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Field and Modelling Studies of Water Quality in the Nansemond River

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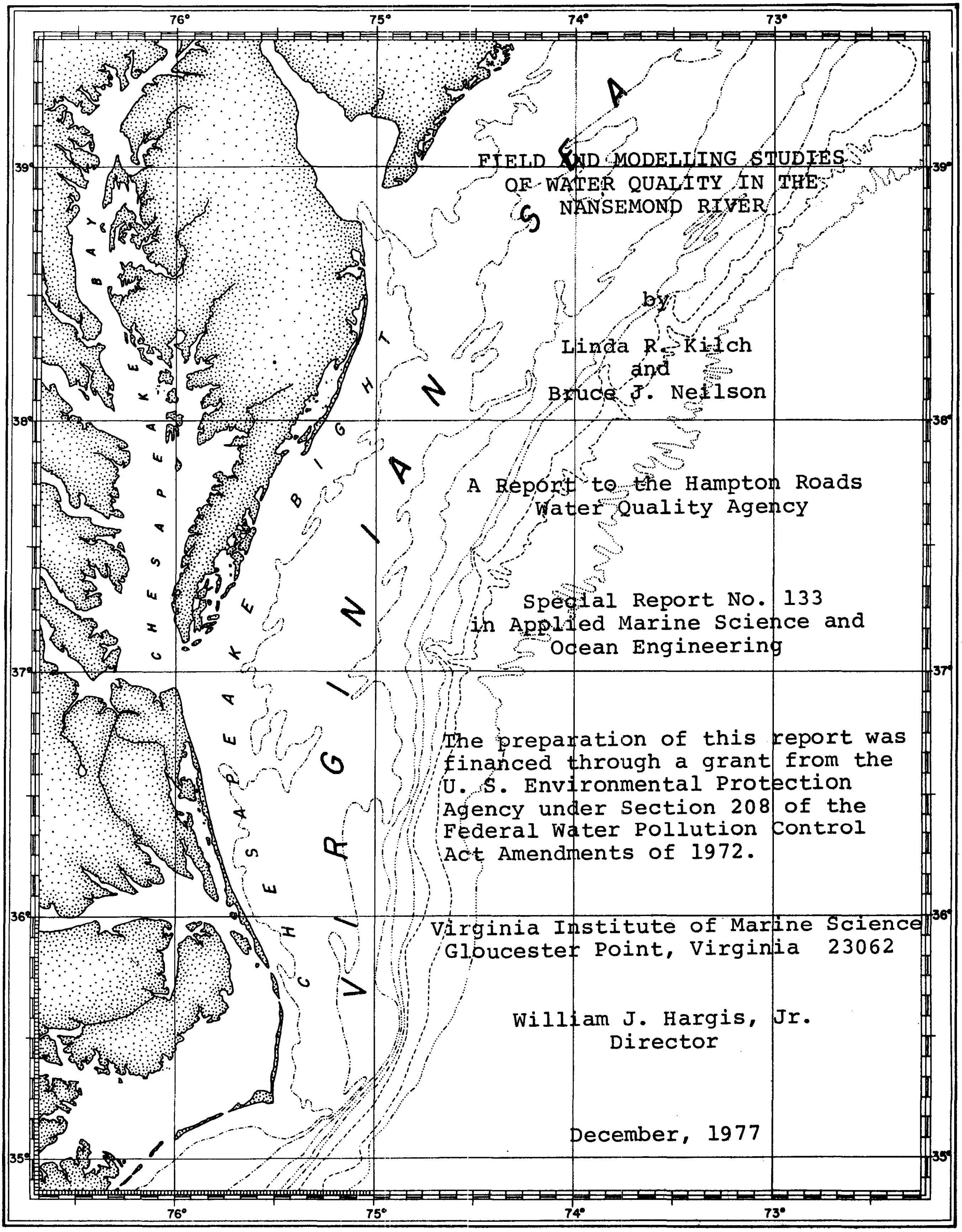

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by

Linda R. Kilch
and
Bruce J. Neilson

A Report to the Hampton Roads Water Quality Agency

Special Report No. 133
in Applied Marine Science and Ocean Engineering

The preparation of this report was financed through a grant from the U. S. Environmental Protection Agency under Section 208 of the Federal Water Pollution Control Act Amendments of 1972.

Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

William J. Hargis, Jr.
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The mathematical model of water quality which was used for this study was developed for the Cooperative State Agencies Program between VIMS and the State Water Control Board. Use of this model greatly facilitated the 208 Study and we would like to express our appreciation for this contribution. Special thanks are given to Drs. Albert Kuo and Paul Hyer who provided guidance and assistance in the use of the model.

I. DESCRIPTION OF THE STUDY AREA

The Nansemond River is a small tributary of the James, entering Hampton Roads along the southern shore approximately 15 kilometers upriver from Fort Wool (see Figure 1). The drainage basin lies primarily in the city of Suffolk (formerly the city of Suffolk and Nansemond County) but also includes portions of Chesapeake, Portsmouth and Isle of Wight County. The total drainage area is around 50,000 hectares (200 square miles), but nearly two-thirds of this area is upstream of water supply reservoirs operated by the cities of Norfolk and Portsmouth. Consequently, freshwater runoff to the river is greatly reduced. The predominant land uses are forest (38%), cropland (24%) pastures (7%) and marshes (22%). The remainder of the area is in residential, industrial and commercial uses. Much of the developed area is in or near the old city of Suffolk although some development has occurred and more is projected for the area near Pig Point. Suffolk is known as the "Peanut Capital"; meat and vegetable production and processing also are major activities. Lumber and wood products, ceramics, seafood and fertilizers all are produced in the area and are important to the local economy.

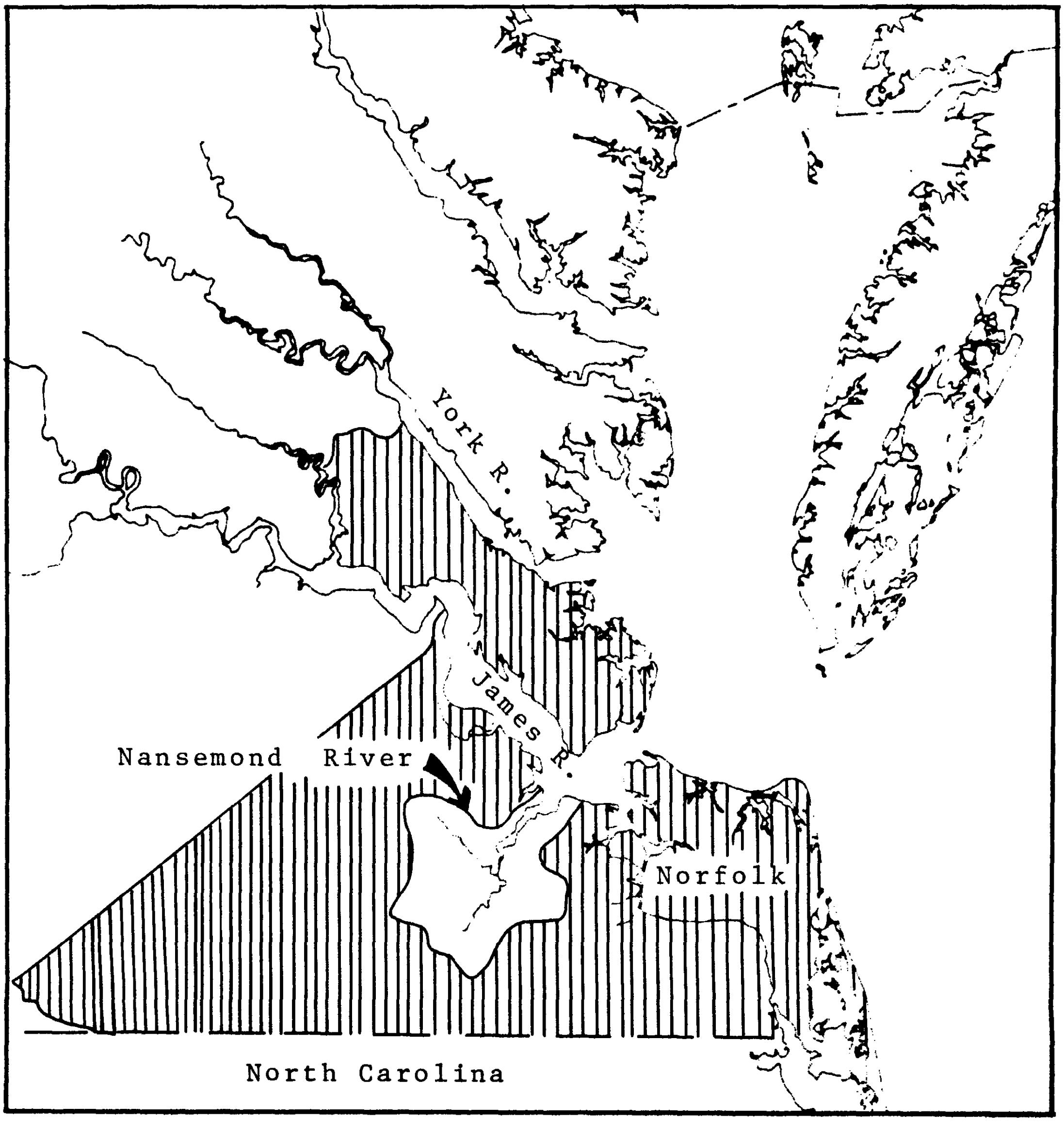

Figure 1. The 208 Study Area showing the location of the Nansemond River drainage basin.

The climate for this area is "humid, subtropical". During 1976, monthly average temperatures at Lake Kilby near Suffolk ranged from 4^{o} in January and December to 25^{o} in July. The maximum temperature measured was 35^{o} (95^{o} F) on July 30 and the minimum temperature was -11^{o} (12^{o} F) on January 19. Two hundred and twenty four days elapsed between the last day in spring with a minimum temperature of 0^{o} (32^{o} F) and the first time that occurred in the fall. Rainfall during 1976 was lower than average; only 1 cm (0.38") of rain was recorded during the month of April and the yearly total was 89.5 cm (35.24"). The rainfall at Driver was slightly greater, 95.8 cm (37.73"), but was 19 cm (7.51") below the average annual rainfall recorded there over the last 34 years. The April rainfall at Driver was only 0.66 cm (0.26") while January, July, September, October and December each had rainfalls greater than 10 cm (4"). On the average, the rainfall is evenly distributed over the year, but significant short term deviations from this mean can occur. Total evaporation was measured at Holland, which is within Suffolk but outside the Nansemond drainage area, and averaged 18.4 cm (7.25") per month during May, June, July and August.

The Nansemond River has a geometry typical of many estuaries: the channel is narrow (less than 100 meters) in the upper reaches, widens in an exponential fashion in the seaward direction and is very broad (4,000 meters) at the mouth. A navigation channel 12 feet deep and 100 feet wide has been maintained in the Nansemond since the early 1930's. Near Suffolk the river course is sinuous and bordered by extensive tidal marshes. Freshwater flow to the river is not great because the drainage area is small and the water supply reservoirs impound much of the runoff. Consequently, brackish waters often reach all the way to the old city of Suffolk and there is little stratification in the water column. During winter and spring the freshwater runoff usually increases, resulting in some salinity stratification and a downriver migration of the brackish water.

The rapid narrowing of the river channel from the mouth towards the headwaters results in a reflection of the tidal wave and an increase in the mean tidal range. The range near the mouth is only 0.85 m (2.8 ft) but increases to 1.16 m (3.8 ft) at the head. There also is a phase lag of about one hour between the river mouth and the head. Tidal currents are reasonably uniform throughout the estuary and have maximum values of about 0.5 m/sec (1 knot).

II. DATA REVIEW

A considerable amount of data is available about the Nansemond River, especially with regards to water quality in the estuary. In order to provide a historical perspective, the available data will be reviewed in chronological order, although the studies/reports vary greatly in aspects covered and depth of analysis.

Perhaps the best source of data about water characteristics in the Nansemond is a study done by Brehmer, Haltiwanger and Simonds for the Federal Water Pollution Control Administration.

For one year, from July 1966 through June 1967, samples were taken at ten stations on a monthly basis. Physical, chemical and biological features studied were: depth, temperature, salinity, dissolved oxygen, pH, transparency, alkalinity, suspended solids, phosphorus and nitrogen species, and chlorophyll concentrations in water. Nutrient levels (phosphorus and nitrogen) in the top 1 cm of the river sediment also were determined. Generic lists of phytoplankton found in the Nansemond River during each sampling effort also were included in the results.

The authors (Brehmer, et al., 1967) noted that: "Nutrient loadings from sewage treatment plant effluents produce overenrichment levels capable of supporting aesthetically undesirable phytoplankton populations. Organic loadings from the Suffolk area exceed the assimilation capacity of the system and subminimal dissolved oxygen levels are produced. Also, the bacterial count in the water of the upper reach exceeds the recommended levels for the direct marketing of shellfish or for water contact sports (Virginia Health Department and Water Control Board data)."

An examination of the data reveals that dissolved oxygen levels as low as 0.2 mg/l were observed, chlorophyll "a" values ranged up to 130 μg/l, nutrient levels often were high and salinity values varied greatly. In Figure 2, longitudinal profiles for depth averages of salinity and dissolved oxygen are given for the 21 July and 22 August 1966 surveys. The dramatically reduced salinities indicate that the freshwater runoff increased between the two surveys. In fact, weather records show a rainfall of only 2.66" at Lake Kilby during July, but 7.84" during August. Brehmer, et al., indicate that on August 13 and 14 there was a flow of some 122 million gallons of water over the reservoir spillways. Water temperatures for both surveys were about 28^{o}. One possible explanation for the depressed DO levels is that the freshwater inflow contained large quantities of degradable organic matter.

A comparison of data for the 7 November and 5 December surveys illustrates the effect temperature can have on dissolved oxygen levels. The salinity profiles for the two surveys are quite similar and no flow from the reservoirs was reported. Water temperatures on 7 November ranged from 10.5 to 12.2^{o} whereas by 5 December they had decreased to the range 3 to 7^{o}. DO concentrations, on the other hand, increased several milligrams per liter. As water temperatures decrease, the saturation

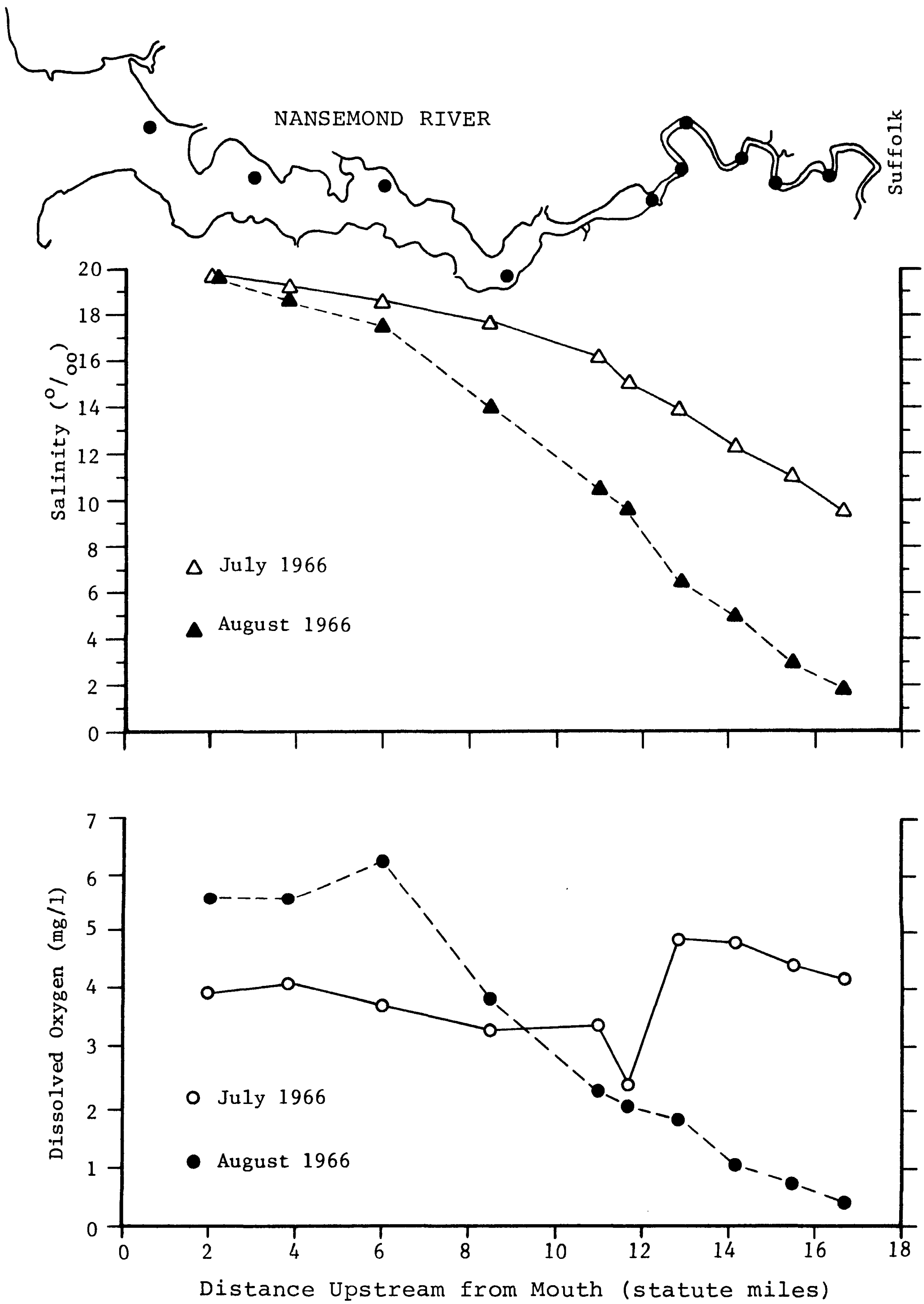

Figure 2. Salinity and dissolved oxygen profiles for 21 July and 22 August 1966.

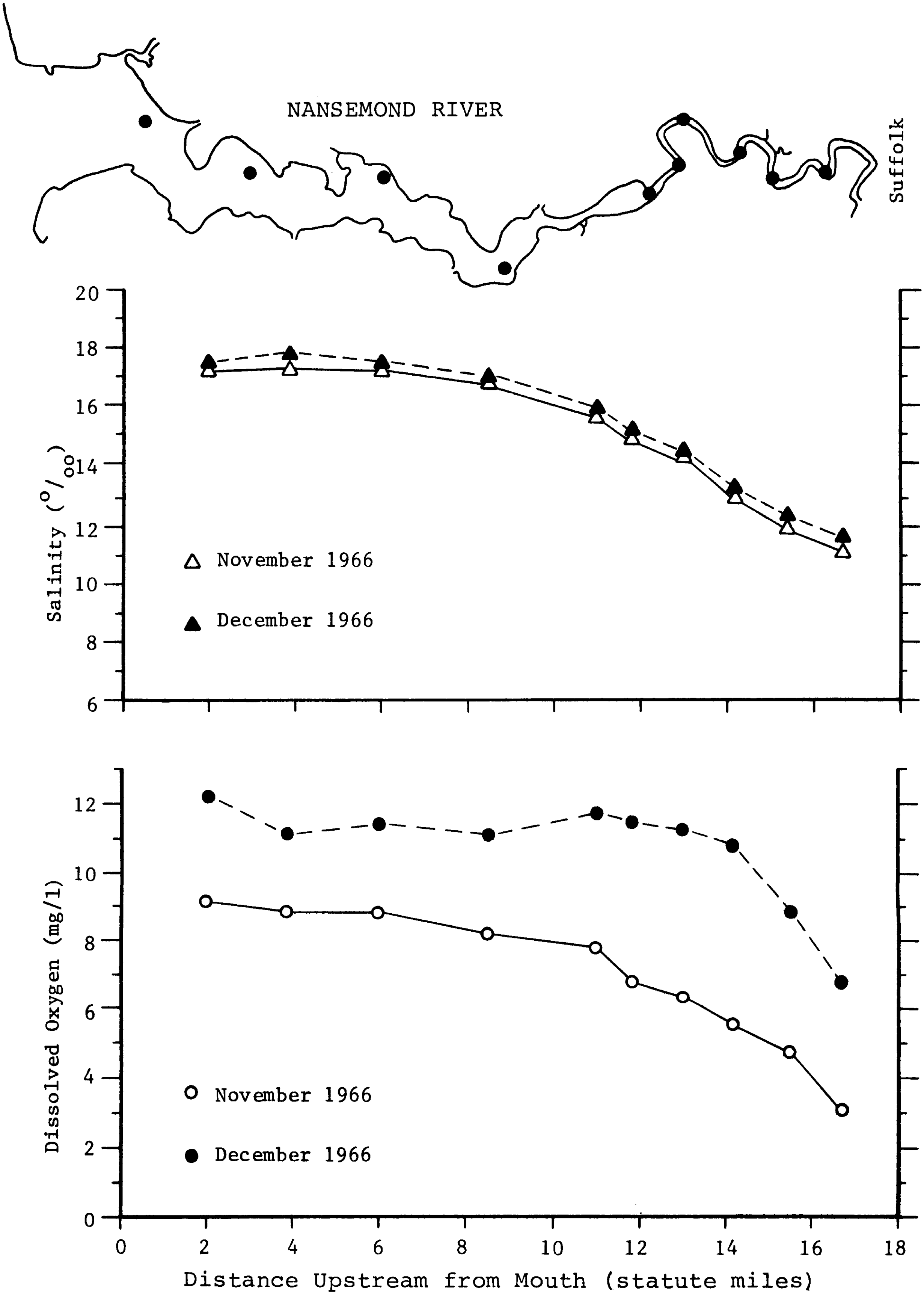

Figure 3. Salinity and dissolved oxygen profiles for 7 November and 5 December 1966.

value for oxygen in water increases and the biological rate of decay of organic matter decreases. The increased potential for reaeration and decreased consumption of dissolved oxygen results in higher DO levels.

Comparison of the 5 December 1966 and 5 January 1967 profiles shows decreased salinity values for the upper reaches. Although no discharge from the reservoirs was reported, rainfall of 3.37" was recorded at Lake Kilby during December (versus 0.61" and 0.78" during October and November). The lowered salinities suggest some runoff occurred in December. Again, dissolved oxygen levels are reduced at the same time that salinity values are low, implying that the freshwater brought BOD (biochemical oxygen demand) with it.

