FINAL REPORT

DELAWARE ESTUARY PROGRAM

INVENTORY AND ASSESSMENT OF HISTORIC WATER QUALITY DATA SETS

PRELIMINARY CHARACTERIZATION AND RESEARCH TOPIC 1: GENERAL WATER QUALITY ASSESSMENT AND TREND ANALYSIS OF THE DELAWARE ESTUARY

PART ONE: STATUS AND TREND ANALYSIS

By

NAJARIAN ASSOCIATES, L.P.
IN COLLABORATION WITH COLUMBIA UNIVERSITY, NEW YORK
DEPARTMENT OF CIVIL ENGINEERING AND ENGINEERING MECHANICS

Submitted To

DELAWARE RIVER BASIN COMMISSION
PLANNING BRANCH
P.O. BOX 1467
WEST TRENTON, N.J. 08628

MAY 1991

NAJARIAN ASSOCIATES, L.P.
1 Industrial Way West, Eatontown N.J.

Final Report

Delaware Estuary Program
Preliminary Characterization and Research Topic 1:

GENERAL WATER QUALITY ASSESSMENT AND TREND ANALYSIS OF THE DELAWARE ESTUARY

PART ONE: STATUS AND TRENDS

By:
Georgia R. Marino
Joseph L. DiLorenzo, pH.D.
Howard S. Litwack
Tavit O. Najarian, Sc.D.
M. Llewellyn Thatcher, Sc.D.

Submitted to:

Delaware Estuary Program
USEPA/Delaware River Basin Commission

May, 1991

Najarian Associates, L.P.
Eatontown, NJ

EXECUTIVE SUMMARY

This report presents a review and evaluation of our present understanding of general water quality conditions in the Delaware Estuary. Towards this objective, an inventory and analysis was performed on historic water quality data sets available for the subject estuary. Results of this analysis were used to define the water quality status of the Delaware Estuary, and to describe both longitudinal and temporal trends. In addition, this study examined the possible masking effects of various external factors such as seasonality, tidal forcing, and freshwater inflow. Work Products of this study include: (a) a study report of Status and Trends in Delaware Estuary water quality (Part I); and (b) an annotated bibliography of historic water quality data reports for the Delaware Estuary (Part II).

To develop the annotatated bibliography, data searches were conducted among a myriad of sources, including: university and agency libraries; university databases; computerized information retrieval services; and federal, state, and local agency. Data sources and reports were screened for applicability to this study. For those reports selected for use in the bibliography, experimental-design specifications were reviewed. These specifications include data type, sampling design, analysis methods, data processing, and companion studies. Results of these studies were then summarized within the Annotated Bibliography.

In the course of the data search, it was determined that the most consistent, long-term computerized database was maintained by the Delaware River Basin Commission (DRBC) on the USEPA STORET system. This database consists primarily of data collected by both DRBC and the Philadelphia Water Department. These data were retrieved and organized into a project database using the Statistical Analysis System (SAS) software on the Najarian Associates VAX Computer Network. The use of a SAS database allowed a single program to be used for the organization, analysis and plotting of approximately 24,000 water quality records. SAS was then used to sort these data into subsets catagorized according to various environmental conditions. These sorting features allowed for analyses of status and trends among data collected under "similar" conditions of tide, temperature, and antecedant freshwater-inflow conditions.

Status and trends in Delaware Estuary water quality data were examined in two basic ways. First, an estuarine-wide analysis was conducted using graphical techniques. This allowed visual assessments of status and trends. Next, statistical methods were used to define the water quality status and temporal trends at individual stations within each defined estuarine zone. This method allowed the raw data at any station

Statistically significant decreasing trends for ammonia, TKN and total phosphorus were found throughout the Estuary. Increasing trends for nitrate were found within portions of both the Tidal River and Transition Zones, but not in the Bay Zone. By contrast, fecal coliform levels showed a statistically significant decline in the Tidal River Zone and Transition Zone, but again no significant trends were found in the Bay Zone. A statistically significant improvement in dissolved oxygen concentrations was found in both the Lower Tidal River Zone and in the Transition Zone. However, no statistically significant DO trends were found in the Upper Tidal River Zone or in the Bay Zone, although there were some indications (statistically insignficant trends) of declining dissolved oxygen concentrations in those regions.

Overall, this study has demonstrated that water quality in the Delaware Estuary has improved dramatically over the past three decades - a period of major STP upgrading. Minimum summer DO levels, which in areas approached 0.1 mg/l during the 1970s, now exceed 4 mg/l. Throughout the Delaware Estuary, average summer DO concentrations meet the applicable standards. Within the lower Tidal River Zone, DO concentrations still remain somewhat depressed, although average summer DO concentrations conform to the local standard of 3.5 mg/l. Data for the last few years suggest continued improvement within the Tidal River Zone. Like the DO data, data for nitrogen species are generally indicative of improvements in water quality. Both total ammonia and total nitrogen concentrations have declined throughout most of the Estuary. However, nitrate levels have increased within the Tidal River Zone and within portions of the Transition Zone. Fecal coliform levels have declined throughout most of the estuary but remain somewhat elevated in a small reach of the Tidal River Zone.

Thus, study results clearly indicate that water pollution control policies implemented in the Delaware Estuary over the last two decades have had a positive influence on the recovery of water quality conditions in both the Tidal River Zone and Transition Zone. Future monitoring and assessment studies will be needed to determine whether the full benefit of these improvements have been realized.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF FIGURES

APPENDIX FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Objectives

This report summarizes a study of historic water quality data sets pertaining to the Delaware Estuary - one of four first-year projects sponsored by the current Delaware Estuary Program (DEP). The overall goal of this study is to review and evaluate our present understanding of general water quality conditions in the Delaware Estuary. This information is needed for the development of a comprehensive conservation and management plan for the Delaware Estuary system.

In recent years, significant progress has been made in reducing certain point-source pollutant loadings to the Delaware Estuary. Several of the Delaware Estuary's major municipal wastewater treatment plants have been upgraded to secondary levels in the last few years. Some effects of these loading reductions on Delaware Estuary water quality have been documented in previous observational studies (e.g., Albert, 1988). However, historic Delaware Estuary monitoring programs have varied greatly in both their design and scope. Comprehensive inventories and analyses of these historic data sets have not been previously performed. For this reason, the present study was conducted to inventory, review and evaluate general water quality data for the subject estuary and to identify trends in these data.

1.2 General Approach

The general approach used in the inventory segment of this study was to identify and collect general water quality data from all obvious sources, including USGS and NOAA/NODC baseline studies, STORET, Delaware River Basin Commission (DRBC) studies, local universities, and both state and interstate agencies. These data sets were inventoried and reviewed, and a search was made using literature and agency contacts toward obtaining additional data from less-obvious sources. An annotated bibliography was prepared (Part II), documenting the quantity, quality, availability, and format of relevant historic data sets.

Methodologies utilized in the water quality assessment portion of this study could be complicated by the fact that long-term trends in estuarine water quality may be masked by natural short-term estuarine variability. Indeed, Delaware Estuary water quality conditions vary both spatially and temporally in response to natural and anthropogenic influences. Studies have shown that physical factors such as tides, wind, and river flow induce variability in constituent concentrations at time scales ranging from several minutes to years. For example, Sharp et al. (1986) demonstrate that tides in the Delaware Estuary regulate vertical mixing processes and thus introduce intratidal variability in the vertical distribution of constituents such as salinity and dissolved oxygen. Fortnightly variations in tidal currents also may regulate vertical exchange at lower frequencies (intertidal variability). Subtidal volume exchange processes - between the Delaware estuary and either the adjacent Atlantic Ocean or the Upper Chesapeake Bay - induce variability at time scales ranging from days to weeks (Wong and Garvine, 1984; Najarian et al., 1980).

Seasonal variability may arise from long-term variations in fresh water inflow and attendant salt intrusion effects (Thatcher and Najarian, 1981). Seasonal variation also is found in concentrations of temperature-dependent water quality parameters such as dissolved oxygen. Biochemical processes may act in concert with these hydrodynamic and seasonal controls to induce additional water quality variability. For example, Pennock (1985) demonstrates that spring phytoplankton blooms in the mid-Estuary are regulated by shallowing of the surface mixed-layer associated with enhanced river flow. Also, a study by Wofsy et al. (1981) indicates that variations in freshwater inflow to the tidal river may inversely affect the rate of nitrification. In some cases, these natural influences may collectively confound the detection of long-term water quality trends.

In light of these potential problems, the following general approach was used in the water quality assessment segment of this study. First, seasonal analyses were conducted for dissolved oxygen in all cases. Dissolved oxygen is the water quality parameter that is the most seasonally dependent. Next, the influence of factors such as tidal variation and freshwater inflow were studied to determine if these factors significantly affected the analysis of status and trends. To this end, surrogates, such as the tidal current interval, were developed as classification varables. These variables were then used to subdivide the data and to test, using graphical and statistical techniques, whether a substantial portion of the variance was explained using these factors.

Overall, the trend analysis was designed to discern long-term trends from short-terms variability. This could assist in evaluating the results of current management practices.

2. DESCRIPTION OF THE STUDY AREA

2.1 Delaware Estuary Features

Basic features of the Delaware Estuary and its watershed (Figure 2.1) influence observed water quality conditions. Salient features of this system are reviewed below, followed by a description of specific methodologies employed in this study.

2.1.1 General Delaware River and Estuary Features

Reservoir storage capacity of the Delaware River Watershed exceeds 271 billion gallons and provides up to 900 million gallons per day of potable water supplies to the New York City area (Bryant and Pennock, 1988). Most of these water supplies are captured at the New York Reservoirs at Cannonsville, Pepacton and Neversink. Numerous other reservoirs on the tributaries are operated to ensure conservation flows (required to protect aquatic life) and to keep the "salt front" in the estuary from endangering potable water supplies taken from public aquifers and from the region of Camden, Philadelphia and upstream (above river kilometer (RK) 158).

The two major freshwater tributaries to the Delaware Estuary, the nontidal Delaware River and the Schuylkill River, contribute approximately 58% and 15%, respectively, of the total freshwater discharge to the Delaware Estuary (Sharp and Wong, 1986). Annual mean flows from these two inflows to the upper Delaware Estuary are 332 m^3/sec and 77 m^3/sec, respectively (Sharp et al., 1982). Variability of these flows can be significant. For example, extreme historic Delaware River flows at Trenton range from a maximum of 9,316 m^3/sec to a minimum of 33.4 m^3/sec (USGS, 1987). Numerous smaller tributaries border the middle and lower Estuary (Figures 2.2 and 2.3).

The Delaware Estuary is a drowned river valley coastal plain estuary. As such, the Delaware Estuary can be classified in a sequence of estuarine types. Under mean-flow, slack-tide conditions, portions of the Delaware Estuary have been classified as a vertically homogeneous estuary (Biggs, 1978). Under high-flow conditions, the Delaware estuary exhibits vertically stratified characteristics (Sharp et al., 1986).

Extensive hydrographic surveys of the Delaware Estuary have been reported recently by Kawabe et al. (1990). These data, averaged over the period 1986-1988, indicate only partial vertical stratification of the water column in the middle of the Estuary. Also, strong longitudinal density gradients are reported, with density varying from 0 to 20 sigma-t units. Seasonally averaged salinity profiles are reported to be similar for each year over the study period.

Historically, water quality conditions in the Delaware Estuary have been degraded primarily by a combination of municipal sewage discharges and industrial influences. Presently, pollutants are introduced directly into the Delaware Estuary from a myriad of sources, including 300 combined sewer overflows and 90 major municipal or industrial dischargers (Albert, 1988). A graphical inventory of current allocations for BOD discharges in the Delaware Estuary is given in Figure 2.4.

As illustrated in Figure 2.4, the major municipal discharges are located along a segment of the Delaware Estuary extending approximately from RK 115 through RK 168 (river mile 90-104). These include: the Philadelphia - Northeast WPCP (RK 167.7); Camden County Municipal Utilities Authority - Delaware No.1 (RK 157.5); Philadelphia - Southeast WPCP (RK 155.6); Philadelphia - Southwest WPCP (RK 145.9); and Wilmington City (RK 115.5). A history of sewage-treatment upgrades for these plants is displayed in Figure 2.5 (After Bryant and Pennock, 1988). Also as shown in Figure 2.4, major industrial discharges are distributed throughout the middle and upper Delaware Estuary. These discharges include plants producing steel, chemicals, refined oil products, and textiles.

The Delaware Estuary is also one of the largest ports in the United States. Commercial shipping activities and associated industries also have influenced the water quality of this system.

2.1.2 Delaware Estuary Zones

The Delaware Estuary system can be divided into three distinct regions (Figure 2.2), based on general patterns of salinity, turbidity, and biological productivity. The uppermost region, the Tidal River Zone, is a freshwater-tidal segment. It extends about 86 km (53 mi)from the head of tide at Trenton, New Jersey (RK 214.6), to Marcus Hook, Pennsylvania (RK 128.7). Below the Tidal River Zone lies the Transition Zone. This region extends approximately 42 km (26 mi) from Marcus Hook (RK 128.7) to Artificial Island, New Jersey (Rk 86.9). The Transition Zone is characterized by relatively low salinities, high turbidity, and relatively low biological productivity. The lowermost region, the Delaware Bay Zone, extends from below Artificial Island to the mouth of Delaware Bay (RK 0). Average salinities in this mesohaline region varied from approximately 28 ppt at the mouth to 8 ppt at the upper boundary during the period 1986-1988. (Kawabe et al., 1990).

The Delaware River Basin Commission (DRBC) has divided the Delaware River and Estuary into 6 separate water quality zones. The Tidal River Zone described above contains DRBC Zones 2, 3, and 4. The Transition Zone contains most of DRBC Zone 5. The Delaware Bay Zone contains the remaining portion of DRBC Zone 5 and all of DRBC Zone 6. Designated uses and water quality standards for these DRBC zones are reviewed below.

Located within the upper Tidal River Zone, DRBC Zone 2 extends from the head of tide (located at the Trenton, New Jersey - Morrisville, Pennsylvania, Pennsylvania

Bridge at RK 214.6) to just below the mouth of Pennypack Creek (near the Tacony-Palmyra Bridge at RK 174.4). At Torresdale, PA, the City of Philadelphia withdraws over 200 million gallons of water per day for potable uses. Smaller municipal and industrial water supply intakes are also found on this portion of the estuary (DRBC, 1990a).

The designated uses of Zone 2 are (DRBC, 1986):

- Public and Industrial Water Supply after reasonable treatment
- Agricultural Water Supply
- Maintenance and propagation of resident fish and other aquatic life; passage of anadramous fish; and wildlife
- Recreation from RK 214.6 to RK 189.6 and secondary contact recreation from RK 189.6 to RK 174.4
- Navigation

Water Quality objectives in Zone 2 are (DRBC, 1986):

1. Dissolved Oxygen
   a. 24-hour average shall not be less than 5.0 mg/l.
   b. From April 1 to June 15 and September 16 to December 31, seasonal average shall not be less than 6.5 mg/l.

2. Temperature
   a. Shall not exceed 5°F (2.8°C) above the average 24-hour temperature gradient during the 1961-1966 period or,
   b. A maximum of 86°F (30°C), whichever is less.

3. pH - Between 6.5 and 8.5

4. Fecal Coliform
   a. Maximum geometric average of 200 per 100 ml above RK 189.6 and of 770 per 100 ml below RK 189.6.

The non-tidal Delaware River is the major tributary to Zone 2. Other tributaries include Crosswicks Creek, Assiscunk Creek, Rancocas Creek, Neshaminy Creek, Poquessing Creek, and Pennypack Creek. Zone 2 supports recreational water uses. Power boating, sailing and fishing predominate while swimming occurs in undesignated areas (DRBC, 1990a).

Within the middle reaches of the Tidal River Zone, DRBC Zone 3 extends from the seaward end of Zone 2 (at RK 174.4) to RK 152.9 (below the mouth of Big Timber Creek on the New Jersey side of the estuary). In the lower Tidal River Zone, DRBC Zone 4 extends from this latter location to RK 126.8, the Pennsylvania-Delaware boundary. The salt front extends into Zone 4 and, under very dry conditions, may extend into Zone 3. Salinity intrusion during drought conditions is of concern for both the protection of industrial water supplies and for the preservation of coastal-plain aquifer supplies in Southern New Jersey (DRBC, 1990a)

The Water Uses to be Protected for Zone 3 are (DRBC, 1986):

- Public and Industrial Water Supply after reasonable treatment
- Agricultural Water Supply
- Maintenance of resident fish and other aquatic life; passage of anadramous fish; and wildlife
- Secondary contact recreation
- Navigation

Protected uses are the same for Zone 4, except that public water supply and agricultural water supply are not protected uses.

Water Quality objectives for Zones 3 and 4 are (DRBC, 1986):

1. Dissolved Oxygen
   a. 24-hour average shall not be less than 3.5 mg/l.
   b. From April 1 to June 15 and September 16 to December 31, seasonal average shall not be less than 6.5 mg/l.

2. Temperature
   a. Shall not exceed 5°F (2.8°C) above the average 24-hour temperature gradient during the 1961-1966 period or,
   b. A maximum of 86°F (30°C), whichever is less.

