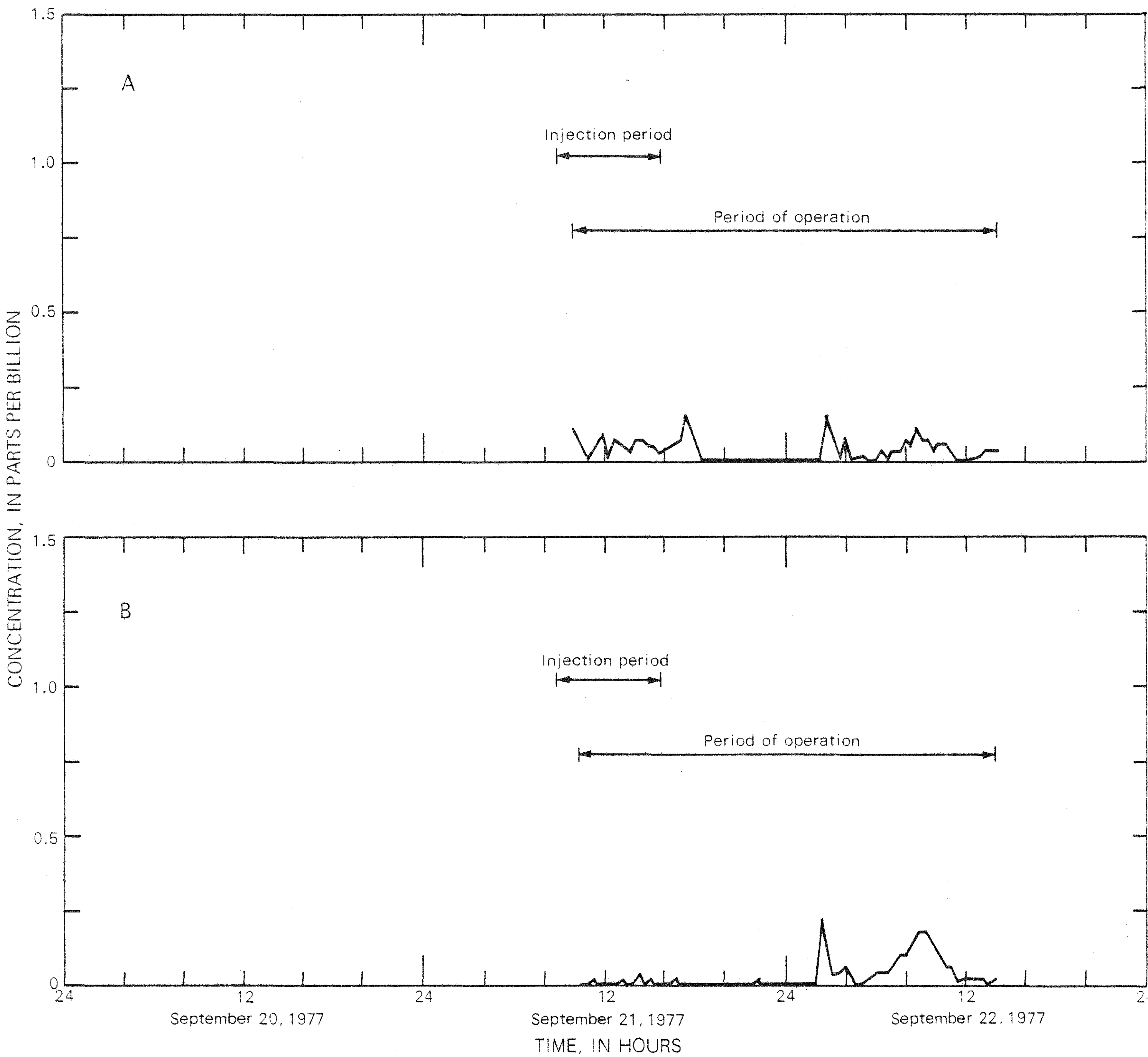


Figure 6.--Dye concentrations in samples collected by automatic samplers A, B, C, and D at section 6. (Continued on next page)

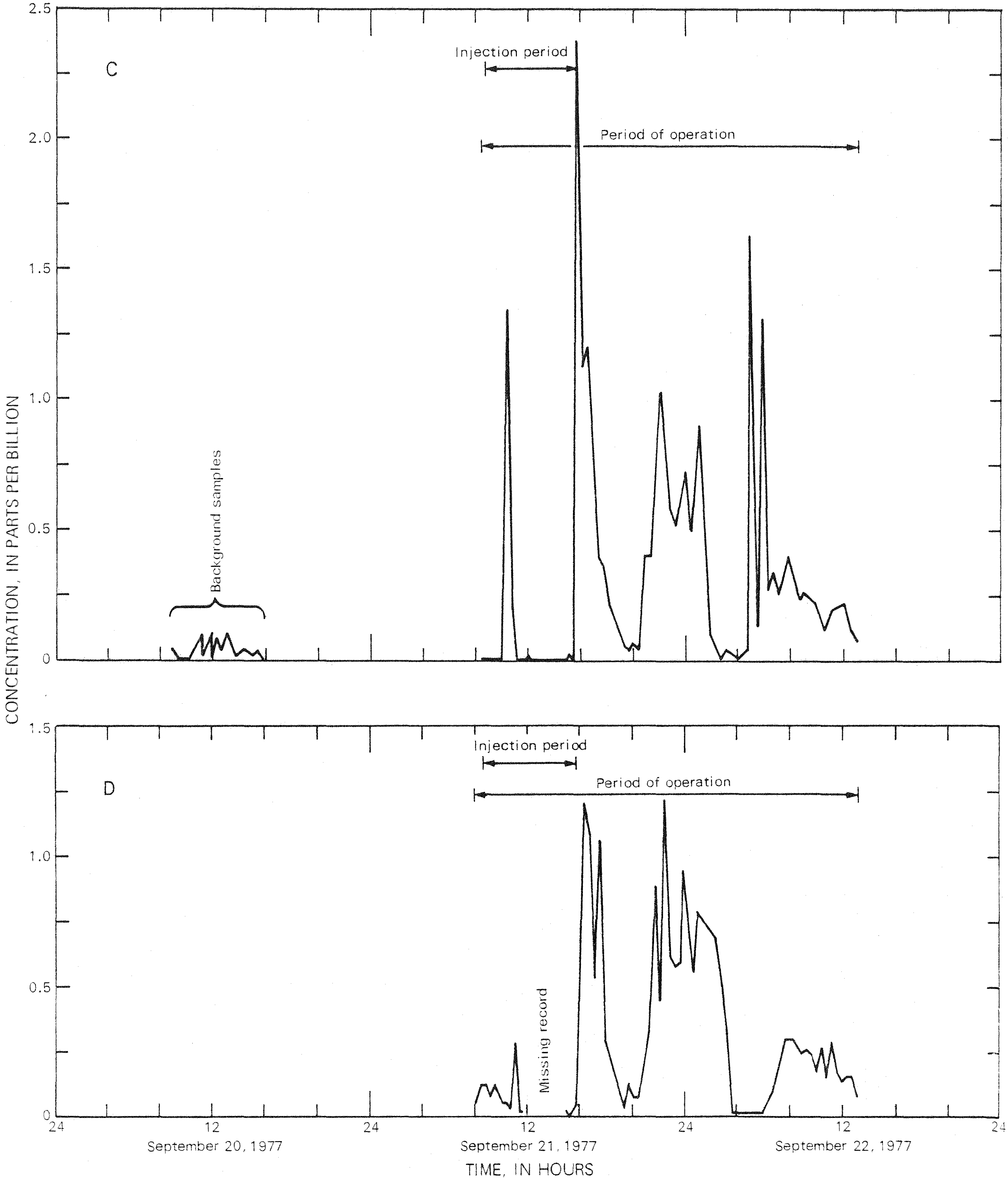


Figure 6.--(Continued)

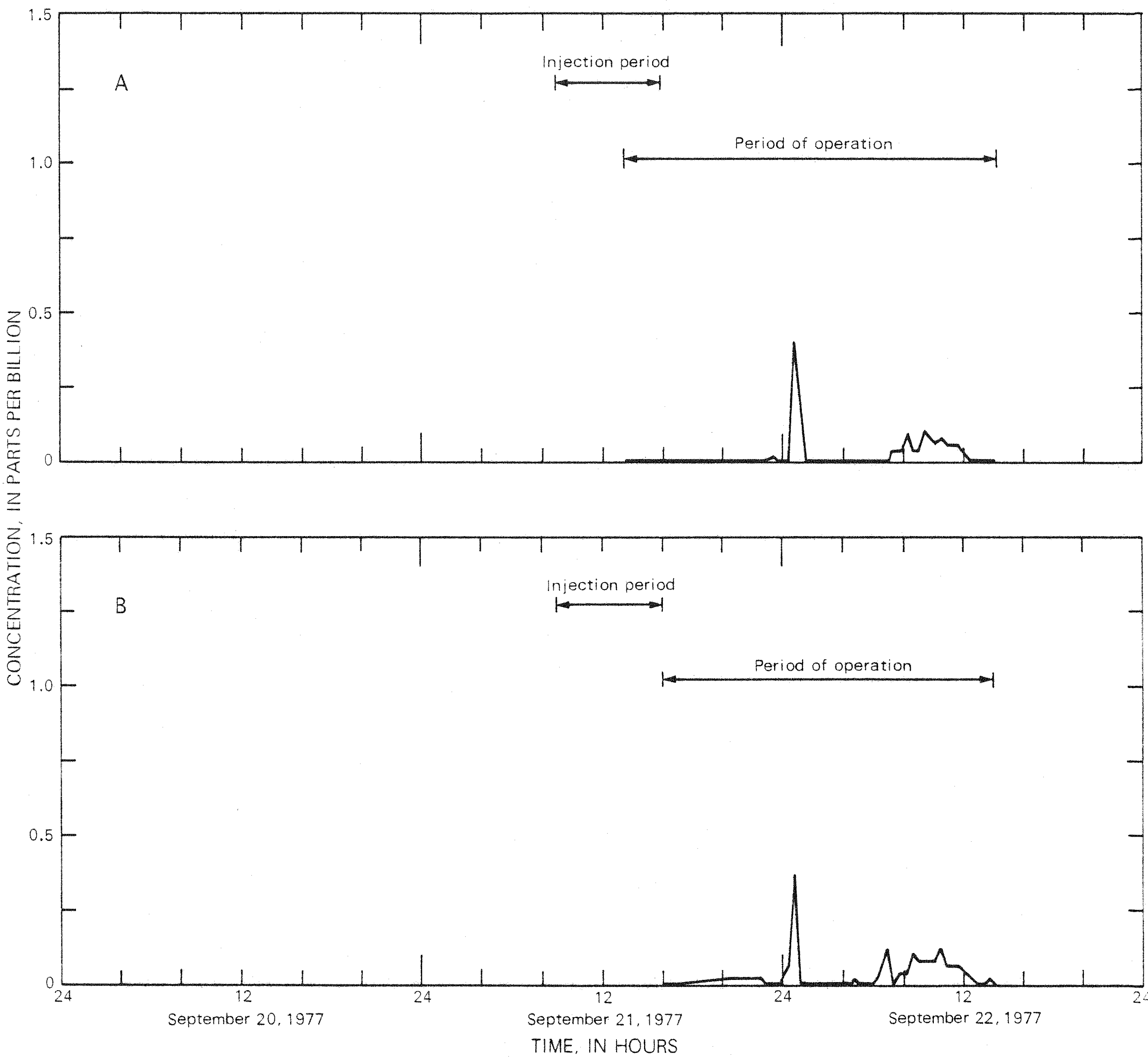


Figure 7.--Dye concentrations in samples collected by automatic samplers A, B, C, and D at section 4. (Continued on next page)

