EVALUATION OF FUTURE BASE-FLOW WATER-QUALITY CONDITIONS IN THE HILLSBOROUGH RIVER, FLORIDA

By Mario Fernandez, Jr., Carole L. Goetz, and Jeffery E. Miller

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EVALUATION OF FUTURE BASE-FLOW WATER-QUALITY CONDITIONS IN THE HILLSBOROUGH RIVER, FLORIDA

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ABSTRACT

A one-dimensional, steady-state, uniform water-quality model was developed for a 30.0-mile reach of the Hillsborough River to simulate water-quality conditions expected from future development. The model was calibrated and verified using data collected under critical base-flow conditions in April and December 1978. Dissolved organic nitrogen, nitrate nitrogen, and total and fecal coliform bacteria were modeled for most of the study reach.

Results from the model were used to evaluate the impacts of two typical housing developments on water-quality conditions in the Tampa Reservoir. One development was in the Cypress Creek basin, one of the major tributaries in the lower part of the study area, and the other was near the upper end of the reach of the Hillsborough River. The model analysis indicated that development in the Hillsborough River basin may cause high total and fecal coliform bacteria conditions. Simulated total coliform bacteria at the Tampa water-treatment plant for 1, 3, and 5 square-mile developments in the Cypress Creek basin were 3,000, 5,400, and 8,300 colonies per 100 milliliters. Similar developments located near the upper end of the study reach were 2,000, 3,600, and 5,100 colonies per 100 milliliters. Simulated fecal coliform bacteria were 360, 700, and 100 and 180, 350, and 510 colonies per 100 milliliters, respectively. Other constituents modeled showed only minor increases in concentrations.

INTRODUCTION

The Hillsborough River has been the principal water-supply source for the city of Tampa since 1926. In 1945, part of the lower Hillsborough River in northeast Tampa was impounded by construction of the Tampa Reservoir dam. In 1964, the city of Tampa Water Department began intermittent pumping from nearby Sulphur Springs into the Hillsborough River above the dam to augment supplies when needed.

In 1975, the city of Tampa, with a population of 350,000, had a withdrawal water use of 52.7 Mgal/d (Healy, 1977). By 1980, the population had grown to about 500,000 and the withdrawal had increased to 64 Mgal/d (Ed Copeland, Tampa Water Department, oral commun., October 1980).

Over the years, the Hillsborough River basin has undergone changes in land use. Rural and agricultural areas of the lower and middle parts of the basin have become urbanized and industrialized. These land-use activities may affect the quality of water in the river. The ability of the lower Hillsborough River to continue to supply water of good quality under existing and future conditions is of major concern to water-resource planners and officials, among others.

A two-phase investigation of the Hillsborough River was initiated by the city of Tampa in cooperation with the U.S. Geological Survey in 1975. The purpose of the first phase of the study was to quantitatively evaluate the water-supply potential of the lower Hillsborough River, including the Tampa Reservoir, under existing conditions. Results of the first study phase are described in a report by Goetz and others (1978).

The purpose of the second-phase study, which is described in this report, is to evaluate (using modeling techniques) water-quality characteristics of the basin under possible future conditions. This study phase involved collection of data to calibrate and verify (testing for acceptance within a specified error range) a water-quality model for a reach of the Hillsborough River that includes the Tampa Reservoir. The model is applicable during critical base-flow periods when concentrations of various constituents are highest. The U.S. Geological Survey one-dimensional, steady-state, uniform water-quality model (Bauer and others, 1979) was used. The purpose of the study is to apply a calibrated and verified model to simulate selected water-quality conditions that result from base-flow discharges from storm sewers for various sized residential developments. Results of the study estimate possible changes in water-quality conditions that may occur in the study reach as future development and stream-waste loadings from storm sewers increase. The model identifies only those changes in stream water quality that occur as a result of ground-water (base flow) infiltration into the storm-sewage system (storm sewers) and not from storm events.

The quality of water in the Hillsborough River has been monitored since 1923. Water-quality data for the period 1923-78 and data collected for this study are available upon request from the U.S. Geological Survey National Water Data Storage and Retrieval System maintained in Reston, Va.

DESCRIPTION OF STUDY REACH

The Hillsborough River basin is in west-central Florida (fig. 1). From its source in Pasco County, the river flows 54 miles southwest to Hillsborough Bay. Land-surface altitudes in the basin range from near sea level at the mouth of the Hillsborough River to about 140 feet above sea level east of Plant City (Menke and others, 1961).

The Tampa Reservoir dam (fig. 2) is on the Hillsborough River, 10 miles above its mouth, and impounds water from a drainage area of about 650 mi^2. During base-flow periods, flow of the Hillsborough River is sustained by discharge from Crystal Springs that supplies an average discharge of 59.4 ft^3/s. Concentrations of various chemical and biological constituents--such as nitrogen species, dissolved solids, and coliform bacteria--are highest during base-flow periods.

Tampa Reservoir is long and narrow and extends about 12.5 miles upstream from the dam, meandering through large urban areas of north Tampa and Temple Terrace. The reservoir has a V-shaped channel that averages about 15 feet at the deepest point in any cross section. During low stages, the lower part of the reservoir has one main deep channel and one or two shallow side channels that span a width of about 1,000 feet near the dam. Upstream channel widths may narrow to about 100 feet or less. Bottom sediments range from sand to soft silt and clay with organic detritus rather than a hard packed or scoured bottom (Goetz and others, 1978).

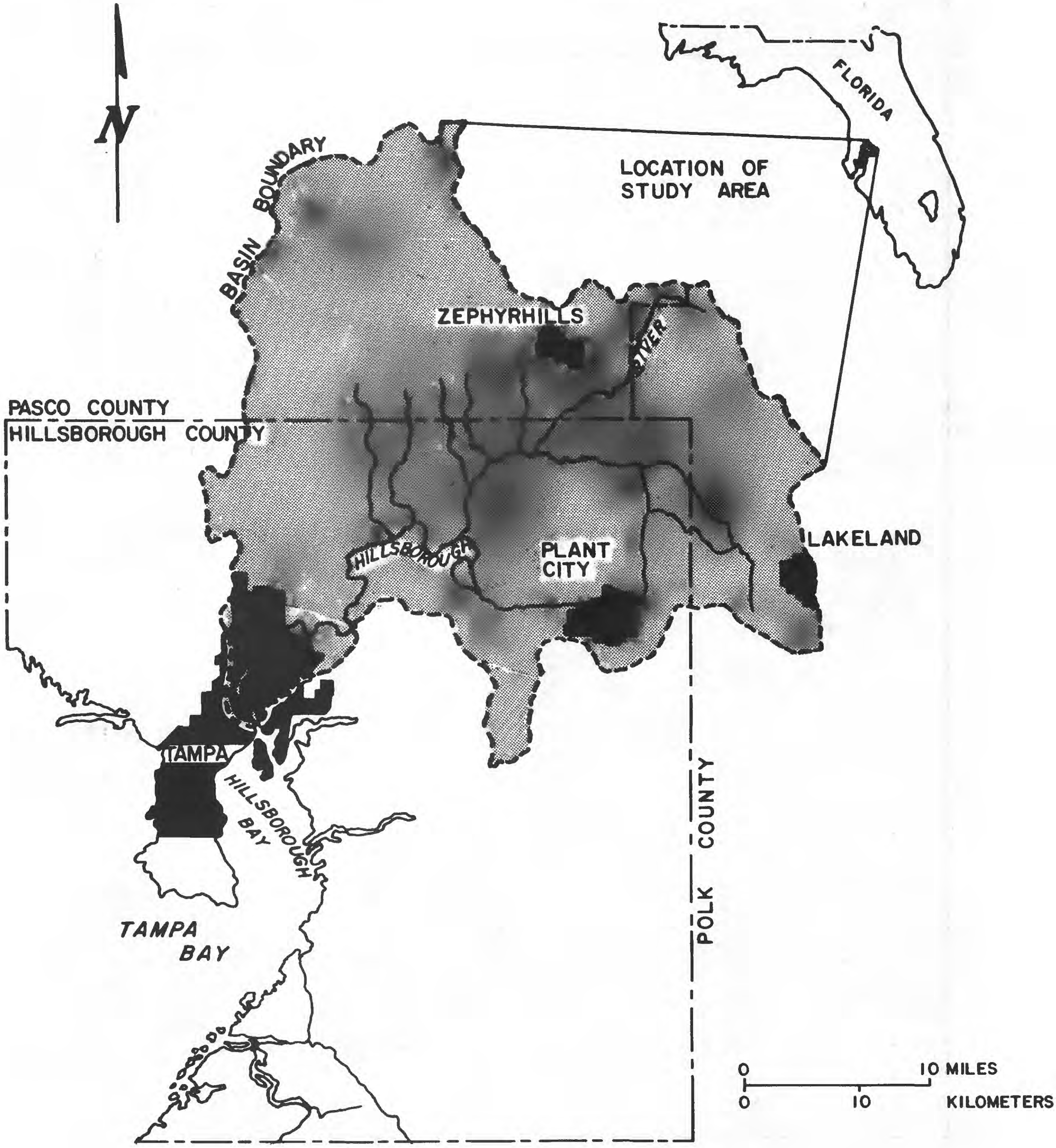

Figure 1.--Hillsborough River basin.

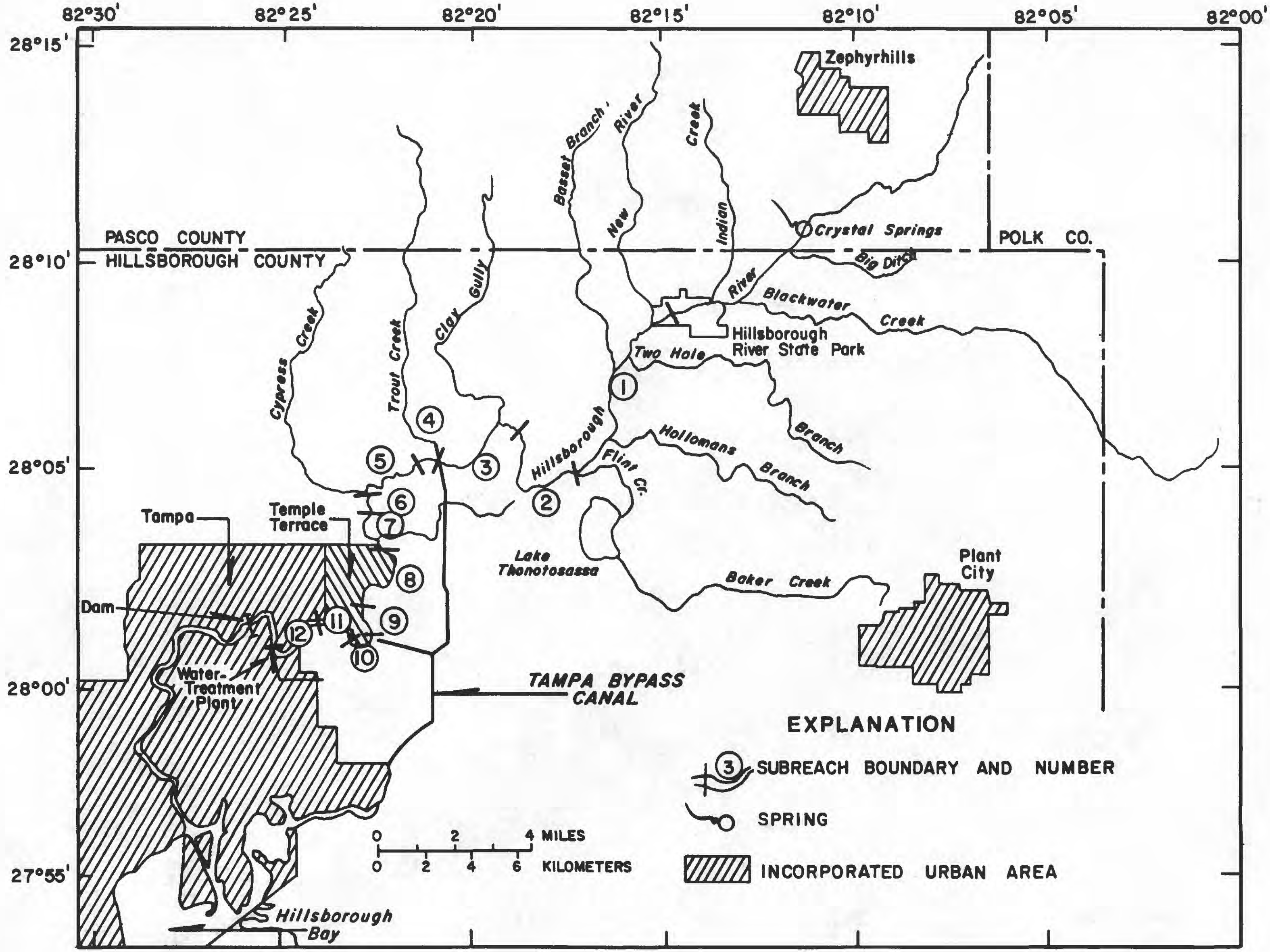

Figure 2.--Hillsborough River, major tributaries, and subreach boundaries used for modeling.

Above Tampa Reservoir, the Hillsborough River has a V-shaped, meandering channel that ranges in depth from about 1 to 16 feet. At low flow, the channel ranges in width from about 30 to 130 feet. In a 4-mile reach upstream from Flint Creek, the river has many shallow channels and flows through a large swampy area. Small rapids are present above New River; bottom sediments are predominantly sand with limestone and chert boulders in the rapids areas.

Tributaries to the Hillsborough River that have perennial flow are Big Ditch, Blackwater Creek, and Flint Creek (fig. 2). Nonperennial or intermittent tributaries include Indian Creek, New River, Two Hole Branch, Basset Branch, Hollomans Branch, Clay Gully, and Trout Creek. Cypress Creek, also a nonperennial stream, is tributary to the study reach via a large swamp area. The Tampa Bypass Canal is used to divert flood waters for the Hillsborough River into Hillsborough Bay.

The modeled reach of the river begins between New River and Indian Creek and ends at the intake of the Tampa water-treatment plant (fig. 2). The study reach consists of 12 subreaches. The first subreach begins in Hillsborough River State Park and ends at the mouth of Flint Creek. The last subreach begins near the city limit between Tampa and Temple Terrace and ends at the reservoir dam. Subreaches were selected using criteria discussed in a later section of this report entitled "Description of Water-Quality Simulation Model."

Climate

The Hillsborough River basin has a subtropical climate that is characterized by mild winters and hot, humid summers. Average annual temperature for the basin is about 72°F. Freezing temperatures are rare. Average annual rainfall is about 51 inches. About 60 percent of the annual precipitation falls from June through early September. July is the wettest month, receiving about 16 percent of the annual rainfall; November is the driest month, receiving slightly less than 4 percent.

Land Use and Environment

Land use in the Hillsborough River basin is highly diversified with 54 percent of the land area agricultural, 14 percent range, 2 percent forest, 1 percent water, 13 percent wetland, 1 percent barren, and 15 percent urban (U.S. Geological Survey, 1976a; 1976b).

The basin is predominantly rural. Northern and central parts of the basin are largely agricultural, whereas the southern part, which includes large areas northeast of Tampa, is urban and industrial. Urbanization and industrialization trends probably will spread into the northern and eastern parts of the basin. Principal municipalities include Tampa, Temple Terrace, Plant City, and Zephyrhills (fig. 2).

Vegetation above Trout Creek is thick and lush. River banks are heavily wooded with a variety of trees, including cypress (Taxodium), red maple (Acer Rubrum), sweetgum (Liquidamber), leadwood (Krugiodendron), ash (Fraxinus), cabbage palm (Sabal Palmetto), and oak (Quercus). Many fallen trees are part of the stream habitat. A variety of submerged and floating aquatic plants are also present.

Downstream of Trout Creek, the basin is urbanized. Vegetation is generally ornamental mixed with native oaks. Submerged and floating aquatic plants are also present; however, the variety of species is less than in upper reaches of the basin.

STEADY-STATE MODELING RATIONALE

Steady-state models have been successfully applied to various stream systems to determine planning information (Jennings and Bryant, 1973; Bauer and others, 1978; Wilber and others, 1979). Steady-state models assume constant discharge through the modeled stream reach for at least the time-of-travel through the reach. Application of a steady-state model, instead of an unsteady, continuous, or perennial-simulation model, is often advantageous when critical water-quality conditions occur during periods for which steady-state flow assumptions apply. Hines and others (1975, p. B5-B6) state "... the failure to recognize critical periods for river-quality model application is usually attributable to a failure to recognize the overriding importance that river hydrology has in controlling river quality," and "attempts to formulate perennial-simulation models may obscure important objectives and waste money and time."