3. pH - Between 6.5 and 8.5

4. Fecal Coliform - Maximum geometric average of 770 per 100 ml.

The Transition Zone (RK 129 - RK 87) contains most of DRBC Zone 5, which extends from RK 126.8 (at Marcus Hook) to RK 77.5 (at Liston Point, Delaware). Zone 5 is used for many different recreational activities including boating, fishing and some swimming. Several wildlife management areas have been designated in this zone. The lower portion of the zone is an important sport and commercial fishery resource (DRBC, 1990a).

The Water Uses to be Protected for Zone 5 are (DRBC, 1986):

- Industrial Water Supply after reasonable treatment

- Maintenance of resident fish and other aquatic life; propagation of resident fish from RK 112.6 to RK 77.6; passage of anadramous fish; and wildlife

- Secondary contact recreation from RK 126.8 to RK 95.7; recreations from RK 95.7 to RK 77.5

- Navigation

Water Quality objectives for Zone 5 are (DRBC, 1986):

1. Dissolved Oxygen
   a. 24-hour average shall not be less than 3.5 mg/l at RK 126.8; 4.5 mg/l at RK 112.6; and 6.0 mg/l at RK 95.7.
   b. From April 1 to June 15 and September 16 to December 31, seasonal average shall not be less than 6.5 mg/l.

2. Temperature
   a. Shall not exceed 5°F (2.8°C) above the average 24-hour temperature gradient during the 1961-1966 period or,
   b. A maximum of 86°F (30°C), whichever is less.

3. pH - Between 6.5 and 8.5

4. Fecal Coliform
   a. Maximum geometric average of 770 per 100 ml from RK 126.8 to RK 95.7 and of 200 per 100 ml from RK 95.7 to RK 77.6.

Within the Delaware Bay Zone (RK 87-0) lies DRBC Zone 6, which extends from Liston Point (at RK 77.5) to the mouth Delaware Bay (KM 0.0). Swimming, sailing and boating are common activities throughout the Bay. Commercial and recreational fishing also occur (DRBC, 1990a).

Protectect uses and water quality standards are the same in DRBC Zone 6 as in the seaward portion of DRBC Zone 5 (DRBC, 1986).

2.2 Watershed Features

2.2.1 General Watershed Features

The Delaware River Watershed (Figure 2.1) drains 33,000 sq. km. (13,500 sq. mi.), covering portions of four states: New York, New Jersey, Pennsylvania, and Delaware. The upper watershed area comprises Appalachian mountain plateaus and hilly piedmont areas; the lower watershed drains the relatively level Coastal Plain. The estuarine watershed includes four densely populated, municipal regions: Philadelphia, Pennsylvania; Trenton and Camden, New Jersey; and Wilmington, Delaware. Tidal wetlands flank the lower terminus of the watershed surrounding the Delaware Estuary. The nation's second largest complex of oil-refining and petrochemical plants are located along these shores.

Agricultural land use is widespread throughout this watershed. In addition, the Delaware River Basin also is among the most highly industrialized watersheds in the United States. Industrial development is concentrated in two areas of the watershed: the lower Lehigh River Valley, and along the stretch of the Delaware River from Trenton to Philadelphia (Tarr and McCurley, 1984). This stretch includes the highly industrialized city of Philadelphia, with its extensive production of chemicals, metals, textiles, and paper. Historically, the growth of the anthracite coal industry in the Lehigh/Schuylkill Valley region resulted in the industrialization of the Delaware River Basin and the growth of the cities of Philadelphia, Trenton, and Camden. Coal mining activities also resulted in the accumulation of coal wastes in local streams and rivers.

The major population centers of the Delaware Estuary are located along the shoreline of a 50-mile segment of the River extending from Philadelphia, Pennsylvania to Wilmington, Delaware. In the century between 1880 and 1980, the total population of the Delaware Estuary watershed grew from 2,191,295 to 7,358,462 - an increase of about 236%. Urban growth accounted for much of this increase. For example, urban dwellers comprised about 63.7% of the population in 1900, compared to 80.6% of the population in 1980. However, the urban population also began to decentralize in the last century, with the proportion living in central cities declining from 69.5% in 1920 to 62.2% in 1940. This trend toward decentralization has continued in recent years. From 1950 to 1980 the urbanized land area in the estuarine watershed increased from 460 square miles to 3,681.8 square miles, while the average population density of the urbanized area declined from 8,000.1 to 3681.8 inhabitants per square mile (Tarr and McCurley, 1984).

Though still predominant in much of the watershed, agricultural land in the Delaware River Watershed has declined significantly over the past century. Between 1880 and 1978 about 58.6% of the total land in farms was lost. Much of this trend is the result of the retirement of unproductive farm land. Closer to the major urban areas, most of the farmland was converted to urban and suburban land uses. Large areas of the Delaware Estuary watershed have remained agricultural, particularly in New Jersey and Delaware (Tarr and McCurley, 1984).

2.2.2 Watershed Features of Each Estuary Zone

The watershed area of the upper Tidal River Zone (DRBC Zone 2) is dominated by industrial and urban/suburban land uses. Located at the head of DRBC Zone 2 are the urbanized areas of Trenton, NJ and Morrisville, PA. These areas have a combined population exceeding 100,000. Seaward of Trenton, the DRBC Zone 2 watershed is dominated by small towns, along with freshwater wetlands, industrial plants, and highway complexes. Suburbanization is encroaching further upon remaining open space areas. The US Steel Fairless Works is located on the Pennsylvania side of the river. Philadelphia and its surrounding suburban area occupy the lower portions of this zone (DRBC, 1990a).

Watershed conditions in the middle and lower Tidal River Zone (DRBC Zones 3 and 4) include the heavily industrialized Philadelphia-Camden metropolitan area. This stretch of river historically has been one of most polluted in the nation due, in large measure, to the discharge of both industrial and municipal wastewater treatment plants (DRBC, 1990a), and combined sewer overflows.

The Schuylkill River is the major tributary to the Delaware Estuary in DRBC Zones 3 and 4. This River drains 15% of the Delware River basin. Other major tributaries include Pennsauken Creek, Big Timber Creek, Mantua Creek, and Raccoon Creek in New Jersey as well as Frankford and Darby Creeks in Pennsylvania. The industrial nature of these zones preclude most recreational activities. Fishing does occur here, and a variety of fish can sometimes be found (DRBC, 1990a).

In the watershed of the transition area (i.e., DRBC Zone 5), Wilmington Delaware and its surrounding suburban area is the only major urban center in this zone. Land use in and around Wilmington includes commercial and industrial port activities, and various other industries. A small portion of the city is served by combined sewers that overflow into the River during intense rainfalls. The remainder is characterized by wetlands, small towns, agricultural areas, and several large landfill and dredge spoil disposal areas (DRBC, 1990a).

Two major power plants are located on Artifical Island (RK 87) in this zone: Salem Generating Station nuclear power plant; and the Hope Creek Generating Station. Major tributaries in this zone include: Oldmans Creek, Salem Creek and Alloways Creek on the New Jersey side; and the Christina River, Brandywine Creek, and Appoqunimink Creek in Delaware. The Chesapeake and Delaware Canal has its eastern terminus at Delaware City, Delaware (DRBC, 1990a).

The Delaware Bay Zone watershed is comprised of small towns, farmlands, and salt marshes. Dover Delaware, with a population of 25,000, is the largest city in the watershed to this zone. Like most of the cities in this area, Dover is also located upland of the Bay boundaries. The bay shoreline consists primarily of salt marshes, many of which are protected as wildlife management areas. Beach resort areas are located near the mouth of the Bay (DRBC, 1990a).

2.3 History of Pollution in the Delaware Estuary

As noted above, the portion of the Delaware River from the head of tide at Trenton seaward to Wilmington is highly industrialized. The anthracite coal industry was a crucial factor in the industrialization of the Schuykill River Basin and the growth of adjacent urban areas. This industry caused early pollution of the River, although upstream dams contained much of these wastes. Industrialization also led to early concern about water quality. In 1832, a Philadelphia law prohibited the discharge of "any putrid or noxious matter from any dye house, still house, tan yard or manufactury that would cause impurities in the rivers". An ordinance from 1847 restricted the manufacturing or refining of certain chemicals in an area along the Schuylkill River. By 1917, the Delaware River was said to receive one of largest and most diverse industrial waste loads of any river in the nation (Tarr and McCurley, 1984).

The growing petroleum industry in the Philadelphia and Wilmington areas added another source of river pollution, causing, at least by some reports, oil slicks in the River and a drastic reduction in fishing. The River also received the mostly untreated sewage of the urbanized areas. By 1917, the tidal portion of the River received sewage from an aggregate population of more than two million people. Low DO levels were noted from the mid-1800s and high bacterial counts were found in the early 1900s. The Delaware Bay, however, remained relatively clean and maintained an edible shellfish population (Tarr and McCurley, 1984).

The water quality of the Delaware River continued to deteriorate as population and industrial growth continued. By 1941, a 22-mile portion of the River surrounding the Philadelphia and Camden areas was subject to gross pollution, with average DO levels at about 8 percent of saturation during the summer. The recovery in DO concentrations began at a point 74 km (46 miles) seaward of Philadelphia (Tarr and McCurley, 1984).

In 1936, the Interstate Commission of the Delaware River Basin (INCODEL) was formed by four states: Delaware, New Jersey, Pennsylvania, and New York. This advisory commission initiated a basin-wide cleanup of the Delaware Estuary. Prior to its formation, all wastewater introduced to the Delaware Estuary was untreated except for: (a) the city of Trenton; and (b) a small section of Philadelphia which had primary treatment plants (Albert, 1988). Through INCODEL, interstate water quality standards were developed and construction of new sewage treatment plants began throughout the Delaware River Basin.

By 1950 it was found that 282 municipal sewage systems serving 3.4 million people discharged into the Delaware River and its tributaries. Less than half of these discharges were treated. Also, 393 industrial sources discharged directly into the River and its tributaries. It was estimated that 60% of this load was discharged in the Philadelphia-Camden area. During the 1950s, sewage treatment plant construction accelerated. By 1960, all of the major cities in the basin had plants which treated wastewater to primary or secondary level. Industrial loads also began decreasing. However, in 1964 about half of the municipal and industrial discharges were untreated and most of the effluent from smaller municipalities was not disinfected, (Tarr and McCurley, 1984; Albert, 1982).

In 1962, the Delaware River Basin Commission (DRBC) was created. Unlike INCODEL, DRBC is not an advisory agency, but rather, a regulatory authority for resource management. In 1968 the DRBC adopted higher water quality standards for the River and began to set wasteload allocations for first-stage oxygen demand (BOD_5). The overall estuarine allocation of first-stage oxygen demand was reduced from 773,000 lbs BOD_5 per day in 1958 to 399,000 lbs BOD_5 per day in 1981. At the same time, allocated loads in the Philadelphia area were increased from 276,500 lbs per day to 287,410 lbs/day. The wasteload allocations were based on the DRBC's determination of the assimilative capacity of the estuary. DRBC determined that first-stage oxygen demand must be limited to 322,000 pounds per day for the entire estuary to meet applicable water quality standards. The current allocations total 264,066 lbs per day which is 82% of the allowable loading. However, in Zone 2 the current allocations are 115% of the calculated assimilative capacity. Reallocation for this zone, and presumably the entire estuary, is pending completion of estuary-wide allocation studies (DRBC, 1990b).

In the period 1977-1981, significant improvement in Delaware Estuary water quality is reported (Albert, 1982). In particular, improvement in ambient DO levels were noted, although lower phosphate, organic nitrogen, and chlorophyll-a levels were also reported. Treatment plant upgrades have continued. For example, in mid-1987, the Camden County plant was upgraded to secondary level with disinfection. Finally, in a recent water quality assessment (DRBC, 1990a), the water quality status of the Delaware Estuary was reported as follows: 96% good water quality; 1% good to fair water quality; 2% fair water quality.

3. DATA RETRIEVAL AND COMPILATION

3.1 Information Retrieval Methods

3.1.1 Library and Bibliographic Database Searches

The initial task in this project was to "cast a wide net" that would capture most of the pertinent reports and databases regarding general water quality in the Delaware Estuary. This task involved searches of university libraries, agency libraries, and computerized bibliographic databases for relevant published scientific articles, "grey-literature" reports, government documents, unpublished Master's or Doctoral theses, and other sources. Libraries of Columbia University, Rutgers University, and University of Delaware were visited. Investigations at all institutions utilized computerized reference services and other reference tools. For example, the University of Delaware's computerized DELCAT reference system was used in this study. Likewise, NOAA's computerized reference service was accessed at their New Jersey Library facility located in Sandy Hook. Computerized bibliographic database searches were also made using the DIALOG retrieval system. The searches were conducted at Columbia University, using their CD-ROM system for the recent data. On-line searches were conducted of bibliographic databases not included on the CD-ROM and for older data. Bibliographic databases were searched using appropriate keywords of location (Delaware River and Delaware Estuary) and data type (water pollution and water quality). Table 3.1 summarizes the results of these searches. The retrieved records were reviewed to determine their applicability to the study of historic water quality data in the estuary. These references were selected for further review.

3.1.2 Agency Contacts

The second major data source for this project was provided by numerous agencies with jurisdiction over the water quality of Delaware River and Bay. These include:

federal agencies such as EPA and USGS; interstate agencies such as DRBC: state agencies, including the New Jersey Department of Environmental Protection (NJDEP), the Pennsylvania Department of Environmental Resources (DER) and the Delaware Department of Natural Resources (DNR); local agencies, such as the City of Philadelphia Water Department; and other agencies, such as the Philadelphia Academy of Natural Sciences. Each of these sources were contacted and solicited for relevant agency data, as summarized in the following paragraphs.

Table 3.1: Computerized Bibliographic Database Search Results

Database	Years Searched	# of Recs. Retrieved
COMPENDEX		
(On-Line)	1970-1985	36
(CD-ROM)	1985-present	15
NTIS		
(On-Line)	1964-1983	180
(CD-ROM)	1983-Present	30
WATER RESOURCES		
(On-Line)	1968-Present	233
OCEANIC ABSTRACTS		
(On-Line)	1964-Present	31
POLLUTION ABSTRACTS		
(On-Line)	1970-Present	84
SCIENCE CITATION INDEX		
(CD-ROM)	1983-Present	40

DRBC - As anticipated, the key agency for Delaware River Water Quality is the DRBC. Several telephone conversations and meetings were held with staff of DRBC to discuss the extent of available data. In addition, a search of the DRBC library was conducted. The agency staff provided invaluable assistance in our data retrieval for this project. Currently, almost all mainstem water quality sampling on the Delaware River is coordinated by DRBC. As discussed further below, the DRBC data have been entered into the USEPA STORET database and were retrieved for this study.

The DRBC also houses some water quality data from early data-collection efforts. These data are not computerized and are generally not readily available.

The DRBC library was visited and searched for any of the non-computerized data that would be essential for this project. One of the important reports found here was the "Preliminary Report - Water Quality Survey - Delaware River Estuary" prepared by the Interstate Commission on the Delaware River Basin (1962). This report included data collected from River surveys conducted in the late 1950s from the boundary of the Delaware River and Bay to the head of tide at Trenton. These data are not computerized and thus were not included in our trend analyses.

Delaware DNREC - The actual collection of water quality data along the main shipping channel of the river is contracted by DRBC to the Delaware Department of Natural Resources and Environmental Control (DENREC). DENREC provides data sheets to DRBC, who then enters it into the appropriate database. There are no contact recreational waters in the Delaware River within the State of Delaware. Thus, no water-quality monitoring is conducted in these waters. The shellfish beds in the bay are currently degraded and are subject only to occasional monitoring.

DENREC does conduct monthly water quality monitoring on all tributaries entering the Bay. Both saline and freshwater sections of the tributaries are monitored. including stations near the mouth of each tributary. Most conventional water quality parameters are monitored. Some of these records extend back to 1958. Data from the tributary monitoring program for 1969 and later has been entered into STORET. For the most part, earlier monitoring data is still in log books (Otto, 1990).

Pennsylvania DER - The Pennsylvania Department of Environmental Resources (DER) collects water quality data at two locations in the River: Morrisville and Marcus Hook. Their samples are collected by boat and are laterally composited across the River. Monthly sampling was initiated in the early to mid-1970s. In addition, data is collected above the head-of-tide on tributaries to the Delaware River. There are no bathing beaches or shellfish areas along the Delaware River in Pennsylvania. Thus, no monitoring is conducted for these purposes (Ryan, 1990).

New Jersey DEP - The New Jersey Deparatment of Environmental Protection (DEP) Bureau of Monitoring Management conducts most of the routine monitoring of ambient water quality in the state of New Jersey. The Bureau does not collect any data within the tidal portion of the Delaware River. Data collection does occur on the non-tidal portions of certain tributaries to the Delaware River.

The DEP collects extensive data in Delaware Bay for its shellfish management programs. Approximately 500 stations in Delaware Bay are sampled for total and fecal coliforms, temperature, tide stage, weather conditions, and, at selected stations, salinity. In the past year, a data collection program for nutrients was initiated. Data are collected at a minimum frequency of 5 samples per year, although some stations are sampled monthly. The sampling program was initiated in the 1960s, although data is available at some stations back until the 1950s. Data collected since 1972 has been entered into the STORET system. Earlier data is in paper files (Osborne, 1990). Examination of these files revealed a low volume of data distributed over a large number of station. Thus, this retrieval was considered a lower priority for this study and was not accomplished. Further review of this data could be appropriate for future studies.

