# WATER QUALITY AND STREAMFLOW DATA FOR THE WEST FORK TRINITY RIVER IN FORT WORTH, TEXAS

by Steve C. McCutcheon, and others

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## ILLUSTRATIONS (Continued)

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5. to 13. Dye concentration as a function of time at site:

## TABLES (Continued)

## CONVERSION FACTORS

| MULTIPLY | BY | TO OBTAIN |
|---|---|---|
| miles | 1.609 | kilometers |
| miles per hour | 1609 | meters per hour |
| square miles | 2.590 | square kilometers |
| foot | 0.3048 | meters |
| feet per second (f/s) | 0.3048 | meters per second (m/s) |
| cubic feet | 0.02832 | cubic meters |
| cubic feet per second ($ft^3/s$) | 0.02832 | cubic meters per second ($m^3/s$) |
| standard cubic feet per minute | 0.02832 | standard cubic meters per minute |
| gallons (gal) | 3.785 | liters (L) |
| gallons per hour (gal/h) | 63.09 | milliliters per minute (mL/min) |
| calories per square centimeters per day ($cal/cm^2/d$) | 0.4843 | Watts per meter squared ($W/m^2$) |

Notes on the reporting of time, altitude or elevation and location along the stream channel:

1) Time in hours and minutes is reported in military time for the Central Standard Time Zone; for example 1412 hours is 2:12 pm central time, 2:12 is 2:12 am central time.

2) Water-surface and bed elevations or altitudes are reported in terms of height above the National Geodetic Vertical Datum of 1929 (NGVD) which is 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".

3) Some locations on the West Fork Trinity River are given in river miles upstream of the mouth of Trinity River on Trinity Bay east of Houston, Texas.

## SYMBOLS AND ABBREVIATIONS

| Symbol | Definition | Units |
|---|---|---|
| A | Area under the dye concentration-versus-time curve. Subscripts refer to cross sections A, B, C, etc. See eq. 4.3-1. | (microgram per liter)-hour |
| a | Constant defined in eq. 4.3-2. | |
| b | Constant defined in eq. 4.3-2. | |
| BOD | Biochemical oxygen demand. | mg/L |
| $C_G$, $C_D$ | Peak concentration of gas and dye used in eq. 4.4-1 | mg/L |
| CBOD, $CBOD_u$ | Carbonaceous BOD, ultimate CBOD. | mg/L |
| Cond. | Conductance. | µmhos/cm |
| DO | Dissolved oxygen. | mg/L |
| GCHC | Gulf Coast Hydroscience Center located at Bay St. Louis, Mississippi | |
| $HgCl_2$ | Mecuric chloride used as a sample preservative in this study. | |
| Inorg. | Inorganic. | |
| J | Correction factor in eq. 4.3-1 where subscripts A, B, C, etc. denote stream cross section. $J_A$=100. | |
| $K_T$ | Desorption coefficient for ethylene or propane, see eqs. 4.4-1, and 4.4-2. | 1/day |
| $K_1$, $K_N$ | Specific rate constant for carbonaceous BOD exertion, and nitrogenous BOD exertion | 1/day |
| $K_2$ | Reaeration coefficient, see eq. 4.4-2 and 4.4-3. | 1/day |
| Kjeld. N | Kjeldalh nitrogen or the sum of ammonia-nitrogen and organic nitrogen. | mg/L |
| mg/L | Milligrams per liter. | |
| mL | Milliliters. | |

## SYMBOLS AND ABBREVIATIONS (Continued)

| Symbol | Definition | Units |
|---|---|---|
| mm Hg | Millimeters of mercury as a measure of barometric pressure. | |
| N | Nitrogen; when used with $NH_3$, $NO_2$, or $NO_3$, that is $NH_3$-N, concentration in terms of nitrogen is implied. | mg/L |
| NBOD, $NBOD_u$ | Nitrogenous BOD, ultimate NBOD. | mg/L |
| $NH_3$, $NH_4$ | Ammonia, ammonium. | mg/L |
| $NO_2$ | Nitrite. | mg/L |
| $NO_3$ | Nitrate. | mg/L |
| P or Phos. | Phosphorus; when used with $PO_4$, that is $PO_4$-P, concentration in terms of phosphorus is implied. | mg/L |
| $PO_4$ | Orthophosphate | |
| Q | Discharge; subscripts refer to discharge at cross sections A, B, C, etc. See eq. 4.3-1. | $m^3/s$ |
| RMS | Root-mean-square. | |
| Sp. cond. | Specific conductance. | µmhos/cm |
| STP | Sewage treatment plant. | |
| t | Time | days |
| TBOD | Total BOD | mg/L |
| $T_p$, $t_d$, $t_u$ | Travel time of the peak dye concentration, travel time to the downstream end of a reach, and travel time to the upstream end of a reach. | hours |
| $\Theta$ | Water temperature | °C |
| µg/L | Micrograms per liter. | |
| µm | Micrometer. | |
| µmhos/cm | Micromhos per centimeter. | |

# WATER QUALITY AND STREAMFLOW DATA FOR THE WEST FORK TRINITY RIVER IN FORT WORTH, TEXAS

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## ABSTRACT

Water-quality and streamflow data were collected on the West Fork Trinity River in Fort Worth, Texas on November 10 to 14, 1980, to test a Lagrangian water-quality model. The data described conditions of steady flow but time varying water-quality conditions. Measured constituents included DO (dissolved oxygen), water temperature, pH, specific conductance, BOD (biochemical oxygen demand) and the following dissolved chemicals: kjeldalh nitrogen, ammonia, nitrite, nitrate, orthophosphate, phosphorus, total carbon and inorganic carbon.

Data were collected to define the initial conditions, boundary conditions, and conditions in the stream that can be compared to model predictions for a subsequent modeling study. The initial data defined stream water-quality at the beginning of the study. The boundary conditions described flow and loads entering the 13.4-mile segment from the headwaters and three tributaries.

Trends in stream conditions were measured in two ways. Sampling every 2 to 4 hours at four sites gave the diel fluctuations. To avoid advective uncertainties, stream conditions were also defined with a Lagrangian sampling program that involved tracking dye through selected reaches and sampling as the dye peak passed selected points.

Several factors seemed to affect stream quality. In addition to diel fluctuations of DO and pH that indicated the importance of photosynthesis in some reaches, deoxygenation and nitrification also seemed important. Lagrangian samples showed a decline in BOD and ammonia with distance downstream from polluted tributaries. The deoxygenation rate constant was approximately 0.1 to 0.2 per day (base e) and carbonaceous BOD varied from 3 to 11 milligrams per liter. The first order rate constant for nitrification from bottles tests was approximately 0.8 per day (base e) and ammonia concentrations ranged from 0.11 to 2.6 milligrams nitrogen per liter. Reaeration coefficients were measured as essentially zero in the pooled reaches and as much as 3.6 per day at 20 degrees Celsius in the riffle-dominated reaches.

Overall the loads into the stream seemed to be well defined by the data. Background loads measured at the head of the study reach came from a mixture of distributed urban and rural sources upstream of the reach. One tributary seemed to consist of untreated sewage. A second tributary conveyed treated sewage to the stream. A minor tributary drained an urban area.

# INTRODUCTION

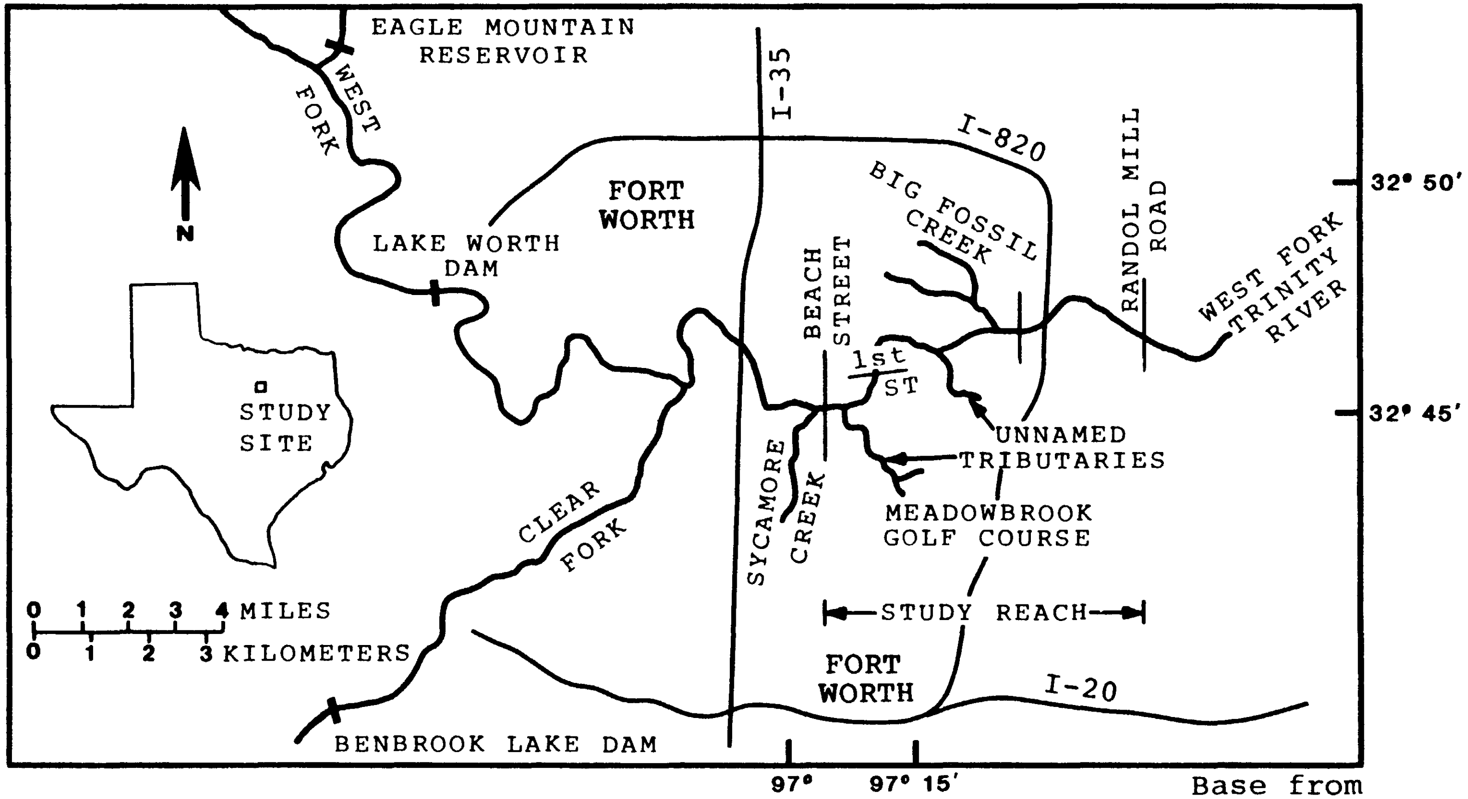
Data were collected over the four day period, November 10 to 14, 1980 on the West Fork Trinity River in Fort Worth Texas to define the diel and longitudinal variation in stream water-quality. These data were collected to calibrate a one-dimensional, dynamic, water-quality model (Jobson, 1981) because a paucity of data existed (McCutcheon, 1983).

A 13.4-mile reach downstream of the U.S. Geological Survey stream gaging station at Beach Street shown in figure 1 was chosen because the records at the site showed significant diel variation in DO (dissolved oxygen), water temperature, and pH and because Promise and others (1979) had shown that unsteady discharge caused by rainfall and reservoir releases had a marked effect on DO. Although these data were collected during a steady flow period, it was desirable to work on a stream where DO was affected by unsteady discharge in the event that a follow up study was carried out to factor in the effect of unsteady discharge. In addition, there were water quality problems that were of interest to local governments (North Central Texas Council of Governments, 1979 and Hydrosciene, 1974) and the effect of reservoir releases was of interest to the U.S. Army Crops of Engineers who assisted in the study. Finally, this choice of a site made it possible to study water-quality transport in a pool and riffle type stream.

The water-quality data collected for model testing, primarily involved constituents that effect DO and nutrients. Reaeration, deoxygenation, nitrification, and photosynethesis were forecast as the important water-quality processes. Accompanying dye studies were conducted to define the transport and mixing in the stream, which were also forecast as important processes.

This report is a compilation of the data that were collected for model testing and a description of how those data were collected and reduced. The second section of this report describes how data were collected. This included collecting water-quality samples once at various sites at the beginning of the study to define the initial or start up conditions, collecting samples frequently at various sites to define diel changes, and collecting Lagrangian data (collected from discrete moving parcels of water) to better define longitudinal changes and reaeration capacity. Meteorological data were collected to model water temperature and phytoplankton if necessary. Discharge measurements were also made to define the amount of water moving through the stream.

The third section of this report describes the analytical techniques used to analyze samples and to make measurements. This establishes that the data is useful for model testing. Most techniques were standard except that an ammonia probe and a long term carbonaceous and nitrogenous BOD (biochemical oxygen demand) test were used.



Base from
Fort Worth
1:62,500

Figure 1.--Study reach and adjacent area.

The fourth section summarizes the water-quality, hydraulic, and meteorological data collected. Accuracy, precision, and the instream lateral variation of some types of data are determined to confirm the usefulness of the data.

Finally, the results of the study are summarized. Several techniques were tested and this section gives improvements that can be implemented in future studies.

Additional reports have been published or are planned on the continuing analysis of the data reported herein. Jobson and Rathbun (1984) have analyzed the gas and dye tracer data collected in reaeration studies using the Lagrangian model of Jobson (1981) to determine reach averaged gas desorption coefficients in this pool-and-riffle stream characterized by low reaeration coefficients. McCutcheon (1984) has also compared BOD tests run during the preliminary sampling phase using the standard 300 mL bottle and 60 mL bottle. There was no significant difference in the five-day and ultimate BOD and the specific rate constant derived from the two different tests. Jennings, McCutcheon, and Flynn (1982) used BOD data collected in this study to illustrate the difference in a linear and nonlinear least squares fitting procedures.

Several agencies assisted in the study. The U.S. Army Corps of Engineer Waterways Experiment Station funded the laboratory work, loaned equipment and Marc Johnson, Linda Johnson, Mary Jo Shiner, John Nestler, and Scott Morris assisted with data collection. The Texas District of the Geological Survey assisted in planning and conduction of the study and loaned equipment. The State of Texas Department of Water Resources loaned equipment and David Buzan and Lynn Coles assisted in reaeration studies. The U.S. Environmental Protection Agency collected aerial photographs and James Gibson assisted in sample handling. The City of Fort Worth Village Creek STP (Sewage Treatment Plant) provided helicopter overflights, information, and made ammoniafree water available on an emergency basis. Calvin O'Neill of the National Mapping Divison of the Geological Survey designed and interpreted the Environmental Protection Agency aerial photography experiment. Dick Peckham of the U.S. Environmental Protection Agency conducted the overflight. Carl Scott and Doreen Tai of the Geological Survey performed sample analysis at the Gulf Coast Hydroscience Center.

The data collected are useful for model testing. Initial, boundary, and instream conditions are well defined by the data. A number of interesting trends were also defined. An overwhelming majority of the data are relatively precise and accurate and are thus reliable for use in testing.

# DATA COLLECTION SCHEMES

## Data Collection at Fixed Sites

Following some preliminary sampling at the head of reach and major tributaries on October 15 and 16, 1980, the detailed sampling began at 0600 hours, November 10, 1980, and lasted until 0600 hours, November 14, 1980. Discharge, temperature, DO, pH, and specific conductance were measured directly at the site. Samples were collected to determine BOD, dissolved kjeldahl nitrogen, dissolved ammonia, dissolved organic nitrogen, dissolved nitrite, dissolved nitrate, dissolved orthophosphate, dissolved phosphorus, dissolved total carbon, dissolved inorganic carbon, and dissolved organic carbon. The November study involved repetitive data collection at several fixed sites on the river supplemented with Lagrangian data collection from tagged parcels of water, and data collection at various meteorological sites.

Data was collected at the eight fixed sites shown as triangles in figure 2. These sites included five sites spaced approximately equidistant over the 13.4-mile stream reach and three sites on tributaries as near the confluence as possible. Typically, these sites were located near a bridge or where access was readily available. Sites were avoided where chemical and biological constituents were not equally distributed over the cross section.

Over the 96-hour study, data were collected at approximately two-hour intervals during the day and four-hour intervals during the night. The rapid change in DO during the day made the two-hour data collection frequency necessary. Data collection began on November 10 at seven sites. On November 12, a tributary south of the abandoned Riverside STP was discovered and data were collected there during the last day of the study. The data collected at Beach Street and from the tributaries, which define the loading into the stream, also were intended to define the boundary conditions for a model of the study reach. The instream data collected at the four sites downstream of Beach Street were collected to evaluate model predictions in the stream by comparing these data with model predictions.

In the first few hours of the study, two crews collected data at nine intermediate sites shown as squares in figure 2. These nine one-time samples plus five samples collected at the fixed sites (Eulerian sites) on the river (all sites spaced roughly 1 mile apart) provided an initial definition or "snapshot" of the water quality. This initial definition was necessary for modeling the stream, in part, because the time of travel through the reach exceeded the 96-hour sampling time.

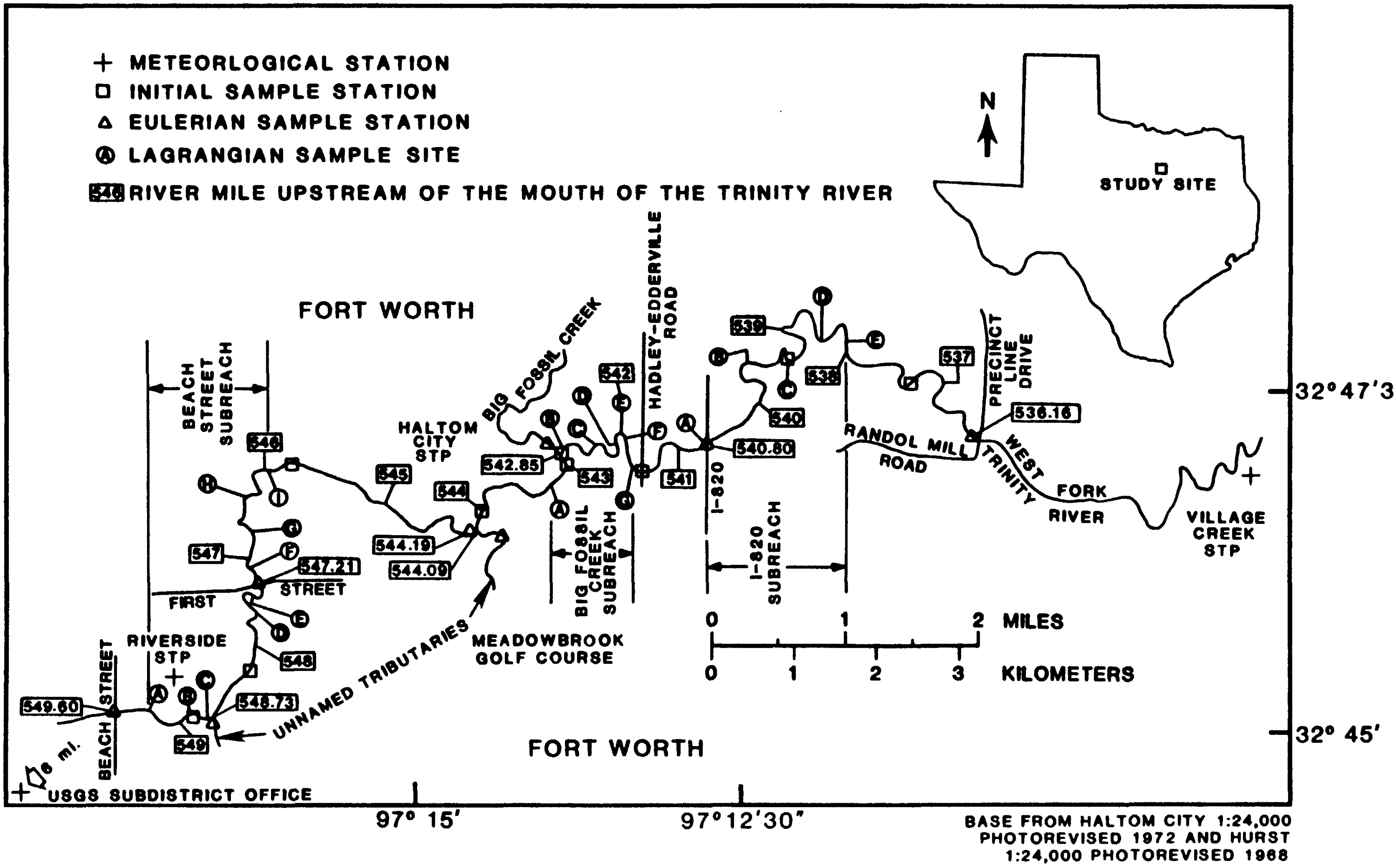


Figure 2.--Data collection sites.

Data also were collected simultaneously at Beach Street and repeated later at I-820 to determine the lateral variability at a fixed site. These data were collected at several equally-spaced points across the stream to measure how well a single grab sample and the accompanying measurement at the site would describe laterally averaged conditions that would have otherwise required a composite measurement and sample. This also gives an idea of how much variation is missed by using a one-dimensional model to simulate the stream.

To separate the random effects of measurement errors and sample handling from the effect of sampling and measuring location in the cross section, two large composite samples were collected; one at I-820 and one at Randol Mill Road. These two samples were split into 10 replicates and processed identically.

### Reaeration, Time of Travel, and Lagrangian Water Quality

One part of the November 10 through 14 study involved following or awaiting the arrival of tagged parcels of water in a Lagrangian fashion to determine reaeration capacity, time of travel, dispersive mixing, dilution, and changes in water quality. Measurements or reliable estimates of reaeration coefficients, times of travel or river velocities, and dispersion coefficients are often times necessary to precisely simulate river water quality. Because estimates of these coefficients and properties are generally unreliable, they were measured over 62 percent of the length of the study reach. Use of this Langrangian water-quality data also simplifies the calibration of a model because the advective uncertainity found in fixed site measurements is reduced. This advective uncertainity arises because the time of travel between points is difficult to measure or estimate.

Three parcels each of approximately 90,000 cubic feet of water, were tagged with hydrocarbon-gas tracers and rhodamine WT dye and followed 20 to 31 hours. Figure 2 shows the three subreaches over which parcels were followed. The first parcel was followed past I-820 Bridge (river miles 541.07 to 538.13) over the first day and night (Nov. 10-11). The second parcel was tagged upstream near the mouth of Big Fossil Creek (river miles 543.39 to 541.70) to avoid interferrence from the first dye injection and followed over the second day and night (Nov. 11-12). The third parcel was tagged at Beach Street (river miles 549.60 to 545.97) and followed for the third day and night and fourth day (Nov. 12-13).

Water-quality data (hereafter referred to as Lagrangian water-quality data) were collected about every three hours at the dye cloud peak. The data collection methods employed at fixed sites (Eulerian sites) were used, except that raw water samples were preserved on ice for up to 12 hours rather than one to four hours. After the dye studies were completed, laboratory analysis of the dye samples indicated that some of the water-quality samples were collected just before or after the actual peak arrival. This difference was generally less than 30 minutes.

Short continuous injections of dye, propane, and ethylene were made simultaneously to measure, time of travel, dilution, mixing, and gas transfer (Rathbun and others, 1975). Table 1 gives information about the injections. The dye solution was injected using a positive displacement metering pump powered by a 12-volt battery. The gases were injected by bubbling through porous plate diffusers placed on the bottom of the river. Average flow rates of the gases through the diffusers were 0.39 standard cubic feet per minute for ethylene and 0.42 standard cubic feet per minute for propane. The gases were injected at the same points and for the same time periods as the dye.

Movement of the dye and dissolved gas downstream was monitored by two boat crews equipped with Turner Designs Model 10[1] fluorometers according to the technique of Rathbun and others (1975). The first sampling site, designated A, was located so that the time of travel from the injection point was about one hour. Subsequent sampling sites designated B and C were located so that there was approximately three hours time of travel between sites. At sites A, B, and C, a boat was anchored downstream of the dye cloud and samples were collected at a frequency ranging from 5 to 40 minutes as the tracers moved pass that point. Dye samples were collected in 60-mL (milliliter) glass bottles with screw caps. Gas samples were collected with a displacement-type sampler, preserved and stored in 40-mL glass vials with septum screw caps. Care was taken to avoid air space in the gas samples. At sites B and C where the tails of the dye distributions were much longer, the procedure was to collect grab samples until the concentration had decreased to about 50 percent of the peak concentration. At this time, an automatic dye sampler (Kilpatrick, 1972) was started and used to collect the rest of the samples.

Additional samples of the dye concentration were obtained by a third sampling crew as the dye moved downstream. These samples were obtained by moving a boat through the dye cloud until the point of maximum concentration, as determined by fluorometer measurements, was reached. At this peak, grab samples for dye, gas, and water quality were collected, the time recorded, and the location of the point was marked on the river bank for later identification. This procedure was repeated at approximately three-hour intervals, and the sites were designated D, E, F, G, H, or I.

Sampling sites for the three Lagrangian subreaches are differentiated by labeling the I-820 subreach as 1, the Big Fossil Creek subreach as 2, and the Beach Street subreach as 3. Therefore sites in the Beach Street subreach become 3A, 3B, 3C,..., 3I.

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[1] The use of brand names is for identification only and does not constitute endorsement by the U.S. Geological Survey.

Table 1.--Details of the dye injections for time of travel determinations

| Nov. 1980 date | Injection point (river mile) | Starting time of injection | Duration of injection (minutes) | Concentration of dye injected (μg/L) | Average injection rate (gal/h) |
|---|---|---|---|---|---|
| 10 | 541.07 | 0953 | 67 | $10.6 \times 10^7$ | 0.336 |
| 11 | 543.39 | 1002 | 38 | $8.99 \times 10^7$ | 0.334 |
| 12 | 549.60 | 0922 | 60 | $12.8 \times 10^7$ | 0.330 |

The sites were marked by painting the bank of the river or some prominent log or piece of debris with different colors of spray paint. Then during a helicopter flight over the study reach, the locations of the sites were marked on topographic maps and aerial photographs.

## Discharge and Meteorological Data Collection

Discharge measurements were made to define model boundary conditions (flow rate at Beach Street and in tributaries) and to confirm that discharge remained steady as expected. Discharge measurements were made at Beach Street (upstream boundary) and Randol Mill Road Bridge (downstream boundary) and on the tributaries, at the beginning and end of the study. Discharge was also measured at some Lagrangian sites as part of the standard reaeration measuring procedure. These measurements were generally made at the time the tracers were passing through the cross sections. Stage was measured periodically at each fixed Eulerian sampling site to check for changes in discharge during the study. A stage recorder at Beach Street provided a continuous record of stage from which discharge could be estimated.

Solar radiation was observed at the subdistrict office in Fort Worth, Texas approximately 6 miles south southwest of the upstream end of the reach. The total incoming solar radiation was determined by use of an Eppley precision spectral pyranometer. The pyranometer was calibrated in March 1979 and stored in the laboratory until used in the study. The sensor was mounted on the roof of the Geological Survey office building at the Forth Worth Federal Center. The horizon was free of obstructions except for a water tank which was approximately 135 feet east of the the sensor. The tank was about 54 feet in diameter and extended about 60 feet above the sensor. It is believed that the effect of the tank shadow on the sensor readings was negligible. The sensor output was recorded on a strip chart recorder housed in the office building.

Wind speed, air temperature, and relative humidity were observed at two sites. One site at the inactive Riverside STP was located about 0.7 river miles downstream of the upper end of the reach. At this site a cottonwood shelter was erected on a small knoll such that the shelter was relatively free of wind obstruction. Figure 3 is a photograph of the site at Riverside STP looking west. The other site was located at the Village Creek STP which is 16.5 miles east of the upstream end of the reach. At the Village Creek STP the cottonwood shelter was shielded from north winds somewhat by the levee along the river. Figure 4 is a photograph of this site looking to the north. The wind fetch from the other directions was much longer than from the north.

The instrumentation at Riverside STP and Village Creek STP was identical. Each shelter contained a hygrothermograph with a 7-day chart from which temperature and relative humidity could be read. A Bedford cup anemometer was mounted on a steel pipe near the shelter

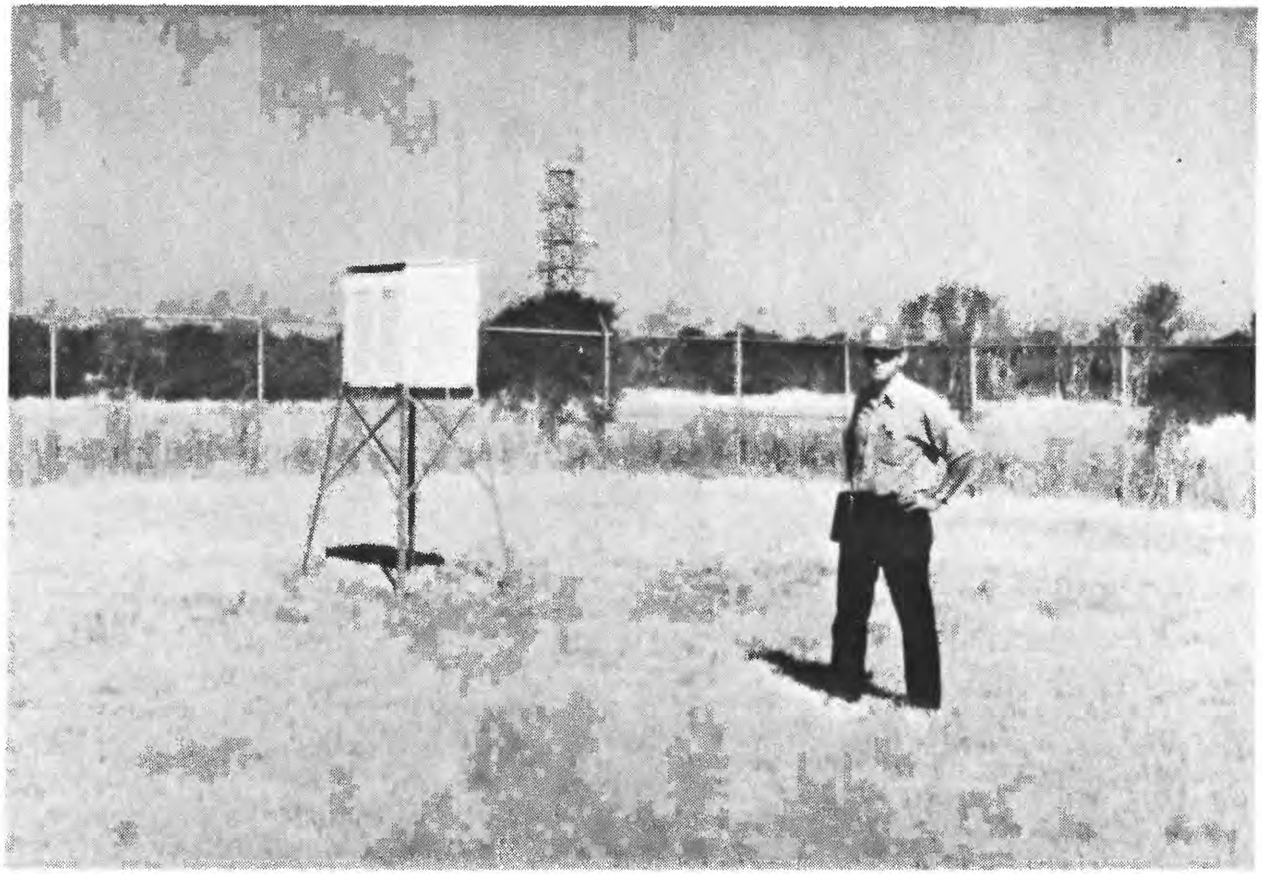

Figure 3.--Exposure at the Riverside STP Meteorologic Station (Sept. 1980).

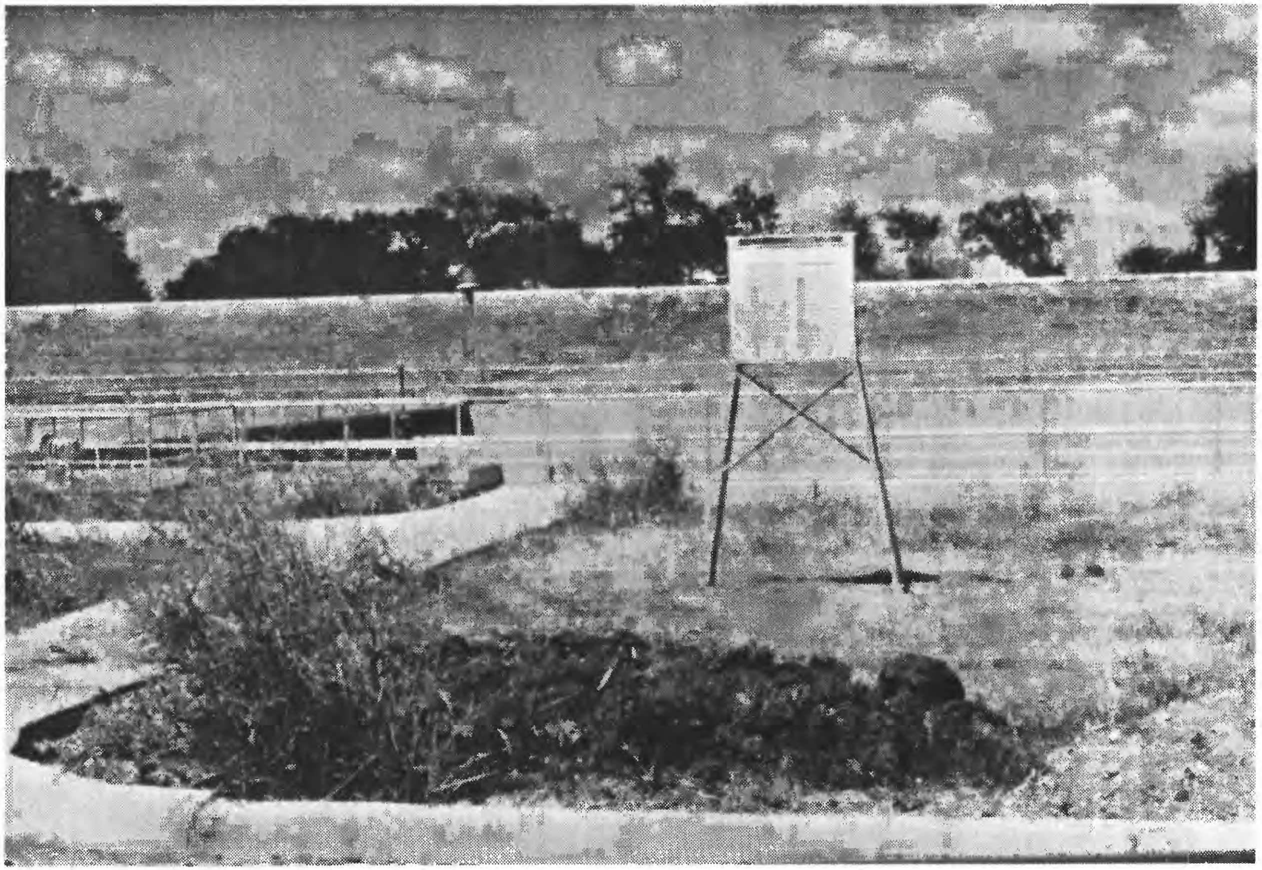

Figure 4.--Exposure at the Village Creek STP meteorological station (Sept. 1980).

at a level of approximately 2 meters (6.6 feet) above the ground. In addition to a dial, recording the total wind passage, the anemometers were equipped with a switch which closed upon the passage of each 10 miles of wind. The time when these switch closures occurred were recorded by an event marker on a circular chart. The chart made one revolution every 7 days.

The hygrothermographs and anemometers were new. Temperatures and humidities were checked by use of a wet and dry bulb psychrometer both in the laboratory and in the field. The hygothermograph appeared accurate to within about 0.5°C for temperature and 5 percent relative humidity as specified by the manufacturer. The accuracy of the anemometers was not checked.

## SAMPLING, MEASUREMENT, AND ANALYSIS

### Water-Quality Sample Collection and Measurement

During the first day of sampling and measuring the stream water quality, composite water samples were collected and corresponding measurements were made at several points across the stream. Later, after the measurements showed very little lateral variation at the various sites, grab samples were collected and measurements made, near the centroid of flow.