Data for four of their stations have been plotted to show seasonal trends. In Figure 5a, one can see a pronounced temperature cycle and further note that there is little variation from the mouth to the head of the river on any given sampling date. Dissolved oxygen concentrations also vary from season to season but in a less organized fashion (Figure 5b). Differences of up to nearly 8 milligrams per liter were observed between levels at the mouth and at the head. In general, longitudinal variations of most water quality measures were weak between stations N-2 and N-11, but were quite pronounced upriver of station N-11. Total Kjeldahl Nitrogen and Total Phosphorus values varied appreciably over the year but with no readily discernible pattern, as can be seen in Figures 5c and 5d.

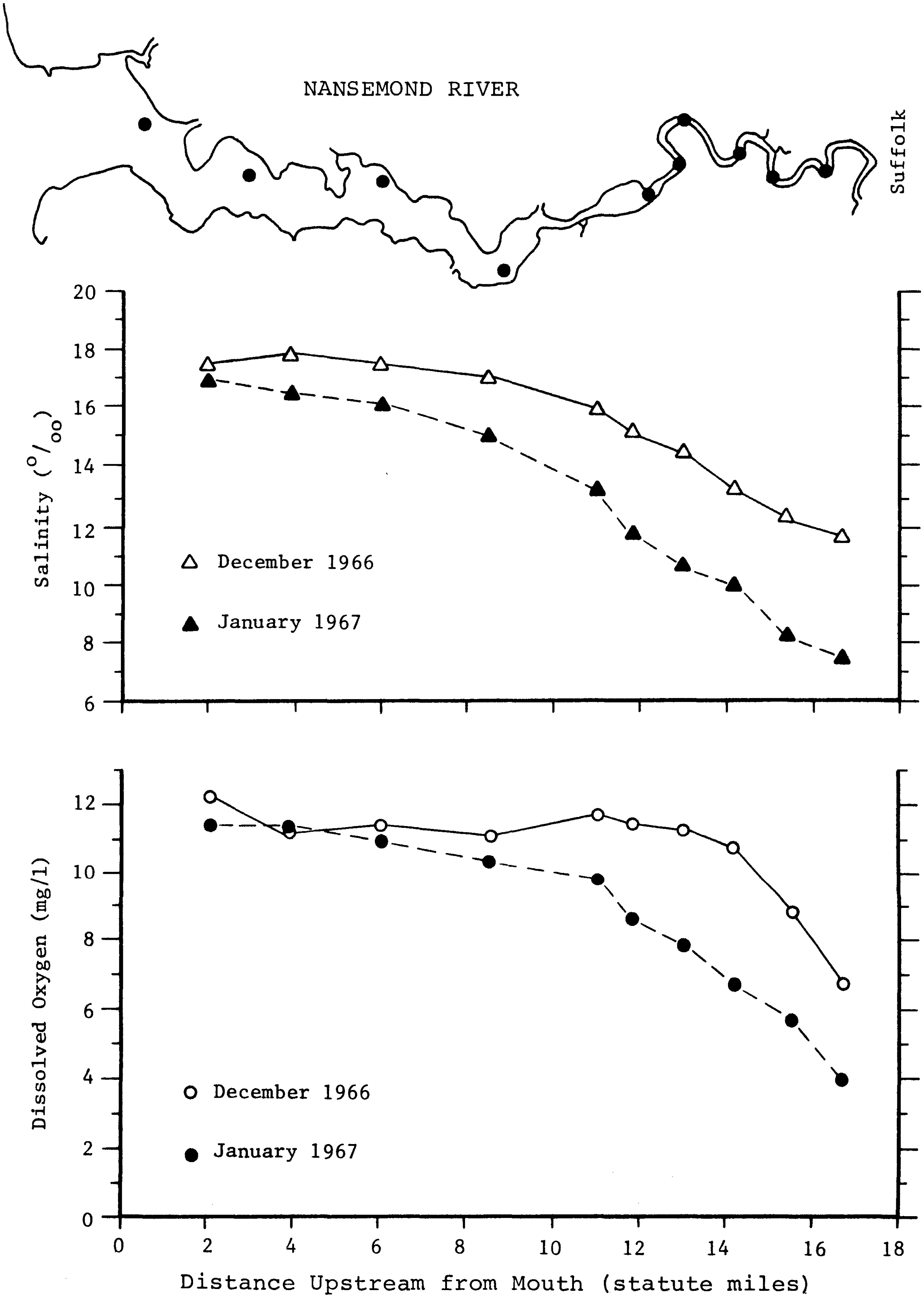

Figure 4. Salinity and dissolved oxygen profiles for 5 December 1966 and 5 January 1966.

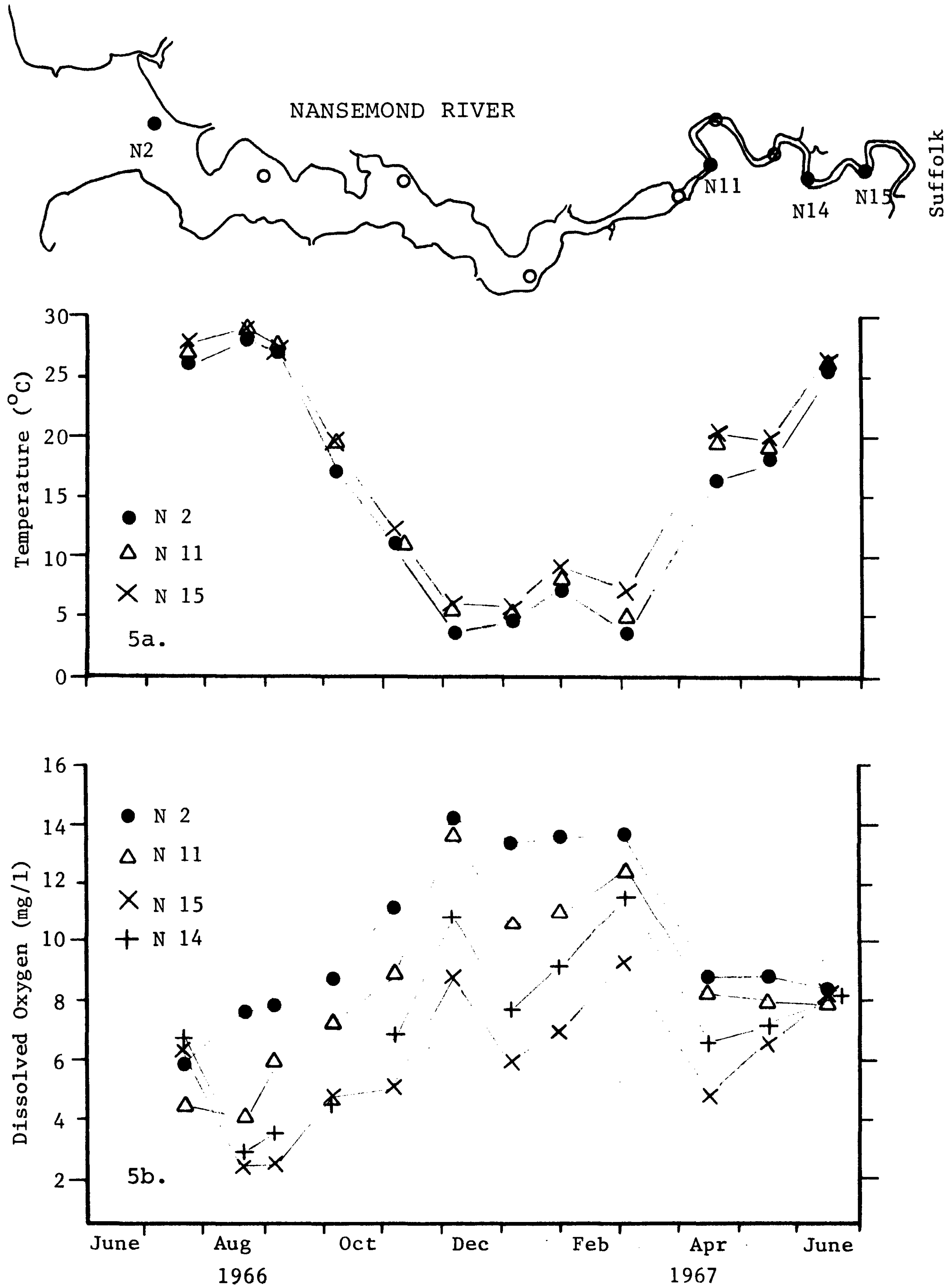

Figure 5. a) Temperature cycle and b) dissolved oxygen variation at stations in the Nansemond River from July 1966 through June 1967.

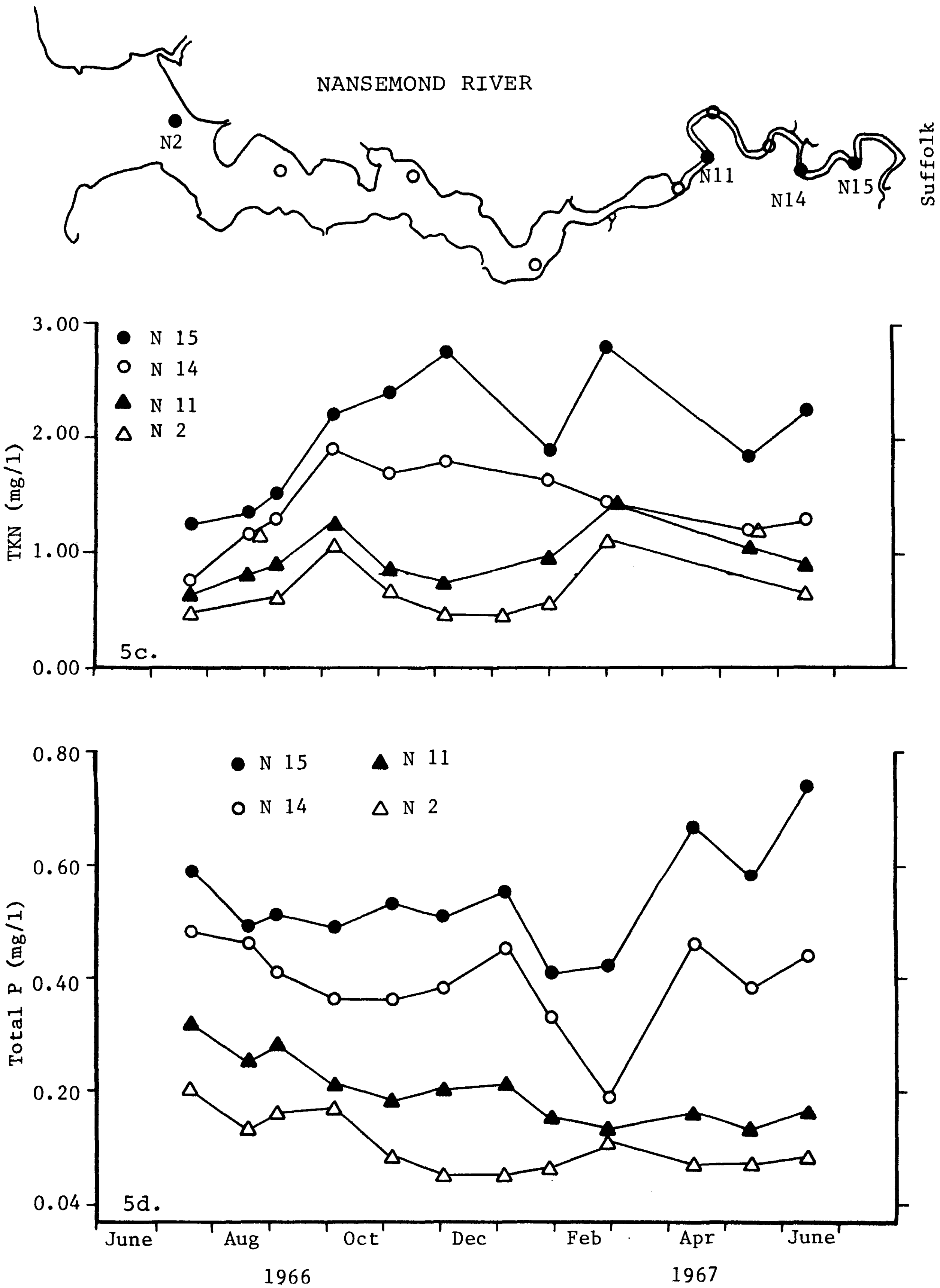

Figure 5. Variation of Total Kjeldahl Nitrogen (c) and Total Phosphorus (d) at stations in the Nansemond River from July 1966 through June 1967.

Nutrient levels, however, consistently increased from Hampton Roads toward the old city of Suffolk. Chlorophyll "a" data, Figure 5e, show considerable scatter but similar trends. The abundant phytoplankton genera (at various stations and at various times) were Cryptomonas sp., Thalassirosira sp., Ankistrodesmus sp., Gomphosphaeria sp., Cyclotella sp. and Anacystis sp. (Brehmer, et al.).

Bottom sediments were analyzed by Brehmer, et al. to determine the phosphorus and nitrogen content. Nutrient concentrations in the sediments increase when particulate organic matter settles to the bottom and is incorporated into the sediments. Also, nutrients and many other compounds as well, can be adsorbed onto clay minerals and other inert particles. When the solids settle to the bottom, the nutrients associated with the particles are carred along. Alternately, when bottom sediments are resuspended due to storms, waves, strong currents or other disturbances, the nutrients may dissociate from the particles and remain within the water column. The direction of the nutrient flow (either onto the sediment particles or from the solids to the water column) depends on the concentration of the particular nutrient in the water, water temperature and several other factors. The important point to note is that the bottom sediments of the estuary act as a reservoir, normally storing nutrients and sometimes releasing them to the overlying waters.

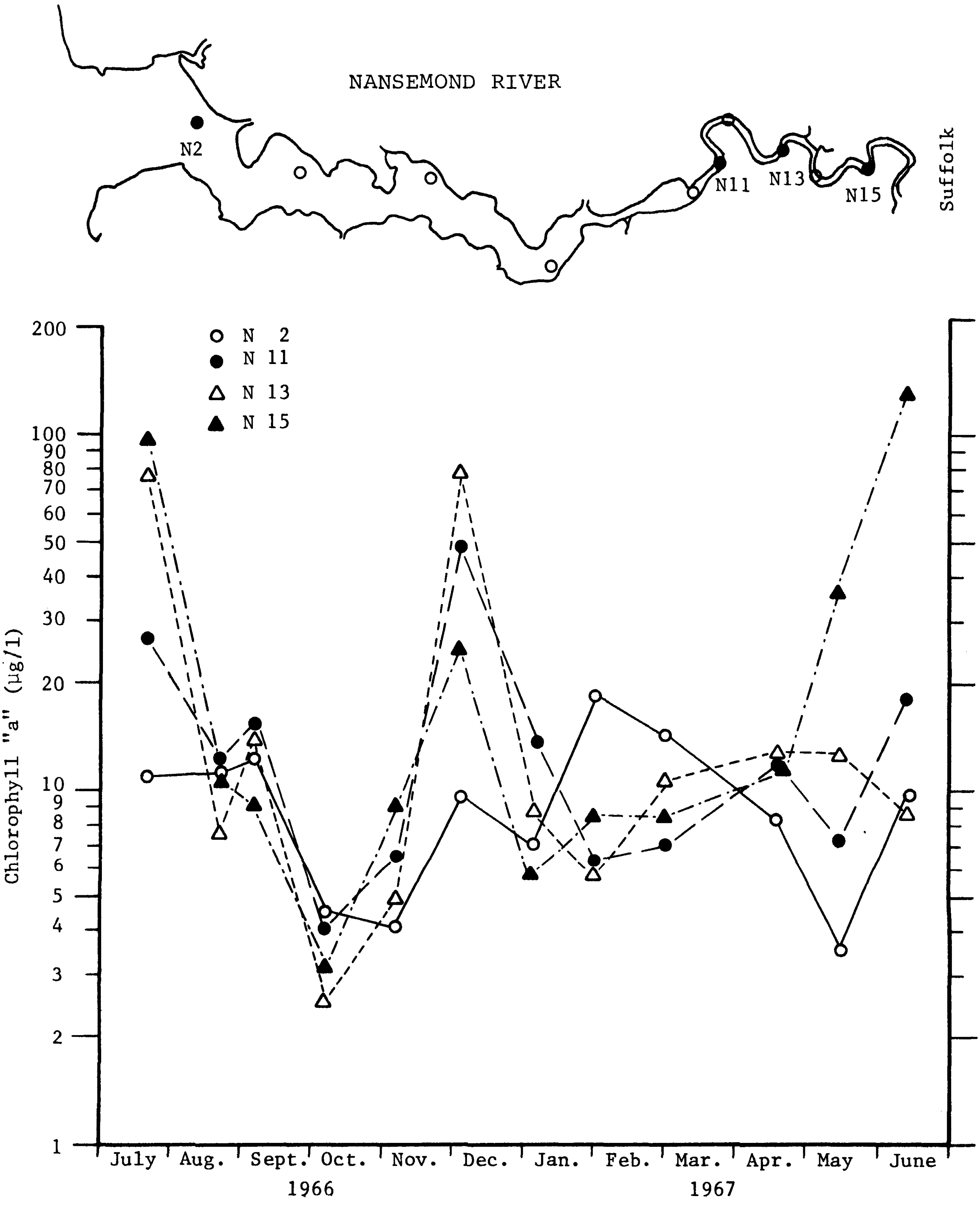

Figure 5e. Chlorophyll "a" variations at stations in the Nansemond River from July 1966 to June 1967.

Analysis of the top 1 cm of the Nansemond River bottom sediments showed greater concentrations of ammonia and organic nitrogen, nitrate and nitrite-nitrogen in the uppermost reaches of the river and around statute mile 9 as shown in Figure 6. Consistently higher phosphate concentrations were found in the uppermost reaches of the river also. The authors state that "The source of the phosphorus is at the head of the river, but distribution is probably the result of direct sedimentation and estuarine hydrodynamics."

In summary, the data collected by Brehmer, et al., show that the Nansemond River received waste loadings greater than its assimilation capacity. As a result nutrient and plankton levels were high and dissolved oxygen reserves were nearly depleted at times. Longitudinal changes in water quality and amounts of nutrients in bottom sediments indicated that the major sources were at or near the headwaters. Although Brehmer, et al., specifically note sewage treatment plant effluents as the likely cause of the overenrichment, an examination of the data shows a correlation between increased freshwater inflows and depressed dissolved oxygen conditions in the estuary, suggesting that runoff from the land was contributing a significant portion of the load.

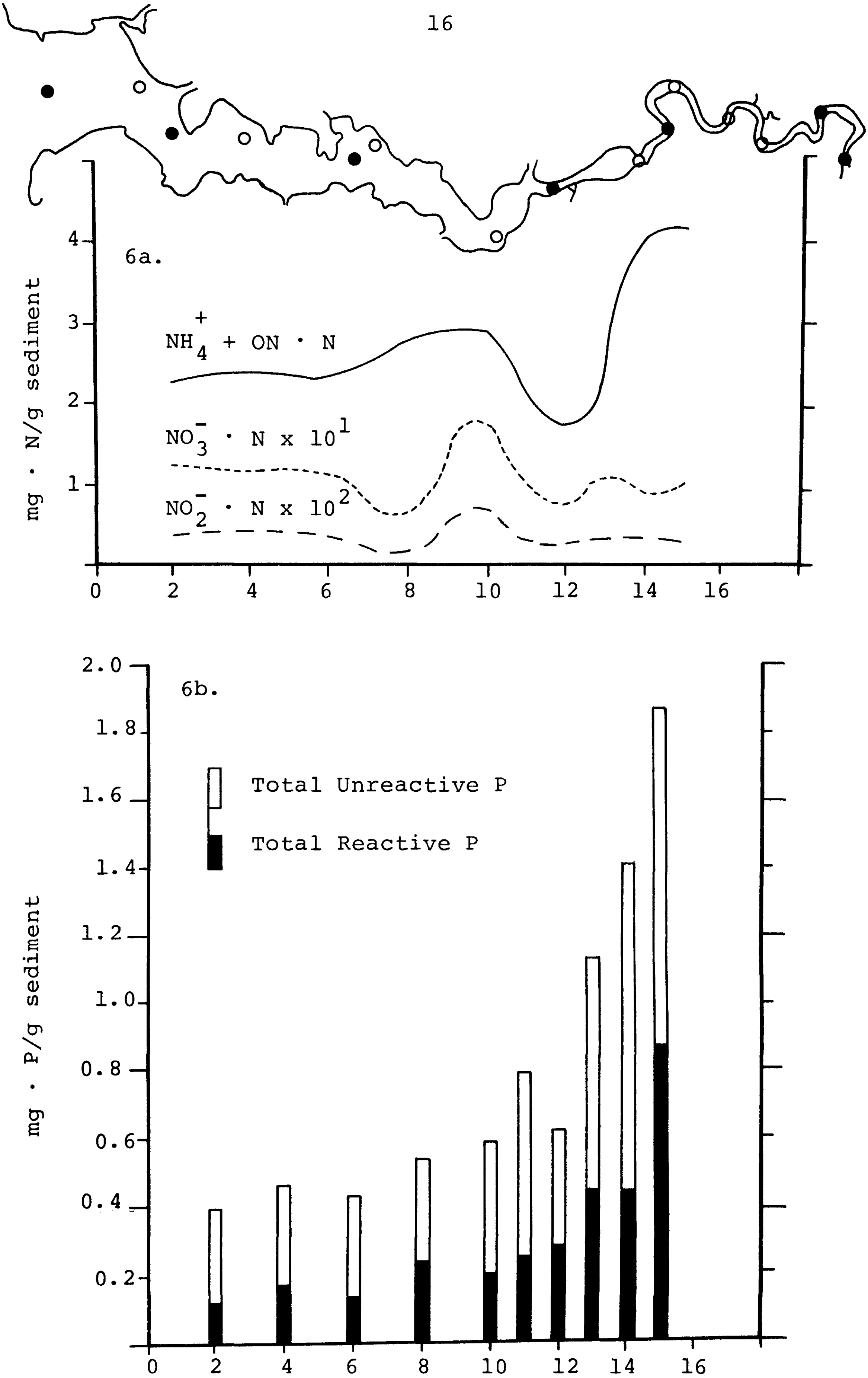

Figure 6. Nutrient concentrations in top 1 cm of Nansemond River sediments: a) nitrite, nitrate and ammonia plus organic nitrogen, b) total unreactive and reactive phosphorus (from Brehmer, et al., 1967).