USEPA - The US Environmental Protection Agency (EPA) does not conduct any routine monitoring in the Delaware River or Bay. The USEPA Edison office conducts routine ocean monitoring only (Kubik, 1990). The USEPA office in Annapolis was also contacted.

US Geological Survey - The US Geological Survey (USGS) Division of Water Resources office in Trenton, New Jersey was contacted. The USGS currently does not conduct any routine sampling in the Delaware River Estuary. They do maintain a station just above the head-of-tide at Trenton. The station is sampled monthly for pH, temperature and conductivity. Flow is recorded continuously (Gibbs, 1990). Flow data for this station were retrieved from WATSTORE.

Several other USGS stations in the estuary were monitored for various water quality parameters over various time intervals. An inventory of the data for those stations included in the STORET database system revealed some data dating back to the 1950s, although most sampling appeared to end in the 1960s or 1970s. Table 3.2 lists the USGS stations in the Delaware Estuary that have been sampled for water quality. It is our understanding that transfer between the USGS WATSTORE database and STORET is not always complete or up-to-date. Therefore, it was desirable to use WATSTORE to retrieve this data. Thus, an attempt was made to retrieve water quality data for all of the stations listed in Table 3.2. The retrievals did not list all of the data indicated in the annual USGS Water Resources Data Reports for

Pennsylvania. For example, certain years of data would be missing. Thus, these data have not been included in the database for this study. It will be submitted separately once it is made available. The USGS data for the Trenton station were retrieved from STORET and are included in the database.

Hourly water quality data for temperature and conductivity, and at certain stations for DO, have been collected by the USGS at the Ben Franklin Bridge, Fort Mifflin, Chester and Reedy Island Stations. There data are the source of the "Maximum, Minimum, and Mean Values" reported by the USGS in their annual Water Resources Data Reports and these values are reported on the WATSTORE and STORET databases. The hourly data for the years 1984 to the present are currently on the USGS computer in Harrisburg. Earlier hourly data are scattered among USGS offices near the station of collection on paper tape recordings (Kolva, 1991).

City of Philadelphia Water Department - In 1963, the City of Philadelphia Water Department initiated ambient water quality data collection in a stretch of the Delaware River from Marcus Hook (RK 127.24) to the Trenton STP (RK 212.3). The data were collected by boat on either a bi-weekly or a monthly frequency. The sampling ceased in 1983. This data was entered into the USEPA STORET system and was retrieved for use in this study.

Philadelphia Academy of Natural Sciences - The Philadelphia Academy of Natural Sciences office was contacted. They provided a list of pertinent data references. Apparently, the Academy has some water quality data primarily from industrial sources. Unfortunately, most of this data is not readily available to the public.

Table 3.2: USGS Monitoring Stations in the Delaware Estuary

Name	Kilometer Point	USGS Station No.
Ship John Island Lighthouse, NJ	58.90	01412350
Reedy Island Jetty, DE	86.67	01482800
Delaware Memorial Bridge	110.54	01482100
Marcus Hook, PA	126.37	01477200
Chester, PA	132.49	01477050
Eddystone, PA	136.04	01476200
League Island, PA	149.97	01467400
Wharton Street, Philadelphia, PA	158.70	01467300
Ben Franklin Bridge	161.22	01467200
Lehigh Avenue, Philadelphia, PA	164.09	01467100
Torresdale Intake, Philadelphia, PA	177.09	01467030
Bristol, PA	191.81	01464600
Trenton, NJ	216.41	01463500

Delaware Sea Grant Program - Numerous bibliographic references were obtained through the Delaware Bay Database of the University of Delaware Sea Grant Program. In particular, data and reports were obtained for various estuary-wide survey cruises, including SCENIC, YABLED, SALSX, and TransX.

Industry - Most industries do not collect ambient water quality data on a regular basis in the Delaware River. During the course of our agency discussions, we were not informed of any industrial data that was essential for this study. The inventory of

Delaware Estuary data in the STORET system revealed sporadic sampling at various industrial locations, including both ambient and effluent data. The ambient data was generally short-term and would not have contributed significantly to the study. Effluent data also was generally sporadic.

3.1.3 Development of Annotated Bibliography

As described above, potential bibliographic references were collected from numerous sources. Once possible references were gathered, they were reviewed to determine their applicability for the project. Then, if possible, the actual paper or report was reviewed to determine the extent of the database and to provide the appropriate information regarding data quality, quantity and methods for the annotated bibliography. If necessary (and within the time and budgetary constraints of the project), either the responsible institution or the author of the reference was contacted to determine the location of the database used for the report. The resulting Annotated Bibliography is provided in Part II of this report.

3.1.4 Computerized Database Retrieval

STORET - Discussions with the responsible agencies, particularly DRBC, revealed that the USEPA STORET database contained most of the accessible, long-term water quality data that would be essential for this project. The STORET database is housed on the National Computer Center IBM mainframe computer. Data is entered into the STORET database by the collectors of the data. A certain amount of data checking is conducted by the system to ensure that data are within an acceptable range. However, most data checking responsibility rests with the person or agency entering the data into the system. For example, DRBC now has a comprehensive data checking system in place.

At the start of this study, an inventory of the STORET database was attempted for the entire Delaware Bay and tidal River. The STORET inventory program was run using the appropriate hyrdologic unit codes for the Bay and several sub-basins of the tidal River. However, this resulted in far too much information to be useable. Next, the inventory request was reduced to the parameters of most interest for the study including DO, conductivity, and ammonia. This inventory identified stations which had long-term records for the requested parameters.

An alphabetical listing of relevant STORET parameter codes was available for our use. However, this document is massive and the parameters are not always listed by the expected names. Thus, one concern with the above approach was that certain parameters that could be important for the study might not be retrieved. However, upon completion of the inventory, it became clear that a limited number of the stations contained long-term records for the parameters of interest. In addition, these stations were almost all sampled either by DRBC or the Philadelphia Water Department, or in limited cases, by the USGS. Thus, individual inventories were run for many of these stations to determine appropriate parameter codes needed for future retrievals.

Data for the selected stations were retrieved using the applicable parameter codes. This data was transferred as ASCII files to the Najarian Associates, L.P. VAX computer network for analysis. Results of this retrieval are described below in Section 3.3.

3.2 Database Design

In this study, a computerized database was utilized to organize and store the historic data, and to ease data access. Two separate types of data were retrieved: (1) bibliographic information on relevant data sets for the system; and (2) constituent concentration data and associated parameters. Two different database systems were implemented for these vastly different data types.

Annotated Bibliography - Based on the results of the First Quarterly Contractors Meeting, WordPerfect was selected as the system to be used for the Annotated Bibliography. The fields of the Annotated Bibliography were numbered and titled as defined by the Delaware Estuary Program.

Water Quality Database - The Statistical Analysis System (SAS) was selected as the database and main statistical analysis program for this project. SAS allows easy manipulation and subsetting of data. It differs from many other databases in that data is not entered into fields. Also, SAS does not use relational tables or indexes. In this database, each data point is identified by its Agency Code, Station Number, Date of Sample, and Time of Sample (if available). This generally provides a unique label for each data point. Difficulties would occur if more than one data point were entered by the same agency for the same station with the same value for the time variable (or with time as a missing value). In this case, some other factor could be used to identify a unique data point. Review of the data revealed some days on which data for more than one sampling event were entered into the database by the same agency. In all cases found, time was included for one point and a missing value given for the other point.

Each observation contains the agency code, station number, latitude, longitude, date, time, river mile, tide-stage code and the concentrations of various water quality parameters. SAS allows for sorting of data by any parameter and provides various methods for combining datasets. Use of SAS as both the database and the statistical analysis program reduced the amount of data transfer required and eased our analyses.

Each water quality parameter was given a unique label name (e.g. DO or NO3-N). The label name and type (i.e. character or numeric) was kept consistent throughout the various files constructed for this database. If the names or datatype were not unique, SAS could not combine data sets.

Additional parameters were calculated for this study and are also included in the database. As discussed in below in Section 3.3, water quality constituents which had different STORET parameter codes sometimes were in fact the same parameter. The two (or in some cases more than two) parameter names were combined into a new name. However, the old parameters were retained in the database for future possible use.

Other parameters were calculated specifically for this project. Salinity was not reported directly in the available estuarine data. Where appropriate, salinity was calculated from conductivity and temperature data. Fecal coliform data were log-transformed for some analyses, and the log transform of the data was included as a parameter in the database. As described in Section 4.2, tidal phase intervals were calculated and added to the database. Annual 90-day low-flow values were also inserted into the database. Certain parameters were developed to improve data handling. The STORET database includes a variable for date. SAS was used to develop variables corresponding to the sampling month and year (from the reported date value) to accommodate various types of data sorting.

The database is constructed so that data for each station is housed in a separate file. This format was selected because certain types of trend analyses over time were conducted on individual stations. Having each station as a separate data file reduces both the actual time and the cpu time required to conduct analyses for individual stations. For analysis of data over the entire estuary, the individual datasets were combined into one large, but temporary dataset.

The data were read directly by SAS from files retrieved from STORET. The SAS system on the NCC computer was used in conjunction with the STORET Retrieval programs to produce files that could be read easily into SAS.

3.3 Database Development

A major task in this study was collecting and organizing the general water quality data sets for the Delaware Estuary. As discussed in Section 3.1, review of the available information indicated that the most complete long-term computerized data sets were collected by DRBC and the Philadelphia Water Department (WDPT) and are available in the USEPA STORET database. These data represent sampling at 45 stations over the period from 1963 to 1990, as shown in Table 3.3. Of these stations, thirteen pairs of stations are located in identical or close-by locations. Of these, seven pairs are located at the identical latitude and longitude. Data from these stations were combined into one data set, as well as data from one additional station for which the two sampling stations were located less than one second of both latitude and longitude apart.

At all but two of the seven combined stations, data collection efforts by the Philadelphia WDPT and the DRBC overlapped during the period 1967 through 1983. At the two others, DRBC collected data from 1967 to 1971, and then discontinued sampling until 1985, when sampling was subsequently resumed. Sampling at these two stations appears to have been discontinued by DRBC for 1990. The combined data set for all of these stations includes over 24,000 observations. The database has been submitted to the Delaware Estuary Program separately.

TABLE 3.3: WATER QUALITY MONITORING STATION INFORMATION

Sta. #	Agency	Station Name / Location	Lat.	Long.	R.M.**	Dates of Sampling***
091023	31DELRBC	Mouth of Mahon River, DE	39 12 20	75 21 34	29.09	05/08/71 - 10/16/90
091020	31DELRBC	Ship John Light, DE	39 18 05	75 22 55	36.53	10/05/71 - 10/16/90
091017	31DELRBC	Mouth of Smyrna River, DE	39 22 33	75 28 05	44.54	10/05/71 - 10/16/90
091014	31DELRBC	Mouth of Appoquinimink R., DE	39 27 18	75 33 36	50.88	10/05/71 - 11/07/90
091002	31DELRBC	Reedy Island, DE RM 54.94	39 30 46	75 33 12	54.94	07/06/67 - 10/16/90
091005	31DELRBC	Pea Patch Is., DE RM 60.55	39 35 27	75 33 49	60.55	07/06/67 - 10/16/90
091008	31DELRBC	New Castle, DE RM 65.96	39 39 17	75 32 48	65.96	07/06/67 - 10/16/90
091011	31DELRBC	Cherry Isl., DE RM 70.96	39 43 11	75 30 24	70.96	07/06/67 - 11/08/90
332046	31DELRBC	Oldmans Pt., NJ, RM 74.88	39 46 06	75 28 26	74.88	07/06/67 - 11/08/90
332049	31DELRBC	Marcus Hook, PA, RM 78.07	39 48 35	75 24 00	78.07	07/06/67 - 11/08/90
DEL- 1	PHILWDPT	Marcus Hook, PA	39 47 55	75 25 48	79.08	10/01/63 - 11/16/83
892062	31DELRBC	Eddystone, PA RM 83.98	39 50 48	75 20 18	83.98	07/06/67 - 11/08/90
DEL- 2*	PHILWDPT	Eddystone, PA	39 50 48	75 20 18	83.98	10/01/63 - 11/16/83
332052	31DELRBC	Paulsboro, NJ, RM 87.90	39 51 33	75 14 20	87.90	07/06/67 - 11/08/90
DEL- 3	PHILWDPT	Paulsboro, NJ	39 50 54	75 13 00	89.23	10/29/63 - 11/16/83
892065	31DELRBC	Navy Yard, Phila. PA, RM 93.18	39 52 54	75 10 44	93.18	07/06/67 - 11/08/90
DEL- 4*	PHILWDPT	Navy Yard, Phila. PA,	39 52 54	75 10 44	93.18	10/01/63 - 11/16/83
892068	31DELRBC	Wharton St., Phila. PA, RM 98.51	39 55 46	75 08 13	98.51	07/06/67 - 9/20/71 AND 10/23/85 - 11/15/89
DEL- 5*	PHILWDPT	Wharton St., Phila. PA,	39 55 46	75 08 13	98.51	10/29/63 - 11/16/83
892071	31DELRBC	Ben Franklin Bridge, Phila. PA RM 100.15	39 57 10	75 08 10	100.15	07/06/67 - 11/08/90
DEL- 6*	PHILWDPT	Pier 11, Phila. PA	39 57 10	75 08 10	100.15	09/13/62 - 11/16/83
892050	31DELRBC	Lehigh Ave., Phila. PA	39 58 13	75 06 47	101.98	04/29/86 - 11/15/89
DEL- 7	PHILWDPT	Lehigh Ave., Phila. PA	39 58 17	75 06 38	101.98	10/29/63 - 11/16/83
892052	31DELRBC	Allegheny Ave., Phila. PA	39 58 27	75 05 45	102.93	04/29/86 - 11/15/89
DEL- 8*	PHILWDPT	Allegheny Ave., Phila. PA	39 58 27	75 05 45	102.93	09/13/62 - 11/16/83
892070	31DELRBC	Betsy Ross Bridge, Phila. PA	39 59 04	75 04 30	103.96	03/12/84 - 11/08/90
DEL- 9	PHILWDPT	Northeast Water Pollution Plant, Phila., PA	39 58 40	75 04 35	104.03	09/13/62 - 11/16/83

TABLE 3.3: WATER QUALITY MONITORING STATION INFORMATION (Continued)

Sta. #	Agency	Station Name / Location	Lat.	Long.	R.M.**	Dates of Sampling***
DEL-10	PHILWDPT	Phila. Coke, Phila. PA	39 59 18	75 03 44	105.80	09/13/62 - 11/16/83
DEL-11	PHILWDPT	Frankford Inlet, PA	40 00 15	75 03 22	106.20	09/13/62 - 11/16/83
332055	31DELRBC	Palmyra, NJ	40 00 41	75 02 35	107.08	07/06/67 - 09/20/71 AND 10/23/85 - 11/15/89
DEL-12*	PHILWDPT	Tacony-Palmyra Bridge, PA	40 00 41	75 02 35	107.08	09/13/62 - 11/16/83
DEL-13	PHILWDPT	Northern Metals	40 01 10	75 01 14	108.57	09/13/62 - 11/16/83
892077	31DELRBC	Torresdale, PA, RM 110.70	40 02 24	75 59 20	110.70	07/06/67 - 11/08/90
DEL-14*	PHILWDPT	Torresdale Intake, PA	40 02 24	74 59 20	110.70	09/13/62 - 11/16/83
DEL-15	PHILWDPT	Poquessing Creek, PA	40 02 58	74 58 22	111.66	10/09/62 - 11/16/83
892054	31DELRBC	Dupont Pier, PA	40 04 10	74 55 50	113.87	04/29/86 - 11/15/89
DEL-16	PHILWDPT	Dupont Pier	40 03 54	75 56 13	113.87	09/13/62 - 11/16/83
DEL-17	PHILWDPT	Neshaminy Creek	40 04 13	74 54 34	115.63	09/13/62 - 11/16/83
892090	31DELRBC	Burlington Bristol Bridge, Bristol, PA	40 04 52	74 52 12	117.80	07/06/67 - 11/08/90
DEL-18*	PHILWDPT	Burlington Bristol Bridge, PA	40 04 52	74 52 12	117.80	09/13/62 - 11/16/83
DEL-19	PHILWDPT	Bristol Municipal Pier, PA	40 05 40	74 51 05	119	09/13/62 - 11/16/83
DEL-20	PHILWDPT	Levittown WW	40 07 39	74 48 56	122.61	09/13/62 - 11/16/83
DEL-21	PHILWDPT	US Steel, Fairless, PA	40 08 05	74 45 16	126.69	09/13/62 - 11/16/83
332061	31DELRBC	Fieldsboro NJ RM 127.48	40 08 28	74 43 55	127.48	07/06/67 - 11/08/90
DEL-22	PHILWDPT	Trenton STP	40 11 21	74 45 22	131.96	09/24/62 - 11/16/83

* Stations marked with * are located at an identical location (by lat./long.) to the station listed directly above. In most cases, the data from these two stations were combined and one analysis was conducted.

** Mileage was listed in the Station Header information included for each station in the STORET database for some of the DRBC stations. Most of the PHILWDPT stations were listed in DRBC, 1988. If a station was not explicitly listed in that document, river mile was estimated based on landmarks in the area. RK-RM*1.609.