Because sampling crews were limited to short visits at each site, the procedure was as streamlined as possible while still insuring that samples were representative. During the first day and at other times where the site may have been poorly mixed (such as Lagrangian samples collected downstream of a tributary), composite samples were collected by filling a one gallon plastic bottle one-third full at each of the quarter points of the cross section. At each of the three equally spaced points, the bottle was uncapped and capped below the surface to avoid surface oils and grease. The sample was collected at 0.6 of the depth with the bottle pointing upstream. The entrainment of bottom material was avoided.

This sample was mixed by rotating the bottle several times by hand. To minimize prolonged contact with the plastic container, one liter was transferred as soon as possible to a glass bottle. Both samples were preserved on ice for one-fourth to twelve hours while enroute to a mobile laboratory at Beach Street for processing.

Measurements of DO, water temperature, pH, and specific conductance were made very near the same points where the samples were collected (at the centerline for grab samples and at the quarter points for composite samples) using the Hydrolab series 4000 multiparameter instrument. The probe was immersed in the stream upon arrival to allow the instrument to stabilize. This typically required 2 to 3 minutes. The instruments were calibrated prior to the study and checked at 2- to 6-hour intervals during the study. Each calibration or calibration check included measurements of pH in two buffered

Table 2.--Field Calibration of four-parameter monitors

[-- means that the reading was not made or not recorded]

| Nov. 1980 date | Time | Sp. cond. readings (µmhos/cm) | | | pH readings | | | Water Temperature (°C) | Barometric pressure (mm Hg) | DO saturation (mg/L)[a] | DO readings (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 500 µmhos/cm solution | 1000 µmhos/cm solution Initial | Adjusted | pH 7.0 solution Initial | Adjusted | pH 10.0 solution | | | | Initial | Adjusted |
| Instrument no. 369929 | | | | | | | | | | | | |
| 10 | 0600 | 496 | 1001 | -- | 7.0 | -- | 10.0 | 20.0 | 765 | 9.2 | 9.2 | -- |
| 10 | 1150 | 493 | 1000 | -- | 7.0 | -- | 10.0 | 25.0 | 765 | 8.4 | 8.7 | 8.4 |
| Instrument no. 354256 | | | | | | | | | | | | |
| 11 | 1209 | 506 | 1018 | -- | 7.00 | -- | 10.03 | 19.0 | 760 | 9.3 | 10.3 | -- |
| 12 | 0600 | 500 | 1000 | -- | 7.02 | -- | 10.08 | 14.0 | 767 | 10.4 | 10.4 | -- |
| 12 | 1000 | 498 | 1000 | -- | 7.01 | -- | 9.97 | 16.8 | 768 | 9.9 | 9.4 | 9.9 |
| 12 | 1400 | -- | 1000 | -- | 7.00 | -- | 9.93 | 25.2 | 765 | 8.4 | 8.2 | 8.4 |
| 12 | 1630 | 496 | 1000 | -- | 7.00 | -- | 9.94 | 25.6 | 765 | 8.4 | 8.2 | 8.4 |
| 13 | 0700 | 500 | 1000 | -- | 7.06 | -- | 10.14 | 9.2 | 765 | 11.7 | 11.7 | -- |
| 13 | 1100 | -- | 961 | 1000 | 7.00 | -- | 9.95 | 21.1 | 765 | 9.0 | 8.4 | 9.0 |
| Instrument no. 345961 | | | | | | | | | | | | |
| 10 | 0545 | 507 | 1000 | -- | 7.00 | -- | 10.03 | 18.0 | 765 | 9.6 | 9.6 | -- |
| 10 | 1000 | 507 | 1000 | -- | 7.00 | -- | 10.10 | 22.0 | 765 | 8.9 | 8.9 | -- |
| 10 | 1440 | 506 | 1005 | 1000 | 7.01 | -- | 9.98 | 22.6 | 760 | 8.7 | 9.1 | 8.7 |
| 11 | 0550 | 500 | 1000 | -- | 7.3 | 7.0 | 10.09 | 19.4 | 760 | 9.3 | -- | 9.3 |
| 11 | 0925 | 503 | 991 | 1000 | 7.6 | 7.0 | 10.03 | 16.1 | 768 | 10.1 | 9.6 | 10.1 |
| 11 | 1415 | 498 | 1001 | -- | 6.9 | 7.0 | -- | 19.2 | 766 | 9.4 | 9.7 | 9.4 |
| 11 | 1800 | 499 | 1000 | -- | 6.98 | -- | 9.98 | 20.6 | 765 | 9.1 | 8.8 | -- |
| 11 | 2145 | 496 | 1002 | -- | 7.00 | -- | 10.00 | -- | -- | 9.2 | 9.1 | -- |
| 12 | 0151 | 496 | 1002 | -- | 7.00 | -- | 10.00 | 17.8 | 770 | 9.7 | 9.7 | -- |
| 12 | 0520 | 496 | 1010 | -- | -- | -- | -- | 15.1 | 780 | 10.3 | 10.2 | -- |
| 12 | 1015 | 498 | 1012 | 1000 | 7.11 | 7.02 | 10.02 | 18.3 | 767 | 9.6 | 9.5 | 9.6 |
| 12 | 1440 | 490 | 1013 | 1000 | 7.03 | 7.00 | 9.95 | 22.2 | 765 | 8.9 | 9.1 | 8.9 |
| 12 | 1807 | 489 | 1011 | -- | 6.97 | -- | -- | 22.7 | 765 | 8.7 | 8.4 | -- |
| 12 | 2109 | 493 | 1000 | -- | 7.08 | -- | 10.02 | 18.0 | 765 | 9.6 | 9.5 | -- |
| 13 | 0035 | 494 | 1001 | -- | 7.02 | -- | 10.04 | 16.4 | 765 | 10.0 | 9.2 | -- |
| 13 | 0605 | 492 | 1004 | -- | 7.10 | -- | -- | 10.4 | 765 | 11.4 | 11.8 | -- |
| 13 | 1035 | 520 | 975 | 1000 | 7.00 | -- | 9.96 | 18.8 | 765 | 9.4 | 11.4 | 9.4 |
| 13 | 1530 | 516 | 1011 | 1000 | 6.88 | 7.00 | 9.93 | 21.2 | 760 | 9.0 | 8.6 | 9.0 |
| 13 | 1600 | -- | 1000 | -- | 7.00 | -- | 9.90 | 24.1 | 763 | 8.5 | 8.4 | 8.5 |
| 13 | 2215 | 490 | -- | -- | 7.11 | -- | 10.01 | 13.8 | 763 | 10.4 | 10.0 | -- |

Table 2.--Field Calibration of four parameter monitors--Continued

[-- means that the reading was not made or not recorded]

| Nov. 1980 date | Time | Sp. cond. readings (µmhos/cm) | | | pH readings | | | Water Temperature (°C) | Barometric pressure (mm Hg) | DO saturation (mg/L)[a] | DO readings (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 500 µmhos/cm solution | 1000 µmhos/cm solution | | pH 7.0 solution | | pH 10.0 solution | | | | | |
| | | | Initial | Adjusted | Initial | Adjusted | | | | | Initial | Adjusted |
| | | | Instrument no. 384441 | | | | | | | | | |
| 11 | 0640 | -- | 1006 | -- | 7.0 | -- | 10.0 | 21.0 | 766 | 9.1 | 9.1 | -- |
| 12 | 0630 | 480 | 1000 | -- | 7.0 | -- | 10.0 | 14.3 | 770 | 10.5 | 10.4 | -- |
| 12 | 2231 | 503 | 1011 | -- | 7.0 | -- | 10.17 | 15.2 | 765 | 10.2 | 10.4 | -- |
| 13 | 0700 | -- | 1000 | -- | 7.0 | -- | -- | [b] 9.7 | 765 | 11.5 | 11.7 | -- |
| | | | ODEC | | | | | | | | | |
| 10 | 0640 | 483 | -- | -- | 7.0 | -- | -- | 19.0 | 765 | 9.4 | 9.4 | -- |

[a] Field estimates that may be in error by as much as 0.2 mg/L.

[b] Mistakenly written as 19.7°C in the original notes.

solutions, measurements of specific conductance in two potassium chloride solutions, one measurement of DO in saturated air, and one measurement of water temperature that was compared to a measurement using a calibrated thermometer approved by the American Society for Testing and Materials. The calibration results are recorded in table 2.

Water temperature did not require adjustment and for that reason is not listed in table 2. The other properties did seem to drift some and the instruments were adjusted to correctly register the conductivity of the 1000 μmhos/cm solution, pH of the pH 7.0 buffer, and the DO of a saturated solution. Checks using the 500 μmhos/cm solution and pH 10.0 buffer did not indicate the need for adjustment. The instrument labeled ODEC, a spare used on one occassion, was an Ocean Data instrument rather than a Hydrolab instrument.

The greatest recorded drift in specific conductance was 39 μmhos/cm. The greatest drift in pH was 0.6. The greatest drift in DO was 2.0 milligrams per liter. However, the actual discrepancies may have been smaller because specific conductance and pH vary with temperature which was not taken into account during the calibration checks. DO calibration should have been checked more frequently. Evidently, the probe membranes fouled easily. In addition, the field tables for DO saturation concentration versus temperature and atmosphere pressure were somewhat imprecise, ± 0.2 milligrams per liter.

## Water-Quality Sample Handling, Preservation, and Control

All water-quality samples were collected, labeled, processed, and preserved in about the same fashion (see fig. 5). By treating each sample in the same way and adhering to a fairly strict sample handling procedure, the study was 99 percent successful in collecting the desired information.

Field crews began the procedure by collecting samples in a one-gallon plastic bottle and a one-liter glass bottle. These containers were stored at the mobile laboratory (furnished courtesy of the Louisiana District of the Geological Survey) at Beach Street. Seperate labels with an assigned control number and spaces for sample type (fixed site, initial, or Lagrangian), location, time, and date were attached to these raw water samples. As the field crew filled out these labels at the time of sampling, a log sheet for each sample was also filled out with sample type, location, time, date, method of sampling (composite versus grab), and site measurements (DO, water temperature, pH, specific conductance, and occasionally, stage). Occurrences of turbidity, aquatic plants, high velocity, and extraordinary conditions were noted on the log sheet.

The two raw water samples collected at each site were placed on ice while enroute to other sites and the mobile laboratory. Samples were usually delivered within 2 hours except for some

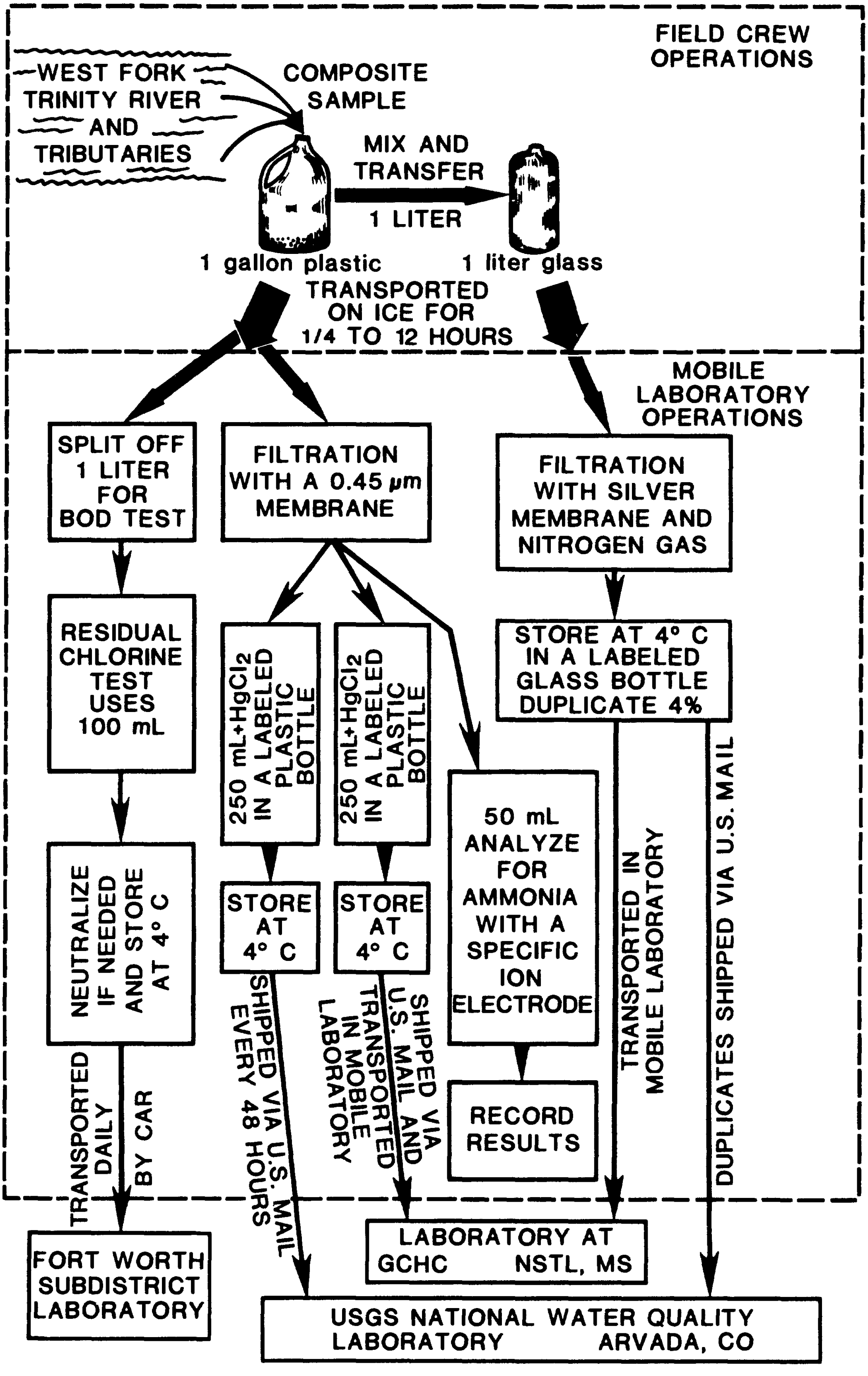

Figure 5.--Sample handling procedures.

Lagrangian samples (collected during dye studies) where the delay may have been as long as 12 hours.

The log sheet and raw water sample labels were checked when the samples were turned over to the laboratory personnel stationed at a mobile laboratory. Here the samples were processed and preserved. The processed samples were stored in prelabeled bottles that had the same control number as the original raw water sample.

At the mobile laboratory, the remainder of the one-gallon raw water sample was thoroughly mixed and one liter was transferred to a pre-labeled plastic bottle for the BOD determination. A test for residual chlorine was also conducted on this part of the sample and the subsample neutralized if necessary. The subsample was then preserved by refrigeration and transferred daily to the Fort Worth Subdistrict Laboratory for analysis.

The remaining part of the raw water sample was filtered with peristaltic pumps connected with silicone tubing to plate-type filters having 0.45- µm (micrometer) porosity membranes. One 250-mL sample subsample was collected for the determination of dissolved kjeldahl nitrogen and dissolved phosphorus at the National Water Quality Laboratory in Arvada, Colorado. A second 250-mL subsample was filtered for the determination of dissolved nitrite plus nitrate, nitrite, and orthophosphate at the Gulf Coast Hydroscience Center. A mercuric chloride ($HgCl_2$) tablet was added to each of the 250-mL filtered nutrient subsamples. The subsamples were then capped and refrigerated to await shipment to the appropriate laboratory. An additional 50 mL of filtrate was collected in a disposable plastic beaker for an ammonia determination in the mobile laboratory. Ammonia was determined immediately after filtration in the mobile laboratory using a specific ion electrode.

A part of the one-liter glass bottled sample, transferred immediately from the one-gallon plastic bottle sample collected directly from the stream, was filtered with a special filtration unit consisting of a small pressure cylinder of zero grade (carbon free) nitrogen gas, a pressure regulator and a stainless steel filter assembly fitted with flexible silicone tubing and 0.45-µm porosity silver membrane. The filtrate was collected in a prelabeled glass bottle, sealed, and refrigerated until shipment to the appropriate laboratories for determination of dissolved organic carbon. Four percent of the samples had replicate samples collected from the filtrate.

Every 48 hours, samples were placed in a cooler and shipped chilled to the National Water-Quality Laboratory in Arvada, Colorado. These included the 250-mL nutrient samples and the replicate dissolved carbon samples. Once the nutrient samples arrived at the laboratory in Arvada, 15 percent of the samples were selected randomly and these samples were also analyzed to determine ammonia, nitrite, nitrite plus nitrate, and orthophosphate. These replicate data were compared to ammonia determinations performed in the mobile lab and nitrite, nitrite plus nitrate, and orthophosphate determinations performed in the laboratory at the Gulf Coast Hydroscience Center.

Those samples to be analyzed at the Gulf Coast Hydroscience Center were refrigerated and transported in the mobile laboratory, except for the nutrient samples collected on the first 2 days that were shipped in a cooler by the U.S. Postal Service.

Testing at Arvada was completed in about 3 weeks. Analyses for nitrite, nitrite plus nitrate, and orthrophosphate at the Gulf Coast Hydroscience Center were completed 6 days after the sampling was finished. Analyses at the Gulf Coast Hydroscience Center for dissolved carbon were completed within 6 weeks.

Data from the three laboratories were later compiled on the original log sheets begun at the sampling site. The data were digitized, plotted, and checked. A few replicate samples for ammonia were retested at the laboratory in Arvada.

Because some tests were not run at the national laboratories, the data were not entered into the WATSTORE System.

## Laboratory Techniques

Laboratory techniques used to analyze samples ranged from standard, well-accepted methods to newer methods that are not yet well accepted. Table 3 lists the constituents determined and the laboratory where the tests were run.

Except for the long-term BOD test and the ammonia test, laboratory techniques were based on well-accepted standard methods. Ethylene and propane concentrations were determine at the National Water Quality Laboratory in Doraville, Georgia using the strip and trap procedure followed by analysis in a gas chromatograph (Shultz and others, 1976). Rhodamine WT dye samples were stored in a constant-temperature incubator until they were analyzed with a Turner Designs Model 10 fluorometer according to standard fluorometric procedures (Wilson, 1968).

Skougstad and others (1979) describe the techniques used to determine nitrite, nitrite plus nitrate, orthophosphate, kjeldahl nitrogen, and phosphorus. One modification to the orthophosphate method was necessary because samples were preserved with mercuric chloride to prevent biological degradation. Here a sodium chloride solution was substituted for the water diluent solution called for by Skougstad and others (1979).

Concentrations of total dissolved carbon and inorganic dissolved carbon were determined using a Beckman Model 915A Total Organic Carbon Analyzer. The laboratory technique is described in Beckman Instruments, Inc. (1974) and American Public Health Association and others (1981).

Table 3.--Laboratory testing and location

| Constituent | Location |
|---|---|
| BOD | Forth Worth Subdistrict Laboratory |
| Dissolved ammonia | Mobile laboratory and replicates tested at the National Water Quality Laboratory in Arvada, Colorado |
| Dissolved nitrite, nitrite plus nitrate, orthophosphate, total carbon, and inorganic carbon | Gulf Coast Hydroscience Center and replicates tested at National Water Quality Laboratory in Arvada, Colorado. |
| Dissolved kjeldahl nitrogen and total phosphorus | National Water Quality Laboratory in Arvada, Colorado |
| Ethylene and propane | National Water Quality Laboratory in Doraville, Georgia |
| Rhodamine WT dye | Gulf Coast Hydroscience Center |

As of 1984, long-term BOD tests have not been widely accepted as a standard method. Several alternative procedures have been used. Nevertheless, the test was deemed useful and the procedure used was that of Stamer and others (1983), modified to fit the requirements of this study. At the time of the study (1980), this procedure had been released as a technical memorandum from the Quality of Water Branch of the Geological Survey. Modifications involved the dilution water and incubation bottle size adopted from the standard procedures given in American Public Health Association and others (1976) and Knopp and McKee (1979). These modifications were checked using preliminary samples collected October 15 and 16, 1980. Details on these modifications are given in the next section.

Not all samples were tested for BOD. Laboratory space and manpower limited the number of carbonaceous BOD test to 250 out of 298 possible and replicate total BOD tests to 64. These total BOD tests were used to determine bottle nitrification. BOD tests were run for all Lagrangian and initial samples and for all samples collected at fixed sites on the first day. Thereafter, fixed-site samples were tested using samples collected every 4 hours (every other sample collected during the day and each sample collected at night). About every 8 hours a replicate total BOD test was run on Lagrangian samples and samples collected at I-820, at Randol Mill Road, from Big Fossil Creek, and on the last day, from the tributary south of Riverside STP.

Ammonia determinations for each sample were made in the mobile laboratory as soon as possible after samples were filtered using a Corning Model 130 pH Meter with a HNU Model ISE-10-10-00 Ammonia Electrode. Because this is not yet a well-accepted technique, 20 percent of the samples were analyzed in the laboratory in Arvada using the standard colorimetric technique (Skougstad and others, 1979) for comparison. More information on this technique follows.

## Carbonaceous Biochemical Oxygen Demand Test

While the 5-day BOD test (American Public Health Association and others, 1981), has been accepted as a standard for some time, long term BOD tests are only now recieving some acceptance (Young and others, 1981) despite the fact that recent studies (McKenzie and others, 1979 and Stamer and others, 1979) show that modeling ultimate BOD is more appropriate than modeling 5-day BOD. The long-term test suggested by Stamer and others (1983) involved checks for chlorine and abnormal pH, dilution if necessary with aged native stream water of high quality to avoid a correction for dilution water, and incubation at 20°C for 20 days.

During incubation in a 300 mL bottle, DO was measured initially and near days 1/2, 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 by inserting a DO probe into the bottle. Glass beads are added to compensate for lost sample volume. When DO approached 2 mg/L, the sample was reaerated. Dilution was limited to allow at least 2 mg/L of DO to be consumed; otherwise the test results were labeled substandard.

The test proposed by Stamer and others was modified by using an artificial water consisting of aged deionized water with the addition of a buffer solution and a bacterial seed from a sewer line near the subdistrict office (as in the 5-day test, see American Public Health Association, 1976) for dilution rather than native stream water.

Since all the blanks (samples of 100 percent dilution water) had a demand that exceed 0.2 mg/L per day by as much as 0.1 - 0.8 mg/L per day a blank correction was applied to all diluted samples (based on American Public Health Association, 1976). This amounted to subtracting the demand of the blank, factored for the amount of dilution, from the diluted sample DO demand. This assumed that DO demand of the dilution water was exerted at the same rate in the sample as in dilution blank.

Two procedural problems had to be investigated in some detail. These included failure of the nitrification inhibitor and the occurance of a chlorine residual.

Replicates with and without the nitrification inhibitor were prepared to test the effectiveness of the nitrification inhibitor, 2-chloro-6 (trichloromethyl) pyridine, known as Nitrapyrin. While the inhibitor seemed to be 100 percent effective during the preliminary study of October 15 and 16, 1980, one month later it was only 79 percent effective, perhaps because the chemical is unstable in a moist environment (Wayne Webb, U.S. Geological Survey, oral commun., 1982). Figure 6 illustrates this failure of the inhibitor after 15 days where the nitrogenous BOD curve shows a decrease. While this particular inhibited BOD sample has a suppressed, but fairly obvious, second stage, the nitrification breakthrough is not as obvious for most samples. The method used to detect and correct this problem is given in the section on deoxygenation coefficients.

Special attention was paid to the chlorine residual test because the Fort Worth Subdistrict Office had observed a reappearance of chlorine residuals in BOD samples taken several miles downstream of the study reach. They collected samples in which the chlorine residuals were tested for and neutralized in the field. Upon return to the laboratory about a day later the residual had reappeared and was again neutralized. At the end of the 5-day test the residual had again reappeared. This phenomenon, which may have been the result of the buildup of nitrite or release of chlorine from bonds with organic nitrogen, casts some doubt on the reliability of such BOD tests. Fortunately, this problem did not occur in this upstream reach.

Another unexpected problem did arise. A residual was measured at several sites upstream of Big Fossil Creek where there were no

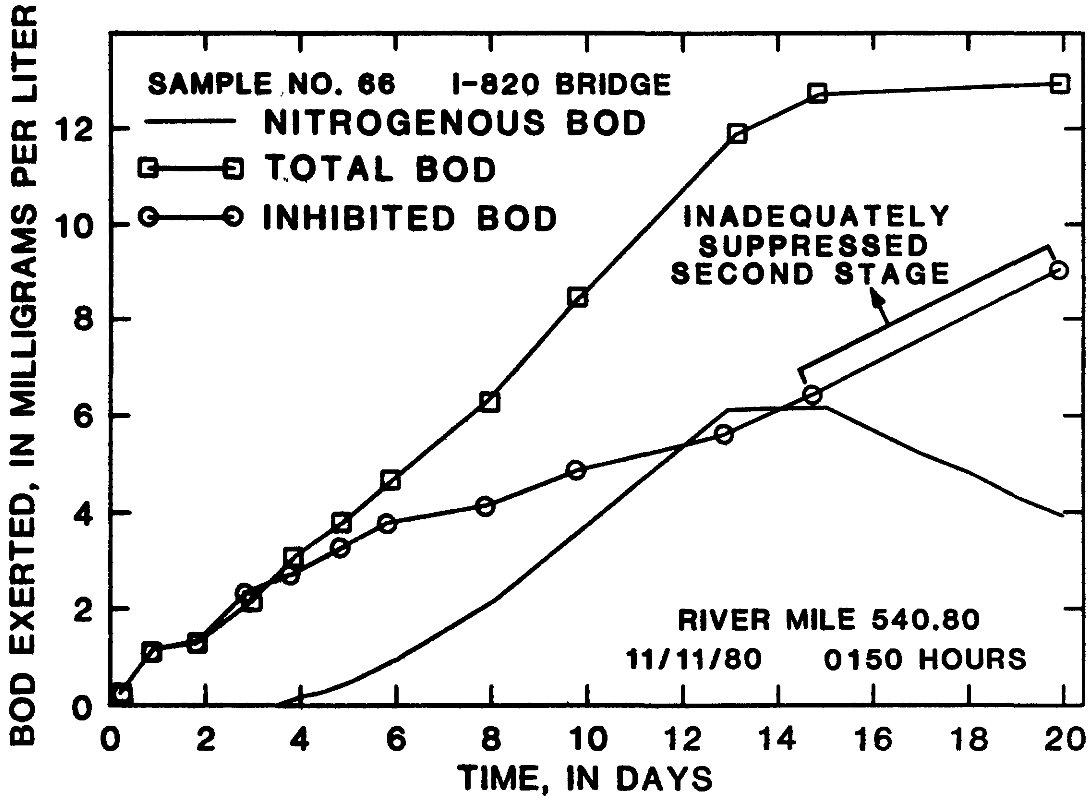

Figure 6.--Example of failure of the nitrification inhibitor after 15 days.

known sources of chlorine. A close examination of the 42 samples having a measured residual indicates that interference from nitrite or perhaps some other ion (American Public Health Association and others, 1981) may explain the measurements. In all cases, the reducing capacity of nitrite measured in each affected sample exceeded the measured reducing capacity from the residual test even in and downstream of Big Fossil Creek where some chlorine was likely to occur. In addition, there was no detection of a chlorine residual in the tributary south of Riverside STP. Here nitrite concentrations were much lower than at the other sampling sites. Furthermore, none of the upstream samples with a measured residual showed a lag in oxygen demand in the BOD test. Downstream, several samples did show a one-third to 1-day lag but so did a number of other samples not having a measured chlorine residual. The lag seemed to be a result of sample dilution rather than the existence of a chlorine residual. Therefore, it seems highly likely that nitrite interferred in the chlorine residual test.

## Ammonia Determinations

Ammonia concentrations were determined at the mobile laboratory near Beach Street using a specific ion probe. This approach avoided the delay and expense in sending the samples to the laboratory in Avrada for the standard colorimetric test. However, analysis onsite may be less precise due to the uncontrolled changes in environmental conditions and there is some suspicion that the probe may be more sensitive to the interference from aromatic amine compounds (Delbert Hicks, U.S. Environmental Protection Agency, oral commum., 1980).

Concentrations of ammonia in standard solutions and samples were determined by rinsing the electrode, submerging the electrode in a continuously stirred 50-mL aliquot (the electrode is tilted about 20 degrees from vertical), adding 0.5 mL of a 10 molal sodium hydroxide ionic strength adjustment buffer, and recording the lowest reading. Readings for a few samples with low concentrations would not stabilize, but continued to decrease slowly. In these cases a reading was taken at the end of 15 minutes.

A stock solution of 0.10 molal ammonium chloride was used to make eight standard solutions, ranging in concentration from 0.042 to 14.0 milligrams per liter as nitrogen. The electrode was calibrated approximately four times (with new standard solutions each time) in each 24-hour period as shown in figure 7. The calibration curves are spread because the air temperature in the mobile lab varied considerably, causing the calibration curve to shift as temperature changed. Linear regression was used to fit a line through the calibration readings. Most of the curves had a break point around 0.2 milligrams per liter as nitrogen. Three curves had two break points.

Calibration curves that preceded and succeeded the measurement in time were used to compute two concentrations for each sample.

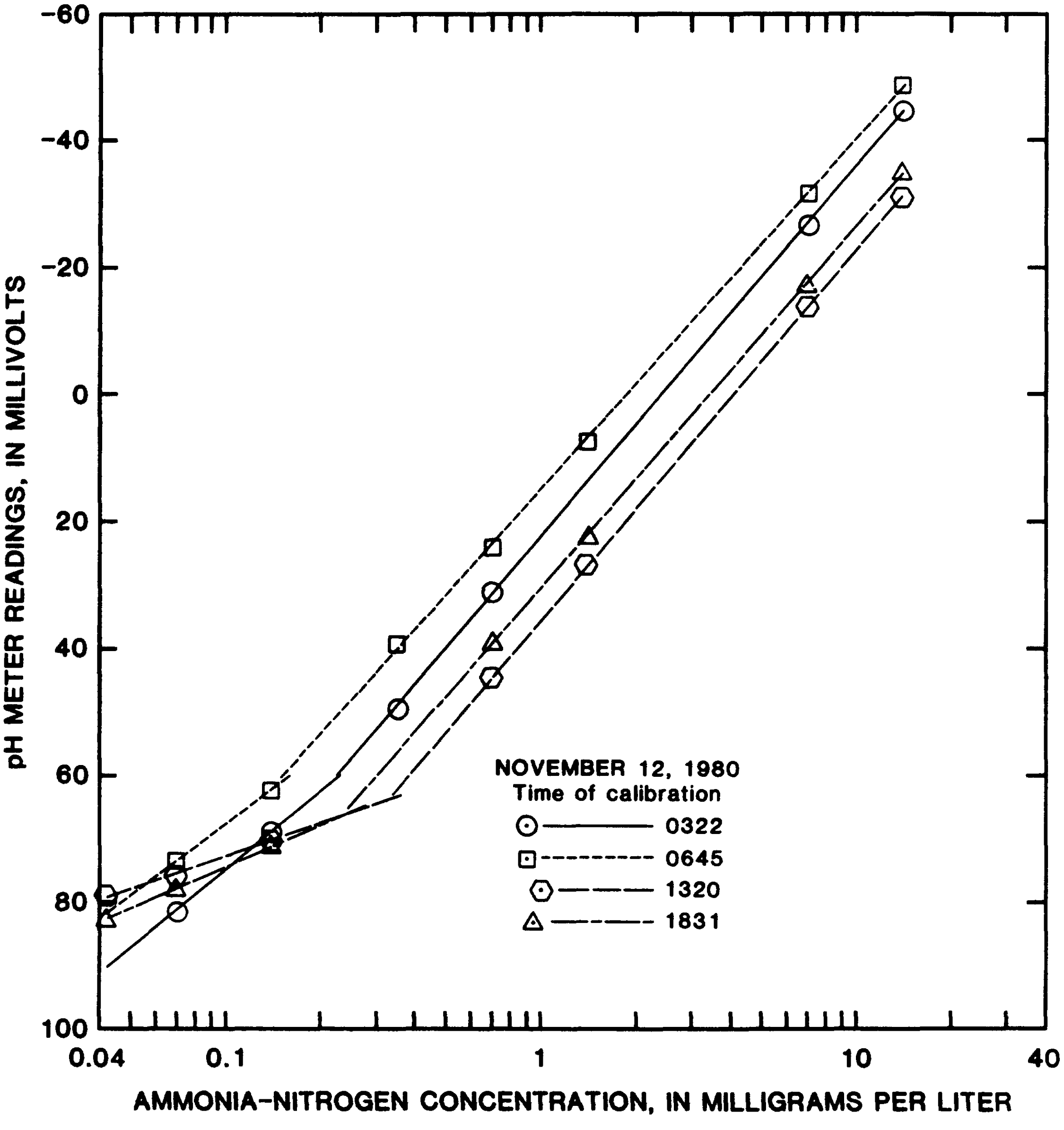

Figure 7.--Typical shift in ammonia probe calibration curves.

A weighted concentration value was then computed based on the time the sample was measured. Figure 8 shows typical concentrations and the bracketing concentrations from which the time weighted concentration was computed.

Results for the standard colorimetric test performed on 20 percent of the samples at the Avrada laboratory are also plotted on figure 8 as triangles. The few data available from the standard method are in close agreement with data collected using the probe. From these few data, there do not seem to be interferences present such as amine compounds that selectively effect one or the other techniques.

## RESULTS

### Streamflow

Flow in the West Fork Trinity River basin upstream of Fort Worth (2100 square miles) is affected by regulated releases from Eagle Mountain Reservoir and uncontrolled flow from Lake Worth (fig. 1). Water is diverted from Lake Worth for municipal and industrial purposes. Water is also released into the Clear Fork Trinity River from Benbrook Lake which was constructed to provide flood control and municipal and industrial water supply. The drainage area of Clear Fork Trinity River above Fort Worth is approximately 520 square miles. These factors along with rainfall occurring in the basin, return flows from residential and industrial areas and ground water seepage usually control the streamflow in study reach.

This study was conducted during a relatively steady, low-flow period (fig. 9) when no releases were reported from upstream at Eagle Mountain Reservoir, only 9 cubic feet per second was being released upstream at Benbrook Lake, and no rainfall was observed during or just before the study. Therefore, the 28 cubic feet per second average flow observed in study reach (table 4) was probably affected by upstream groundwater seepage into the channel and drainage from residential and industrial areas.

Figure 9 shows that discharge at Beach Street had been steady for about 8 days before the study having increased by about 5 cubic feet per second from a preceeding 12 day steady period. Therefore discharge had been very steady for 1.7 times the travel time through the study reach (110 hours) and relatively steady for about 4 times the travel time through the reach. Prior to that time and since the October 15 to 16 study, a large storm had significantly increased the discharge, perhaps flushing out the stream. In any event, that high flow or the high flows of September (uncharacteristically having the highest discharge of the year) did flush out quite a bit of the periphyton observed in early September.

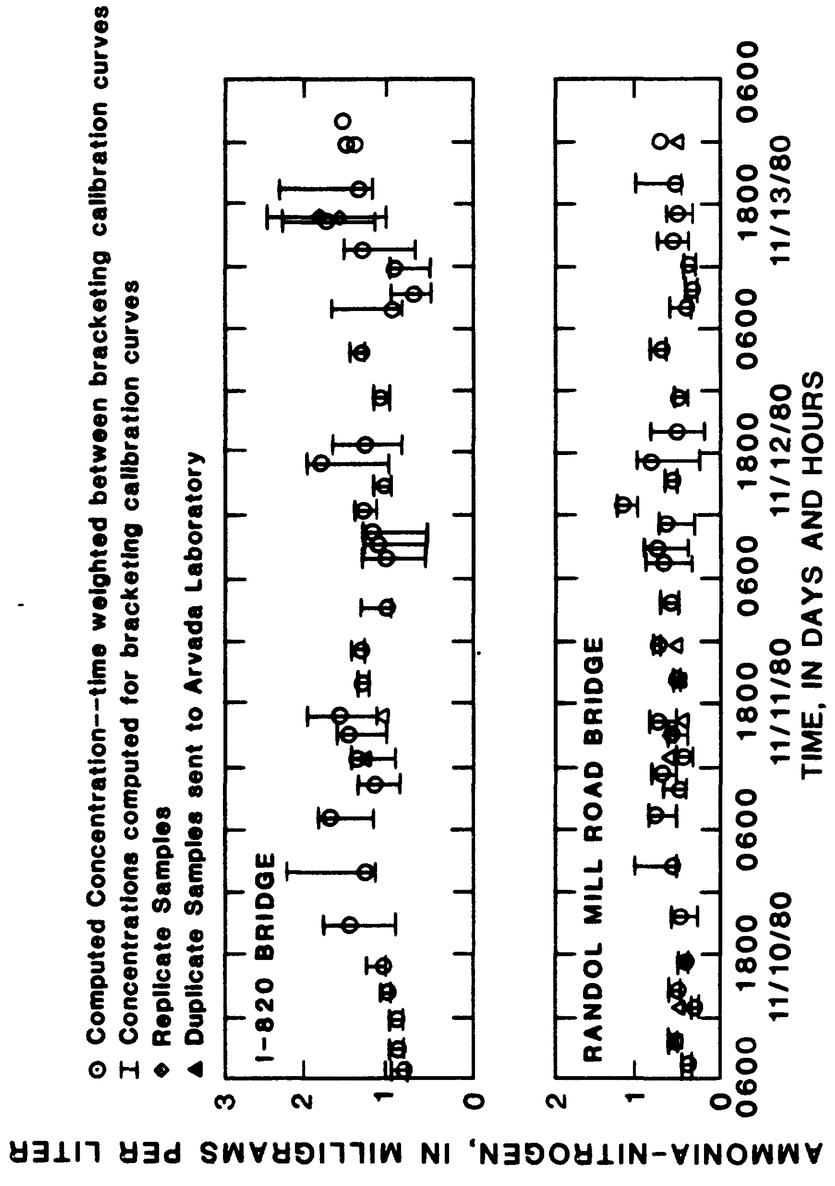

Figure 8.--Typical ammonia concentrations.