The advantages of using steady-state models over continuous-simulation models are as follows:

1. Model parameters are calibrated and relied upon over a small range in stream conditions, which provides more confidence in model predictions for similar conditions.
2. Simulation periods are selected to coincide with critical base-flow events so that predictions can be related to probability of occurrence of annual minimum flows. Critical base-flow events, for example, might be the average 7-day base flow that is expected to occur, on the average, about once every 10 years (7-day, 10-year minimum flow).
3. Normally, fewer data are required for calibration and verification of steady-state models than for unsteady, continuous, or perennial-smulation models.

In this study, a steady-state model was calibrated and verified for various water-quality parameters for base-flow conditions. The assumptions of steady-state flow were met.

DESCRIPTION OF WATER-QUALITY SIMULATION MODEL

The steady-state, water-quality model used is a one-dimensional model based on the Streeter-Phelps oxygen-sag equation for dissolved oxygen and carbonaceous biochemical oxygen demand. The model is described in detail by Bauer and others (1979). The model simulates nonconservative constituents, such as dissolved oxygen, carbonaceous biochemical oxygen demand, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, total and fecal coliform bacteria, and orthophosphate phosphorus. Conservative constituents, such as sulfate, chloride, and sodium, can also be simulated by the model.

Nitrogen cycle components are modeled using procedures described by Thomann and others (1971). Cycle components can be modeled jointly or individually. Individual components were modeled in this study.

Total and fecal coliform bacteria are modeled using an equation by Mahloch (1973) where the decay rate is the coliform bacteria die-off rate. Orthophosphate phosphorus concentrations are modeled by a relation describing the first-order decay rate related to bottom deposit and chlorophyll a uptake rates as described by Willis and others (1975). Conservative substances are modeled using a mass-balance relation of discharge and constituent concentration.

Application of the model to a stream may require subdividing the study reach into subreaches when major changes in hydraulic characteristics, stream temperature, or reaction coefficients occur. Other factors considered in determining subreach boundaries include tributary discharge, point-waste sources, linear runoff (nonpoint source), and traveltime. Linear runoff, when used, indicates flow or waste inputs per foot of stream length.

The model computes a mass balance for each constituent at each waste source, accumulates discharge, and computes constituent concentrations for sample sites in each subreach. Results are listed in tabular form and are shown as plots of simulated and observed concentrations versus stream distance and traveltime. Reaction rates for various physical, chemical, and biological constituents modeled can be input or calculated internally by the model. Reaeration-rate coefficients are determined by the model using an equation by Bennett and Rathbun (1972). The model can compute oxygen demand due to bottom deposits and plant respiration, as well as daily-mean (net) photosynthetic production of dissolved oxygen.

Data required to calibrate and verify the model are described in detail by Bauer and others (1979). The data must be collected when streamflow and waste-source discharge approximate steady-state conditions. The required data include:

1. Mean depth, velocity, and discharge at stream cross sections for each subreach;
2. Concentrations of all constituents modeled and stream temperature over a 24-hour period at selected sites in each subreach;
3. Discharges and concentrations for all waste-source constituents modeled.

Usually, two sets of data are collected for calibrating and verifying the model. Data are usually collected during conditions similar to flow conditions under which the model is to be applied for evaluation purposes. Sampling sites may be located at subreach boundaries, particularly where there is tributary inflow, and at intermediate points within subreaches.

DATA COLLECTION

Data to calibrate and verify the model were collected when discharge in the study reach was uniform for the time-of-travel through the reach. Sampling sites selected for collection of water-quality data were located at existing gaging stations, confluences of tributaries, and easily accessible points along the reach (fig. 3). Cross-section data were obtained from previous flood studies and field measurements. Four continuous-record gaging stations, located on or near the study reach (fig. 3), are presented in table 1.

Discharge hydrographs for October 1977 through December 1978 for the Hillsborough River near Zephyrhills and at the Morris Bridge Road gaging stations are shown in figure 4. Based on data for 1940 to 1980, the 7-day, 10-year base flow for Hillsborough River near Zephyrhills is about 55 ft^3/s. Data for 1973 to 1979

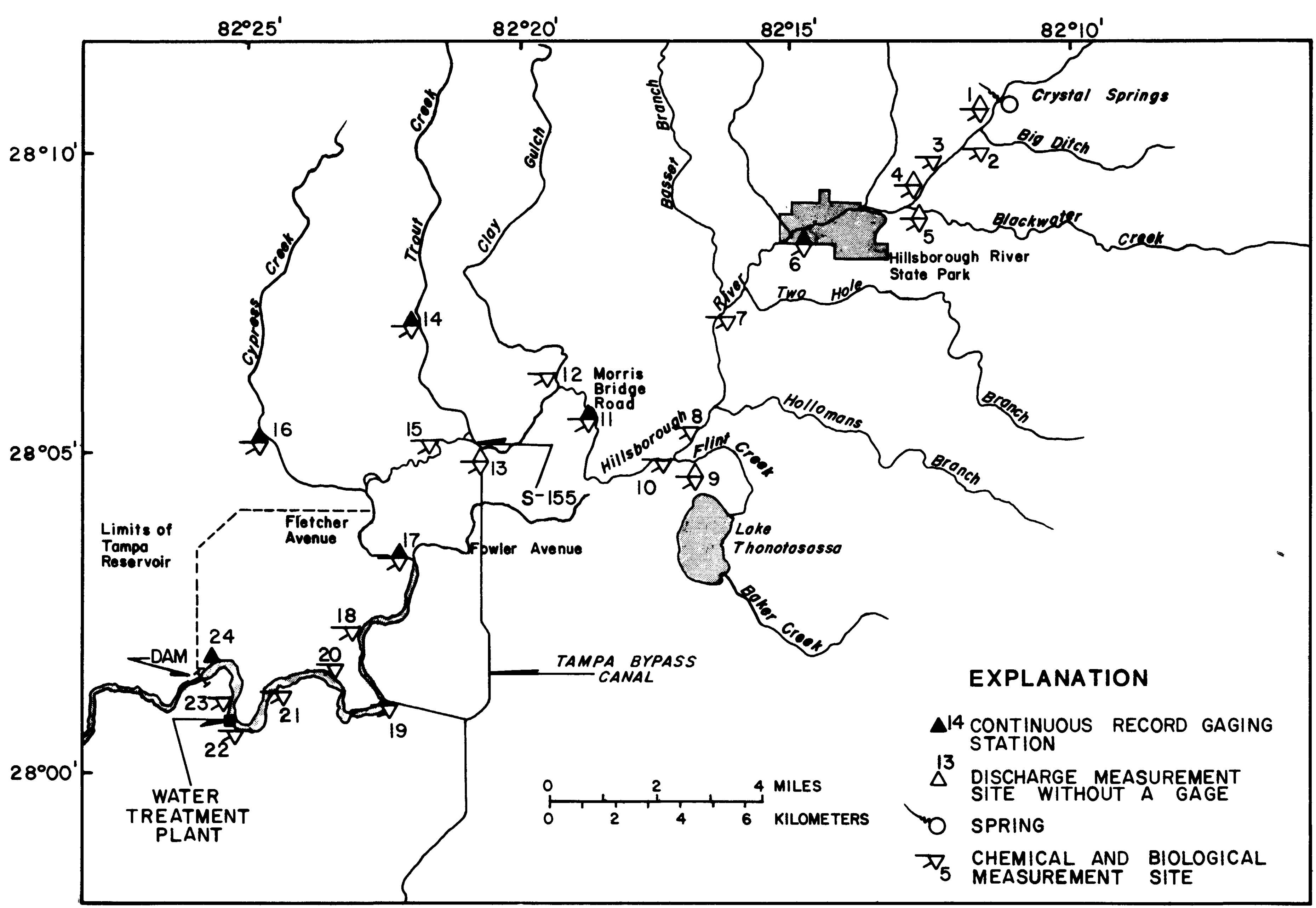

Figure 3.--Location of chemical-, biological-, and discharge-measurement sites in the study reach.

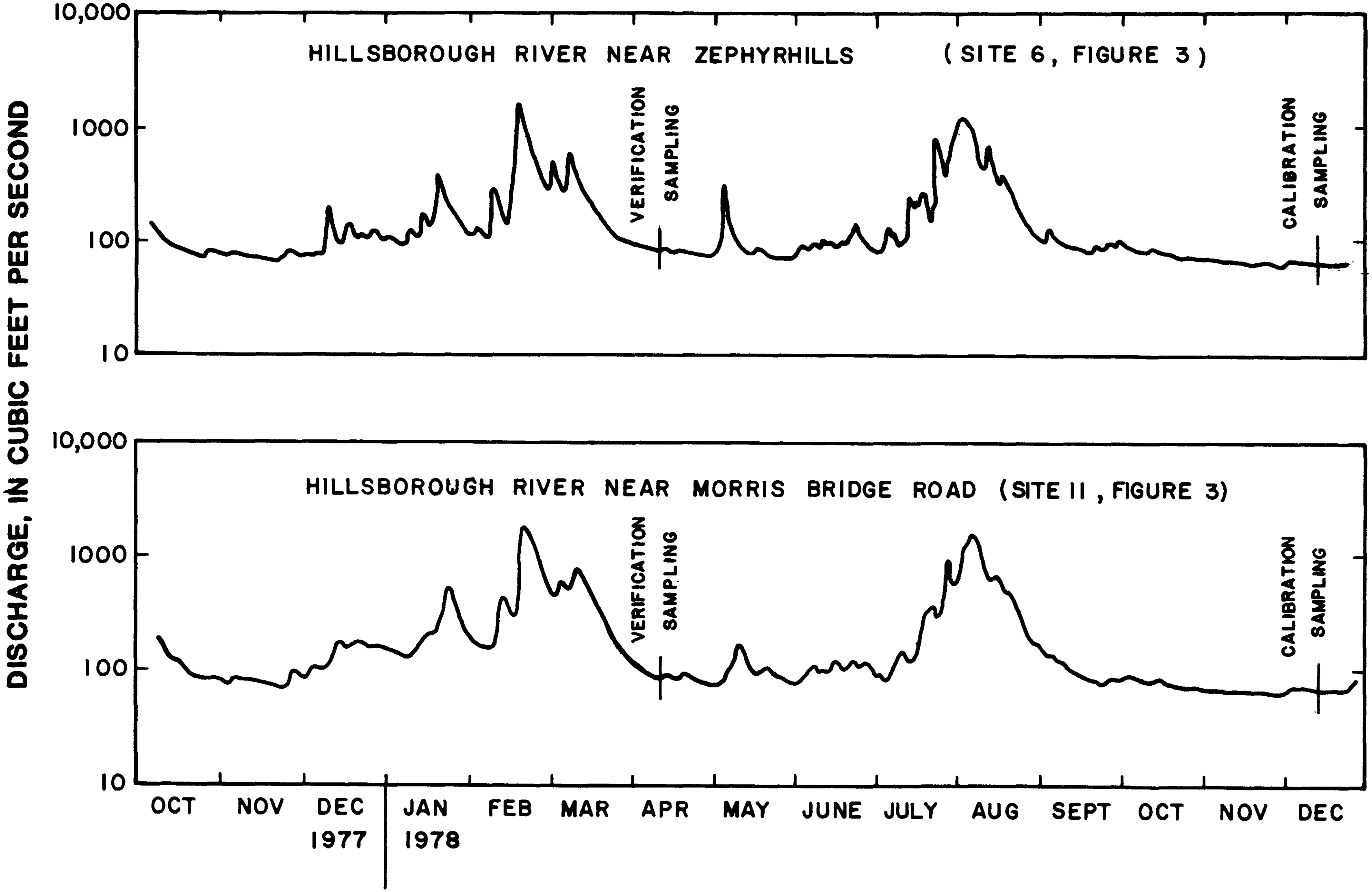

Figure 4.--Discharge hydrographs for two gaging stations on the Hillsborough River.

Table 1.--Description and water-quality data collected for four continuous-record gaging stations

Distance upstream from mouth, in miles	Name	Site no.	Drainage area, in square miles	Type of data available[1/]
	Hillsborough River:			
40.0	Near Zephyrhills	6	220	QW, PKT, PY, BCT, SED, FLO, WL
29.0	At Morris Bridge Road near Thonotosassa	11	375	QW, FLO, WL
20.0	At Fowler Avenue near Tampa	17	630	QW, WL
10.0	Near Tampa	24	650	QW, FLO, WL

[1/] QW, water quality; PKT, phytoplankton; PY, periphyton; BCT, bacteriology; SED, sediment; FLO, flow; and WL, water level.

show a 7-day, 10-year base flow of about 45 ft^3/s for Hillsborough River at Morris Bridge Road. Low discharges that range from about 60 to 100 ft^3/s occurred at both stations during late October to early December 1977, April through mid-July 1978, and late September through late December 1978. In contrast, high discharges at these stations showed ranges from about 500 to 1,200 ft^3/s and occurred during February and March 1978 and again during mid-July through August 1978.

Data collection included steady-flow periods in April and December 1978 when discharge was minimum (fig. 4). The April data were collected 32 days after the last rainfall. Therefore, steady-flow conditions existed during sampling. The December samples were collected during a period following rainfalls of 0.06, 0.03, and 0.27 inch that occurred 1, 3, and 7 days earlier, respectively. Steady-flow conditions had prevailed for about 55 days prior to the December sampling.

Results of analyses of water-quality samples collected on the Hillsborough River and study-reach tributaries for December 12-13, 1978, and used for model calibration are listed in table 2. Similar data for the April 12-13, 1978, sampling and used for model verification are listed in table 3. The data represent average values for surface, mid-depth, and bottom samples. The samples were analyzed for the following constituents or properties: dissolved sulfate, nitrate, nitrite, ammonia, organic nitrogen, and orthophosphate; specific conductance; temperature; dissolved oxygen; ultimate carbonaceous biochemical oxygen demand; total and fecal coliform bacteria; and total organic carbon.

Temperature, pH, dissolved oxygen, and specific conductance measurements were made in the field according to standard U.S. Geological Survey procedures described by Skougstad and others (1979). Other constituents, except ultimate carbonaceous biochemical oxygen demand, were analyzed in the laboratory according to standard procedures (Skougstad and others, 1979).

Table 2.--Discharge and water-quality data collected December 12-13, 1978, and used for model calibration, Hillsborough River

[Site locations are shown in figure 3. Concentrations are in milligrams per liter, except as noted]

Site no.	Distance upstream from mouth (miles)	Day	Time	Discharge (cubic feet per second)	Sulfate, dissolved as SO_4	Nitrate, dissolved as N	Nitrite, dissolved as N	Nitrogen, ammonia, dissolved as N	Nitrogen, dissolved organic as N	Phosphorus, dissolved orthophosphate as P	Specific conductance (micromho per centimeter at 25°C)	Water temperature (°C)	Dissolved oxygen	Ultimate carbonaceous biochemical oxygen demand	Coliform, total (colonies per 100 milliliters)[1]	Coliform, fecal (colonies per 100 milliliters)[1]	Carbon, organic total
1	43.6	12	0735	-	6.3	1.4	0	0.03	0.21	0.04	280	21.5	6.5	1.2	390	62	3.2
		12	1300	55.1	6.4	1.4	0	.02	.26	.04	280	22.0	7.9	.9	560	48	1.0
		12	1920	-	6.4	1.4	0	.01	.38	.03	290	22.0	6.5	.6	830	32	5.7
		13	0130	-	6.4	1.5	0	.01	.25	.04	290	21.0	5.8	.7	630	42	0
2	[2]43.5		(3)	2.4	150	1.8	.02	.04	.57	2.4	700	14.0	8.6	3.1	3,400	700	11
3	42.2	12	0940	-	13	1.4	0	.01	.27	.14	330	20.5	7.1	.9	1,700	66	1.7
		12	1450	-	13	1.3	0	.02	.22	.14	300	20.5	8.0	.7	710	40	12
		12	2220	-	13	1.4	0	.01	.21	.15	330	19.0	7.7	.5	1,100	56	4.7
		13	0340	-	13	1.4	0	.01	.35	.14	350	17.0	7.0	.7	680	62	4.5
5	[2]41.4		(3)	16.3	18	1.4	.01	.02	.50	1.2	350	18.0	5.5	.8	890	64	4.3
6	40.0	12	1015	-	13	1.3	0	.02	.28	.34	360	19.0	6.6	1.2	1,100	38	2.5
		12	1520	65.2	13	1.3	0	.02	.34	.33	330	19.3	6.9	2.0	490	30	3.1
		12	2235	-	14	1.4	0	.01	.23	.29	320	18.5	5.9	.7	730	38	5.8
		13	0430	-	14	1.2	.0	.01	.23	.31	320	18.0	5.8	.7	340	44	1.5
7	37.2	12	0930	-	13	1.1	0	.02	.30	.37	380	18.5	6.7	1.8	610	30	2.4
		12	1440	-	13	1.1	0	.02	.35	.37	290	19.0	6.6	.9	670	30	2.6
		12	2200	-	14	1.1	0	.02	.23	.35	400	18.0	4.1	1.6	670	20	5.8
		13	0340	-	15	1.3	0	.02	.35	.35	340	17.1	6.6	.8	420	27	7.1

Footnotes are at end of table.