The Virginia State Water Control Board (SWCB) samples the waters of the Nansemond River on a regular basis. Water quality conditions in the river have been noted in several reports done by or for the SWCB. In 1971, a "Water Resources Requirements and Problems" report was issued by the Division of Water Resources (now part of the SWCB). In that report it is stated that: "Freshwater inflow to the Nansemond River during dry conditions is non-existent, and dissolved oxygen concentrations of zero mg/l at the sag point are common." The final report of the Lower James River Basin Comprehensive Water Quality Management Study (sometimes referred to as the 3-C Report) done for the SWCB in 1974, notes that "There are water quality problems from the vicinity of the dam to a point about six miles downstream. High coliform organism levels, nutrient levels and low dissolved oxygen concentrations are common to this reach of the Nansemond River because of the waste materials discharged to the river near the dam by Suffolk and other dischargers." And finally the 1975 water quality inventory, the so called 305b Report to the Environmental Protection Agency noted that "The Nansemond River (segment 29) presently experiences water quality problems of high fecal coliforms and low dissolved oxygen levels that mainly stem from the City of Suffolk and their municipal discharges. Boating activities on the river have also resulted in fecal coliforms being discharged to the Nansemond River." In another section the causes of the problems are addressed in somewhat greater detail. "On the Nansemond River, the City of Suffolk has a trickling filter type secondary sewage treatment plant, which needs to be upgraded so water quality standards can be met. Meanwhile considerable growth in the Suffolk Area has made it necessary to construct several satellite sewage treatment facilities, some of which have not operated at design efficiency, and have caused water quality problems."

Five stations at the lower end of the estuary were surveyed as part of an environmental study (VIMS, 1975) for the proposed Nansemond wastewater treatment plant of the Hampton Roads Sanitation District. This plant would be located near Pig Point and would have a service area running west from the Elizabeth River including much of Suffolk and possibly part of Isle of Wight County. When this plant becomes operational, the Western Branch Sewage Treatment Plant (STP) would be eliminated as would those in the old city of Suffolk and perhaps most of the other dischargers to the Nansemond River. At this time (December, 1977) some interceptors are under construction and the Nansemond plant is in the design stage. The sampling stations were located between the mouth and Holliday's Point, about 14 km (8 miles) up the Nansemond. Twelve slack water surveys were conducted. Near Pig Point water quality characteristics generally were similar to the rest of Hampton Roads. However, some changes could be noted along the Nansemond. Both Total and Fecal Coliform counts increased in the upriver direction. This trend was especially pronounced and values were higher at low water slack. Total Phosphorus levels also increased with distance from the river mouth and values at Holliday's Point were several times higher than those found in

Hampton Roads. During the sampling period (May thourgh September) DO levels were above 5 mg/l at all stations, but concentrations at Holliday's Point usually were less than levels at the mouth during August and September.

In August, 1974, the Physical Oceanography Department of VIMS conducted an intensive field survey as part of their CSA (Cooperative State Agencies) Program with the Water Control Board (Kuo, et al., 1977). Two slack water surveys were made in the spring of 1975 as well. Eight stations were manned for either 26 hours (13 hours on each of two consecutive days) or 35 consecutive hours on August 14 and 15, 1974. Water temperature was measured and samples were analyzed for dissolved oxygen (DO), salinity and biochemical oxygen demand (BOD). For the lower half of the river (mouth to mile 11 or km 18), DO levels were always above 4 mg/l and above 5 mg/l most of the time. A diurnal trend could be discerned, with minimum values occurring around 6 a.m. and maximum values around 6 p.m., presumably in response to photosynthetic oxygen production by phytoplankton. The daily variation was on the order of 3 milligrams per liter. Minimum values of around 7 mg/l and maximum values of about 10 mg/l were recorded at kilometer 4. By kilometer 18, both minimum and maximum values had decreased to 4.5 mg/l and 7.5 mg/l respectively.

Upriver of that station violations of the 4 mg/l standard were observed. Bottom DO values often differed appreciably (by up to 5 mg/l) from surface readings. At kilometer 28 (just above Shingle Creek near Suffolk) bottom DO's were consistently below 4 mg/l from 6 a.m. on August 14 through 7 a.m. on August 15.

Numerous readings below 2 mg/l were recorded for the bottom waters during the night. At kilometer 30, surface DO readings showed a diurnal variation while bottom concentrations showed a distinct response to tides. The diurnal variations for the three upriver stations was on the order of 5 mg/l, perhaps indicating higher levels of algal standing crop. However, no nutrient or chlorophyll "a" analyses were performed so no definitive statement can be made.

A. 208 Field Studies

On August 23 and 24, 1976, a high water slack survey and a low slack survey were made of the Nansemond River. The Elizabeth River (main stem and Southern Branch), the James River (Fort Wool to the mouth of the Chickahominy) and the Pagan River were sampled at the same slack tides. Water samples were taken at seven stations (Figure 7) and were analyzed for DO, carbonaceous BOD, nutrient species, chlorophyll "a" and fecal coliforms. Bottom DO's of less than 4 mg/l were observed at the mouth on August 23 and near mile 20 on both days (Figure 7b). Surface dissolved oxygen concentrations were always higher, ranging from around 5 mg/l to 10 mg/l. At several stations concentrations were above the saturation value, indicating that photosynthetic oxygen production was great.

Nutrient and chlorophyll levels were high. Chlorophyll "a" readings ranged up to 80 μg/l (Figure 7e). In a study of the Upper Chesapeake Bay, the Annapolis Field Office of the Environmental Protection Agency recommended that chlorophyll

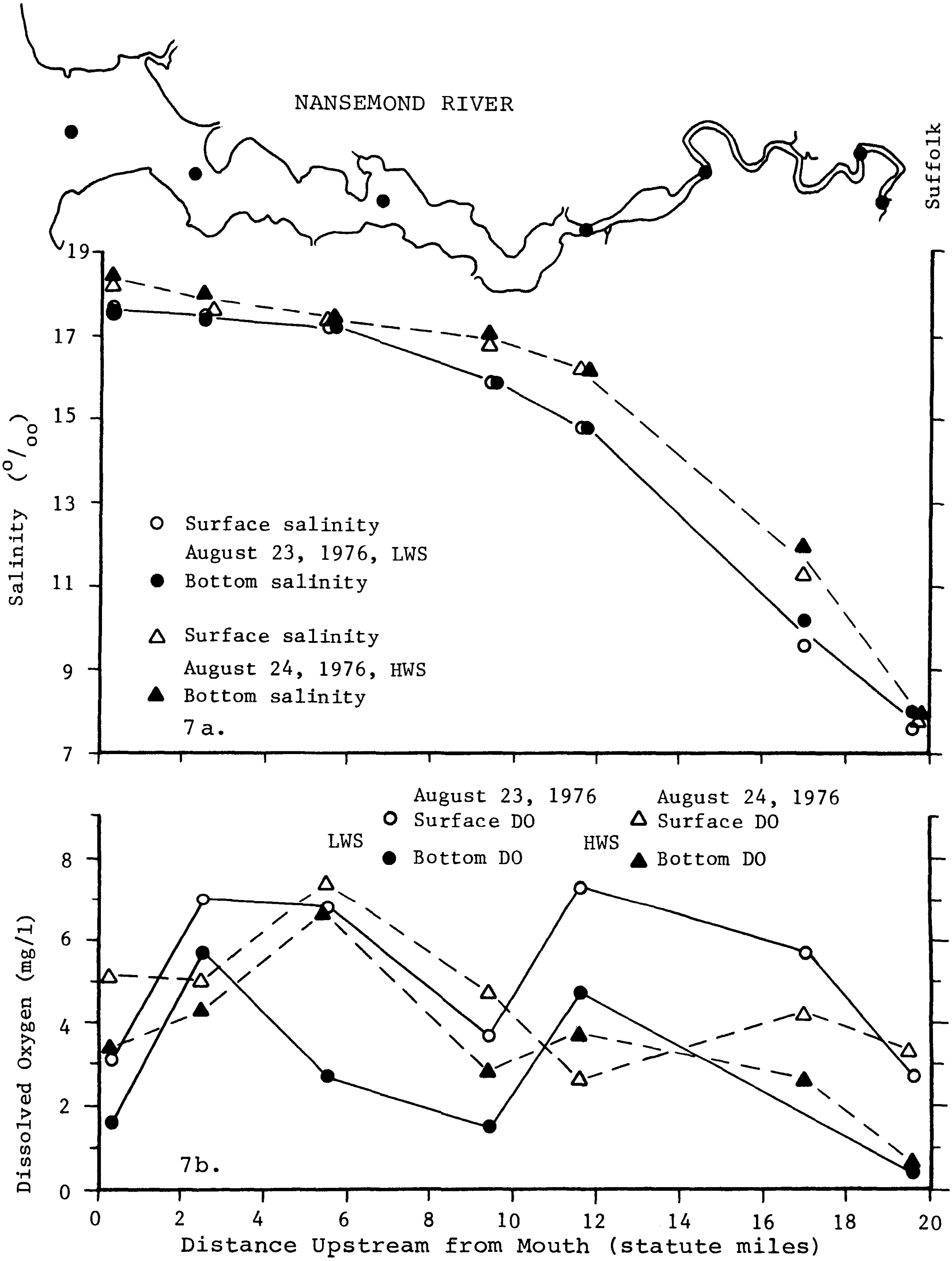

Figure 7. Longitudinal profiles of salinity (a) and dissolved oxygen (b) during 208 survey in August 1976.

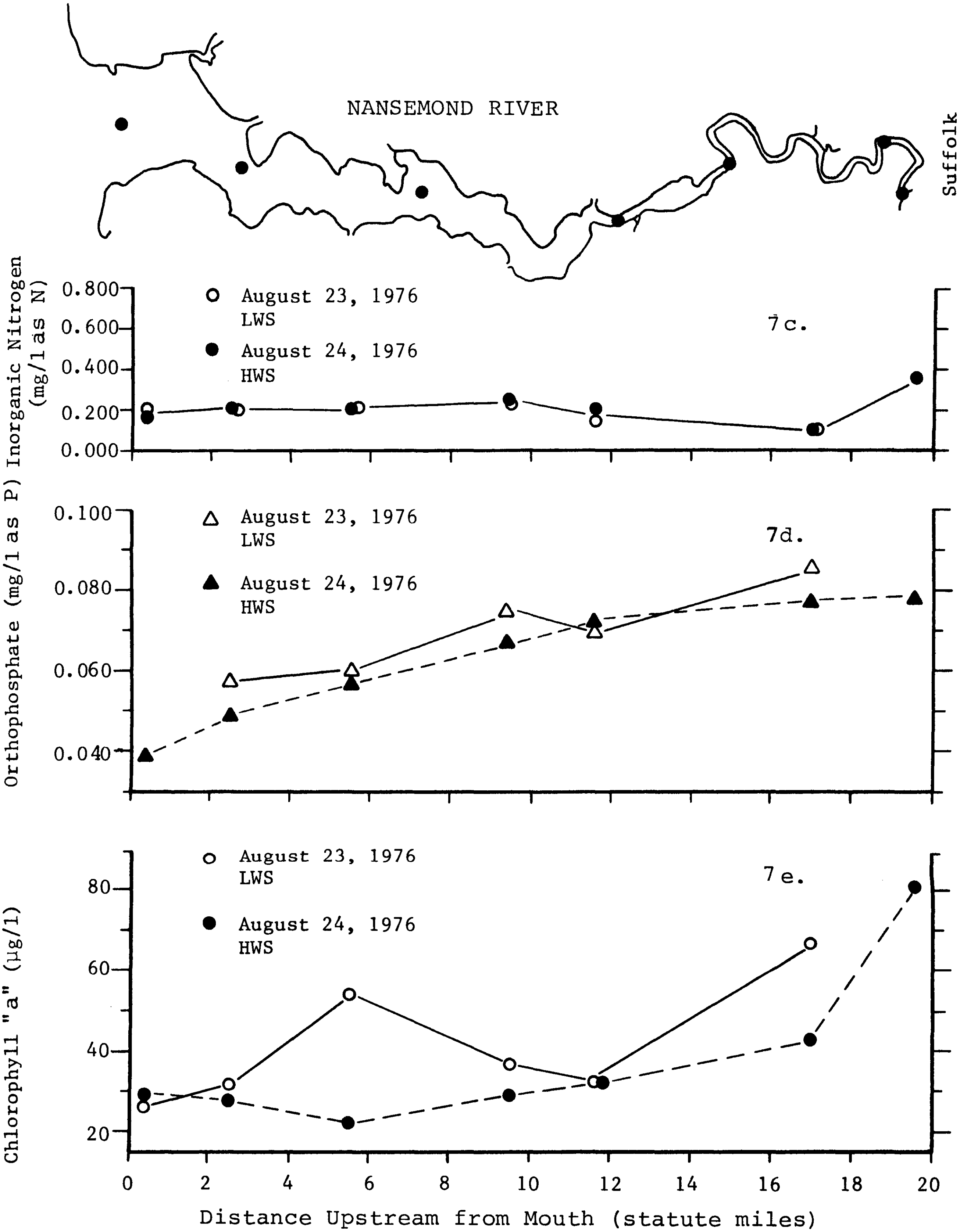

Figure 7. Longitudinal profiles of Inorganic Nitrogen (c), Orthophosphate (d) and chlorophyll "a" (e) during 208 survey in August 1976.

levels be maintained at or below 40 μg/l in order to eliminate undesirable water quality. In order to control phytoplankton levels, nutrient levels would need to be at or below the following levels: Inorganic Phosphorus - 0.04 mg/l (as P), and Total Inorganic Nitrogen - 0.8 mg/l (as N). In a few instances the chlorophyll levels in the Nansemond were above the recommended upper limit, and nutrient levels almost always above the recommended levels, as can be seen in Figure 8.

Fecal coliform levels observed during the two slack surveys showed a dramatic rise with distance from the river mouth, as shown in Figure 9. Values near Suffolk were about three orders of magnitude higher than those observed near the mouth. For about half the river, bacterial levels are sufficiently high to preclude the direct harvesting of shellfish. At the upper end of the estuary bacterial levels are high enough that primary contact recreation should not be allowed. At mile 20, even the water quality standards for secondary contact recreation were contravened. Much of the river has been closed to shellfish harvesting since 1933. This area was enlarged in 1975, as shown in Figure 10. Bennett Creek and Knott's Creek also are closed, and a closure zone is located at Pig Point near the Tidewater Community College campus.

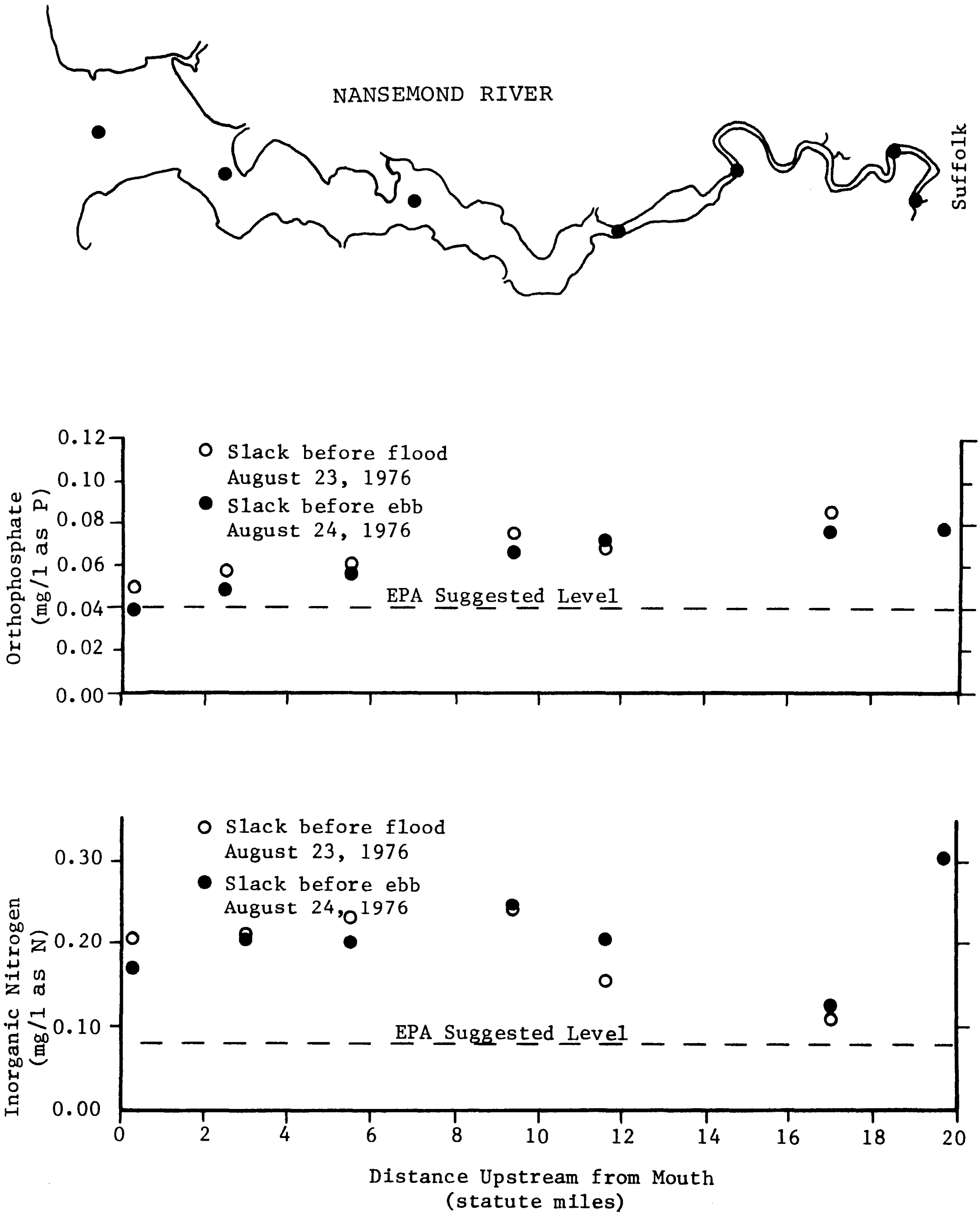

Figure 8. Inorganic nutrient concentrations during 208 survey compared to suggested levels for controlling algal densities.

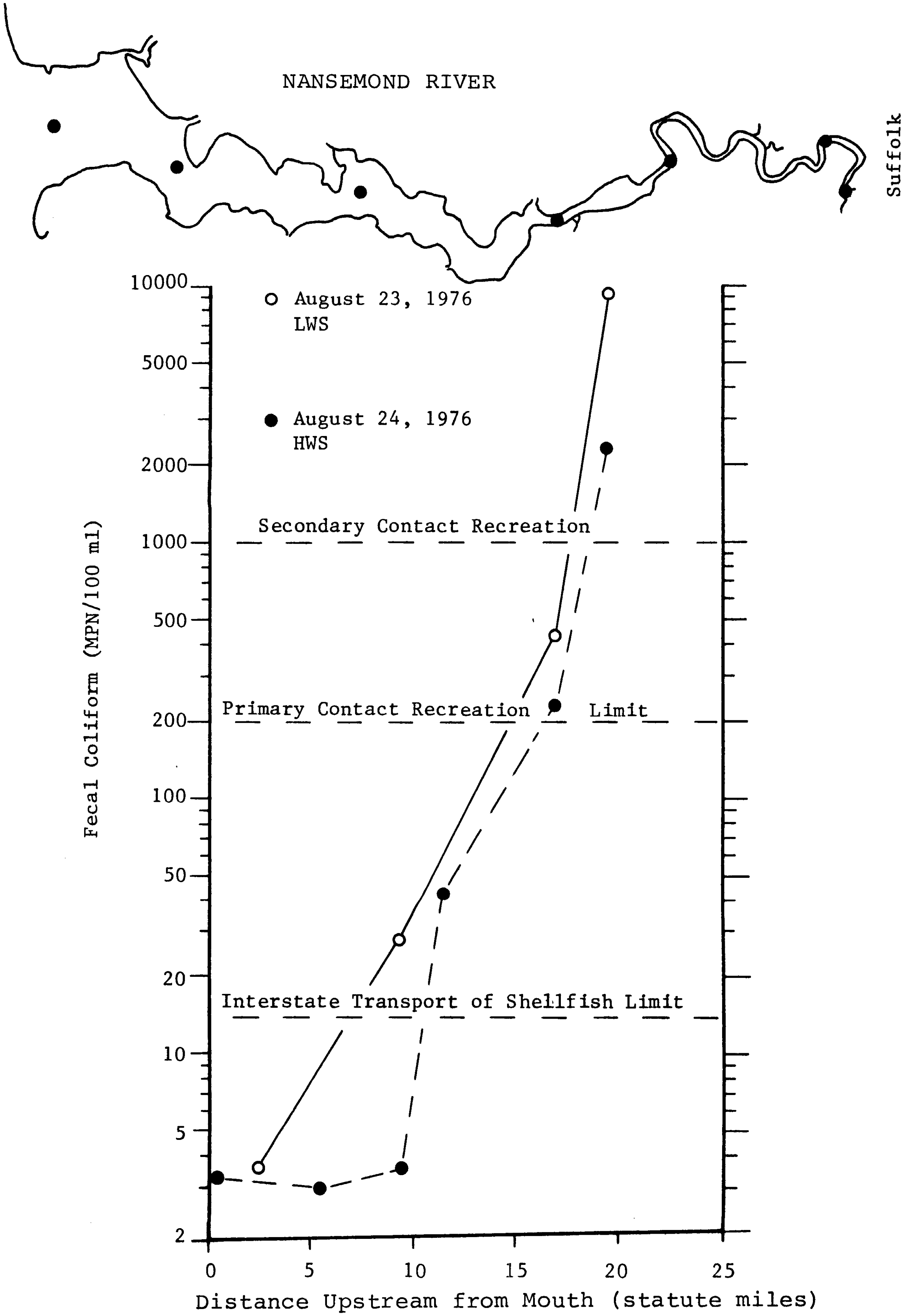

Figure 9. Fecal coliform levels in August 1976.