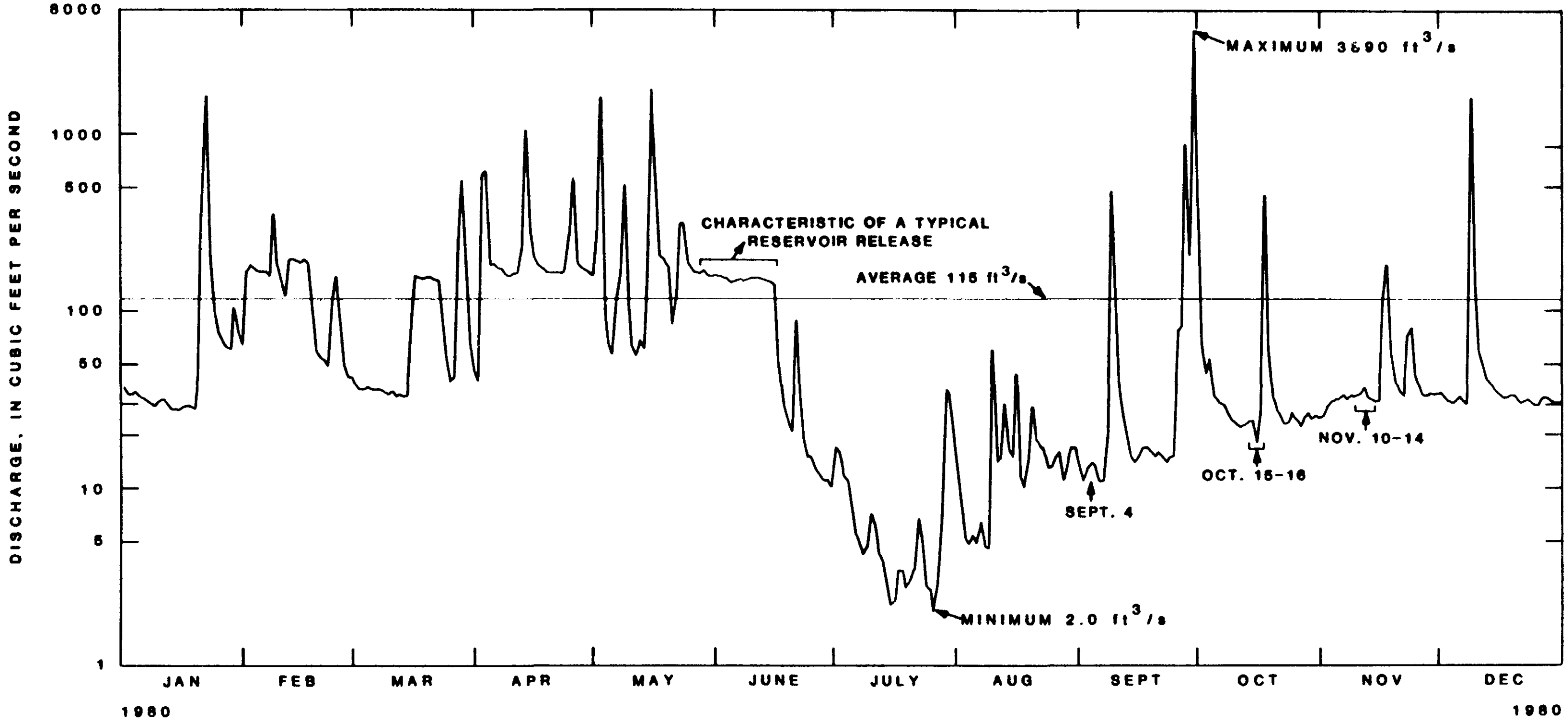

Figure 9.--Discharge in 1980 at Beach Street.

Table 4.--Measured stream flow in cubic feet per second

[For locations see fig. 2]

| Location | River mile | November 1980 date | | | |
|---|---|---|---|---|---|
| | | 10 | 11 | 12 | 14 |
| **West Fork Trinity River** | | | | | |
| At Beach Street Bridge | 549.60 | 33.6 | | | 29.4 |
| At Riverside STP approximately 0.25 miles upstream of site 3B | 549.14 | | | 26.2 | |
| Downstream of Riverside STP at site 3C | 548.73 | | | 26.0 | |
| Upstream of Big Fossil Creek at site 2A | 543.25 | | 27.2 | | |
| Downstream of Big Fossil Creek at site 2B | 542.77 | | 28.9 | | |
| At I-820 Bridge | 540.80 | 25.5 | | | 25.7 |
| River mile 639.41 at site 1C | 539.41 | 28.9 | | | |
| At Randol Mill Road Bridge | 536.11 | 26.6 | | | 25.2 |
| **Tributaries** | | | | | |
| Tributary south of Riverside STP | 548.73 | | | | 0.40 |
| Tributary near Meadowbrook Golf Course | 544.09 | 0.16 | | | 0.14 |
| Big Fossil Creek | 542.85 | 1.74 | | | 1.91 |

Except for the September event having the greatest discharge of year, the flows occuring during the year were typical. Spring rainfall results in high flows from March to May followed by reservoir release in early June. Low flows occur in July and August as a result of decreased rainfall and increased evapotranspiration.

While the streamflow measured during the November study was lower than the 1980 average of 115 cubic feet per second it was much greater than the lowest 1980 discharge of 2 cubic feet per second which occurs at least once every 3 or 4 years. The 7-day-10 year low flow is 1.8 cubic feet per second. The highest 1980 discharge of 3890 cubic feet per second which occurred about six weeks before the November 10 through 14 study is expected to occur once in about every 1.5 years. Thus the high and low flow during 1980 was not extraordinary.

While much of the flow arriving at Beach Street may have consisted of groundwater seepage and drainage, some flow in the study reach was lost, probably due to evapotranspiration exceeding study reach groundwater seepage and drainage into the channel. The average of discharge measurements decreased from 32 cubic feet per second at Beach Street to 26 cubic feet per second at reach end over the four-day study. The known inflows included flow entering from the tributary south of Riverside STP which seemed to consist of untreated sewage; flow entering from the tributary near Meadowbrook Golf Course which seemed to be urban drainage; and flow entering from Big Fossil Creek which was predominately treated sewage from the Halton City STP.

## Water Surface and Channel Profiles

At low flow the river consists of a series of pools separated by riffles (fig. 10). The riffles were formed by naturally deposited gravel and sand bars, stabilized in some cases by vegetation, and mats of filamentous algae. The bed of the channel is composed of sand, gravel, cobbles, and firm clay. The banks are fairly steep, 30 to 40 feet high, irregular, and eroded in some places, but having a dense cover of weeds, brush, and trees in other places. The 13.4-mile reach between Beach Street and Randol Mill Road Bridge meanders across the floodplain several times.

The depth of the water in the study reach in November varied from a few tenths of a foot at some of the riffles to more than 10 feet in some of the deeper pools. A typical depth for the entire reach was 5 to 6 feet.

The water surface profiles shown in figure 10 were estimated using channel cross sections from the U.S. Army Corps of Engineers, depth measurements collected September 3 to 4, 1980 while traveling downstream by boat, and elevations measured at several bridges. It was assumed that the loss of water from the channel was minor. The September flow routing was used to estimate travel time which was used to select sampling sites for the November study.

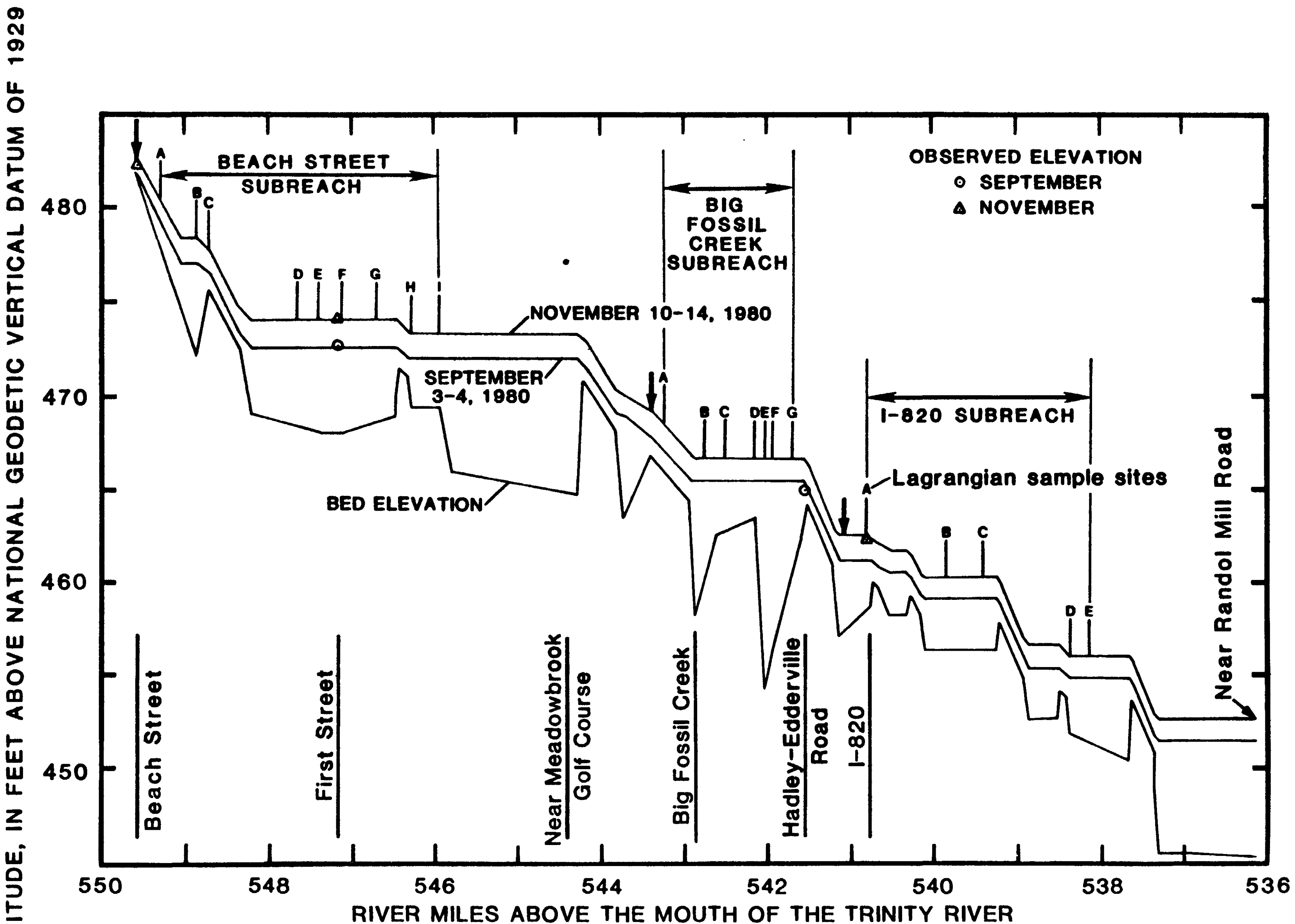

Figure 10.--Bed profile and water surface profiles for September and November steady flows.

The profiles of the channel thalweg and water surface in figure 10 also show hydraulic differences in the subreaches marked by arrows and lettered Lagrangian sampling sites where reaeration coefficients were measured. The Beach Street subreach is initially shallow followed by a long deep pool. The Big Fossil Creek subreach is largely contained in one long deep pool. The I-820 subreach covers a series of relatively shallow pools. Except for the Beach Street site, the fixed sampling sites (First Street, near Meadowbrook Golf Course, I-820, near Randol Mill Road) are located in pools or near the downstream end of a pool.

## Time of Travel

Time of travel and dye distribution were typical of pool and riffle streams. The peak and centroid of the dye cloud gradually separated and the trailing tail became elongated as the cloud moved downstream, (fig. 11).

The trailing edge was defined as the time at which the concentration had decreased to 1.00 percent of the peak concentration. If the concentration-versus-time data did not extend to this time, then the procedure used was to plot the logarithm of the concentration versus time for data in the tail region. A straight line through the data was then extrapolated to the time at which the concentration was 1.00 percent of the peak concentration.

One apparent anomaly occurred in the time of travel data for the trailing edge in the Beach Street subreach. The time of travel for the trailing edge at site 3C was slightly smaller than the time of travel of the trailing edge at site 3B. This apparently occurred because the sampling point at 3C was just upstream of a riffle section which caused the concentrations on the tail of the curve to decrease more rapidly than at 3B where the sampling point was in the center of a deep pool. At site 2B, (Big Fossil Creek subreach), the automatic sampler failed, missing the tail of the distribution. Therefore, time of travel of the trailing edge and centroid could not be determined for reach from sites 2A to 2B.

The time of travel or velocity (fig. 11) properly reflects hydraulic conditions. Velocity is highest for the subreach near I-820 Bridge that consisted of a series of shallow pools. Velocity is lowest in the long pool near Big Fossil Creek. The combination of shallows and a deep long pool downstream of Beach Street resulted in an intermediate velocity.

The times of travel of the leading edge, the peak, the centroid, and the trailing edge of the dye mass were determined from the dye concentration-versus-time data for sites A, B, and C of each of the three injections. These data are presented in tables 5 through 13. Time of travel of the peak dye concentration from tables 5 to 13 and from the measurements at sites D, E, F, G, H and I are summarized in the next section with the peak gas

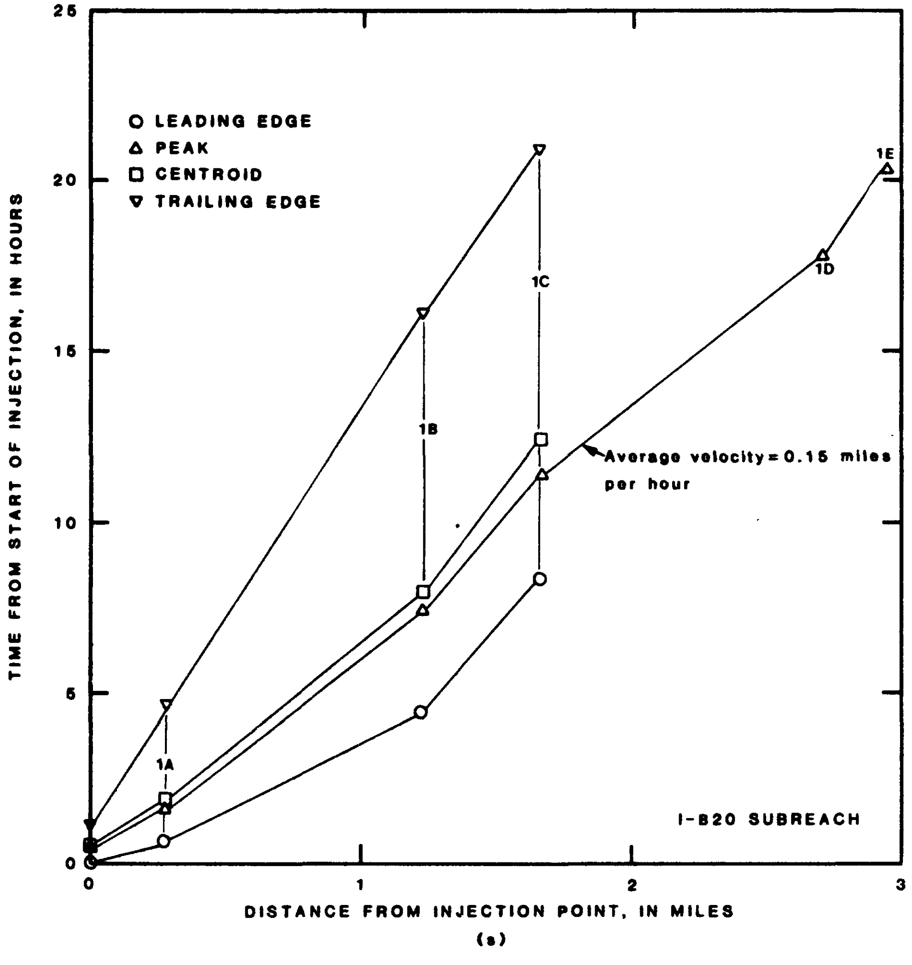

Figure 11.--Time of travel of parcels of water as a function of distance (a) I-820 subreach.

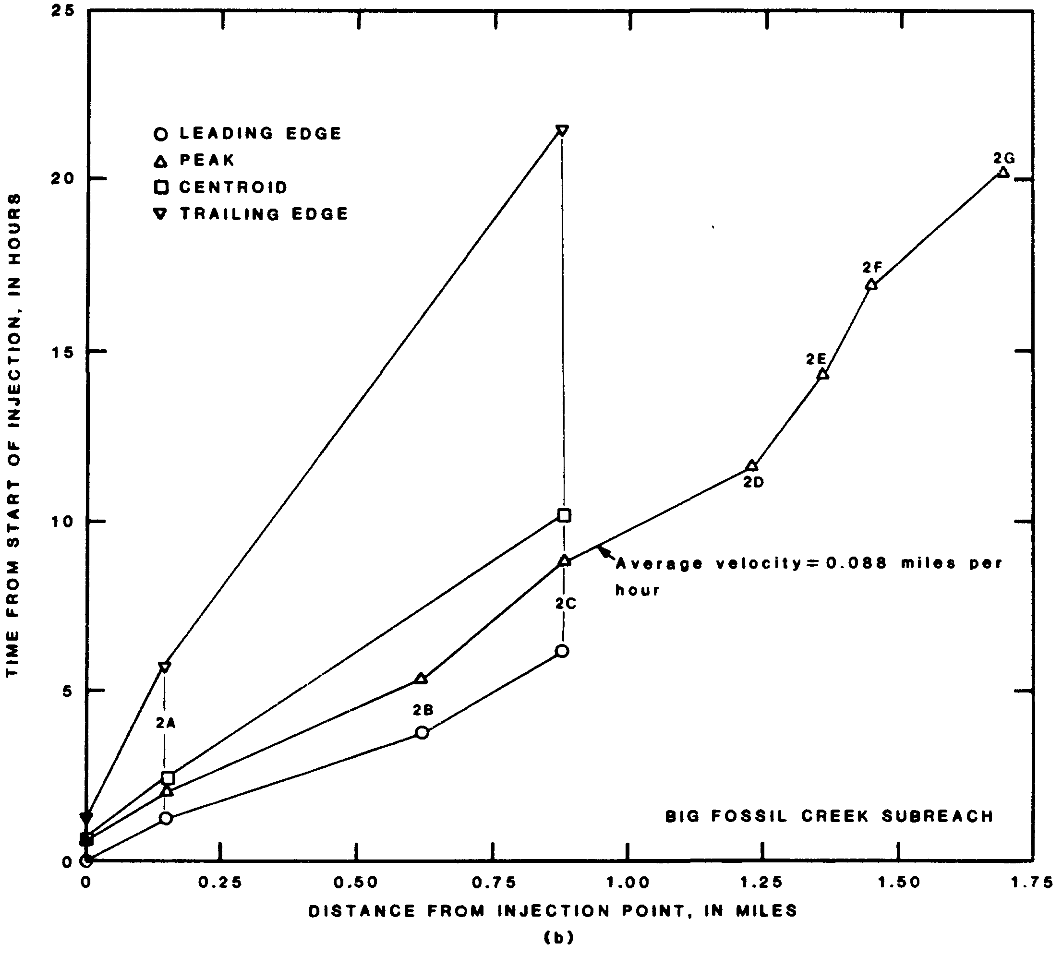

Figure 11.--Time of travel of parcels of water as a function of distance (b) Big Fossil Creek subreach.

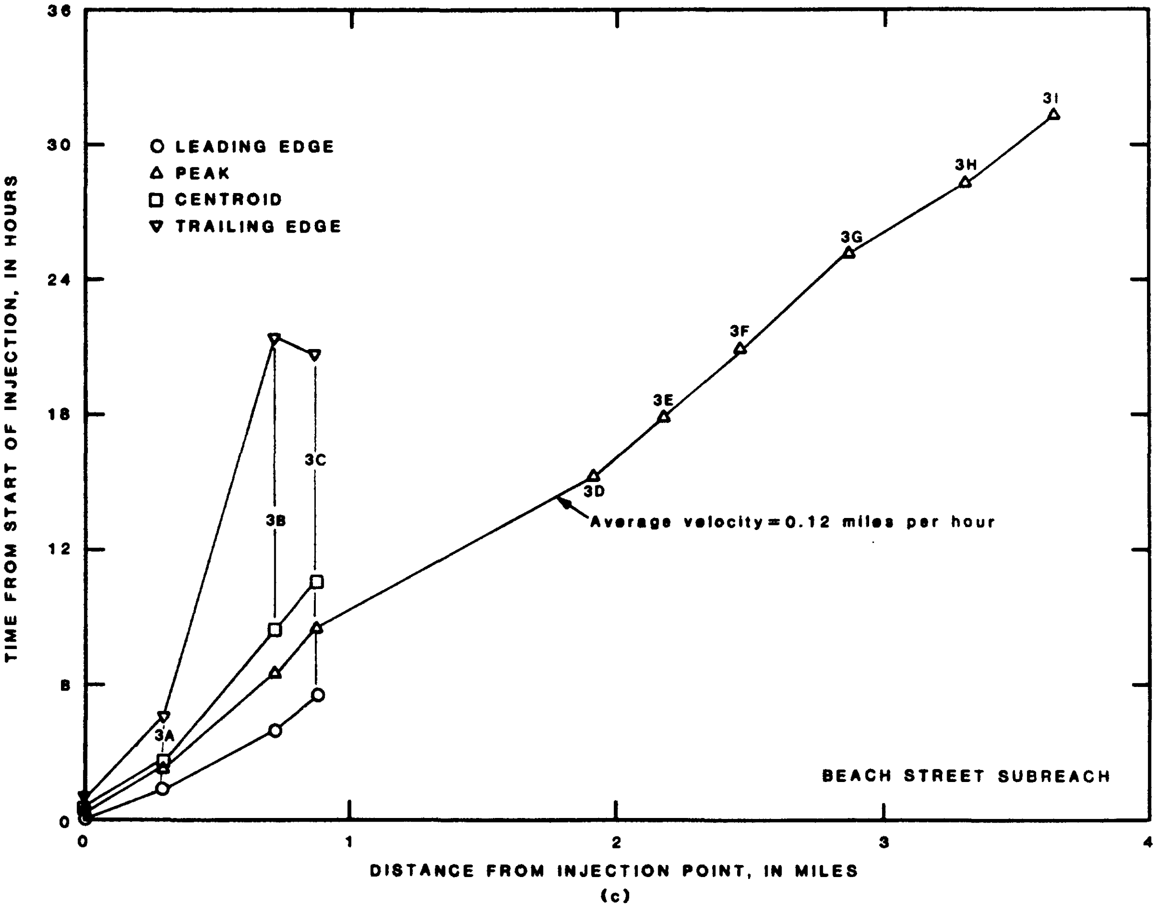

Figure 11.--Time of travel of parcels of water as a function of distance (c) Beach Street subreach.

Table 5.--Dye concentration as a function of time at site 1A, river mile 540.80, injection of November 10, 1980 starting at 0953 hours

| Time from start of injection (hours) | Dye concentration (µg/L) |
|---|---|
| 0.700 | 1.80 |
| .783 | 5.04 |
| .867 | 10.4 |
| .950 | 17.0 |
| 1.03 | 20.3 |
| 1.12 | 24.5 |
| 1.20 | 30.1 |
| 1.28 | 30.1 |
| 1.37 | 31.3 |
| 1.45 | 36.3 |
| 1.53 | 37.0 |
| 1.62 | 39.0 |
| 1.70 | 37.6 |
| 1.78 | 34.5 |
| 2.03 | 28.6 |
| 2.12 | 24.5 |
| 2.28 | 15.6 |
| 2.45 | 12.3 |
| 2.62 | 9.59 |
| 2.78 | 7.03 |
| 2.95 | 5.54 |
| 3.12 | 3.23 |
| 3.28 | 2.90 |
| 3.45 | 2.14 |
| 3.62 | 1.53 |
| 3.78 | 1.32 |
| 3.95 | 1.15 |
| 4.13 | .86 |
| 4.32 | .66 |

Table 6.--Dye concentration as a function of time at site 1B, river mile 539.85, injection of November 10, 1980 starting at 0953 hours

| Time from start of injection (hours) | Dye concentration (µg/L) |
|---|---|
| Grab Samples | |
| 5.12 | 1.13 |
| 5.37 | 1.77 |
| 5.45 | 2.27 |
| 5.53 | 3.16 |
| 5.62 | 3.49 |
| 5.70 | 4.10 |
| 5.78 | 4.45 |
| 5.87 | 5.58 |
| 5.95 | 7.14 |
| 6.03 | 7.14 |
| 6.12 | 8.20 |
| 6.28 | 10.2 |
| 6.37 | 10.7 |
| 6.45 | 11.5 |
| 6.53 | 12.5 |
| 6.62 | 12.6 |
| 6.70 | 13.3 |
| 6.78 | 14.3 |
| 6.87 | 14.0 |
| 7.03 | 14.6 |
| 7.20 | 14.7 |
| 7.37 | 14.8 |
| 7.53 | 14.4 |
| 7.62 | 14.1 |
| 7.78 | 13.7 |
| 7.87 | 13.0 |
| 8.03 | 12.4 |
| 8.20 | 11.0 |
| 8.37 | 10.2 |
| 8.53 | 9.48 |
| 8.70 | 8.84 |
| 8.87 | 7.78 |
| 9.20 | 5.88 |
| Grab Samples-Continued | |
| 9.50 | 5.03 |
| 9.72 | 4.32 |
| 9.97 | 3.53 |
| 10.2 | 3.01 |
| 10.4 | 2.25 |
| Automatic Samples | |
| 10.6 | 2.71 |
| 11.0 | 1.95 |
| 11.5 | 1.55 |
| 11.9 | 1.25 |
| 12.4 | .94 |
| 12.8 | .71 |
| 13.2 | .54 |
| 13.6 | .38 |
| 14.1 | .35 |
| 14.5 | .24 |
| 15.0 | .30 |
| 15.4 | .20 |
| 15.8 | .18 |
| 16.2 | .15 |
| 16.7 | .14 |
| 17.1 | .12 |
| 17.6 | .11 |
| 18.0 | .08 |
| 18.4 | .07 |
| 18.8 | .40 |
| 19.3 | .07 |
| 19.7 | .06 |
| 20.2 | .06 |
| 20.6 | .07 |

Table 7.--Dye concentration as a function of time at site 1C, river mile 539.41, injection of November 10, 1980 starting at 0953 hours

| Time from start of injection (hours) | Dye concentration (µg/L) |
|---|---|
| Grab Samples | |
| 8.57 | 0.17 |
| 8.70 | .34 |
| 8.87 | .54 |
| 9.10 | 1.03 |
| 9.28 | 1.63 |
| 9.37 | 1.92 |
| 9.47 | 2.53 |
| 9.62 | 3.23 |
| 9.78 | 3.86 |
| 9.95 | 5.25 |
| 10.1 | 6.39 |
| 10.3 | 7.56 |
| 10.4 | 8.63 |
| 10.6 | 9.69 |
| 10.8 | 10.2 |
| 11.0 | 10.6 |
| 11.1 | 11.1 |
| 11.3 | 11.3 |
| 11.4 | 11.4 |
| 11.6 | 11.0 |
| 11.8 | 11.0 |
| 12.0 | 10.6 |
| 12.2 | 10.0 |
| 12.4 | 9.80 |
| 12.5 | 9.38 |
| 12.8 | 8.80 |
| 13.0 | 8.03 |
| 13.3 | 7.35 |
| 13.5 | 6.61 |

| Time from start of injection (hours) | Dye concentration (µg/L) |
|---|---|
| Automatic Samples | |
| 13.8 | 5.67 |
| 14.0 | 5.36 |
| 14.3 | 4.53 |
| 14.5 | 3.88 |
| 14.8 | 3.51 |
| 15.0 | 3.08 |
| 15.3 | 2.62 |
| 15.5 | 2.42 |
| 15.8 | 2.00 |
| 16.0 | 1.90 |
| 16.3 | 1.60 |
| 16.5 | 1.36 |
| 16.8 | 1.17 |
| 16.8 | 1.11 |
| 17.1 | .96 |
| 17.4 | .79 |
| 17.7 | .65 |
| 18.0 | .52 |
| 18.3 | .45 |
| 18.6 | .37 |
| 18.9 | .32 |
| 19.2 | .27 |
| 19.5 | .22 |
| 19.8 | .22 |
| 20.1 | .19 |

Table 8.--Dye concentration as a function of time at site 2A, river mile 543.25, injection of November 11, 1980 starting at 1002 hours

| Time from start of injection (hours) | Dye concentration (µg/L) |
|---|---|
| 1.38 | 0.15 |
| 1.47 | 1.68 |
| 1.55 | 3.29 |
| 1.63 | 7.67 |
| 1.72 | 11.4 |
| 1.80 | 13.4 |
| 1.88 | 13.0 |
| 1.97 | 17.1 |
| 2.05 | 21.5 |
| 2.13 | 20.8 |
| 2.22 | 19.2 |
| 2.30 | 16.4 |
| 2.38 | 13.9 |
| 2.47 | 13.0 |
| 2.63 | 9.69 |
| 2.72 | 8.77 |
| 2.80 | 7.67 |
| 2.97 | 6.80 |
| 3.20 | 4.82 |
| 3.30 | 3.73 |
| 3.52 | 2.74 |
| 3.67 | 2.24 |
| 3.80 | 2.31 |
| 3.97 | 1.79 |
| 4.13 | 1.39 |
| 4.30 | 0.89 |

Table 9.--Dye concentration as a function of time at site 2B river mile 542.77, injection of November 11, 1980 starting at 1002 hours

| Time from start of injection (hours) | Dye concentration (µg/L) |
|---|---|
| 3.97 | 0.40 |
| 4.13 | 1.30 |
| 4.30 | 2.29 |
| 4.38 | 3.49 |
| 4.47 | 4.08 |
| 4.55 | 4.55 |
| 4.63 | 5.02 |
| 4.72 | 5.54 |
| 4.80 | 6.40 |
| 4.88 | 6.66 |
| 4.97 | 6.88 |
| 5.05 | 7.32 |
| 5.13 | 7.58 |
| 5.22 | 7.75 |
| 5.30 | 7.97 |
| 5.38 | 8.23 |
| 5.47 | 7.97 |
| 5.55 | 7.97 |
| 5.63 | 7.75 |
| 5.72 | 7.54 |
| 5.80 | 7.32 |
| 5.97 | 6.99 |
| 6.13 | 6.45 |
| 6.30 | 6.01 |
| 6.47 | 4.96 |
| 6.63 | 4.81 |
| 6.80 | 4.26 |

Table 10.--Dye concentration as a function of time at site 2C, river mile 542.51, injection of November 11, 1980 starting at 1002 hours

| Time from start of injection (hours) | Dye concentration (μg/L) |
|---|---|
| Grab Samples | |
| 6.83 | 0.47 |
| 6.97 | .90 |
| 7.13 | 1.77 |
| 7.30 | 1.77 |
| 7.47 | 2.48 |
| 7.63 | 3.30 |
| 7.80 | 4.10 |
| 7.97 | 4.24 |
| 8.13 | 4.34 |
| 8.30 | 4.12 |
| 8.47 | 4.48 |
| 8.63 | 4.92 |
| 8.80 | 5.01 |
| 8.97 | 4.87 |
| 9.13 | 4.81 |
| 9.30 | 4.48 |
| 9.47 | 4.37 |
| 9.72 | 4.31 |
| 9.90 | 4.15 |
| 10.0 | 3.61 |
| 10.2 | 3.56 |
| 10.4 | 3.17 |
| 10.6 | 2.95 |
| 10.7 | 2.95 |

| Time from start of injection (hours) | Dye concentration (μg/L) |
|---|---|
| Automatic Samples | |
| 10.9 | 2.63 |
| 11.5 | 2.30 |
| 12.1 | 1.53 |
| 12.7 | 1.23 |
| 13.4 | .92 |
| 14.0 | .59 |
| 14.6 | .47 |
| 15.2 | .36 |
| 15.8 | .30 |
| 16.4 | .24 |
| 17.0 | .20 |
| 17.6 | .17 |
| 18.2 | .14 |
| 18.8 | .12 |
| 19.4 | .11 |
| 20.0 | .08 |
| 20.6 | .08 |
| 21.2 | .05 |

Table 11.--Dye concentration as a function of time at site 3A, river mile 549.32, injection of November 12, 1980 starting at 0922 hours

| Time from start of injection (hours) | Dye concentration (µg/L) |
|---|---|
| 1.55 | 2.33 |
| 1.63 | 4.56 |
| 1.72 | 8.00 |
| 1.80 | 15.9 |
| 1.88 | 29.4 |
| 1.97 | 33.4 |
| 2.05 | 33.4 |
| 2.13 | 39.4 |
| 2.22 | 39.4 |
| 2.30 | 38.1 |
| 2.38 | 47.0 |
| 2.55 | 44.8 |
| 2.63 | 40.8 |
| 2.72 | 37.7 |
| 2.80 | 32.1 |
| 2.88 | 28.1 |
| 2.97 | 18.3 |
| 3.13 | 14.8 |
| 3.30 | 10.80 |
| 3.47 | 6.90 |
| 3.63 | 4.82 |

Table 12.--Dye concentration as a function of time at site 3B, river mile 548.89, injection of November 12, 1980 starting at 0922 hours

| Time from start of injection (hours) | Dye concentration (µg/L) |
|---|---|
| Grab Samples | |
| 4.63 | 1.95 |
| 4.80 | 1.69 |
| 4.97 | 3.77 |
| 5.13 | 5.23 |
| 5.30 | 2.99 |
| 5.38 | 9.61 |
| 5.47 | 6.77 |
| 5.63 | 8.63 |
| 5.80 | 9.83 |
| 5.97 | 10.3 |
| 6.13 | 11.1 |
| 6.32 | 12.1 |
| 6.47 | 12.8 |
| 6.63 | 12.8 |
| 6.80 | 12.7 |
| 6.97 | 11.7 |
| 7.13 | 11.2 |
| 7.30 | 11.1 |
| 7.47 | 10.7 |
| 7.63 | 10.3 |
| 7.80 | 9.72 |
| 7.97 | 8.85 |
| 8.13 | 9.17 |
| 8.30 | 8.52 |
| 8.47 | 8.23 |
| 8.63 | 7.14 |
| 8.80 | 7.65 |
| 8.97 | 6.62 |
| 9.13 | 6.55 |
| Grab Samples-Continuted | |
| 9.30 | 6.29 |
| 9.47 | 6.01 |
| 9.63 | 5.54 |
| 9.80 | 5.66 |
| 9.97 | 4.85 |
| 10.1 | 5.18 |
| 10.9 | 4.40 |
| 11.4 | 3.17 |
| Automatic Samples | |
| 11.5 | 2.67 |
| 12.2 | 1.84 |
| 12.9 | 1.70 |
| 13.6 | 1.41 |
| 14.3 | 1.12 |
| 15.0 | .96 |
| 15.7 | .80 |
| 16.4 | .60 |
| 17.1 | .49 |
| 17.8 | .40 |
| 18.5 | .32 |
| 19.2 | .31 |
| 19.9 | .20 |
| 20.6 | .46 |
| 21.2 | .38 |
| 22.0 | .04 |
| 22.7 | .01 |

## Table 13.--Dye concentration as a function of time at site 3C, river mile 548.73, injection of November 12, 1980 starting at 0922 hours

| Time from start of injection (hours) | Dye concentration (µg/L) |
|---|---|
| Grab Samples | |
| 5.97 | 0.33 |
| 6.13 | .50 |
| 6.30 | 1.20 |
| 6.47 | 2.52 |
| 6.63 | 3.61 |
| 6.80 | 4.70 |
| 6.97 | 5.14 |
| 7.13 | 5.79 |
| 7.30 | 7.10 |
| 7.47 | 7.58 |
| 7.63 | 8.63 |
| 7.80 | 9.72 |
| 7.97 | 9.50 |
| 8.13 | 9.94 |
| 8.30 | 10.1 |
| 8.47 | 10.8 |
| 8.63 | 10.9 |
| 8.80 | 9.61 |
| 8.97 | 10.6 |
| 9.13 | 10.6 |
| 9.30 | 10.6 |
| 9.47 | 10.4 |
| 9.63 | 10.2 |
| 9.80 | 9.72 |
| 9.97 | 9.63 |
| 10.1 | 9.28 |
| 10.3 | 9.17 |
| 10.5 | 8.63 |
| 10.6 | 8.41 |
| Grab Samples-Continued | |
| 10.8 | 7.75 |
| 11.0 | 7.58 |
| 11.1 | 7.32 |
| 11.3 | 6.88 |
| 11.6 | 6.01 |
| 11.9 | 5.79 |
| Automatic Samples | |
| 12.2 | 5.25 |
| 12.8 | 4.11 |
| 13.4 | 3.46 |
| 14.0 | 2.85 |
| 14.6 | 2.22 |
| 15.2 | 1.84 |
| 15.8 | 1.32 |
| 16.4 | 1.03 |
| 17.0 | .71 |
| 18.2 | .42 |
| 18.8 | .31 |
| 19.4 | .23 |
| 20.0 | .16 |
| 20.6 | .11 |
| 21.2 | .09 |
| 21.8 | .54 |
| 22.4 | .04 |
| 23.0 | .02 |
| 23.6 | .02 |

concentrations. Time given in the tables was measured from the start of the injection of the tracers. The use of the automatic dye sampler is indicated at some sites. Samples are grab samples unless otherwise indicated.