*** Discrepancies in the ending date for 1990 may be an artifact of when the data was retrieved or of the input process by DRBC. These stations have ongoing data collection activities; the ending dates represent the ending date for data included in the database for this project.

3.3.1 Station Locations

Water quality is and has been monitored at numerous stations in the Delaware Estuary for many different purposes and by many different agencies. Using the USEPA STORET database system as a starting point, the relevant parameters of this study were inventoried at all stations in the Delaware Estuary. The results listed literally thousands of stations; however, essentially, all of these stations contained short-term data. Only a few stations contain long-term records amenable to trend analyses. Forty-five long-term stations have been sampled in the Delaware Bay and River. The location of current and past water quality monitoring stations in the Delaware Estuary are provided in Table 3.3 and the current monitoring stations are plotted on Figure 2.2.

Currently, the Delaware River Basin Commission (DRBC) coordinates essentially all of the regular ambient water quality monitoring in the Delaware Bay and River. Twenty-three stations are monitored on a regular basis. During the approximate period 1963 to 1983, the Philadelphia Water Department conducted regular water quality monitoring surveys from Marcus Hook to Trenton. Fewer measurements were taken in the first and last years of this period. Sampling by the Water Department ceased in 1983. Some Water Department stations coincided with DRBC monitoring stations. In any case, DRBC continued to sample their own stations regularly after 1983. DRBC also initiated data collection at 6 additional stations in the period 1984 to 1986. Thus, a gap in sampling is noted from 1984 to 1986 at some stations.

3.3.2 Water Quality Parameters

DRBC has collected and continues to collect concentration data for a vast array of water quality parameters. The list of parameters was reviewed to determine those relevant to this study. Those selected were retrieved, including: dissolved oxygen (DO), dissolved oxygen percent saturation (DOsat)temperature, BOD_5, ammonia

(NH_3+NH_4-N), nitrate (NO_3-N), nitrite (NO_2-N), pH, total phosphorus as P (tot. P), nonfiltrable residue, conductivity at 25°C (conductivity), total kjeldahl nitrogen (TKN), total phosphate (tot. PO4), chlorides, dissolved phosphate, turbidity (HLG until 1987; HACH turbidimeter since 1987), fecal coliforms, total coliforms and acidity.

Somewhat different water quality constituents were sampled by the Philadelphia Water Department. Parameters from their stations used in this study include temperature, turbidity (Jackson Candle Method), field conductivity, DO, DOsat, BOD_5, pH, total alkalinity, ammonia (NH_3+NH_4-N), nitrate (NO_3-N), nitrite (NO_2-N), ortho-phosphate (PO_4), total phosphorus (tot. Phos as P), chloride, total coliform (analyzed by membrane filter, with immed. m-endo medium at 35°C), fecal coliform (analyzed by membrane filter with m-fc broth at 44.5°C).

No salinity values were available in the STORET database. Therefore, salinity was calculated from conductivity and temperature. Very limited historical data were found for COD, TOC and SiO_3 - parameters which were originally envisioned as part of this study. Therefore, these parameters were not included in this study.

3.3.3 Agency Sampling Strategies

DRBC's Delaware Estuary data were collected by boat. The usual sampling approach was to collect data primarily at slack-before-flood (SBF) tide (often referred to as "Low Water Slack" tide), although data also were collected at slack before ebb (SBE) tide ("High Water Slack"). At other times, the data were collected during the mid-tide interval.

Overall, the DRBC strategy was to collect data from all stations at the same slack-water phase. This approach was initiated during the Delaware-INCODEL survey in the late 1950s (ICDRB, 1962). This so-called "same slack" sampling procedure was implemented using a fast boat to collect slack-tide samples starting at the most seaward station in the Delaware Estuary. The appropriate time for sampling was generally determined by watching the orientation of nearby buoys until they shifted direction. Sampling in this manner generally required about 8 hours (Gross, 1990).

Recently, questions were raised concerning the appropriate holding times for bacterial samples. Generally, these are set at about 6 hours. Thus, the 8 hours required for the same slack sampling violated these holding times at certain stations. To correct this, an additional stop was added to the data collection protocol to off-load samples. Thus, actual sampling times are not "same slack" at all locations. After studying past data, DRBC is confident that the hour or so departure from the same slack sampling does not affect comparability of data collected under these conditions (Gross, 1990).

As discussed above, the current main-stem Delaware Estuary monitoring program is governed by the DRBC. However, the actual data collection is performed by various agencies for DRBC. Currently, the river data are collected by the State of Delaware. These data are transferred to DRBC, who checks it and then enters it into the STORET database under the DRBC agency code "31DELRBC". Data was collected about 20 times per year in 1971. Currently, data is collected 18 times per year; that is, twice monthly from March through November (Gross, 1990).

Since 1987, DRBC has conducted a consistent and relatively rigorous program of data checking. DRBC's data are reviewed on the data sheets upon receipt from the State of Delaware. The data are then punched into the DRBC computer and printed. The print-out is checked against the original data on the data sheets. Finally, the data are transferred to STORET and retrieved. The retrieved data are reviewed for errors. Prior to 1987, however, a detailed methodology for error checking was not in use (Gross, 1990).

3.3.4 Data Acceptability Criteria

The results of the STORET data retrieval revealed that 45 stations were available on the main stem of the Delaware Estuary, with almost 20 years of data available at most stations. As discussed above, these data were generally listed under agency codes of both the DRBC and the Philadelphia Water Department. These data were selected for inclusion in the Status and Trends database.

Use of long-term, high-volume data sets from these two agencies eliminated potential variability that would result if data had to be combined from a myriad of agency sources. Nevertheless, many possible sources of error remain. For example, data collection and laboratory analysis techniques have improved dramatically over the past twenty years. In any case, the volume of data insured that the most appropriate statistical methods could be employed without undue concern about data availability.

The STORET database does not report the analysis method for many parameters. In this case, analysis methods were reported only for coliform data and turbidity. Two different laboratory methods were used for both fecal coliform and total coliform data. Until 1987, the parameter that was used for total coliform was "total coliform, membrane filter, immed. m-endo medium, 35°C". Recent data, however, was entered as "total coliform, mpn, confirmed test 35°C". At a number of stations, it appeared that total coliform data were not collected from 1977 to 1987. From the start of data collection until 1987, fecal coliform counts were analyzed using the membrane filter technique with m-fc broth at 44.5°C. After 1987, fecal coliform data were analyzed by the membrane filter method using m-tec medium. There do not appear to be long-term gaps in the fecal coliform data. The Philadelphia Water Department coliform data were reported under the same parameter codes as the pre-1987 DRBC data.

Turbidity data were collected by three different methods. The Philadelphia Water Department reports turbidity data using the Jackson Candle Method in Jackson Turbidity Units (jtu). Until 1986, the DRBC reported turbidity as hellige in ppm as silica dioxide. In 1987, the methodology changed to HACH turbidimeter reported in formazin turbidity units (ftu).

Chlorophyll-a data were entered into STORET under three different parameter codes. Many of these data were entered into STORET under a parameter code which has units of mg/l. However, DRBC recently discovered that the values entered into this parameter appear to be in units of ug/l (Gross, 1990). Thus, recent chlorophyll-a data were entered under a parameter code with units of ug/l, and a parameter was added to STORET called chlorophyll-a, corrected. Review of the chlorophyll-a data suggests that it all is reported in units of ug/l, because the values as mg/l would be unacceptably high. Based on this review and on information provided by the DRBC, all of the chlorophyll-a data in the study database was combined into one parameter which has units of ug/l.

Before 1980, phosphorus data was reported as "Total Phosphate as PO4." After 1981, phosphorus was reported as "Total Phosphorus as P". Clearly, the concentrations reported as P should be smaller than (about 1/3) the same concentration reported as PO_4. Initially it was though that the total phosphate data would be converted to total phosphorus as phosphorus and all of the data would be combined into one parameter. Graphs of this data revealed a distinct trough in the data collected from about 1979 to 1982. Review of the actual data showed that some of the phosphorus data collected in 1981 and early 1982 is reported under both parameter codes as the exact same value. Thus, it appears that at least some of the data reported as PO_4 is in fact in units of total P. Initially, this led to the decision to combine all of the phosphorus data as reported into a single Total Phosphorus parameter, knowing there would be some error in the earlier data. Further analysis of graphed data for several stations suggested transforming the data collected before March of 1980 from phosphate to phosphorus and not transforming the later data even though it was reported as TPO_4 as PO_4. This was done for purpose of allowing review and testing of the phosphorus data over time. In the database provided for this project, the only the original untransformed data are included because each station could not be checked to determine if the same transformation would be appropriate there.

BOD_5 data also presented some concerns. Most of the data for the period of record is given as less than 2.4 mg/l. However, in the early years of the monitoring program, values below 2.4 mg/l were sometimes reported. After about 1980, all of these data were reported as <2.4 mg/l. The values reported below 2.4 mg/l are likely to be subject to errors, since 2.4 mg/l is the generally accepted detection limit for BOD_5 analysis techniques. These data were not removed from the database. However, in some of the analyses, all data reported as 2.4 or less were translated to 2.4, and ranks of data were used for testing.

Review of the chloride data generally presented a few anamolous data points at each station. Usually, however, only one or two of these points were large enough to allow removal from the database. According to DRBC, infrequent high levels of chlorides were noted throughout the estuary in some years. These levels may have been associated with a certain point source, but this has never been proven. The anamolous data were removed from certain data sets, but probably not from all of them.

The retrieved data were processed according to the procedures described in the preceeding paragraphs. The data were then plotted over time. Each graph was reviewed for any obvious outliers. Obvious outliers most often were noted for the conductivity data. These points were clearly outliers in that one or two data points would be 10 to 100 times greater than the next highest data point. Any data points removed from the database are described in Chapter 6.

Data were not deleted from the database unless the values were clearly erroneous. If there was any possibility that the data point was valid it was not removed from the database.

4. STATISTICAL ANALYSIS METHODS

4.1 Exploratory Data Analysis

Using SAS, an exploratory data analysis was conducted on the retrieved STORET data for each station. To this end, individual time histories were plotted for selected parameters. Graphs were checked visually for: (a) detection of outliers; (b) the period of record; (c) data gaps; and (d) obvious visual trends in the data. As described above, obvious outliers were removed from the database when possible. Trends over time were explored visually for both the overall data sets and, at certain stations, for data classified by attributes such as: (a) the collection agency; (b) the tidal phase interval; and (c) the 90-day low-flow classification.

At each station, descriptive statistics for each parameter were calculated using SAS. When appropriate, these statistics were calculated on a seasonal basis.

4.2 Data-Sorting Methods

As discussed in section 1.2, a key feature of this study is the historical trend analysis of water quality data collected under "similar" conditions of tidal stage, season, and antecedent fresh water inflow. To accommodate these analyses, certain historical data sets were sorted into subsets corresponding to similar conditions, as described below.

It should be noted that creating data subsets for similar environmental conditions also reduces the number of data points available for analysis. At some point, the subset of like conditions may provide a data set that is too small to allow for meaningful statistical analyses. In addition, certain factors may not be important in providing a "similar" data set. Thus, a compromise must be reached between reducing the variance in the data and retaining a sufficient number of data points to allow meaningful analyses. In this study, tests were conducted at certain stations to determine the importance of identified conditions in reducing the variance. This is discussed further in Chapters 5 and 6.

4.2.1 Seasonal Sorting of Water Quality Data

Certain water quality parameters, particularly DO, display marked seasonal variation. For example, DO saturation is inversely related to temperature, with higher DO concentrations generally found during winter months. Thus, to separate long-term trends of parameters such as DO from seasonal effects, trend analyses must use data collected under similar ambient temperature conditions. Initially, the approach selected for this study was to compare data collected each year in a given month. However, the number of data points available for many months in the retrieved data were too few to be provide a useful comparison. In addition, the variability in a number of data points over time could badly skew the results. Thus, a seasonal approach was explored.

Summer is usually the critical period for low DO concentrations. Therefore, many data analyses were conducted on combined summer data, with summer defined as the period from June through September. Where appropriate, winter data also was analyzed separately, especially for the estuarine-wide trend analyses. In this study, winter was defined as the period from December through March.

Other parameters do not exhibit high seasonal dependence. These data were not analyzed by season. This reduced the number and complexity of the computations, and avoided unnecessarily reducing the number of data points.

4.2.2 Tidal Sorting of Water Quality Data

Like temperature variability, tidal variability may confound water quality trend analyses. Processes such as tidal advection and tidal mixing may induce significant water quality variability, independent of other controlling factors. Methods are described below to group the historical data into common tidal phases.

In the STORET database, data supplied by the Philadelphia Water Department is not coded for tidal stage. However, DRBC's STORET codings often includes a tidal-stage parameter. DRBC planned to conduct most of its surveys around the time of slack-before-flood (SBF) tide, corresponding to STORET parameter "3". Thus, parameter code 3 often accompanies a recorded STORET water quality measurement. Analysis of STORET collection times revealed that many of the reported samples labeled 3 were not collected at SBF tide as predicted by the NOS Tidal Tables. These analyses were performed by checking the collection time against the time of slack tide predicted in the NOS Tidal Current Tables. In many cases, "slack tide" data were collected *several* hours (as much as 6 hours in some cases) before or after the predicted time. Although it is not uncommon for predicted and observed times of slack tide to differ by one hour, differences of several hours are unlikely. Therefore, an independent means for sorting the tidal data was required. This method could then be used both to check the DRBC codings and to classify retrieved data with missing tide codes.

To perform tidal sorting, the tidal current phase must be determined at all historical sampling times and locations. This is a formidable task, especially since complete historical tidal current records are unavailable for the entire Delaware Estuary. Thus, approximate methods must be developed. As a first step, standard tidal prediction methods may be used to approximate actual tidal current phases. This approach was employed in this study, as outlined below.

Daily predictions of tidal elevations and tidal currents at various Delaware Estuary locations have been published annually since 1923 in the National Ocean Survey's

(NOS) Tide Tables and Tidal Current Tables, respectively. The NOS Tidal Current Tables include daily predictions of the following tidal current stages at primary reference stations: maximum flood, maximum ebb, slack before flood tide and slack before ebb. These predictions are based on Fourier decompositions of long-term tidal records into spectral components of the astronomical tide. Naturally, the actual times of these tidal phases may differ from the predicted times, owing to unpredictable meteorological influences. As discussed in the NOS Tidal Current Tables:

> "...actual times of slack or maximum occasionally differ from the predicted times by as much as half an hour and in rare instances the difference may be as much as an hour. Comparisons of predicted with observed times of slack water indicate that more than 90% of the slack waters occurred within half an hour of the predicted times."

Given the level of accuracy of NOS predictions, a reasonable approach would be to sort the historical water quality data into individual tidal-phase intervals. For this study, four equal tidal intervals were chosen, each corresponding to one-quarter of a tidal cycle (3 lunar hours).

Unfortunately, computer-formatted records of published NOS tidal *current* data are not readily available for the entire study area and period. However, as discussed below, tidal *elevation* data may be synthesized. Moreover, the phase relation between tidal elevation and tidal current is nearly constant at each estuarine location, as determined from comparisons of the NOS tidal elevation and tidal current tables. These factors suggested a rational approach for hindcasting the tidal currents over the entire study area and period.

In a previous study of the Delaware Estuary, Thatcher et al. (1981) developed a tidal prediction model for the Delaware Estuary. This model generates computerized tidal-height predictions throughout the study area and time period, based on standard Fourier synthesis techniques (Pore and Cummings, 1975). Using this tool, the following approach was used for this study. First, historical tidal elevations at an arbitrary reference station (Breakwater Harbor, in this case) were approximated with the tidal prediction/hindcast algorithm. These computer-generated tidal heights were then processed by a second algorithm designed to generate the corresponding times of high water and low water for each simulated tidal cycle. Results were then compared to corresponding NOS Tide Table predictions for the reference station. The computed tidal heights were found to be within approximately 3 minutes of the published times of high/low water.

Next, the phase relationship between tidal elevations and tidal currents at the reference station was computed from NOS Tide Table and Tidal Current Table data. To this end, published times of high water and low water at the reference station were compared to corresponding times of SBF tide (often misnamed "low-slack", although low tide rarely coincides with slack tide) and SBE tide (misnamed "high-slack"). Time differences between low water and SBF tide, as well as between high water and SBE tide, were averaged over an entire lunar cycle (29 days) to yield mean tidal current-elevation phase relationships. On the average, SBF tide at Breakwater Harbor occurs 39 $\pm$ 8 minutes after low water; SBE tide occurs 6 $\pm$ 6 minutes after high water. These relationships were then applied to the entire set of simulated times of high/low water at the reference station to generate the corresponding times of slack tide at the reference station. Thus, a system was devised to hindcast the approximate times of SBF and SBE tide at the reference station over the historic study period.

Given the times of slack tide at one location in the Delaware Estuary, the NOS Tidal Current Tables can be used to compute the corresponding times of slack tide at other locations. These tables provide the relative time differences between the time of slack tide at one reference station in the estuary and subordinate stations. For the

Delaware Estuary, the NOS tidal current reference station is located at the Delaware Bay entrance. Times of slack tide at 83 subordinate stations are listed, including Breakwater Harbor. Time differences for other intermediate locations are found through interpolation procedures. Figures 4.1, 4.2, and 4.3 illustrate the results of such procedures for corresponding stations located along: (a) the main shipping channel of the Estuary; (b) the New Jersey shore of the Estuary; and (c) the Delaware shore of the Estuary. The time difference between slack tide at any particular station location and slack tide at the Breakwater Harbor reference station (mile 1.6 on these plots) is easily read off these graph. Using these time differences, along with the computed times of SBF and SBE tide at Breakwater Harbor, one can estimate the time of SBF and SBE tide throughout the study area and period. This procedure is presently automated on Najarian Associates' computer system.