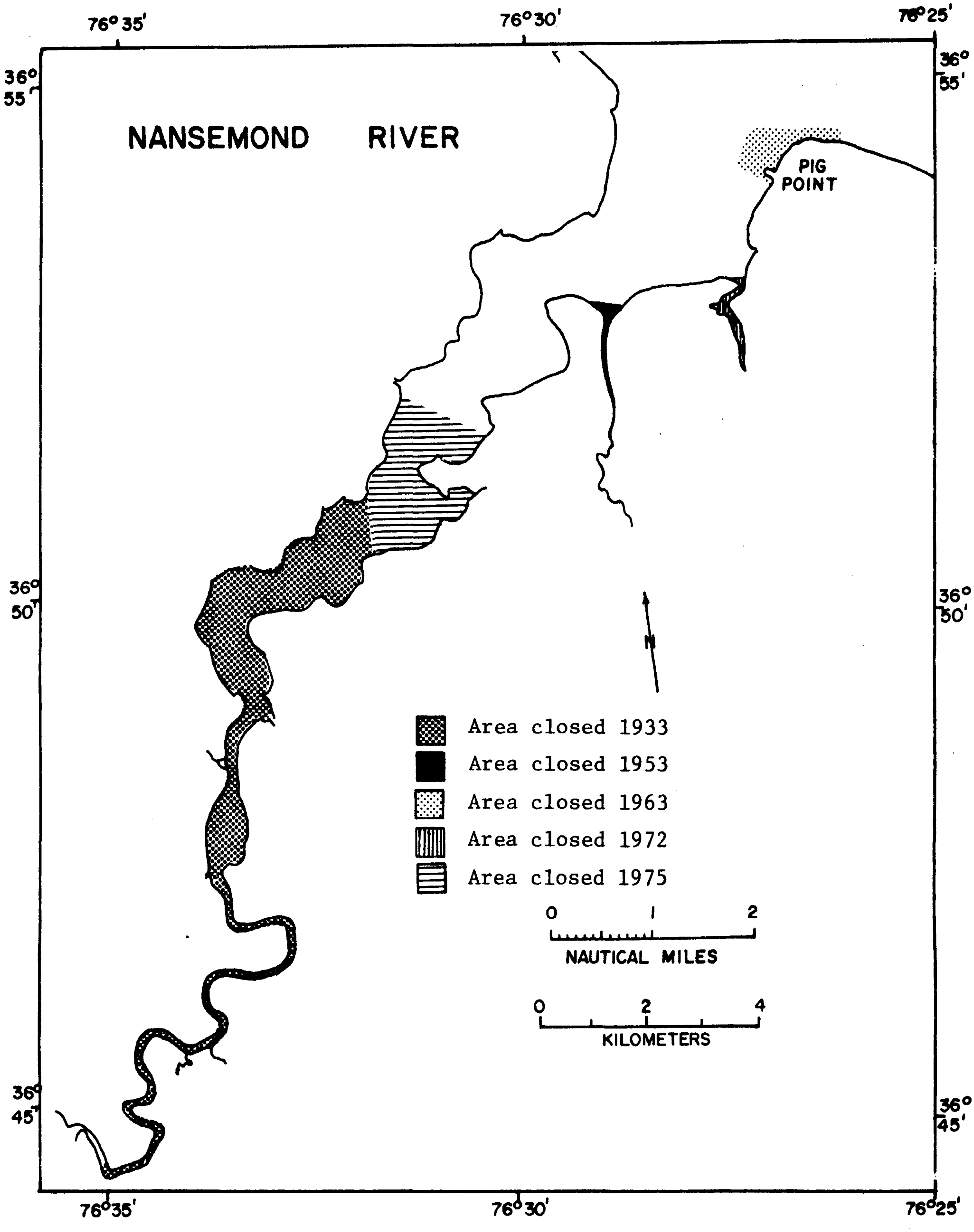

Figure 10. Shellfish condemnation zones in the Nansemond River.

III. WATER QUALITY MODEL

The water quality model applied to the Nansemond River is one-dimensional, real-time and includes intra-tidal features. The model is based on the mass balance equation and simulates the distributions of both carbonaceous (biochemical) oxygen demand (CBOD) and nitrogenous oxygen demand (NBOD), as well as dissolved oxygen (DO) and salinity (S). This model was developed for the Cooperative State Agencies (CSA) Program by VIMS and is described in detail in a forthcoming CSA report (Kuo, et al., 1977). The model was calibrated with data collected during an intensive survey in August 1974, which was reviewed in the previous chapter. Verification was accomplished using data from a slack water survey made in March 1975.

The CSA model was adopted for use in the 208 study, but with minor changes. First the model was reverified using the data set from the slack water surveys on August 23 and 24, 1976. Second, model simulations for the 208 study included estimates of nonpoint source pollutant loads. These nonpoint load projections were made by Malcolm Pirnie Engineers, Inc., using the mathematical model of stormwater runoff known as "STORM". The model STORM was calibrated with data collected in the study area during the period March through October 1976. These data on stormwater runoff quality and quantity were collected by the Virginia Institute of Marine Science.

In the first section of this chapter, a brief description of the model and the underlying principles is given. The second section describes the hydrographic data necessary to implement the model and the field surveys to gather this information. The next section provides information on the point and nonpoint sources of pollution, and the following section is a presentation of the model calibration results. The concluding section describes the model verification for the 208 study.

A. Basic Principles of the Model

The model is based on the one-dimensional equation describing the mass-balance of a dissolved or suspended substance in a water body:

$$\frac{\partial}{\partial t}(AC) + \frac{\partial}{\partial x}(QC) = \frac{\partial}{\partial x}\left(EA\frac{\partial C}{\partial x}\right) + A \cdot Se + A \cdot Si \qquad (1)$$

where

- t is time,
- x is the distance along the axis of the estuary,
- A is the cross-sectional area
- Q is discharge,
- C is the concentration of dissolved or suspended substance,
- E is the dispersion coefficient,
- Se is the time rate of external addition (or withdrawal) of mass across the boundaries, i.e. free surface, bottom and lateral boundary,
- Si is the time rate of increase or decrease of mass of a particular substance by biochemical reaction processes.

The advective term, the second term on the left hand side of the equation, represents advection of mass by water movement; the dispersive, the first term on the right hand side, represents dispersion of mass by turbulence and shearing flow.

These two terms represent the physical transport processes in the flow field and, are identical for all dissolved and suspended substances in the water. The last two terms of the equation represent the external additions and internal biochemical reactions and differ for different substances.

To facilitate the numerical computation, equation (1) needs to be written in terms of finite difference form. This may be done by dividing the river into a number of volume elements, called reaches, with a series of lateral transects perpendicular to its axis and by integrating equation (1) with respect to x over each of the reaches.

Because of advective and dispersive transport across the transects bounding each end of a particular reach of the estuary, the concentration of a substance in one reach will depend on the concentrations in two adjacent reaches. Because of this interdependence of concentrations in neighboring reaches the equation cannot be solved for the concentration at the mth reach alone. Rather, equations must be written for every reach of the estuary and solved for the concentrations in every reach simultaneously.

Suppose that the total length of the estuary to be modeled is divided into N reaches. (N-2) equations will be obtained for m = ML+1 to m + MU-1, where the MLth and MUth reaches are the most upstream and downstream ones, respectively. Since there are (N-2) equations for N unknowns, two boundary conditions must be specified. The principal operation of numerical computations in the model is then to compute the concentrations in each reach at time $t_o + \Delta t$ with a given initial concentration field at time t_o and appropriate boundary conditions. The computed concentration field at $t_o + \Delta t$ will then be used as the initial condition to compute the concentration field at time $t_o + 2\Delta t$, and so forth. Each computation cycle will advance the time by the increment of Δt. Within each computation cycle, the (N-2) simultaneous equations are solved by an elimination method.

The model treats the carbonaceous and nitrogenous fractions of the biochemical oxygen demand (CBOD and NBOD) independently, each having a distinct and separate decay rate. The dissolved oxygen budget depends on the oxidation of CBOD and NBOD, reaeration through air-water interface, benthic oxygen demand and phytoplankton photosynthesis-respiration. Figure 11 is a schematic diagram showing the kinematics of these interactions. Each rectangular box represents one component being simulated by the model, with its name in the computer program shown in parentheses. The arrows represent the external or internal sources (or sinks).

The model also simulates salinity as an independent system. The simulation of the salinity distribution not only serves to calibrate the dispersion coefficient for the model, but also provides the required parameter to calculate the saturation oxygen concentration of the saline water.

The mathematical representation of the terms Se and Si (eq. (1)) for each of the modeled components are explained as follows:

(1) Carbonaceous Biochemical Oxygen Demand, CBOD in mg/l

$$Se = W_b - k_s \cdot CBOD$$

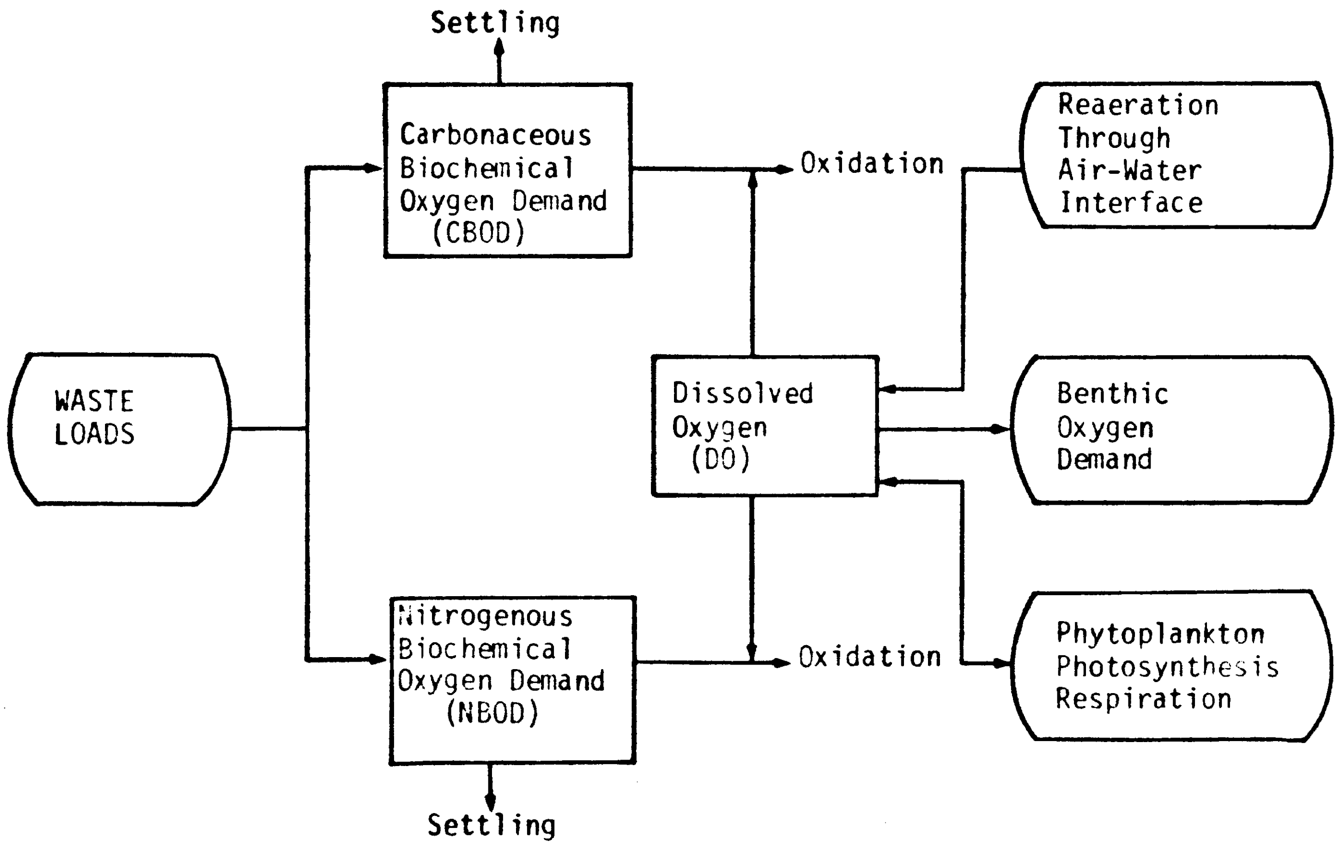

Figure 11. Kinematics of CBOD-NBOD-DO mathematical model.

where W_b is the wasteload from point and non-point source, k_s is the settling rate.

$$Si = -k_1 \cdot CBOD$$

where k_1 is the oxidation rate of CBOD.

(2) Nitrogenous Biochemical Oxygen Demand, NBOD in mg/l.

$$Se = W_n - k_{ns} \cdot NBOD$$

where W_n is the wasteload from point and non-point sources, k_{ns} is the settling rate.

$$Si = -k_n \cdot NBOD$$

where k_n is the oxidation rate of NBOD.

(3) Dissolved Oxygen, DO in mg/l.

$$Se = k_2 \ (DO_s - DO) - BEN$$

where k_2 is reaeration rate, DO_s is the saturated oxygen concentration, BEN is the benthic oxygen demand.

$$Si = -k_1 \cdot CBOD - k_n \cdot NBOD + PHOTO$$

where the first two terms represent the oxygen demands by oxidation of CBOD and NBOD, the last term is the net oxygen production due to phytoplankton photosynthesis-respiration.

(4) Salinity, S in parts per thousand

$$Se = 0$$

$$Si = 0$$

The Nansemond model is described in greater detail in a forthcoming CSA report (Kuo, et al., 1977). General information on the model, formulations for various environmental factors (eg. dispersion coefficient) method of solution and so on also can be found in an earlier report (Kuo, et al., 1975) which describes the application of the basic model to the Rappahannock River.

B. Hydrographic Data

Hydrographic data for the model were collected for the CSA program during the summer of 1974. Twenty-three transects were included in a bathymetric survey (see Figure 13a) and cross-sectional areas were determined for each bottom profile. The resulting data were then plotted as a function of distance as shown in Figure 12.

For modelling purposes, the river was divided into 34 reaches with 35 transects (Figure 13a). The transects in the uppermost reaches of the river (upstream of kilometer 24.7) were located 0.4 km (0.25 mi) apart; the transects in the central portion (kilometer 24.7 to kilometer 15.86) were located 0.8 km (0.5 mi) apart; and the transects near the mouth were located 1.61 km (1.0 mi) apart. Cross-sectional areas for model transects were taken from the smooth curve drawn through the field data points (Figure 12).

The direct drainage area (excluding impounded areas) used for calculating lateral freshwater input in the model is represented as accumulated drainage area versus distance from mouth in Figure 14. Current measurements were made at four locations at the time of the intensive survey. The meters give 20 minute averages of current speed and direction.

C. Sources of Pollution

The major point sources of pollution are listed in Table 1 along with flow and BOD5 emission rates for the months of August 1974 and August 1976, the times for model calibration and verification respectively. Data presented in this table

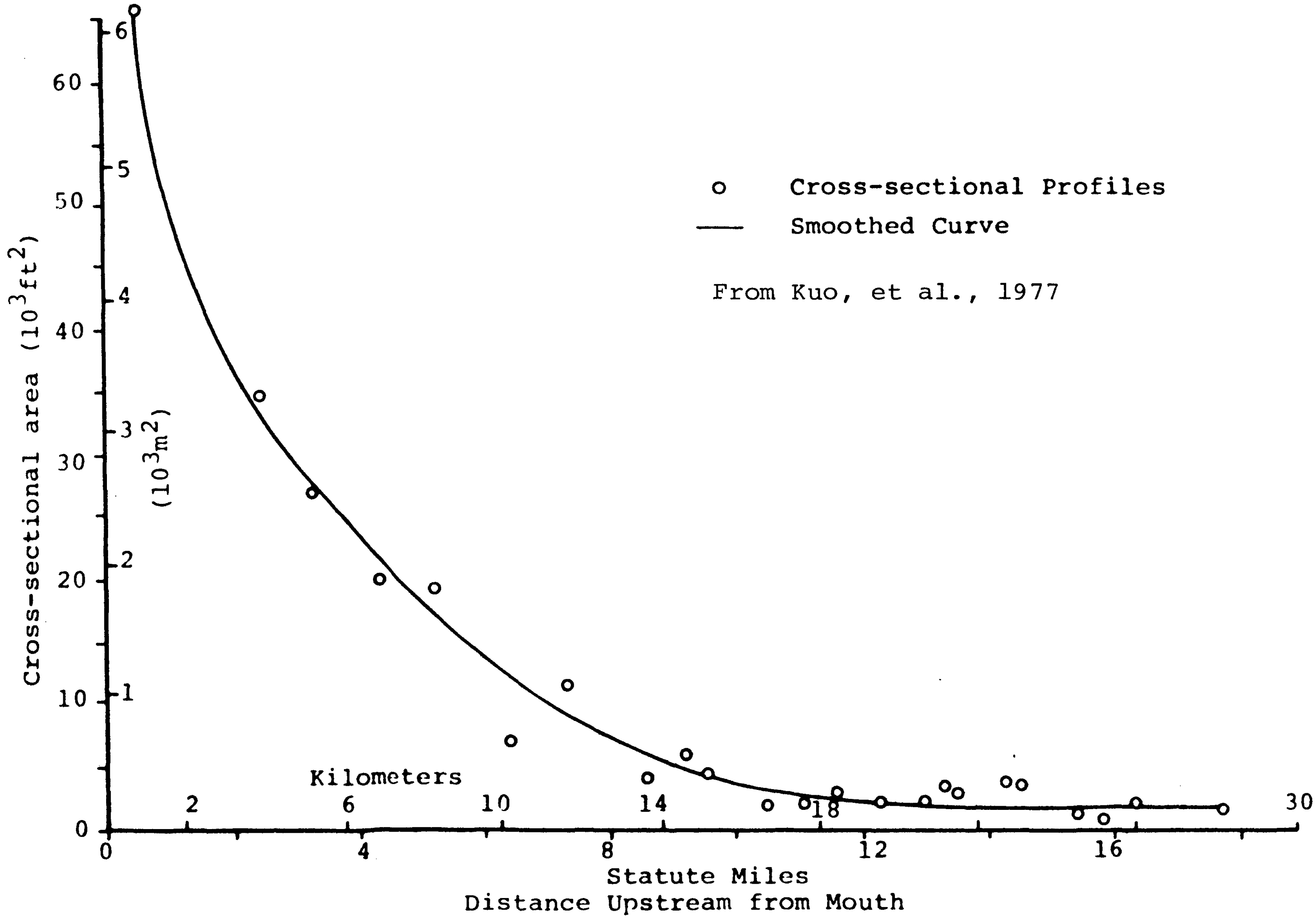

Figure 12. Cross-sectional areas versus distance along the river.

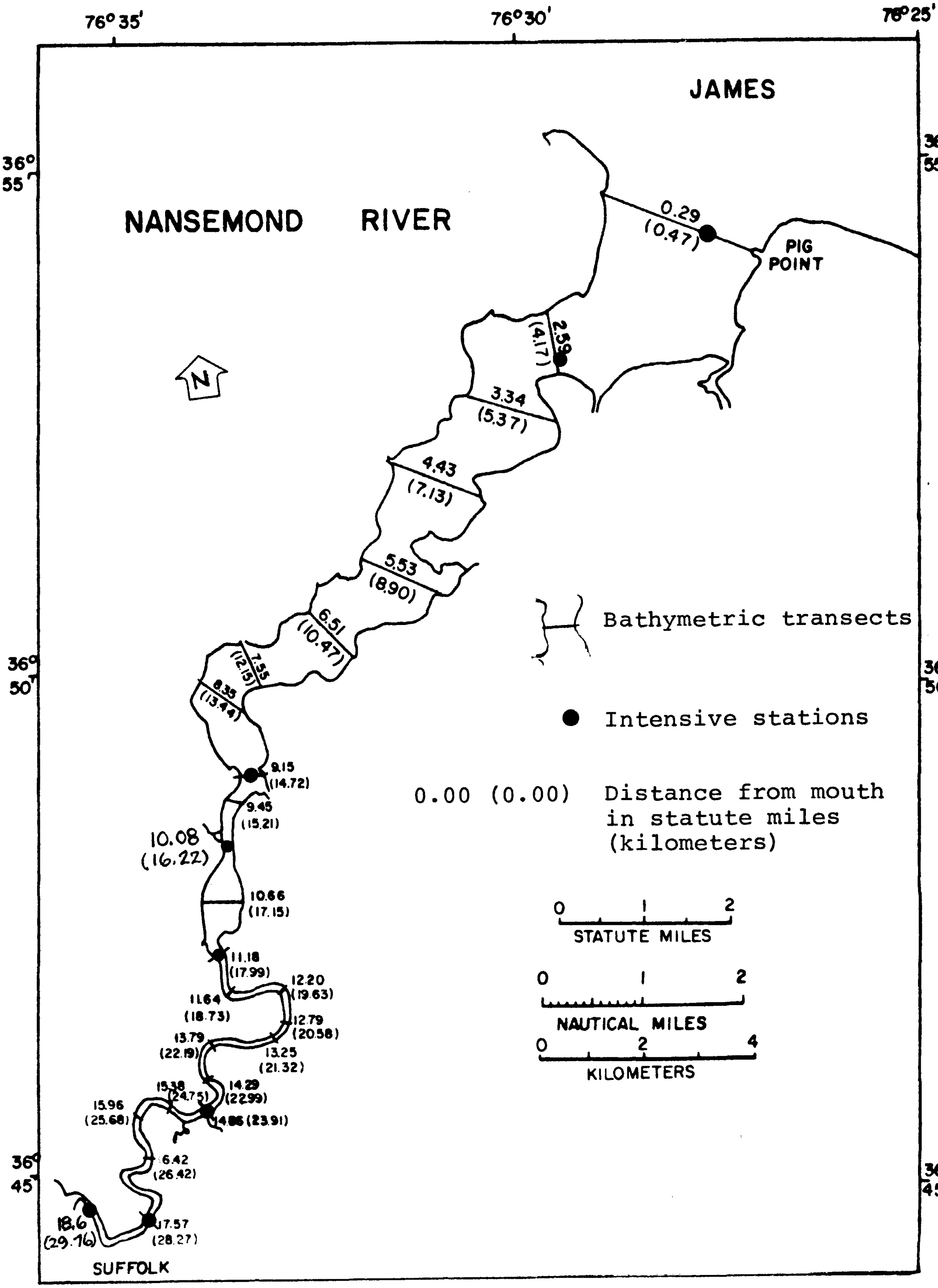

Figure 13a. Location of field survey stations.
From Kuo, et al., 1977.