Table 2.--Discharge and water-quality data collected December 12-13, 1978, and used for model calibration, Hillsborough River--Continued

Site no.	Distance upstream from mouth (miles)	Day	Time	Discharge (cubic feet per second)	Sulfate, dissolved as SO_4	Nitrate, dissolved as N	Nitrite, dissolved as N	Nitrogen, ammonia, dissolved as N	Nitrogen, dissolved organic as N	Phosphorus, dissolved orthophosphate as P	Specific conductance (micromho per centimeter at 25°C)	Water temperature (°C)	Dissolved oxygen	Ultimate carbonaceous biochemical oxygen demand	Coliform, total (colonies per 100 milliliters)[1]	Coliform, fecal (colonies per 100 milliliters)[1]	Carbon, organic total
8	33.0	12	0810	-	13	1.0	0	0.02	0.32	0.39	370	17.8	6.5	1.1	540	88	9.0
		12	1330	-	13	1.0	0	.02	.26	.37	380	18.0	6.6	1.1	420	33	3.1
		12	2020	-	13	1.1	0	.02	.24	.34	340	17.5	5.8	1.1	620	76	4.9
		13	0230	-	14	1.1	0	.02	.25	.36	360	16.5	5.5	2.2	510	86	4.3
9	2/32.8		(3)	3.4	28	.24	.01	.06	.74	.49	370	14.5	6.0	5.0	1,100	260	14
11	29.0	12	0700	-	15	.88	0	.02	.39	.42	360	16.5	6.5	1.3	660	46	1.0
		12	1210	68.8	16	.83	0	.02	.42	.41	400	17.0	7.8	1.4	320	35	4.5
		12	1845	-	15	.92	0	.01	.45	.40	400	17.2	4.8	1.7	490	32	5.6
		13	0105	-	14	1.0	0	.02	.38	.38	340	15.8	5.7	1.2	390	64	3.3
12	26.6	12	1100	-	17	.91	0	.02	.28	.42	90	11.0	8.5	1.2	570	82	4.4
		12	1420	-	17	.86	0	.02	.40	.39	140	12.0	7.5	1.3	-	-	4.1
		12	2030	-	18	.84	0	.01	.45	.42	170	16.7	6.2	1.0	970	230	4.9
		13	0230	-	17	.86	0	.01	.43	.41	170	16.6	6.3	1.4	720	180	5.6
4/13	2/25.5		(3)	3.8	130	.01	0	.12	.36	.04	610	24.0	1.5	1.4	21	0	9.2
14	2/25.6		(3)	0	-	-	-	-	-	-	-	-	-	-	-	-	-
15	24.0	12	1000	-	20	.67	.01	.04	.37	.30	220	18.5	5.3	.9	400	13	4.4
		12	1345	-	19	.66	.01	.03	.28	.31	220	19.0	6.2	1.9	320	20	3.2
		12	2000	-	19	.69	.01	.03	.41	.31	200	18.8	5.2	.9	490	12	5.8
		13	0130	-	21	.70	.01	.03	.42	.33	190	17.6	4.2	1.5	320	20	5.6
16	2/24.7		(3)	0	-	-	-	-	-	-	-	-	-	-	-	-	-

Footnotes are at end of table.

Table 2.--Discharge and water-quality data collected December 12-13, 1978, and used for model calibration, Hillsborough River--Continued

Site no.	Distance upstream from mouth (miles)	Day	Time	Discharge (cubic feet per second)	Sulfate, dissolved as SO_4	Nitrate, dissolved as N	Nitrite, dissolved as N	Nitrogen, ammonia, dissolved as N	Nitrogen, dissolved organic as N	Phosphorus, dissolved orthophosphate as P	Specific conductance (micromho per centimeter at 25°C)	Water temperature (°C)	Ultimate carbonaceous biochemical oxygen demand	Dissolved oxygen	Coliform, total (colonies per 100 milliliters)1/	Coliform, fecal (colonies per 100 milliliters)1/	Carbon, organic total
17	20.0	12	0830	-	20	0.57	0.01	0.04	0.32	0.29	210	19.0	5.0	1.4	540	30	5.8
		12	1310	5/ 68.3	20	.55	.01	.03	.33	.30	215	19.5	6.7	1.3	670	-	4.9
		12	1930	-	19	.59	.01	.03	.35	.29	190	18.8	4.6	.9	370	48	6.1
		13	0100	-	19	.60	.01	.03	.41	.28	190	18.3	4.1	1.5	320	68	7.5
19	16.2	12	0655	-	21	.49	.01	.03	.22	.18	200	19.5	4.8	3.9	420	15	3.6
		12	1230	-	20	.48	.01	.02	.24	.18	200	19.5	6.9	1.2	420	17	3.6
		12	1845	-	21	.50	0	.02	.28	.19	190	19.2	7.1	1.4	560	12	5.2
		13	0025	-	21	.49	.01	.01	.33	.18	180	18.4	5.3	1.2	240	23	7.0
22	12.0	12	0600	-	24	.16	.01	.02	.36	.16	180	19.5	7.7	1.3	440	18	4.3
		12	1200	-	23	.16	.01	.02	.21	.16	180	19.0	7.3	1.8	420	12	4.0
		12	1800	-	23	.17	.01	.01	.33	.16	200	19.4	7.1	2.2	440	25	20.0
		13	0005	-	23	.16	.01	.01	.32	.15	170	18.9	4.4	1.6	260	35	8.4

1/ Data include non-ideal colony count.

2/ Distance of tributary confluence upstream from mouth, in miles.

3/ For tributary sites, chemical constituent concentrations are averages of samples obtained during the 24-hour sampling period.

4/ Discharge from dewatering operation at S-155 associated with construction of Tampa Bypass Canal.

5/ Discharge measured at a site about 3,000 feet downstream.

Table 3.--Discharge and water-quality data collected April 12-13, 1978, and used for model verification, Hillsborough River

[Site locations are shown in figure 3. Concentrations are in milligrams per liter, except as noted]

Site no.	Distance upstream from mouth (miles)	Day	Time	Discharge (cubic feet per second)	Sulfate, dissolved as SO_4	Nitrate, dissolved as N	Nitrite, dissolved as N	Nitrogen, ammonia, dissolved as N	Nitrogen, dissolved organic as N	Phosphorus, dissolved orthophosphate as P	Specific conductance (micromho per centimeter at 25°C)	Water temperature (°C)	Dissolved oxygen	Ultimate carbonaceous biochemical oxygen demand	Coliform, total (colonies per 100 milliliters)[1]	Coliform, fecal (colonies per 100 milliliters)[1]	Carbon, organic total
2	[2]43.5		(3)	2.7	730	3.0	0.10	14	1.0	1.7	1,560	25.0	4.2	15	6,000	190	4
4	41.8	12	0830		29	1.6	.03	.19	.19	.14	360	22.5	6.2	.6	1,000	52	.0
		12	1445	72.6	29	1.7	.03	.18	.15	.13	380	23.5	6.6	1.0	2,200	22	0
		12	2000	-	30	1.6	.02	.19	.17	.13	350	23.0	5.4	.6	2,100	28	0
		13	0215	-	28	1.6	.02	.16	.01	.13	350	23.0	2.0	.6	1,400	40	0
		13	0835	-	29	1.6	.02	.15	.03	.13	360	23.5	6.6	.8	1,300	36	3.0
5	[2]41.4		(3)	22.2	23	1.2	.02	.14	.23	.52	340	24.0	5.3	1.6	880	26	2
6	40.0	12	0615	-	29	1.6	.03	.13	.12	.25	360	23.0	6.2	.8	1,300	110	0
		12	1410	82.9	29	1.5	.03	.07	.20	.24	400	24.5	6.7	1.0	1,400	110	0
		12	1800	-	28	1.5	.02	.07	.17	.24	370	24.0	7.1	.7	1,100	15	0
		13	0045	-	29	1.6	.02	.14	.12	.24	350	22.5	5.5	0	700	33	2.0
		13	0630	-	30	1.5	.02	.08	.09	.24	360	23.5	6.1	1.0	1,700	110	0
9	[2]32.8		(3)	8.0	30	1.0	.02	.02	.38	.37	400	23.4	7.0	3.1	1,800	43	4
10	32.5	12	0915	-	31	1.3	.02	.05	.22	.31	390	22.7	6.4	.9	1,200	15	2
		12	1525	-	30	1.4	.02	.04	.23	.30	480	23.3	6.9	.7	500	32	3
		12	2220	-	30	1.2	.02	.02	.26	.31	390	23.5	6.4	.6	1,200	36	4
		13	0315	-	32	1.3	.01	.02	.28	.31	400	23.5	6.2	.4	1,000	170	3
		13	0900	-	30	1.3	.01	.03	.18	.29	490	23.2	6.2	.7	1,200	170	0

Footnotes are at end of table.

Table 3.--Discharge and water-quality data collected April 12-13, 1978, and used for model verification, Hillsborough River--Continued

Site no.	Distance upstream from mouth (miles)	Day	Time	Discharge (cubic feet per second)	Sulfate, dissolved as SO_4	Nitrate, dissolved as N	Nitrite, dissolved as N	Nitrogen, ammonia, dissolved as N	Nitrogen, dissolved organic as N	Phosphorus, dissolved orthophosphate as P	Specific conductance (micromho per centimeter at 25°C)	Water temperature (°C)	Dissolved oxygen	Ultimate carbonaceous biochemical oxygen demand	Coliform, total (colonies per 100 milliliters)[1]	Coliform, fecal (colonies per 100 milliliters)[1]	Carbon, organic total
11	29.0	12	0825	-	34	1.2	0.02	0.05	0.42	0.32	390	22.4	6.2	0.9	1,000	18	3
		12	1425	89.0	30	1.2	.02	.05	.20	.32	380	23.3	7.4	.6	400	10	2
		12	2045	-	29	1.2	.01	.02	.23	.31	390	25.0	7.3	.4	1,600	10	2
		13	0215	-	30	1.2	.01	.03	.29	.30	400	24.0	6.4	.5	500	22	0
		13	0805	-	30	1.2	.01	.03	.18	.31	390	23.1	6.1	.3	1,600	64	1
12	26.6	12	0740	-	24	.99	.01	.03	.18	.31	390	22.8	6.1	.6	700	16	2
		12	1330	-	29	.99	.01	.03	.21	.31	380	24.2	-	.6	900	12	2
		12	1945	-	29	1.1	.01	.02	.19	.31	380	23.0	5.5	.8	-	7	1
		13	0120	-	29	.99	.01	.02	.27	.32	400	23.0	5.4	.4	700	2	2
		13	0725	-	30	.99	.01	.02	.32	.32	480	23.5	5.6	.8	1,100	22	1
[4]13	[2]25.5		(3)	0	-	-	-	-	-	-	-	-	-	-	-	-	-
14	[2]25.6		(3)	.07	-	-	-	-	-	-	-	-	-	-	-	-	-
15	24.0	12	0620	-	21	.31	.01	.03	.34	.26	340	22.2	4.9	.2	700	18	7
		12	1220	-	22	.30	.01	.04	.39	.27	340	22.0	3.5	1.0	900	20	8
		12	1820	-	23	.30	.01	.02	.47	.27	350	-	6.8	.6	2,000	40	6
		13	0010	-	23	.31	.01	.02	.34	.25	360	23.0	7.0	.6	540	25	8
		13	0630	-	23	.31	.01	.03	.23	.27	360	22.7	4.7	.6	4,900	28	9
16	[2]24.7		(3)	11	9.9	.02	.02	.06	1.2	.02	210	23.0	2.0	4.0	650	12	28

Footnotes are at end of table.

Table 3.--Discharge and water-quality data collected April 12-13, 1978, and used for model verification, Hillsborough River--Continued

Site no.	Distance upstream from mouth (miles)	Day	Time	Discharge (cubic feet per second)	Sulfate, dissolved as SO_4	Nitrate, dissolved as N	Nitrite, dissolved as N	Nitrogen, ammonia, dissolved as N	Nitrogen, dissolved organic as N	Phosphorus, dissolved orthophosphate as P	Specific conductance (micromho per centimeter at 25°C)	Water temperature (°C)	Dissolved oxygen	Ultimate carbonaceous biochemical oxygen demand	Coliform, total (colonies per 100 milliliters)[1]	Coliform, fecal (colonies per 100 milliliters)[1]	Carbon, organic total
17	20.0	12	1000	-	20	0.25	0.01	0.06	0.37	0.24	160	23.0	3.1	0.8	280	14	9
		12	1415	-	22	.24	.01	.04	.41	.24	180	24.0	3.6	.8	700	40	10
		12	2140	-	22	.24	.01	.05	.32	.24	170	23.7	2.7	.8	410	12	12
		13	0245	-	22	.24	.01	.05	.35	.24	180	23.3	3.1	.4	670	40	17
		13	0820	-	22	.25	.01	.04	.34	.24	180	23.4	3.4	.7	220	18	9
18	17.6	12	0930	-	20	.19	.01	.06	.41	.23	160	23.6	3.2	.8	500	12	12
		12	1340	-	20	.19	.01	.05	.45	.23	170	23.8	3.6	.7	320	14	12
		12	2100	-	21	.19	.01	.05	.37	.23	170	24.1	3.2	.9	1,400	64	12
		13	0200	-	20	.19	.01	.05	.42	.23	170	24.0	2.8	1.0	700	35	9
		13	0800	-	21	.19	.01	.04	.39	.24	170	23.9	3.2	.6	230	15	10
19	16.2	12	0900	-	20	.11	.01	.06	.45	.22	160	23.7	3.9	1.2	180	16	16
		12	1315	-	20	.11	.01	.04	.43	.22	170	24.3	3.7	1.5	100	40	13
		12	2035	-	20	.07	.01	.04	.43	.20	160	25.2	3.3	2.3	380	24	14
		13	0130	-	20	.09	.01	.04	.42	.21	160	24.4	3.0	1.5	180	18	15
		13	0730	-	20	.13	.01	.05	.58	.22	160	24.3	3.2	1.0	150	18	14
20	14.0	12	0750	-	19	.07	0	.04	.47	.20	120	22.8	2.3	1.4	170	10	16
		12	1250	-	18	.06	.01	.03	.54	.21	130	23.6	2.9	2.0	200	30	14
		12	1925	-	18	.11	.01	.05	.47	.23	130	23.9	2.3	1.8	220	20	14
		13	0050	-	18	.03	0	.04	.54	.17	140	23.7	2.4	1.4	-	13	17
		13	0650	-	17	.06	.01	.03	.51	.23	130	23.1	2.3	1.3	280	16	15

Footnotes are at end of table.

Table 3.--Discharge and water-quality data collected April 12-13, 1978, and used for model calibration, Hillsborough River--Continued

Site no.	Distance upstream from mouth (miles)	Day	Time	Discharge (cubic feet per second)	Sulfate, dissolved as SO_4	Nitrate, dissolved as N	Nitrite, dissolved as N	Nitrogen, ammonia, dissolved as N	Nitrogen, dissolved organic as N	Phosphorus, dissolved orthophosphate as P	Specific conductance (micromho per centimeter at 25°C)	Water temperature (°C)	Dissolved oxygen	Ultimate carbonaceous biochemical oxygen demand	Coliform, total (colonies per 100 milliliters)[1]	Coliform, fecal (colonies per 100 milliliters)[1]	Carbon, organic total
21	13.0	12	0725	-	15	0.01	0.01	0.04	0.56	0.22	120	23.8	2.0	0.8	270	10	19
		12	1215	-	13	.03	.01	.04	.59	.22	130	24.6	2.4	1.6	59	8	16
		12	1905	-	14	.01	.01	.04	.58	.19	140	26.7	3.6	1.4	380	8	21
		13	0025	-	12	.01	.01	.06	1.10	.20	140	26.7	3.4	1.6	320	12	16
		13	0630	-	16	.06	.01	.01	.53	.23	110	22.8	1.8	1.4	62	12	15
23	11.3	12	0655	-	16	.08	.01	.08	.65	.26	130	21.8	1.0	1.1	500	28	18
		12	1200	-	17	.09	.01	.09	.59	.28	120	21.1	1.1	1.1	160	8	13
		12	1845	-	24	.08	.01	.06	.54	.24	140	22.4	1.0	1.3	1,800	73	17
		13	0004	-	20	.09	.01	.07	.54	.25	160	22.4	1.0	1.2	1,800	200	13
		13	0600	-	16	.11	.01	.10	.96	.26	140	22.3	1.0	.8	1,700	44	16

1/ Data include non-ideal colony count.

2/ Distance of tributary confluence upstream from mouth, in miles.

3/ For tributary sites, chemical constituent concentrations are averages of samples obtained during the 24-hour sampling period.

4/ Discharge from dewatering operation at S-155 associated with construction of Tampa Bypass Canal.