The following algorithm was employed to sort the data. First, the times of SBF tide and SBE tide at a given sampling station were determined over the entire study period, using the procedure discussed above. Next, the date and time of each historic water quality measurement at that station were identified (if time-coding information was available). The nearest times of SBF and SBE tide at the station were also determined. The water quality sample was then classified into one of four separate quarter-intervals of the corresponding tidal cycle, each of approximately 3-hours duration (Figure 4.4). Two of these intervals were centered on slack tide. For example, the "SBF interval" (interval "3" in Figure 4.4) was arbitrarily defined as the predicted time of SBF tide, plus or minus 1.5 lunar hours (1.55 hours). Likewise, the "SBE interval" (interval "1") was defined as the predicted time of SBE tide, plus or minus 1.5 lunar hours. The two adjacent intervals were simply defined by the endpoints of intervals 1 and 3. Thus, interval 2 represents the approximate "maximum-ebb interval"; interval 4 corresponds to the "maximum-flood interval".

The computed intervals were checked against available tidal current phase data reported directly in the NOS Tidal Current Tables. Results indicate that the computerized method partitions the data correctly into the appropriate quarter-interval in all but a few isolated cases.

4.2.3 Sorting of Data According by Freshwater Inflow

Freshwater inflow into the Delaware Estuary may influence concentrations of water quality constituents. Instantaneous streamflow measured at the time of data collection comprises one component of this influence. However, antecedent rainfall and streamflow conditions are also important. For example, a hot dry summer may produce a different DO regime in the Estuary than a cold wet summer. A complex time series analysis of streamflow and antecedent conditions was beyond the scope of this project. Instead, two simple surrogate measures were used.

The United States Geological Survey (USGS) has maintained a continuous streamflow monitoring station at Trenton, N.J. (Station # 01463500) since 1914. Initially, monthly average streamflow was considered for use in this analysis. Using the USGS WATSTORE computer database, average monthly streamflows were calculated for each month over the period of record (generally 1964 to 1990). A review of the water quality monitoring data over time, however, revealed that the number of data points for each month was missing or relatively limited - in some cases consisting of only 1 to 2 data points. Thus, it was not feasible to conduct a trend analysis for the data sorted by month. In addition, because of the size of the database, the number of analyses would have been prohibitive and complex. A second approach was then sought.

The streamflow data were also analyzed for annual 1-day, 7-day, 14-day, 30-day, 60-day, 90-day, and 180-day low flows through WATSTORE. It was determined that the critical summer period might best be represented by the 90-day low-flow values. Typically, but not always, the lowest streamflows of the year occur during the summer months. Figure 4.5 illustrates the annual 90-day low flows by year for the period of record.

A frequency analysis of 90-day low-flow events was conducted for each selected station. This provided the maximum, minimum, and quartile values of the 90-day low-flow values. The quartile values were used to developed four flow classes: (1) <25%; (2) >25%-50%; (3) >50%-75%; and (4) >75%. These classifications would then be used to conduct an Analysis of Variance for the water quality data classified by flow. The actual 90-day low-flow values were also used in the regression analyses done at certain stations.

As discussed below, the results of these analyses were initially puzzling. That is, if flow was a significant control on the concentration of water quality parameters in the Estuary, one might expect data collected during the driest years (Class 1) to be more like the 25% - 50% class (Class 2) than like the >75% class (Class 4). However, in some instances the Class 2 concentrations were significantly different from the other three classes but the other three classes were not significantly different from each other. This result was found primarily for stations having a very clear upward or downward trend in water quality parameter concentration over time.

Further review of the distribution of the 90-day low-flow data produced some interesting results. As shown on Figure 4.6, the annual 90-day low-flow values are not evenly distributed among the years studied. The years from 1964 to 1967 are the four driest of the data set, including 1966 - the driest year since 1914 at the Trenton streamflow monitoring station based on 90-day low-flows. The other years in the lowest-flow class are 1981 and 1982. The years 1968 to 1972 are characterized by higher than average 90-day low flows, with the exception of 1973 which is a relatively dry year. The period from 1984 to 1987 is characterized by below-normal 90-day low flows and are all in Class 2, while the last three years have been wetter than normal. Clearly, the 90-day low-flows are not evenly distributed over the study period. Class 2 low-flows occurred frequently in the 1980's - a period when point-source discharges were reduced and overall improvements in Delaware Estuary water quality were realized. For stations showing strong trends, this may account for the inconsistent results..

Another difficulty discovered in the possible use of the 90-day low flow to classify the water quality data is that the classification may not reflect actual conditions at the time of sampling. For example, 1981 is included in Class 1. However, this was due to very low flows in January. Summer flows, however, were about normal although the 1981 monthly flows for September and October were still categorized as Class 1 in relation to other September and October flows since 1969.

Figure 4.7 illustrates annually averaged streamflows for the USGS gaging station at Trenton New Jersey. This figure provides an alternate measure of antecedant flow-conditions. Also, it indicates an uneven distribution of high and low flow years over the time period of interest.

4.2.4 Loading Analyses

Water quality trend analyses of the Delaware Estuary also require information concerning both point and non-point source pollutant discharges. For this study, a reasonable approach might be to incorporate actual pollutant loading data into a database, and to test for trends in such data. Also, correlations between changes in concentrations of key water quality parameters and loading rates could be tested. However, the collection of appropriate loading data is hampered by the fact that historic data for key parameters, such as nutrients, is probably non-existent or not readily available. The collection would require review and compilation of discharge monitoring data for each discharge, and calculation of corresponding loading rates. In any event, the collection and compilation of actual loading data from all discharges was well beyond the scope of this study. Instead, an indirect approach was adopted. That is, temporal trends in constituent concentrations were compared to the general history of treatment plant upgrades within the basin.

4.3 Statistical Analysis Methods

After exploring the data, statistical methods were employed to: (a) summarize the data for the Status and Trends; (b) determine if sorting the data contributes significantly to a reduction in variance; and (c) to identify possible trends in the data. Common summary statistics include the mean and variance, and common tests for trend and classification differences include t-tests, regression analysis or analysis of variance (ANOVA). However, these techniques require that the data being tested are independent and normally distributed. Often, water quality data is not normally distributed. Among typical water quality constituents, only dissolved oxygen, temperature and pH may, at times, be considered normally or near-normally distributed (Hirsch and Slack, 1984). Certain parameters of interest in this study, particularly coliform data, are very non-normal.

Another difficulty with many parametric tests for trend in serial data is that these tests require a uniform sampling frequency. Moreover, these tests are not appropriate when significant data gaps occur. Censored data, such as data reported as less than a detection limit, also violate the assumptions of parametric tests. Such data are common in water quality analyses (Hirsch and Slack, 1984). In this study, for example, most of the BOD_5 data were reported as less than the detection limit of 2.4 mg/l.

For these reasons, nonparametric statistical analyses were employed in this study. These tests do not assume normality or require specification of the mean or variance of a data set. These tests avoid assumptions inherent in parmetric tests and prove more powerful, unless the data actually meets the restrictive assumptions of parametric tests. Often, however, the corresponding parametric test is also reported by SAS. In these cases, both results are documented in this report. This was done for two reasons. First, parametric tests are still more commonly employed in water quality analysis than nonparametric methods, and some of the users of this document may be more familiar with those techniques. Secondly, some parametric methods do not have readily available nonparametric equivalents. For example, regression analysis does not have a common nonparametric alternative. In certain cases it may be possible to demonstrate that tests results are the same using either the parametric or nonparametric tests. The parametric tests can then be used with less uncertainty.

The database for the stations selected for detailed study generally had a data record extending for 25 to 30 years. For some parameters, over a thousand total data points were available for analysis. This reduced the overall uncertainty in employing either technique. In addition, difficulties in the statistical analyses due to data gaps were minimized.

4.3.1 Summary Statistics

Summary statistics are presented for selected long-term monitoring stations. For most parameters, these statistics include the mean, standard deviation, coefficient of variation, maximum, minimum, and the three other quartile endpoints. The first three statistics are parametric statistics with the inherent assumption of normality. The 50% quartile value is the median of the data and provides a better estimate of the central tendency of a parameter that is not normally distributed than the mean does.

For coliform data, the geometric mean is reported. For BOD_5, the statistics described above are sometimes reported, although the aforementioned problem with censored data is noted.

Summary statistics were calculated at each selected station location for: (a) all data; (b) summer and winter data where appropriate; and (c) recent data, to define current status.

4.3.2 Trend Analysis Methods

Section 4.2 describes sorting techniques designed to reduce the inherent variance in water quality data due to external influences. In addition to these influences, actual trends over time in water quality data trends may be masked by errors in sampling and analysis procedures, by inherent difficulties in the statistical methods, and by other sources of uncertainty. Historic data, in particular, presents additional sources of uncertainty due to inconsistencies in analytical methods, improvements in detection limits over time, and the inherent variability that arises when data is collected by different investigators under different conditions.

A given time series of water quality data may contain both random and deterministic components. Deterministic components include temporal trends which are periodic, monotonic, step, or some combination thereof. Periodic trends are those which recur with regularity, such as diurnal variation in dissolved oxygen concentrations or semi-diurnal variation in tidal flow. Monotonic trends are those which vary gradually in one direction over time, and result from gradual changes in the environment. Step trends are abrupt changes that can often be linked to a specific event, such as the introduction of a new discharge.

The data available for this study has been collected over a 25- to 30-year period. In the exploratory study phase, visual review of data plotted over time revealed that temporal trends at a given station could generally be considered monotonic trends. With the exception of some pH and coliform data, no significant data gaps are apparent at the stations studied in detail. Thus, step trend analyses were not needed to detect differences between data points located on opposite sides of a gap.

Initially, it was anticipated that the seasonal Kendall test (developed at the USGS by Hirsch et al., 1982), would be used to identify long-term, monotonic trends in water quality concentrations. This test uses a modified version of Kendall's rank correlation coefficient to determine if a monotonic trend in data can be observed. The data are analyzed separately for each month and then combined into a single statistic. It would also be possible to use other groupings of the data. However, the available data was not appropriate for a month-by-month analysis because only limited data were collected during each month. At certain times over the period of record, winter sampling may or may not have been accomplished. In addition, several of the water quality parameters under consideration are not seasonally correlated and so no benefit would be derived by using a month-by-month analysis.

To simplify the analysis, Kendall's Rank Correlation Coefficient (Kendall's tau (t)) was used to test for trends over time. This test uses the rank of the data, and not the data values themselves. The statistic tests each pair of data (concentration and sampling time) to determine whether it is concordant or discordant. That is, the tests determine whether both members of the pair change in the same direction when compared to the next pair in the data set. If so, the test is concordant; otherwise, it is discordant. In this study, this analysis is simplified because the reported time parameters all increase monotonically over the study period. Thus, the Kendall "k" statistics (k^+ and k^-) test each data point (e.g., concentration) to determine if it is larger ($k^+=1$) or smaller ($k^-=1$) than each data point which precedes it in time. Individual k^+ and k^- statistics are summed for each data set, and then k^- is subtracted from k^+. This value is then divided by a correction factor for the number of tied data pairs.

If there is no monotonic trend in the data, k^+ and k^- would be expected to be essentially the same. Thus, the test determines whether the difference between these two values is significantly different from zero. The test can be conducted with relatively few years of data. However, in those cases the trends must be consistent over nearly all of the data to allow a significant finding. This is not an issue in this study as relatively long-term data were available. It must be noted that in many cases the data were not uniformly distributed over time. In particular, at certain stations far more data were available in the early years of the sampling program because two agencies were collecting the data and also because sampling was more intensive. This could cause some bias in the trend analyses. However, in the case of the Delaware River Estuary, the trends in most parameters are so strong that the lack of uniform sampling appears to be of minor importance.

The Kendall's rank correlation statistic was calculated for water quality parameters of interest at selected stations. The parametric Pearson correlation coefficient, r, is also reported for comparative purposes.

The trend analysis simply identifies whether or not there is a trend in the level of a water quality parameter over time. A regression analysis allows exploration of possible factors associated with such a trend. Multiple regression techniques were conducted for several stations. The results of a regression analysis are reported for the Reedy Island Station.

4.3.3 Analysis of Variance Techniques

In addition to testing for monotonic trends over time, this study was designed to examine differences among water quality data classified according to various external influences. Tests which compare data using classification variables with more than two levels are called Analysis of Variance (ANOVA) techniques. The null hypothesis for these tests is that the each set of classified data come from the same population and, thus, have the same location parameters. For a given variable, the null hypothesis implies that no statistically significant difference can be found among the various classification levels. If no significant difference is found, then no significant reduction in the variance of the parameter would be gained by sorting the data according to that classification variable.

The traditional ANOVA assumes that the data being tested are normally distributed with equal variances. The nonparametric equivalent, called the Kruskal-Wallis test, uses the ranks of the data, and not the data values themselves, to conduct the analysis. Both the Kruskal-Wallis and the traditional ANOVA tests were run and the results of both tests are reported.

The ANOVA techniques simply determine that at least one of the parameter levels is different from the others. It does not indicate how many are different or identify the differences. Further analysis can be conducted using special pairwise comparison techniques, such as those developed by Tukey. These tests were conducted in case where the results of the ANOVA and the Kruskal-Wallis test were the same.

5. ESTUARINE-WIDE WATER QUALITY STATUS AND TRENDS

This chapter provides graphical analysis of the current status of and historic changes in Delaware Estuary water quality. This analysis allow review of spatial and temporal trends in water quality throughout the estuary. Graphical techniques were also used to explore effects of some of the possible confounding factors on the data.

In Section 5.1, constituent concentrations are averaged over three separate three-year periods spanning three decades: 1968-1970, 1978-1980, and 1988-1990. Corresponding plots, Figures 5.1 through 5.10, illustrate water quality changes over the length of the Delaware Estuary during this period of major STP upgrades. For these plots, three-year averages were computed to smooth some of the inherent variability in the data. This technique is perhaps the simplest method for eliminating some of the confounding influences of various external factors.

Section 5.2 provides a second set of estuarine-wide plots based on selected 90-day averages of water quality data (Figures 5.11 - 5.28). These plots are intended to provide heuristic assessments of: (a) historic water quality trends under "similar" environmental conditions; and (b) inherent variability due to various external influences.

In Section 5.3, estuarine-wide plots are displayed for the period 1988-1990. These plots (Figures 5.29 through 5.39) provide a qualitative assessment of "current" water quality status. Finally, Chapter 6 provides detailed quantitative analyses for individual stations within the three Delaware Estuarine zones. Results are then synthesized to characterize each of the three zones.

5.1 Estuarine-wide Trend Analysis.

Previous studies of the Delaware Estuary report dramatic improvements in general water quality conditions over the past 30 years (e.g., Albert, 1988). These improvement have been attributed primarily to local STP upgrades.

In this study, representative changes in Delaware Estuary water quality over the last two decades are displayed in Figures 5.1 to 5.10. These plots consist of estuarine-wide profiles of constituent concentrations averaged over the periods 1968-1970, 1978-1980 and 1988-1990. Consistent with previous studies, these figures illustrate an overall improving trend in general water quality conditions.

It should be noted that examination of historical trends using graphical methods requires a certain degree of caution. Apparent differences in water quality from one time period to another may be the result of various internal and external influences. For example, an "actual" improving trend in water quality may be the result of a decrease in loading. However, apparent differences among water quality conditions at various points in time may also be caused by different hydrologic, physical, biochemical, and meteorological conditions. In an attempt to account for some of these factors, each historic time period was represented by averaging the data over a three-year period. This reduces the effect data from any one year has on the average for that period (Albert, 1982). A longer period of time might reduce this effect further, but may also include possible effects of actual trends in water quality data.

In some cases, the data from these three periods of time were collected by two separate agencies using various sampling protocols and quality control procedures. Uncertainty may also occur because: the data were sampled at different frequencies; the samples were analyzed by different laboratory techniques with varying detection limits; and the data were entered into STORET by numerous personnel - in some cases under more than one STORET parameter code for the same constituent. The unusual patterns in some of the 1968-1970 profiles may reflect these problems. However, the magnitude of change in many parameters indicates that a real change in estuarine water quality has occurred.

In light of these considerations, the following sections provide descriptions of overall water quality changes displayed in Figures 5.1 through 5.10. In these discussions, note that the largest municipal sewage treatment plants are located along the Estuary between RK 145 and RK 169 (RM 90 - RM 105).

Salinity and Chlorides: The three-year profiles of salinity each show a slightly different profile (Figure 5.1). The highest salinities occured in the 1978-1980 profile while the lowest salinities were found in the 1988-1990 profile. Thus, as expected, there is no distinct pattern to the salinity profiles.

Chloride concentrations are shown for the Tidal River Zone. The overall pattern is the same as that of the salinity profiles.