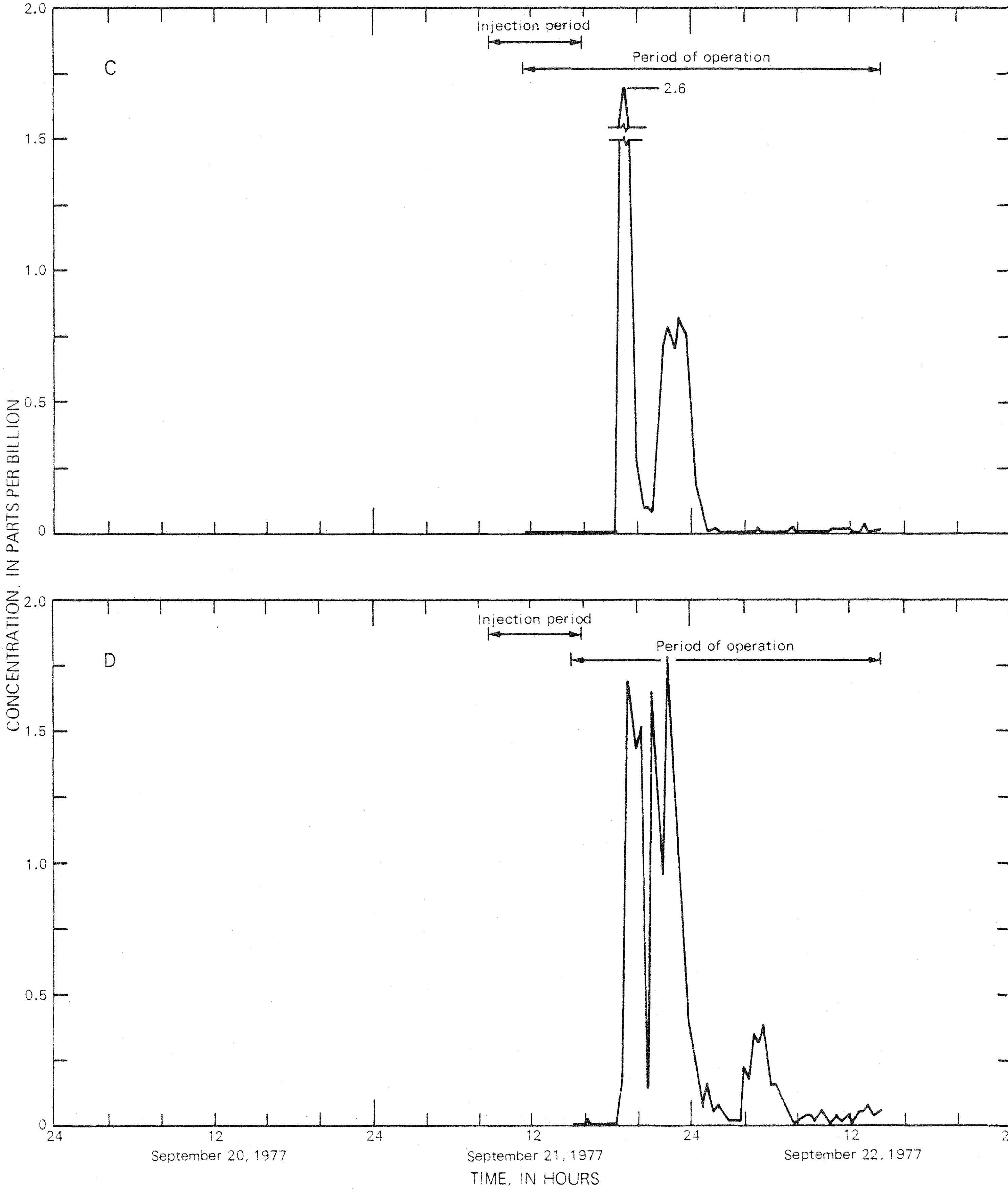


Figure 7.--(Continued)

FIGURE 8.--(on pages 22-27):

Graphs showing dye concentrations at section 9 at selected depths and times, September 21, 1977:

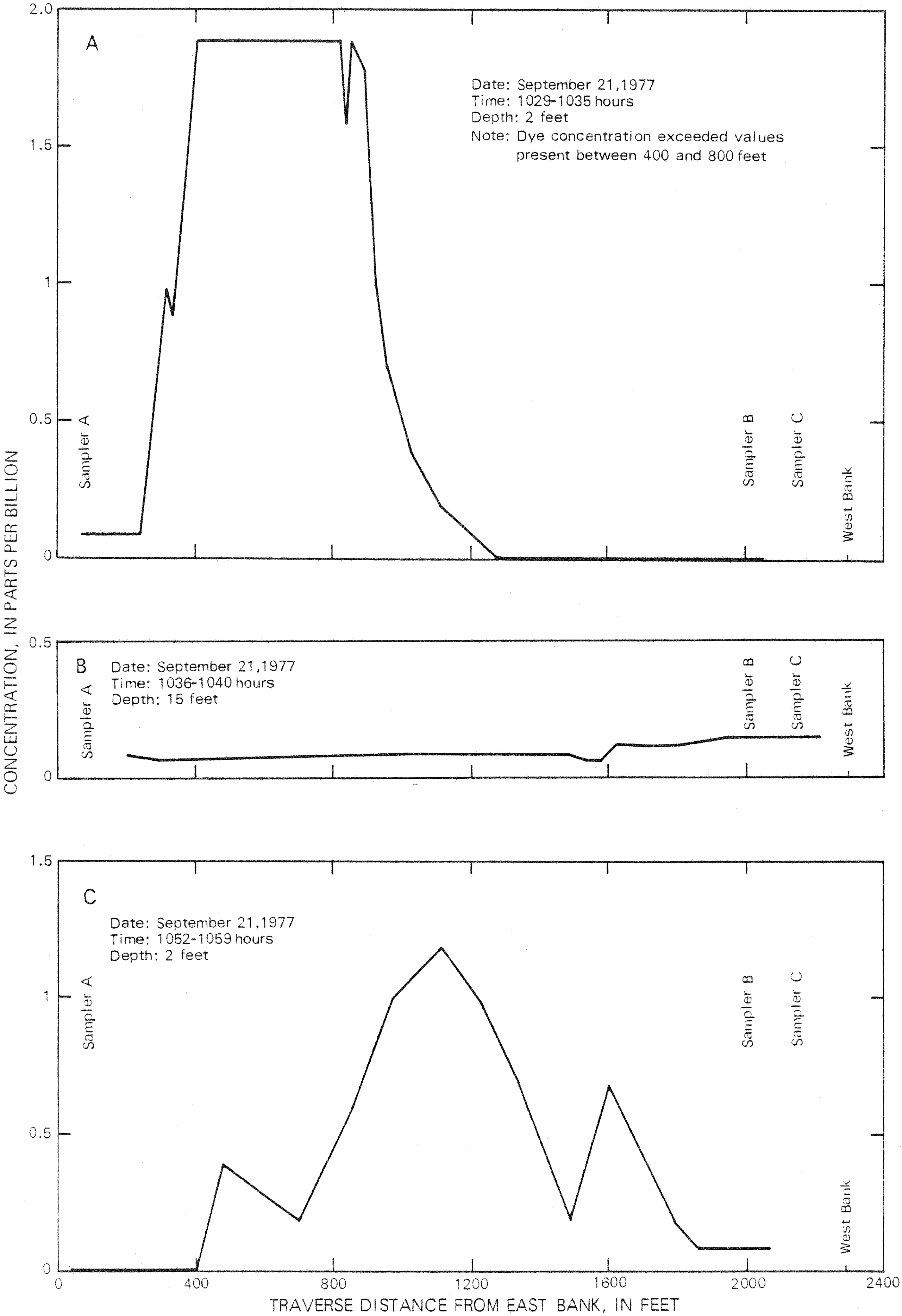


Figure 8.--(Captions on preceding page)