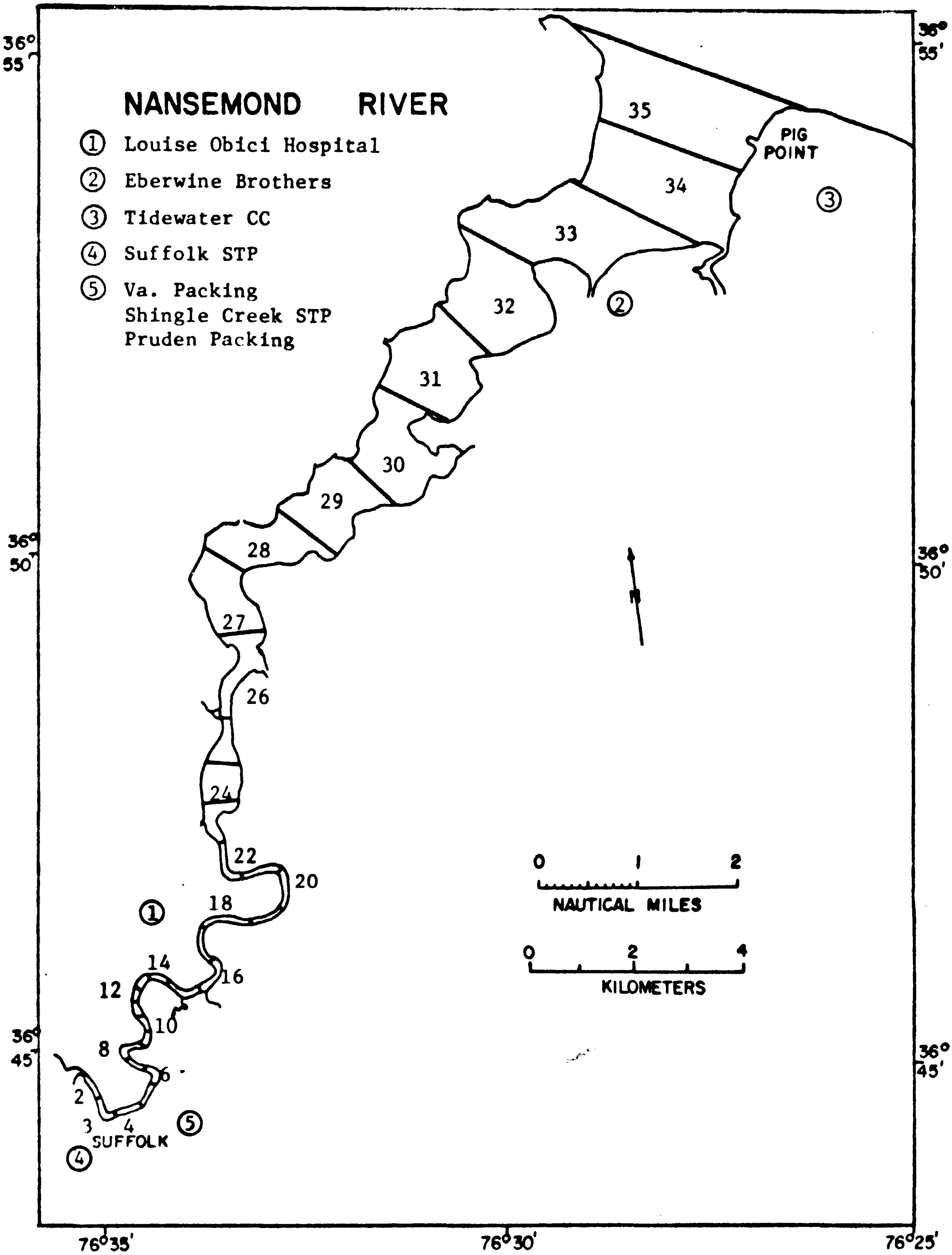

Figure 13b. Location of model reaches and point sources. From Kuo, et al., 1977.

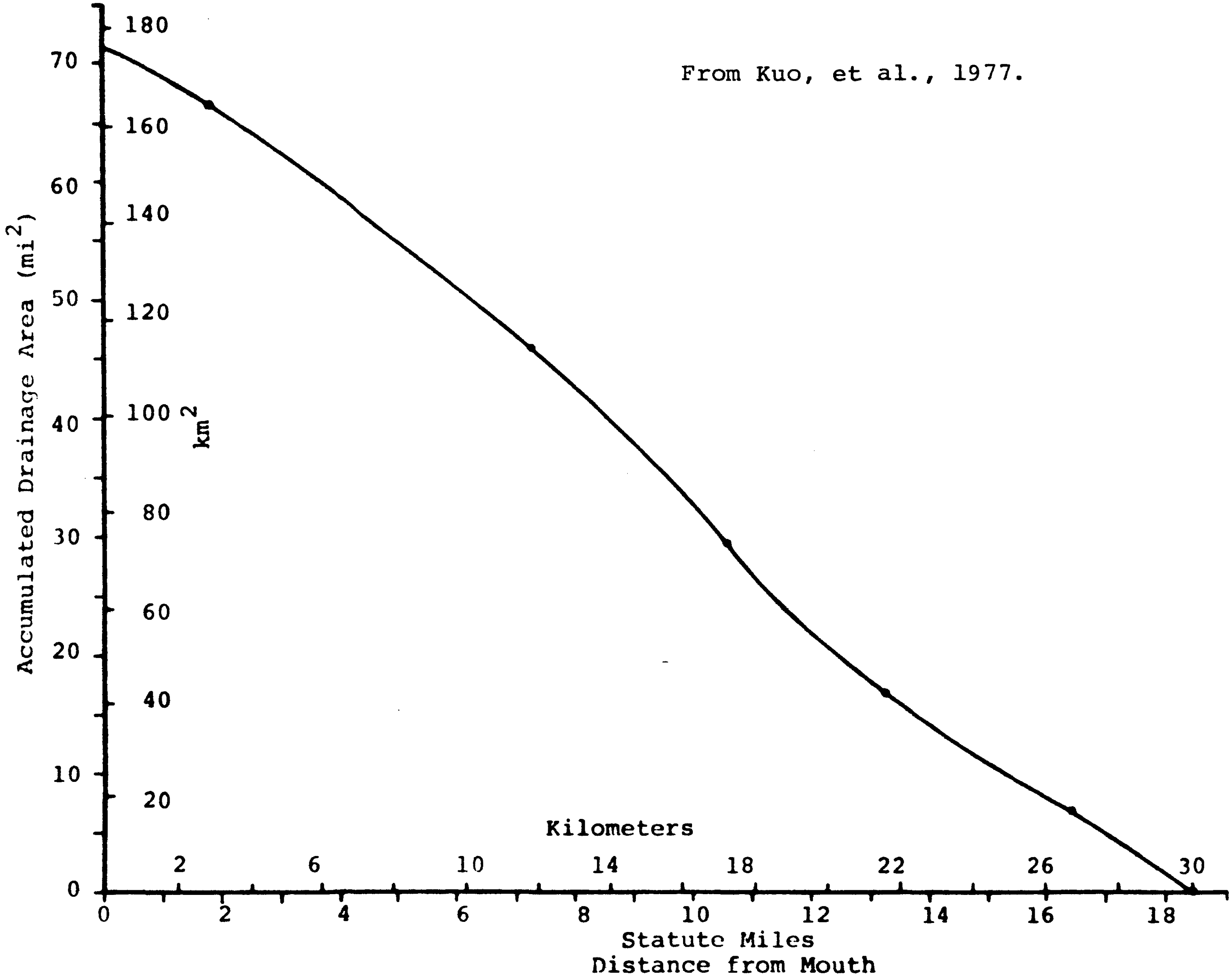

Figure 14. Accumulated drainage area versus distance along the river.

TABLE 1. Point Sources
Discharging to the Nansemond River

Source	Distance from River Mouth	Model Reach Number	Flow Rate (MGD)		Waste Discharge Rate $CBOD_5$ (lbs/day)	
Louise Obici Hospital	14.1	17	.086[1]	.066[2]	21[1]	11[2]
Eberwine Brothers	2.6	33	.02		132	134[3]
Tidewater Community College	.8	35	.043	.078	5	8
Suffolk STP	18.1	3	.866	1.21	377	201
Va. Packing	17.7	5	.068		35	60[3]
Pruden Packing	17.7	5	.0001		5	
Shingle Creek STP	17.7	5	.17	.141	9	4

(1) August 1974 (from Kuo, et al., 1977)

(2) August 1976

(3) estimated

come from the Water Control Board files. The locations of the major dischargers are shown in Figure 13b. For August 1974, about six hundred twenty pounds of 5-day BOD were discharged to the river each day. In 1976, the daily discharge was on the order of four hundred pounds per day, the reduction occurring primarily in the Suffolk STP effluent. The discharges to the Nansemond have not been studied or monitored in great detail, probably because the flow rates are small (all but the Suffolk STP discharge much less than half a million gallons per day) and the BOD loads are small, at least relative to the major municipal treatment plants on the James and Elizabeth Rivers. Consequently, there was little information to characterize these waste streams. The loadings used for the model were calculated using available information (flow and BOD5) and ratios of wastewater characteristics for "typical secondary effluents". The ultimate carbonaceous BOD was assumed to be 1.5 times the 5-day BOD, and the nitrogenous BOD 1.815 times the 5-day BOD. Thus, August 1976 loadings from point sources were on the order of 625 pounds of ultimate CBOD and 760 pounds of NBOD per day.

Nonpoint loadings were estimated by Malcolm Pirnie Engineers, Inc., using the mathematical model STORM. Nonpoint loadings for the thirty day period preceding the August 1976 slack water surveys are given in Table 2. The "STORM" outputs include both ultimate BOD and total nitrogen. These were allocated to river model segments using the natural drainage collection systems, land use and drainage area. For the Western

TABLE 2. Nonpoint Source Model Input Values

Reach No.	Flow (mgpd)	CBOD (lbs/day)	NBOD (lbs/day)
July 30, 1976 (rainfall = 0.10")			
3	0.45	13	9
5	4.27	120	82
16	1.29	77	137
23	0.52	22	41
25	0.78	34	59
27	0.78	34	59
28	1.03	45	82
29	0.79	43	78
30	0.45	29	50
31	0.45	29	50
32	0.45	29	50
33	2.59	233	407
34	1.94	132	229
35	0.26	11	18
July 31, 1976 (rainfall = 0.14")			
3	0.65	6	5
5	3.23	53	37
23	0.26	10	18
25	0.39	15	28
27	0.39	15	28
28	0.52	19	37
29	0.26	16	27
30	0.13	10	18
31	0.13	10	18
32	0.13	10	18
33	0.13	73	128
34	0.84	55	105
35	0.13	5	9
August 3, 1976 (rainfall = 0.19")			
3	0.65	16	14
5	3.23	147	119
16	1.29	93	165
23	0.26	14	50
25	0.38	42	78
27	0.38	42	78
28	0.52	56	101
29	0.45	126	96
30	0.32	126	64
31	0.32	36	64
32	0.32	36	64
33	2.39	36	503
34	1.55	164	320
35	0.13	286	27

Table 2 (cont'd)

Reach No.	Flow (mgpd)	CBOD (lbs/day)	NBOD (lbs/day)
August 8, 1976 (rainfall = 0.19")			
3	2.59	89	96
5	21.33	801	882
16	10.34	920	1631
19	11.63	1327	2367
23	2.59	209	375
25	3.23	313	567
26	12.28	1207	2299
27	3.23	313	567
28	4.52	418	754
29	4.20	430	759
30	2.78	293	516
31	2.78	293	516
32	2.78	293	516
33	21.39	2468	4300
34	10.60	1235	2171
35	1.16	104	187
August 9, 1976 (rainfall = 0.57")			
3	1.94	40	59
5	16.16	361	516
19	9.69	986	1764
23	1.94	128	233
25	2.59	192	352
26	10.34	837	1595
27	2.59	192	352
28	3.88	257	466
29	3.30	261	466
30	2.20	178	320
31	2.20	178	320
32	2.20	178	320
33	16.61	1483	2605
34	8.21	671	1197
35	0.90	64	119
August 16, 1976			
3	0.13	3	2
5	1.10	25	14

Branch reservoir system, there was no flow of water to the Nansemond. All of the runoff was assumed to have been stored within the reservoirs and diverted to the Norfolk water supply system. For the Portsmouth system above Suffolk, most rain events had small amounts of precipitation and no runoff was projected. However, for large rain events runoff did pass through the reservoirs, but with reduced quantity due to storage in the system. Pollutant loads were reduced even more since considerable settling would occur as the runoff passed through the relatively quiescent waters of the reservoirs. The NBOD loads were calculated by assuming that a fixed portion of the total nitrogen was Kjeldahl nitrogen (70% for urban areas and 90% for rural areas) and multiplying this number by 4.57. This factor was derived from stoichiometric relationships for the transfer of organic nitrogen to nitrate-nitrogen.

For the thirty days preceding the slack surveys, about 1.7" (4.3 cm) of rainfall occurred, resulting in nonpoint runoff on six days. Several points must be noted. First, the 30-day average for nonpoint loadings is 640 pounds of ultimate CBOD and 1100 pounds of NBOD per day, or slightly more than the loading from point sources. Second, the nonpoint loads vary greatly in magnitude. On August 16, loadings were very small, but on August 8, 0.7" of rain produced nonpoint loadings about twenty times greater than the daily loads from point sources. Consequently, one must assume that nonpoint sources of pollution are a major factor in determining water quality in the Nansemond River, at least with respect to BOD. During rainy periods when there is runoff from the land, nonpoint loads are likely to be several times larger than point loads.

D. Model Calibration

Normally the first step in water quality model calibration is to determine the physical parameters (such as dispersion coefficient) for the system by calibrating the model to reproduce the distribution of a conservative substance such as dye or salt. However, background flouorescence readings were elevated in the Nansemond River in August 1974 so no dye study could be conducted. Freshwater runoff to the river is controlled primarily by the water supply reservoirs. The data available concerning flow over the spillways is not suitable for the model studies. Therefore, the empirical constant for the dispersion coefficient which was determined in model studies of the Rappahannock River (Kuo, et al., 1975) was adopted for the Nansemond. Since the model results are rather insensitive to changes in the dipsersion coefficient, the error introduced by this assumption is negligible. For the Nansemond, freshwater discharge was varied to achieve calibration of the model. In Figure 15a, the longitudinal salinity profile from the model calibration is presented along with field data from the intensive survey.

Decay rates for CBOD and NBOD were adjusted to achieve calibration of these parameters and dissolved oxygen. The longitudinal DO profile and field data are shown in Figure 15b. Values for the decay rates and other environmental factors are given in Table 3. Additional information concerning the model calibration is given in the CSA report.

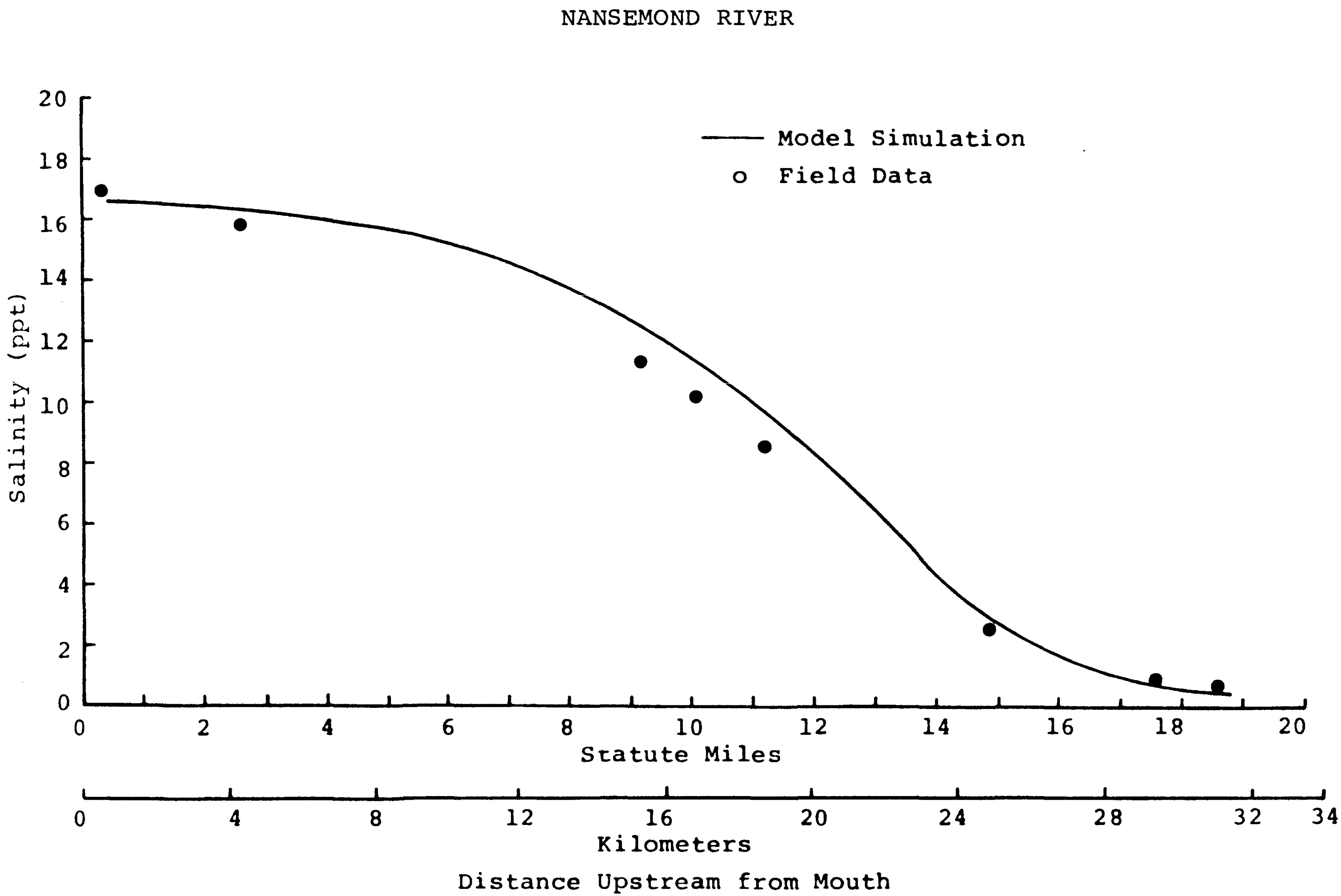

Figure 15a. Longitudinal salinity distribution, August 14-15, 1974.
(from Kuo, et al., 1977)

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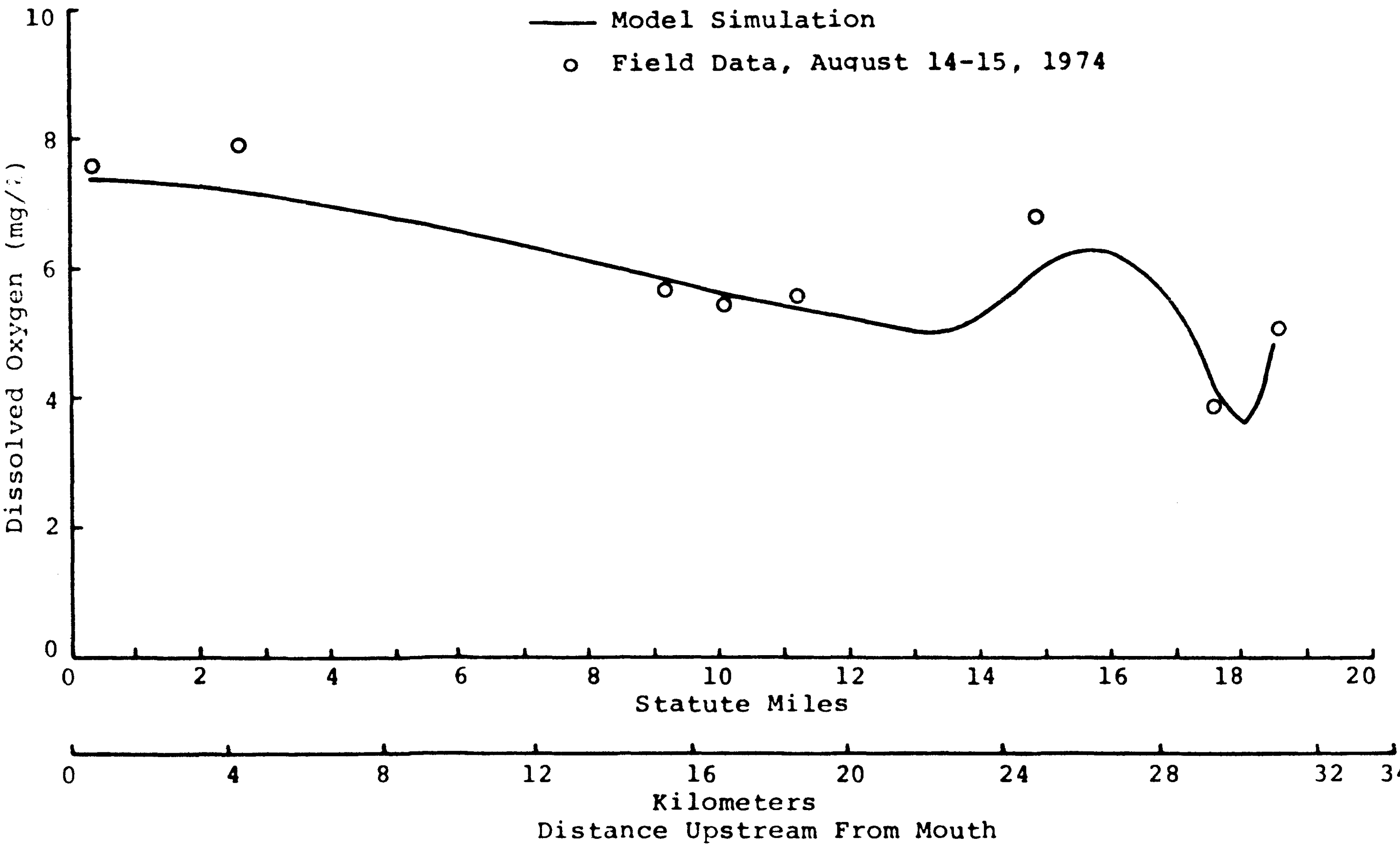

Figure 15b. Longitudinal distribution of dissolved oxygen, August 14-15, 1974. (from Kuo, et al., 1977)

TABLE 3. Values of Rate Constants and Coefficients Used in the Nansemond River Models, August 1974 and August 1976.