Temperature: The three-year profiles of the mean water temperature are shown in Figure 5.2. Each of the three profiles present a somewhat different temperature regime. Thus, as expected, there appears to be no overall trend in the data and water temperature appears to be controlled by the vagaries of prevailing meteorologic conditions.

pH: The annual profiles of mean pH levels are shown in Figure 5.3. Data from 1968-1970 and 1978-1980 indicate that a distinct pH minimum exists just upstream of the Transition Zone (RK 129). pH levels approximately 0.5 units higher than this minimum were present near the Estuary's freshwater and ocean boundaries. In contrast, the 1988-1990 data showed little longitudinal variation in pH. The mean 1988-1990 pH values were 0.5 to 1.0 units higher than those of the two other years. This apparent trend may be related to a change in data collection methods following a gap in pH data at many stations during the mid-1980s. This issue is discussed further in Section 3.3.4.

BOD_5: The annual-mean profiles of BOD_5 concentration are shown in Figure 5.4. There appears to have been an overall reduction in BOD_5 concentrations since the 1968-1970 profile. In particular, the maximum BOD_5 concentrations have declined over the last two decades. The data also show a reduction in "noise" or data variability. This is a result of changes in data-reporting. In particular, as discussed in Section 3.3.4, BOD_5 data below the 2.4 mg/l detection limit were reported during the early years of data collection. Presently, only the detection level is reported for these data. For most stations, very few detectable BOD_5 levels have been reported in recent years.

Total Phosphorus: The annual-mean profiles of total phosphorus concentration are shown in Figure 5.5. The 1988-1990 data show little longitudinal variation with no apparent data peaks. The 1978-1980 profile shows an increasing trend into the Tidal River Zone, with a maximum at about RK 161. The profile from 1968-1970 also shows a distinct peak around RK 161. The mean 1988-1990 concentration has been reduced by approximately 0.15 mg/l from that of 1978-1980. As discussed further in the following sections, this reduction is indicative of a significant long-term trend in the water quality conditions of the estuary. However, the 1968-1970 data appears to be anomalous due to the magnitude of this difference (over 1 mg/l). The reason for this difference is unknown. The high phosphorus values appeared to be more pronounced in the winter months. In addition, the decline occurred over several years. The DRBC has hypothesized that the decline could have been related to completion of the Cannonsville Reservoir in 1967. The reservoir might have affected the timing and concentration of phosphorus released to the freshwater portion of the Delaware River (Albert, 1991). The 1978-1980 profile may be affected by the data reporting problems described in section 3.3.4 as this is the period in which the phosphorus data began to be reported as total P, instead of as PO_4.

Ammonia: The annual-mean profiles of ammonia concentration are shown in Figure 5.6. Clearly, a reduction in ammonia-nitrogen concentration has occurred over time. The largest reduction appears to have occurred between the time of the 1968-1970 profile and the 1978-1980 profile.

A spatial trend appears to accompany this long-term reduction. In all three profiles, it appears that the source of elevated ammonia concentrations is in the Philadelphia-Camden area (between RK 145 and RK 169) where large gradients in the ammonia concentrations appear. The elevated concentrations persist in the seaward direction and eventually diminish within the Bay Zone. Over time, it appears that the influence of the Philadelphia-Camden area has been reduced, resulting in a far smaller concentration gradient in that area, and producing a "flatter" and "less peaked" concentration profile. It should be noted that a seasonal component is apparent in the ammonia concentrations, with higher winter levels. This is discussed further in Chapter 6.

Nitrate: The three-year mean profiles of nitrate concentration are shown in Figure 5.7. The longitudinal distribution of the data for these three periods is quite similar. For all data, nitrate concentrations are higher within the Transition Zone. Diminished concentrations are seen in both the Bay Zone and the Tidal River Zone. Figure 5.7 also suggests that a long-term increase in nitrate concentrations has occurred within the Tidal River Zone.

Total Nitrogen: The three-year mean profiles for total nitrogen ($TKN + NO_2 + NO_3$) are provided in Figure 5.8. All three profiles display a peak around river kilometer 125. The peak in the 1968-1970 profile is almost 2 mg/l higher than that in the later two profiles. The 1968-1970 profile drops dramatically in the upstream direction and is below the 1978-1980 data in the uppermost portion of the Tidal River Zone. The 1988-1990 profile is generally slightly lower than the 1978-1980 profile and the peak is somewhat less pronounced. The profiles for 1968-1970 and for 1978-1980 converge around RK 90, but the 1978-1980 show somewhat higher levels at the most seaward portion of the upper Bay Zone.

Dissolved Oxygen: The summer profiles of the mean dissolved oxygen concentrations are displayed in Figure 5.9. This figure illustrates dramatic improvements in the plotted DO-distributions from one time period to the next. The most pronounced difference is seen when comparing the 1978-1980 profile versus the 1988-1990 profile for the middle and upper Estuary.

Each profile exhibits a sag in DO concentrations that extends from approximately RK 169 seaward to the boundary of the Bay Zone. For the 1968-1970 data, DO concentrations drop about 4 mg/l between about RK 177 and RK 161. At RK 161, the average summer DO concentration for 1968-1970 is about 1 mg/l. Almost 113 km (70 miles) of River had a mean DO concentration below 5 mg/l in the 1968-1970 profile. By the 1978-1980 profile, the magnitude of the sag had barely diminished, but the extent of the Estuary having mean DO concentrations below 5 mg/l had been reduced to about 64 km (40 miles). Finally, in the 1988-1990 profile, the magnitude of the DO sag had been further reduced to approximately 1.5 mg/l, and the extent of river with mean concentrations below 5 mg/l had been further reduced to about 16 km (10 miles). The 1988-1990 longitudinal concentration profile shows relatively little spatial variation; it has little resemblance to the classic "sag" curves displayed for the earlier periods.

Fecal Coliforms: The annual profiles of the geometric mean (GM) of the fecal coliform count are shown in Figure 5.10. All profiles show elevated fecal coliform levels in the Philadelphia-Camden area. However, the magnitude and extent of the elevated fecal coliform levels has been reduced dramatically as follows:

	1969	1979	1989
Peak GM Fec. Coliform Count	3,500	10,000	1,500
Miles w/ GM Fec. Col. Count over 200	50	25	12
Miles w/ GM Fec. Col. Count over 1,000	20	30	1
Miles w/ GM Fec. Col. Count over 5,000	0	10	0

These reductions have produced a more uniform fecal coliform distribution, with a lower geometric mean in the Tidal River Zone for the 1988-1990 profile. In all three profiles, the Bay Zone and the Transition Zone had much lower geometric mean fecal coliform counts than the Tidal River Zone. While some improvement in geometric mean fecal coliform counts was noted in the Transition Zone, little change has occurred in the Bay Zone.

5.2 Implications of Data Sorting Techniques

In the previous set of figures, temporal averaging methods were used to remove some of the natural variability due to external influences such as tide, temperature, discharge, and antecedent freshwater inflow. In this section, an alternate means is employed to remove this inherent variability. To this end, two 90-day intervals were selected for analysis; namely, June-August, 1981 and June-August, 1985. These intervals correspond to similar low-flow conditions. Moreover, the period between the selected intervals corresponds to significant STP upgrades. Thus, differences in average water quality conditions over this interval should be influenced minimally by confounding effects of freshwater inflow. For contrast, the next corresponding "high-flow" interval - June-August, 1986 - also is selected. This additional interval is included to compare the magnitude of a water quality trend (due to STP upgrades) with the variability due to a factor such as freshwater inflow. Relevant streamflow statistics for these intervals are provided in Table 5.1 below.

Table 5.1: 90-day Average Flow Statistics for Selected Intervals

YEAR	JUNE FLOW (cfs)	JUNE RANK*	JULY FLOW (cfs)	JULY RANK*	AUGUST FLOW (cfs)	AUGUST RANK*
1981	6,840	33	5,170	36	3,510	23
1985	6,220	27	4,850	32	3,630	25
1986	12,800	62	5,630	44	7,450	61

* Ranked over 78 years of monthly data
SOURCE: USGS flow statistics for Delaware River at Trenton

Due to the uneven distribution of dry and wet years over the study period (Figure 4.6 and 4.7), it was difficult to select other intervals having all the features described above. Comparable dry-flow intervals spanning the last decade were never followed by extreme high-flow intervals in the following year. Thus, the selected 1986 interval is only a moderately high-flow period. In any case, Figures 5.11 through 5.18 represent estuarine-wide plots of various constituent concentrations averaged over the 3 selected 90-day intervals.

Like the previous set of plots, Figures 5.11 through 5.18 suggest overall improved water quality conditions in recent years. Qualitative comparisons of the curves for the two low-flow intervals (during 1981 and 1985) reveal improvements in DO, BOD_5, and ammonia concentrations in the vicinity of greatest STP loading: RK 145 - RK 169 (RM 90 - RM 105). Improvements in water quality level for the extreme upper and lower Estuary are less obvious during the 1981-1985 time span. Furthermore, comparisons of the curves for the 1985 and 1986 intervals in Figures 5.11 through 5.18 indicate some variability due to the influence of freshwater inflow, particularly for ambient nitrate concentrations. However, the difference in the profiles between the wet and dry years is of lesser magnitude than that attributed to actual improvements in water quality of the estuary.

Like freshwater inflow, tidal variability may confound trend analyses of water quality conditions. To examine this influence, the data for the June-August, 1985 interval was sorted into two tidal current phase classifications, SBF and SBE (see section 4.2.2), and averaged over the time interval. Figures 5.19 through 5.28 show the results of this sorting procedure. For most parameters, tidal variations are quite noticeable. Curves corresponding to parameters such as DO, nitrate, organic nitrogen, total phosphorus, and fecal coliforms all appear to be displaced towards the head of the estuary at the end of the flooding interval (i.e., at SBE tide) compared to the profiles at the end of the ebbing period (i.e., at SBF tide). This displacement of the profile curves is comparable to the 10-20 km tidal excursion reported for the Delaware Estuary (Sharp, 1986). Thus, tidal advection may cause significant short-term variability in water quality conditions of the Delaware Estuary.

5.3. Estuarine-Wide Status Analyses

The current status of estuarine water quality was assessed based on data collected during the past three years. This time period was selected because the results presented in Chapter 6 indicate continued trends in water quality through the late 1980s. Thus, data from a longer time span might be influenced by trends in water quality and would not represent current status. On the other hand, more than one year of data was used to characterize estuarine status to reduce the effect of natural variability in estuarine water quality. In addition, 1989, the last full year of record, represents an unusual year in terms of meteorologic influences. Rainfall during 1989 occurred at near record levels. However, the annual rainfall distribution was uncommon. Near drought condition existed during the winter while record rainfalls occurred during late spring and summer. Thus, the normal hydrologic pattern of high winter and low summer flows did not occur during this year. In addition, only 8 to 10 data points are collected per station during each summer. The use of a three-year period reduces the influence any one anomalous measurement would have on the overall averages.

The 1980s were a decade in which most of the major wastewater treatment facilities that discharge to the Delaware River Estuary were upgraded (Figure 2.5). Thus, the water quality status of the Estuary would be expected to have improved significantly. The assessment of seasonal water quality for the appropriate parameters is described in the following paragraphs.

Salinity: Seasonal plots of mean salinity concentrations are shown in Figure 5.29. As shown in this figure, the upper Delaware Estuary is essentially a tidal-freshwater zone. The salinity front is usually contained within the defined Transition Zone (between RK 87 and RK 129). Above RK 129, the mean salinity remains well below 1 ppt on an annual basis, with no apparent seasonal differences. Below RK 129, some slight seasonal differences are apparent. Near RK 87, average salinity was approximately 3 ppt. During summer, the salinity front intruded an additional 1 to 3 km upstream. An intrusion of salinity would be expected in the summer due to lower seasonal freshwater input.

Turbidity: Seasonal plots of mean turbidity levels are shown in Figure 5.30. High levels of turbidity are normally associated with the salinity front in estuaries. Indeed, both of these plots show a distinct longitudinal variation in turbidity. These levels display a turbidity peak within the Transition Zone which is approximately 300% of background levels in summer and 200% of background levels in winter. Due to limited data, no significance can be ascribed to the apparent turbidity increase within the Bay Zone.

Temperature: Seasonal plots of mean water temperature are shown in Figure 5.31. Of course, the magnitude of mean temperature shows a tremendous seasonal variation. However, the longitudinal variation in the temperature profile is comparatively minor. During summer, there is less than 2°C change in mean temperature across the entire length of the Estuary, with only about 1°C of local variation. During winter, it appears that areas most influenced by freshwater or wastewater input (above RK 145) are about 1°C to 2°C warmer than in the lower estuary.

pH: Seasonal plots of mean pH are shown in Figure 5.32. Both the summer and winter pH profiles display an apparent minimum in the vicinity of RK 145. Mean concentrations in the Bay Zone are approximately 0.2 to 0.6 pH units higher than those at the minimum during summer and winter respectively. With the exception of the Bay Zone, mean winter pH levels are approximately 0.3 to 0.5 pH units less than the corresponding summer values. Winter pH levels appear to increase above summer levels within the Bay Zone. In general, the mean pH data appear to be relatively uniform over most of the estuary. However, within the Philadelphia-Camden area (RK 145 to RK 193), pH data is highly variable, with the station-to-station variation ranging from 0.25 to 0.5 standard units.

It should be noted that mean summer pH levels are somewhat high, ranging between 7.7 and 8.0 over the length of the estuary. As described in Chapter 6, pH values plotted over time revealed an unusual pattern. A gap in the pH data was noted in the mid 1980s. Data reported after this gap is higher than the earlier data at almost all stations. This may explain the high pH levels found in this status analysis.

BOD_5: Seasonal plots of mean BOD_5 concentrations are shown in Figure 5.33. As discussed in previous sections, limits on the accuracy and precision of the reported BOD_5 data strongly inhibit extended analysis. This limitation is reflected in Figure 5.33 which shows a virtually no variation in BOD_5 concentrations through the estuary and almost all of the data are below the detection limit of 2.4 mg/l. The apparent limits of detection of the BOD_5 data limit possible spatial analysis, but no large increases in BOD_5 appeared in the vicinty of the treatment plants.

Total Phosphorus: Seasonal plots of mean total phosphorus concentrations are shown in Figure 5.34. The longitudinal variation displayed in these plots is relatively small, and the few isolated concentration peaks are not considered to be important. There is little evidence of elevated concentrations near the wastewater discharges in the Philadelphia-Camden area, a generally unexpected result. There appears to be a slight drop in concentrations in the Bay Zone (below RK 87), possibly due to the increased dilution. Mean summer concentrations generally vary between 0.10 and 0.20 mg/l with the corresponding winter values often about 0.05 mg/l lower.

Ammonia: Seasonal plots of mean ammonia concentrations are shown in Figure 5.35. The mean ammonia concentrations display a very pronounced seasonal and longitudinal variation. For summer, the plots show little longitudinal variation with no significant peaks. Mean ammonia concentrations range between 0.10 mg/l and 0.25 mg/l. However, a distinct zone of elevated concentrations is evident in the winter data. Between RK 169 and RK 145, the mean ammonia concentration abruptly increases from 0.30 mg/l to over 0.70 mg/l. A reciprocal decrease is present between RK 64 and RK 96.5. Decreases in concentration within this Zone are generally attributed to the dilution capacity of the Delaware Bay.

However, the concentration gradient that occurs between RK 169 and RK 145 appears to be related to an anthropogenic source. The four major Philadelphia-Camden wastewater treatment plants discharge to this segment of the River. Thus, both the elevated winter ammonia concentrations and the pronounced longitudinal variation appear to be related to these discharges. However, the absence of this same longitudinal variation in the summer is an unexpected result.

Nitrate: Seasonal plots of mean nitrate concentrations are shown in Figure 5.36. The two seasonal nitrate profiles show similar, pronounced longitudinal variations that are generally centered about the Transition Zone. The summer profile is distinguished by a region of elevated nitrate concentrations between RK 96 and RK

161. The winter profile exhibits a similar zone of elevated concentrations between RK 80 and RK 145. The increased concentrations are of similar magnitude, approximately 1.5 mg/l to 2 mg/l. The higher concentrations are present in the summer and are within a region located about ten miles farther upstream.

Nitrate concentrations in these peak regions are approximately 0.7 mg/l above the upstream background levels and 1.0 mg/l above the Bay background levels. Due to the location of this region, the source of the elevated nitrate concentrations is unclear. The zone of elevated nitrate concentrations is displaced about 10 to 20 miles downstream from the aforementioned zone of increased ammonia concentrations. This lag suggests nitrification as a contributory process. However, no elevated ammonia concentrations were present during summer to fuel the nitrification process. Thus, other processes may be occurring. In summer, the location of elevated nitrates suggests a direct discharge in the Philadelphia-Camden area. Other possible sources include denitrification in the river sediments and non-point source contributions from agricultural areas in Southern New Jersey and Delaware.

Total Nitrogen: Seasonal plots of average total nitrogen for 1988-1990 are provided on Figure 5.37. Seaward of approximately RK 140, total nitrogen concentrations are higher in the winter months. Upstream of this point, the opposite pattern applies. This pattern may be related to possible nitrification in the Tidal River and lack thereof in the lower portions of the estuary.