The peak concentrations of dye in figure 11 have been corrected for dye loss using

$$Q_A A_A = Q_B A_B J_B = Q_C A_C J_C \tag{1}$$

where Q is discharge in cubic feet per second, A is the area under the dye concentration-versus-time curve in (micrograms per liter)-hours, J is a correction factor, and the subscript denotes the site. This correction uses site A as a basis ($J_A$=1.00). Downstream at sites D, E, F, G, H, and I where discharge measurements were not made, the dye correction factor was assumed to depend on the time of travel of the peak concentration $t_p$ in hours according to

$$J = a\ t_p^{\ b} \tag{2}$$

a and b are constants determined from the values of J for sites A, B, and C. The values of a in equation 2 were 0.986 and 0.984 and the values of b were 0.0237 and 0.0229 for the I-820 and Big Fossil Creek subreaches, respectively. Dye loss for the Beach Street subreach was negligble.

## Reaeration Coefficients

The reaeration coefficient is one model coefficient that can be measured rather than estimated by trial-and-error calibration. The coefficient is calculated from the ratio of peak concentrations of gas and dye. The results are shown in table 14.

The slopes of the lines, given in figure 12, connecting ratios of the peak-gas concentration to the peak-dye concentrations at two cross sections indicate the degree of gas transfer, with the propane expected to desorb at a slower rate than the ethylene. The data from which these ratios were computed are given in tables 15 through 18.

For the November 10 injection in the I-820 subreach, there was relatively high gas transfer for reach 1A - 1B, virtually zero transfer for reach 1B - 1C, and again relatively high transer for reach 1C - 1D. For reach 1D - 1E, the propane-to-dye ratio increased slightly, giving a negative desorption coefficient for propane for this reach. This is physically unrealistic, and is probably the result of a combination of experimental errors and the low transfer characteristics of this reach. The ethylene-to-dye ratio showed a positive desorption coefficient for this reach.

For the November 11 injection in the Big Fossil Creek subreach, both the ethylene-to-dye and propane-to-dye ratios for site 2C were

Table 14.--Experimental reaeration coefficients, average water temperatures, and reaeration coefficients at 20°C

| Reach | River miles | Exp. reaeration coefficient (days $^{-1}$) Ethylene | Exp. reaeration coefficient (days $^{-1}$) Propane | Water temperatures (°C) | Reaeration coefficient at 20°C (days $^{-1}$) Ethylene | Reaeration coefficient at 20°C (days $^{-1}$) Propane |
|---|---|---|---|---|---|---|
| November 10-11, 1980, I-820 subreach | | | | | | |
| 1A-1B | 540.80-539.85 | 2.57 | 2.67 | 18.7 | 2.65 | 2.75 |
| 1B-1E | 539.85-538.13 | 1.78 | 0.924 | 18.7 | 1.84 | 0.953 |
| November 11-12, 1980, Big Fossil Creek subreach | | | | | | |
| 2A-2F[1] | 543.25-541.94 | 0.820 | 0.369 | 18.6 | 0.848 | 0.382 |
| 2F-2G | 541.94-541.70 | 2.78 | 3.44 | 18.5 | 2.88 | 3.56 |
| November 12-13, 1980, Beach Street subreach | | | | | | |
| 3B-3D | 548.89-547.69 | 3.46 | 2.25 | 19.7 | 3.48 | 2.27 |
| 3D-3I | 547.69-545.97 | 1.02 | 0.242 | 18.9 | 1.05 | 0.248 |

[1] Site 2C data ignored.

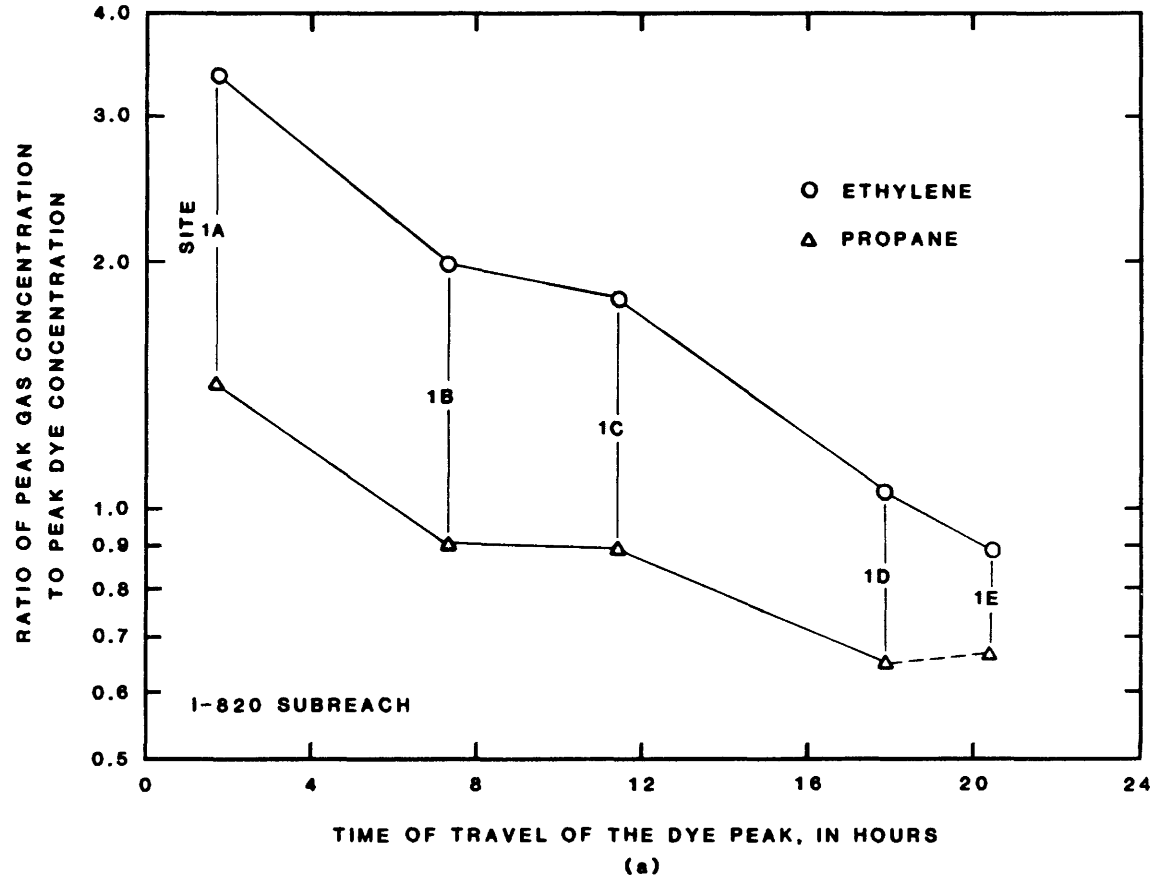

Figure 12.--Ratio of the peak gas and dye concentrations as a function of time and travel (a) I-820 subreach.

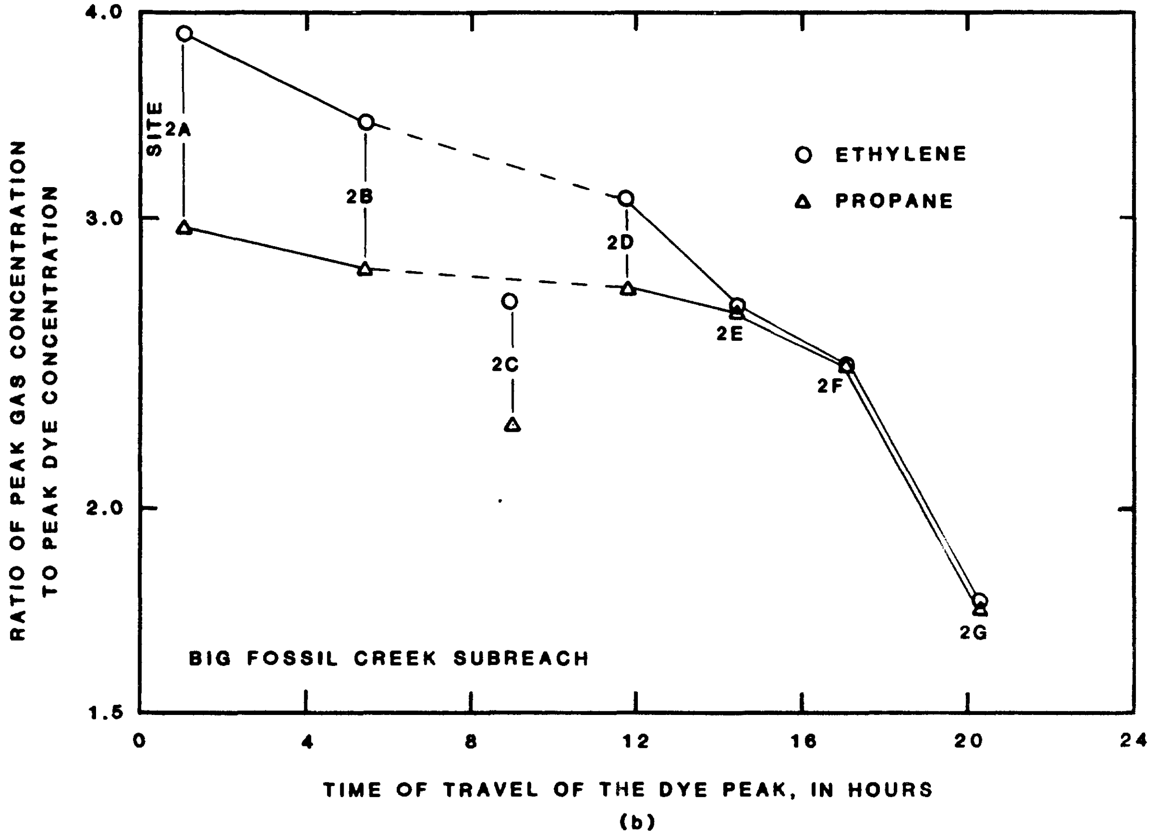

Figure 12.--Ratio of the peak gas and dye concentrations as a function of time and travel (b) Big Fossil Creek subreach.

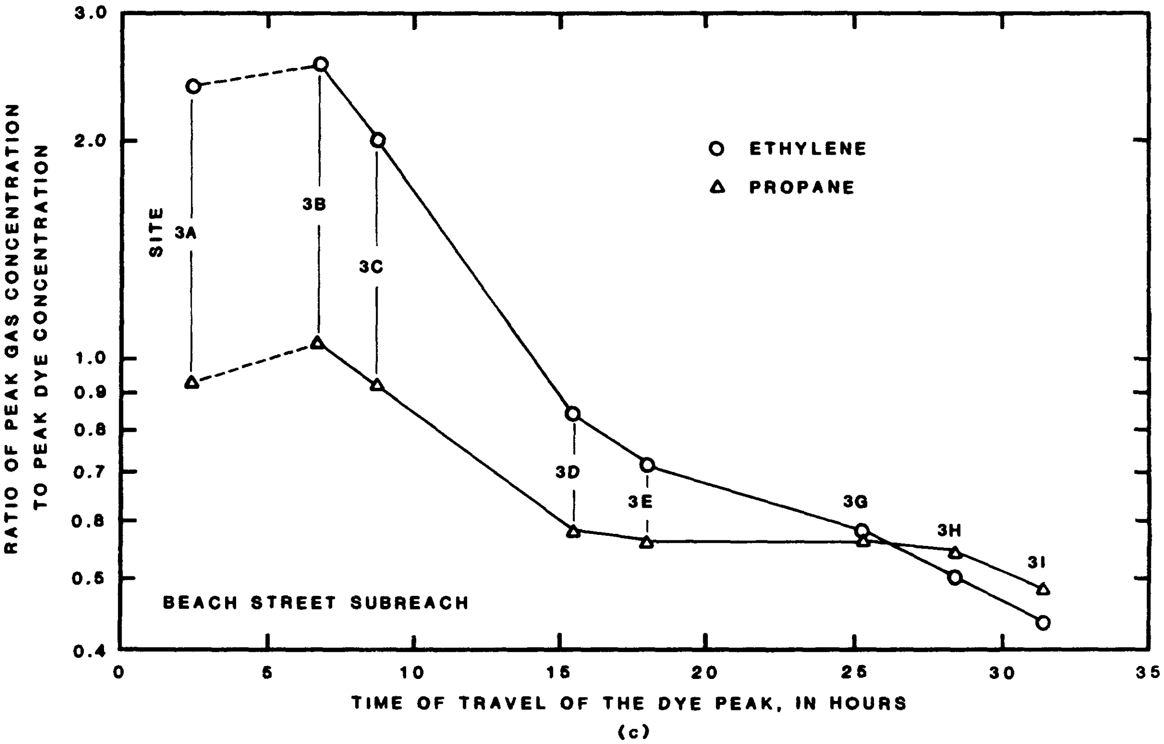

Figure 12.--Ratio of the peak and gas and dye concentrations as a function of travel (c) Beach Street subreach.

Table 15.--Peak concentrations of ethylene, propane, and dye and time of travel of the dye peak

[--Sample broken in shipment]

| Nov. 1980 date | Site | River mile | Peak concentration(μg/L) | | | Time of travel of dye peak (hours from start of injection) |
|---|---|---|---|---|---|---|
| | | | Ethylene | Propane | Dye | |
| 10 | 1A | 540.80 | 132 | 55.4 | 39.0 | 1.62 |
| 10 | 1B | 539.85 | 30.4 | 13.8 | 15.3 | 7.30 |
| 10 | 1C | 539.41 | 21.4 | 10.6 | 11.9 | 11.4 |
| 11 | 1D | 538.37 | 9.82 | 6.09 | 9.34 | 17.9 |
| 11 | 1E | 538.13 | 7.84 | 5.86 | 8.75 | 20.4 |
| 11 | 2A | 543.25 | 83.5 | 63.5 | 21.5 | 2.05 |
| 11 | 2B | 542.77 | 28.8 | 23.4 | 8.39 | 5.42 |
| 11 | 2C | 542.51 | 13.8 | 11.6 | 5.17 | 8.83 |
| 11 | 2D | 542.16 | 12.5 | 11.0 | 4.06 | 11.7 |
| 12 | 2E | 542.03 | 9.91 | 9.81 | 3.74 | 14.4 |
| 12 | 2F | 541.94 | 8.15 | 8.11 | 3.34 | 17.0 |
| 12 | 2G | 541.70 | 5.80 | 5.72 | 3.31 | 20.3 |
| 12 | 3A | 549.32 | 112 | 43.9 | 47.0 | 2.38 |
| 12 | 3B | 548.89 | 33.3 | 13.9 | 12.8 | 6.63 |
| 12 | 3C | 548.73 | 22.4 | 10.4 | 10.9 | 8.63 |
| 13 | 3D | 547.69 | 7.12 | 4.91 | 8.08 | 15.3 |
| 13 | 3E | 547.43 | 5.83 | 4.57 | 7.75 | 17.9 |
| 13 | 3F | 547.15 | -- | -- | 7.10 | 20.9 |
| 13 | 3G | 546.73 | 4.13 | 4.01 | 6.72 | 25.2 |
| 13 | 3H | 546.30 | 3.46 | 3.72 | 6.45 | 28.4 |
| 13 | 3I | 545.97 | 2.86 | 3.18 | 6.15 | 31.4 |

Table 16.--Gas concentrations as a function of time, injection of November 10, 1980, I-820 subreach, starting at 0953 hours

| Site | River mile | Time from start of injection (hours) | Gas Concentration (µg/L) | |
|---|---|---|---|---|
| | | | Ethylene | Propane |
| 1A | 540.80 | 1.45 | 118 | 50.4 |
| | | 1.53 | 120 | 51.7 |
| | | 1.62 | 132 | 55.4 |
| | | 1.70 | 125 | 54.3 |
| | | 2.03 | 108 | 37.6 |
| 1B | 539.85 | 6.87 | 30.2 | 15.1 |
| | | 7.03 | 40.7 | 20.1 |
| | | 7.20 | 30.3 | 13.8 |
| | | 7.37 | 30.4 | 13.8 |
| | | 7.53 | 29.9 | 13.8 |
| | | 7.62 | 29.6 | 13.9 |
| 1C | 539.41 | 11.0 | 19.3 | 9.38 |
| | | 11.1 | 20.5 | 10.4 |
| | | 11.3 | 21.4 | 11.0 |
| | | 11.4 | 20.8 | 10.5 |
| | | 11.6 | 20.4 | 10.4 |
| | | 11.8 | 19.6 | 10.2 |
| 1D | 538.37 | 18.2 | 9.82 | 6.09 |
| 1E | 538.13 | 20.4 | 7.84 | 5.86 |

Table 17.--Gas concentrations as a function of time, injection of November 11, 1980, Big Fossil Creek subreach, starting at 1002 hours

| Site | River mile | Time from start of injection (hours) | Gas Concentration (μg/L) | |
|---|---|---|---|---|
| | | | Ethylene | Propane |
| 2A | 543.25 | 1.88 | 51.6 | 39.8 |
| | | 1.97 | 64.7 | 49.9 |
| | | 2.05 | 62.6 | 46.6 |
| | | 2.13 | 81.7 | 62.5 |
| | | 2.22 | 73.7 | 56.8 |
| | | 2.30 | 65.8 | 52.4 |
| | | 2.38 | 53.5 | 41.8 |
| 2B | 542.77 | 5.22 | 27.8 | 22.3 |
| | | 5.30 | 26.3 | 20.1 |
| | | 5.38 | 28.6 | 23.1 |
| | | 5.47 | 28.8 | 23.4 |
| | | 5.63 | 26.4 | 21.3 |
| | | 5.72 | 26.7 | 18.6 |
| 2C | 542.51 | 8.33 | 12.7 | 9.48 |
| | | 8.52 | 13.7 | 11.1 |
| | | 8.88 | 13.5 | 10.8 |
| | | 9.02 | 13.9 | 12.1 |
| | | 9.17 | 15.5 | 13.6 |
| | | 9.35 | 13.8 | 12.3 |
| 2D | 542.16 | 11.7 | 12.5 | 11.0 |
| 2E | 542.03 | 14.4 | 9.91 | 9.81 |
| 2F | 541.94 | 17.0 | 8.15 | 8.11 |
| 2G | 541.70 | 20.3 | 5.80 | 5.72 |

Table 18.--Gas concentrations as a function of time, injection of November 12, 1980, Beach Street subreach, starting at 0922 hours

| Site | River mile | Time from start of injection (hours) | Gas Concentration (µg/L) Ethylene | Gas Concentration (µg/L) Propane |
|---|---|---|---|---|
| 3A | 549.32 | 2.13 | 110 | 40.2 |
| | | 2.22 | 111 | 41.1 |
| | | 2.55 | 138 | 54.0 |
| | | 2.63 | 111 | 43.2 |
| | | 2.72 | 109 | 41.6 |
| 3B | 548.89 | 6.13 | 33.3 | 13.9 |
| | | 6.32 | 53.3 | 22.6 |
| | | 6.47 | 32.4 | 13.8 |
| | | 6.63 | 32.0 | 13.7 |
| | | 6.80 | 30.4 | 12.9 |
| | | 6.97 | 30.2 | 13.1 |
| | | 7.13 | 30.4 | 13.2 |
| 3C | 548.73 | 8.63 | 22.2 | 10.3 |
| | | 8.80 | 22.2 | 9.84 |
| | | 8.97 | 20.7 | 9.18 |
| | | 9.13 | 21.4 | 9.40 |
| | | 9.30 | 20.1 | 8.63 |
| | | 9.47 | 20.4 | 8.56 |
| 3D | 547.69 | 15.3 | 7.12 | 4.91 |
| 3E | 547.43 | 17.9 | 5.83 | 4.57 |
| 3G[1] | 546.73 | 25.2 | 4.13 | 4.01 |
| 3H | 546.30 | 28.4 | 3.46 | 3.72 |
| 3I | 545.97 | 31.4 | 2.86 | 3.18 |

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[1] Sample from site 3F was broken in shipment to the laboratory.

much smaller than expected on the basis of the ratios for other sites, probably because of experimental errors. Excluding site 2C, there was relatively low gas transfer for reaches 2A - 2B and 2B - 2D, somewhat higher transfer for reaches 2D - 2E and 2E - 2F, and high transfer for reach 2F - 2G.

For the November 12 injection in the Beach Street subreach, both the ethylene-to-dye and propane-to-dye ratios for site 3A were slightly less than the ratios at site 3B. This indicates that the gas transfer of reach 3A - 3B was very small and experimental errors resulted in the smaller ratios at site 3A. There was relatively high gas transfer for reaches 3B - 3C and 3C - 3D and somewhat lower transfer for reach 3D - 3E. The propane-to-dye ratio showed very small gas transfer for reaches 3E - 3G and 3G - 3H; the ethylene-to-dye ratios showed somewhat larger gas transfer for these reaches. The ethylene-to-dye ratio suggested somewhat larger gas transfer for reach 3H - 3I; the propane-to-dye ratio also suggested larger transfer.

The desorption coefficient $K_T$, in days $^{-1}$, for ethylene or propane is usually calculated for each reach from

$$K_T = \frac{24}{t_d - t_u} \log_e \frac{\left(\frac{C_G}{C_D}\right)_u}{\left(\frac{C_G}{C_D}\right)_d} \tag{3}$$

where $C_G$ and $C_D$ are the peak concentrations of the gas and dye, respectively, in micrograms per liter, t is the time of travel of the dye peak in hours measured from the start of the injection of the tracers, and the d and u subscripts denote the downstream and upstream ends of the reach, respectively. Because the ethylene-to-dye and propane-to-dye peak concentration ratios changed very little for many of the reaches, the argument of the logarithm in equation 3 was only slightly larger than 1.00. This is undesirable because taking the logarithm as required by equation 3 magnifies the experimental error, and the extent of the magnification increases rapidly as the argument of the logarithm approaches 1.00. For example, a five percent error in ratios of 1.25, 1.10, and 1.05 results in errors of 23, 51, and 100 percent, respectively, when the logarithm is taken.

To avoid the magnification of experimental errors desorption coefficients were not calculated for the individual reaches, but instead, coefficients were computed for each gas for those reaches for which the coefficients were approximately constant as indicated by the shapes of the curves in figure 12. While accuracy is improved, the effect on the the gas transfer process of the various unique hydraulic features within the short reaches are reduced as a result of using the longer reaches.

Desorption coefficients were calculated by linear regression analysis of the logarithm of the ratio given in equation 3 as a function of time of travel for those reaches having more than two data points. Desorption coefficients were converted to reaeration coefficients using (Rathbun and others, 1978)

$$K_2 = 1.15\, K_{T_E} \quad \text{and} \quad K_2 = 1.39\, K_{T_P} \qquad (4)$$

where $K_2$ is the reaeration coefficient in days $^{-1}$ and the E and P subscripts denote ethylene and propane, respectively.

The experimental reaeration coefficients ranged from 0.242 to 3.46 days $^{-1}$. A comparison of table 14 and figure 10 (bed and water-surface profiles) shows that the largest coefficients were observed on those reaches containing a number of riffles. The smallest coefficients were observed on those reaches containing mostly deep pools and limited riffles.

The reaeration coefficients computed from equation 4 were adjusted to a base temperature of 20°C (degrees Celsius) using

$$K_{2_{20}} = K_{2_{\Theta}}\, 1.0241^{20 - \Theta} \qquad (5)$$

where $\Theta$ is the average water temperature in degrees Celsius in the river at the time of the measurement and 1.0241 is the temperature correction factor determined by Elmore and West (1961). The reaeration coefficients adjusted to 20°C are given in table 14.

Some of the reaeration coefficients calculated from the ethylene and propane desorption coefficients differ considerably, with the coefficients based on ethylene averaging about 47 percent higher than the coefficients based on propane. This result contrasts with previous studies such as Rathbun and Grant (1978) and Bauer, and others (1979) where the differences between the coefficients averaged about 10 percent. An explanation for the larger differences observed in the present study is not readily apparent. However, the reaeration coefficients measured in this study were considerably smaller than those measured in previous studies. Thus, the greater experimental error inherent in the measurement of small reaeration coefficients probably contributed to the observed differences.

## Deoxygenation Coefficients

The results of the long-term BOD tests were analyzed using a nonlinear least squares technique (Barnwell, 1980, Jenning and Bauer, 1976, and Jennings and others, 1982) to determine ultimate carbonaceous BOD ($CBOD_u$) and the deoxygenation coefficient $K_1$ which are related as follows

$$CBOD(t) = CBOD_u \, [\exp(-K_1 t)] \qquad (6)$$

in which t is time. Not only is equation 6 valid for bottle BOD exertion, but it has also been proven valid for instream BOD exertion during steady-state conditions when dispersive effects are small. The value of $K_1$ derived from the test can occassionally be used for the instream deoxygenation coefficient (Stamer and others, 1979, and McKenzie and others, 1979) or at least as a first estimate in calibrating the model.

Despite the usefulness of these parameters, some difficulty arose in computing them. Nitrification breakthrough occurred in 21 percent of the November 1980 samples. Calculations using the nitrification-affected data gave $K_1$ values that were low and $CBOD_u$ values that were high. This was determined by comparing the questionable $K_1$ values to values computed from control samples and by comparing $CBOD_u$ values to measurements of the organic carbon available for oxidation. The control values for $K_1$ were derived from samples having an inhibited and total BOD test showing that the nitrification inhibitor was effective. The control values were also based on 20-day tests as a standard test period. The suspicious data were excluded by analyzing 10, 12, or 15 days of test data. This was done when one of three conditions occurred: 1) $K_1$ was significantly lower than the control values, 2) $CBOD_u$ was larger than measurements of organic carbon would support and, 3) the rate of DO exertion increased rather than continually decreasing. Marginal or borderline values were not reanalyzed and are reported herein. The data based on these records are not, however, fully satisfactory. Therefore they are labeled as such when the values are reported in this report.

These values are not fully satisfactory because even in the absence of a nitrification break-through $K_1$ is sensitive to the length of testing involved. For this river water, the growth phases of bacteria and protozoa are separate because of small seed populations (Gaudy, 1972, p. 320). See figure 13. As a result, equation 6 is less accurate in describing how BOD is exerted with time. Therefore, shortening the test record analyzed from 20 days generally causes estimates of $K_1$ to increase and $CBOD_u$ to decrease. In samples unaffected by nitrification, computed $K_1$ values based on a five-day record were twice as large as values based on a 20 day record. Typically $K_1$ increased about 30 percent and $CBOD_u$ decreased about 8 percent by shortening the record to 15 days.

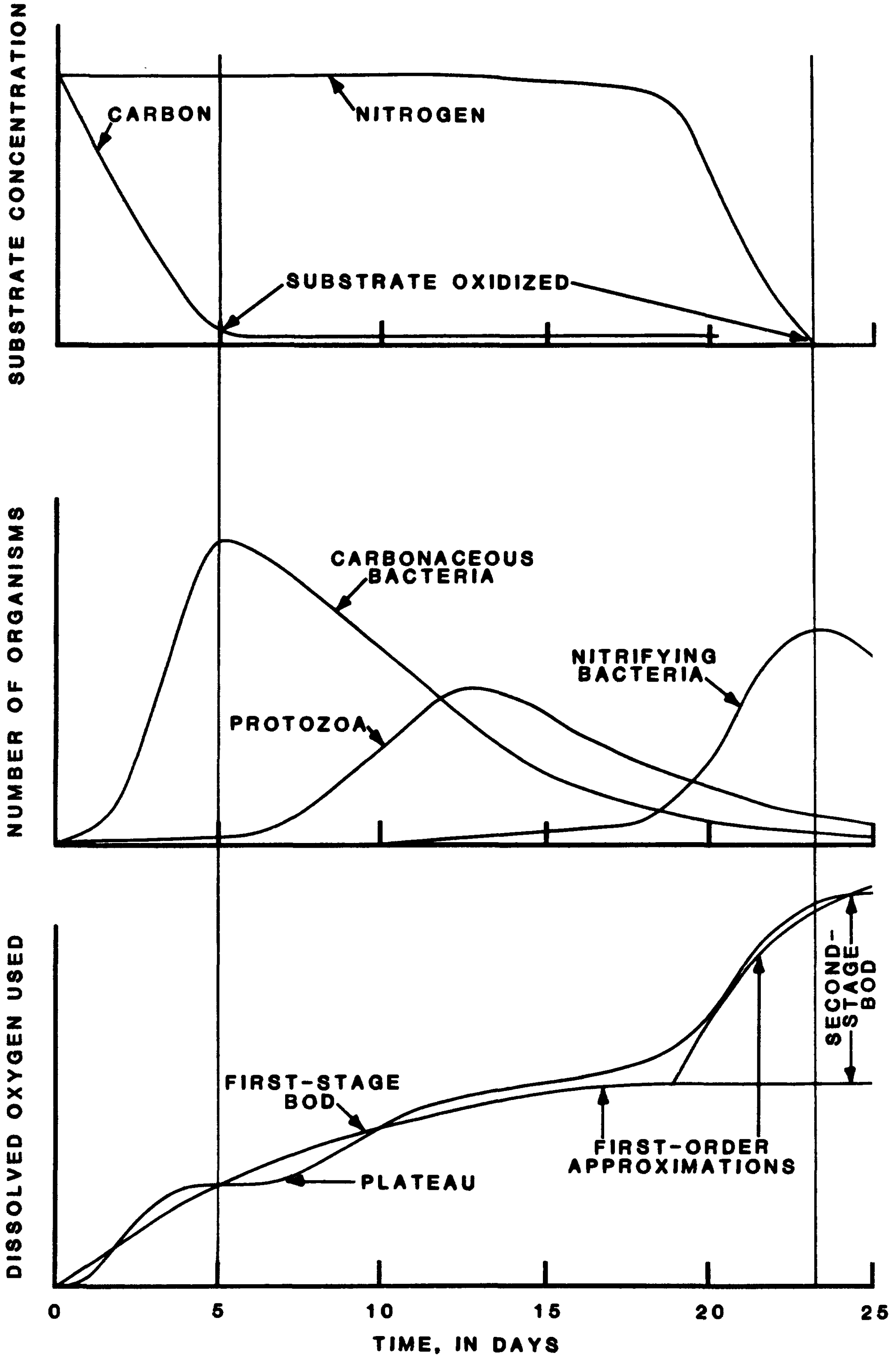

Figure 13.--Generalized relationship between dissolved oxygen exertion, heterotrophic and autotrophic organisms, and substrates. [Adapted from O'Conner and others, 1976]

In effect, the samples treated in this way balance the tendency for the calculations based on shorter record to produce higher estimates of $K_1$ against the initial nitrification breakthrough causing lower estimates of $K_1$. Therefore, the adjusted data are less reliable but are still useful.

The samples from the tributary south of Riverside STP and Big Fossil Creek did not experience these problems. A high initial concentration of seed bacteria and protozoa did not lead to separate growth phases and the values of $K_1$ and $CBOD_u$ did not depend on the length of record. Low concentrations of nitrifying bacteria in these sewage-dominated, low DO waters also delayed a nitrification breakthrough.

One particular asset of the nonlinear least squares technique for samples with a slight breakthrough is that it does not weigh the 15- and 20-day DO measurements at the end of the test like other methods (Jennings and others, 1982).

A second difficulty in calculating CBOD parameters involved the excessive dilution of some samples. Overdilution reduces the precision of the test and points to the need to improve the BOD test by carefully diluting samples. This small reduction in precision does not, however, invalidate the results. Figure 14 shows the data scatter introduced by overdiluting a river sample. This reduced the precision of the estimated parameters for river samples collected downstream of Big Fossil Creek. These samples were usually diluted to 67 percent of full strength (a few Lagrangian samples were undiluted and diluted to 33 and 17 percent). The preliminary samples collected October 15 and 16 from Big Fossil Creek and the tributary near Meadowbrook Golf Course erroneously indicated that $CBOD_u$ would exceed 8 to 10 mg/L compared to 3 to 8 mg/L actually measured in November. Dilution was undertaken to avoid reaeration of the large number of samples collected since manpower was limited.

Preliminary work on the tributary near Meadowbrook Golf Course was very misleading and indicates a need for better preliminary sampling design. In October, $CBOD_u$ was 20 mg/L. By November $CBOD_u$ was 2 to 12 mg/L and discharge had decreased, making the load to the river negligible.

Dilution of samples from the other tributaries worked well. Dilutions of 17 and 3 percent for samples collected from Big Fossil Creek and the tributary south of Riverside STP, respectively, were intended to duplicate the natural dilution of the tributaries in the river that was 6 and 2 percent, respectively. The natural dilution was not duplicated exactly because of poor estimates of discharge and because 2 milligrams per liter of DO exertion was required for each test.