Constant or Coefficient	August 1974	August 1976
BETA (weighting factor for advection of sea salt)	0.500	0.500
ALPHA (weighting factor for advection of oxygen and biochemical oxygen demand (BOD)	0.700	0.700
FC (Manning Friction Coefficient	0.030	0.030
AK (salinity dispersion coefficient	1.00	1.00
CBODLA (concentration of CBOD in lateral freshwater inflow)	1.50	1.50
NBODLA (concentration of NBOD in lateral fresh-water inflow)	1.50	1.50
DOLA (concentration of dissolved oxygen in lateral freshwater inflow	6.00	6.00
CKC (decay coefficient, base e, of carbonaceous BOD at 20°C. Unit 1/day	0.15	0.15
TCCKC (temperature coefficient for CKC)	1.047	1.047
CKN (decay coefficient of nitrogenous BOD at 20°C (base e) in unit of 1/day	0.08	0.08
TCCKN (temperature coefficient for CKN)	1.017	1.017

The model was verified (for the CSA Program) with data collected in March of 1975. At that time an additional set of model runs was made to show the sensitivity of the model to various input parameters. For example, the dispersion coefficient was varied by an order of magnitude. With a tenfold increase in the dispersion coefficient, the salinity increased somewhat in the middle region of the river (mile 8 to mile 14) but the salinity intrusion was not altered nor were downstream salinities altered appreciably (see Figure 16). A tenfold decrease in the dispersion coefficient increased the salinity between mile 5 and mile 10, but hardly changed the profile elsewhere. The numerical calculations become somewhat unstable when very low values are used for the dispersion coefficient, as can be noted in Figure 16. The same order of magnitude change in dispersion coefficient had virtually no effect on the CBOD (Figure 17), NBOD (Figure 18) or DO (Figure 19) profiles. Hence, it appears that the use of Rappahannock River data in the Nansemond is unlikely to result in any serious errors in the model predictions. Any errors which are introduced are likely to be greatest for salinity values and to be very small for the BOD and DO concentrations.

Changes in the BOD decay rates have larger impacts. In Figure 20, one can note that a threefold change in decay rate can alter CBOD concentrations by as much as 50%. Two-fold changes in the NBOD decay rate result in comparable changes to the NBOD profile (Figure 21). When both decay rates are varied by the above amounts, the dissolved oxygen profile is altered significantly, as shown in Figure 22. In the region

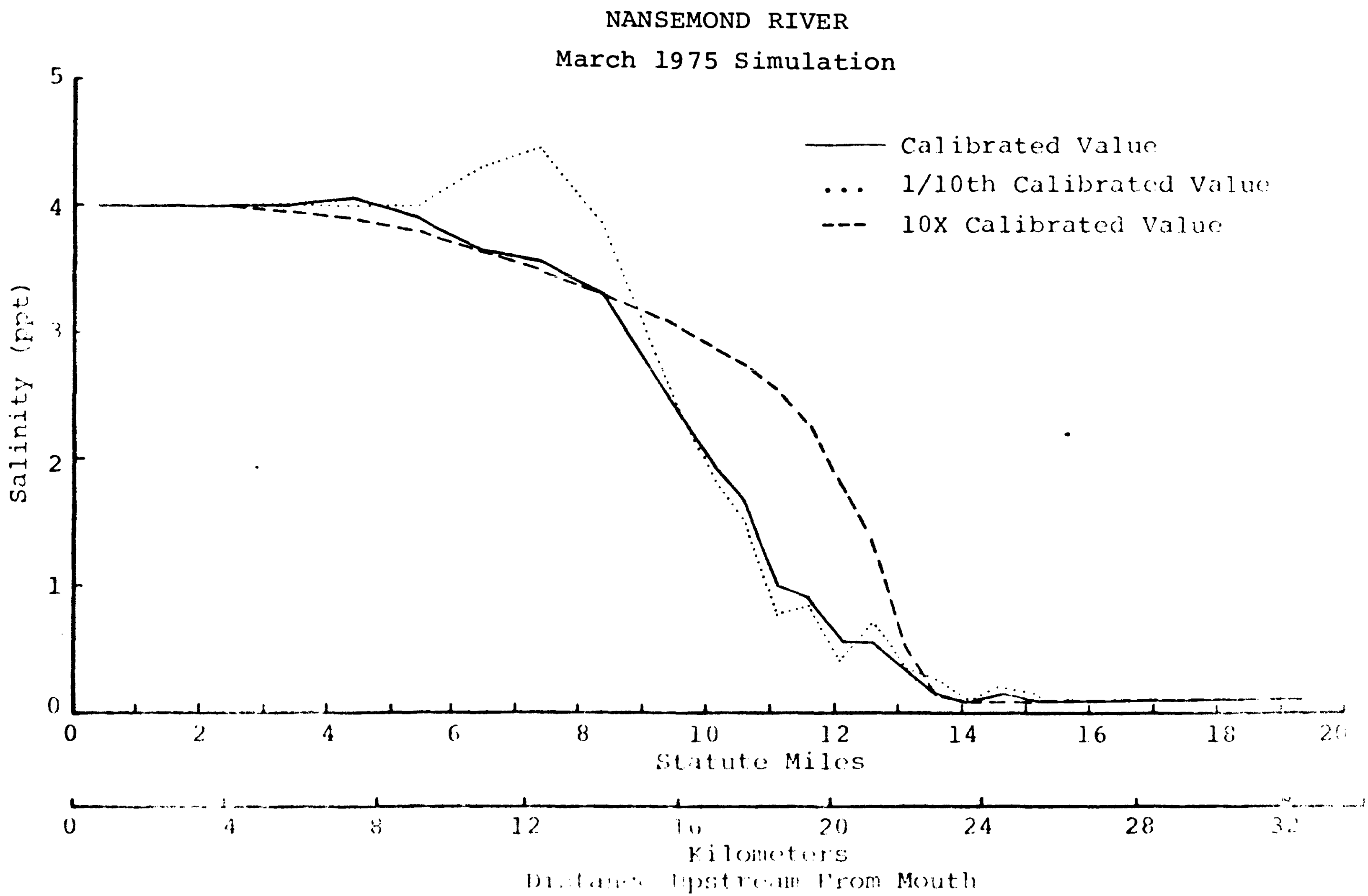

Figure 16. Effects of dispersion coefficient on salinity distributions. (from Kuo, et al., 1977)

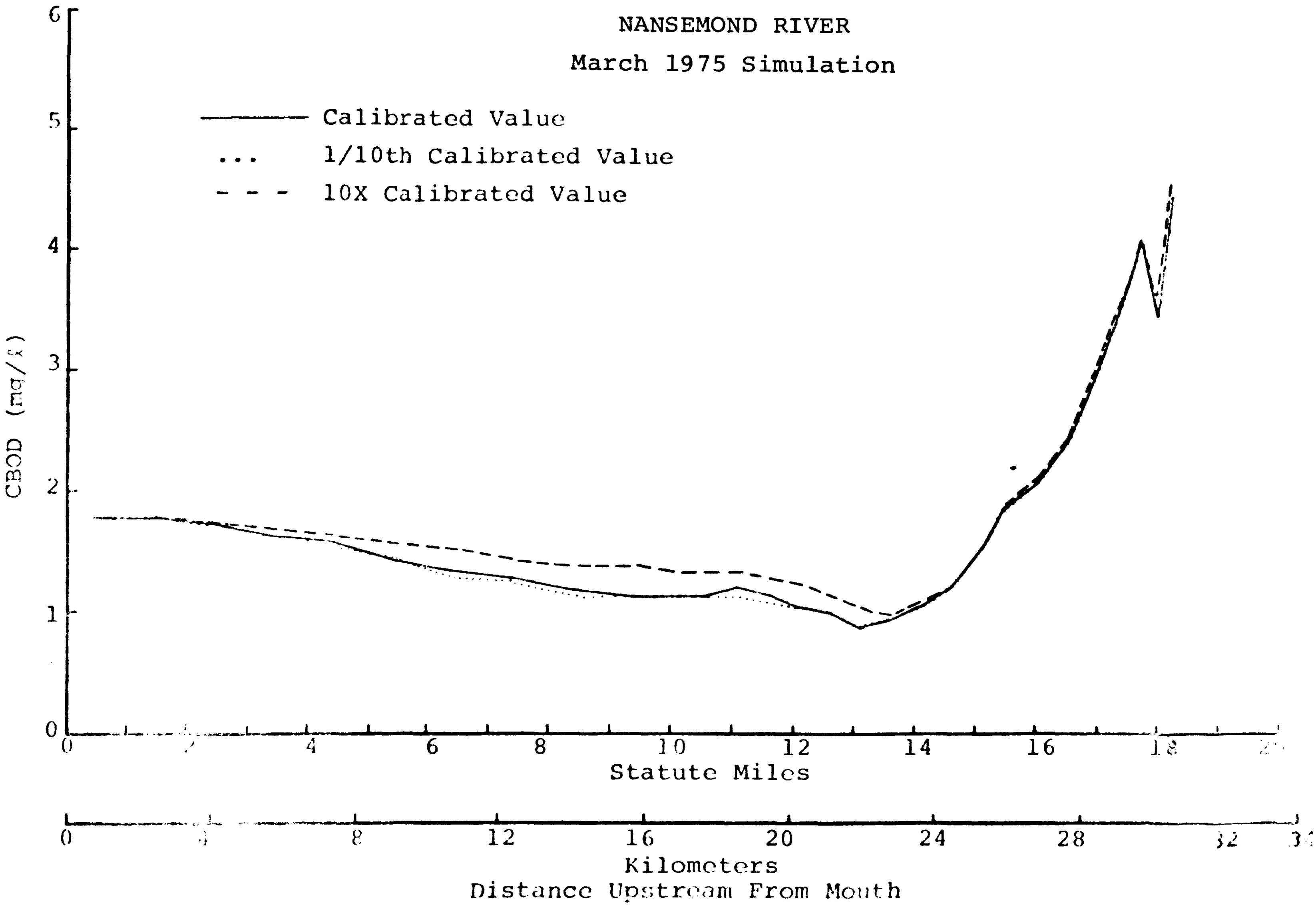

Figure 17. Effects of dispersion coefficient on CBOD distribution.
(from Kuo, et al., 1977)

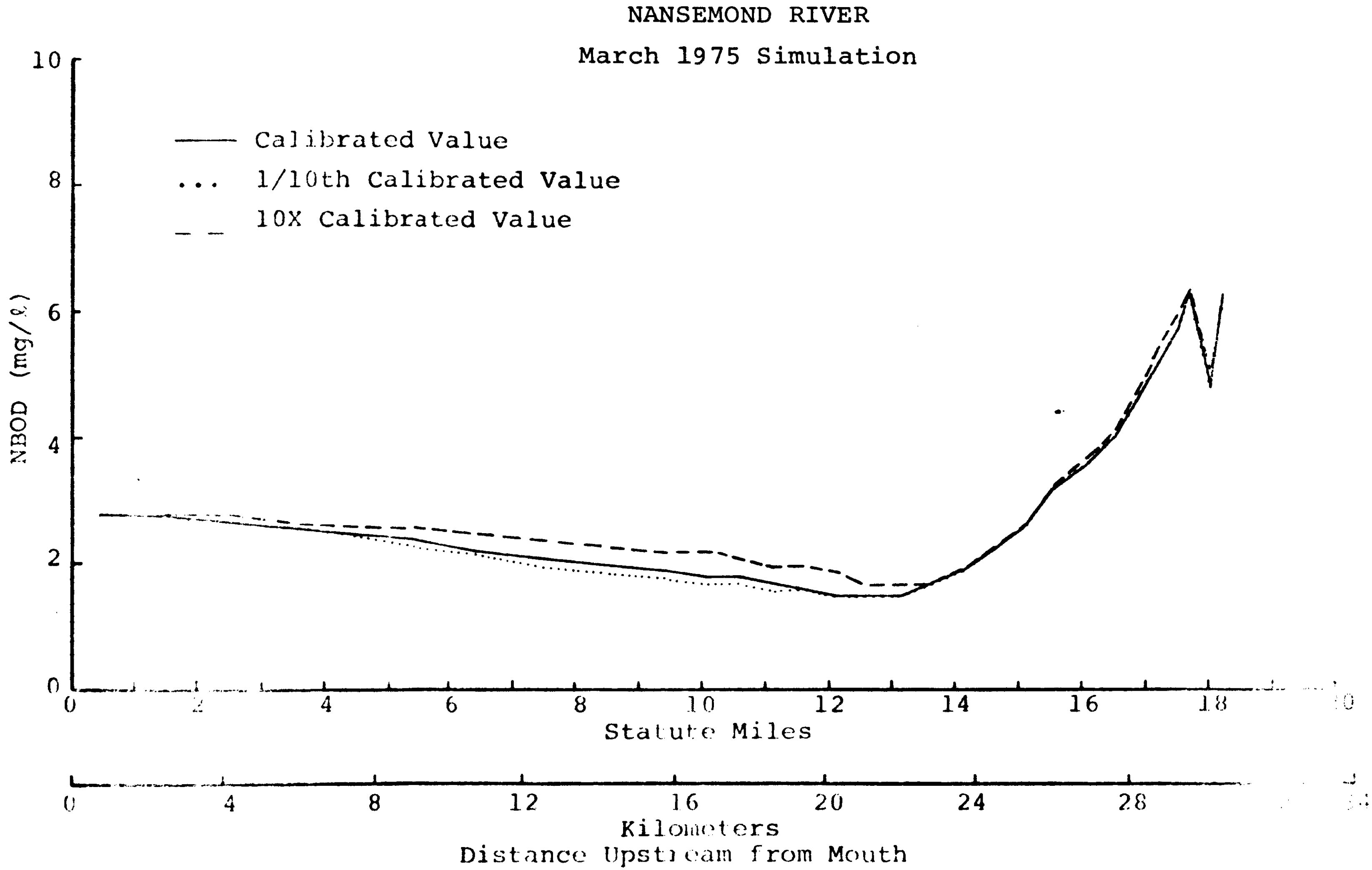

Figure 18. Effects of dispersion coefficient on NBOD distribution.
(from Kuo, et al., 1977)

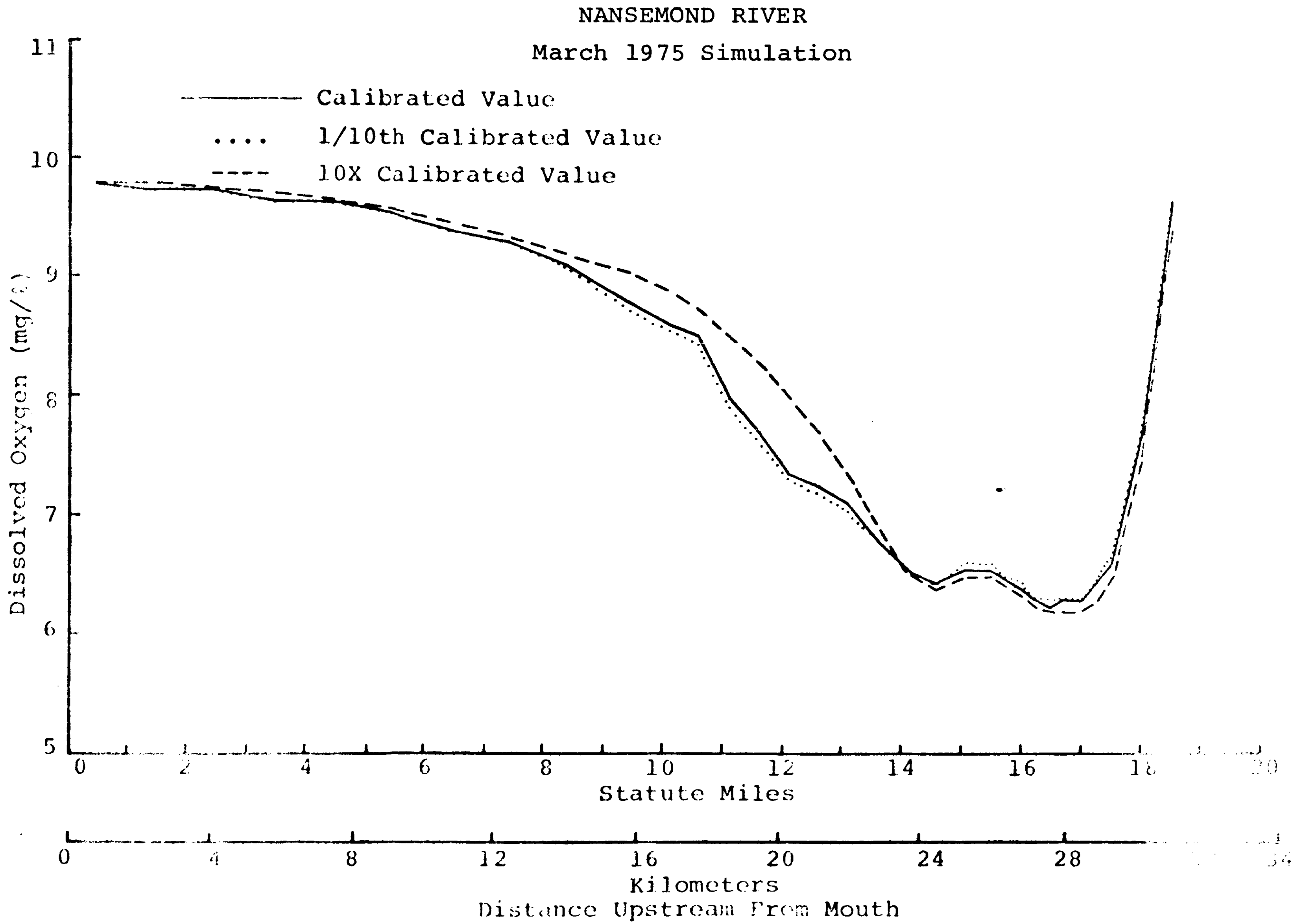

Figure 19 Effects of dispersion coefficient on DO profiles.
(from Kuo, et al., 1977)

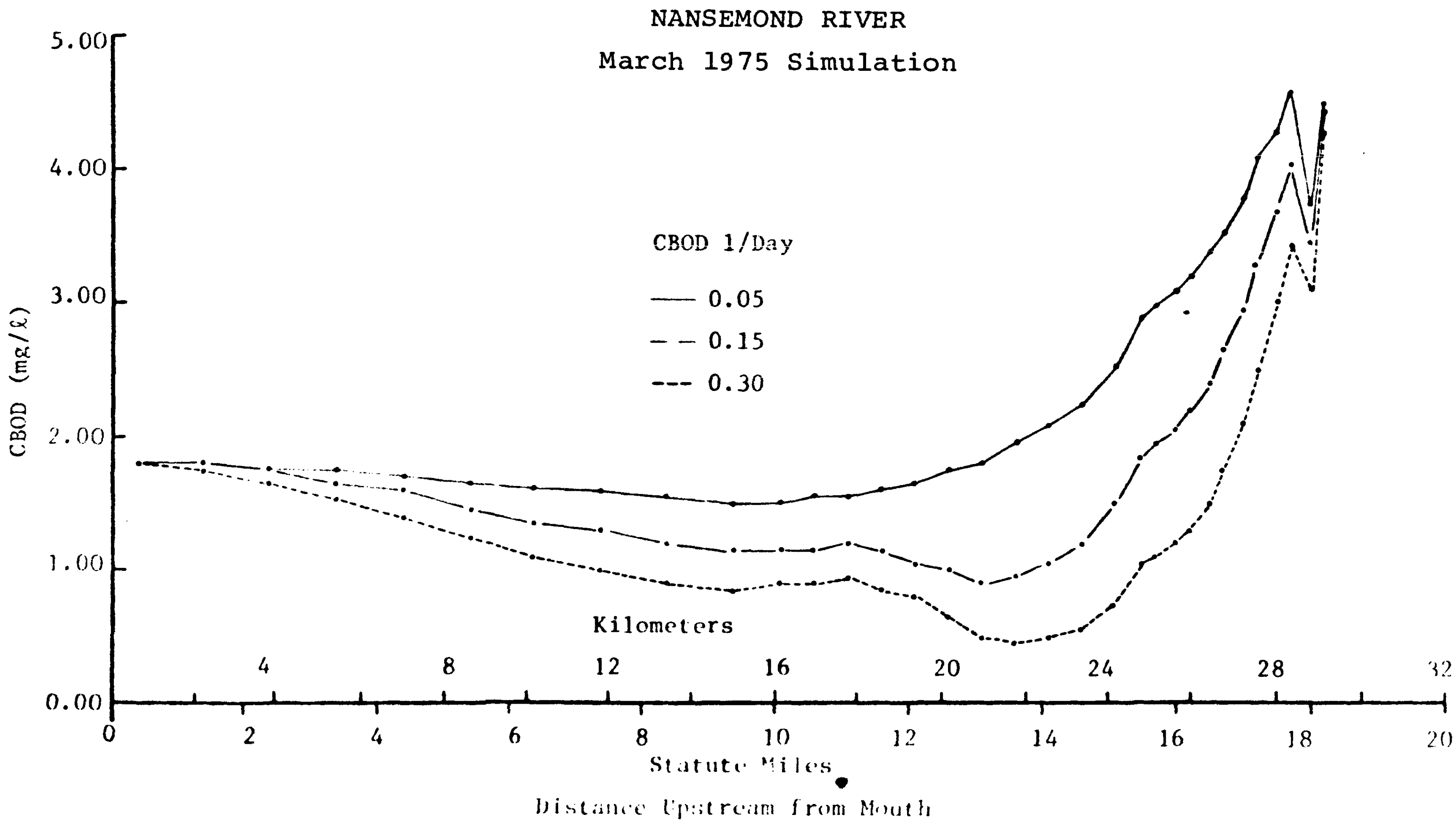

Figure 20. Effect of CBOD decay rate on CBOD profiles.
(from Kuo, et al., 1977)