Depth-integrated samples were collected in 1-gallon containers, chilled, and sent to the laboratory for determination of ultimate carbonaceous biochemical oxygen demand. Biochemical oxygen demand levels were so low that only a very few samples required dilution. Samples were not treated with a nitrification inhibitor; thus, any oxygen consumed by nitrification would be reflected in the ultimate carbonaceous biochemical oxygen demand rate. The amount of oxygen consumed by each sample was determined after 1, 2, 3, 5, 7, 10, 15, and 20 days. These data were used to compute the 5-day carbonaceous biochemical oxygen demand and the ultimate carbonaceous biochemical oxygen demand rate constants. Ultimate carbonaceous biochemical oxygen demand was computed by a method described by Jennings and Bauer (1976). The method that yielded concentrations having the least error was used as input to the model. Ultimate carbonaceous biochemical oxygen demand was also computed by the linear and nonlinear least-squares method as given in "Determination of Biochemical-Oxygen-Demand Parameters" (Jennings and Bauer, 1976).

Chemical constituent concentrations for tributaries (tables 2 and 3) are listed as averages of samples obtained during the 24-hour sampling period. Big Ditch, Blackwater Creek, and Flint Creek discharge directly into the study reach and are treated as point sources. Cypress and Trout Creeks are treated as a combined source that discharges into a swamp area and drains into the Hillsborough River between Morris Bridge Road and Fletcher Avenue and are nonpoint sources of discharge. Water-quality data were collected on Cypress Creek (site 16, fig. 3) during the April 1978 sample period; however, Trout Creek was not sampled in April 1978 because flow was very low (0.07 ft^3/s). Cypress and Trout Creeks were not sampled during December 1978 because they had no flow. Concentrations of various chemical and biological constituents for Cypress and Trout Creeks for April 1978 were estimated from water-quality data collected upstream from the mouth of Cypress Creek (site 16, fig. 3).

Initially, 11 sites sampled in December 1978 were selected for calibration; however, only the 9 that were within the selected boundary of the study reach were used. The nine sites included 6, 7, 8, 11, 12, 15, 17, 19, and 22 (fig. 3). Of the 12 sites sampled in April 1978 that were selected for verification, the 11 that were within the boundary of the study reach were used. The 11 sites included 6, 10, 11, 12, 15, 17, 18, 19, 20, 21, and 23 (fig. 3). Site 6 was used as the upstream boundary. Flow during the December sample period was about 33 percent less than flow during the April sample period and, therefore, more critical (higher constituent concentrations) for key constituents, such as ultimate carbonaceous biochemical oxygen demand and organic nitrogen. Concentrations of dissolved oxygen were correspondingly lower. Therefore, the December sample data were used for model calibration and the April data for model verification.

Data on stream cross-sectional areas, widths, and mean depths for subreaches were obtained from field measurements of August 30, 1978. Channel cross sections were plotted on grid paper and a digital planimeter was used to determine their areas. Cross sections were adjusted to approximate stage conditions that existed in each subreach during sampling in April and December 1978. Adjustments were based on observed changes in stage at gaging stations located near the lower, middle, and upper parts of the study reach. The area, width, and mean depth of the stream cross section at the beginning of each subreach were assumed to represent the entire subreach. Cross-sectional data for the April and December samplings are summarized by subreach (table 4). Cross-sectional data in the Tampa Reservoir were obtained from a previous study by Turner (1974).

Table 4.--Summary of cross section pertaining to geometry, velocity, and discharge data by subreach, Hillsborough River

[ft, foot; ft^2, foot squared; ft/s, foot per second; ft^3/s, cubic foot per second]

Subreach no.[1/]	April 12, 1978					December 12, 1978				
	Width (ft)	Mean depth (ft)	Area (ft^2)	Velocity[2/] (ft/s)	Discharge (ft^3/s)	Width (ft)	Mean depth (ft)	Area (ft^2)	Velocity[2/] (ft/s)	Discharge (ft^3/s)
1	65	6.0	390	0.21	82.9	65	5.8	377	0.17	65.2
2	115	4.0	460	.20	[3/]90.9	115	3.9	448	.15	[3/]68.6
3	65	8.6	559	.17	[4/]92.7	65	7.4	481	.14	68.6
4	135	16.4	2,214	.04	[5/]94.0	135	14.9	2,012	.04	[6/]72.4
5	105	12.6	1,323	.08	[7/]99.5	105	10.7	1,124	.06	72.4
6	152	12.5	1,900	.06	[7/]105	152	10.4	1,581	.05	72.4
7	115	10.0	1,150	.09	105	115	7.8	897	.08	72.4
8	222	6.0	1,332	.08	[8/]106	186	4.2	781	.09	72.4
9	633	4.2	2,659	.04	[8/]108	336	4.1	1,378	.05	72.4
10	639	5.0	3,195	.03	[8/]110	524	3.6	1,886	.04	72.4
11	653	5.5	3,592	.03	[8/]113	491	4.1	2,013	.04	72.4
12	642	8.2	5,264	.02	[8/]117	516	7.0	3,612	.02	72.4

1/ Subreach locations are shown in figure 2.

2/ Velocity is computed as discharge divided by respective area.

3/ Sum of instantaneous discharges at sites 6 and 9, figure 3.

4/ Includes 1.8 ft^3/s as linear runoff (nonpoint source) from large swamp areas in subreach 3.

5/ Includes 1.3 ft^3/s as linear runoff from large swamp areas in subreach 4.

6/ Includes 3.8 ft^3/s as point source from dewatering operation at S-155 (site 13, fig. 3).

7/ Includes 5.5 ft^3/s as linear runoff from Cypress Creek swamp.

8/ Includes adjustment for changes in reservoir storage.

Average discharge and velocity for each sampling period are also included in table 4. Discharges shown were determined from measurements made during sampling and from gaging-station records. The discharge at Fowler Avenue was estimated from a base-flow correlation between the Hillsborough River near Zephyrhills and the Fowler Avenue site (Goetz and others, 1978). The total flow at the Tampa Reservoir dam reflects adjustment for water-supply diversion (water-treatment plant), evaporation, inflow and outflow (at dam), and rainfall. When the sum of water-supply diversion and outflow at the dam was more than the flow at Fowler Avenue, the deficit was made up as linear runoff (nonpoint source of flow and wastes) from storage and reported, though not identified, as springs in the reservoir. Flow estimates are averages.

MODEL CALIBRATION

Calibration of the model consisted of determining the following reaction-rate coefficients using data collected December 12-13, 1978:

1. Deoxygenation rate coefficient for ultimate carbonaceous biochemical oxygen demand (reflects oxygen depletion by biochemical oxygen demand);
2. Decay rate coefficient for ultimate carbonaceous biochemical oxygen demand (reflects total loss of biochemical oxygen demand);
3. Forward reaction-rate coefficient for organic nitrogen, ammonia nitrogen, and nitrite nitrogen (reflects rate that one form of nitrogen decays sequentially forward to the next form);
4. Decay rate coefficient for organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen (rate describes the total rate of decay of each nitrogen form);
5. Die-off rate coefficient for fecal and total coliform bacteria (reflects rate at which coliforms die);
6. Uptake rate coefficient (bottom deposit and chlorophyll *a*) for orthophosphate phosphorus (reflects rate at which orthophosphate phosphorus is taken up by benthic vegetation and phytoplankton).

Reactions governing biochemical oxygen demand concentration in streams at steady-state conditions are described in detail by Bauer and others (1979). Also described are reactions that govern concentrations of dissolved oxygen, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, orthophosphate phosphorus, and fecal and total coliform bacteria. The decay rate must always be equal to or greater than the forward reaction coefficient (Bauer and others, 1979, p. 9).

A first approximation of reaction-rate coefficients was determined by the following procedure:

1. Observed concentration versus traveltime, based on estimated velocity (table 4), was plotted on semilog paper.
2. Best-fit, straight-line segments were drawn through the points. The line slope varied depending on the stream waste characteristics.
3. The reaction-rate coefficients were computed for each line segment according to the following equation given by Bauer and others (1979):

$$K = \frac{2.3}{t_1 - t_2} \log \frac{conc_2}{conc_1} \qquad (1)$$

where K = reaction-rate coefficient, in base e per day;

$t_1 - t_2$ = traveltime, in days, between concentration 1 and concentration 2;

$conc_1$ = concentration of constituent at some initial time, t_1; and

$conc_2$ = concentration of constituent at some time, t_2, later than t_1.

The reaction-rate coefficients were adjusted to best fit the median or range of the observed data at each sampling point. A summary of the reaction-rate coefficients used in the model for calibration data are given in table 5.

The criteria used in model calibration are as follows:

1. Simulated concentrations of chemical and biological constituents fall within the range of observed concentrations at each sampling point.
2. The differences between simulated concentrations of chemical and biological constituents and the median of observed concentrations at sample sites in each subreach could be decreased no further.

Simulated and observed constituent concentrations for sites 6, 7, 8, 11, 12, 15, 17, 19, and 22 (fig. 3) are shown in figures 5 through 13. Simulated constituent concentrations are based on refined reaction-rate coefficients (table 5). The data shown in figures 5 through 13 illustrate how well calibration data met the first criterion. The ranges of observed and simulated concentrations for nonconservative constituents are listed in table 6.

The median, mean, and their corresponding absolute errors in simulated concentrations for the chemical and biological constituents modeled are listed in table 7. Median and absolute errors were computed using modified relations from Wilson and MacLeod (1974), as follows:

$$\text{Median error} = \frac{x_{sim} - \tilde{x}_{ob}}{\tilde{x}_{ob}} \times 100\text{; in percent;} \qquad (2)$$

$$\text{Absolute error} = x_{sim} - \tilde{x}_{ob}\text{; in units of individual constituents;} \qquad (3)$$

where x_{sim} = simulated concentration; and

$\tilde{x}_{ob}$ = median of the observed concentrations.

The mean of the log transformation was used for biological data. Computation was the same as for the median error.

When the computed value was observed to be outside the range of the observed data set, the standard deviation was applied. Two standard deviations (2S) about the mean were used in determining model verification. For the purpose of calibrating and verifying the model for biological data, the mean, standard deviation, and 95 percent confidence limit of the log transform of the data were used. The data

Table 5.--Reaction-rate coefficients for modeled constituents by subreach, Hillsborough River

[All coefficients given in base e per day at 20°C]

Subreach no.	Ultimate CBOD deoxygenation rate coefficient	Ultimate CBOD decay rate coefficient	Organic nitrogen forward reaction rate coefficient	Organic nitrogen decay rate coefficient	Ammonia nitrogen forward reaction rate coefficient	Ammonia nitrogen decay rate coefficient
1	0.001	0.001	0.00	0.001	0.001	0.001
2	.001	.001	.001	.001	.001	.001
3	.001	.001	.001	.001	.001	.001
4	.001	.001	.001	.001	.001	.001
5	.001	.001	.001	.001	.001	.001
6	.001	.001	.001	.001	.001	.001
7	.001	.001	.001	.001	.001	.001
8	.001	.001	.001	.001	.001	.001
9	.001	.001	.001	.001	.001	.001
10	.001	.001	.001	.001	.001	.001
11	.001	.001	.001	.001	.001	.001
12	.001	.001	.001	.001	.001	.001

Subreach no.	Nitrite nitrogen forward reaction rate coefficient	Nitrite nitrogen decay rate coefficient	Nitrate nitrogen decay rate coefficient	Fecal coliform die-off rate coefficient	Total coliform die-off rate coefficient	Orthophosphate phosphorus stream bottom deposit uptake rate	Orthophosphate phosphorus chlorophyll *a* uptake rate
1	2.5	2.5	0.06	0.10	0.10	0.0	0.0
2	2.5	2.5	.06	.10	.10	0	0
3	2.5	2.5	.16	.10	.10	0	0
4	2.5	2.5	.16	.10	.01	0	0
5	2.5	2.5	.20	.05	.01	0	0
6	2.5	2.5	.20	.01	.01	0	0
7	2.5	2.5	.10	.01	.01	0	0
8	2.0	2.0	.10	.01	.01	.1	.2
9	2.0	2.0	.10	.01	.01	.1	.2
10	2.0	2.0	.10	.01	.01	.1	.2
11	2.0	2.0	.05	.01	.01	.1	.2
12	2.0	2.0	.05	.01	.01	.1	.2

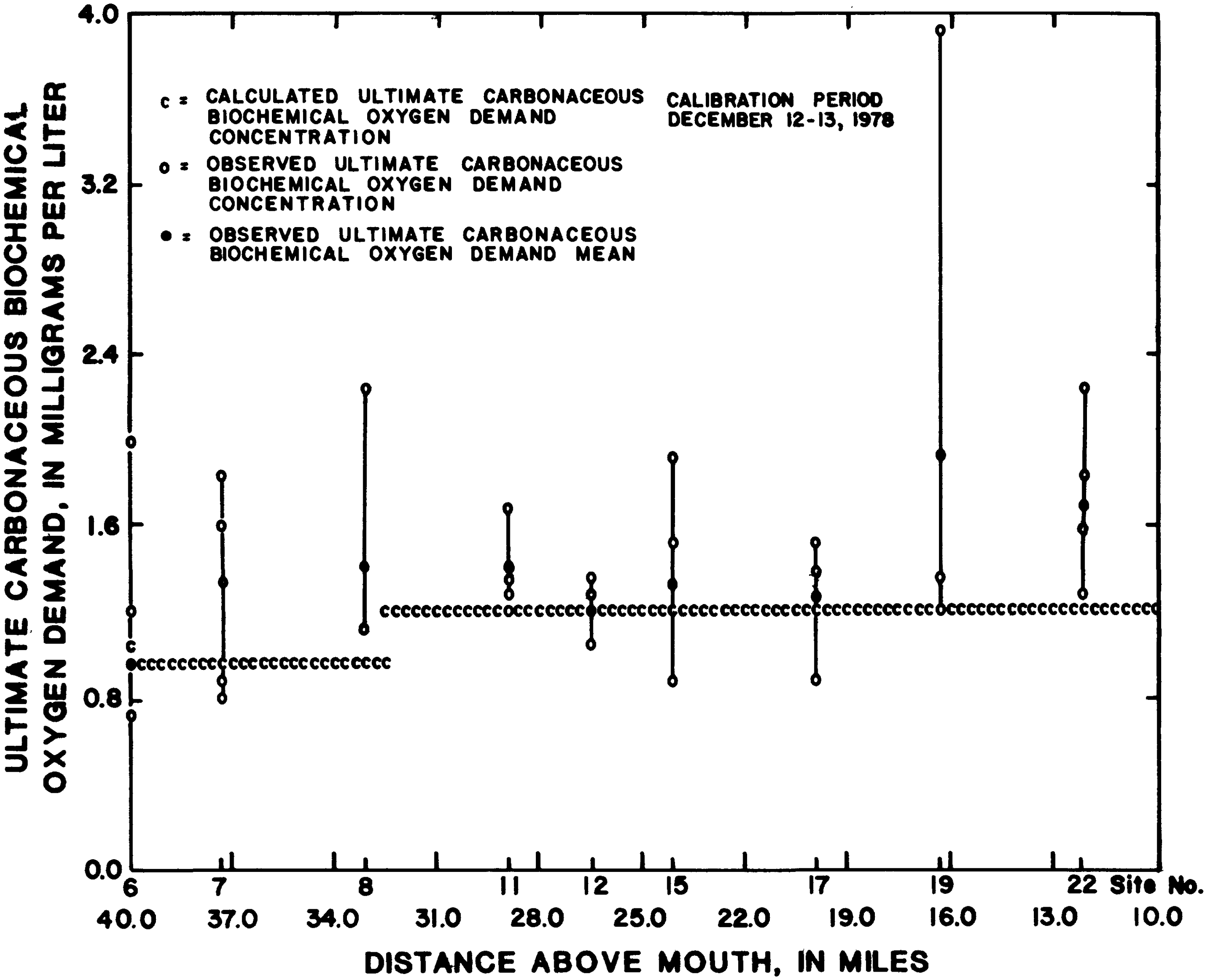

Figure 5.--Simulated and observed concentrations of ultimate carbonaceous biochemical oxygen demand, Hillsborough River.