There was also some indication that the blank corrections were inexact. In the blanks, the dilute seed typically contributed to

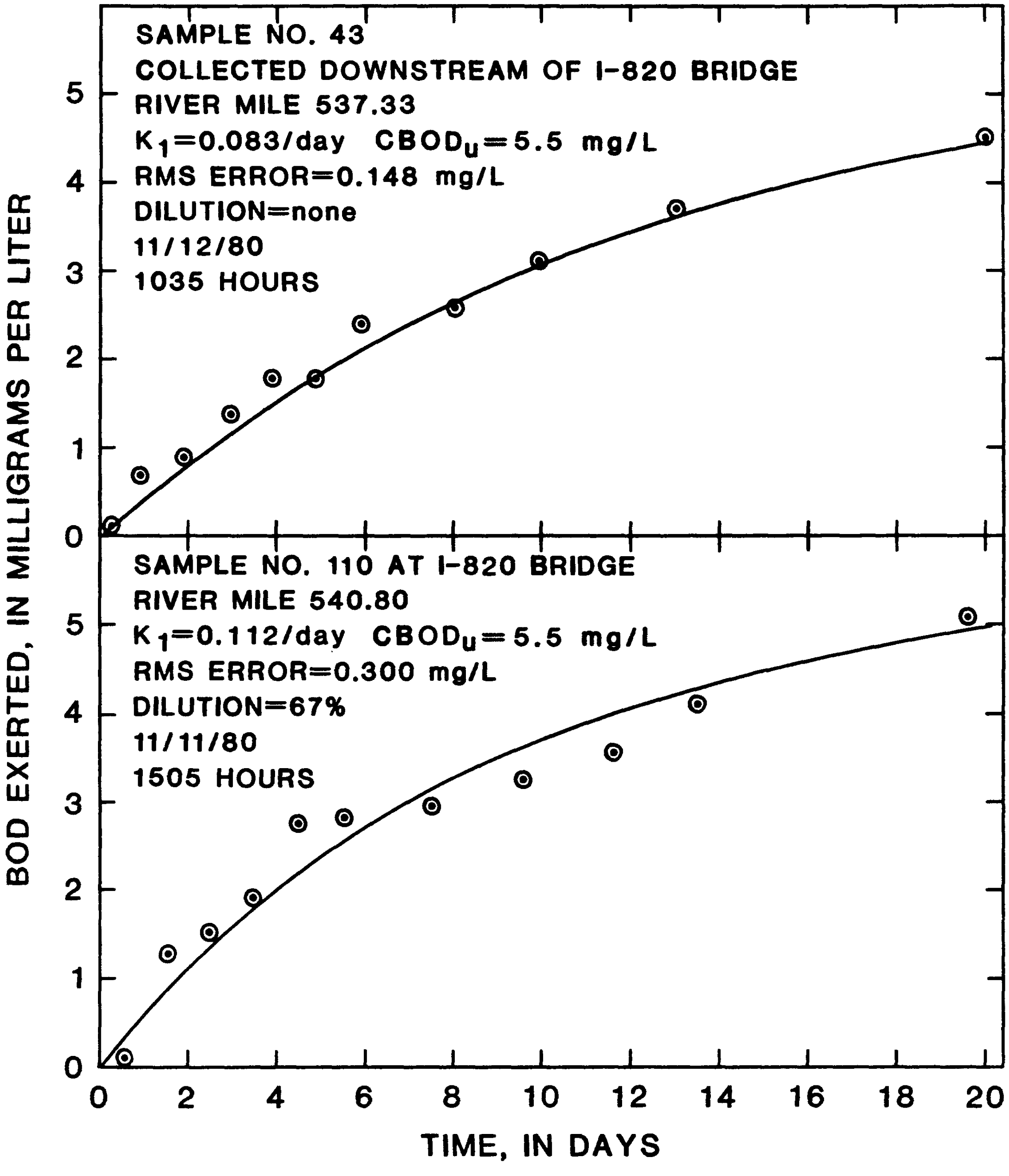

Figure 14.--The effect of dilution on BOD samples collected in downstream reaches.

an initial lag and a prolonged plateau between the initial respiratory demands of bacteria in the dilution water and the respiratory demands associated with protozoa growth. In the undiluted samples, this plateau was less pronounced presumably because seed organisms existed in greater numbers. In the diluted stream samples, typical 8- and 10-day values were a little larger than would be expected in an undiluted sample and the 12- and 15-day values a little smaller than expected. On occasion, CBOD would decrease from one measurement to the next rather than continually increasing as expected (fig. 15). The result was that determinations of CBOD parameters were less precise but not necessarily less accurate especially if the dilution water DO demand was shifted but the total demand was not changed.

Not only did overdilution result in less precise parameter estimates, 25 percent of the diluted river samples showed an intial lag in CBOD exertion of one-half to one day. For all river samples the data were fitted with and without the lag as shown in figure 15. In all cases the root-mean-square (RMS) error was lower for the fit that ignored the lag. This is compatible with the common practice of BOD modeling in rivers where small lags in DO exertion are usually ignored. The few undiluted samples collected in the downstream reaches had no lags and seem to confirm that the lag was an artifact introduced by overdilution.

The parameters $K_1$ and $CBOD_u$ are listed later in the report in tables with water-quality measurements.

## Nitrification Coefficients

Sixty-four BOD samples, collected at the tributary south of Riverside STP, Big Fossil Creek, I-820, Randol Mill Road, and at several Lagrangian sites were duplicated except that the nitrification inhibitor was left out. The difference in this TBOD (total BOD) and the CBOD, assumed to be due to the exertion of NBOD or the oxidation of ammonia and nitrite, was analyzed to determine $NBOD_u$ (ultimate NBOD) and the specific rate constant $K_N$ using the same nonlinear least-squares technique used for CBOD, except that a third parameter, the initial lag time to onset of nitrification, $\Delta t$, was introduced. The lag time was determined by a trial-and-error procedure. $NBOD_u$, $K_N$, and $\Delta t$ are related by

$$NBOD\,(t-\Delta t) = NBOD_u \left\{\exp[-K_N(t-\Delta t)]\right\} \qquad (7)$$

in which t is time since the TBOD test was begun and $\Delta t$ is the lag time until the full exertion of nitrification begins (fig. 16).

Values of NBOD $(t-\Delta t)$, like those shown on figure 16, were determined by substracting measurements of CBOD from measurements of TBOD. Typically, these replicate DO measurements were made with-

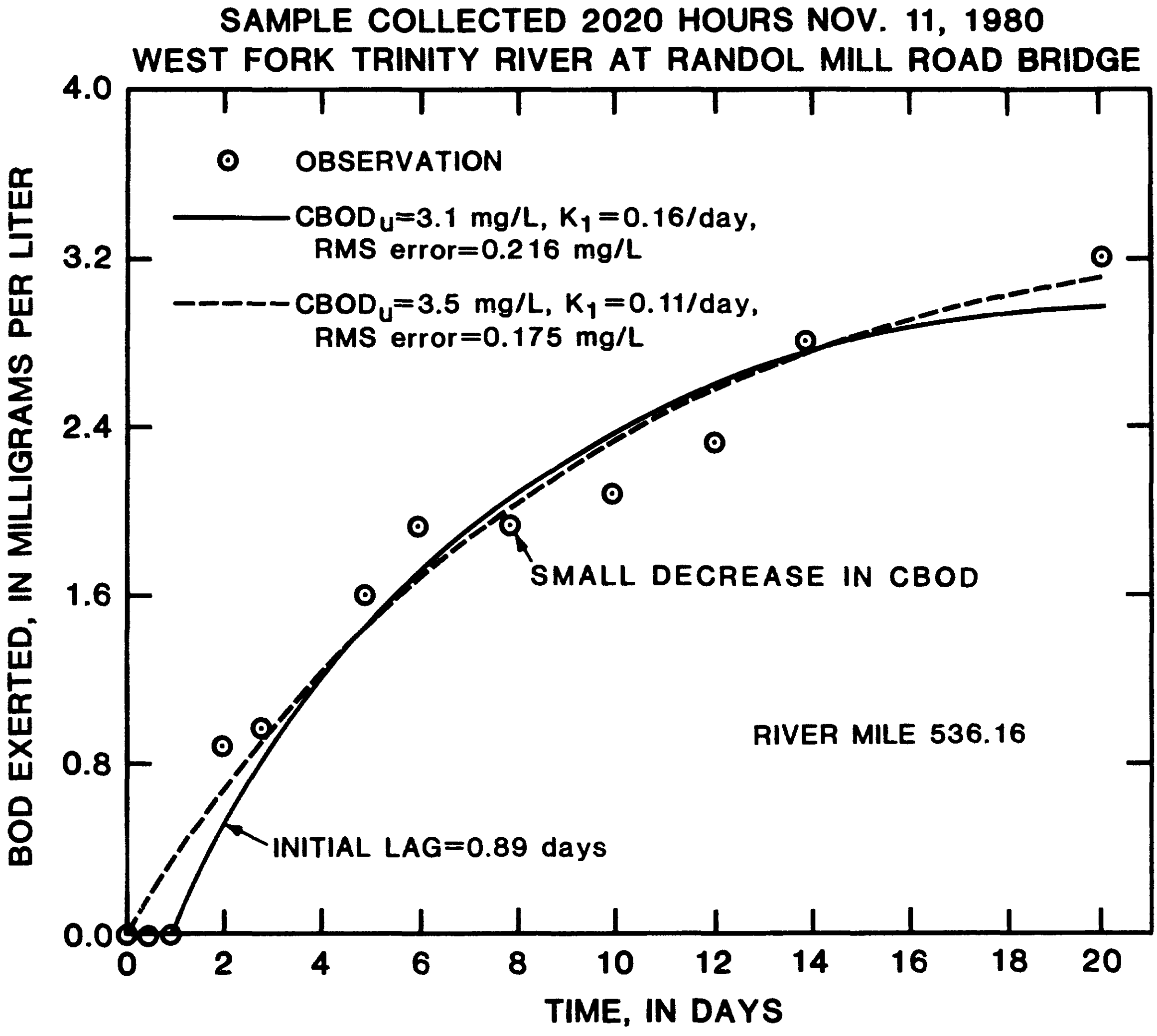

Figure 15.--Effect of the initial lag on DO exertion.

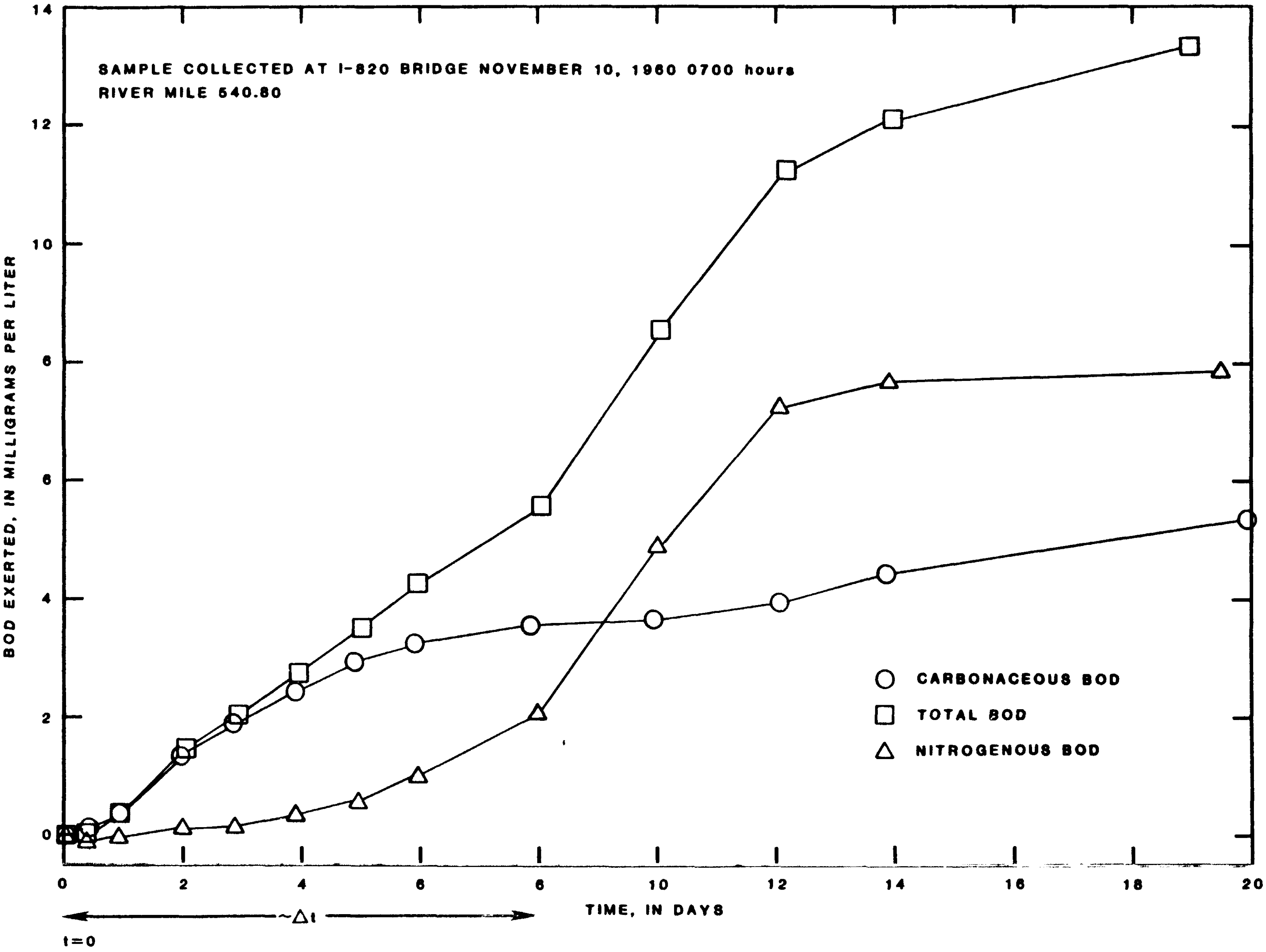

Figure 16.--Total, carbonaceous, and nitrogenous BOD exerted.

in a period of hours or shorter. When nitrification affected the CBOD data and some CBOD values were discarded, values of NBOD were computed from

$$NBOD(t) = TBOD(t) - CBOD_u[\exp(-K_1 t)] \qquad (8)$$

where $CBOD_u$ and $K_1$ (different from $K_N$) were determined by fitting all or part of the 20-day record from the inhibited BOD test.

A computer program was written that varied $\Delta t$ from 0 to 20 days in increments 0.1 days and computed $NBOD_u$, $K_N$, and the root-mean-square error for each increment. The best fit was accepted when the root-mean square error was the smallest.

Figure 16 indicates that the number of nitrifying bacteria is initially low in the water column, causing a lag in nitrification. The NBOD is exerted slowly until the heterotrophic bacteria have most likely attained a peak number and begun to decline. After about 6 to 12 days for the river samples, nitrification becomes independent of the number of nitrifying bacteria and proceeds according to equation 7. $K_N$ was found to be three to five times as large as $K_1$ and thus nitrification was essentially completed in about 15 days which includes the lag period. Note that NBOD measurements near days 14 and 20 are essentially the same (fig. 16). The result was that the process was imprecisely defined, sometimes by only three or four points compared to 12 for CBOD tests. In this respect, the uninhibited BOD tests were poorly designed.

Lag times for tributary samples usually exceeded 12 days, leaving too few points to fit. More than likely, low DO concentrations in the tributaries limited the number of nitrifying bacteria in the water column and upon the bottom. This would explain the greater delay in the onset of nitrification compared to the typical lag for river samples.

Table 19 gives the computed values for $K_N$, and $NBOD_u$ along with $NBOD_u$ computed from measurements of dissolved kjeldahl nitrogen and nitrite (Velz, 1970, p. 155-156). $K_N$ averages 0.8 day$^{-1}$. Lag time varies from 6.1 to 11.6 days. Estimated $NBOD_u$ (from the BOD test) is usually smaller than $NBOD_u$ inferred from kjeldahl nitrogen measurements indicating that not all the available ammonia and organic nitrogen is oxidized (Velz, 1970, p. 156). On average, the ratio of estimated to measured $NBOD_u$ is 0.80 or 3.7 milligrams per liter of DO is required to oxidize 1 milligram per liter of kjeldahl nitrogen compared to a theoretical value of 4.6 and a practical value of 4.3. Evidently, some of the organic nitrogen in the water is not converted to ammonia and oxidized.

### Table 19.--Nitrification coefficients and estimated and measured nitrogenous biochemical oxygen demand

| Nov. 1980 date | Time | Kjeld. N (mg/L) | $NO_2$- N (mg/L) | Measured $NBOD_u$[a] (mg/L) | Lag time (days) | $K_N$ (1/day) | Estimated $NBOD_u$ (mg/L) |
|---|---|---|---|---|---|---|---|
| Site 2B at River Mile 542.77 | | | | | | | |
| 11 | 1545 | 2.9 | 0.06 | 13 | 9.0 | 0.35 | 17 |
| Site 2C at River Mile 542.51 | | | | | | | |
| 11 | 1925 | 2.2 | 0.07 | 10 | 9.5 | 1.4 | 11 |
| Site 1C at River Mile 539.41 | | | | | | | |
| 10 | 2145 | 1.4 | 0.11 | 6.5 | 7.5 | 0.71 | 5.0 |
| Site 1D at River Mile 538.37 | | | | | | | |
| 11 | 0345 | 1.3 | 0.11 | 6.1 | 7.4 | 0.68 | 4.6 |
| Site 1E at River Mile 538.13 | | | | | | | |
| 11 | 0610 | 1.2 | 0.11 | 5.6 | 6.9 | 0.78 | 5.2 |

## Table 19.--Nitrification coefficients and estimated and measured nitrogenous biochemical oxygen demand--Continued

| Nov. 1980 date | Time | Kjeld. N (mg/L) | $NO_2$- N (Mg/L) | Measured $NBOD_u$ [a] (mg/L) | Lag time (days) | $K_N$ (1/day) | Estimated $NBOD_u$ (mg/L) |
|---|---|---|---|---|---|---|---|
| | | | | I-820 Bridge | | | |
| 10 | 0645 | 2.3 | 0.08 | 11 | 11.6 | 1.2 | 8.0 |
| 10 | 1140 | 2.2 | .08 | 10 | 11.5 | 1.2 | 7.1 |
| 10 | 1645 | 1.9 | .07 | 8.8 | 9.5 | 1.6 | 7.3 |
| 10 | 2045 | 2.1 | .07 | 9.7 | 8.0 | .62 | 7.1 |
| 11 | 0150 | 1.8 | .07 | 8.3 | 7.1 | .56 | 5.4 |
| 11 | 0700 | 1.8 | .07 | 8.3 | 8.7 | .70 | 8.0 |
| 11 | 1015 | 2.0 | .07 | 9.2 | 9.1 | .85 | 8.6 |
| 11 | 1505 | 2.6 | .08 | 12 | 8.9 | .44 | 9.2 |
| 11 | 1958 | 3.3 | .08 | 15 | 9.0 | 1.4 | 8.3 |
| 11 | 2315 | 1.9 | .09 | 8.8 | 7.0 | .57 | 10 |
| 12 | 0315 | 1.8 | .09 | 8.3 | 7.2 | .60 | 6.8 |
| 12 | 1130 | 2.0 | .08 | 9.2 | 9.0 | .62 | 8.8 |
| 12 | 1455 | 2.5 | .08 | 12 | 8.9 | .69 | 10 |
| 12 | 1845 | 1.8 | .08 | 8.3 | 10.9 | 1.1 | 3.7 |
| 12 | 2310 | 2.0 | .08 | 9.2 | 6.9 | .47 | 9.2 |
| 13 | 0340 | 1.9 | .09 | 8.8 | 9.5 | .73 | 8.3 |
| | | | | Randol Mill Road Bridge | | | |
| 10 | 0725 | 1.4 | 0.11 | 6.5 | 8.7 | 0.71 | 4.1 |
| 10 | 1245 | 1.3 | .11 | 6.1 | 7.9 | 1.3 | 3.0 |
| 10 | 1710 | 1.3 | .10 | 6.1 | 7.2 | .52 | 3.5 |
| 10 | 2139 | 1.5 | .10 | 7.0 | 6.4 | .40 | 3.7 |
| 11 | 0225 | 1.3 | .11 | 6.1 | 8.0 | .59 | 4.0 |
| 11 | 0715 | 1.3 | .12 | 6.1 | 7.5 | 1.2 | 3.7 |
| 11 | 1115 | 1.4 | .12 | 6.5 | 8.0 | .49 | 5.3 |
| 11 | 1500 | 1.4 | .11 | 6.5 | 8.8 | 1.3 | 4.5 |
| 11 | 2020 | 1.4 | .10 | 6.5 | 7.9 | .53 | 4.6 |
| 11 | 2335 | 1.2 | .10 | 5.6 | 7.9 | .48 | 4.4 |
| 12 | 0340 | 1.2 | .10 | 5.6 | 7.3 | .89 | 4.2 |
| 12 | 0730 | 1.3 | .10 | 6.1 | 6.1 | .32 | 5.9 |
| 12 | 1110 | 1.4 | .10 | 6.5 | 9.3 | .68 | 5.8 |
| 12 | 2000 | 1.2 | .10 | 5.6 | 9.5 | .67 | 5.2 |
| 12 | 2325 | 1.3 | .10 | 6.1 | 7.4 | .70 | 4.5 |
| 13 | 0355 | 1.4 | .11 | 6.5 | 7.2 | .62 | 5.5 |

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[a] Measured $NBOD_u$ = (Kjeld-N) 4.57 + ($NO_2$-N) 1.14

## Initial Water-Quality Data

Water-quality data obtained at the 14 fixed measurement sites at the beginning of the November study seemed to adequately define the initial conditions because the data define longitudinal trends commonly found in streams. Figure 17 shows that DO, ammonia, nitrate, $CBOD_u$, and organic carbon follow trends that are typically found downstream of polluted tributaries (Krenkel and Novotny, 1980). Downstream of the tributary south of Riverside STP and Big Fossil Creek (the polluted tributaries) there is some evidence of the classical DO sag and recovery pattern. Ammonia, $CBOD_u$, and organic carbon concentrations increase at the tributaries and tend to decrease in the downstream direction while nitrate increases. This suggests the importance of CBOD decay and nitrification in the river.

A third minimum DO concentration shown in Figure 17 is not a classical DO sag point. This measurement was made at Beach Street (river mile 549.60) at 0715 hours and represents a near minimum for the diel cycle.

Increases in phosphorus at the confluence with the polluted tributaries confirms the effect of those tributaries on instream water quality. As in most natural waters (American Public Health Association and others, 1981, p. 409), dissolved phosphorus seems to consist chiefly of orthophosphate. At two sites, some error in measurement is apparent because dissolved orthophosphate exceeds dissolved phosphorus.

These suspicious phosphorus measurements and the scattered kjeldahl nitrogen measurements, points to a sample-handling problem. When these samples were preserved on ice just after collection, the resulting thermal shock evidently caused the plankton to lysis (cell rupture) and release phosphorus and nitrogen rich protoplasm that would have otherwise been filtered from the sample (Arron Stein, U.S. Army Waterways Experiment Station, oral commun., 1982). The unequal exposure time to the thermal shock probably explains some of the scatter.

Water temperature tends to decrease in the downstream direction. Perhaps the shading of the river explains some of this trend. Higher temperatures would be expected near the unshaded upstream end of the study reach compared to the shaded downstream segment.

Table 20 presents the initial data. All measurements of chemical species are of the dissolved phased (material passing through a 0.45 μm filter).

## Lagrangian Water Quality

The Lagrangian data collected at peak dye concentrations from three dyed parcels of water show some of the same longitudinal

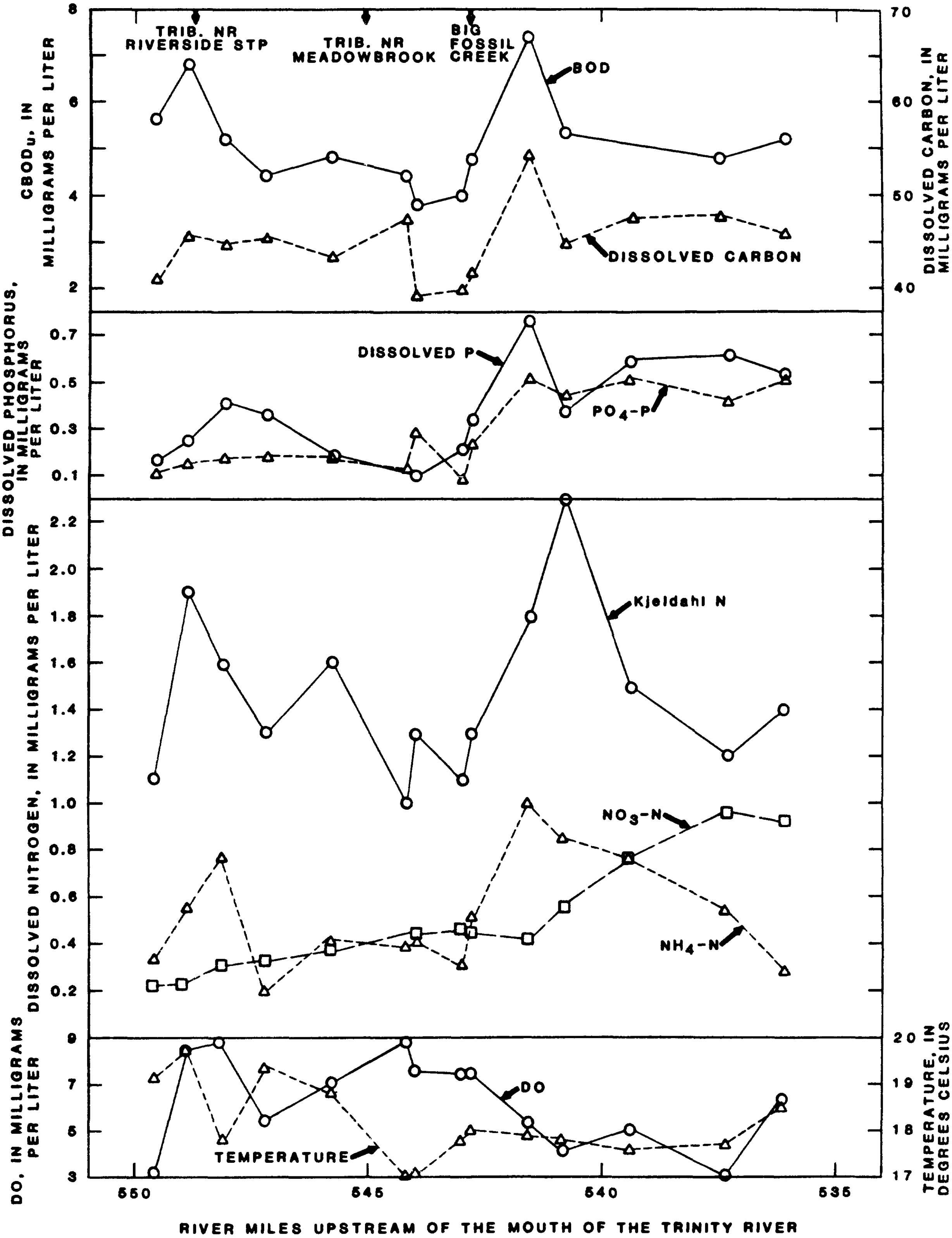

Figure 17.--Longitudinal variations in water quality.

Table 20.--Water-quality data from the initial sampling

[-- indicates first-order parameters could not be drived from test data]

| Nov. 10 time | River mile | Temp. (°C) | Specific cond. (µmho/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos. (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0715 | [a] 549.60 | 19.1 | 570 | 7.37 | 3.2 | [b] 5.6 | [b] 0.18 | 1.1 | 0.34 | 0.06 | 0.2 | 0.11 | 0.17 | 41.1 | 27.5 |
| 0643 | 548.89 | 19.7 | 580 | 7.45 | 8.4 | 6.8 | .16 | 1.9 | 0.55 | .06 | .2 | .15 | .25 | 45.6 | 39.7 |
| 0710 | 548.15 | 17.8 | 590 | 7.45 | 8.8 | [b] 5.2 | [b] .16 | 1.6 | 0.77 | .07 | .3 | .17 | .41 | 44.9 | 37.4 |
| 0620 | [c] 547.21 | 19.3 | 590 | 7.54 | 5.4 | [b] 4.4 | [b] .18 | 1.3 | 0.18 | .08 | .3 | .18 | .36 | 45.3 | 31.8 |
| 0700 | 545.82 | 18.8 | 600 | 7.50 | 7.0 | 4.8 | .12 | 1.6 | 0.42 | .07 | .4 | .17 | .19 | 43.6 | 29.9 |
| 0835 | [d] 544.19 | 17.0 | 590 | 7.37 | 8.8 | 4.4 | .15 | 1.0 | 0.37 | .07 | .4 | .12 | .12 | 47.5 | 31.3 |
| 0810 | 544.03 | 16.9 | 610 | 7.20 | 7.5 | 3.8 | .16 | 1.3 | 0.40 | .06 | .4 | [e] .29 | [e] .10 | 39.4 | 30.7 |
| 0740 | 543.00 | 17.8 | 610 | 7.60 | 7.4 | 4.0 | .12 | 1.1 | 0.31 | .06 | .5 | .09 | .21 | 40.0 | 30.1 |
| 0805 | 542.80 | 18.0 | 650 | 7.60 | 7.4 | 4.8 | .16 | 1.3 | 0.53 | .05 | .4 | .23 | .34 | 41.9 | 36.0 |
| 0904 | 541.58 | 17.9 | 630 | 7.60 | 5.3 | [b] 7.4 | [b] .10 | 1.8 | 1.0 | .06 | .4 | .51 | .76 | 54.4 | 42.6 |
| 0645 | [f] 540.80 | 17.8 | 620 | 7.47 | 4.1 | 5.3 | .13 | 2.3 | 0.85 | .08 | .6 | [e] .45 | [e] .38 | 44.9 | 33.4 |
| 0950 | 539.42 | 17.6 | 630 | 7.50 | 5.0 | -- | -- | 1.5 | 0.76 | .13 | .8 | .51 | .59 | 47.7 | 31.7 |
| 1035 | 537.33 | 17.7 | 620 | 7.70 | 3.0 | [b] 4.8 | [b] .11 | 1.2 | 0.55 | .12 | 1.0 | .42 | .62 | 47.8 | 36.7 |
| 0725 | [g] 536.13 | 18.5 | 630 | 7.63 | 6.3 | [b] 5.2 | [b] .11 | 1.4 | 0.38 | .11 | .9 | .51 | .54 | 45.8 | 33.6 |

[a] Beach Street Bridge.

[b] BOD parameters based on a nonstandard BOD test. Record length shorter than 20 days.

[c] First Street Bridge.

[d] Trinity River near Meadowbrook Golf Course.

[e] Orthrophosphate concentration exceeds phosphorus concentration.

[f] I-820 Bridge.

[g] Randol Mill Road Bridge.

trends noted in the last section on the initial water quality. However, these trends are combined with the same diel fluctuations noted at fixed points and that will be discussed in the next section. Figure 18 shows some of the trends.

DO and water temperature show clear diel trends. Unfortunately, the studies near I-820 and Big Fossil Creek stopped just as the morning's increase in temperature and DO were expected. The diel fluctuation is greatest at Beach Street where less shading occurs.

The effects of the pollution laden tributaries are not quite as evident as in the initial data. Ammonia and $CBOD_u$ clearly increase at Big Fossil Creek but only organic nitrogen shows up as a significant load from the tributary south of Riverside STP. Ammonia, $CBOD_u$, and DO tend to decrease in the downstream direction. Nitrate, which is not shown in figure 18, tends to increase in the downstream direction.

What appears to be an anomalously low value of DO occurs at site 3B (table 21) for the injection begun November 12, 1980 downstream of Beach Street. A check of the field notes indicates that this represents a single measurement taken near the centerline at mid-depth. At this site the water velocity was extremely low and the maximum water depth was 9.7 feet. Some stratification may have occurred in the area and the DO measurement could have been made below the thermocline. The specific conductance appears somewhat high at this point which could also indicate the measurement was obtained in the stagnant water below the fresher overflowing water. In addition, the pH value was also slightly low at this site.

The scatter in the $CBOD_u$ data, may result from the precision of the test, failure to obtain a representative sample, or the influence of the bacteria or character of the waste swept in from the tributaries. It was highly unlikely that the site just downstream of Big Fossil Creek was mixed. Therefore, the sample may not have been representative here or at the next two sites downstream. However, except for one measurement of orthophosphate there is little else to indicate that the samples were not representative. There is some indication that the bacteria in the river may have taken some time to adapt to the waste. The $K_1$ values decreased somewhat just downstream of the tributary and recovers to values equivalent to upstream values or greater. This aclimation may have affected $CBOD_u$.

The Lagrangian water-quality measurements are presented in table 21. Measurements of the various chemical species are of the dissolved phase (material passing through a 0.45 μm filter).

## Water Quality at Fixed Sites

Water-quality measurements at fixed sites define the temporal variation for the river and tributaries. In the river, DO and pH

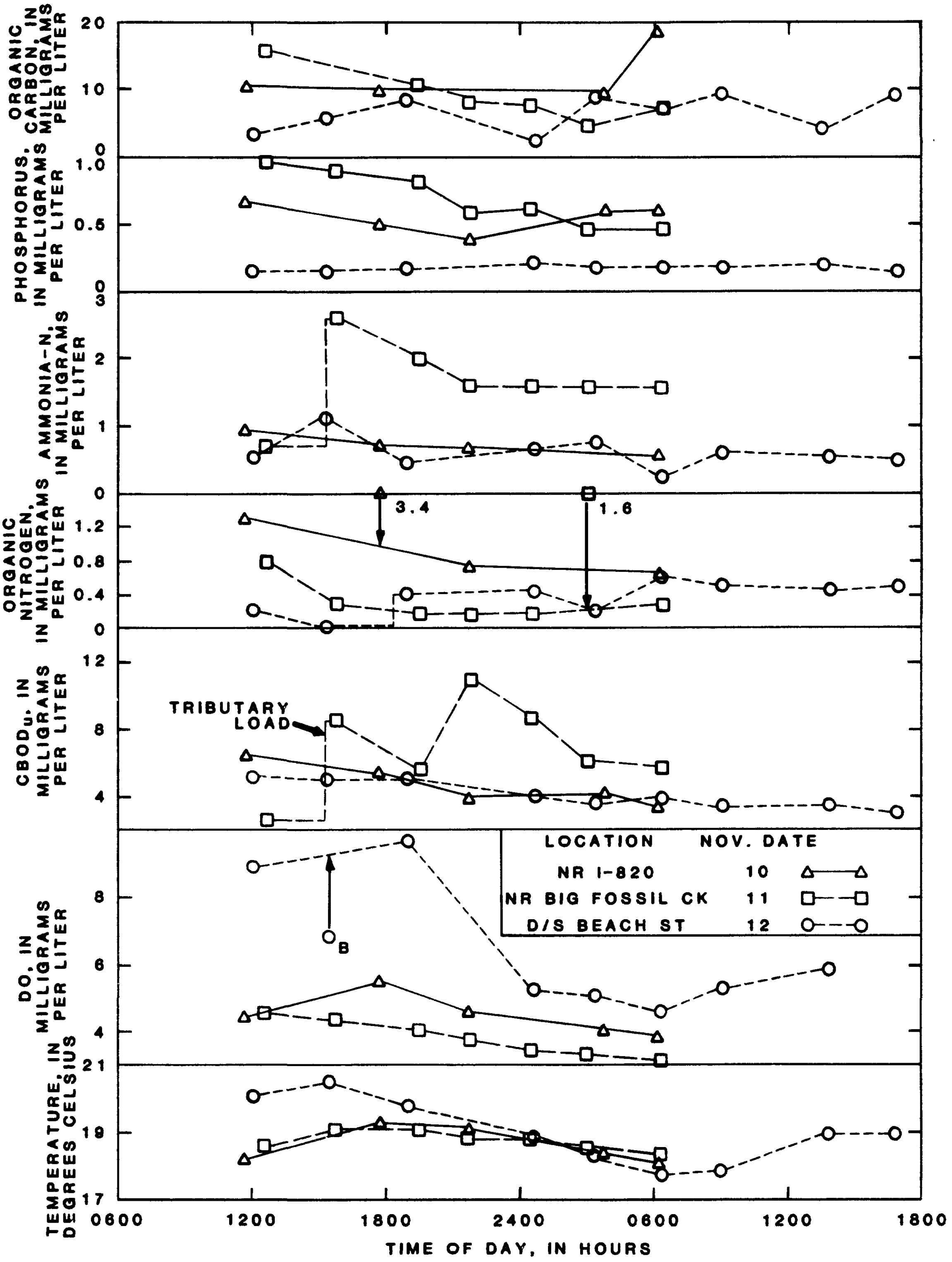

Figure 18.--Temporal and longitudinal trends in Lagrangian water-quality data.