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March 1975 Simulation

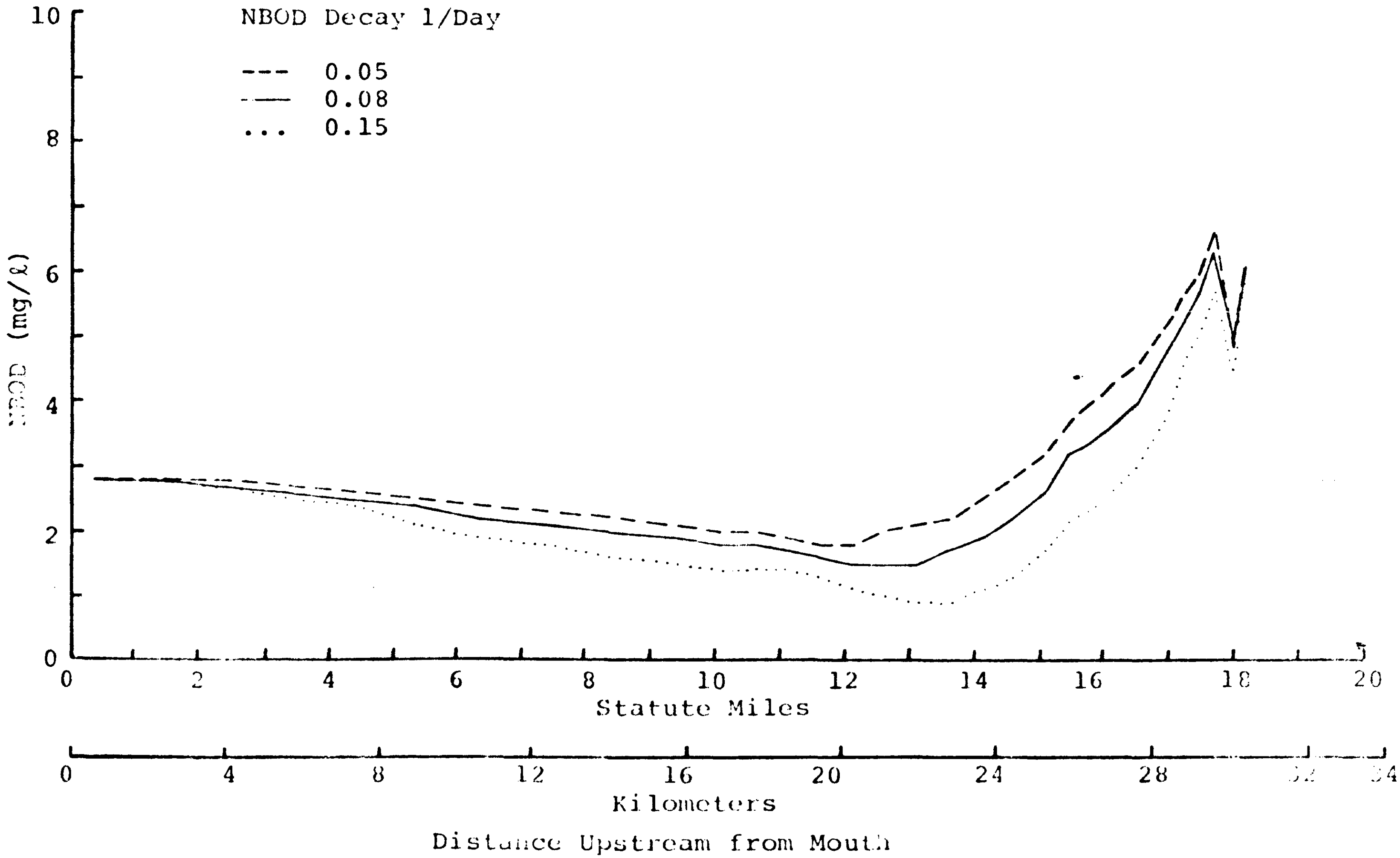

Figure 21. Effect of decay rate on NBOD distribution.
(from Kuo, et al., 1977)

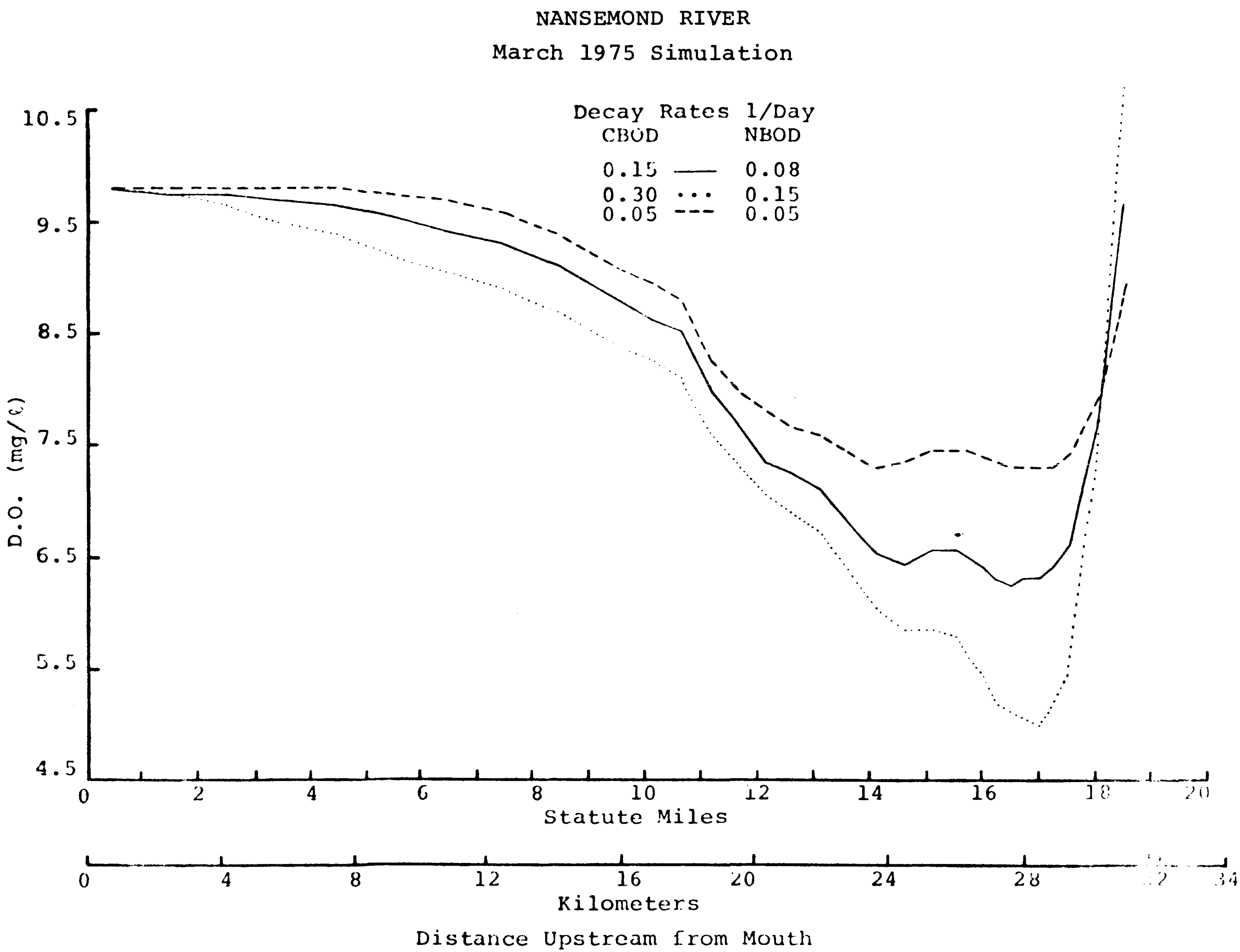

Figure 22. Effect of CBOD and NBOD decay rates on DO profiles. (from Kuo, et al., 1977)

of the oxygen sag, DO concentrations vary by about 1 mg/l. However, on a percentage basis, the decay rate affects BOD values much more than it affects DO levels.

E. Model Verification for the 208 Study

The CSA model was reverified using the slack water data collected for the 208 study in August of 1976. Nonpoint loadings were provided to VIMS by Malcolm Pirnie Engineers and have been presented in section C of this chapter, along with the point source loadings used for these model simulations. Since the Nansemond drainage basin is not large, and since most of the watershed is upstream of water supply reservoirs, it is likely that the base freshwater flow would be small, especially in late summer. There are no stream gaging stations in the Nansemond drainage basin and little information is available on flows from the reservoirs. Therefore, the base freshwater flow was assumed to be zero. Stormwater runoff flows predicted by STORM were used in the model simulation. No freshwater flow to the Nansemond was projected for the Norfolk water supply reservoir system on the Western Branch. Following major rain events some flow was projected for the Portsmouth reservoirs above the old City of Suffolk, but with both flow and pollutant loads reduced to account for storage and settling.

The predicted salinity profile is shown in Figure 23 along with the field data for August 1976. Agreement is reasonably good, especially considering the limited information available concerning base freshwater flow and discharges from

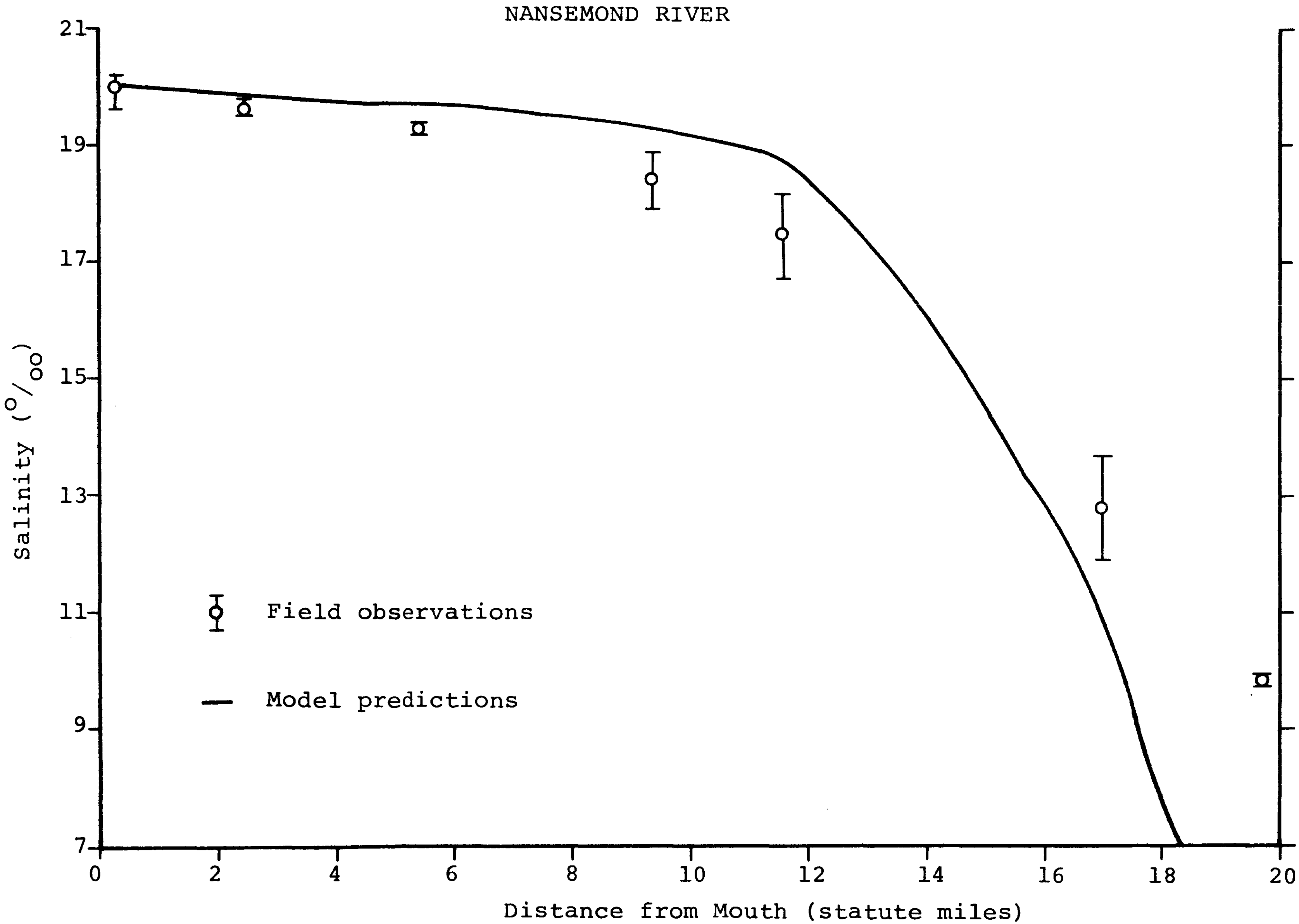

Figure 23. Verification comparison of salinity values for August 23-24, 1976.

the water supply reservoirs. Model predictions for dissolved oxygen with both CBOD and NBOD decay rates held constant, but adjusted for the correct temperature, are shown in Figure 24. With the exception of the most upriver station, model predictions are close to the average values and within the limits of observed values. The highly elevated DO's (many well above the saturation value for the actual salinity and temperature) which were observed in the field probably result from phytosynthetic oxygen production. However, the model does not include phytosynthesis, so predictions tend to be less than observed levels.

It should be noted that model predictions for the 1976 verification period showed very poor water quality in the uppermost several kilometres of the river both during dry weather and following rain events. It appears that BOD loads which enter these reaches remain there for long periods of time since tidal currents are weak and freshwater discharge is low. The weak tidal currents also result in limited reaeration, so that DO reserves are not rapidly renewed.

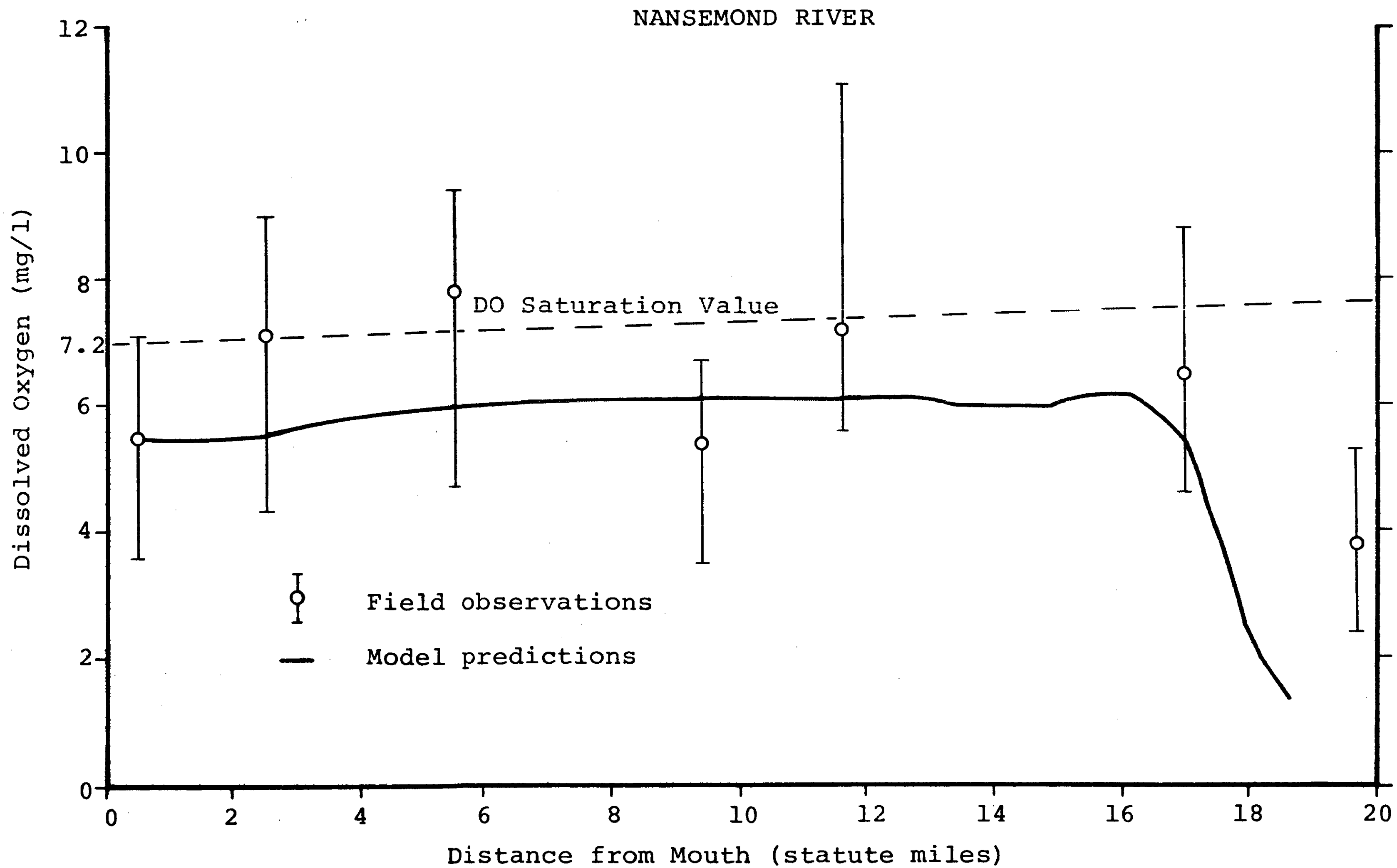

Figure 24. Verification comparison of DO values for August 23-24, 1976.

IV. SUMMARY

Water quality in the Nansemond River has been degraded for many years. The first shellfish closure was enacted in 1933. Depressed dissolved oxygen levels and elevated nutrient and phytoplankton levels have existed for at least ten years. A comparison of dissolved oxygen profiles for late August in 1966 and 1976 (Figure 25) indicates that water quality has improved over the past decade, although no detailed analysis of meteorological and hydrographic conditions was performed to guarentee that the situations were similar. Whatever past trends have been, it is likely that water quality will improve when the proposed Nansemond treatment plant is constructed. Virtually all present day point discharges to the Nansemond will be diverted to the new plant, and its outfall will extend more than a mile into Hampton Roads. The net result will be the near total elimination of point discharges to the Nansemond River.

Almost all published reports refer to municipal and other point discharges as likely causes of the degraded water quality conditions. However, a review of the data collected by Brehmer, et al., 1966-67, indicates that runoff from the drainage basin also could be contributing a significant portion of the waste load. Nonpoint loads have been estimated for the 208 study and indeed are large relative to 1976 point source loads. On an average basis, nonpoint loads are as large as or greater than point source loads, and following major rain events, they increase dramatically. The nonpoint load from a

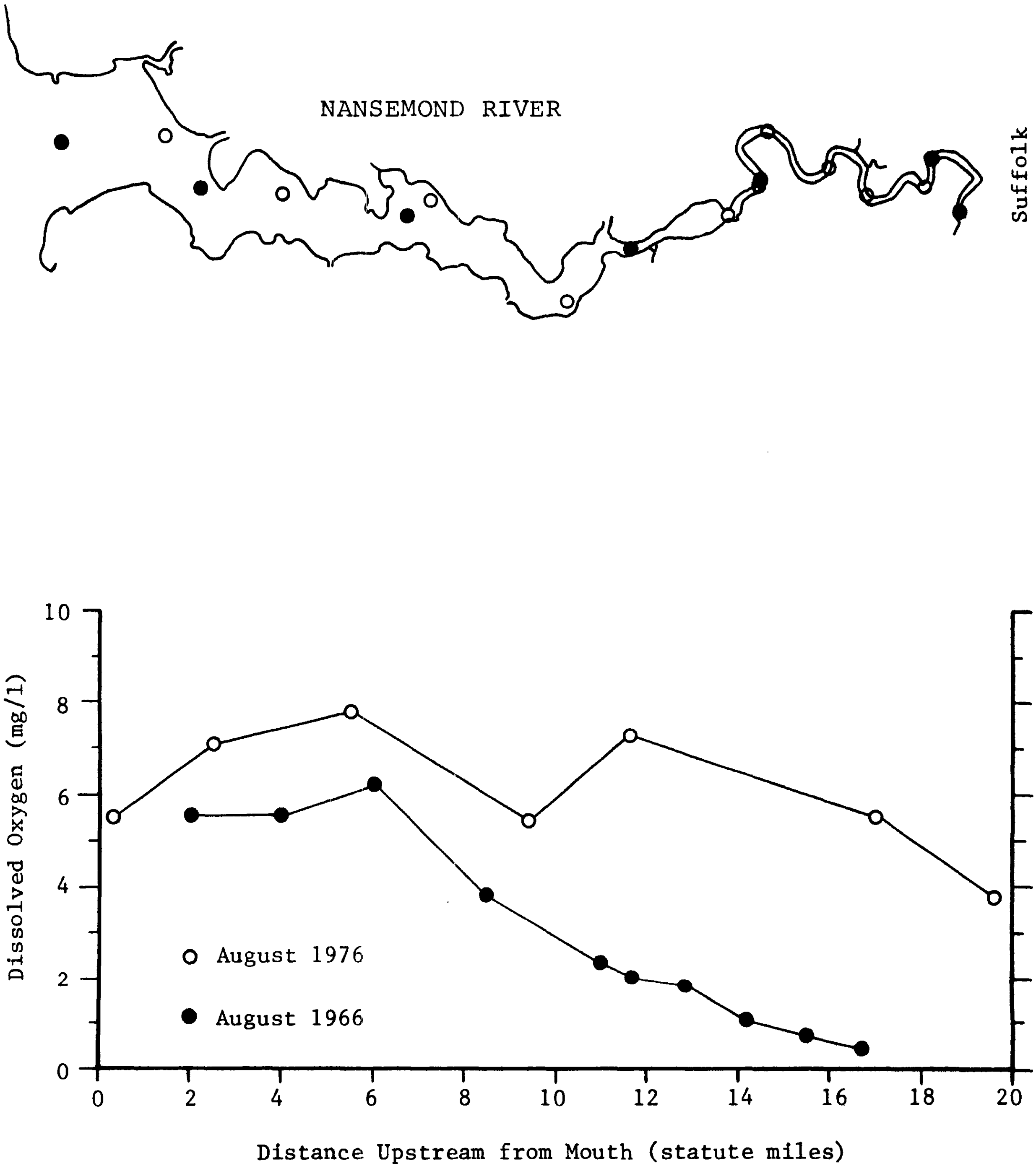

Figure 25. Comparison of dissolved oxygen profiles for late August in 1966 and 1976.

single rain event can equal all point source loads for several weeks or even months.