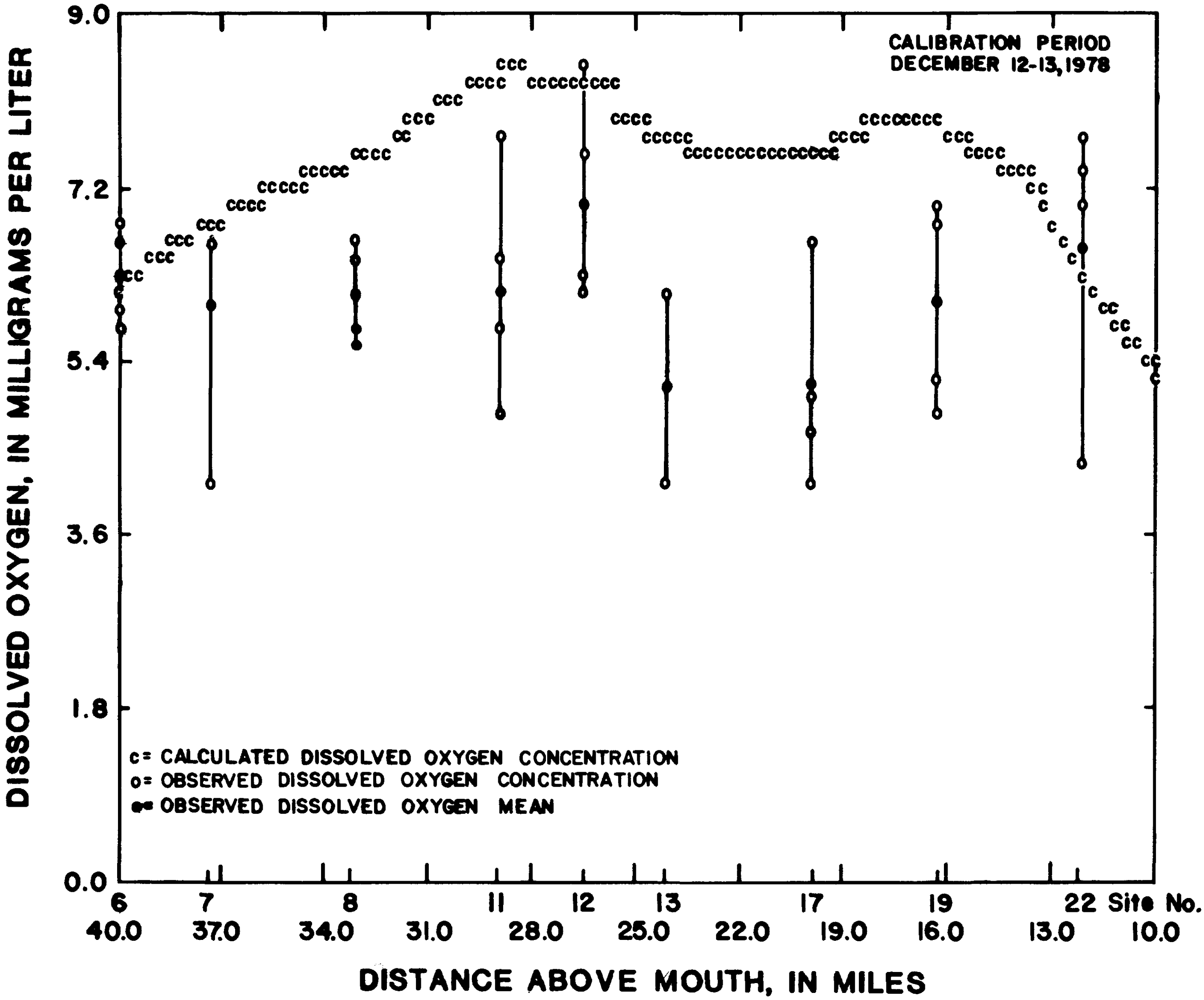

Figure 6.--Simulated and observed concentrations of dissolved oxygen, Hillsborough River.

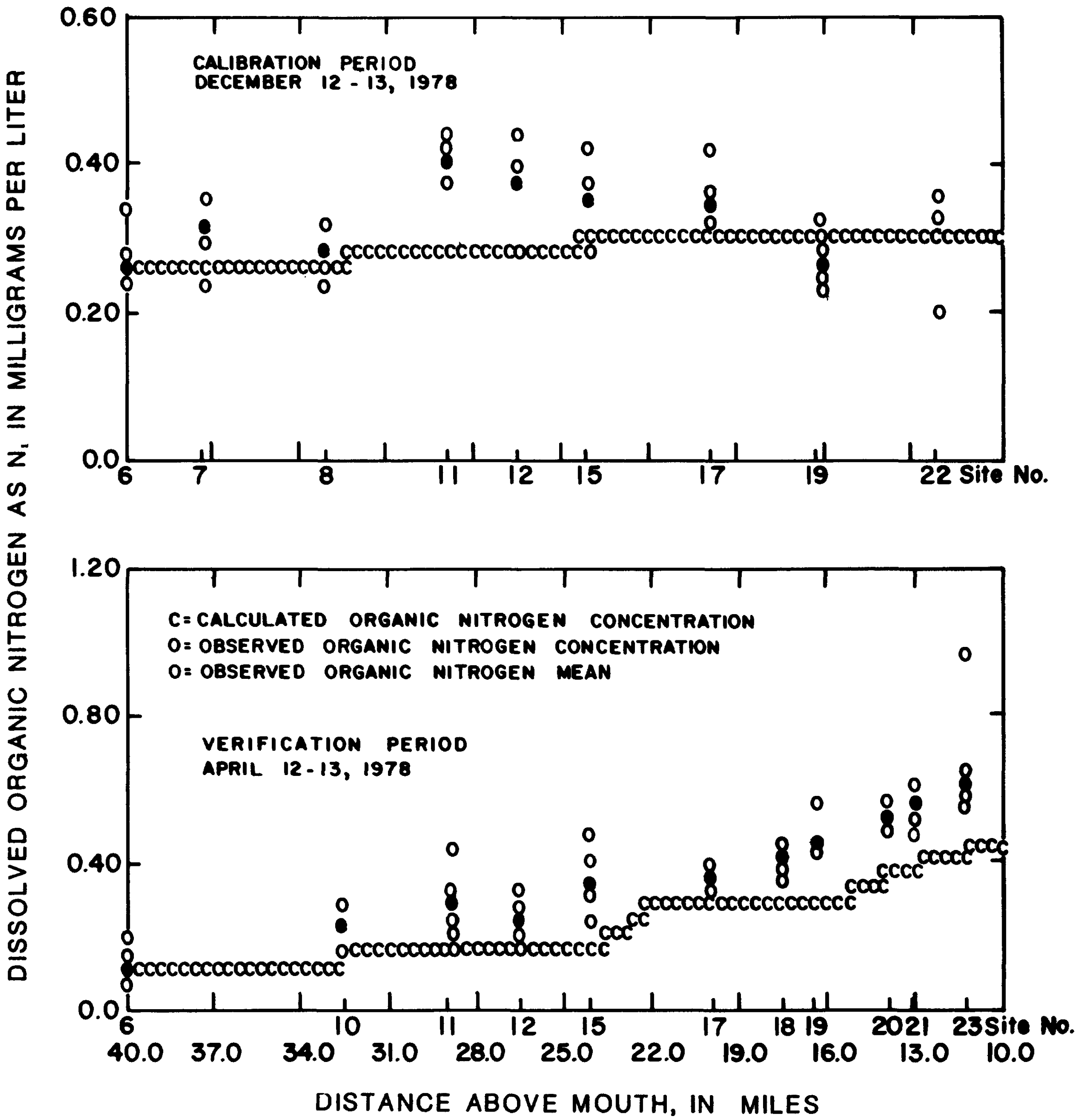

Figure 7.--Simulated and observed concentrations of dissolved organic nitrogen, Hillsborough River.

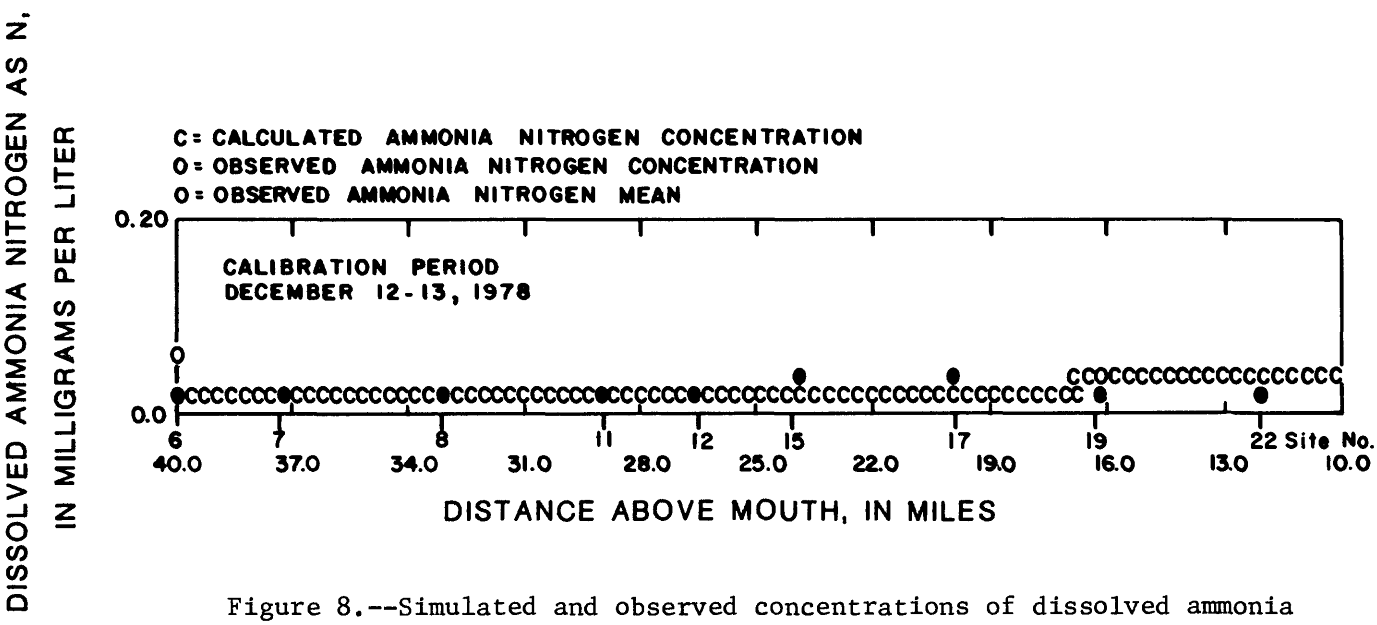

Figure 8.--Simulated and observed concentrations of dissolved ammonia nitrogen, Hillsborough River.

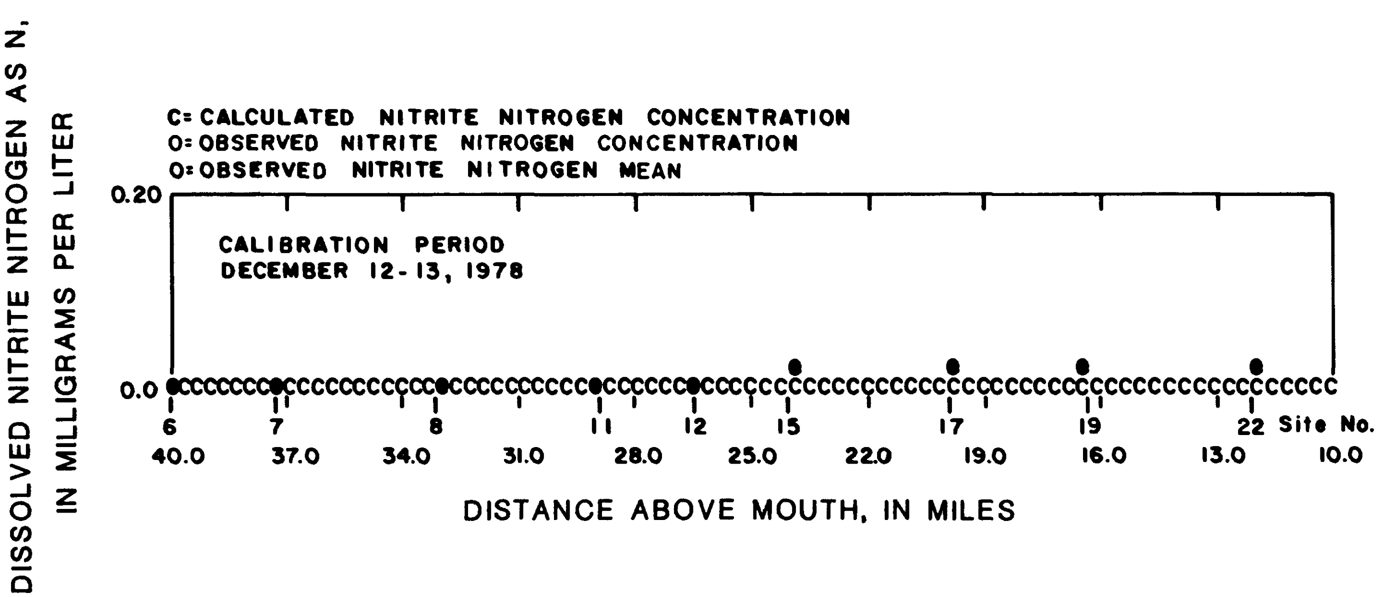

Figure 9.--Simulated and observed concentrations of dissolved nitrite nitrogen, Hillsborough River.

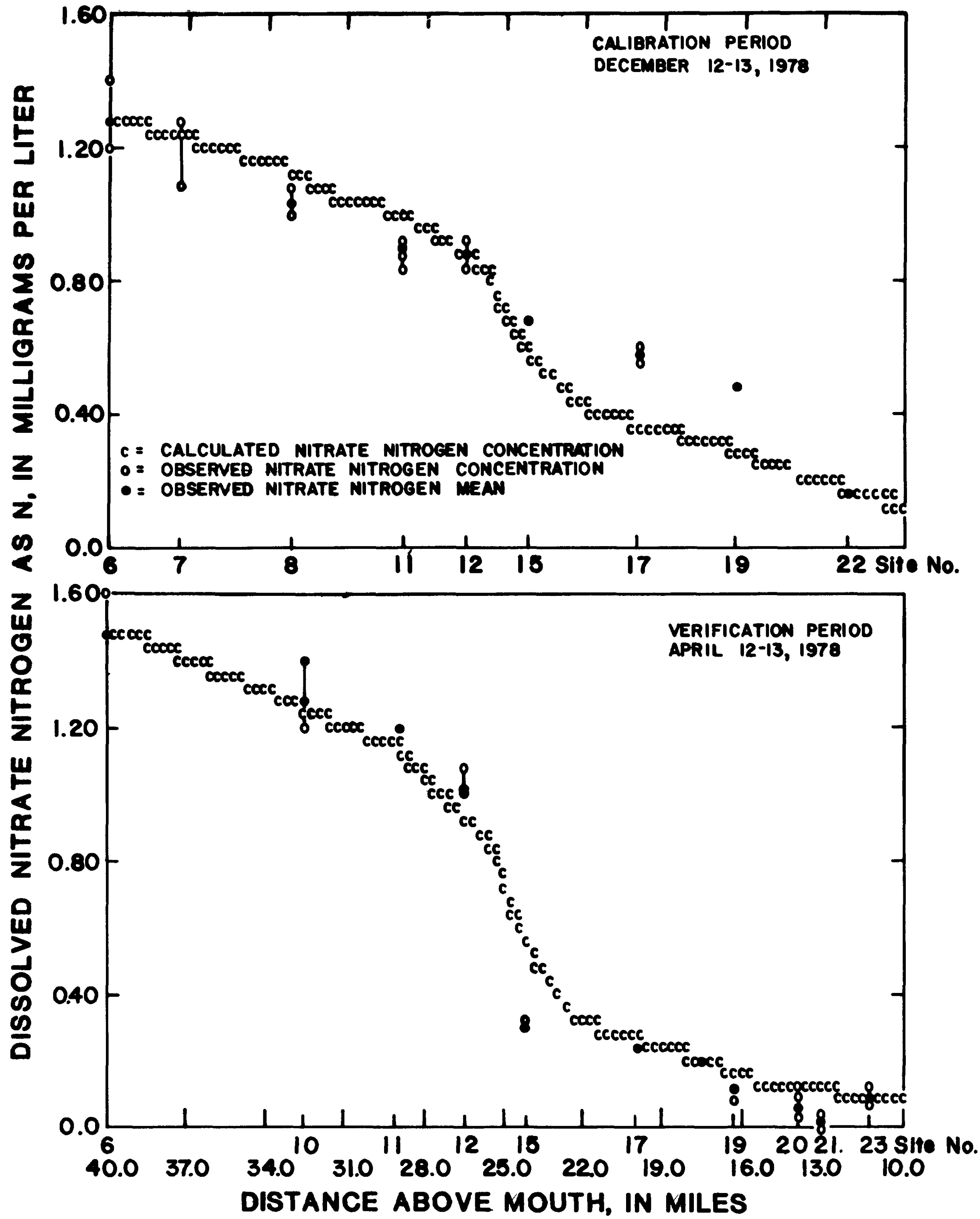

Figure 10.--Simulated and observed concentrations of dissolved nitrate nitrogen, Hillsborough River.

used included ideal and nonideal colony counts. The log transforms were used to normalize their frequency and to fulfill other requirements of a normal distribution (Greeson and others, 1977, p. 9). The 90 percent confidence limit above the mean was used to establish the population limits at the 95 percent probability and thus to determine whether the computed value falls within this limit for calibration and verification purposes.