Table 21.--Water-quality data from particular parcels of water

[-- indicates missing data due to instrument malfunction or misplaced sample]

| Nov. 1980 date | Time | Site | River mile | Temp (°C) | Specific cond. (μmho/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos. (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parcel Tagged on November 10, 1980 near I-820 | | | | | | | | | | | | | | | | | |
| 10 | 1140 | A | 540.80 | 18.2 | 600 | 7.1 | 4.4 | [a] 6.4 | [a] 0.12 | 2.2 | 0.94 | 0.08 | 0.5 | 0.47 | 0.66 | 44.8 | 34.5 |
| 10 | 1740 | B | 539.85 | 19.3 | 610 | 7.6 | 5.5 | [a] 5.3 | [a] .10 | 4.1 | .72 | .11 | .8 | .45 | .50 | 44.9 | 35.2 |
| 10 | 2145 | C | 539.41 | 19.1 | 620 | 7.3 | 4.6 | [a] 4.0 | [a] .12 | 1.4 | .68 | .11 | .8 | [b] .45 | [b] .39 | -- | -- |
| 11 | 0345 | D | 538.37 | 18.4 | 630 | 7.3 | 4.1 | [a] 4.2 | [a] .14 | 1.3 | -- | .11 | .9 | .44 | .59 | 46.5 | 37.4 |
| 11 | 0610 | E | 538.13 | 18.1 | 620 | 7.4 | 3.9 | [a] 3.4 | [a] .16 | 1.2 | .56 | .11 | .9 | .44 | .60 | 56.7 | 38.3 |
| Parcel Tagged on November 11, 1980 near Big Fossil Creek | | | | | | | | | | | | | | | | | |
| 11 | 1230 | A | 543.25 | 18.6 | 570 | 7.1 | 4.6 | 2.6 | 0.12 | 1.5 | 0.70 | 0.07 | 0.4 | 0.17 | 0.97 | 46.5 | 30.8 |
| 11 | 1545 | B | 542.77 | 19.1 | 590 | 7.1 | 4.4 | 8.4 | .10 | 2.9 | 2.6 | .06 | .4 | .90 | .90 | -- | -- |
| 11 | 1925 | C | 542.51 | 19.1 | 630 | 7.3 | 4.1 | [a] 5.6 | [a] .14 | 2.2 | 2.0 | .07 | .4 | .53 | .81 | 46.5 | 36.3 |
| 11 | 2145 | D | 542.16 | 18.9 | 630 | 7.4 | 3.8 | [a] 11 | [a] .16 | 1.8 | 1.6 | .07 | .4 | .51 | .59 | 44.9 | 36.8 |
| 12 | 0025 | E | 542.03 | 18.8 | 630 | 7.3 | 3.5 | [a] 8.8 | [a] .14 | 1.8 | 1.6 | .07 | .4 | .52 | .62 | 46.5 | 38.6 |
| 12 | 0300 | F | 541.94 | 18.6 | 630 | 7.4 | 3.4 | [a] 6.1 | [a] .23 | 3.2 | 1.6 | .07 | .4 | [b] .52 | [b] .47 | 47.2 | 42.4 |
| 12 | 0620 | G | 541.70 | 18.4 | 630 | 7.4 | 3.2 | [a] 5.8 | [a] .22 | 1.9 | 1.6 | .07 | .4 | [b] .52 | [b] .47 | 46.5 | 39.4 |
| Parcel Tagged on November 12, 1980 Downstream of Beach Street | | | | | | | | | | | | | | | | | |
| 12 | 1200 | A | 549.32 | 20.1 | 530 | 7.6 | 8.9 | 5.2 | 0.28 | 0.74 | 0.52 | 0.04 | 0.2 | 0.10 | 0.15 | 40.2 | 36.9 |
| 12 | 1545 | B | 548.89 | 20.5 | 570 | 7.5 | 6.8 | [a] 5.0 | [a] .28 | 1.1 | 1.1 | .04 | .2 | .11 | .15 | 40.2 | 34.3 |
| 12 | 1900 | C | 548.73 | 19.8 | 550 | 7.6 | 9.7 | [a] 5.0 | [a] .26 | 0.86 | .45 | .04 | .2 | .12 | .17 | 44.9 | 36.6 |
| 12 | 0034 | D | 547.69 | 18.8 | 570 | 7.4 | 5.2 | 4.0 | .28 | 1.1 | .64 | .07 | .3 | .16 | .21 | 42.5 | 40.0 |
| 13 | 0310 | E | 547.42 | 18.3 | 570 | 7.4 | 5.1 | 3.5 | .24 | 1.0 | .77 | .06 | .3 | .17 | .19 | 76.3 | 67.8 |
| 13 | 0612 | F | 547.15 | 17.7 | 570 | 7.4 | 4.6 | [a] 4.0 | [a] .28 | 1.0 | .25 | .07 | .3 | .16 | .19 | 41.8 | 34.8 |
| 13 | 1035 | G | 546.73 | 17.9 | 540 | 7.0 | 5.3 | 3.4 | .25 | 1.1 | .60 | .07 | .3 | .17 | .19 | 42.5 | 33.2 |
| 13 | 1345 | H | 546.30 | 19.0 | 533 | 7.2 | 5.9 | [a] 3.6 | [a] .28 | 1.0 | .54 | .07 | .3 | .16 | .21 | 41.8 | 37.5 |
| 13 | 1645 | I | 545.97 | 19.0 | -- | -- | -- | [a] 3.0 | [a] .49 | 1.0 | .50 | .07 | .4 | [b] .16 | [b] .15 | 42.5 | 31.5 |

[a] BOD parameters based on a nonstandard BOD test. Record was shorter than 20 days.

[b] Measured orthophosphate concentration exceeded measured phosphorus concentration.

follow diel patterns usually associated with photosynthesis (fig. 19). For a 24-hour period, DO varied by as much as 9.1 milligrams per liter at Beach Street and as little as 1.4 milligrams per liter at I-820. Variations in pH at Beach Street follows the same diel trend as DO (varing from 7.0 to 8.4). Temperature follows a diel trend usually caused by solar heating and subsequent nighttime cooling. Other constituents do not show a consistent diel trend. While some scatter is apparent in measurements of organic nitrogen, ammonia, $CBOD_u$, organic carbon, and phosphorus, the tributary concentrations for these and other constituents are fairly steady over the four-day November study.

It is possible to get an idea of longitudinal trends by correlating measurements at the adjacent river sites lagged by the travel time between sites. A routing model by Jobson and Rathbun (1984) was calibrated with the dye measurements to estimate the following travel times to each river site from Beach Street:

| to | hours |
|---|---|
| First Street | 18.6 |
| Near Meadowbrook Golf Course | 44.7 |
| I-820 | 72.5 |
| Randol Mill Drive | 109.9 |

These correlations or mass balances between the various sites made it possible to check the data and also showed several interesting trends. For example, figure 20 explains why bimodal DO peaks are observed at First Street. The 0900 hour DO peaks at First Street correlate with the 1400 hour DO peaks observed at Beach Street about 19 hours earlier. In this short reach, advective transport (net downstream movement by stream currents) dominated the effects of reaeration, deoxygenation, nitrification, sediment demand, and algae respiration.

The data collected at fixed sites are tabulated in table 22. Measurements for chemical species are of the dissolved phase that is defined as the material passing through a 0.45 µm filter. The available data seems to adequately define the quality of the water entering the study reach at Beach Street and the instream trends downstream.

## Precision of Water-Quality Data

Except for ammonia and phosphorus, measurement precision in the study compares well with published criteria. Table 23 presents the computed mean, standard deviation, coefficient of variation (standard deviation divided by mean), and number of observations for samples collected at the same time at different points over

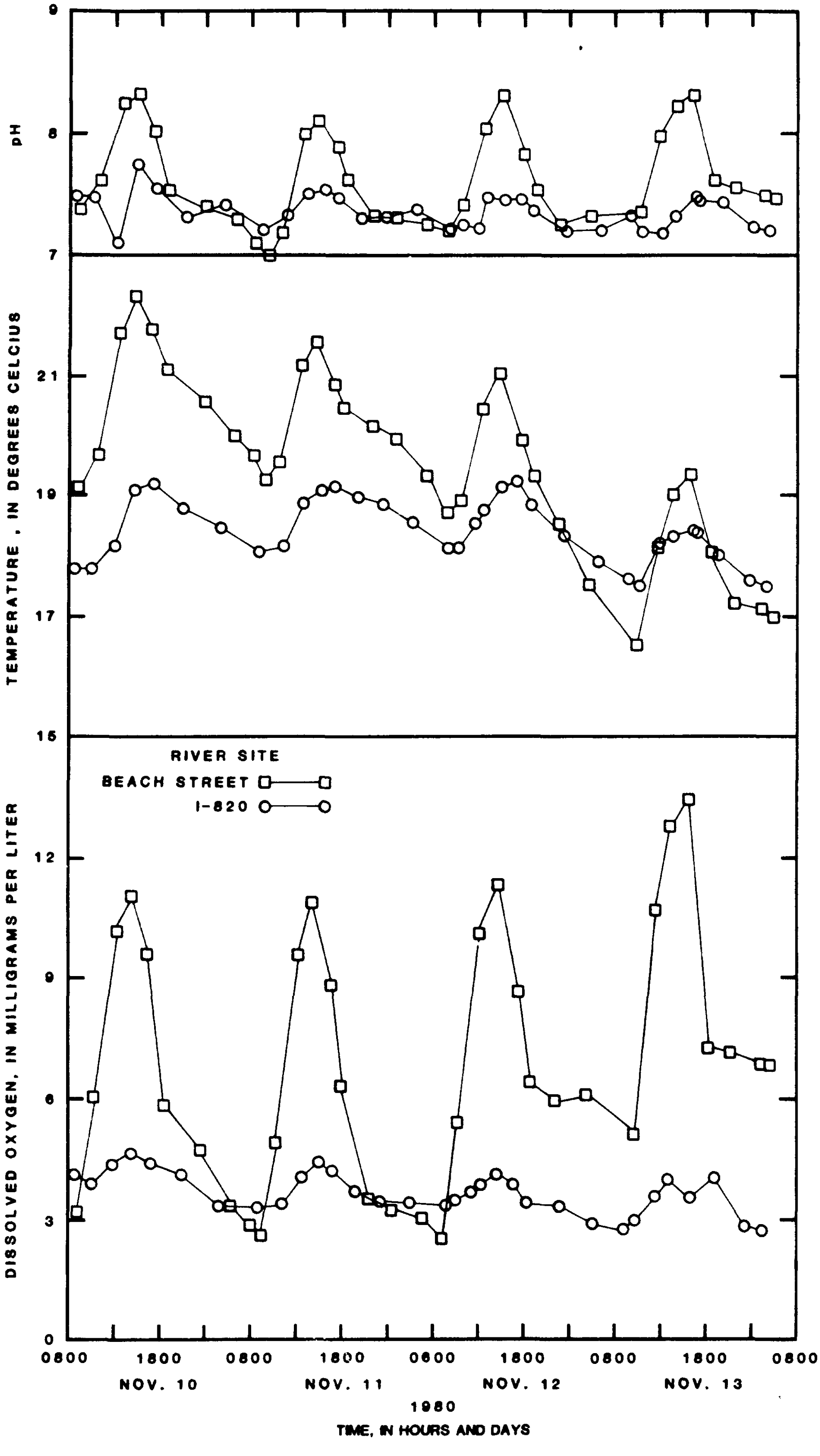

Figure 19.--Diel variation in DO, temperature, and pH at Beach Street and I-820.

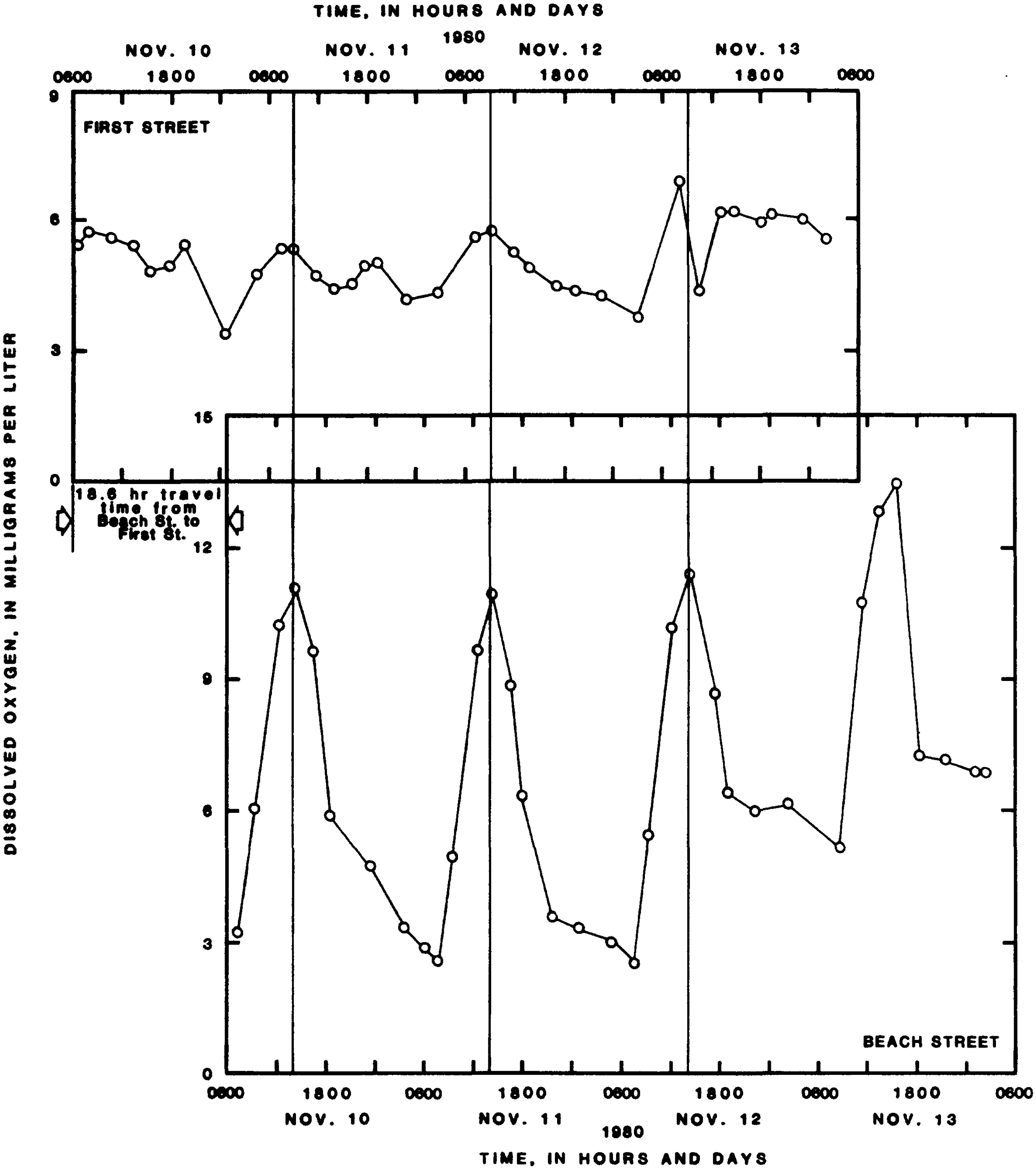

Figure 20.--Convective effects on dissolved oxygen at First Street.

Table 22.--Water-quality data from fixed sites

[— indicates the sample was not collected or lost]

| Nov. 1980 date | Time | Temp. (°C) | Specific cond. (µmhos/cm) | pH | DO (mg/L) | CBOD$_u$ (mg/L) | Base e K$_1$ (1/day) | Kjeld. N (mg/L) | Organic nit. (mg/L) | NH$_4$-N (mg/L) | NO$_2$-N (mg/L) | NO$_3$-N (mg/L) | PO$_4$-P (mg/L) | Phos. (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BEACH STREET BRIDGE | | | | | | | | | | | | | | | | |
| 10 | 0715 | 19.1 | 570 | 7.4 | 3.2 | $^{a}$ 5.6 | $^{a}$ 0.17 | 1.1 | 0.76 | 0.34 | 0.06 | 0.2 | 0.11 | 0.17 | 41.1 | 27.5 |
| 10 | 0920 | 19.7 | 570 | 7.6 | 6.0 | 6.4 | .14 | 1.2 | .85 | .33 | .06 | .3 | $^{b}$ .10 | $^{b}$ .09 | 42.2 | 25.5 |
| 10 | 1215 | 21.7 | 570 | 8.2 | 10.4 | 7.4 | .14 | 1.3 | .87 | .46 | .06 | .3 | $^{b}$ .11 | $^{b}$ .10 | 40.4 | 26.6 |
| 10 | 1415 | 22.3 | 570 | 8.3 | 11.4 | 7.2 | .14 | 1.5 | .92 | .58 | .07 | .3 | .11 | .15 | 43.6 | 30.7 |
| 10 | 1620 | 21.8 | 580 | 8.0 | 9.6 | 8.0 | .20 | 1.8 | .95 | .88 | .07 | .3 | .11 | .15 | 34.9 | 24.0 |
| 10 | 1825 | 21.1 | 580 | 7.5 | 5.9 | 7.6 | .20 | 2.0 | 1.2 | .83 | .07 | .2 | .12 | .20 | 42.2 | 27.1 |
| 10 | 2320 | 20.6 | 590 | 7.4 | 4.7 | 10 | .14 | 1.3 | .34 | .97 | .05 | .2 | .15 | .29 | 46.7 | 35.6 |
| 11 | 0325 | 20.0 | 570 | 7.3 | 3.4 | 7.6 | .16 | 1.5 | .96 | .50 | .05 | .2 | .13 | .22 | 39.0 | 30.6 |
| 11 | 0555 | 19.7 | 550 | 7.1 | 2.9 | 5.8 | .18 | 1.7 | .86 | .81 | .10 | .2 | $^{b}$ .11 | $^{b}$ .04 | 39.7 | 25.7 |
| 11 | 0735 | 19.3 | 550 | 7.0 | 2.3 | 6.2 | .18 | .97 | .25 | .72 | .05 | .2 | .12 | .14 | 39.7 | 27.8 |
| 11 | 0920 | 19.6 | 550 | 7.2 | 4.5 | — | -- | 1.0 | .62 | .42 | .05 | .2 | $^{b}$ .07 | $^{b}$ .06 | 40.8 | 31.9 |
| 11 | 1215 | 21.2 | 550 | 8.0 | 9.8 | 6.0 | .16 | 1.1 | .58 | .48 | .06 | .2 | .09 | .24 | -- | -- |
| 11 | 1400 | 21.6 | 560 | 8.1 | 11.2 | — | -- | 1.3 | .83 | .52 | .06 | .3 | $^{b}$ .10 | $^{b}$ .09 | 40.1 | 26.2 |
| 11 | 1630 | 20.9 | 580 | 7.9 | 8.7 | 6.2 | .22 | 1.5 | .60 | .88 | .06 | .2 | .10 | .16 | 41.8 | 26.2 |
| 11 | 1745 | 20.5 | 590 | 7.6 | 6.0 | — | -- | 1.6 | .66 | .94 | .06 | .2 | .10 | .11 | 44.2 | 26.0 |
| 11 | 2130 | 20.2 | 600 | 7.3 | 3.5 | 8.6 | .20 | 1.5 | .32 | 1.1 | .04 | .2 | .11 | .18 | 43.9 | 26.3 |
| 12 | 0035 | 20.0 | 600 | 7.3 | 3.3 | 6.4 | .24 | 1.2 | .45 | .74 | .04 | .2 | .11 | .22 | 41.8 | 25.7 |
| 12 | 0440 | 19.4 | 570 | 7.3 | 2.8 | 5.6 | .22 | 1.2 | .46 | .76 | .04 | .2 | .12 | .21 | 39.0 | 27.7 |
| 12 | 0725 | 18.8 | 570 | 7.2 | 2.4 | 5.8 | .24 | 1.1 | .58 | .52 | .04 | .2 | .11 | .16 | 37.7 | 22.6 |
| 12 | 0915 | 19.0 | 570 | 7.4 | 5.3 | — | -- | $^{c}$ .99 | $^{c}$ 0 | $^{c}$ 1.0 | .04 | .2 | .10 | .15 | 39.7 | 25.4 |
| 12 | 1200 | 20.5 | 570 | 8.1 | 10.2 | 6.4 | .22 | 1.2 | .20 | 1.0 | .05 | .2 | .11 | .15 | 39.7 | 25.8 |
| 12 | 1420 | 21.1 | 580 | 8.4 | 11.5 | — | -- | 1.3 | .77 | .55 | .05 | .2 | $^{b}$ .11 | $^{b}$ .09 | 40.4 | 24.1 |
| 12 | 1710 | 20.0 | 580 | 7.9 | 8.4 | 5.2 | 0.22 | 1.7 | 0.85 | .82 | .04 | .2 | $^{b}$ .08 | $^{b}$ .07 | — | -- |
| 12 | 1847 | 19.4 | 600 | 7.6 | 6.4 | 3.4 | .30 | .91 | .10 | .81 | .05 | .2 | .07 | .12 | 41.8 | 24.2 |
| 12 | 2205 | 18.6 | 600 | 7.3 | 5.8 | 3.6 | .26 | .98 | .76 | .22 | .04 | .3 | .08 | .09 | 42.5 | 32.9 |
| 13 | 0210 | 17.6 | 600 | 7.4 | 6.3 | 3.2 | .30 | $^{c}$ .81 | $^{c}$ 0 | $^{c}$ .89 | .04 | .2 | .08 | .20 | 39.7 | 31.5 |
| 13 | 0825 | 16.6 | 570 | 7.4 | 6.2 | 4.4 | .20 | .76 | .53 | .24 | .05 | .2 | .07 | .14 | 39.0 | 32.8 |
| 13 | 1105 | 18.2 | 580 | 8.0 | 10.7 | — | -- | .87 | .22 | .65 | .05 | .3 | .07 | .14 | 39.7 | 28.4 |
| 13 | 1310 | 19.1 | 580 | 8.3 | 12.6 | 3.0 | .28 | .74 | .20 | .54 | .05 | .3 | .07 | .13 | 39.4 | 28.4 |
| 13 | $^{d}$ 1520 | 19.5 | 580 | 8.4 | 13.3 | 3.2 | .20 | .79 | .18 | .61 | .05 | .3 | .07 | .13 | 42.5 | 29.2 |
| 13 | $^{d}$ 1520 | 19.4 | 580 | 8.4 | 12.9 | 3.0 | .28 | .85 | .33 | .52 | .05 | .3 | .07 | .12 | 38.7 | 34.8 |
| 13 | $^{d}$ 1520 | 19.4 | 580 | 8.3 | 12.9 | 3.2 | .20 | .80 | .34 | .46 | .04 | .3 | .07 | .11 | 42.5 | 36.5 |
| 13 | $^{d}$ 1520 | 19.4 | 580 | 8.3 | 13.3 | 3.6 | .20 | .73 | .32 | .41 | .05 | .3 | .07 | .11 | 38.3 | 35.6 |
| 13 | $^{d}$ 1520 | 19.4 | 580 | 8.4 | 13.6 | 3.0 | .28 | .81 | .40 | .41 | .04 | .3 | .07 | .12 | 40.8 | 34.8 |
| 13 | 1811 | 18.1 | 580 | 7.7 | 7.2 | 3.9 | .10 | $^{c}$ .92 | $^{c}$ 0 | $^{c}$ 1.2 | .03 | .2 | .07 | .11 | 41.1 | 34.0 |
| 13 | 2115 | 17.3 | 590 | 7.6 | 6.9 | 3.4 | .23 | .87 | .53 | .34 | .05 | .3 | .09 | .13 | 41.8 | 30.0 |
| 14 | 0055 | 17.2 | 600 | 7.5 | 6.9 | 3.2 | .22 | .87 | .47 | .40 | .05 | .3 | .07 | .13 | 42.5 | 34.8 |
| 14 | 0217 | 17.1 | 590 | 7.5 | 6.9 | 3.0 | .16 | 1.1 | .36 | .71 | .05 | .3 | .07 | .10 | 41.1 | 34.8 |

Table 22.--Water-quality data from fixed sites--Continued

[-- indicates the sample was not collected or lost]

| Nov. 1980 date | Time | Temp. (°C) | Specific cond. (µmhos/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | Organic nit. (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos. (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TRIBUTARY SOUTH OF RIVERSIDE SEWAGE TREATMENT PLANT | | | | | | | | | | | | | | | | |
| 12 | 2246 | 15.7 | 740 | 7.5 | 0.7 | 83 | 0.16 | [c] 22 | [c] 0 | [c] 32 | 0.01 | 0.01 | [b] 5.7 | [b] 4.2 | 43.3 | 33.3 |
| 12 | 2400 | 15.3 | 740 | 7.4 | 2.1 | 95 | .21 | [c] 19 | [c] 0 | [c] 23 | .02 | .01 | 6.1 | 7.0 | 93.5 | 64.1 |
| 13 | 0225 | 14.9 | 740 | 7.4 | .5 | 120 | .34 | [c] 18 | [c] 0 | [c] 25 | .01 | .02 | 7.4 | 8.3 | 92.0 | 64.1 |
| 13 | 0710 | 13.1 | 710 | 7.5 | .7 | 130 | .28 | 24 | 4.3 | 20 | .02 | .02 | 7.2 | 7.8 | 83.5 | 56.6 |
| 13 | 0905 | 13.5 | 700 | 7.4 | .5 | -- | -- | 24 | 5.8 | 18 | .02 | .00 | 7.1 | 7.9 | 88.1 | 56.6 |
| 13 | 1130 | 14.8 | 700 | 7.5 | .7 | 79 | .29 | 23 | 4.2 | 18 | .02 | .01 | 6.4 | 7.2 | 78.9 | 48.4 |
| 13 | 1340 | 16.1 | 840 | 7.8 | 1.5 | -- | -- | 23 | 4.1 | 19 | .06 | .02 | [b] 4.6 | [b] 4.4 | 91.2 | 58.6 |
| 13 | 1640 | 17.4 | 840 | 7.7 | .9 | 91 | .27 | [c] 28 | [c] 0 | [c] 33 | .02 | .00 | [b] 4.2 | [b] 3.8 | 89.7 | 58.6 |
| 13 | 1840 | 16.8 | 680 | 7.7 | .6 | 110 | .23 | 27 | 1.7 | 25 | .01 | .01 | [b] 4.6 | [b] 4.4 | 86.6 | 53.8 |
| 13 | 2245 | 15.4 | 770 | 7.4 | .8 | 190 | .25 | 25 | 5.3 | 20 | .01 | .2 | 4.6 | 4.8 | 91.2 | 58.6 |
| FIRST STREET BRIDGE | | | | | | | | | | | | | | | | |
| 10 | 0620 | 19.3 | 590 | 7.5 | 5.4 | 5.2 | 0.14 | 1.3 | 1.1 | 0.18 | 0.08 | 0.3 | 0.18 | 0.36 | 45.5 | 31.8 |
| 10 | 0745 | 19.4 | 590 | 7.7 | 5.7 | 4.8 | .15 | 1.2 | .87 | .36 | .08 | .3 | .17 | .32 | 42.9 | 31.5 |
| 10 | 1035 | 19.6 | 590 | 7.7 | 5.6 | [e] 4.8 | [e] .13 | 1.3 | .76 | .53 | .09 | .4 | .17 | .31 | -- | -- |
| 10 | 1310 | 20.3 | 590 | 7.8 | 5.6 | 5.2 | .11 | 1.4 | .90 | .53 | .09 | .4 | .16 | .30 | 45.1 | 30.0 |
| 10 | 1515 | 20.1 | 580 | 7.7 | 4.8 | [e] 4.6 | [e] .16 | 1.5 | .91 | .56 | .08 | .3 | .17 | .30 | 43.2 | 30.0 |
| 10 | 1730 | 20.1 | 580 | 7.5 | 4.9 | [e] 4.6 | [e] .17 | 1.5 | .81 | .66 | .08 | -- | .16 | .31 | 43.2 | 32.2 |
| 10 | 1925 | 20.8 | 580 | 7.3 | 5.4 | [e] 4.7 | [e] .17 | 1.6 | .85 | .79 | .08 | .3 | .18 | .31 | 49.9 | 32.9 |
| 11 | 0030 | 20.0 | 580 | 7.3 | 3.4 | 6.1 | .16 | 1.1 | .53 | .55 | .08 | .3 | .18 | .32 | 42.9 | 36.3 |
| 11 | 0415 | 20.0 | 570 | 7.2 | 4.8 | 5.8 | 0.13 | 1.3 | 0.66 | .67 | .08 | .4 | .17 | .30 | 43.2 | 31.8 |
| 11 | 0715 | 19.9 | 560 | 7.2 | 5.2 | 4.4 | .16 | 1.5 | .58 | .89 | .10 | .3 | .16 | .29 | 42.5 | 29.6 |
| 11 | 0845 | 19.8 | 560 | 7.2 | 4.9 | 4.8 | .16 | 1.4 | .73 | .67 | .10 | .4 | .16 | .28 | 42.5 | 30.7 |
| 11 | 1130 | 20.1 | 570 | 7.4 | 4.9 | 4.5 | .18 | 1.6 | .88 | .70 | .10 | .4 | .16 | .30 | 42.9 | 29.3 |
| 11 | 1340 | 20.2 | 570 | 7.4 | 4.7 | 6.0 | .12 | 1.6 | .85 | .72 | .09 | .3 | .15 | .28 | -- | -- |
| 11 | 1550 | 20.1 | 570 | 7.4 | 4.4 | [e] 4.1 | [e] .18 | 1.6 | .67 | .80 | .04 | .4 | .15 | .18 | 49.2 | 33.7 |
| 11 | 1730 | 20.2 | 570 | 7.4 | 4.7 | 3.8 | .18 | 1.8 | 1.1 | .72 | .08 | .3 | .16 | .29 | 46.9 | 31.1 |
| 11 | 1900 | 20.9 | 570 | 7.3 | 5.0 | 4.3 | .22 | 1.8 | 1.1 | .78 | .09 | .3 | .17 | .31 | 45.8 | 34.1 |
| 11 | 2230 | 20.2 | 560 | 7.3 | 4.2 | 4.6 | .21 | 1.6 | .82 | .80 | .09 | .3 | .20 | .33 | 42.5 | 30.7 |
| 12 | 0220 | 19.9 | 530 | 7.1 | 4.3 | 4.4 | .23 | 1.7 | 1.1 | .58 | .08 | .3 | .18 | .33 | 41.8 | 34.8 |
| 12 | 0700 | 19.6 | 560 | 7.4 | 5.5 | 4.8 | .23 | 1.3 | .82 | .48 | .08 | .4 | .17 | .21 | 40.3 | 28.9 |
| 12 | 0855 | 19.5 | 560 | 7.5 | 5.7 | 4.1 | .26 | 1.2 | .61 | .62 | .08 | .4 | .17 | .18 | -- | -- |
| 12 | 1135 | 19.8 | 570 | 7.5 | 5.3 | 3.4 | .26 | 1.4 | .59 | .85 | .08 | .4 | [b] .17 | [b] .16 | 45.5 | 29.6 |
| 12 | 1330 | 19.9 | 570 | 7.5 | 5.1 | -- | -- | 1.7 | .87 | .82 | .08 | .4 | [b] .17 | [b] .13 | 44.4 | 30.4 |
| 12 | 1650 | 19.5 | 580 | 7.5 | 4.3 | 4.4 | .23 | 1.7 | .78 | .92 | .07 | .3 | [b] .16 | [b] .10 | 43.2 | 34.1 |
| 12 | 1910 | 19.6 | 590 | 7.4 | 4.4 | 4.8 | .23 | 1.3 | .46 | .82 | .07 | .3 | .15 | .22 | 46.2 | 33.3 |
| 12 | 2220 | 19.3 | 580 | 7.2 | 4.0 | 4.1 | .26 | 1.4 | .70 | .70 | .07 | .2 | [b] .17 | [b] .13 | 44.0 | 33.3 |
| 13 | 0250 | 18.3 | 570 | 7.3 | 4.0 | 3.4 | .26 | 1.3 | .52 | .80 | .07 | .3 | .21 | .22 | 42.1 | 35.5 |
| 13 | 0750 | 18.0 | 560 | 7.3 | 7.7 | 4.4 | .19 | 1.1 | .67 | .46 | .07 | .3 | .18 | .25 | 43.2 | 36.6 |
| 13 | 1009 | 18.2 | 560 | 7.5 | 6.3 | -- | -- | 1.3 | .93 | .34 | .05 | .2 | [b] .13 | [b] .12 | 43.2 | 35.5 |
| 13 | 1245 | 18.8 | 590 | 7.5 | 6.1 | [e] 3.1 | [e] .24 | 1.5 | .73 | .74 | .07 | .4 | [b] .16 | [b] .11 | 42.5 | 30.4 |

Table 22.--Water-quality data from fixed sites--Continued

[-- indicates the sample was not collected or lost]

| Nov. 1980 date | Time | Temp. (°C) | Specific cond. (µmhos/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | Organic nit. (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | FIRST STREET BRIDGE -- Continued | | | | | | | | | | | | | |
| 13 | 1425 | 18.6 | 600 | 7.5 | 6.0 | -- | -- | 1.2 | 0.61 | 0.61 | 0.06 | 0.4 | [b] 0.14 | [b] 0.10 | 42.1 | 33.7 |
| 13 | 1745 | 18.2 | 600 | 7.5 | 5.9 | 4.9 | .12 | 1.0 | .34 | .66 | .06 | .3 | [b] .12 | [b] .09 | 46.6 | 34.8 |
| 13 | 1905 | 18.1 | 600 | 7.6 | 6.0 | 3.5 | .17 | 1.0 | .61 | .47 | .06 | .3 | [b] .12 | [b] .08 | 42.5 | 31.1 |
| 13 | 2258 | 17.7 | 610 | 7.4 | 6.1 | [e] 3.6 | [e] .17 | 1.2 | .03 | 1.1 | .06 | .3 | [b] .15 | [b] .10 | 42.5 | 35.5 |
| 14 | 0145 | 17.2 | 600 | 7.4 | 5.6 | 4.0 | .15 | [c] 1.0 | [c] 0 | [c] 1.1 | .05 | .3 | [b] .14 | [b] .09 | 46.6 | 29.8 |
| | | | NEAR MEADOWBROOK GOLF COURSE | | | | | | | | | | | | | |
| 10 | 0835 | 17.0 | 590 | 7.4 | 8.8 | 4.4 | 0.15 | 1.0 | 0.63 | 0.36 | 0.07 | 0.4 | 0.12 | 0.23 | 47.5 | 31.3 |
| 10 | 1120 | 19.1 | 600 | 7.7 | 6.0 | 4.3 | .15 | 1.1 | .72 | .34 | .07 | .4 | .11 | .21 | 43.6 | 38.8 |
| 10 | 1345 | 19.8 | 590 | 7.8 | 6.6 | 4.1 | .11 | 1.2 | .90 | .32 | .07 | .4 | .12 | .20 | 43.9 | 33.8 |
| 10 | 1555 | 19.9 | 590 | 7.6 | 6.1 | [e] 5.4 | [e] .11 | 1.1 | .72 | .41 | .08 | .4 | .13 | .21 | 68.6 | 56.3 |
| 10 | 1750 | 19.6 | 590 | 7.5 | 5.5 | [f] -- | [f] -- | 1.6 | 1.2 | .45 | .08 | .4 | .13 | .15 | 43.7 | 32.2 |
| 10 | 2010 | 19.4 | 600 | 7.4 | 5.3 | [f] -- | [f] -- | 1.2 | .54 | .64 | .08 | .4 | .14 | .26 | 50.3 | 32.5 |
| 11 | 0105 | 18.8 | 600 | 7.4 | 4.0 | [e] 5.0 | [e] .12 | .66 | .11 | .54 | .08 | .4 | .16 | .20 | 48.5 | 33.1 |
| 11 | 0445 | 18.6 | 590 | 7.2 | 4.0 | 4.1 | .16 | 1.6 | .94 | .61 | .07 | .4 | .17 | .22 | 46.6 | 31.3 |
| 11 | 0650 | 18.5 | 580 | 7.0 | 3.8 | 4.5 | .13 | 1.1 | .36 | .76 | .07 | .4 | .18 | .26 | 43.3 | 32.2 |
| 11 | 0820 | 18.7 | 580 | 7.1 | 4.1 | -- | -- | 1.2 | .72 | .47 | .07 | .4 | .17 | .44 | 44.8 | 31.6 |
| 11 | 1110 | 19.4 | 580 | 7.4 | 5.4 | 3.9 | .14 | 1.2 | .77 | .39 | .08 | .4 | [b] .17 | [b] .13 | 43.0 | 31.6 |
| 11 | 1315 | 19.9 | 580 | 7.4 | 5.6 | -- | -- | 1.1 | .68 | .42 | .08 | .4 | .17 | .24 | 46.5 | 33.3 |
| 11 | 1535 | 20.1 | 580 | 7.5 | 5.3 | 3.9 | .15 | 1.1 | .43 | .69 | .08 | .4 | .17 | .25 | 42.0 | 31.6 |
| 11 | 1715 | 19.9 | 580 | 7.5 | 4.8 | -- | -- | 1.2 | .57 | .63 | .09 | .4 | .16 | .19 | 44.8 | 32.2 |
| 11 | 1925 | 19.6 | 580 | 7.3 | 4.5 | 3.4 | .16 | 1.2 | .56 | .60 | .09 | .4 | .16 | .21 | 45.6 | 32.2 |
| 11 | 2255 | 19.3 | 580 | 7.3 | 3.9 | 4.4 | .15 | 1.3 | .41 | .86 | .09 | .4 | [b] .17 | [b] .14 | 44.7 | 33.3 |
| 12 | 0240 | 19.0 | 570 | 7.2 | 3.2 | 3.8 | .14 | 1.1 | .61 | .51 | .08 | .4 | .17 | .24 | 46.4 | 33.1 |
| 12 | 0640 | 18.8 | 570 | 7.2 | 3.8 | 3.6 | .26 | 1.2 | .86 | .35 | .08 | .4 | [b] .17 | [b] .11 | -- | -- |