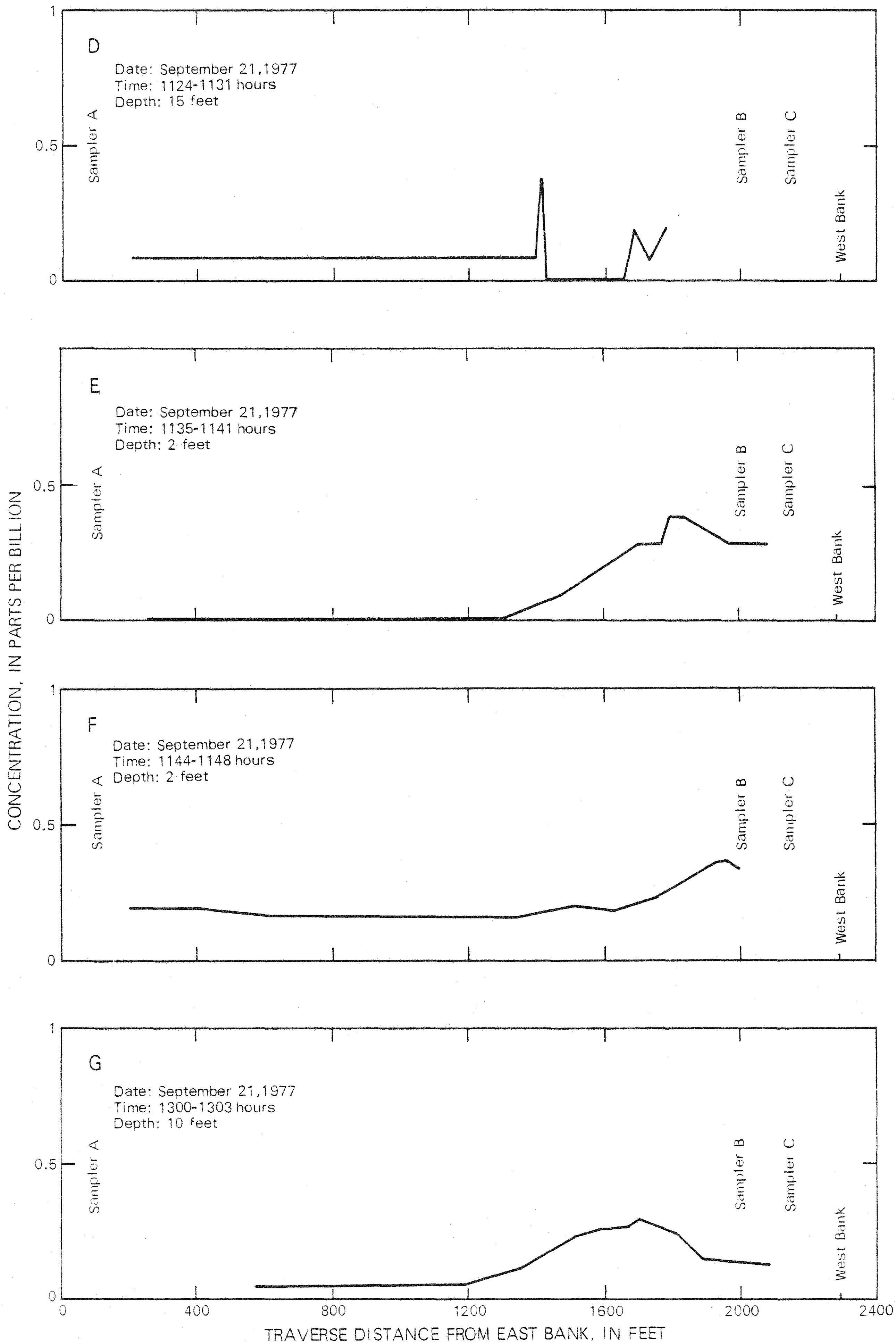


Figure 8.--(Continued)

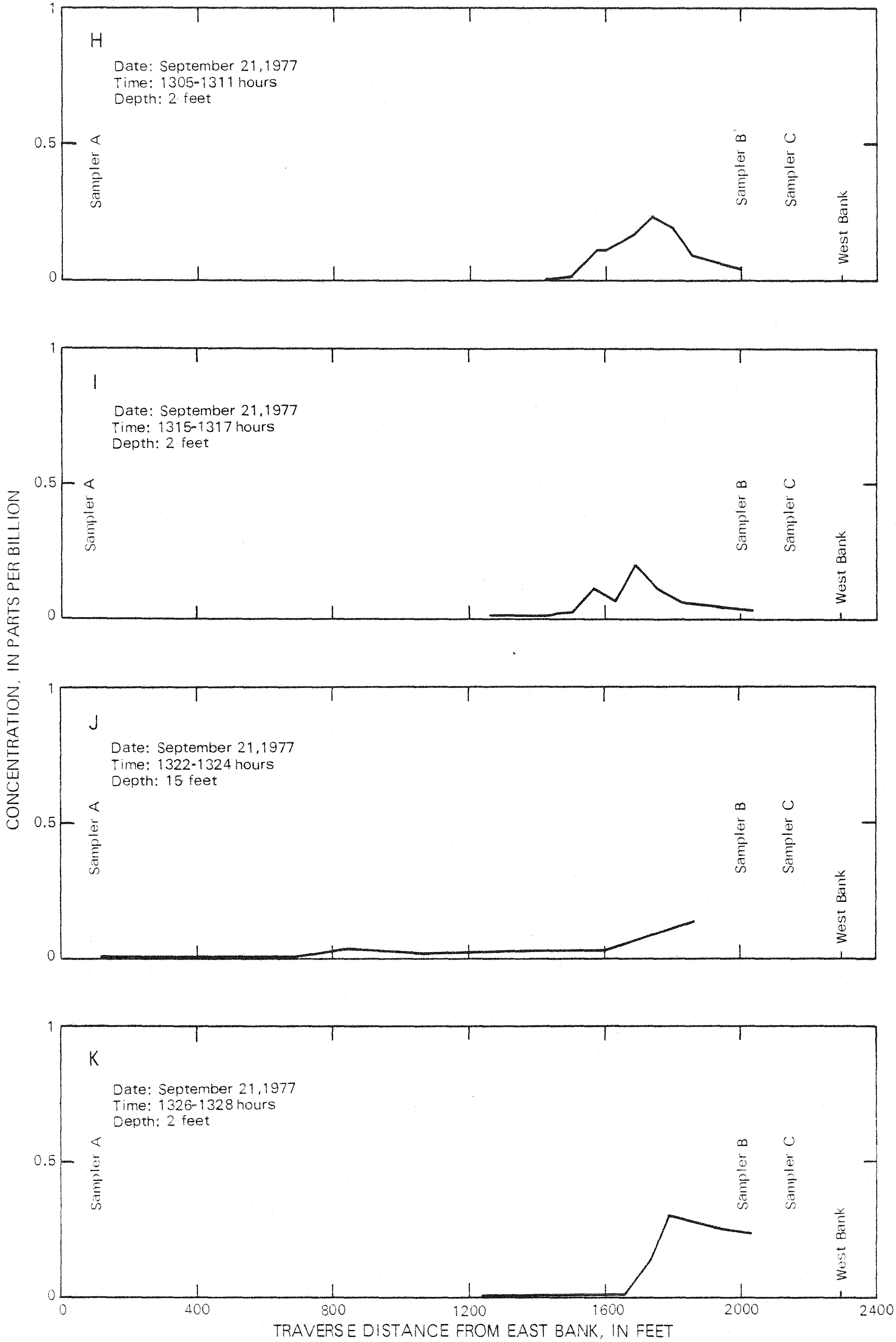


Figure 8.--(Continued)

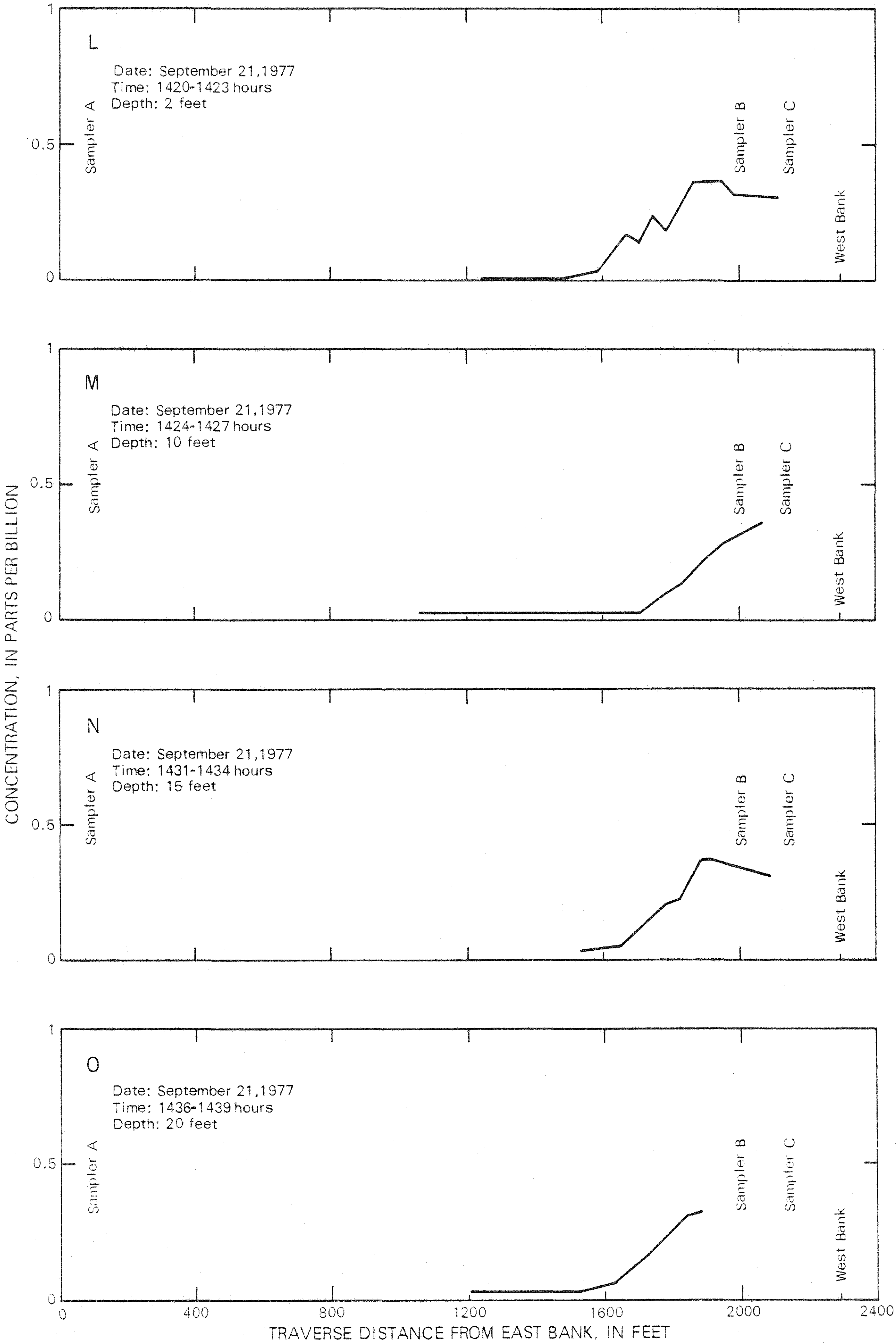


Figure 8.--(Continued)