A discussion of each nonconservative constituent modeled with respect to calibration criteria is as follows:

1. Ultimate carbonaceous biochemical oxygen demand: Although calibration was achieved for the entire study reach, with all sample sites (fig. 5, table 6) meeting the criteria, calibration was only successful in a qualitative way. The computed dissolved oxygen was greater than the observed dissolved oxygen (table 6), which indicates the carbonaceous biochemical oxygen demand deoxygenation rate should have been greater than 0.001 (table 5), which would, in turn, require the carbonaceous biochemical oxygen demand decay rate to be less than the carbonaceous biochemical oxygen demand deoxygenation rate. According to Bauer and others (1979, p. 9), this should not happen, and it is contrary to the assumptions used when constructing the model; thus, the model should not be considered calibrated.
2. Dissolved oxygen: Calibration was achieved for the entire study reach; only two sites (fig. 6, table 6) did not meet the criteria.
3. Organic nitrogen: Calibration was achieved for most of the study reach; seven of the eight sample sites (fig. 7, table 6) met the criteria.

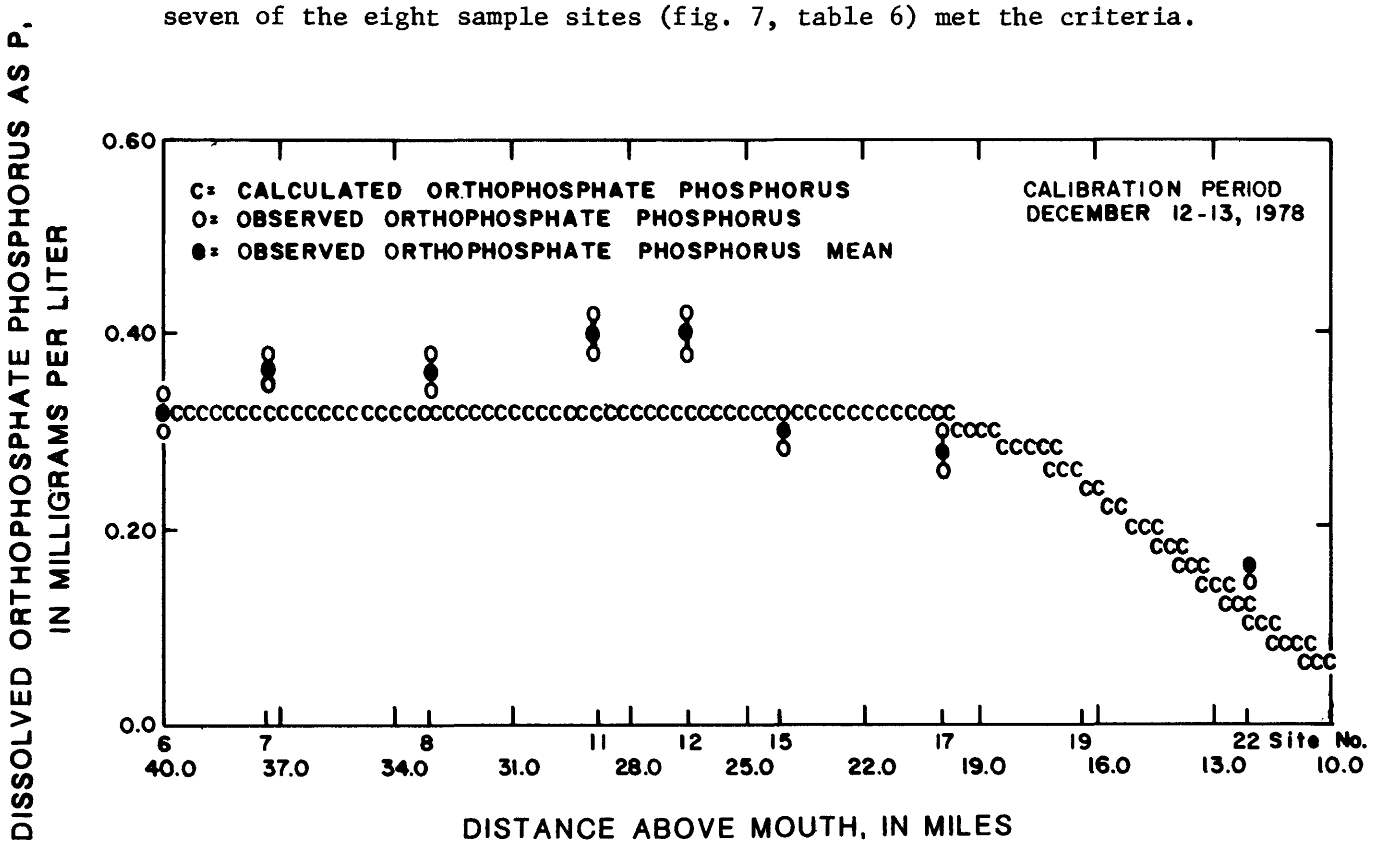

Figure 11.--Simulated and observed concentrations of dissolved orthophosphate phosphorus, Hillsborough River.

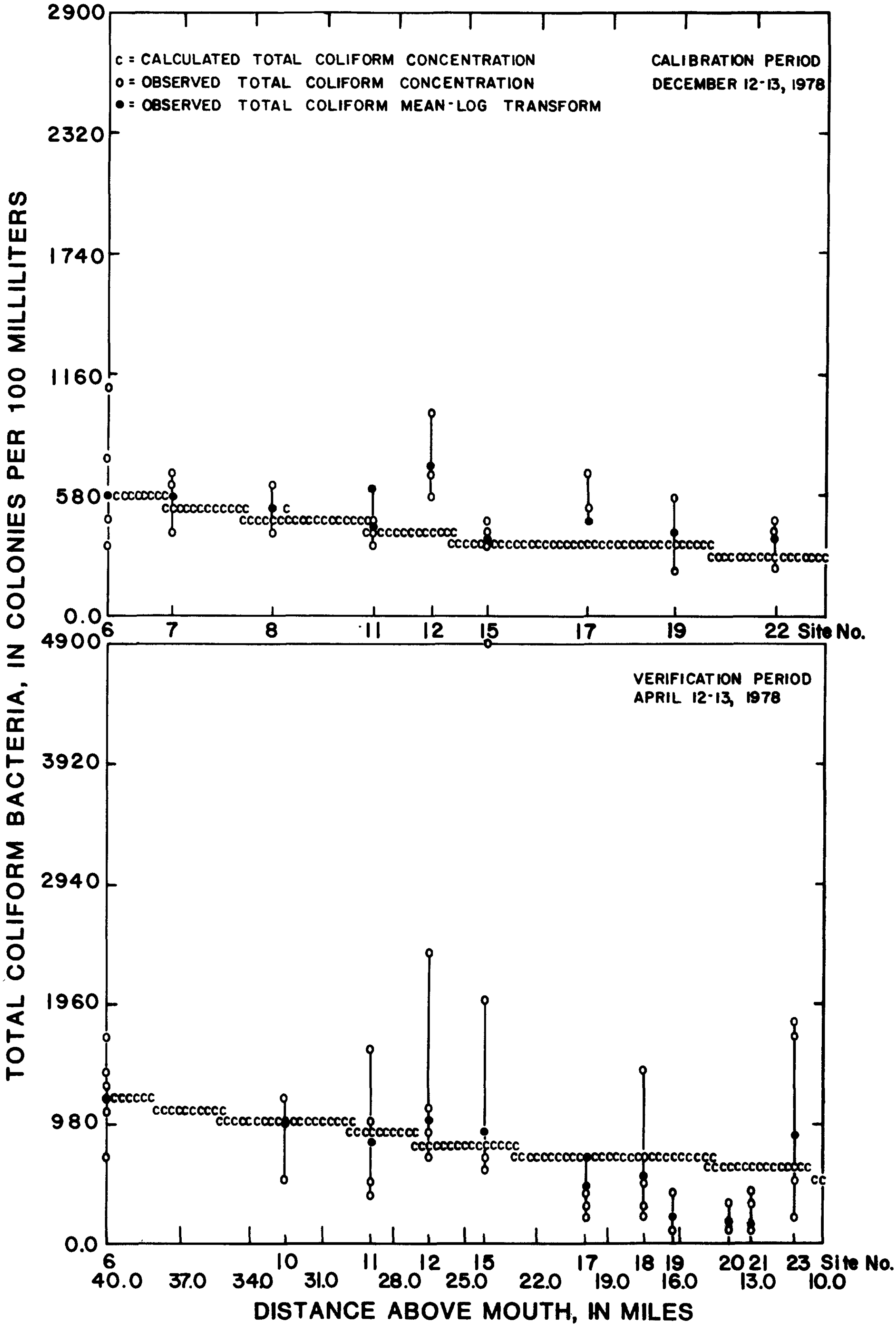

Figure 12.--Simulated and observed concentrations of total coliform bacteria, Hillsborough River.

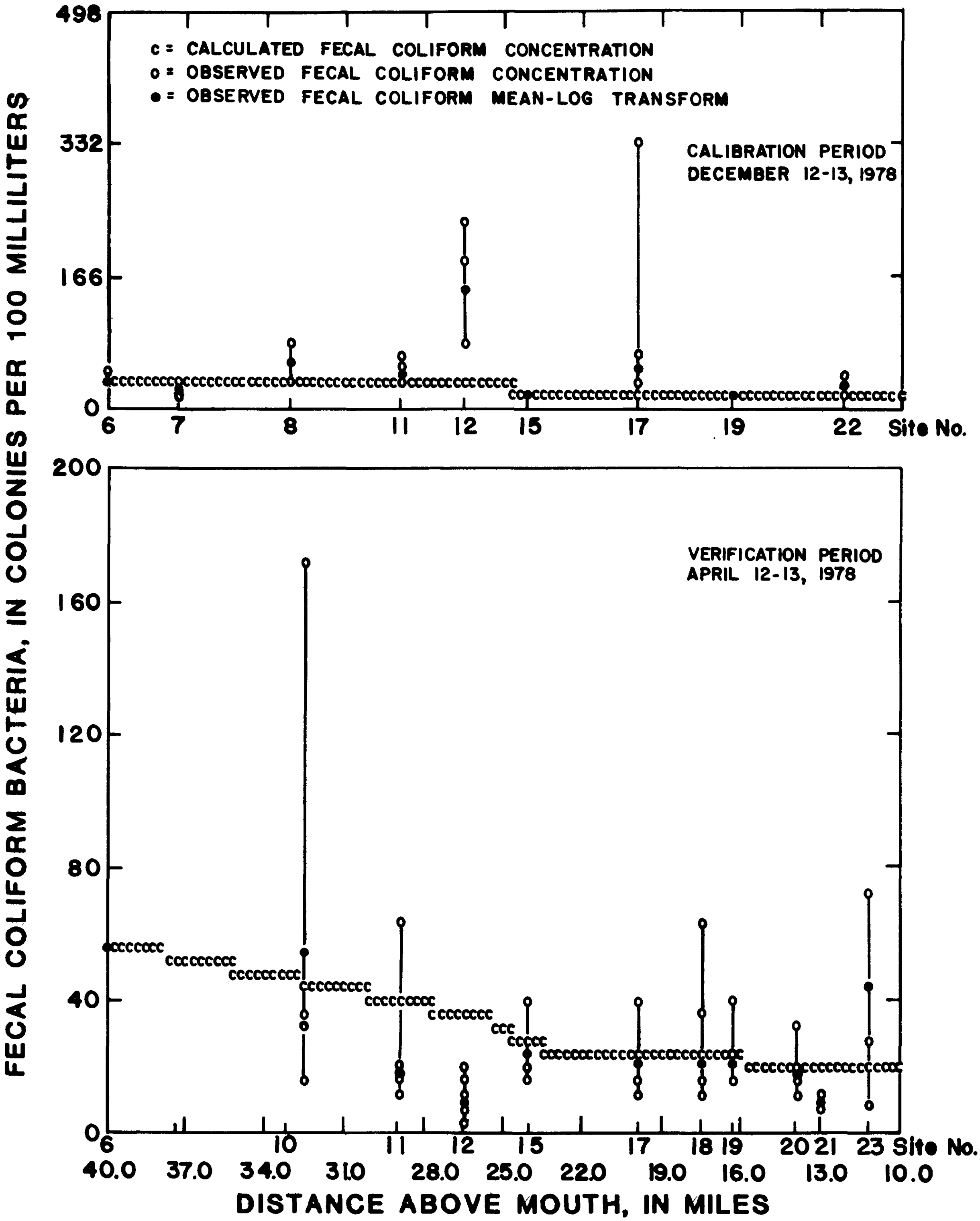

Figure 13.--Simulated and observed concentrations of fecal coliform bacteria, Hillsborough River.

Table 6.--Simulated and observed concentrations of nonconservative constituents for calibration period, December 12-13, 1978, Hillsborough River

[Upper set of figures shows range of means for observed concentrations; simulated concentrations are shown in parenthesis. Concentrations are in milligrams per liter, except for coliforms, which are in colonies per 100 milliliters]

Site no.	Ultimate carbonaceous biochemical oxygen demand	Dissolved oxygen	Nitrogen, dissolved organic as N	Nitrogen, ammonia, dissolved as N	Nitrite, dissolved as N	Nitrate, dissolved as N	Phosphorus, dissolved orthophosphate as P	Coliform	
								Total	Fecal
6	0.7-2.0 (1.0)	5.8-6.9 (6.2)	0.23-0.34 (0.26)	0.01-0.02 (0.02)	0 (0)	1.2-1.4 (1.3)	0.29-0.34 (0.32)	340-1,100 (600)	30-44 (37)
7	0.8-1.8 (1.0)	4.1-6.7 (6.9)[1]	0.23-0.35 (0.26)	(0.02) (0.02)	0 (0)	1.1-1.3 (1.2)	0.35-0.37 (0.32)[2]	420-670 (540)	20-30 (34)[2]
8	1.1-2.2 (1.0)	5.5-6.6 (7.5)[2]	0.24-0.32 (0.26)	0.02 (0.02)	0 (0)	1.0-1.1 (1.1)	0.34-0.39 (0.32)[2]	420-620 (470)	33-88 (29)[2]
11	1.2-1.7 (1.2)	4.8-7.8 (8.4)[1]	0.38-0.45 (0.28)[1]	0.01-0.02 (0.02)	0 (0)	0.83-1.0 (1.0)	0.38-0.42 (0.33)[2]	320-660 (430)	32-64 (35)
12	1.0-1.4 (1.2)	6.2-8.5 (8.4)	0.28-0.45 (0.29)	0.01-0.02 (0.02)	0 (0)	0.84-0.91 (0.88)	0.39-0.42 (0.33)[2]	570-970 (390)[2]	82-230 (32)[2]
15	0.9-1.9 (1.2)	4.2-6.2 (7.7)[1]	0.28-0.42 (0.29)	0.03-0.04 (0.03)	0.01 (0)	0.66-0.70 (0.57)[2]	0.30-0.33 (0.31)	320-490 (350)	12-20 (23)[2]
17	0.9-1.5 (1.2)	4.1-6.7 (7.5)[2]	0.32-0.41 (0.29)[1]	0.03-0.04 (0.03)	0.01 (0)	0.55-0.60 (0.37)[2]	0.28-0.30 (0.31)[2]	320-670 (340)	30-68 (21)[2]
19	1.2-3.9 (1.2)	4.8-7.1 (7.8)[1]	0.22-0.33 (0.29)	0.01-0.03 (0.03)	0-0.01 (0)	0.48-0.50 (0.28)[2]	0.18-0.19 (0.24)[2]	240-560 (330)	12-23 (20)
22	1.3-2.2 (1.2)	4.4-7.7 (6.2)	0.21-0.36 (0.30)	0.01-0.02 (0.03)[2]	0.01 (0)	0.16-0.17 (0.17)	0.15-0.16 (0.10)[2]	260-440 (300)	12-35 (19)

1/ Simulated value, although outside the range of observed data, is within two standard deviations (2S) about the mean; therefore, the site is considered calibrated (p. 21).

2/ Simulated value falls outside range of observed data.

Table 7.--Median, mean, and absolute errors in calibrated simulated constituent concentrations for calibration period, December 12-13, 1978, Hillsborough River

[Concentrations are in milligrams per liter, except for coliforms, which are in colonies per 100 milliliters. Median and mean errors are in percent and absolute error is in units of individual constituent]

Site no.	Nitrogen, dissolved organic as N		Nitrate, dissolved as N		Total coliforms		Fecal coliforms	
	Median	Absolute	Median	Absolute	Mean[1/]	Absolute	Mean[1/]	Absolute
7	0	0	9.1	0.1	6.9	40	31	8
8	0	0	10	.1	9.6	50	56	37
11	30	.12	11	.1	4.4	20	19	8
12	31	.13	2.3	.02	47	350	19	118
15	26	.10	16	.11	7.9	30	44	7
17	14	.05	36	.21	26	120	54	25
19	12	.03	43	.21	15	60	25	4
22	6.2	.02	6.2	.01	21	80	9.5	2
Average for reach	20	.08	17	.11	17	94	40	26

[1/]Mean-log transforms.