Table 22.--Water-quality data from fixed sites--Continued

[-- indicates the sample was not collected or lost]

| Nov. 1980 date | Time | Temp. (°C) | Specific Cond. (µmhos/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | Organic nit. (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos. (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NEAR MEADOWBROOK GOLF COURSE - CONTINUED | | | | | | | | | | | | | | | | |
| 12 | 0820 | 18.9 | 570 | 7.4 | 4.3 | -- | -- | 1.1 | .62 | 0.51 | 0.07 | 0.4 | [b] 0.17 | [b] 0.09 | 43.8 | 31.6 |
| 12 | 1115 | 19.4 | 560 | 7.4 | 4.9 | 3.9 | 0.23 | 1.4 | .64 | .79 | .08 | .5 | .17 | 4.4 | 43.3 | 31.6 |
| 12 | 1310 | 19.8 | 560 | 7.4 | 5.2 | -- | -- | 1.3 | .67 | .58 | .08 | .5 | .16 | 4.4 | 43.4 | 32.2 |
| 12 | 1550 | 19.8 | 550 | 7.5 | 4.9 | 4.0 | .21 | 1.5 | .91 | .55 | .08 | .4 | .16 | .16 | 67.3 | 55.2 |
| 12 | 1925 | 19.3 | 560 | 7.4 | 4.0 | 4.2 | .20 | 1.1 | .53 | .56 | .08 | .4 | .16 | .24 | 11.8 | 5.8 |
| 12 | 2235 | 18.8 | 560 | 7.2 | 3.8 | 4.1 | .20 | 3.2 | 2.6 | .56 | .08 | .4 | .16 | .19 | 46.9 | 33.1 |
| 13 | 0310 | 18.1 | 560 | 7.2 | 3.5 | [e] 4.1 | [e] .19 | 1.4 | .86 | .49 | .08 | .4 | .17 | 1.9 | 48.0 | 32.5 |
| 13 | 0655 | 17.7 | 540 | 7.2 | 4.4 | 4.4 | .14 | .88 | .59 | .28 | .07 | .4 | .17 | .20 | 46.7 | 28.4 |
| 13 | 0950 | 17.9 | 540 | 7.3 | 5.7 | -- | -- | 1.1 | .95 | .16 | .07 | .4 | [b] .17 | [b] .14 | 44.7 | 33.1 |
| 13 | 1230 | 18.6 | 560 | 7.4 | 5.1 | 3.8 | .16 | .79 | .26 | .52 | .07 | .4 | .15 | .17 | 47.9 | 31.9 |
| 13 | 1405 | 18.9 | 560 | 7.4 | 5.4 | -- | -- | .84 | .37 | .47 | .07 | .4 | .15 | .19 | 48.0 | 31.3 |
| 13 | 1725 | 18.8 | 570 | 7.4 | 5.0 | 3.7 | .15 | .97 | .44 | .53 | .08 | .5 | [b] .15 | [b] .13 | 45.2 | 33.1 |
| 13 | 1920 | 18.3 | 570 | 7.5 | 4.9 | [e] 3.6 | [e] .10 | 1.0 | .55 | .45 | .08 | .4 | [b] .14 | [b] .13 | 49.9 | 33.1 |
| 13 | 2315 | 17.7 | 590 | 7.3 | 3.9 | [e] 3.3 | [e] .20 | 1.1 | .37 | .70 | .08 | .4 | [b] .14 | [b] .11 | 48.3 | 32.5 |
| TRIBUTARY NEAR MEADOWBROOK GOLF COURSE | | | | | | | | | | | | | | | | |
| 10 | 0655 | 16.9 | 830 | 7.6 | 4.3 | 6.6 | 0.25 | 0.51 | 0.45 | 0.06 | 0.03 | 0.1 | 0.07 | 0.12 | -- | -- |
| 10 | 0815 | 16.7 | 830 | 7.7 | 4.4 | 3.9 | .13 | .60 | .50 | .10 | .03 | .04 | .06 | .12 | -- | -- |
| 10 | 1110 | 17.9 | 800 | 7.8 | 7.3 | [g] 2.7 | [g] .18 | .62 | .47 | .15 | .04 | .02 | .05 | .11 | -- | -- |
| 10 | 1335 | 21.5 | 820 | 7.8 | 3.3 | [g] 3.3 | [g] .16 | .46 | .38 | .08 | .04 | .03 | .04 | .07 | -- | -- |
| 10 | 1540 | 22.5 | 810 | 7.6 | 8.2 | 4.3 | .15 | .61 | .51 | .10 | .04 | .03 | .05 | .06 | -- | -- |
| 10 | 1740 | 21.8 | 820 | 7.6 | 6.6 | [g] 2.9 | [g] .18 | .48 | .37 | .11 | .04 | .04 | .05 | .08 | -- | -- |

Table 22.--Water-quality data from fixed sites--Continued

[-- indicates the sample was not collected or lost]

| Nov. 1980 date | Time | Temp. (°C) | Specific cond. (µmhos/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | Organic nit. (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos. (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TRIBUTARY NEAR MEADOWBROOK GOLF COURSE--Continued | | | | | | | | | | | | | | | | |
| 10 | 2026 | 20.2 | 820 | 7.5 | 5.0 | [g] 2.5 | [g] .21 | 0.54 | 0.38 | 0.16 | 0.05 | 0.03 | 0.05 | 0.10 | 69.7 | 54.3 |
| 11 | 0120 | 17.8 | 820 | 7.6 | 3.9 | [g] 3.0 | [g] .14 | 1.9 | 1.7 | .21 | .04 | .03 | .05 | .16 | 72.0 | 69.2 |
| 11 | 0455 | 16.4 | 800 | 7.4 | 4.3 | [g] 2.3 | [g] .14 | .48 | .23 | .25 | .04 | .02 | .05 | .07 | -- | -- |
| 11 | 0630 | 16.0 | 790 | 7.3 | 3.9 | [g] 2.0 | [g] .66 | [c] .51 | [c] 0 | [c] .63 | .04 | .01 | .07 | .09 | 65.0 | 62.1 |
| 11 | 0800 | 15.8 | 790 | 7.4 | 4.5 | -- | -- | .46 | .19 | .28 | .04 | .01 | .07 | .09 | 69.7 | 69.5 |
| 11 | 1045 | 17.3 | 790 | 7.6 | 7.0 | [g] 1.3 | [g] .22 | .45 | .12 | .33 | .03 | .01 | .04 | .09 | 68.9 | 58.5 |
| 11 | 1305 | 20.3 | 780 | 7.6 | 9.1 | -- | -- | .40 | .01 | .39 | .03 | .01 | .07 | .10 | -- | -- |
| 11 | 1525 | 21.7 | 760 | 7.7 | 9.5 | 2.3 | .38 | .59 | .04 | .56 | .03 | .02 | .04 | .07 | -- | -- |
| 11 | 1710 | 21.5 | 760 | 7.7 | 8.6 | -- | -- | .65 | .02 | .63 | .03 | .03 | .04 | .06 | -- | -- |
| 11 | 1940 | 20.4 | 780 | 7.5 | 5.7 | 2.1 | .33 | .48 | .35 | .14 | .04 | .03 | .05 | .10 | 66.6 | 58.0 |
| 11 | 2300 | 19.2 | 790 | 7.5 | 4.1 | [g] 1.8 | [g] .26 | [c] .41 | [c] 0 | [c] .44 | .04 | .02 | .05 | .09 | 65.0 | 51.8 |
| 12 | 0300 | 17.6 | 790 | 7.5 | 4.0 | 2.5 | .24 | .79 | .68 | .11 | .04 | .02 | .05 | .14 | 69.7 | 56.8 |
| 12 | 0625 | 16.1 | 790 | 7.5 | 3.9 | 3.3 | .35 | .69 | .68 | .01 | .03 | .04 | .03 | .03 | 68.9 | 59.2 |
| 12 | 0810 | 15.6 | 790 | 7.6 | 4.3 | -- | -- | .55 | .31 | .24 | .03 | .04 | .04 | .05 | 67.4 | 53.0 |
| 12 | 1100 | 16.7 | 710 | 7.7 | 6.9 | [g] 2.8 | [g] .22 | .73 | .40 | .33 | .04 | .1 | .04 | .08 | 63.5 | 53.0 |
| 12 | 1300 | 18.8 | 760 | 7.7 | 9.4 | -- | -- | .61 | .47 | .13 | .03 | .04 | .04 | .06 | 67.4 | 51.8 |
| 12 | 1505 | 20.0 | 750 | 7.8 | 9.8 | [g] 3.5 | [g] .33 | .79 | .57 | .22 | .08 | .00 | .04 | .07 | -- | -- |
| 12 | 1935 | 18.4 | 770 | 7.7 | 6.6 | [g] 2.8 | [g] .29 | .48 | .19 | .29 | .03 | .04 | .04 | .12 | 68.1 | 51.8 |
| 12 | 2250 | 16.7 | 780 | 7.5 | 4.9 | 3.1 | .30 | .72 | .67 | .05 | .03 | .1 | .03 | .07 | 68.9 | 51.8 |
| 13 | 0325 | 15.0 | 780 | 7.6 | 3.9 | [g] 2.9 | [g] .27 | 1.0 | .76 | .26 | .03 | .1 | .03 | .06 | 69.7 | 59.2 |
| 13 | 0640 | 13.7 | 770 | 7.5 | 4.0 | 5.0 | .41 | .40 | .39 | .01 | .03 | .1 | .03 | .06 | 77.3 | 59.2 |

Table 22.--Water-quality data from fixed sites--Continued
[-- indicates the sample was not collected or lost]

| Nov. 1980 date | Time | Temp. (°C) | Specific cond. (µmhos/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | Organic nit. (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos. (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | TRIBUTARY NEAR MEADOWBROOK GOLF COURSE--Continued | | | | | | | | | | | | | |
| 13 | 0932 | 13.6 | 770 | 7.6 | 4.0 | -- | -- | 0.46 | 0.44 | 0.02 | 0.02 | 0.04 | 0.02 | 0.04 | 72.0 | 69.2 |
| 13 | 1205 | 16.2 | 810 | 7.8 | 8.4 | 3.1 | .31 | .56 | .13 | .43 | .03 | .04 | .03 | .05 | 77.3 | 75.4 |
| 13 | 1350 | 17.9 | 810 | 7.6 | 9.5 | -- | -- | .56 | .19 | .37 | .02 | .1 | .03 | .07 | 79.7 | 66.7 |
| 13 | 1710 | 18.6 | 790 | 7.7 | 8.6 | [f] -- | [f] -- | .49 | .20 | .29 | .03 | .1 | .02 | .04 | 72.7 | 61.7 |
| 13 | 1930 | 17.2 | 790 | 7.8 | 7.1 | 12 | .21 | .39 | .30 | .09 | .03 | .1 | .03 | .04 | 71.2 | 64.2 |
| 13 | 2325 | 15.6 | 810 | 7.6 | 4.7 | 4.8 | .29 | [c] .55 | [c] 0 | [c] .96 | .03 | .1 | .03 | .09 | 71.2 | 66.7 |
| | | | BIG FOSSIL CREEK | | | | | | | | | | | | | |
| 10 | 0800 | 20.2 | 1280 | 7.5 | 0.6 | 81 | 0.082 | 17 | 5.1 | 12 | 0.06 | 0.1 | 6.3 | 6.8 | 116.7 | 84.6 |
| 10 | 1010 | 20.3 | 1270 | 7.5 | .6 | 70 | .10 | 18 | 4.2 | 14 | .01 | .01 | 6.4 | 6.6 | 112.7 | 84.6 |
| 10 | 1315 | 20.9 | 1240 | 7.6 | .4 | 77 | .074 | 23 | 9.0 | 14 | .01 | .01 | 7.0 | 7.6 | 108.1 | 77.7 |
| 10 | 1530 | 21.2 | 1200 | 7.5 | .5 | 63 | .10 | 15 | 2.1 | 13 | .01 | .01 | 6.6 | 7.2 | 115.4 | 89.3 |
| 10 | 1755 | 21.9 | 1250 | 7.2 | .6 | 74 | .094 | 15 | .3 | 14 | >.01 | >.01 | -- | 7.8 | 122.7 | 79.1 |
| 10 | 2237 | 21.9 | 1340 | 7.3 | 1.1 | 83 | .067 | [c] 17 | [c] 0 | [c] 19 | .05 | .01 | 6.3 | 6.7 | 118.0 | 78.4 |
| 11 | 0259 | 21.1 | 1340 | 7.5 | .6 | 72 | .084 | 17 | .3 | 17 | .02 | .00 | 6.1 | 6.7 | 111.4 | 81.8 |
| 11 | 0755 | 20.3 | 1330 | 7.3 | .5 | 87 | .076 | [c] 18 | [c] 0 | [c] 26 | .02 | .02 | 6.3 | 6.8 | 120.7 | 86.3 |
| 11 | 1020 | 20.4 | 1320 | 7.2 | .5 | -- | -- | [c] 18 | [c] 0 | [c] 20 | .01 | .03 | 7.0 | 7.0 | 123.0 | 77.7 |
| 11 | 1150 | 20.9 | 1320 | 7.3 | .5 | 83 | .074 | 18 | 1.2 | 17 | .01 | .02 | 6.8 | 8.0 | 117.4 | 84.6 |
| 11 | 1315 | 21.1 | 1310 | 7.3 | .5 | -- | -- | 18 | 2.0 | 16 | .01 | .02 | 7.2 | 8.0 | 123.0 | 87.3 |
| 11 | 1530 | 21.0 | 1260 | 7.3 | .5 | 97 | .067 | 17 | 1.3 | 16 | .02 | .02 | 6.9 | 7.2 | 103.5 | 68.9 |
| 11 | 1650 | 21.4 | 1270 | 7.2 | .5 | -- | -- | 19 | 1.5 | 17 | .01 | .02 | 6.9 | 7.9 | 112.7 | 79.1 |

Table 22.--Water-quality data from fixed sites--Continued

[-- indicates the sample was not collected or lost]

| Nov. 1980 date | Time | Temp. (°C) | Specific cond. (µmhos/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | Organic nit. (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos. (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BIG FOSSIL CREEK--continued | | | | | | | | | | | | | | | | |
| 11 | 2107 | 21.6 | 1240 | 7.2 | 0.4 | 75 | 0.071 | [c] 15 | [c] 0 | [c] 18 | 0.38 | 0.1 | 6.3 | 6.4 | 104.1 | 73.0 |
| 12 | 0010 | 21.3 | 1220 | 7.3 | .4 | 83 | .070 | [c] 14 | [c] 0 | [c] 16 | .44 | .1 | 5.8 | 5.9 | 104.8 | 70.9 |
| 12 | 0420 | 20.5 | 1210 | 7.4 | .3 | 81 | .070 | 20 | .40 | 20 | .28 | .03 | 5.7 | 5.7 | 111.4 | 74.3 |
| 12 | 0645 | 20.2 | 1200 | 7.3 | .7 | 74 | .081 | [c] 16 | [c] 0 | [c] 18 | .11 | .02 | 5.7 | 6.6 | 100.8 | 70.2 |
| 12 | 0830 | 19.9 | 1200 | 7.3 | .6 | -- | -- | [c] 17 | [c] 0 | [c] 21 | .02 | .02 | 6.1 | 7.5 | 114.7 | 77.7 |
| 12 | 1035 | 20.0 | 1200 | 7.3 | .5 | 130 | .12 | [c] 17 | [c] 0 | [c] 22 | .03 | .01 | 6.1 | 7.2 | 114.1 | 78.4 |
| 12 | 1330 | 20.5 | 1180 | 7.3 | .5 | -- | -- | [c] 16 | [c] 0 | [c] 18 | .02 | .00 | 6.5 | 7.3 | -- | -- |
| 12 | 1605 | 20.4 | 1190 | 7.3 | .4 | 85 | .072 | [c] 16 | [c] 0 | [c] 17 | .02 | .01 | 6.7 | -- | 108.1 | 68.2 |
| 12 | 1800 | 20.3 | 1170 | 7.3 | .5 | -- | -- | [c] 18 | [c] 0 | [c] 21 | .01 | .00 | [b] 6.6 | [b] 4.6 | 102.1 | 70.2 |
| 12 | 2047 | 20.0 | 1150 | 7.3 | .5 | 74 | .090 | [c] 15 | [c] 0 | [c] 17 | .38 | .1 | [b] 6.6 | [b] 4.6 | 73.9 | 32.7 |
| 13 | 0001 | 19.7 | 1160 | 7.1 | .4 | 67 | .091 | [c] 14 | [c] 0 | [c] 16 | .34 | .1 | 6.5 | 6.9 | 111.4 | 68.2 |
| 13 | 0430 | 19.0 | 1180 | 7.2 | .6 | 97 | .047 | [c] 15 | [c] 0 | [c] 19 | .01 | .00 | 6.3 | 6.6 | 104.8 | 70.9 |
| 13 | 0830 | 18.7 | 1180 | 7.3 | .5 | 110 | .12 | [c] 16 | [c] 0 | [c] 18 | .01 | .02 | [b] 6.3 | [b] 4.2 | 112.7 | 70.9 |
| 13 | 1015 | 18.8 | 1170 | 7.2 | .5 | -- | -- | 15 | .67 | 15 | .01 | .01 | 6.2 | 6.5 | 104.8 | 68.2 |
| 13 | 1240 | 19.2 | 1210 | 7.2 | .5 | 76 | .087 | [c] 16 | [c] 0 | [c] 17 | .02 | .01 | 6.1 | 6.3 | 104.8 | 66.8 |
| 13 | 1505 | -- | -- | 7.3 | .5 | -- | -- | [c] 18 | [c] 0 | [c] 20 | .16 | .04 | 6.4 | 7.1 | 109.4 | 68.2 |
| 13 | 1735 | 19.1 | 1200 | 7.3 | .5 | 74 | .093 | [c] 17 | [c] 0 | [c] 30 | .08 | .01 | 6.5 | 7.1 | 104.8 | 55.9 |
| 13 | 2100 | -- | -- | -- | -- | 150 | .15 | [c] 16 | [c] 0 | [c] 21 | .43 | .1 | 6.6 | 7.4 | 103.4 | 65.4 |
| 14 | 0035 | 18.8 | 1160 | 7.3 | .6 | 63 | .091 | [c] 15 | [c] 0 | [c] 16 | .39 | .1 | 6.5 | 7.1 | 106.1 | 61.3 |

Table 22.--Water-quality data from fixed sites--Continued

[-- indicates the sample was not collected or lost]

| Nov. 1980 date | Time | Temp. (°C) | Specific cond. (µmhos/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | Organic nit. (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos. (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | I-820 BRIDGE | | | | | | | | | | |
| 10 | 0645 | 17.8 | 620 | 7.5 | 4.1 | 5.3 | 0.13 | 2.3 | 1.4 | 0.85 | 0.08 | 0.6 | [b]0.45 | [b]0.38 | 44.9 | 33.4 |
| 10 | 0855 | 17.8 | 610 | 7.5 | 3.9 | [e] 5.2 | [e] .14 | 1.9 | .95 | .93 | .08 | .5 | .44 | .49 | 48.0 | 36.1 |
| 10 | 1140 | 18.2 | 600 | 7.1 | 4.4 | [e] 6.4 | [e] .13 | 2.2 | 1.3 | .94 | .08 | .5 | .47 | .66 | 44.8 | 34.5 |
| 10 | 1415 | 19.1 | 620 | 7.7 | 4.7 | [e] 6.5 | [e] .13 | 1.9 | .92 | 1.0 | .07 | .5 | .49 | .73 | 45.8 | 36.1 |
| 10 | 1645 | 19.2 | 630 | 7.6 | 4.4 | [e] 6.6 | [e] .11 | 1.9 | .78 | 1.1 | .07 | .4 | [b] .53 | [b] .45 | 43.2 | 35.3 |
| 10 | 2045 | 18.8 | 640 | 7.3 | 4.2 | [e] 7.5 | [e] .13 | 2.1 | .55 | 1.5 | .07 | .4 | .56 | .73 | 48.1 | 34.4 |
| 11 | 0150 | 18.5 | 640 | 7.4 | 3.4 | [e] 7.5 | [e] .12 | 1.8 | .48 | 1.3 | .07 | .4 | .51 | .77 | 44.9 | 34.0 |
| 11 | 0700 | 18.1 | 640 | 7.2 | 3.3 | 5.2 | .15 | 1.9 | .11 | 1.7 | .07 | .4 | .46 | .64 | 43.1 | 33.9 |
| 11 | 1015 | 18.2 | 640 | 7.3 | 3.5 | 4.9 | .13 | 2.0 | .82 | 1.2 | .07 | .4 | .47 | 1.1 | 44.2 | 34.9 |
| 11 | 1245 | 18.9 | 640 | 7.5 | 4.3 | -- | -- | 1.8 | .41 | 1.4 | .07 | .4 | .49 | .66 | 43.4 | 35.8 |
| 11 | 1505 | 19.1 | 640 | 7.6 | 4.4 | 5.2 | .11 | 2.6 | 1.1 | 1.5 | .08 | .5 | .50 | .72 | 45.9 | 32.0 |
| 11 | 1650 | 19.2 | 640 | 7.5 | 4.0 | -- | -- | 2.0 | .40 | 1.6 | .08 | .5 | [b] .51 | [b] .41 | 42.6 | 36.8 |
| 11 | 1958 | 19.0 | 640 | 7.3 | 3.7 | 5.2 | .14 | 3.3 | 2.0 | 1.3 | .08 | .5 | [b] .52 | [b] .48 | 45.6 | 36.3 |
| 11 | 2315 | 18.9 | 630 | 7.3 | 3.5 | 4.3 | .14 | 1.9 | .59 | 1.3 | .09 | .5 | .51 | .68 | 46.1 | 35.1 |
| 12 | 0315 | 18.6 | 620 | 7.4 | 3.4 | 3.7 | .13 | 1.8 | .77 | 1.1 | .09 | .4 | .45 | .70 | 43.5 | 36.4 |
| 12 | 0755 | 18.2 | 620 | 7.3 | 3.2 | 7.9 | .11 | 1.9 | .80 | 1.1 | .07 | .3 | .40 | .54 | 43.5 | 36.7 |
| 12 | 0920 | 18.2 | 610 | 7.3 | 3.1 | -- | -- | 1.9 | .69 | 1.2 | .09 | .4 | .41 | .59 | 31.4 | 24.7 |
| 12 | 1130 | 18.6 | 620 | 7.3 | 3.7 | 4.3 | .34 | 2.0 | .79 | 1.2 | .08 | .4 | .44 | .58 | 45.5 | 36.9 |
| 12 | 1235 | 18.8 | 620 | 7.5 | 4.0 | -- | -- | 1.8 | .49 | 1.3 | .03 | .5 | [b] .47 | [b] .43 | 46.7 | 39.3 |
| 12 | 1455 | 19.2 | 630 | 7.5 | 4.1 | 5.5 | .19 | 2.5 | 1.4 | 1.1 | .08 | .4 | [b] .49 | [b] .40 | 45.1 | 40.8 |
| 12 | 1700 | 19.3 | 620 | 7.5 | 4.0 | -- | -- | 1.8 | 0.0 | 1.8 | .08 | .4 | .53 | .61 | 45.4 | 36.1 |
| 12 | 1845 | 18.9 | 620 | 7.4 | 3.4 | 6.8 | .15 | 1.8 | .53 | 1.3 | .08 | .4 | .51 | .67 | 43.6 | 42.5 |

Table 22.--Water quality data from fixed sites--Continued

[-- indicates the sample was not collected or lost]

| Nov. 1980 date | Time | Temp. (°C) | Specific cond. (µmhos/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | Organic nit. (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos. (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I-820 BRIDGE--Continued | | | | | | | | | | | | | | | | |
| 12 | 2310 | 18.4 | 620 | 7.2 | 3.0 | 5.6 | 0.19 | 2.0 | 0.81 | 1.1 | 0.08 | 0.4 | 0.53 | 0.75 | 42.9 | 39.7 |
| 13 | 0340 | 18.0 | 610 | 7.2 | 3.0 | 6.4 | .12 | 1.9 | .52 | 1.4 | .09 | .4 | .48 | .68 | 48.2 | 39.0 |
| 13 | 0745 | 17.7 | 590 | 7.4 | 2.8 | 6.1 | .15 | 1.6 | .56 | .99 | .09 | .4 | .42 | .56 | 46.4 | 39.9 |
| 13 | 0910 | 17.6 | 590 | 7.2 | 3.1 | -- | -- | 1.8 | 1.1 | .73 | .08 | .4 | .40 | .52 | 44.5 | 39.2 |
| 13 | 1150 | 18.3 | 610 | 7.2 | 3.7 | 4.2 | .25 | 1.8 | .84 | .96 | .08 | .4 | .50 | .73 | 50.3 | 38.2 |
| 13 | 1334 | 18.4 | 620 | 7.4 | 3.9 | -- | -- | 2.2 | .85 | 1.3 | .08 | .4 | .45 | .75 | 50.9 | 36.7 |
| 13 | [d] 1620 | 18.5 | 610 | 7.5 | 3.7 | 5.0 | .15 | 2.1 | .29 | 1.8 | .08 | .4 | [b] .47 | [b] .44 | -- | -- |
| 13 | [d] 1640 | 18.5 | 610 | 7.5 | 3.6 | 4.7 | .24 | 2.1 | .18 | 1.9 | .07 | .4 | .47 | .72 | 50.6 | 37.1 |
| 13 | [d] 1640 | 18.4 | 610 | 7.6 | 3.7 | 4.7 | .24 | 2.1 | .44 | 1.6 | .09 | .4 | [b] .46 | [b] .42 | 48.7 | 43.7 |
| 13 | [d] 1640 | 18.5 | 610 | 7.5 | 3.7 | 4.7 | .24 | 2.0 | .09 | 1.9 | .08 | .4 | .48 | .63 | 45.3 | 36.9 |
| 13 | [d] 1640 | 18.5 | 610 | 7.5 | 3.6 | 4.7 | .24 | 2.0 | .14 | 1.9 | .08 | .4 | .46 | .70 | 48.3 | 37.8 |
| 13 | [d] 1640 | 18.5 | 610 | 7.5 | 3.6 | 4.7 | .24 | 1.9 | .01 | 1.9 | .09 | .4 | .47 | .69 | 46.5 | 31.9 |
| 13 | 1943 | 18.1 | 600 | 7.5 | 4.1 | 5.8 | .20 | 2.0 | .67 | 1.4 | .08 | .4 | .50 | .78 | 49.4 | 37.8 |
| 13 | [h] 2345 | 17.7 | 610 | 7.3 | 3.0 | 5.3 | .21 | 2.0 | .46 | 1.5 | .08 | .4 | .48 | .65 | 48.9 | 35.8 |
| 13 | [h] 2345 | -- | -- | -- | -- | 5.8 | .20 | -- | -- | 1.4 | .09 | .4 | .51 | -- | -- | -- |
| 13 | [h] 2345 | -- | -- | -- | -- | 4.8 | .24 | -- | -- | -- | .09 | .4 | .52 | -- | -- | -- |
| 13 | [h] 2345 | -- | -- | -- | -- | 4.0 | .26 | -- | -- | -- | .09 | .4 | .51 | -- | -- | -- |
| 13 | [h] 2345 | -- | -- | -- | -- | 4.8 | .20 | -- | -- | -- | .09 | .4 | .50 | -- | -- | -- |
| 13 | [h] 2345 | -- | -- | -- | -- | 5.4 | .20 | -- | -- | -- | .09 | .4 | .51 | -- | -- | -- |
| 13 | [h] 2345 | -- | -- | -- | -- | 4.7 | .25 | -- | -- | -- | .09 | .4 | .52 | -- | -- | -- |
| 13 | [h] 2345 | -- | -- | -- | -- | 5.3 | .18 | -- | -- | -- | .09 | .4 | .50 | -- | -- | -- |
| 13 | [h] 2345 | -- | -- | -- | -- | 5.6 | .19 | -- | -- | -- | .09 | .4 | .51 | -- | -- | -- |
| 13 | [h] 2345 | -- | -- | -- | -- | 5.6 | .16 | -- | -- | -- | .09 | .4 | .50 | -- | -- | -- |
| 13 | [h] 2345 | -- | -- | -- | -- | 5.0 | .19 | -- | -- | -- | .09 | .4 | .50 | -- | -- | -- |
| 14 | 0158 | 17.6 | 610 | 7.3 | 2.9 | 4.8 | .20 | 2.2 | .63 | 1.6 | .09 | .4 | .48 | .65 | 45.5 | 44.3 |

Table 22.--Water Quality data from fixed sites--Continued
[-- indicates the sample was not collected or lost]

| Nov. 1980 date | Time | Temp. (°C) | Specific cond. (µmhos/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | Organic nit. (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RANDOL MILL ROAD BRIDGE | | | | | | | | | | | | | | | | |
| 10 | 0725 | 18.5 | 640 | 5.9 | 6.3 | e 5.2 | e 0.11 | 1.4 | 0.97 | 0.38 | 0.11 | 0.9 | 0.51 | 0.54 | 45.8 | 33.6 |
| 10 | 0930 | 18.4 | 630 | 7.6 | 5.9 | e 4.1 | e .11 | 1.3 | .75 | .54 | .11 | .9 | .50 | .60 | 45.1 | 34.3 |
| 10 | 1245 | 18.6 | 630 | 7.8 | 5.6 | e 4.0 | e .11 | 1.3 | .98 | .32 | .11 | .9 | .48 | .64 | 46.8 | 34.2 |
| 10 | 1450 | 18.3 | 630 | 7.7 | 5.0 | e 4.0 | e .13 | 1.6 | 1.1 | .52 | .10 | 1.0 | .46 | .66 | 46.1 | 35.0 |
| 10 | 1710 | 18.3 | 630 | 7.5 | 5.6 | e 4.2 | e .12 | 1.3 | .84 | .43 | .10 | 1.0 | .43 | .47 | 47.2 | 33.4 |
| 10 | 2139 | 18.4 | 630 | 7.4 | 6.2 | e 3.9 | e .12 | 1.5 | .96 | .50 | .10 | 1.0 | .43 | .48 | 45.6 | 33.9 |
| 11 | 0225 | 19.0 | 640 | 7.6 | 6.0 | e 4.0 | e .10 | 1.3 | .72 | .61 | .11 | 1.0 | .47 | .54 | 46.5 | 34.3 |
| 11 | 0715 | 18.8 | 630 | 7.4 | 5.6 | e 3.0 | e .12 | 1.3 | .51 | .81 | .12 | 1.0 | .49 | .54 | 47.8 | 35.5 |
| 11 | 0940 | 18.5 | 620 | 7.3 | 4.5 | -- | -- | 1.4 | .88 | .51 | .12 | 1.0 | .47 | .53 | 45.8 | 35.2 |
| 11 | 1115 | 18.5 | 620 | 7.3 | 4.1 | 2.7 | .11 | 1.4 | .64 | .74 | .12 | .9 | .46 | .52 | 47.5 | 33.7 |
| 11 | 1240 | 18.5 | 620 | 7.4 | 4.0 | -- | -- | 1.5 | .99 | .48 | .12 | 1.0 | .42 | .54 | 45.4 | 34.5 |
| 11 | 1500 | 18.5 | 610 | 7.5 | 4.6 | e 3.5 | e .10 | 1.4 | .76 | .60 | .11 | .9 | .46 | .50 | 46.5 | 33.4 |
| 11 | 1615 | 18.6 | 620 | 7.4 | 4.5 | -- | -- | 1.4 | .62 | .78 | .11 | .9 | .45 | .50 | 43.7 | 36.5 |
| 11 | 2020 | 18.7 | 620 | 7.4 | 4.9 | 3.5 | .11 | 1.4 | .83 | .55 | .10 | .9 | .46 | .49 | 47.2 | 32.9 |
| 11 | 2335 | 18.9 | 620 | 7.4 | 5.0 | e 3.6 | e .10 | 1.2 | .48 | .75 | .10 | .9 | .48 | .53 | 47.2 | 32.8 |
| 12 | 0340 | 19.1 | 620 | 7.5 | 5.7 | e 3.6 | e .13 | 1.2 | .57 | .60 | .10 | .8 | .51 | .60 | 47.8 | 32.8 |
| 12 | 0730 | 18.6 | 620 | 7.3 | 4.4 | 4.3 | .17 | 1.3 | .61 | .70 | .10 | .6 | b .48 | b .45 | 45.1 | 33.0 |
| 12 | 0855 | 18.4 | 620 | 7.3 | 3.8 | -- | -- | 1.5 | .73 | .80 | .09 | .6 | .43 | .43 | 44.4 | 34.9 |
| 12 | 1110 | 18.4 | 630 | 7.3 | 3.6 | 5.1 | .16 | 1.4 | .70 | .67 | .10 | .6 | .47 | .62 | 46.8 | 33.2 |
| 12 | 1300 | 18.6 | 620 | 7.3 | 3.7 | -- | -- | 1.5 | .32 | 1.2 | .10 | .6 | .44 | .62 | 44.7 | 31.7 |
| 12 | 1525 | 18.4 | 630 | 7.5 | 3.9 | e 8.3 | e .11 | 1.4 | .76 | .56 | .09 | .6 | .45 | .59 | 46.5 | 32.6 |

Table 22.--Water-quality data from fixed sites--Continued

[-- indicates the sample was not collected or lost]

| Nov. 1980 date | Time | Temp (°C) | Specific cond. (µmhos/cm) | pH | DO (mg/L) | $CBOD_u$ (mg/L) | Base e $K_1$ (1/day) | Kjeld. N (mg/L) | Organic nit. (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$-P (mg/L) | Phos. (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RANDOL MILL ROAD BRIDGE--Continued | | | | | | | | | | | | | | | | |
| 12 | 1720 | 18.4 | 620 | 7.5 | 4.3 | -- | -- | 1.4 | .51 | 0.85 | 0.08 | 0.6 | 0.38 | 0.49 | 44.4 | 30.9 |
| 12 | 2000 | 18.2 | 630 | 7.5 | 4.0 | 4.9 | 0.17 | 1.2 | .68 | .54 | .10 | .8 | .44 | .49 | 45.8 | 31.6 |
| 12 | 2325 | 18.0 | 630 | 7.3 | 4.1 | [e] 4.0 | [e] .15 | 1.3 | .77 | .52 | .10 | .7 | .45 | .62 | 42.7 | 39.1 |
| 13 | 0355 | 18.2 | 630 | 7.4 | 5.7 | 4.6 | .14 | 1.4 | .70 | .72 | .11 | .7 | .47 | .62 | 46.5 | 33.3 |
| 13 | 0805 | 17.9 | 620 | 7.5 | 4.8 | [e] 5.2 | [e] .14 | 1.2 | .79 | .41 | .12 | .7 | .47 | .62 | 44.4 | 31.3 |
| 13 | 0940 | 17.8 | 610 | 7.4 | 4.3 | -- | -- | 1.4 | 1.0 | .36 | .07 | .6 | .45 | .52 | 44.7 | 33.9 |
| 13 | 1210 | 17.9 | 630 | 7.3 | 4.0 | [e] 3.2 | [e] .25 | 1.4 | .97 | .40 | -- | -- | .40 | .59 | 43.7 | 32.0 |
| 13 | 1425 | 17.6 | 620 | 7.4 | 4.0 | -- | -- | 1.4 | .79 | .60 | .12 | .7 | .40 | .48 | 46.8 | 31.1 |
| 13 | 1705 | 17.4 | 620 | 7.4 | 4.0 | 3.8 | .22 | 1.3 | .78 | .53 | .13 | .7 | .41 | .46 | 44.1 | 29.9 |
| 13 | 1955 | 17.1 | 610 | 7.7 | 5.7 | 5.1 | .17 | 1.4 | .84 | .56 | .10 | .7 | [b] .64 | [b] .55 | 43.0 | 37.3 |
| 14 | [h] 0001 | 17.1 | 620 | 7.4 | 4.7 | 4.3 | .16 | 1.4 | .68 | .74 | .11 | .7 | [b] .43 | [b] .32 | 46.5 | 34.8 |
| 14 | [h] 0001 | -- | -- | -- | -- | 3.5 | .23 | -- | -- | -- | .11 | .8 | .42 | -- | -- | -- |
| 14 | [h] 0001 | -- | -- | -- | -- | 3.9 | .17 | -- | -- | -- | .11 | .8 | .43 | -- | -- | -- |
| 14 | [h] 0001 | -- | -- | -- | -- | 4.4 | .15 | -- | -- | -- | .10 | .8 | .42 | -- | -- | -- |
| 14 | [h] 0001 | -- | -- | -- | -- | 4.6 | .13 | -- | -- | -- | .11 | .8 | .43 | -- | -- | -- |
| 14 | [h] 0001 | -- | -- | -- | -- | 3.8 | .18 | -- | -- | -- | .11 | .8 | .43 | -- | -- | -- |
| 14 | [h] 0001 | -- | -- | -- | -- | 4.4 | .15 | -- | -- | -- | .11 | .8 | .42 | -- | -- | -- |
| 14 | [h] 0001 | -- | -- | -- | -- | 3.8 | .15 | -- | -- | -- | .11 | .8 | .42 | -- | -- | -- |
| 14 | [h] 0001 | -- | -- | -- | -- | 4.0 | .15 | -- | -- | -- | .11 | .8 | .42 | -- | -- | -- |
| 14 | [h] 0001 | -- | -- | -- | -- | 4.4 | .10 | -- | -- | -- | .11 | .8 | .42 | -- | -- | -- |
| 14 | [h] 0001 | -- | -- | -- | -- | 4.4 | .15 | -- | -- | -- | .11 | .8 | .43 | -- | -- | -- |

[a] BOD sample split after five days.