Dissolved Oxygen: Seasonal plots of mean dissolved oxygen concentrations are shown in Figure 5.38. Dissolved oxygen concentrations are strongly influenced by wastewater discharges. Thus, it is remarkable that there is only a minor longitudinal variation in the dissolved oxygen profile. A sag of about 1.5 to 2.0 mg/l occurs in the longitudinal distribution of the mean dissolved oxygen concentration. The minimum sag point is located between RK 153 and RK 161. Dissolved oxygen concentrations recover to unimpacted levels (6.0 mg/l) by RK 97. Winter concentrations are, understandably, much higher and reflect a similar longitudinal pattern.

Comparisons of dissolved oxygen concentrations with appropriate water quality standards are of prime importance. An analysis of Figure 5.38 shows that the average summer dissolved oxygen concentration is not less than the established water quality standard at any point on the River. In Figure 5.38, the range of the summer dissolved oxygen concentration data is compared with this standard. While this figure indicates that mean dissolved oxygen concentrations are in conformance with the standard, the minimum concentrations at most stations are not. Thus, short-term summer violations of the dissolved oxygen standard may occur at any point within the Delaware Estuary. The degree of violation is dependent on the diurnal variation of the data (the dissolved oxygen standard is defined as a 24-hour average) which can not be fully represented by grab samples collected between 7:00 AM and 12:00 PM.

Fecal Coliforms: Seasonal plots of the geometric mean of the fecal coliform count are shown in Figure 5.39. Generally the summer and winter profiles for this parameter are quite similar. However, there is a distinct longitudinal variation in these profiles. A 5 to 10 mile wide zone of elevated fecal coliform counts is present between RK 153 and RK 169. Elsewhere in the freshwater zone, the geometric mean of the fecal coliform count remains between 40 per 100ml and 100 per 100 ml, with relatively little longitudinal variation. In this saline zone (below RK 88.5), fecal coliform counts rapidly diminishes to minimal levels.

The conformance of fecal coliform data to the respective water quality standard is also shown in Figure 5.39. As the fecal coliform standard is defined as a geometric mean, a comparison of the results and standard is appropriate. Exceedances of the fecal coliform standard occur only in a narrow 5 mile wide zone between RK 152 and RK 161 in which the geometric mean briefly approaches 2,000 per 100 ml. At all other points, data is in conformance with this standard.

6. ESTUARINE ZONE ANALYSIS

In chapter 5, the historic water quality data for the Delaware Estuary are presented through the use of graphical analysis techniques. These techniques allow for a visual assessment of long-term trends in the longitudinal distribution of water quality parameters. While such techniques do provide a preliminary assessment of status and trends, they do not provide for a definitive quantitative analysis. In this Chapter, such a detailed status and trend analysis is conducted for individual stations within each of the three defined estuarine zones. Results of these analyses are then synthesized to provide an overall characterization of the water quality status and trends in each of these zones.

6.1 Tidal River Zone

The Tidal River Zone comprises a tidal-fresh segment of the Delaware Estuary. The average salinity in this zone over the last three years is 0.11 ppt. The Tidal River Zone has been subject to the most dramatic changes in water quality over time of any of the Delaware Estuarine Zones. A reach of special consideration exists in this Zone between about RK 144.8 (RM 90) and RK 168.9 (RM 105). This reach directly receives most of the treated effluent from the highly urbanized and industrial Philadelphia-Camden area.

Four stations were selected for detailed analysis in this zone: Fieldsboro, NJ at RK 205.11 (RM 127.48); Torresdale, PA at RK 178.12 (RM 110.70); Navy Yard, Phila. PA at RK 149.93 (RM 93.18); and Eddystone, PA at RK 135.12 (RM 83.98). These four stations represent the wide range of current and historic water quality conditions found in the Tidal River Zone.

6.1.1 Analysis for Station at Fieldsboro, NJ (RK 205.11)

Data at the Fieldsboro Station was collected by DRBC. The period of record for water quality data extends from 1967 to 1990. Table 6.1 summarizes the data analyzed for this study at the Fieldsboro Station.

Over 500 data points were available over the 24-year period of record for many parameters. One phosphorus value of over 50 mg/l was deleted from the database; all other phosphorus values were below 5 mg/l.

STATUS

Table 6.2 provides a summary of the data at the Fieldsboro Station from 1988 to 1990.

The recent average DO concentration at this station is 7.0 mg/l during the summer. About 50% of the measured summer DO concentrations were above 7.1 mg/l; less than 25% of the summer measurements were below 6.2 mg/l. The minimum recent DO concentration of 4.2 mg/l indicates that violations of the applicable 24-hour standard of 5 mg/l may have occurred. The geometric mean of the Fecal Coliform data over this period was 74.9 which is below the standard geometric mean of 200. The maximum fecal coliform count was 2,600 which is above that standard. However, the 75th percentile value of 178 falls below the applicable standard.

Table 6.1: Summary of Historic Data - Fieldsboro, NJ

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO - All	8.8	14.3	1.7	7.2	8.5	10.4	2.2	25.3%	536
DO - Summer	7.1	10.9	2.9	6.3	7.2	8.0	1.3	18.1%	231
DO Sat.(%)	88.2	125.7	17.0	80.5	89.6	97.6	14.0	15.8%	521
NH3+NH4-N	0.32	3.7	0	0.15	0.25	0.4	0.30	92.4%	536
NO3-N	0.86	2.72	0.01	0.61	0.81	1.05	0.35	40.1%	522
TKN	0.85	3.0	0	0.52	0.8	1.1	0.47	55.7%	507
Tot. N	1.75	5.22	0.41	1.36	1.65	2.06	0.58	33.2%	494
BOD5[2]	2.5	9	0.5	2.2	2.4	2.5	0.92	36.8%	501
Total Phos-P	0.21	6	0.02	0.1	0.15	0.26	0.29	138.9%	531
Nonfil. Res.	14.7	107	0	6.25	11.0	16.0	15.8	107.1%	240
pH	7.5	9.0	5.8	7.3	7.5	7.7	0.42	5.5%	496
Turb. HLGE	9.40	100	0	5	7	10	9.4	100.3%	456
Chloro. a	14.5	97.5	0.0	3.0	8.9	20.0	16.4	113.2%	324
Fec. Col.[3]	210.1	66000	10	60	210	590	-	-	525
Tot. Col.[3]	2610.0	160000	0	1000	2500	5605	-	-	225

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric Mean of the data per 100 ml.

Table 6.2: Summary of Recent Data (1988-1990) - Fieldsboro, NJ

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO - All	8.4	14.2	4.2	7.0	7.8	9.7	2.1	25.1%	51
DO - Summer	6.9	9.0	4.2	6.0	7.25	7.8	1.2	17.1%	24
DO Satur.(%)	86.0	125.7	45.6	79.5	87.3	92.9	13.3	15.4%	52
NH_3+NH_4-N	0.16	1.07	0.05	0.07	0.12	0.18	0.17	107.1%	52
NO_3-N	1.03	2.14	0.01	0.79	1.0	1.20	0.44	42.6%	52
TKN	0.50	1.0	0.1	0.36	0.49	0.6	0.21	43.1%	52
Tot. N	1.61	2.9	0.85	1.3	1.6	1.7	0.4	28.0%	52
Chlorides	14.5	32.0	4,0	10.6	14.0	17.75	5.3	36.3	52
BOD_5[2]	2.44	3.0	-	-	-	-	-	-	25
Total Phos-P	0.11	0.26	0.02	0.08	0.10	0.13	0.05	47.0%	52
Nonfil. Res.	10.9	74	0	5	8	11.75	13.4	123.5%	52
pH (su)	7.7	8.9	6.8	7.4	7.7	7.9	0.5	6.0%	35
Turb. (ftu)	6.7	45	1.5	3	4	6.0	8.3	123.8%	53
Chlorophyll-a	3.6	30	0	0	1.9	4.5	3.6	174.0%	25
Fec. Col.[3]	74.9	2600	10.0	30.0	70.0	178	-	-	53
Tot. Col.[3]	2140.1	24000	170	1120	2300	3500	-	-	25

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric Mean of the data per 100 ml.

TRENDS

Appendix A provides graphs of selected water quality parameters over time at the Fieldsboro station. Review of these graphs reveals possible trends in a number of water quality parameters over time.

Dissolved Oxygen - Minimum annual summer DO concentrations and the percentage of the measurements that were below 5 mg/l and 6 mg/l are provided in

Table 6.3. Review of these data reveals possible occasional summer violations of the 24-hour DO standard of 5 mg/l over time.

As shown in Table 6.3, the limited number of summer samples collected at this station indicate occasional violation of the applicable DO standard. Over the past six years, violations have occurred in three years. Interestingly, during the first six years of the study, when more than twice as many samples were collected each summer, violations occurred in only one year. This, coupled with the insignificant, but decreasing trend, in DO concentrations noted during the trend analysis (see following paragraph) for this station suggest a possible deterioration in DO levels at the Fieldsboro station. Additional data would be needed to determine if such a trend is real or a result of fluctuations in natural conditions in the system.

Table 6.4 provides a summary of the trend analyses conducted for the Fieldsboro station. The table presents both the non-parametric Kendall's tau (τ) and the parametric Pearson correlation coefficient (r). The prob value for each results also is provided. A 5% level of significance was selected for these analyses. Therefore, because this is a two-tailed test, a significant positive (+) or negative (-) trend is represented by a prob value of 0.025 or less. A perfect correlation would be represented by a value of 1.0.

Review of the results in Table 6.4 indicates a statistically insignificant negative trend (at the 5% level) over time in DO data for both the entire data set and for the summer data only. A similar insignificant negative trend in DO saturation also is noted.

Table 6.3: Minimum Summer DO Concentrations and Percent Violation - Fieldsboro, N.J

Year	Min. DO	% < 5 mg/l*	% < 6 mg/l	N
1967	6.4	0.0%	0.0%	11
1968	5.5	0.0%	0.0%	23
1969	3.6	20.0%	26.7%	15
1970	5.7	0.0%	5.3%	19
1971	5.4	0.0%	11.1%	9
1972	6.2	0.0%	0.0%	6
1973	5.2	0.0%	12.5%	8
1974	4.5	28.6%	28.6%	7
1975	3.6	12.5%	12.5%	8
1976	5.6	0.0%	12.5%	8
1977	4.9	12.5%	12.5%	8
1978	5.0	0.0%	12.5%	8
1979	5.0	0.0%	12.5%	8
1980	5.3	0.0%	11.1%	9
1981	2.9	28.6%	28.65	7
1982	6.1	0.0%	0.0%	10
1983	5.5	0.0%	12.5%	8
1984	4.6	11.1%	11.1%	9
1985	4.8	10.0%	10.0%	10
1986	6.1	0.0%	0.0%	8
1987	4.6	12.5%	12.5%	8
1988	5.1	0.0%	37.5%	8
1989	4.2	12.5%	25.0%	8
1990	5.9	0.0%	12.5%	8

*24-hour DO Standard

Table 6.4: **Trend Analysis Results - Fieldsboro, NJ**

Parameter	Kendall's Tau[1] τ	prob val.	Pearson Corr. Coeff.[2] r	prob val.	No. of Obs.
DO	-0.044	0.1294	-0.076	0.0796	536
DO - Summer	-0.0337	0.4676	-0.049	0.4577	231
DO Saturation	-0.127	0.6654	-0.022	0.613	521
NH_3+NH_4-N	-0.265	0.0001	-0.280	0.0001	536
NO_3-N	0.259	0.0001	0.353	0.0001	522
TKN	-0.279	0.0001	-0.356	0.0001	507
BOD_5	0.073	0.023	-0.057	0.197	501
Tot. Phosphorus	-0.431	0.0001	-0.281	0.0001	532
Nonfilterable Res.	-0.253	0.0000	-0.275	0.0001	240
Turbidity (HLGE)	-0.255	0.0001	-0.215	0.0001	456
pH	-0.051	0.0978	-0.119	0.0077	496
Chlorophyll a	-0.397	0.0001	-0.490	0.0001	324
Total Nitrogen	-0.051	0.082	-0.0906	0.0440	494
Fecal Coliform	-0.115	0.0001	-0.071	0.1058	525
Total Coliform	0.067	0.134	0.215	0.0011	225

1 τ=Kendall's tau; a prob value <0.025 represents a significant decreasing (-) or increasing (+) trend.

2 r=Pearson's correlation coefficient; a prob value <0.025 represents a significant decreasing (-) or increasing (+) trend.

Nutrients, BOD_5 and other Parameters - Significant decreasing trends are noted for ammonia, TKN, total phosphorus, nonfilterable residue, turbidity, and chlorophyll-a. A significant increasing trend is noted in nitrate and no significant trend is found in total N. As discussed for the other stations, trends in BOD_5 are difficult to test for because the data below 2.4 is now reported simply as <2.4 (the detection limit) in recent years while earlier data was sometimes reported as actual value.

Total phosphorus also demonstrated a significant decline over time. As discussed in Section 3.3.4, the reported STORET parameter code for phosphorus changed over the course of the study period. Even with this problem, the total phosphorus values declined dramatically during the initial years of the study and then continued a gradual reduction. The change in parameter code seems to have affected the data collected in the late 1970s and early 1980s. Overall, however, it is clear that total phosphorus levels have decreased.

Coliform Bacteria - The use of nonparametric statistical techniques is especially relevant in the study of the coliform data. Coliform data are generally distributed as log-normal and will often include a few very high values. These values would tend to skew the calculation of means and other parametric statistics for coliform data. The nonparametric techniques relay on the rank of the data and so are unaffected by a the actual value of the data. In this case, a significant decreasing trend in fecal coliform levels was noted using the Kendall's tau method; an insignificant decreasing trend was found using the parametric method. For total coliform, the nonparametric technique found no significant trend while the corresponding parametric trend found a significant, increasing trend. It must be noted that the number of data points for total coliform is about half of that for fecal coliform.

The trend analysis for the Fieldsboro station, then, reveals no significant trend in DO concentrations over time. Ammonia concentrations have decreased while nitrate concentrations have increased in the river at this station.

DATA SORTING

Effect of Tidal Stage - Further analysis was conducted to determine if concentrations of DO and other parameters were influenced by tidal stage. The clasification was based on the tide stage codes included in the STORET database. Both a non-parametric Kruskal-Wallis test and the parametric ANOVA were used to test for differences in the water quality parameter concentrations among tide stage codes. These tests compare the variance among the groups to that within the groups to determine if these groups are statistically significantly different. Table 6.5 provides the results of this analysis.

Table 6.5: Comparison of Data by Tide Stage at Sampling Time - Fieldsboro, NJ

	Kruskal-Wallis[1]		ANOVA[2]	
Parameter	**chisq**	**prob val.**	**F**	**prob val.**
DO	0.13	0.9373	0.03	0.967
DO - Summer	7.13	0.0283	3.92	0.0212
DO Saturation	3.11	0.2116	2.25	0.11
NH_3+NH_4-N	11.98	0.0025	1.47	0.2311
NO_3-N	8.71	0.0128	4.62	0.0103
TKN	4.79	0.0913	0.63	0.5353
BOD_5	3.68	0.1592	2.01	0.1351
Tot. Phosphorus	18.86	0.0001	5.10	0.0064
Nonfilterable Res.	0.44	0.8018	0.20	0.8216
Turbidity (HLGE)	0.26	0.8800	0.30	0.7444
pH	5.84	0.0539	2.83	0.0602
Chlorophyll a	16.19	0.0003	9.08	0.0001
Fecal Coliform	3.62	0.1633	0.74	0.4768
Total Coliform	8.02	0.0181	2.00	0.1374

1 chisq = the chi square test statistic for the Kruskal-Wallis test; a prob value of <0.025 indicates a significant difference.

2 F= the F statistic for the ANOVA; a prob value of <0.025 indicates a significant difference.

Significant differences in concentrations among tide stage were noted only for ammonia, total phosphorus, and chlorohphyll-a at the 5% level, using the non-parametric analysis of variance technique. Thus, these results do not suggest that subdividing the data by tide code would substantially reduce the variance in the date set.

6.1.2 Analysis for Station at Torresdale, PA (RK 178.12)

Appendix B graphs the data over time for the parameters of interest at this station, located in the tidal river zone. Data for this analysis includes that collected by both the Philadelphia Water Department (WDPT)and the DRBC. The period of record for this station extends from 1963 to 1990.

Review of the sorted data revealed one anomalous data point for conductivity. This value was over 2,000 umhos which is clearly an outlier in this freshwater area. Therefore, this point was removed from the database. One BOD_5 value of 57 mg/l was reported. The next highest BOD_5 value is 12.6 mg/l, or over 4.5 times smaller, and all but three of the BOD_5 concentrations were below 10 mg/l. Thus, the value of 57 mg/l deleted from the database.

Table 6.6 summarizes the data retrieved for this station. Almost 1300 data points were retrieved for many parameters at this station.

STATUS

Table 6.7 provides a summary of data for the last three years at the Torresdale Station.