4. Ammonia nitrogen: Observed concentrations ranged from 0.01 to 0.04 mg/L, approximately the detection level of measurement of 0.01 mg/L (Erdman and others, 1982, p. 3-2). Therefore, the model could not be realistically evaluated for this constituent (fig. 8, table 6).

5. Nitrite nitrogen: Observed concentrations ranged from 0 to 0.01 mg/L, approximately the detection level of measurement of 0.01 mg/L (Erdman and others, 1982, p. 3-2). Therefore, the model could not be realistically evaluated for this constituent (fig. 9, table 6).

6. Nitrate nitrogen: Calibration was achieved for the upper half of the study reach; five of the eight sample sites (fig. 10, table 6) met the criteria. Simulated concentrations did not fall within the range of observed concentrations between river mile 26.6 and 12.0 (fig. 10).

7. Orthophosphate phosphorus: Calibration was not considered to be achieved for the study reach since observed data showed an unexplained increase in concentration for the observed data for the upper half of the reach (fig. 11). An unknown quantity of orthophosphate phorphorus appears to have entered the study reach below Flint Creek (fig. 3) prior to collecting the December 12, 1978, data (table 3).

8. Total coliform bacteria: Calibration was achieved for the study reach although only seven of the eight sample sites (fig. 12, table 6) met the criteria. However, since the computed value for the site that did not meet the criteria fell within the 90 percent confidence interval, the model is assumed to be fully calibrated for total coliform bacteria.

9. Fecal coliform bacteria: Calibration was achieved for the study reach although only three of the eight sample sites (fig. 13, table 6) met the criteria. However, since the computed values for the sites that did not meet the criteria fell within the 90 percent confidence interval, the model is assumed to be fully calibrated for fecal coliform bacteria.

Results of the calibration study indicate that models have been calibrated for ultimate carbonaceous biochemical oxygen demand (UCBOD) and dissolved oxygen (DO) in a qualitative way (similar trends in the computed values as those of the observed data). The model was not calibrated for UCBOD and DO because to calibrate the DO would have required that the UCBOD deoxygenation rate be greater than the UCBOD decay rate, which would cause the coefficients to be unreasonable. This condition can only be explained by the existence, at the time of sampling, of an additional source of UCBOD that was not measured. Models of ammonia nitrogen and nitrite nitrogen could not be evaluated because concentrations were near zero or approximated the precision of the analysis. The model for nitrate nitrogen was only successful for the upper study reach. The model for orthophosphate phosphorus was not considered to be calibrated since observed data showed an unexplained increase in concentration for the observed data for the upper half of the reach. Calibration of the model for total and fecal coliform bacteria was achieved.

MODEL VERIFICATION

Sample data collected on April 12-13, 1978, at sites 6, 10, 11, 12, 15, 17, 18, 19, 20, 21, and 23 (fig. 3) were used to verify models of the various constituents successfully calibrated and reported in the preceding section. Site 6 was used for background conditions and the succeeding 10 sites for verification. Plots of simulated and observed constituent concentrations are also shown in figures 5 through 13. The range in observed and simulated concentrations for nonconservative constituents are listed in table 8. The mean and absolute errors in simulated concentrations for the various constituents modeled are presented in table 9. Verification of each constituent modeled, with respect to calibration criteria discussed in the preceding section, is as follows:

1. Organic dissolved nitrogen: Only four of the sample sites (fig. 7, table 8) met both criteria. For sites that did not meet the criteria, simulated concentrations were consistently lower than two standard deviations about the mean (table 8) by no more than 0.09 mg/L. The model can be considered verified with a median error of 36 percent and an absolute error of 0.14 mg/L for the reach (table 9).

2. Nitrate nitrogen: Only 4 of the 10 sample sites (fig. 10, table 8) met the criteria. For sites that did not meet the criteria, simulated concentrations exceeded the two standard deviations about the mean by 0.02 to 0.22 mg/L. Although the median error for the reach is 127 percent, it only represents an absolute error of 0.8 mg/L for the reach. The model could be considered verified within the limits of the median and the absolute errors (table 9).

Table 8.--Simulated and observed concentrations of nonconservative constituents for verification period, April 12-13, 1978, Hillsborough River

[Upper set of figures shows range in observed concentrations; simulated concentrations are shown in parenthesis. Concentrations are in milligrams per liter, except for coliforms, which are in colonies per 100 milliliters]

Site no.	Nitrogen, dissolved organic as N	Nitrate, dissolved as N	Coliform	
			Total	Fecal
6	0.09-0.20 (0.12)	1.5-1.6 (1.5)	700-1,700 (1,200)	15-110 (58)
10	0.18-0.28 (0.14)[1]	1.2-1.4 (1.2)	500-1,200 (1,000)	15-170 (46)
11	0.18-0.42 (0.14)[2]	1.2 (1.1)[1]	400-1,600 (910)	10-64 (40)
12	0.18-0.32 (0.15)[1]	0.99-1.1 (0.94)[2]	700-1,100 (810)	2-22 (36)[1]
15	0.23-0.47 (0.15)[2]	0.30-0.31 (0.54)	540-2,000 (750)	18-40 (27)
17	0.32-0.41 (0.26)[1]	0.24-0.25 (0.27)[1]	220-700 (710)[1]	12-40 (24)
18	0.37-0.45 (0.26)[1]	0.19 (0.21)[1]	230-1,400 (690)	12-64 (23)
19	0.42-0.58 (0.27)[1]	0.07-0.13 (0.16)[1]	150-380 (670)[1]	16-40 (22)
20	0.47-0.54 (0.35)[1]	0.03-0.11 (0.12)[2]	170-280 (620)[1]	10-30 (21)
21	0.53-1.1 (0.38)[2]	0.01-0.06 (0.11)[1]	59-380 (600)[1]	8-12 (21)
23	0.54-0.96 (0.41)[2]	0.08-0.11 (0.09)	160-1,800 (560)	8-200 (20)

1/ Simulated value falls outside range of observed data.

2/ Simulated value, although outside the range of observed data, is within two standard deviations (2S) about the mean; therefore, site is considered calibrated (p. 21).

3. Total coliform bacteria: Six of the 10 sample sites (fig. 12, table 8) met the criteria. For sites that did not meet the criteria, simulated concentrations exceeded the range in observed concentrations by 10 to 340 col/100 mL. The model can be considered verified with a median error of 100 percent and an absolute error of 260 col/100 mL for the reach (table 9).

4. Fecal coliform bacteria: Nine of the 10 sample sites (fig. 13, table 8) met the criteria. For the site that did not meet the criteria, simulated concentrations exceeded range in observed concentrations by 14 col/100 mL. Although the median error is 64 percent, it represents an absolute error of 10 col/100 mL for the reach.

Results of the model verification study discussed above indicate that models have been verified within the stated limits for organic nitrogen, nitrate nitrogen, and fecal and total coliform bacteria.

Table 9.--Median, mean, and absolute errors in simulated nonconservative constituent concentrations for verification period, April 12-13, 1978, Hillsborough River

[Concentrations are in milligrams per liter, except for coliforms, which are in colonies per 100 milliliters. Median and mean errors are in percent and absolute error is in units of individual constituents]

Site no.	Nitrogen, dissolved organic as N		Nitrate, dissolved as N		Total coliforms		Fecal coliforms	
	Median	Absolute	Median	Absolute	Mean[1/]	Absolute	Mean[1/]	Absolute
10	39	0.09	7.7	0.1	3.1	30	16	9
11	39	.09	8.3	.1	4.6	40	110	21
12	29	.06	12	.12	19	190	300	27
15	56	.19	74	.24	18	160	12	3
17	26	.09	12	.03	73	300	9	2
18	37	.15	11	.02	35	180	4	1
19	37	.16	45	.05	270	490	4	1
20	35	.19	100	.06	260	450	24	4
21	36	.21	1,000	.10	280	440	110	11
23	30	.18	0	0	34	290	53	23
Average for reach	36	.14	127	.08	100	260	64	10

1/ Mean-log transform.

FUTURE CONDITIONS EVALUATION

The model was used to simulate water quality that results from storm-sewer loadings during base flow under varying sizes of residential development. Because verification criteria were not fully met for the calibrated constituents, simulation results can only be used in predicting chemical and microbiological water-quality trends or changes associated with development rather than predicting actual constituent concentrations. Predicted concentrations are subject to limitations of the model itself and errors associated with input data (water quality of urban runoff base flow).

The following development conditions were selected for simulation:

1. Housing developments, 100-percent storm sewered, with no open-surface channels.
2. The developments assume sizes of 1, 3, and 5 mi^2.
3. Developments were located at the upstream end and near the middle of the study reach.
4. Discharge from the storm-sewer systems would not vary with time (base flow).

Locations of development sites are shown in figure 14.

Site A is in the lower Cypress Creek basin, and site B is near the Hillsborough River State Park (fig. 14). Runoff from development at site A enters the Hillsborough River through Cypress and Trout Creeks. Discharge from Cypress and Trout Creeks enters the Hillsborough River as nonpoint sources in subreaches 4 and 5 (fig. 14). For purposes of simulation, treatment within the system of the storm-sewer base flow is assumed not to occur (a worse case situation). Discharge and waste loads from development at site B enter the Hillsborough River as a point source in subreach 1 (fig. 14).

Urban Area Runoff and Constituent Loads

Base-flow discharges and chemical and biological constituent loads and concentrations used for developments at sites A and B are based on water-quality and discharge data for small urban watersheds in the Tampa Bay area (Lopez and Michaelis, 1978). Chemical, biological, and runoff data for developments at sites A and B (fig. 14) were estimated from data collected during base-flow periods (1975-80) on nine urbanized basins in the Tampa Bay area. Discharges from these basins, under base-flow conditions, included base flow and drainage from lawn irrigation, car washings, and so forth. Discharges from developments at sites A and B were estimated from a regression that involved drainage areas, as follows:

$$y = 0.37 + 0.44x \tag{4}$$

where y = discharge, in cubic feet per second; and
x = drainage area, in square miles.

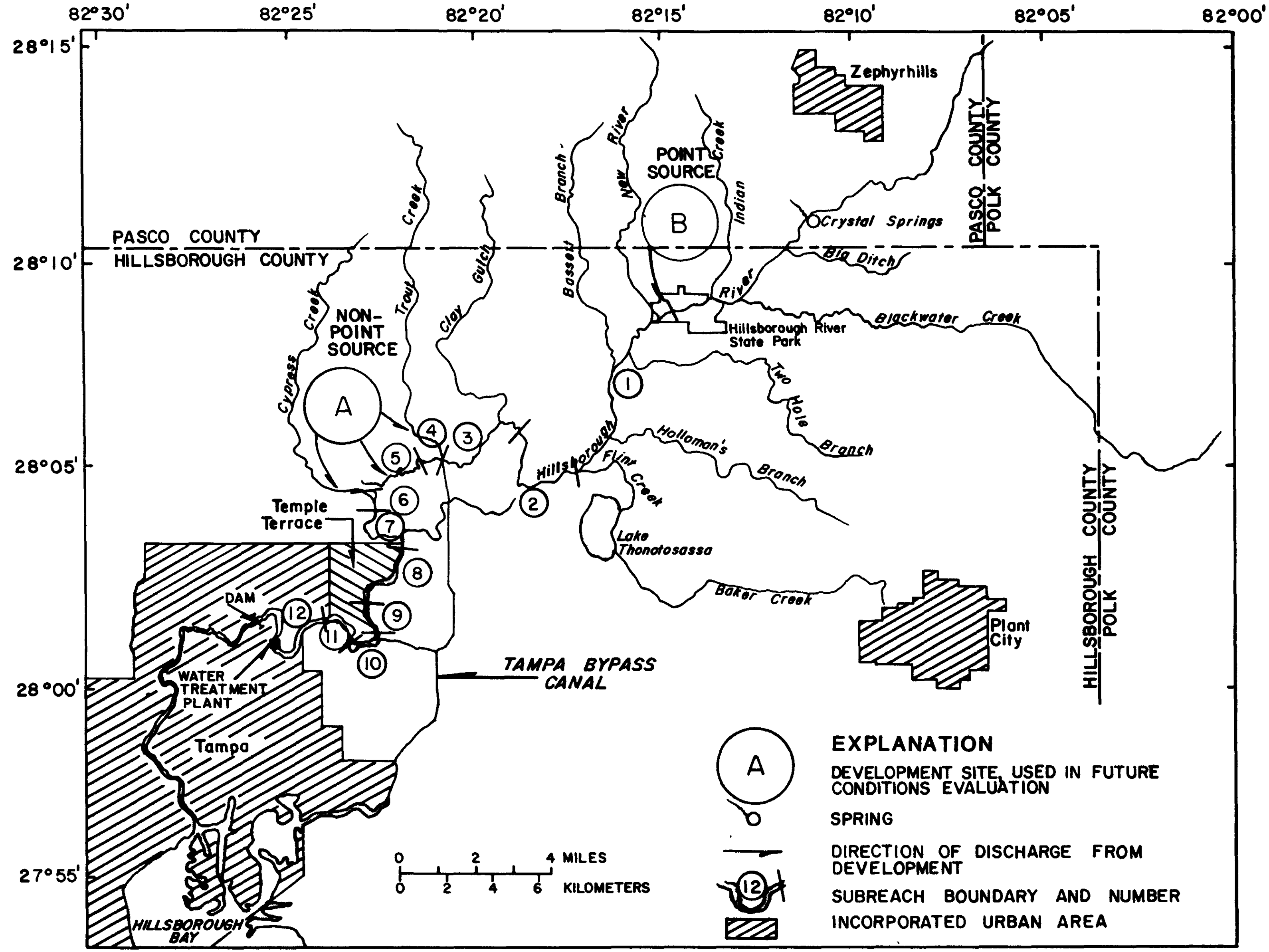

Figure 14.--Location of developments used to simulate water-quality changes, Hillsborough River.

This relation is based on drainage areas that range in size from about 0.5 to 3.5 mi^2 and discharges that range from 0.7 to 1.8 $(ft^3/s)/mi^2$. The relation has a correlation coefficient of 0.93 and a standard error of estimate of 0.27 ft^3/s. Although it is not a sound statistical practice to extrapolate the regression curve beyond the maximum value used (3.5 mi^2), for the purpose of this study, it has been extrapolated to 5 mi^2. Discharges estimated from equation 4 for various size developments at sites A and B (fig. 14) are listed in table 10.

The chemical and biological data used as waste loads from developments at sites A and B (fig. 15) are listed in table 10. Average concentrations shown for various chemical and biological constituents are averages of data collected in the nine urbanized basins during various base-flow periods. Daily constituent loads listed in table 10 were determined from average concentrations and discharges listed. For example, the daily load for ultimate carbonaceous biochemical oxygen demand from a 5-mi^2 development is shown in table 10 as 85 lb/d. This load was computed by multiplying the average concentration by discharge by conversion factor, as follows:

$$(6.1 \text{ mg/L})(2.57 \text{ ft}^3/\text{s})(5.4) = 85 \text{ lb/d}.$$

Table 10.--Discharge and water-quality data for storm sewers of the Tampa Bay area during base-flow periods, Hillsborough River basin

[ft^3/s, cubic foot per second; lb/d, pound per day; mi^2, square mile; mg/L, milligram per liter; col/100 mL, colonies per 100 milliliters]

Parameter	Average concentration	Discharge in ft^3/s and load in lb/d		
		1-mi^2 drainage-area basin	3-mi^2 drainage-area basin	5-mi^2 drainage-area basin
Discharge	--	0.81	1.69	2.57
Ultimate carbonaceous biochemical oxygen demand	6.1 mg/L	27	56	85
Dissolved oxygen	0 mg/L	0	0	0
Total coliforms	420,000 col/100 mL	1/8,400	1/17,000	1/27,000
Fecal coliforms	58,000 col/100 mL	1/1,200	1/2,400	1/3,700

1/In billions of coliforms per day.