[b] Measured orthophosphate-phosphorus concentration exceeded measured phosphorus concentration.

[c] Measured ammonia-nitrogen concentration exceeded measured kjeldahl nitrogen concentration. Organic nitrogen concentration reported as zero.

[d] Water quality sampled and measured at several points across the stream and each sample treated separately.

[e] Nitrification inhibitor failed in the later stages of this BOD test. Less than the standard 20-day record was analyzed to estimate $CBOD_u$ and $K_1$.

[f] BOD sample did not follow the standard first order approximation.

[g] Sample used less than 2mg/L dissolved oxygen during the 20-day test.

[h] A large composite sample was split into 11 replicates and analyzed for selected constituents.

Table 23.--Estimates of measurement precision reflecting differences in sampling, handling, and analysis

[Mean and standard deviation have the units shown on the column head, Coefficient of variation is in percent]

| Statistical parameter | DO (mg/L) | Temp. (°C) | pH | Specific cond. (µmhos/cm) | $CBOD_u$ (mg/L) | Kjeld. N (mg/L) | Org. nit. (mg/L) | $NH_4$-N (mg/L) | $NO_2$-N+ $NO_3$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | Phos. (mg/L) | $PO_4$-P (mg/L) | Carbon (mg/L) | Inorg. carbon (mg/L) | Organic carbon (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Samples collected at Beach Street November 13, 1980, 1520 hours | | | | | | | | | | | | | | | | |
| Mean | 13.3 | 19.4 | 8.4 | 580 | 3.2 | 0.80 | 0.31 | 0.48 | 0.3 | 0.05 | 0.3 | 0.12 | 0.07 | 40.5 | 34.2 | 6.4 |
| Standard deviation | 0.15 | 0.069 | .029 | 0 | 0.24 | 0.043 | 0.081 | 0.085 | 0.017 | 0.005 | 0.013 | 0.0084 | 0 | 2.00 | 2.87 | 4.1 |
| Coefficient of variation | 1.1 | 0.36 | 0.34 | 0 | 7.5 | 5.4 | 26 | 18 | 5.7 | 10 | 4.3 | 7.0 | 0 | 4.94 | 8.39 | 64 |
| No. of observations | 7 | 7 | 7 | 7 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Samples collected at I-820 Bridge November 13, 1980, 1620 hours | | | | | | | | | | | | | | | | |
| Mean | 3.6 | 18.5 | 7.5 | 610 | 4.8 | 2.0 | 0.18 | 1.8 | 0.5 | 0.08 | 0.4 | 0.64 | 0.47 | 46.4 | 37.9 | 8.9 |
| Standard deviation | 0.034 | 0.032 | 0.027 | 0.53 | 0.46 | 0.08 | 0.15 | 0.12 | 0.012 | 0.008 | 0.010 | 0.10 | 0.008 | 2.91 | 3.53 | 5.0 |
| Coefficient of variation | 0.94 | 0.17 | 0.36 | 0.087 | 9.6 | 4.0 | 80 | 6.6 | 2.4 | 10 | 2.5 | 16 | 1.7 | 6.27 | 9.31 | 56 |
| No. of observations | 10 | 10 | 10 | 10 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Measurement errors in percent | | | | | | | | | | | | | | | | |
| From this study | 1.1 | 0.36 | 0.36 | 0.087 | 9.6 | 5.4 | 80 | 18 | 5.7 | 10 | 4.3 | 16 | 1.7 | 6.3 | 9.3 | 64 |
| Standard Methods | 1 | [a] -- | .3 | 8.4 | [b] 19 | 3.7 | 70 | 2.2 | 4.1 | -- | 4 | 4.0 | 12.5 | 5 | -- | -- |
| EPA | 3 | -- | 1.3 | 1 | [b] 15 | 80 | -- | 1.1 | 4.1 | -- | [c] 4 | 3 | 3 | -- | -- | 80. |
| USGS | -- | -- | 2.0 | 0.452 | -- | [d] 6 | -- | [d] 6 | 14 | -- | [c] 14 | 3 | 20 | -- | -- | -- |

[a] Estimate not available.
[b] Interlaboratory comparision for 5-day BOD.
[c] Interlaboratory precision.
[d] Wet chemistry precision estimate rather than precision for probe measurements.

the cross-section. The magnitude of the coefficient of variation is related to measurement errors in the analytical technique, differences in handling and processing of samples, and differences in sampling location at a given site.

The number of observations in table 23 differ because at Beach Street, five samples were collected at approximately 0.6 of the depth at points evenly spaced across the stream. At the deeper points, DO, temperature, pH, and specific conductance were measured at 0.2 and 0.8 of the depth, accounting for seven measurements at the site. At I-820 Bridge, the same procedure resulted in six samples and ten measurements. The typical measurement error from this study is assumed to equal the largest observed coefficient of variation for each constituent.

Measurements of DO, temperature, pH, specific conductance, and orthophosphate were relatively precise compared with other types of measurements; $CBOD_u$, kjeldahl nitrogen, ammonia nitrite, nitrate, phosphorus, carbon, and inorganic carbon less so; and organic nitrogen and carbon were imprecise. The imprecision in organic carbon and nitrogen, and phosphorus seems to be due to the thermal shock given to the biota in the water when preserving the samples on ice. However, the data in table 23 do not fully reflect two factors which indicates these estimates are perhaps conservative. Firstly, these data collected at Beach Street and I-820 do not show as much variation as data from the deeper pools, especially variations in DO and pH. Secondly, these replicate samples were handled in exactly the same fashion, whereas, other samples were preserved on ice for varing lengths of time and were stored different lengths of time after filtration. Nevertheless, the computed measurement errors do explain what trends can be detected at the fixed sites which are all similar to Beach Street and I-820 sampling sites.

The measurement precision, excluding the variation due to sampling location in the cross section, was also estimated for $CBOD_u$, nitrite plus nitrate, nitrite, nitrate, and orthophosphate. Ten or eleven samples were split from a composite sample and handled and analyzed separately. Table 24 shows that except for $CBOD_u$, measurement errors decrease as expected. This may indicate that there is very little actual variation in $CBOD_u$ in a cross section like the one sampled at I-820.

Table 23 shows that except for ammonia and phosphorus the precision obtained in this study compares well with published criteria for the laboratory methods used in this study (American Public Health Association and others, 1981, Standard Methods, Knopp and McKee, 1979, EPA, and Skougstad and others, 1979, USGS). There are, however, reasons for ammonia and phosphorus measurements to be less precise. Ammonia determinations were made in the uncontrolled environment of the mobile laboratory where the calibration curve was constantly shifting. This along with possible lateral variations in the stream result in the greater coefficient of variation. The

Table 24.--Estimates of measurement precision reflecting differences in analytical techniques

[Mean and standard deviation in milligrams per liter and coefficient of variation in percent]

| Statistical parameter | $CBOD_u$ (mg/L) | $NO_2 + NO_3$ (mg/L as N) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | $PO_4$ (mg/L) |
|---|---|---|---|---|---|
| Composite sample no. 432 - I-820, November 13, 1980, 2345 hours | | | | | |
| Mean | 5.1 | 0.5 | 0.09 | 0.4 | 0.51 |
| Standard deviation | 0.52 | .0047 | 0 | .0047 | .0079 |
| Coefficient of variation | 10 | .94 | 0 | 1.2 | 1.5 |
| No. of observations | 11 | 10 | 10 | 10 | 10 |
| Composite sample no. 399 - Randol Mill Road, November 14, 1980, 0001 hours | | | | | |
| Mean | 4.1 | 0.9 | 0.11 | 0.8 | 0.42 |
| Standard deviation | 0.35 | .022 | .0032 | .019 | .0052 |
| Coefficient of variation | 8.5 | 2.4 | 2.9 | 2.4 | 1.2 |
| No. of observations | 11 | 10 | 10 | 10 | 10 |

greater coefficient of variation for measurements of dissolved phosphorus is probably due to the thermal shock to the plankton caused by being preserved on ice before filtering and some lateral variation that may occur in the stream.

Comparison of the published criteria for precision (bottom of table 23 and the coefficients of variation in table 23) show that the laboratory procedures were well controlled in the laboratories at the Gulf Coast Hydroscience Center for nitrite, nitrate, and orthophosphate and the Forth Worth Subdistrict Office for BOD. Laboratory procedures at the Central Laboratories were not checked.

Other checks on accuracy and precision involved comparisons of independent measurements. Ammonia-nitrogen measurements exceeded kjeldahl-nitrogen measurements for 31 of 298 tests. Most of the 31 samples were collected from Big Fossil Creek (20 samples) and the tributary south of Riverside STP (3 samples) in which ammonia concentrations were high and organic nitrogen concentrations were low. Only one of the remaining river measurements of organic nitrogen was significantly different from zero (confidence interval of 95 percent using a t-test). That is, the organic nitrogen measurement exceeded the 95 percent confidence interval for measurements of $\sigma t_{0.05}$= where $\sigma$ is the standard deviation (0.15 mg/L from table 23).

Orthophosphate-phosphorus measurements exceeded phosphorus measurements 50 times out of 298 tests. This was probably due to the imprecision of the phosphorus test and the fact that most of the phosphorus consisted of orthophosphate. The difference was significant only in one river sample and seven samples from the polluted tributaries where variance in the data was estimated using river measurements.

Seven measurements of dissolved inorganic carbon from the tributary near Meadowbrook Golf Course exceeded measurements of dissolved organic plus inorganic carbon. These measurements were not fully examined nor reported in this report because carbon was a minor constituent and the load from the tributary was insignificant.

Dissolved organic carbon measurements were compared to $CBOD_u$ measurements by assuming that organic carbon times 2.67 should exceed $CBOD_u$. The value 2.67 is the ratio of carbon to oxygen in carbon dioxide, the end product in microbial degradation, assuming that the original carbon compounds do not release additional oxygen as a result of degradation (Eckenfelder, 1970, p. 23-32). Except for samples taken from the unnamed tributary near the Riverside STP where the $CBOD_u$ due to suspended particles was significant and two samples at I-820 where dissolved organic carbon measurements were low, the dissolved organic carbon and $CBOD_u$ measurements were in good agreement ($CBOD_u < 2.67 \times oc$). Therefore, the conclusion is that the overwhelming majority of these measurements seem to be useful and valid.

## Accuracy of Water Quality Data

Selected measurement procedures were checked and found to be accurate. Tests of ammonia, nitrite plus nitrate, nitrite, orthophosphate, and inorganic and organic carbon were repeated by the National Water-Quality Laboratory at Arvada, Colorado to check the procedures used in the mobile laboratory and at the Gulf Coast Hydroscience Center. The quality control program at Arvada was deemed sufficient to ensure the accuracy of these comparative measurements and measurements of kjeldahl nitrogen and phosphorus. Twenty percent of the tests for ammonia, nitrite plus nitrate, nitrite, and orthophosphate were repeated. Six percent of the carbon tests were repeated. Fewer tests were duplicated for carbon because it was deemed to be less important than the other constituents.

A t-test of the paired samples (Kennedy and Neville, 1976, p. 210-215) analyzed in two different laboratories indicated that the tests for ammonia, orthophosphate, and organic carbon were of comparable accuracy. A significant difference was indicated for nitrite and nitrite plus nitrate, but the mean difference was only 0.01 and 0.07 milligrams per liter as nitrogen, respectively with the methods being sensitive to only 0.01 and 0.1 milligrams per liter as nitrogen, respectively. The statistical tests used the 95 percent confidence interval and assumed that the null hypothesis was that the mean difference was not significantly different from zero.

It was also possible to gage the accuracy of the four-parameter water-quality monitors. In figure 21 measurements of water temperature, specific conductance, DO, and pH at Beach Street are compared with records collected at the Beach Street monitor during the study. To aid in the comparison, table 25 lists the expected accuracy for the hand-held probe.

The two sets of water temperature measurements are in excellent agreement and most of the specific conductance measurements are in agreement. DO and pH measurements, however, show some differences. Evidently, making measurements by wading just upstream of the fixed monitor affected those DO measurements and reduce the usefulness of this comparison. Aerial photographs taken during the third day of the study show a "trail" worn across the fine sediments on the bottom upstream of the Beach Street monitor. This site also has a history of low DO concentration when storm or high flow events disturb the sediments (North Central Texas Council of Governments, 1979). It is also worth noting that the measurement technique (wading) seems to have a localized effect that was not foreseen in planning the study.

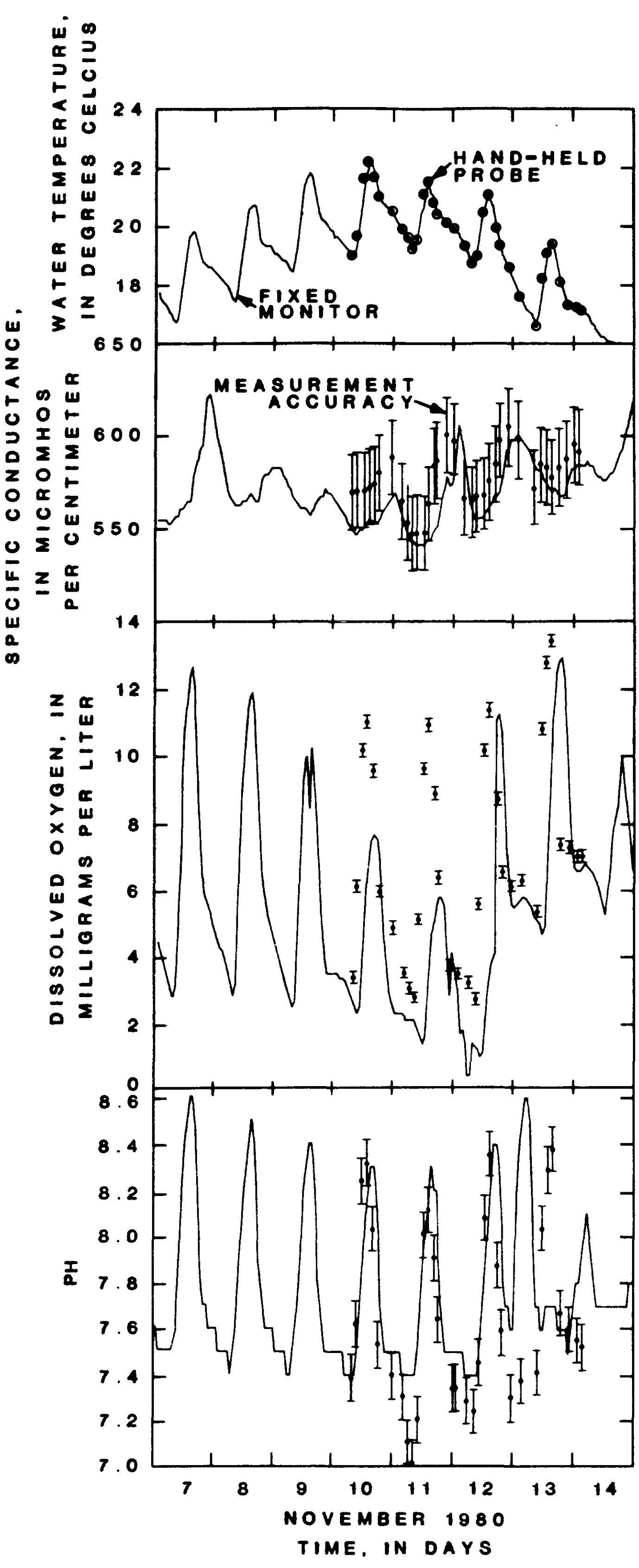

Figure 21.--Comparison of measurements made at the Beach Street Bridge by the continuous water-quality monitor to measurements made with the Hydrolab 4000 Series probes.

Table 25.--Manufacturer's specifications for the Hydrolab 4000 series water-quality monitor

| Parameter | Accuracy |
|---|---|
| Dissolved oxygen | ± 0.2 mg/L |
| Temperature | ± 0.2° C |
| pH | ± 0.1 pH units |
| Specific conductance | ± 20 μmhos/cm |

### Meteorological Data

Meteorological information was recorded on charts during the study. These charts were interpreted to produce the solar radiation, air temperature, relative humidity, and wind speed values listed on table 26.

The average solar radiation during 15-minute intervals was estimated from the strip chart and averaged to give the hourly values. The first and third days of the study, November 10 and 12, 1980 were clear and the fourth day had only a few scattered clouds betwen 1000 and 1200 hours. The second day was nearly clear until about 1100 hours and had scattered clouds the rest of the day.

Temperatures and relative humidities were read from the chart at hourly intervals. The recorded number represents the observed value at the time of observation and does not necessarily represent the average of the values during the hour. The times of passage of each 10 miles of wind were determined from the times the event mark occurred on the circular chart. The average windspeed was computed between each event mark by dividing the miles of wind (10) by the time of passage. The windspeed was assumed to be constant and equal to this average value between the times of the event mark. The average windspeed for each hour of record was then computed from these speeds and the times of occurrence of the event marks.

All sensors performed well during the study and no episodes of missing records occurred.

## SUMMARY AND NEED FOR ADDITIONAL STUDY

### Summary

The sampling program to collect water-quality data for testing a dynamic model seemed to be successful. Data defining the initial water-quality conditions, the unsteady headwater loads (at Beach Street), steady tributary loads, flow into and out of the reach, and meteorological conditions were adequate. This was true despite some differences in measurement precision for the various water-quality constituents. Measurements of DO, temperature, pH, specific conductance, kjeldahl nitrogen, nitrate, orthophosphate, and phosphorus were relatively precise compared with other measurements. Measurements of $CBOD_u$, organic nitrogen, ammonia, nitrite, and carbon were less precise.

The tributary loads seemed to be adequately defined. The three tributaries introduced drainage from what seemed to be a broken sewer line, the effluent from a small STP, and drainage from an urban area. The headwaters seem to consist chiefly of nonpoint flow from urban and rural areas.

Table 26.--Meteorologic data collected near the study reach

| Nov. 1980 date | Time | Solar radiation (cal/$cm^2$/dy) | Riverside STP | | | Village Creek STP | | |
|---|---|---|---|---|---|---|---|---|
| | | | Air temperature (°C) | Relative humidity | Wind speed (ft/s) | Air temperature (°C) | Relative humidity | Wind speed (ft/s) |
| 10 | 0630 | 0.0 | 11.2 | 0.98 | 6.6 | 14.4 | 0.97 | 1.6 |
| 10 | 0730 | 118.9 | 13.0 | .97 | 2.6 | 21.1 | .97 | 1.6 |
| 10 | 0830 | 477.8 | 19.7 | .92 | 2.6 | 26.1 | .88 | 1.6 |
| 10 | 0930 | 828.7 | 23.3 | .88 | 2.6 | 27.8 | .74 | 1.6 |
| 10 | 1030 | 1120.9 | 26.6 | .70 | 2.6 | 28.3 | .58 | 1.6 |
| 10 | 1130 | 1292.3 | 26.8 | .48 | 2.6 | 28.3 | .50 | 1.6 |
| 10 | 1230 | 1342.9 | 28.9 | .43 | 4.6 | 28.9 | .42 | 1.6 |
| 10 | 1330 | 1236.9 | 29.8 | .35 | 6.6 | 29.4 | .38 | 3.3 |
| 10 | 1430 | 1020.1 | 30.3 | .31 | 5.2 | 29.4 | .36 | 7.2 |
| 10 | 1530 | 704.8 | 30.3 | .31 | 1.3 | 29.4 | .35 | 5.9 |
| 10 | 1630 | 310.6 | 28.9 | .31 | 1.3 | 27.8 | .39 | 1.3 |
| 10 | 1730 | 37.4 | 27.7 | .36 | 1.3 | 26.1 | .44 | 1.3 |
| 10 | 1830 | 0.0 | 24.5 | .45 | 1.3 | 24.4 | .53 | 1.3 |
| 10 | 1930 | 0.0 | 22.7 | .56 | 1.3 | 23.3 | .56 | 1.3 |
| 10 | 2030 | 0.0 | 22.4 | .60 | 1.3 | 21.7 | .67 | 1.3 |
| 10 | 2130 | 0.0 | 21.5 | .70 | 1.3 | 20.6 | .74 | 1.3 |
| 10 | 2230 | 0.0 | 19.7 | .79 | 1.3 | 18.9 | .83 | 1.3 |
| 10 | 2330 | 0.0 | 20.0 | .87 | 1.3 | 17.8 | .88 | 1.3 |
| 11 | 0030 | 0.0 | 16.1 | .98 | 1.3 | 16.1 | .94 | 1.3 |
| 11 | 0130 | 0.0 | 14.7 | .98 | 1.3 | 15.6 | .94 | 2.3 |
| 11 | 0230 | 0.0 | 13.8 | .98 | 2.3 | 15.0 | .95 | 4.3 |
| 11 | 0330 | 0.0 | 13.5 | .98 | 5.9 | 14.4 | .96 | 4.3 |
| 11 | 0430 | 0.0 | 13.0 | .98 | 5.9 | 14.4 | .96 | 7.2 |
| 11 | 0530 | 0.0 | 12.6 | .98 | 10.2 | 13.9 | .96 | 8.5 |
| 11 | 0630 | 0.0 | 12.6 | .98 | 9.2 | 13.9 | .95 | 9.2 |
| 11 | 0730 | 118.1 | 13.0 | .98 | 8.5 | 13.9 | .93 | 9.8 |
| 11 | 0830 | 460.7 | 14.4 | .92 | 8.5 | 17.2 | .85 | 14.8 |
| 11 | 0930 | 719.9 | 18.3 | .77 | 8.5 | 20.6 | .70 | 7.2 |
| 11 | 1030 | 1082.7 | 22.7 | .64 | 3.0 | 23.3 | .57 | 7.2 |
| 11 | 1130 | 1070.7 | 24.1 | .55 | 3.0 | 24.4 | .51 | 5.9 |
| 11 | 1230 | 1382.3 | 25.4 | .48 | 3.0 | 25.6 | .46 | 5.9 |
| 11 | 1330 | 969.7 | 25.9 | .41 | 3.0 | 25.6 | .45 | 7.2 |
| 11 | 1430 | 702.7 | 25.9 | .40 | 3.0 | 26.1 | .42 | 8.5 |
| 11 | 1530 | 585.6 | 25.9 | .40 | 3.0 | 26.1 | .42 | 9.2 |
| 11 | 1630 | 281.3 | 25.9 | .40 | 3.0 | 24.4 | .46 | 10.2 |
| 11 | 1730 | 20.2 | 25.0 | .44 | 3.0 | 23.3 | .48 | 8.5 |
| 11 | 1830 | 0.0 | 20.9 | .60 | 3.0 | 22.2 | .55 | 8.5 |
| 11 | 1930 | 0.0 | 20.0 | .69 | 3.0 | 22.2 | .56 | 8.5 |
| 11 | 2030 | 0.0 | 20.9 | .65 | 5.2 | 21.7 | .57 | 2.6 |
| 11 | 2130 | 0.0 | 20.6 | .65 | 5.2 | 21.1 | .59 | 2.6 |
| 11 | 2230 | 0.0 | 20.0 | .65 | 4.3 | 19.4 | .60 | 2.6 |
| 11 | 2330 | 0.0 | 18.8 | .68 | 3.0 | 19.4 | .58 | 2.6 |
| 12 | 0030 | 0.0 | 17.9 | .72 | 3.0 | 18.9 | .56 | 2.6 |

Table 26.--Meteorologic data collected near the study reach--Continued

| | | | Riverside STP | | | Village Creek STP | | |
|---|---|---|---|---|---|---|---|---|
| Nov. 1980 date | Time | Solar radiation (cal/cm$^2$/dy) | Air temperature (°C) | Relative humidity | Wind speed (ft/s) | Air temperature (°C) | Relative humidity | Wind speed (ft/s) |
| 12 | 0130 | 0.0 | 17.9 | 0.65 | 3.0 | 18.3 | 0.54 | 4.3 |
| 12 | 0230 | 0.0 | 17.0 | .63 | 3.0 | 17.8 | .52 | 5.1 |
| 12 | 0330 | 0.0 | 17.0 | .60 | 3.3 | 16.7 | .54 | 5.2 |
| 12 | 0430 | 0.0 | 16.1 | .56 | 9.8 | 15.0 | .60 | 9.8 |
| 12 | 0530 | 0.0 | 15.3 | .58 | 12.8 | 13.9 | .60 | 12.1 |
| 12 | 0630 | 2.1 | 13.5 | .65 | 12.8 | 12.2 | .79 | 13.1 |
| 12 | 0730 | 107.0 | 12.1 | .79 | 10.8 | 12.2 | .78 | 11.8 |
| 12 | 0830 | 435.5 | 13.0 | .78 | 9.8 | 15.0 | .56 | 11.8 |
| 12 | 0930 | 830.7 | 17.4 | .56 | 9.8 | 18.3 | .44 | 9.8 |
| 12 | 1030 | 1125.0 | 20.6 | .41 | 6.6 | 21.7 | .37 | 6.9 |
| 12 | 1130 | 1304.5 | 21.8 | .34 | 3.3 | 22.8 | .33 | 3.9 |
| 12 | 1230 | 1357.9 | 24.1 | .28 | 3.3 | 25.0 | .28 | 3.9 |
| 12 | 1330 | 1233.8 | 25.4 | .24 | 3.3 | 25.6 | .26 | 3.9 |
| 12 | 1430 | 1015.2 | 26.3 | .22 | 3.3 | 26.7 | .32 | 3.9 |
| 12 | 1530 | 688.7 | 26.8 | .20 | 4.9 | 26.7 | .22 | 4.6 |
| 12 | 1630 | 296.3 | 25.9 | .18 | 4.9 | 26.1 | .21 | 4.6 |
| 12 | 1730 | 27.3 | 24.5 | .18 | 4.9 | 23.9 | .26 | 4.3 |
| 12 | 1830 | 0.0 | 20.9 | .22 | 2.0 | 19.4 | .42 | 4.3 |
| 12 | 1930 | 0.0 | 19.7 | .27 | 2.0 | 20.0 | .35 | 4.3 |
| 12 | 2030 | 0.0 | 15.6 | .47 | 2.0 | 18.9 | .36 | 4.3 |
| 12 | 2130 | 0.0 | 14.7 | .50 | 2.0 | 17.8 | .38 | 2.6 |
| 12 | 2230 | 0.0 | 17.4 | .37 | 2.0 | 18.9 | .36 | 2.6 |
| 12 | 2330 | 0.0 | 17.0 | .37 | 2.0 | 17.2 | .39 | 2.6 |
| 13 | 0030 | 0.0 | 16.5 | .49 | 2.0 | 15.0 | .45 | 2.6 |
| 13 | 0130 | 0.0 | 13.5 | .50 | 3.6 | 14.4 | .49 | 2.3 |
| 13 | 0230 | 0.0 | 10.3 | .72 | 8.5 | 14.4 | .52 | 6.2 |
| 13 | 0330 | 0.0 | 9.1 | .86 | 11.5 | 13.9 | .54 | 9.8 |
| 13 | 0430 | 0.0 | 8.5 | .88 | 14.8 | 13.3 | .60 | 14.8 |
| 13 | 0530 | 0.0 | 7.6 | .98 | 14.8 | 12.2 | .68 | 14.8 |
| 13 | 0630 | 2.1 | 9.9 | .95 | 12.1 | 10.0 | .52 | 14.8 |
| 13 | 0730 | 133.2 | 12.1 | .72 | 9.8 | 10.6 | .50 | 9.8 |
| 13 | 0830 | 480.9 | 14.4 | .56 | 9.8 | 15.6 | .48 | 8.5 |
| 13 | 0930 | 805.6 | 17.9 | .36 | 6.2 | 18.9 | .32 | 7.2 |
| 13 | 1030 | 1143.2 | 20.9 | .22 | 2.3 | 21.1 | .26 | 5.2 |
| 13 | 1130 | 1326.6 | 22.4 | .20 | 2.3 | 22.2 | .26 | 3.0 |
| 13 | 1230 | 1392.2 | 23.2 | .18 | 2.3 | 23.9 | .21 | 3.0 |
| 13 | 1330 | 1267.1 | 24.5 | .16 | 2.3 | 25.0 | .19 | 3.0 |
| 13 | 1430 | 1012.1 | 25.4 | .15 | 2.3 | 25.6 | .18 | 3.0 |
| 13 | 1530 | 644.3 | 26.3 | .11 | 2.3 | 26.7 | .16 | 2.3 |
| 13 | 1630 | 191.6 | 25.9 | .12 | 2.3 | 25.0 | .19 | 2.0 |
| 13 | 1730 | 20.2 | 23.6 | .15 | 2.3 | 23.3 | .22 | 2.0 |
| 13 | 1830 | 0.0 | 28.8 | .26 | 2.3 | 18.9 | .42 | 2.0 |

Table 26.--Meteorologic data collected near the study reach--Continued

| | | | Riverside STP | | | Village Creek STP | | |
|---|---|---|---|---|---|---|---|---|
| Nov. 1980 date | Time | Solar radiation (cal/cm$^2$/dy) | Air temperature (°C) | Relative humidity | Wind speed (ft/s) | Air temperature (°C) | Relative humidity | Wind speed (ft/s) |
| 13 | 1930 | 0.0 | 15.3 | 0.42 | 2.3 | 15.6 | 0.52 | 2.0 |
| 13 | 2030 | 0.0 | 11.7 | .60 | 2.3 | 13.3 | .66 | 2.0 |
| 13 | 2130 | 0.0 | 11.2 | .70 | 2.3 | 13.3 | .66 | 2.0 |
| 13 | 2230 | 0.0 | 11.7 | .73 | 11.8 | 13.3 | .69 | 2.0 |
| 13 | 2330 | 0.0 | 12.6 | .75 | 5.2 | 13.9 | .72 | 9.8 |
| 14 | 0030 | 0.0 | 13.8 | .74 | 12.1 | 15.0 | .72 | 8.5 |
| 14 | 0130 | 0.0 | 14.4 | .74 | 11.5 | 15.0 | .72 | 7.2 |
| 14 | 0230 | 0.0 | 14.4 | .74 | 11.5 | 15.6 | .72 | 9.5 |
| 14 | 0330 | 0.0 | 15.6 | .62 | 11.5 | 16.7 | .54 | 11.8 |
| 14 | 0430 | 0.0 | 16.5 | .54 | 11.5 | 16.1 | .60 | 10.2 |
| 14 | 0530 | 0.0 | 13.8 | .66 | 11.5 | 13.9 | .70 | 10.2 |

Several instream trends were defined. Diel patterns in DO, pH, and temperature suggest that photosynthesis may be important in some reaches. The classical DO sag and recovery occurred downstream of the polluted tributaries. Downstream decreases in $CBOD_u$ and ammonia and increases in nitrate below the tributaries indicate that deoxygenation and nitrification are important.

Simulation of water-quality data from dyed parcels of water will provide an easy way to calibrate a model. In addition, several model coefficients and time of travel were independently measured. These including reaeration, deoxygenation, and nitrification coefficients. Reaeration coefficients were low (~0 to 3.6 per day). Deoxygenation coefficients were 0.1 to 0.2 per day. Nitrification coefficients were about 0.8 per day.

## Need for additional study

The need for additional study and procedural improvements was indicated in several areas of the study. For a small stream of this type, the preliminary study was too far in advance of the November study and conditions changed somewhat. Innovative procedures like Lagrangian sampling with measurement of reaeration coefficients, and determination of nitrification coefficients hold great promise but the precision of the estimates needs improvement.

Sample handling procedures also affected measurements of organic nitrogen and carbon, and phosphorus. The test procedure for $CBOD_u$ is new and requires further development. Better procedures are also needed for calibrating ammonia, DO, pH, temperature, and specific conductance probes in the field.

Preliminary sampling of the headwaters and known tributaries was conducted about 4 weeks before the main sampling effort in November, 1980. Some measurements were misleading in that greater loads were expected; this lead to the unnecessary sampling of a minor tributary. Sampling of the headwaters and tributaries one week before or about one to two times the travel time through the study reach before the main sampling effort, seems more appropriate. This does, however, pose some difficulty in testing for BOD where the 20-day test period is longer than the 1 week recommended.

The preliminary sampling should also define the amount of variability due to sampling location and sample handling, and analysis, by collecting approximately 10 replicate samples at each proposed sampling site. With this estimate of precision and the measurement of diel trends, sampling frequency at a site for different constitutents can be rationally determined. For example, it would be desireable to collect replicate BOD samples since BOD measurements are less precise than DO measurements. Preliminary, one-time sampling at as many river sites as practical in a short period (like initial sampling in this November 1980 study) would define water-quality gradients and assist in choosing sampling sites on the river.

The innovative Lagrangian sampling of dyed parcels of water could be improved by collecting three or more replicate samples near the peak dye concentration. Because dispersion may be important and because field measurements of dye concentration may miss the actual dye peak by as much 1/2 to 1 hour, replicate sampling should be repeated just before and just after the dye peak passes a sampling site.

Where reaeration coefficients are small, data should be collected over longer reaches between sampling sites to avoid experimental errors. Dye sampling should also be carried out at several points across the first sampling section to confirm that the tracers are well mixed laterally. In addition, the cause of the 47 percent difference in reaeration coefficients based on the propane tracer versus the ethylene tracer, may deserve further study. It is not clear whether interference by unknown sources or sinks of the tracers cause the discrepency or whether experimental errors can explain the difference.

Study of long-term CBOD testing procedures is needed to establish a standard procedure for testing surface waters. The procedure by Stamer and others (1983) should be more than adequate if more guidance on diluting samples is added. Precision was lowered for some samples by diluting river samples unnecessarily. Excess dilution lead to some lag in DO exertion. On the other hand, the dilution of polluted tributary samples by roughly the natural dilution of the tributary by the receiving stream seemed to work well. Use of an artifical dilution water in favor of the recommended aged native stream water (Stamer and others, 1983) also reduced the precision of the test and should be avoided.

Care should also be exercised in the storage and preservation of the nitrification inhibitor nitrapyrin. Fresh stock worked well for the preliminary samples. Four weeks later, 21 percent of the November samples showed some breakthrough in nitrification. Evidently, some breakdown occurs when moist air is in prolonged contact with the chemical.

The sample handling procedure also caused some data scatter in measurements of organic nitrogen and carbon, and phosphorus. Thermal shock to plankton, causing lysis, evidently resulted when raw water samples were stored on ice prior to filtration. These samples should be filtered onsite or stored at the ambient water temperature and filtered shortly thereafter (say 1 to 4 hours).

Determination of ammonia concentrations using a specific ion probe proved economical and accurate but less precise than wet-chemistry methods. Measurement should be conducted in a controlled laboratory environment to avoid the constantly shifting calibration characteristics caused by the unmitigated, diurnal changes in air temperature. Interference in surface waters due to amine compounds should also be explored further despite the fact that no interference was detected in this study.

It is also possible to improve the reliability of measurements at the sampling site by collecting a number of replicate samples for the determination of pH and specific conductance in a controlled environment with a precise laboratory instrument. These laboratory measurements in addition to the 4 to 6 hour field calibration checks, seems to be the best way to insure accurate pH and field specific conductance measurements. The data can be adjusted after comparing field measurements of pH and specific conductance to measurements made in a controlled laboratory environment and after taking measurement errors into account.

Because the DO probe membrane is more prone to fouling and puncture, the calibration should be checked every hour or before and after each measurement. Roughly 10 percent of the samples should be checked using the Winkler Method (American Public Health Association, 1981, p. 388) and the data adjusted as necessary.

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