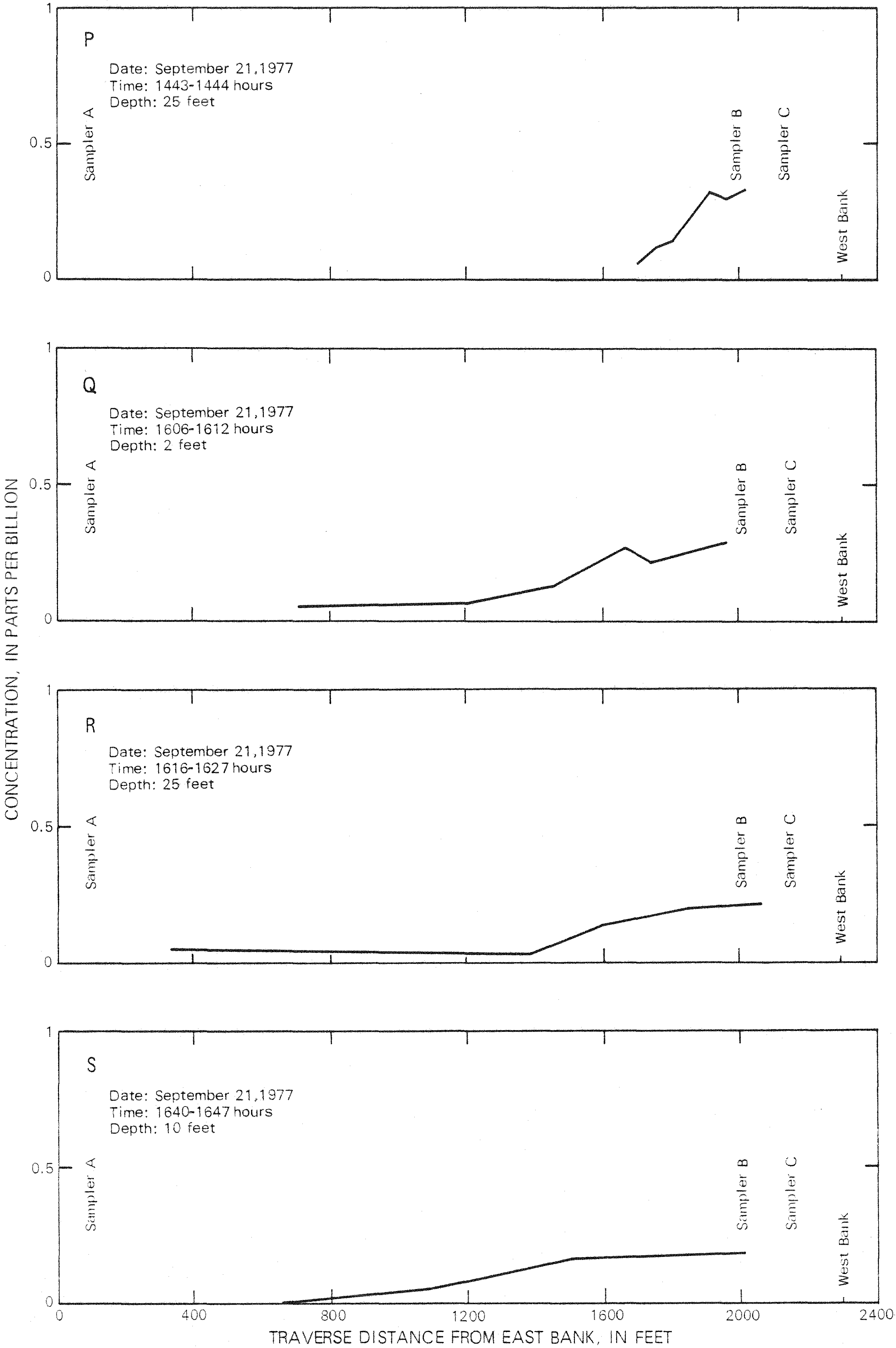


Figure 8.--(Continued)

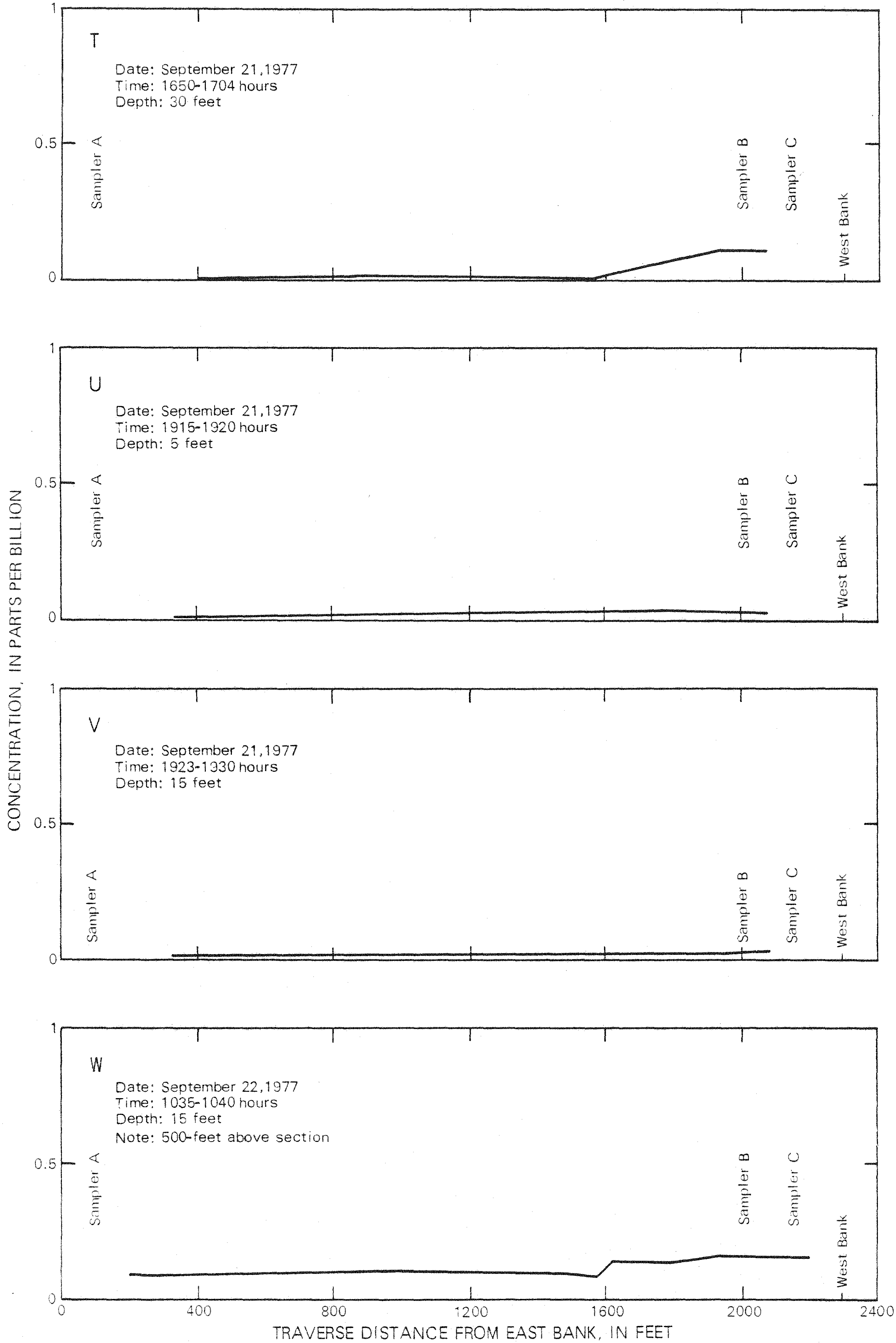


Figure 8.--(Continued)

FIGURE 9.--(on pages 29-30):

Graphs showing dye concentrations at section 6 at selected depths and times, September 21, 1977:

A. 1719-1720 hours, depth 2 feet

B. 1810-1815 hours, depth 15 feet

C. 1816-1820 hours, depth 30 feet

D. 1838-1848 hours, depth 5 feet

E. 1951-2000 hours, depth 15 feet

F. 2012-2020 hours, depth 2 feet

G. 0922-0931 hours, depth 15 feet, September 22, 1977, 500 feet above section 6

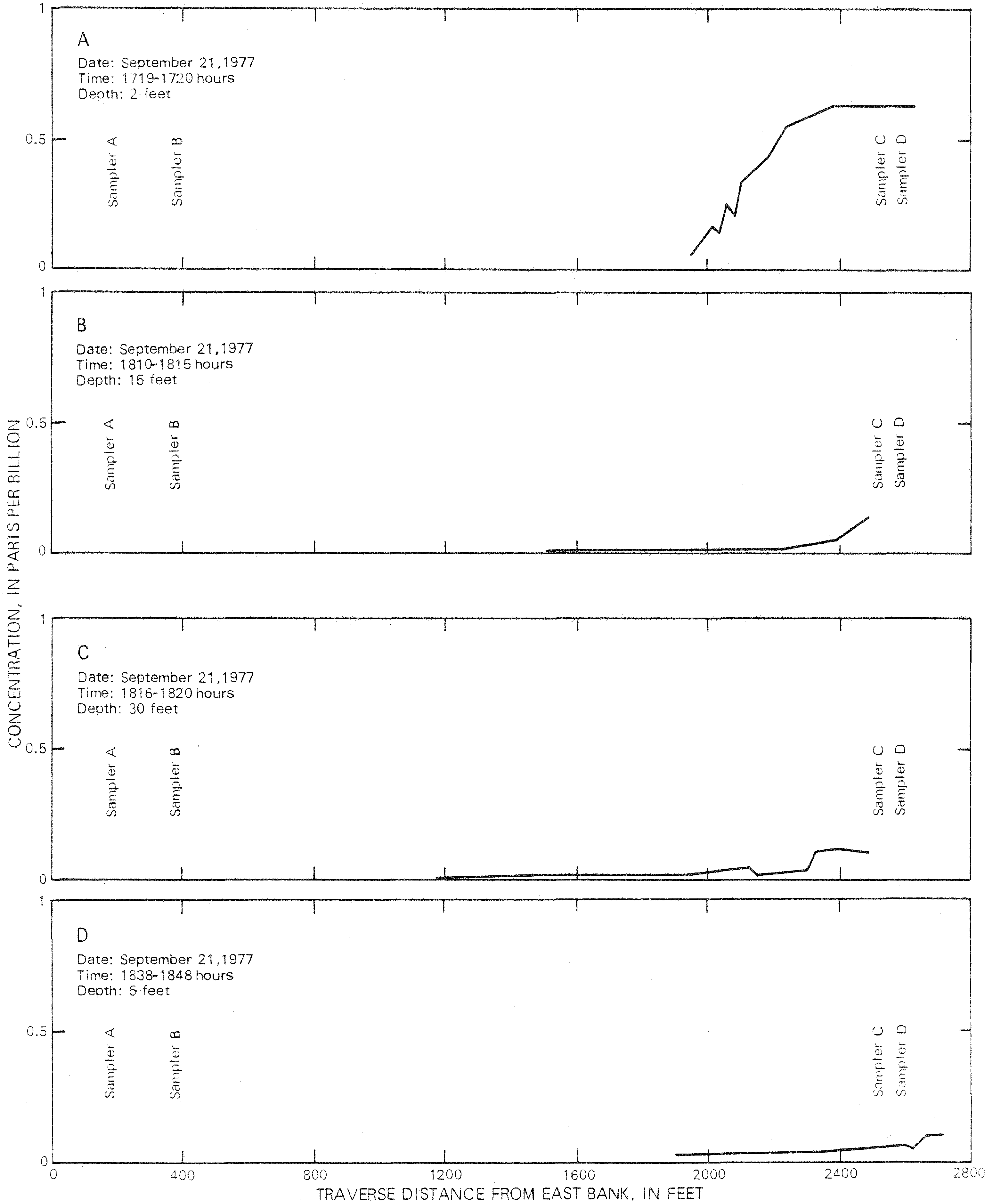


Figure 9.--(Captions on preceding page)

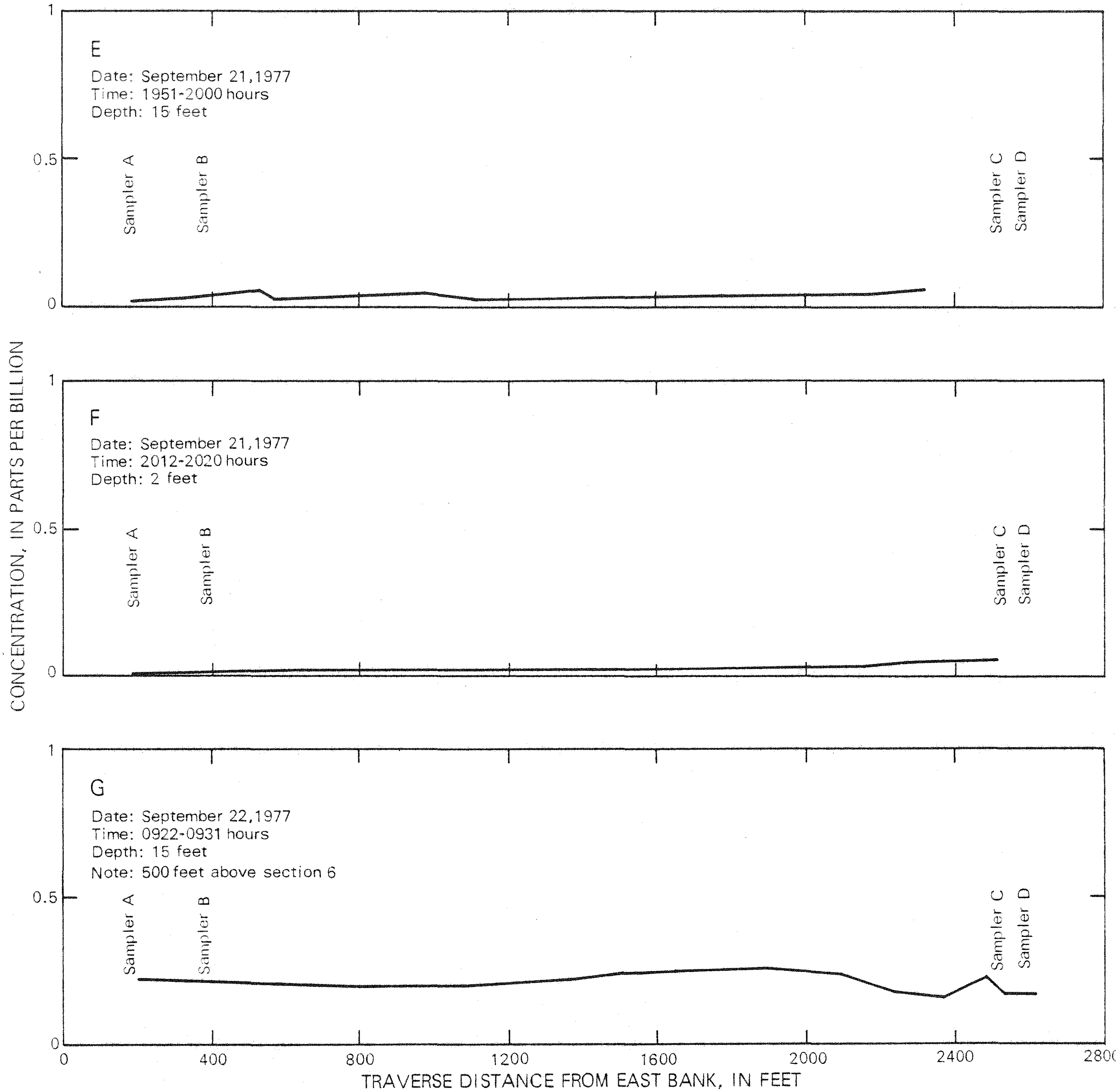


Figure 9.--(Continued)

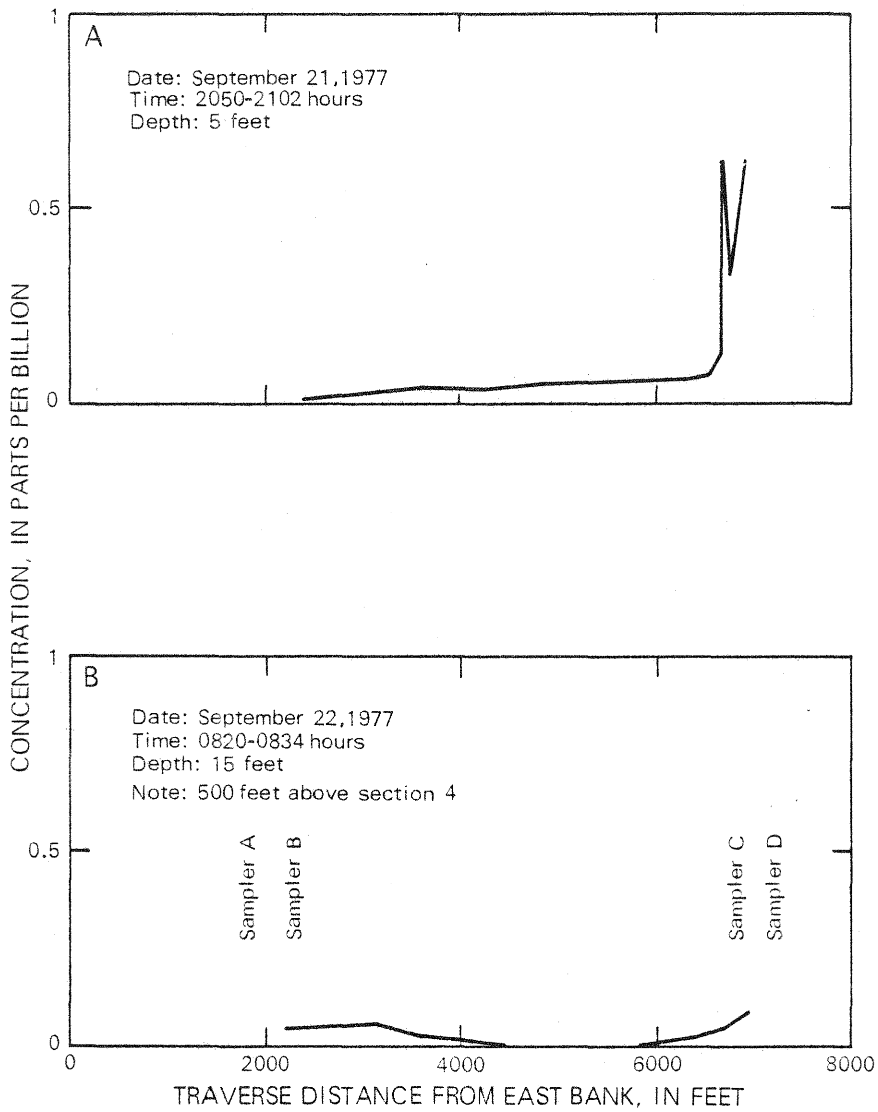


Figure 10.--Dye concentrations at selected depths and times:

A. 2050-2102 hours, depth 5 feet, section 4, September 21, 1977

B. 0820-0834 hours, depth 15 feet, 500 feet above section 4, September 22, 1977

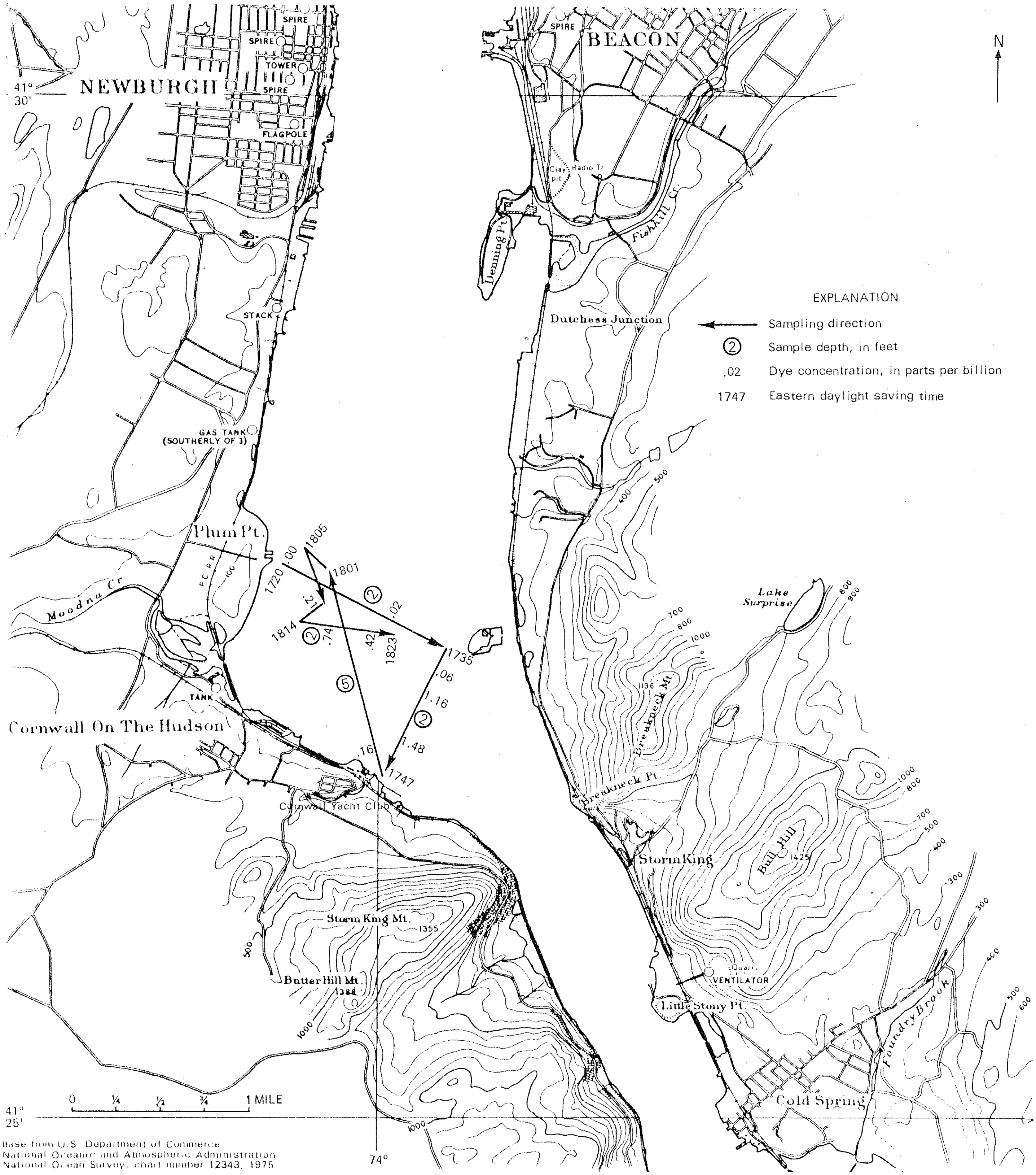


Figure 11.--Longitudinal and depth variation of dye concentration at Cornwall-on-the-Hudson, September 21, 1977

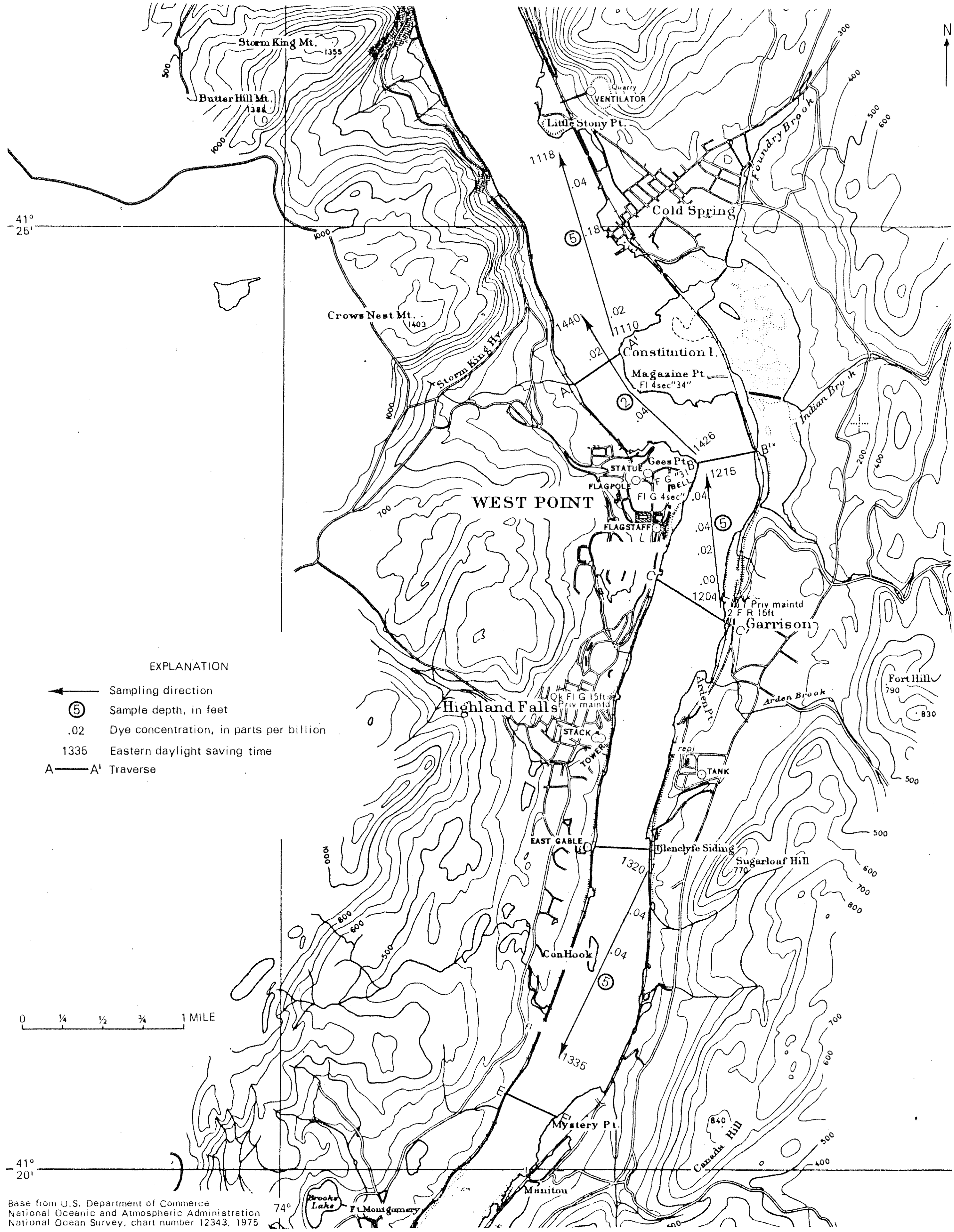


Figure 12.--Longitudinal and depth variation of dye concentration within study reach, September 21, 1977

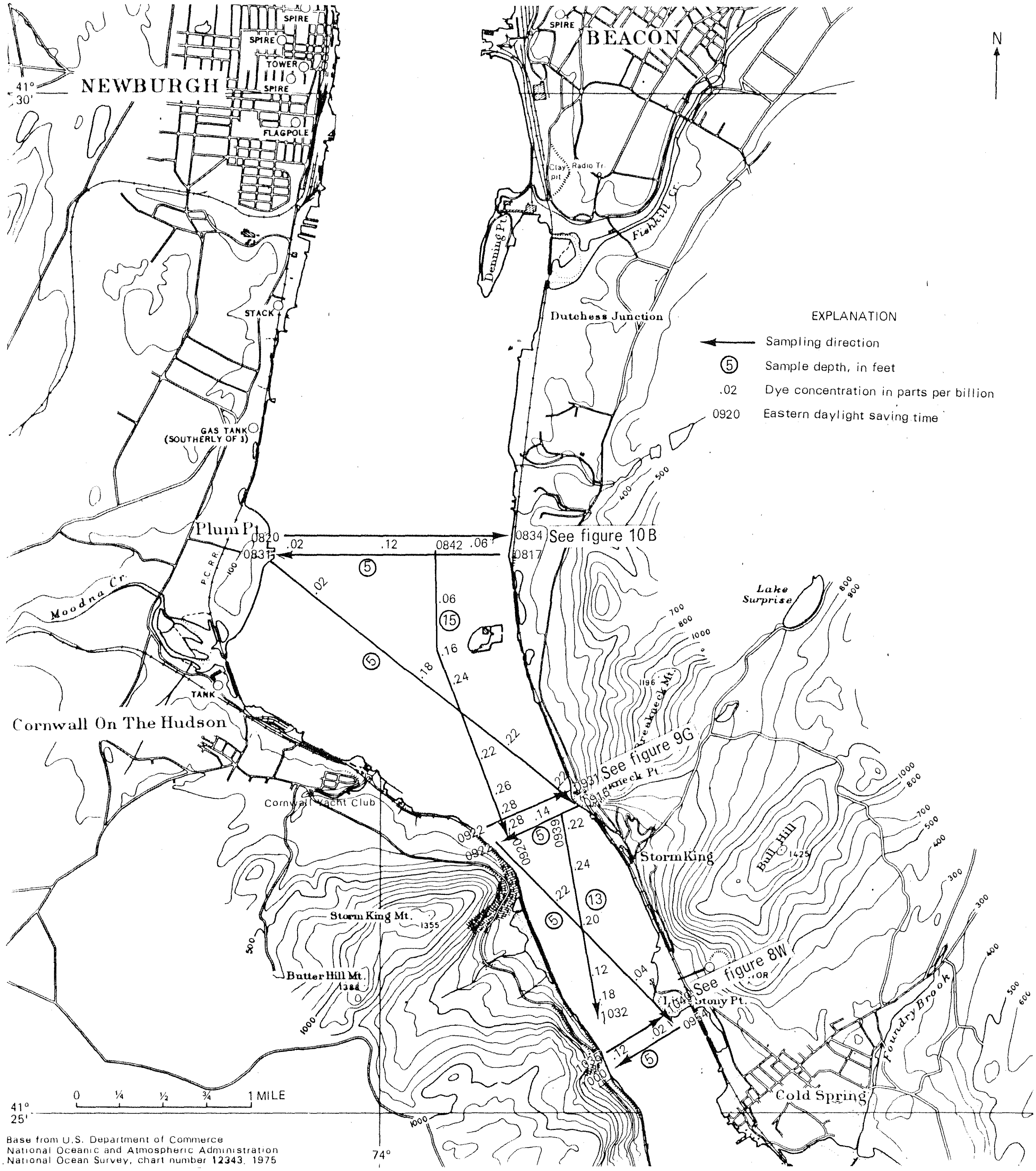


Figure 13.--Longitudinal and depth variation of dye concentration at Cornwall-on-the-Hudson, September 22, 1977