A one-dimensional, real-time model with intra-tidal features was applied to the Nansemond River in the Cooperative State Agencies Program between the State Water Control Board and the Virginia Institute of Marine Science. This model was calibrated to reproduce the concentration distribution of salinity, nitrogenous biochemical oxygen demand (NBOD), carbonaceous BOD (CBOD) and dissolved oxygen. This model was adopted for use in the 208 study and reverified using field data gathered in August 1976. Verification projections showed reasonable agreement with field data.

Future field and/or modelling studies of the Nansemond should include measurement of base freshwater flow, including flow from the several water supply reservoirs, and nonpoint loads. The former can alter the salinity profile in the river while nonpoint loads appear to be a major cause of the degraded water quality conditions. The Nansemond River also would provide an excellent case study to follow the response of an estuarine system when point loads are removed.

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APPENDIX A

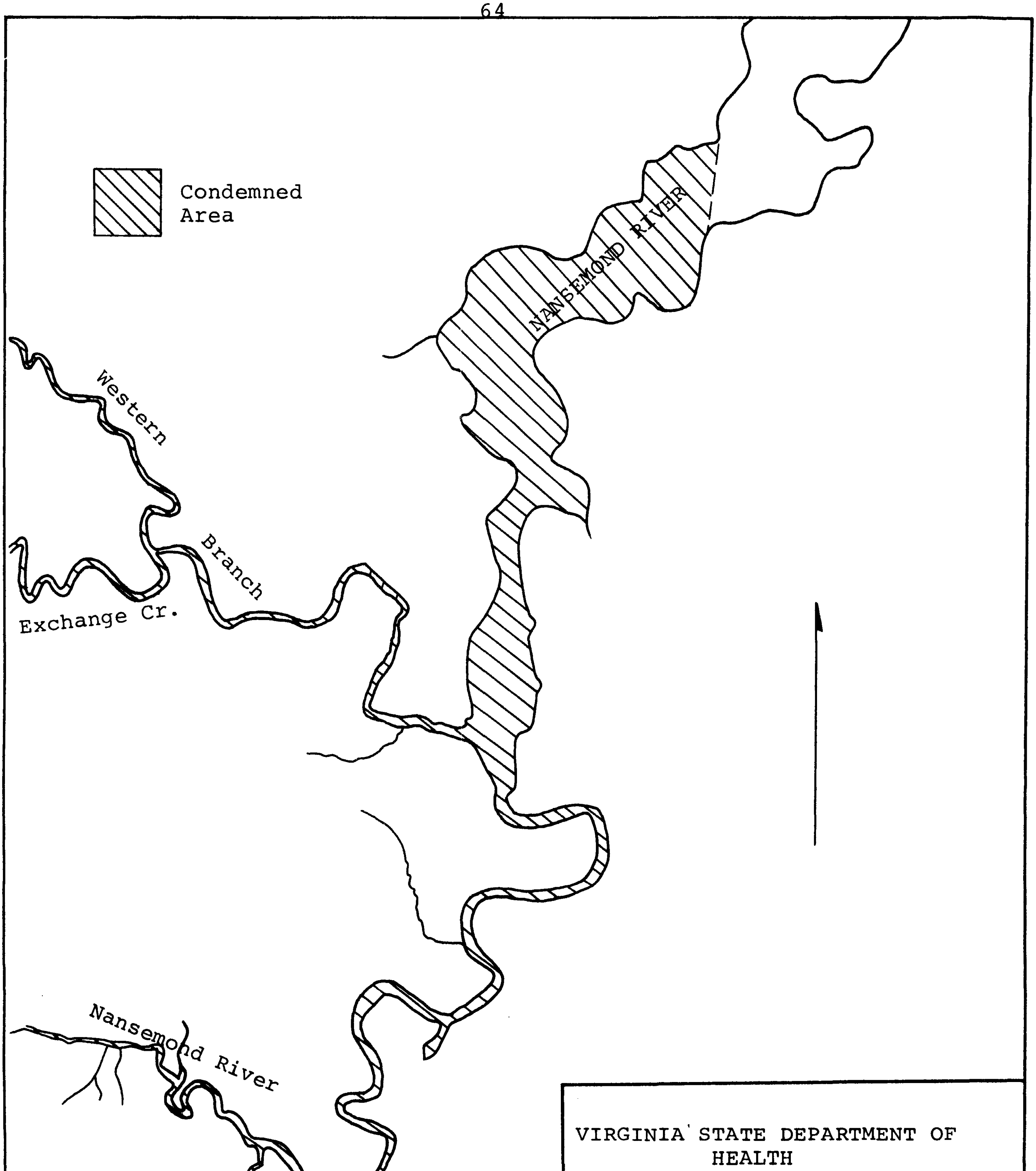
Shellfish Condemnation Zones

Area 8 - Nansemond River - Nov. 15, 1933
Revised - Mar. 24, 1975

Area 46 - Bennett Creek - Sept. 12, 1953

Area 77 - Knotts Creek - March 9, 1972

Area 30 - Pig Point - November 6, 1963

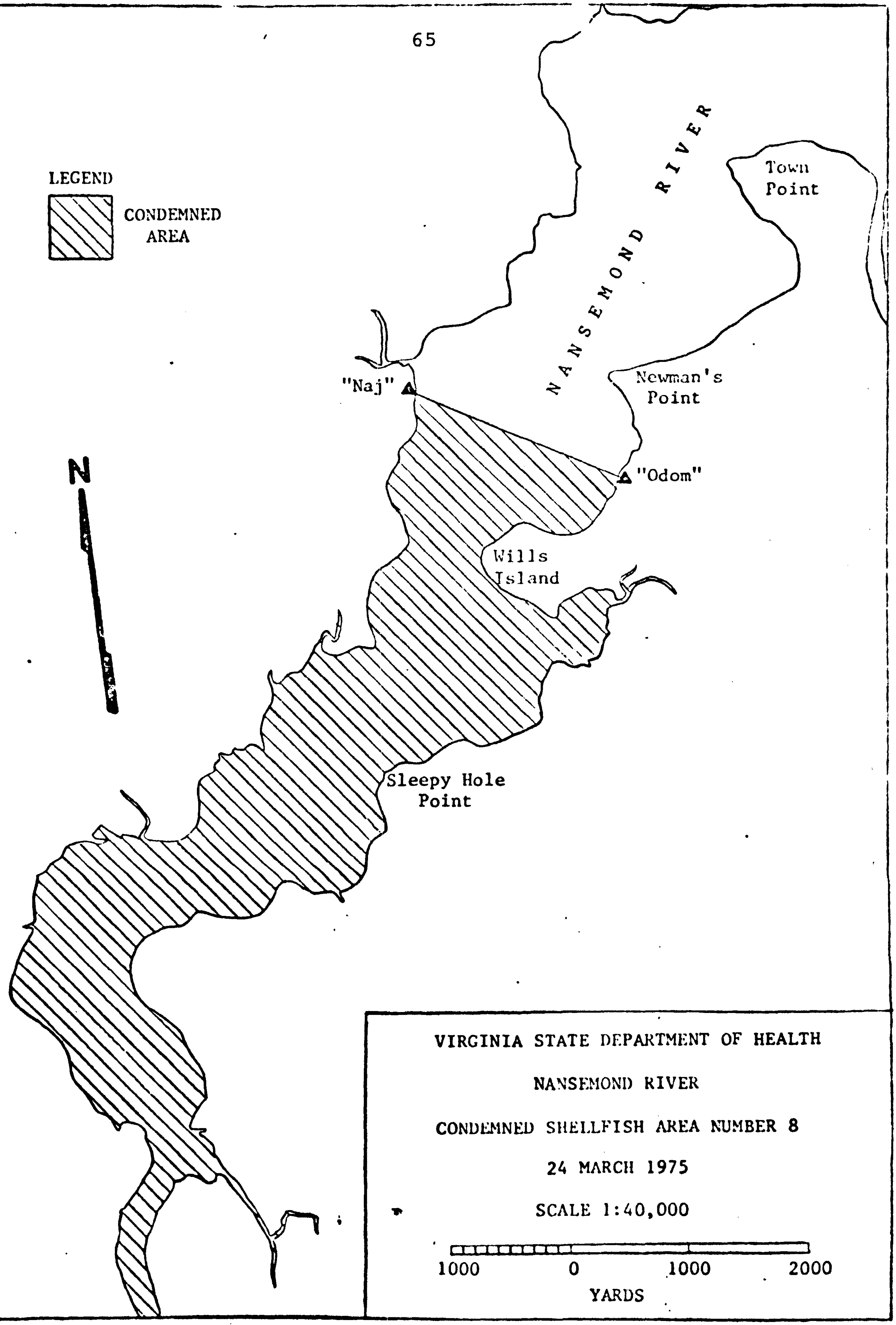


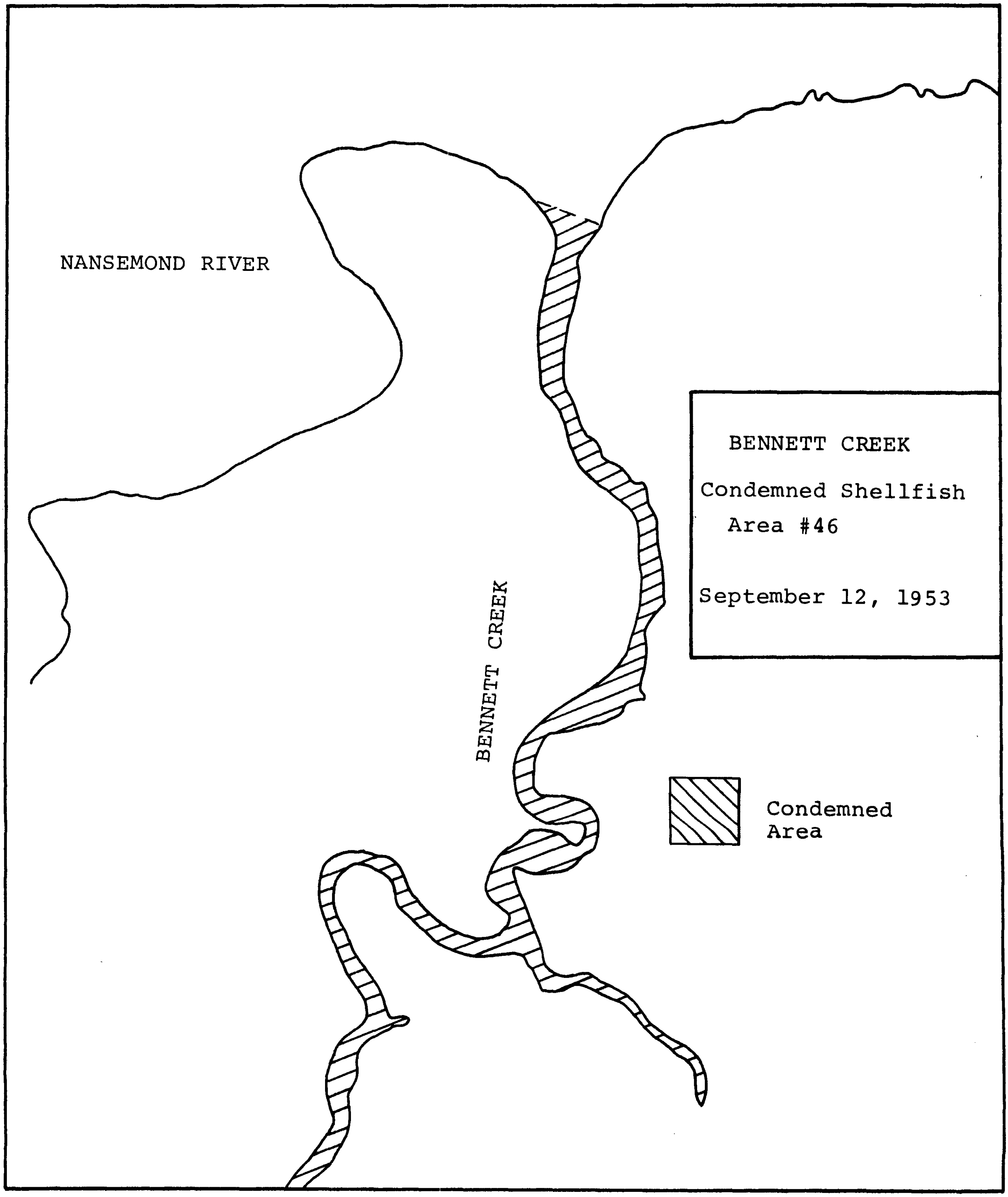
VIRGINIA STATE DEPARTMENT OF
HEALTH

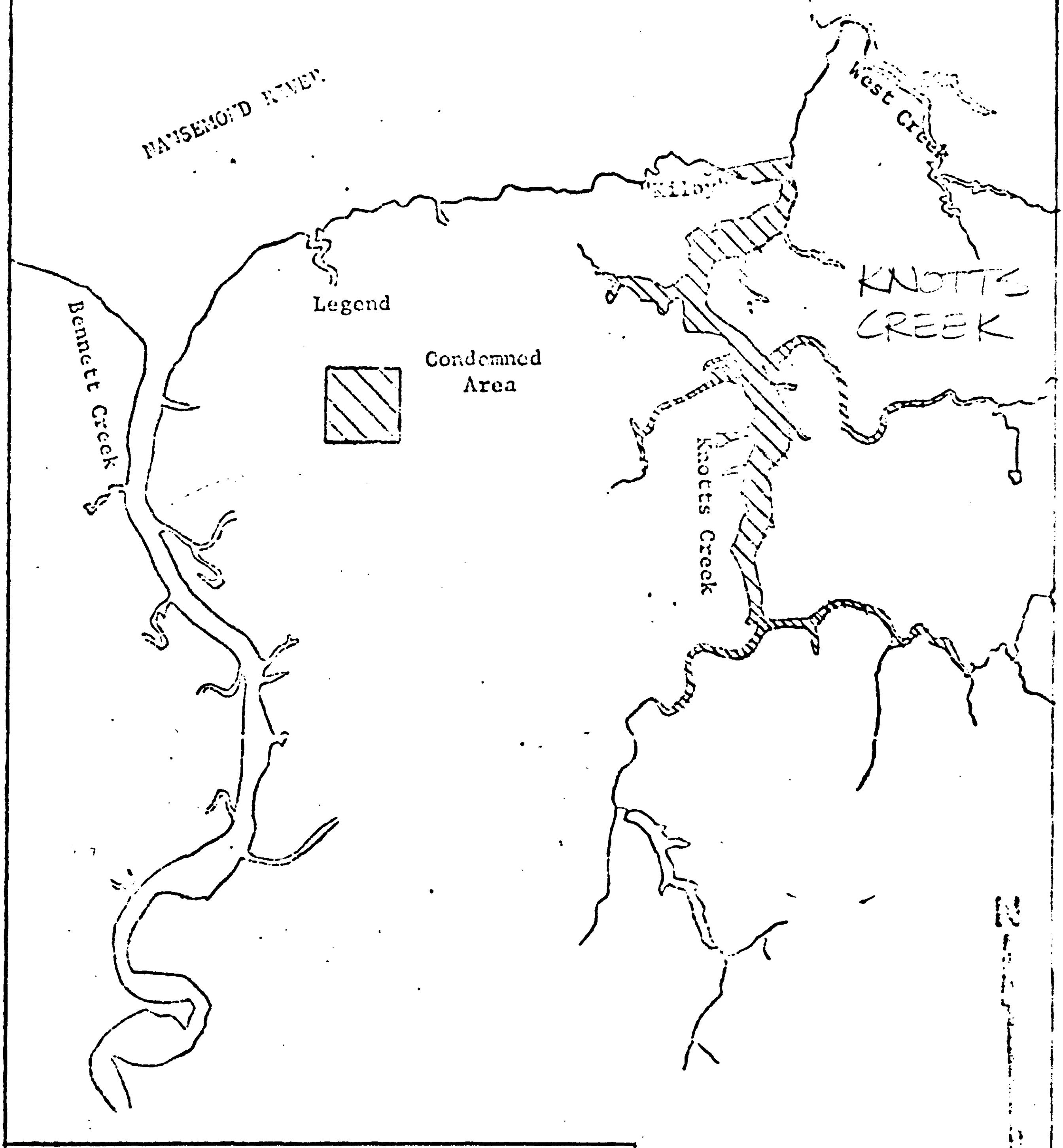
NANSEMOND RIVER

Restricted Shellfish Area #8

November 15, 1933


LEGEND
CONDEMNED AREA
N
NANSEMOND RIVER
Town Point
Newman's Point
"Naj"
"Odom"
Wills Island
Sleepy Hole Point
VIRGINIA STATE DEPARTMENT OF HEALTH
NANSEMOND RIVER
CONDEMNED SHELLFISH AREA NUMBER 8
24 MARCH 1975
SCALE 1:40,000
1000
0
1000
2000
YARDS


NANSEMOND RIVER
BENNETT CREEK
BENNETT CREEK
Condemned Shellfish
Area #46
September 12, 1953
Condemned
Area



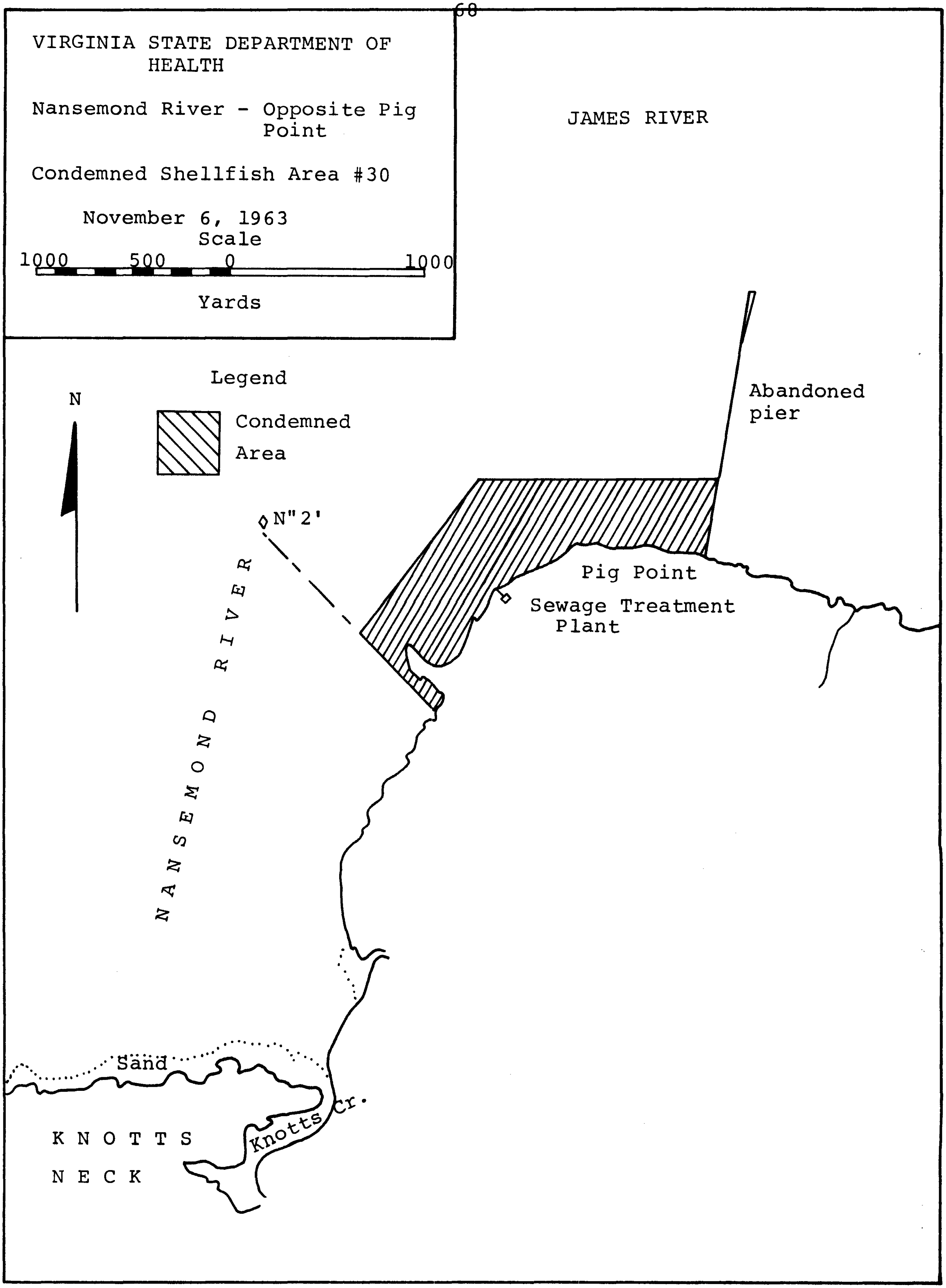
VIRGINIA STATE DEPARTMENT OF HEALTH
Nansemond River: Knotts Creek

Condemned Shellfish Area No. 77

9 March 1972

Scale 1:24,000

1000 0 1000 2000 3000
Feet


VIRGINIA STATE DEPARTMENT OF HEALTH
Nansemond River - Opposite Pig Point
Condemned Shellfish Area #30
November 6, 1963
Scale
1000 500 0 1000
Yards
JAMES RIVER
Legend
N
Condemned Area
Abandoned pier
N"2'
Pig Point
Sewage Treatment Plant
NANSEMOND RIVER
Sand
Knotts Cr.
KNOTTS NECK