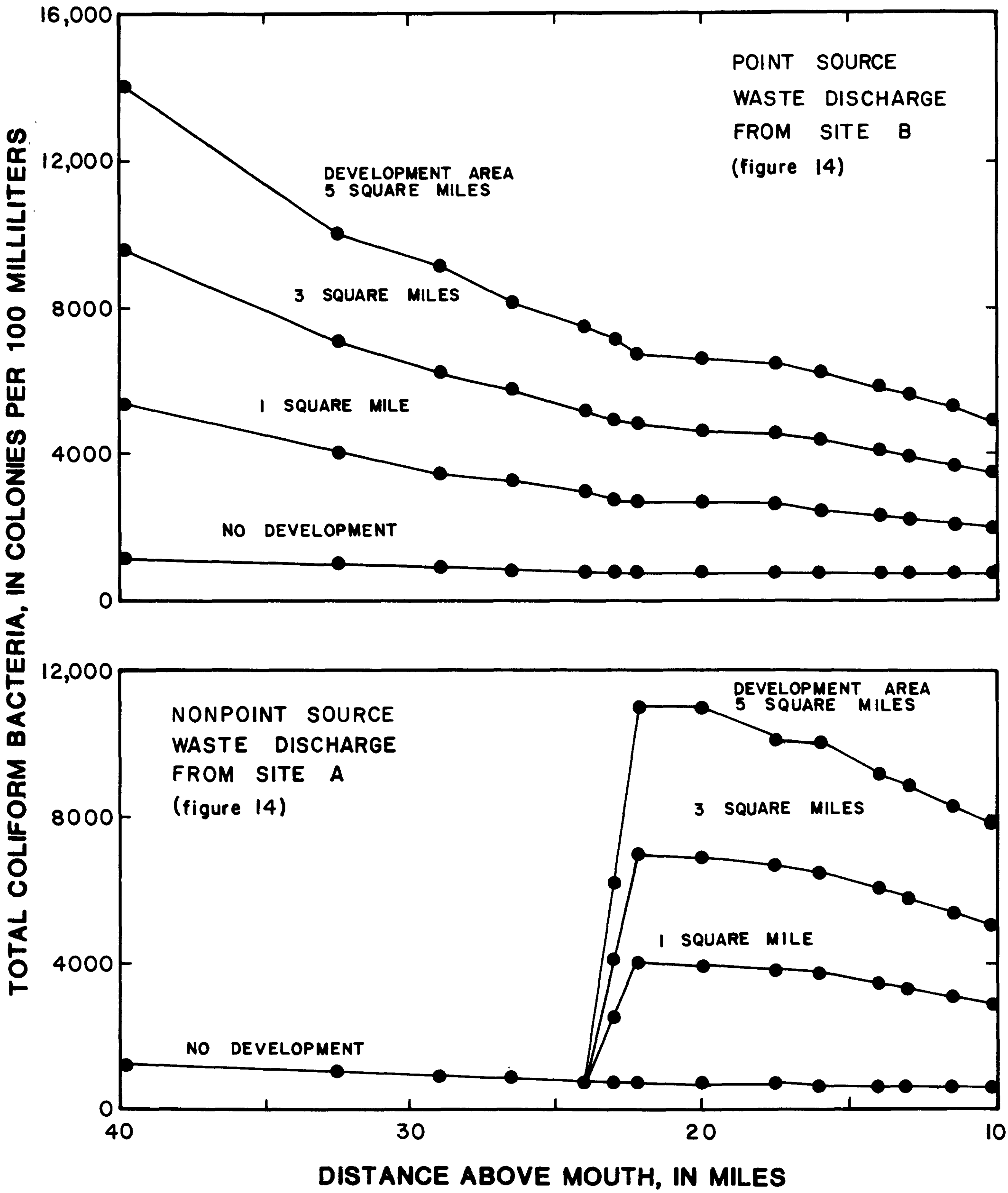

Figure 15.--Profiles of total coliform bacteria concentrations resulting from various levels of development at sites A and B, Hillsborough River.

For development at site B (fig. 14), the chemical and biological constituent loads given in table 10 were converted to concentrations for point-source waste-load input to the study reach. Waste loads from development A, however, were combined with flow of Cypress Creek for nonpoint-source input to the study reach. A modified set of equations by Kittrell (1969) was used to compute total loads in Cypress Creek, following waste-load input from development at site A (fig. 14), and to convert the combined load to concentration. Concentrations for biological constituents were determined in the same manner. The equations used in determining combined waste loads and concentrations (chemical and biological constituents) for development at site A are discussed below.

Chemical constituent loads from development at site A were combined with Cypress Creek loads by use of the following equation:

$$C_x = 5.4(C_s \cdot Q_s + C_d \cdot Q_d) \qquad (5)$$

where C_x = combined load, in pounds per day;

C_s = concentration of chemical constituent in Cypress Creek, in milligrams per liter;

Q_s = Cypress Creek discharge, in cubic feet per second;

C_d = concentration of chemical constituent in discharge from development at site A, in milligrams per liter;

Q_d = discharge from development located at site A, in cubic feet per second;

5.4 = conversion constant.

Concentrations of combined loads were estimated by use of the following equation:

$$C_y = \frac{C_t}{(Q_t)5.4} \qquad (6)$$

where C_y = concentration of constituents, in milligrams per liter;

C_t = combined load in Cypress Creek, in pounds per day from constituent discharged;

Q_t = combined discharge of Cypress Creek and discharge from site A, in cubic feet per second.

Combined bacteriological constituent loads were estimated as follows:

$$B_x = (B_s \cdot Q_s \cdot 24.6\text{x}10^6) + (B_d \cdot Q_d \cdot 24.6\text{x}10^6) \qquad (7)$$

where B_x = combined number of bacteria per day, in colonies per 100 milliliters;

B_s = bacteria, total or fecal coliform in Cypress Creek, in colonies per 100 milliliters;

B_d = bacteria, total or fecal coliform, in discharge from development at site A, in colonies per 100 milliliters;

$24.6\text{x}10^6$ = conversion constant.

Concentration of combined bacterial loads was estimated as follows:

$$B_y = \frac{B_t}{(Q_t)24.6x10^6} \qquad (8)$$

where B_y = bacterial concentration, in colonies per 100 milliliters;

B_t = total number of bacteria per day, in colonies per 100 milliliters;

Q_s = Cypress Creek discharge, in cubic feet per second;

Q_t = combined discharge of Cypress Creek and discharge from site A, in cubic feet per second.

Impact of Development on Water Quality of Tampa Reservoir

Results of model simulation that show the impact of the development at site A (fig. 14) are presented in table 11. An evaluation of chemical and biological constituent concentrations listed for two points in Tampa Reservoir, Fowler Avenue (fig. 14), and the water-treatment plant, is as follows:

1. Dissolved organic nitrogen--Increases in dissolved organic nitrogen are negligible and range from 0.01 to 0.03 mg/L above background conditions. Significant changes in dissolved organic nitrogen are not expected from development conditions tested.
2. Dissolved nitrate nitrogen--There was no change above background conditions in dissolved nitrate nitrogen. Changes in dissolved nitrate nitrogen are not expected from development conditions.
3. Coliform bacteria--Concentrations increase as the size of development increases. Increases in total coliform bacteria above background conditions are significant and range from about 2,400 to 10,000 col/100 mL. Increases in fecal coliform bacteria are also significant and range from about 340 to 1,400 col/100 mL.

Results of model simulations that show the impact of development located at site B (fig. 14) are presented in table 12. Changes in chemical and biological constituents for the reservoir reach from Fowler Avenue to the water-treatment plant are as follows:

1. Dissolved organic nitrogen--Increases in dissolved organic nitrogen are negligible and range from 0.02 to 0.03 mg/L above background conditions. Significant changes in dissolved organic nitrogen are not expected from development conditions tested.
2. Dissolved nitrate nitrogen--There was no change above background conditions in dissolved nitrate nitrogen (0.01 mg/L). Changes in dissolved nitrate nitrogen are not expected from development conditions.
3. Coliform bacteria--Concentrations increase as the size of development increases. Increases in total coliform bacteria above background conditions are significant and range from about 1,900 to 5,900 col/100 mL. Increases in fecal coliform bacteria are also significant and range from about 160 to 640 col/100 mL.

Table 11.--Simulated water-quality data for selected sites resulting from nonpoint discharge from various sized developments at site A, Hillsborough River

[mi^2, square mile; mg/L, milligram per liter; col/100 mL, colonies per 100 milliliters]

Site location and distance, in miles, above mouth	Development size (mi^2)	Nitrogen, dissolved organic as N (mg/L)	Nitrate, dissolved as N (mg/L)	Total coliforms (col/100 mL)	Fecal coliforms (col/100 mL)
Cypress Creek confluence, river mile 22.9	0	0.21	0.40	740	25
	1	.21	.40	2,500	260
	3	.22	.40	4,100	500
	5	.22	.40	6,100	750
Fowler Avenue, river mile 20.0	0	.26	.27	710	24
	1	.27	.27	3,900	460
	3	.28	.27	7,000	900
	5	.29	.27	11,000	1,400
Tampa water-treatment plant, river mile 11.3	0	.41	.09	560	20
	1	.42	.09	3,000	360
	3	.43	.09	5,400	700
	5	.43	.09	8,300	1,100

Effects of Development Location

Data listed in tables 11 and 12 indicate that coliform bacteria are the only constituents (simulated) that will significantly change as a result of development. Profiles of total coliform bacteria and fecal coliform bacteria for various levels of development at sites A and B are presented in figures 15 and 16, respectively. The profiles of total coliform bacteria for development at site A (fig. 15) increase dramatically between river miles 25.5 and 20.0 because waste loads enter this part of the study reach as a nonpoint source; the profiles then gradually decrease as coliform bacteria die off. Profiles of total coliform bacteria for development at site A decline immediately because discharge from the development enters the upper end of the study reach at one point. Total coliform bacteria counts at the water-treatment plant are lower with development at site B than at site A because site A is much closer than site B to the water-treatment plant. Profiles of fecal coliform bacteria in figure 16 indicate similar trends, but fecal coliform bacteria counts are much lower than for total coliform bacteria.

Table 12.--Simulated water-quality data for selected sites resulting from point discharge from various sized developments at Site B, Hillsborough River

[mi^2, square mile; mg/L, milligram per liter; col/100 mL, colonies per 100 milliliters]

Site location and distance, in miles, above mouth	Development size (mi^2)	Nitrogen, dissolved organic as N (mg/L)	Nitrate, dissolved as N (mg/L)	Total coliforms (col/100 mL)	Fecal coliforms (col/100 mL)
Hillsborough River State Park, river mile 40.0	0	0.12	1.5	1,200	58
	1	.13	1.5	5,200	620
	3	.14	1.5	9,600	1,200
	5	.15	1.5	14,000	1,800
Trout Creek, river mile 25.5	0	.15	.86	780	35
	1	.16	.86	3,000	340
	3	.17	.86	5,400	680
	5	.18	.85	7,000	1,000
Cypress Creek confluence, river mile 22.9	0	.21	.40	740	25
	1	.22	.41	2,700	240
	3	.23	.41	4,900	480
	5	.24	.41	7,100	710
Fowler Avenue, river mile 20.0	0	.26	.27	710	24
	1	.27	.27	2,600	220
	3	.28	.27	4,600	440
	5	.29	.27	6,600	660
Tampa water-treatment plant, river mile 11.3	0	.41	.09	560	20
	1	.42	.09	2,000	180
	3	.43	.09	3,600	350
	5	.43	.09	5,100	510

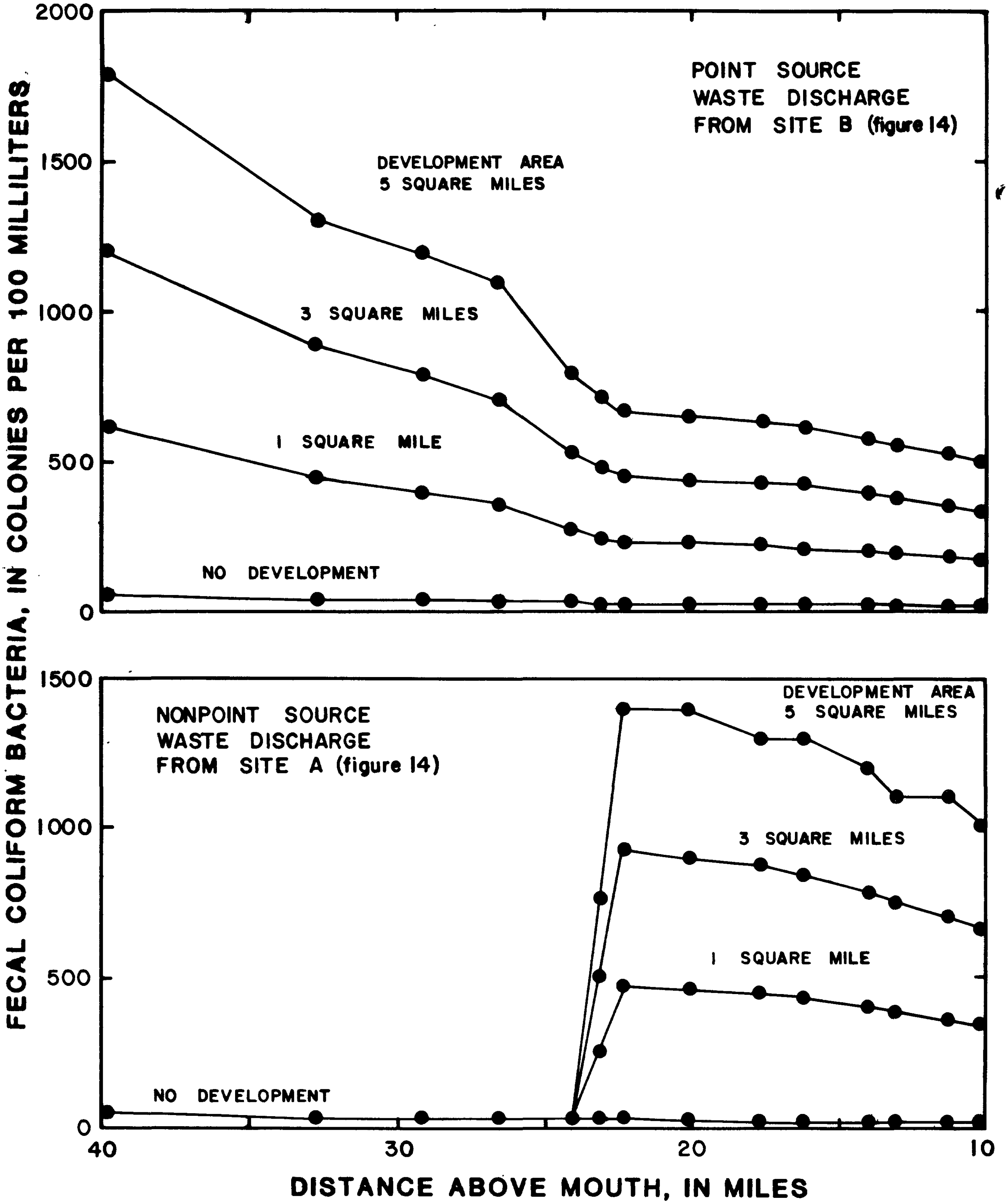

Figure 16.--Profiles of fecal coliform bacteria concentrations resulting from various levels of development at sites A and B, Hillsborough River.

SUMMARY AND CONCLUSIONS

The Tampa Reservoir, located on the Hillsborough River, impounds drainage from an area of about 650 mi^2. Although the upper basin is predominantly rural, the lower basin is largely urban and industrial.

Water-quality data collected above the dam in April and December 1978 were used to calibrate and verify a water-quality model for a 30.0-mile reach of the river above the dam. Calibration criteria included: (1) simulated data fall within two standard deviations about the mean of observed data at each sample site, and (2) differences between simulated data and the median of observed data could be decreased no further.

Water-quality data for December 1978 were used to calibrate the model for organic nitrogen, nitrate nitrogen, and total coliform bacteria. Calibration for fecal coliform bacteria was only partially successful for the study reach. Water-quality data for April 1978 were used to verify the model; dissolved organic nitrogen, dissolved nitrate nitrogen, and fecal and total coliform bacteria met criteria set for verification data; other parameters did not fully satisfy the established criteria for the entire study reach.

The model was used to estimate selected water-quality conditions in the study reach that result from base-flow discharges from two variable-sized residential developments. Each of the developments was conceptualized to represent a community that was 100-percent storm sewered. One development was arbitrarily located near the midreach of the river and the other development was located at the upper end of the 30-mile study reach. During model simulation, the relative sizes of the two arbitrary developments were assigned variable areas of 1, 3, and 5 mi^2, respectively. The sizes were varied to estimate a range of impacts on the study reach that result from different quantities of residential base flow. Base-flow characteristics for the two developments in the study reach were approximated using water-quality and discharge data for small-urban watersheds in the Tampa Bay area (Lopez and Michaelis, 1978).

Results of the study indicated that total and fecal coliform bacteria may significantly exceed background conditions for development configurations tested. Further, high coliform bacteria levels occur for some distance in the study reach because of low die-off rates. For example, concentrations of total and fecal coliform bacteria in the Tampa Reservoir from a 5-mi^2 development having a nonpoint-source waste input between Trout and Cypress Creeks (site A, fig. 14) exceed background levels from about 2,400 to 10,000 and 340 to 1,400 col/100 mL, respectively. Concentrations that result from point-source waste input by development at the upper end of the study reach (site B, fig. 14) exceed background levels from about 1,900 to 5,900 and 160 to 640 col/100 mL, respectively.

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