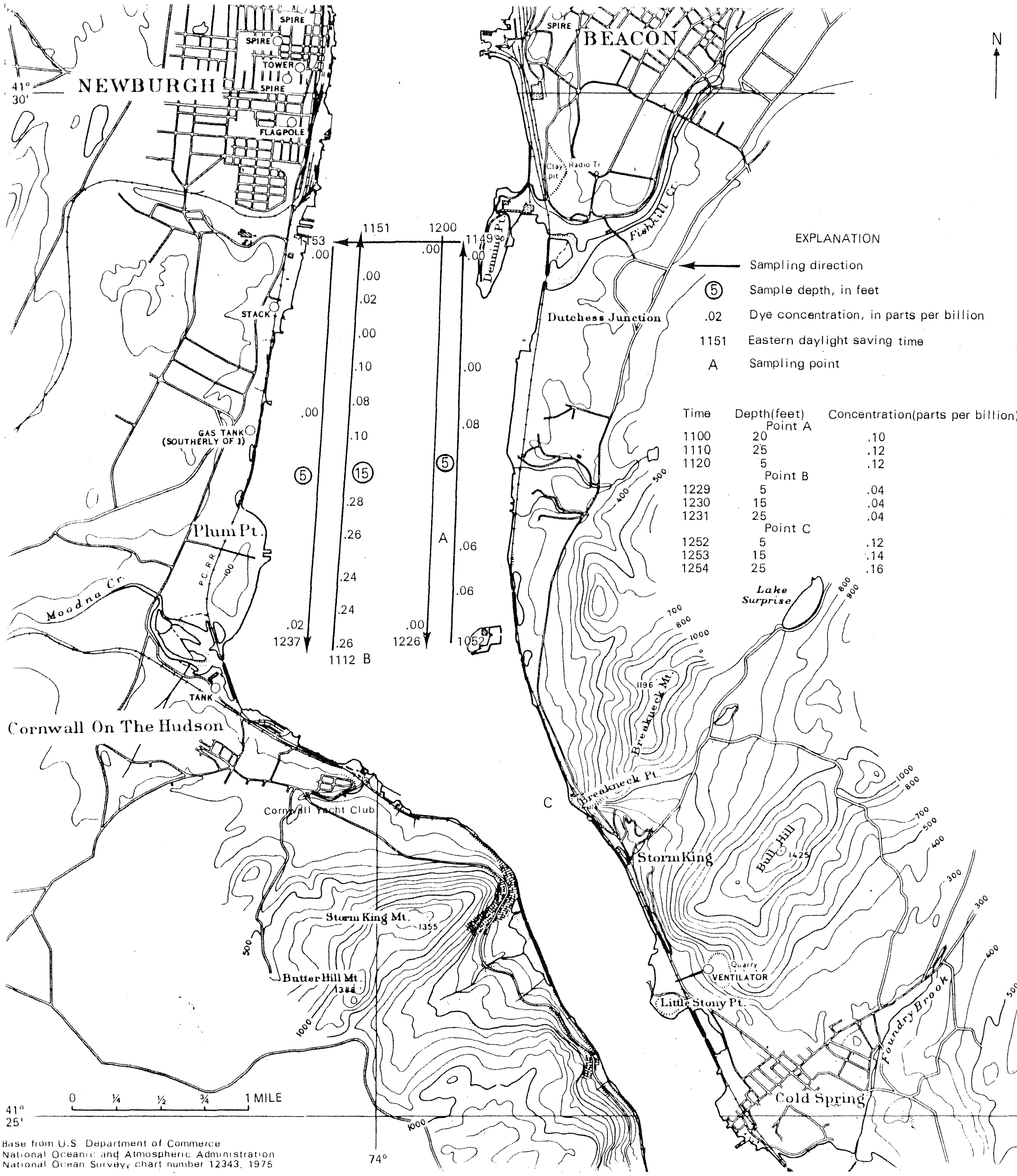


Figure 14.--Longitudinal and depth variation of dye concentration within study reach, September 22, 1977

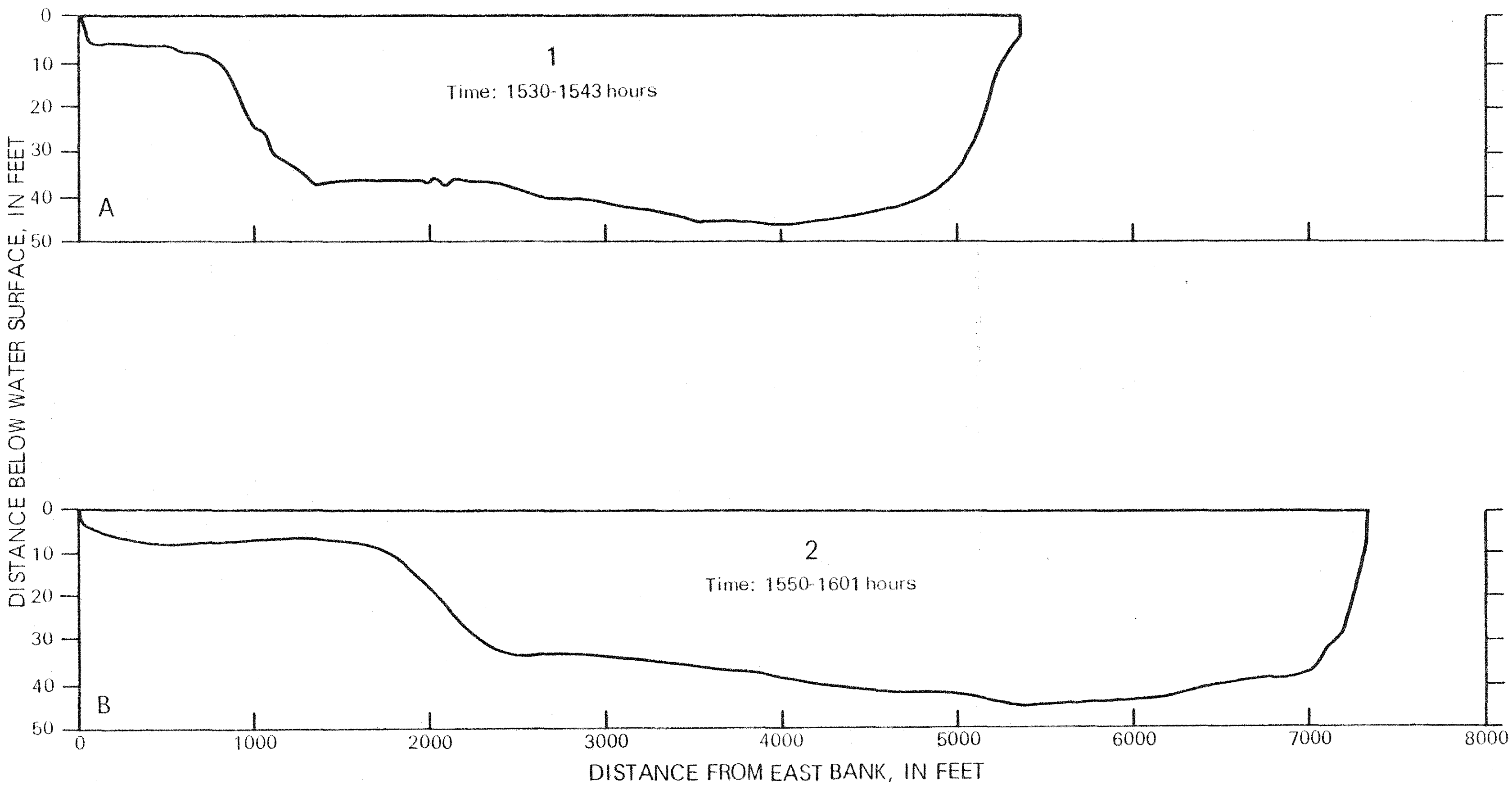


Figure 15.--Depth profiles of selected cross sections, September 22, 1977:

A. Section 1. B. Section 2.

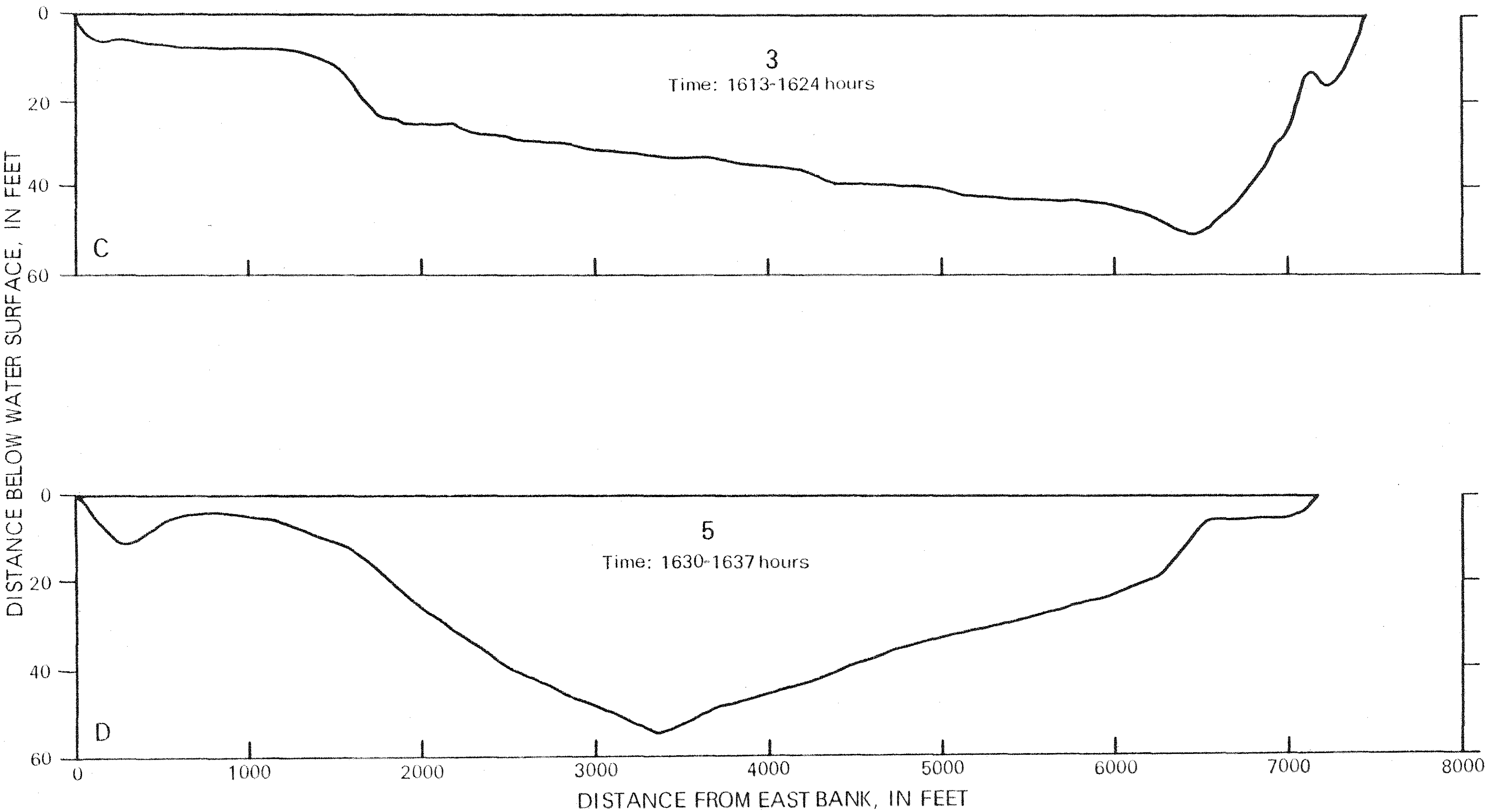


Figure 15.--Depth profiles of selected cross sections, September 22, 1977 (continued):

C. Section 3. D. Section 5.

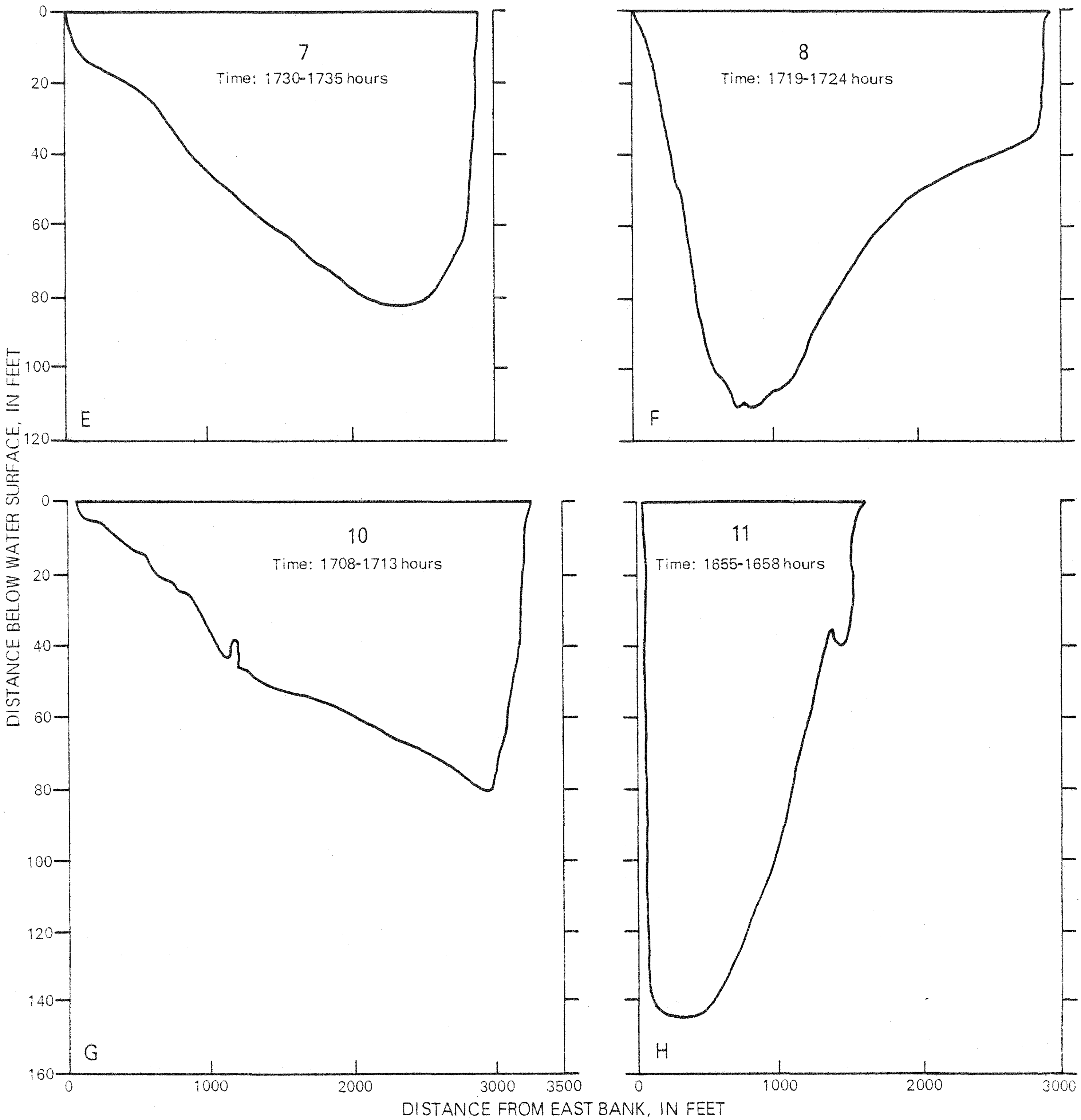
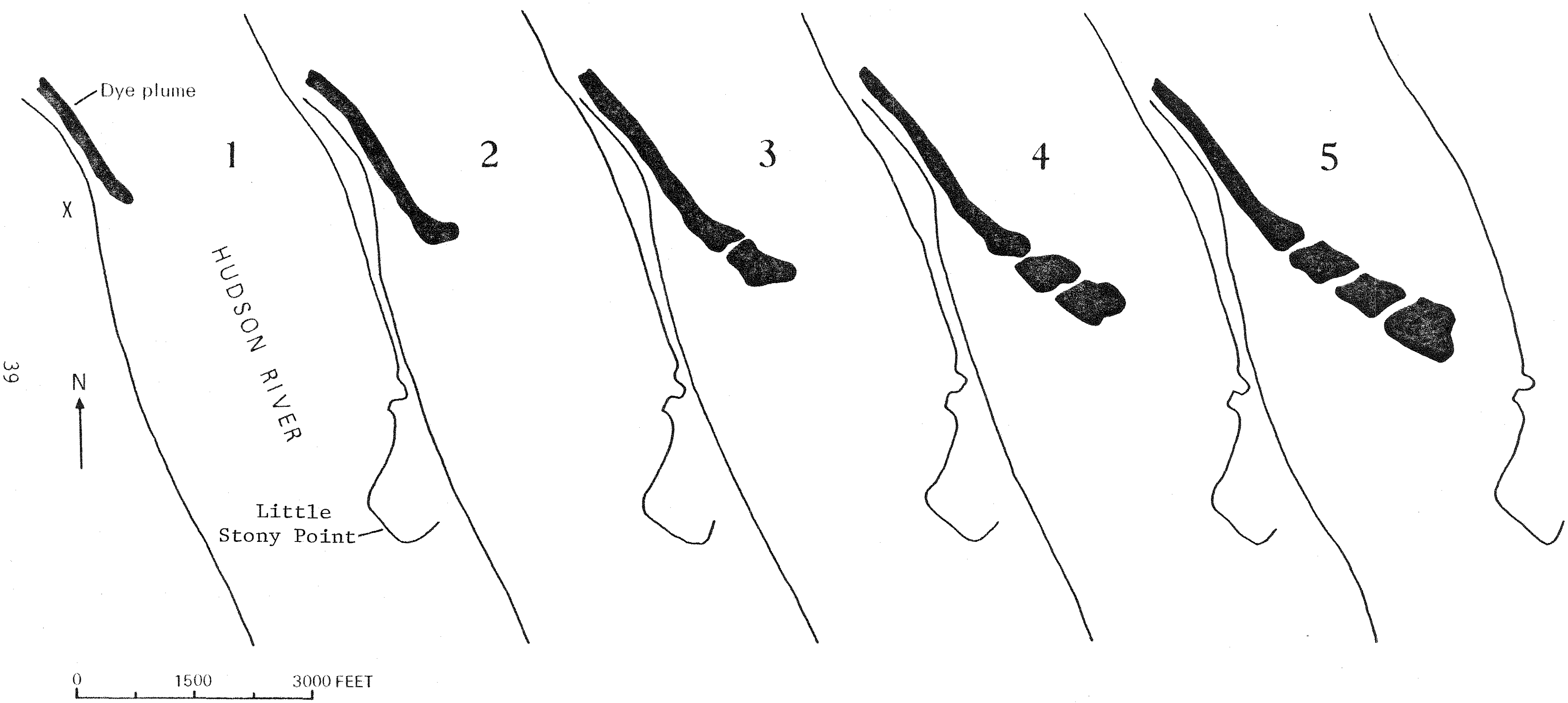


Figure 15.--Depth profiles of selected cross sections, September 22, 1977 (continued):

E. Section 7 G. Section 10
F. Section 8 H. Section 11



1.-- Plume tip about same width as rest of plume

2.-- Tip of plume widens as it starts across river

3, 4, and 5.-- Blotches of dye break off from widened tip of plume; blotches broaden in crossing river

Figure 16.--Dye cloud as observed from Storm King Mountain between 0935 and 0950 hours, September 21, 1977.

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