Table 6.6: Summary of Historic Data - Torresdale, PA

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO	8.0	14.0	1.4	5.5	7.7	10.7	2.9	36.9%	1284
DO-Summer	5.5	14.8	1.4	4.4	5.4	6.5	1.5	28.3%	515
DO Sat. (%)	76.3	117.0	16.7	63.3	80.6	90.4	17.8	23.3%	1278
Temp. (°C)	16.2	30	0	9	17	24	8.5	-	1294
NH_3+NH_4-N	0.42	3.2	0.0	0.19	0.35	0.57	0.34	80.3%	1274
NO_3-N	0.96	4	0.01	0.7	0.9	1.19	0.38	39.4%	1184
TKN	0.85	3.1	0.1	0.55	0.8	1.1	0.42	50.0%	526
Tot. N	1.89	5.25	0.75	1.5	1.8	2.1	0.6	31.1%	513
BOD_5[2]	2.4	12.6	-	-	-	-	-	-	1217
Total Phos-P	0.21	3.1	0.02	0.11	0.14	0.26	0.2	97.4%	549
Chlorophyll_a	15.2	90.3	0	5	12	19.7	15.2	100.1%	336
pH (su)	7.2	9.5	5.7	7.1	7.2	7.4	0.3	3.6%	1238
Chloride	13.8	185	1	10	12	16	8.5	61.8%	1256
Total Col.[3]	4558.3	54100	0	1500	3800	12250	-	-	878
Fec. Col.[3]	302.4	106000	0	90	240	940	-	-	1080

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric Mean of the data per 100 ml.

Table 6.7: Summary of Recent Data (1988-1990) - Torresdale, PA

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	# of Obs.
DO - All	7.8	13.9	4.5	5.9	7.3	9.7	2.3	29.0%	56
DO - Summer	6.2	8.4	4.5	5.3	5.9	7.1	1.0	16.6%	25
DO Sat. (%)	78.1	103.0	48.0	67.8	78.0	89.2	13.5	17.2%	55
Temp. (°C)	15.2	30	0	8.2	16	22.4	8.5	55.7%	64
NH3+NH4-N	0.20	1.13	0.05	0.09	0.13	0.20	0.20	104.7%	64
NO3-N	1.07	1.93	0.01	0.88	1.05	1.34	0.40	37.5%	54
TKN	0.51	0.914	0.12	0.4	0.5	0.6	0.16	31.1%	54
Tot. N	1.7	2.6	1.0	1.4	1.6	1.96	0.4	22.2%	54
BOD_5[2]	2.43	3.1	<2.4	-	-	-	-	-	26
Total Phos-P	0.10	0.29	0.04	0.07	0.10	0.13	0.44	42.3%	54
Non-Fil. Res.	12.9	66.0	0.0	7.0	11.0	16.75	9.7	75.1%	64
Turbid. (ftu)	7.3	26.5	1	3	5	10	5.8	80.3%	65
Chlorophyll_a	7.5	38.9	0	0	5.2	11	9.0	120.7%	26
pH	7.5	9.5	6.8	7.1	7.5	7.7	0.5	6.6%	36
Chloride	15.0	26.1	6.1	11	14.4	18.0	4.8	32.3%	56
Tot. Col.[3]	2433.	35000.	140.	1300.	2300.	4825.	-	-	36
Fec. Col.[3]	112.1	2133	6.	51.5	106.	196.5	-	-	65

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric Mean of the data per 100 ml.

The DO standard for the Delaware River at Torresdale is a 24-hour average of 5.0 mg/l. During the period from 1988 to 1990, DO concentrations below this level were reported twice (4.5 mg/l and 4.8 mg/l). This represents 2.2% of the 90 available measurements. It should be noted that only one value below 5 mg/l was reported during a summer month (June through September) or 2.4% of the 41 recorded summer data points. Clearly, the reported values do not represent continuous sampling and so can not be considered to represent the true minimum. However, since over 40 points were taken during the summer months, it seems likely that the sampling is representative and only occasional DO violations occur. DO saturation levels are also relatively high, averaging 80%. The minimum over DO saturation the last five year was 49%.

TRENDS

Appendix B provides graphs of the data versus time at this station.

Trend analyses for select water quality parameters were conducted at this station according to the methods outlined in Section 4.3. The results of the trend analysis are presented in Table 6.8. The table presents both the non-parametric Kendall's tau (τ) and the parametric Pearson correlation coefficient (r). The prob value for each result is also provided. A 5% level of significance was selected for these analyses. Therefore, because this is a two-tailed test, a significant positive (+) or negative (-) trend is represented by a prob value of 0.025 or less. A perfect correlation would be represented by a value of 1.0.

The results from Table 6.8 indicate a statistically significant (at the 5% level) trend in essentially all parameters over time. It must be noted that the statistically significant results simply reflect a general trend in the data over time that is statistically significant. It says nothing about whether this represents a true change in water quality conditions or simply is caused by other factors, such as a change in sampling methods or analysis technique. For example, chloride concentrations show a significantly increasing trend over time. Generally, chloride concentrations would not be affected by upgrades in municipal treatment levels. The increasing chloride concentrations may be the results of reductions in chloride loadings to the River from industrial wastewater discharges, increased freshwater loadings from treatment plants, changes in freshwater diversions or other factors. Alternatively, the negative trend may simply be due to the reduced number of samples collected during recent years or some other unknown factor.

Table 6.8: Trend Analysis Results - Torresdale, PA

Parameter	Kendall's Tau[1] τ	Kendall's Tau[1] prob val.	Pearson Corr. Coeff.[2] r	Pearson Corr. Coeff.[2] prob val.	n
DO	0.0614	0.0010	0.0653	0.0192	1284
DO - Summer	0.2602	0.0001	0.3225	0.0001	515
DO Saturation	0.1289	0.0001	0.2002	0.0001	1278
NH_3+NH_4-N	-0.3680	0.0001	-0.4774	0.0001	1274
NO_3-N	0.1933	0.0001	0.2251	0.0001	1184
TKN	-0.3264	0.0001	-0.42741	0.0001	526
Tot. N	-0.1467	0.0000	-0.220	0.0001	513
BOD_5	0.00261	0.8946	-0.0147	0.6078	1218
Tot. Phosphorus	-0.7061	0.0001	-0.7158	0.0001	549
Nonfilterable Res.	-0.1670	0.0001	-0.1884	0.0016	279
Turbidity (HLGE)	-0.2740	0.0001	-0.1674	0.0003	471
pH	-0.025	0.2128	-0.0140	0.6227	520
Chlorophyll-a	-0.2610	0.0001	-0.2896	0.0001	336
Fecal Coliform	-0.0671	0.0010	-	-	1080
Total Coliform	-0.0442	0.0503	-	-	1080
Chlorides	0.1136	0.0000	0.1203	0.0001	1256

1 τ=Kendall's tau; a prob value <0.025 represents a significant decreasing (-) or increasing (+) trend.

2 r=Pearson's correlation coefficient; a prob value <0.025 represents a significant decreasing (-) or increasing (+) trend.

Dissolved Oxygen - Visual inspection of the graph of DO versus time indicates a possible increasing trend in dissolved oxygen values over time. The trend analysis results in Table 6.8 demonstrate a significant improving trend in DO concentrations for the summer subset and for the entire dataset using the Kendall Rank Correlation method. Figure 6.1 provides a graph of minimum DO levels over time, with the applicable standard of 5.0 mg/l indicated on the graph. Clearly, minimum DO levels have increased over time. Table 6.9 provides data on the minimum annual DO levels and the percent of measurements below the 24-hour DO standard of 5 mg/l reported by year over the period of record.

Table 6.9 and Figure 6.1 illustrate the improvement in minimum DO levels at the Torresdale station over the past 27 years. After 1970, no samples indicated a DO level below 2 mg/l. By 1974 all of the minimum summer concentrations, with the exception of 1985, were above 3.5 mg/l. In addition, over the last five years only one reported measurement violated the DO standard. It must also be noted that only 8 to 9 samples are now collected during each summer period, in comparison to over 20 samples per year collected prior to 1980.

The results in Table 6.8 reveal a statistically significant increasing trend in DO concentrations over time for the summer data.

Nutrients - A statistically significant decreasing trend (5% level) in ammonia concentrations was found for the period of record at this station. Review of the graph of ammonia data over time supports this conclusion. With a few exceptions, most of the data from the mid-1980s on is below 1.0 mg/l. The variance of the data appears to be decreasing in recent years, although no statistical test of this hypothesis was conducted and it may be an artifact of the decreased number of samples taken in later years. Concurrently, a statistically significant increase in nitrate concentration occurs over the period of record. No dramatic jumps in nitrate concentration are noted. A statistically significant (5% level) decreasing trend in total nitrogen also is noted.

Table 6.9: Minimum Summer DO Concentrations and Percent Violation - Torresdale, PA (RK 178.12)

Year	Min. DO	% <2 mg/l	% <3.5 mg/l*	% <5 mg/l	N
1963	2.4	0%	17.6%	70.6%	17
1964	3.8	0%	0%	16.7%	18
1965	1.7	12.5%	31.3%	62.5%	16
1966	1.7	9.1%	9.1%	45.5%	11
1967	2.2	0%	18.5%	66.7%	27
1968	1.4	2.6%	10.3%	51.3%	39
1969	3.3	0%	5.6%	61.1%	18
1970	1.9	2.7%	21.6%	70.3%	37
1971	3.1	0%	8.0%	60.0%	25
1972	2.6	0%	17.4%	52.2%	23
1973	2.2	0%	4.0%	48.0%	25
1974	2.9	0%	20.8%	58.3%	24
1975	4.3	0%	0%	22.7%	22
1976	4.7	0%	0%	4.2%	24
1977	4.0	0%	0%	34.6%	26
1978	3.7	0%	0%	20.0%	20
1979	4.4	0%	0%	15.0%	20
1980	4.4	0%	0%	14.3	21
1981	4.6	0%	0%	13.3%	15
1982	4.3	0%	0%	15.4%	13
1983	4.4	0%	0%	41.7%	12
1984	3.7	0%	0%	22.2%	9
1985	3.2	0%	10.0%	50.0%	10
1986	5.4	0%	0%	0%	8
1987	5.5	0%	0%	0%	8
1988	5.0	0%	0%	0%	8
1989	4.5	0%	0%	11.1%	9
1990	5.8	0%	0%	0%	8

* 24-Hour DO Standard

Analysis of total phosphorus concentrations reveal a statistically significant decreasing trend over time. A sharp decline in total phosphorus concentrations is apparent in the late 1960s to early 1970s with a more gradual decline in the ensuing years. This may have been caused by a sharp reduction in phosphorus loadings to the system, possible by changes in loadings from the freshwater portion of the river, or may be an artifact of early sampling and analysis techniques. The highest early concentration consistently occurred during the winter months.

pH - Review of the graph of pH over time reveals a gap in the data in the mid 1980s. Data collected subsequent to the this gap appear generally appear to be higher than the earlier data. A similar result was noted at many other stations. Additional data are needed to explore this phenomenom, which may be the result of a change in analysis method.

Coliform Data - A decreasing trend over time is noted in the fecal coliform data using the non-parametric test for trend. Analysis of the graph of fecal coliform counts over time support this conclusion. In particular, a reduction of the high counts appears to begin in the mid-1970s. Review of a graph of annual geometric means of the fecal coliform data reveals several years in the late 1960s and early 1970s with standard violations; all years since that time have not shown any standard violations. A possible decreasing trend in the recent annual geometric means is also noted.

No trend in total coliform data is noted. There are large data gaps in the total coliform record.

DATA SORTING

Sorting by Tidal Phase Interval - The possible effects of freshwater inflow and tidal stage on concentrations of water quality constituents were explored at this station. As described in Section 4.2.2, tidal sorting was conducted based on both the tide stage codes included in the STORET database and on the tidal current phase intervals calculated for this study. A comparison of the data classification by tide stage code and tidal current phase interval is provided in Table 6.10.

Calculation of tidal phase interval decreased the number of missing values from 321 to 48, a reduction of 273 points. In addition the proportion of SBE data increased and that of SBF decreased.

Table 6.10: Comparison of Tide Stage Code and Tidal Phase Interval Torresdale, PA

Class	Tide Stage Code (from STORET)	Tidal Phase Interval (Calculated)
Missing Value	321	48
Slack before Ebb (1)	171	291
Mid-Tide Ebb (2)	267	310
Slack before Flood (3)	351	495
Mid-Tide Flood (4)	200	167

An analysis of variance was conducted on several parameters using both the tide stage code classification and the tidal phase interval classifications to categorize the data. For this station, chloride was analyzed as a conservative substance. Using the calculated tidal phase intervals, no significant difference was found among chloride concentrations among intervals for all of the data using both the Wilcoxon Rank Sum test ($p=0.0635$) and for the traditional parametric ANOVA ($p=0.2387$).

However, using the tide stage codes from the retrieved database, the same analysis revealed a significant difference among classes using both tests (p=0.0001). The results indicate that the mid-tide concentrations were significantly different from the slack tide concentrations. There is no readily apparent explanation for this result.

Using the calculated tidal phase intervals as a classification variable, significant differences were found among the four tidal phase intervals for ammonia and total phosphorus but not for nitrate. For ammonia, the average mid-tide flood concentration was significantly higher than the average concentration at the other tide phases. For total phosphorus, the average mid-tide ebb concentration was significantly lower than both the slack before flood and slack before ebb concentrations but not than the mid-tide flood concentration. No other significant differences were noted for total phosphorus.

Summer dissolved oxygen concentrations showed significant differences in concentrations collected at different tidal phase intervals. The results indicated that the average mid-tide ebb concentration (5.91 mg/l) was significantly higher than the average concentrations of samples collected during both the slack before flood and slack before ebb intervals. The average mid-tide flood concentration (5.43 mg/l) was next highest, but this concentration was not found to be significantly different from the average concentration from samples taken during either the slack tide interval or from the mid-tide ebb average. It must be noted that the mid-tide flood interval contained only 49 data points compared to 114 to 199 in each of the other intervals.

Tests for other parameters, including non-filterable residue and turbidity, revealed no significant differences in concentration among the calculated tidal phase intervals.

No distinct pattern emerges from the results of the tidal sorting analysis. This may be a confounding effect of the trends over time found at this station. In an effort to explore the possible effect of trends over time, similar tests were conducted on the data collected since 1985. However, no significant differences at the 5% level were found for ammonia, total phosphorus, or nitrate. Using only the last few years of data severely limits the number of data points in each class and thus very large differences between parameters may be needed for a significant result.

Flow Classification - Data were also analyzed for the possible impacts of dry years versus wet years on concentrations of water quality parameters. However, as discussed in Section 4.2.3, the results of this analysis were confounded by the distribution of wet and dry years over time. For example, the flow class representing 90-day low flows that were ranked in Class 2 (25% to 50% quartile) during the sampling period had a higher average DO concentration than any other class at the Torresdale Station. This result is apparently due to the fact that most of the Class 2 years occur in the 1980s when water quality had improved at this station. As explained in Section 4.2.3, this demonstrates the difficulties with the use of the 90-day low flow values as a surrogate for the relative dryness of a year for analysis in this data set because of the distribution of dry and wet years over time.

6.1.3 Analysis for Station at Navy Yard, Philadelphia (RK 149.93)

This station is located within the boundaries of the city of Philadelphia at RK 149.93 (RM 93.18), in the Tidal River Zone. Data at this station were collected by both the DRBC and the Philadelphia WDPT. The period of record extends from 1963 to 1990. Table 6.11 summarizes the data for this station. About 1,250 data points are available for many parameters.

Table 6.11: Summary of Historic Data - Navy Yard, Phila.

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO - All	4.6	13.9	0.1	1.5	3.5	7.91	3.6	77.6%	1259
DO - Summer	1.8	7.5	0.1	0.8	1.5	2.4	1.4	78.2%	500
DO Sat. (%)	42.2	111.2	1.0	16.7	36.7	68.9	28.3	67.1%	1256
NH3+NH4-N	1.08	6.94	0.05	.57	0.95	1.41	0.76	70.0%	1246
NO3-N	0.96	3.0	0.0	0.64	0.9	1.2	0.47	49.7%	1155
TKN	1.57	4.8	0.2	0.9	1.5	2.1	0.8	51.8%	519
Tot. N	2.75	6.23	0.78	2.14	2.65	3.25	0.85	30.9%	505
BOD_5[2]	3.3	15.5	<2.4	<2.4	2.8	5	-	-	1194
Total Phos-P	0.25	1.1	0.02	0.13	0.20	0.31	0.18	69.4%	552
Turb. (HLGE)	10.6	75	0	5.85	9.2	12	7.6	72.0%	468
Turb. (jtu)	10.8	120	2	6	9	12	9.8	91.0%	689
Chloro. a	19.0	128	0	5.5	12	24	21.8	115.0%	338
pH (su)	6.9	9.8	5.5	6.7	6.8	7.0	0.3	4.5%	1210
Chloride	28.2	692	3	14	19	26	43.5	154.1%	1246
Fec. Col.[3]	3207	150000	0	1466	4200	9300	-	-	1083
Tot. Col.[3]	41444	945000	0	22100	49000	90000	-	-	849

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric mean of the data per 100 ml.

STATUS

Table 6.12 provides a summary of data collected at the Navy Yard station during the period from 1988 to 1990. Initially, because of the inherent variability in the data, the last five years were to be used for the status analysis. However, review of the trend results indicated that DO concentrations at this station had continued to improve in the period from 1985 to 1990 (see following section). Therefore, the shorter time period was used to illustrate current conditions.

Table 6.12: Summary of Recent Data (1988-1990) - Navy Yard, Phila.

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO - All	6.8	11.9	3.0	5.0	6.3	8.9	2.5	35.9%	53
DO - Summer	5.0	7.2	3.0	3.8	5.2	6.0	1.3	26.1%	24
DO Sat. (%)	68.1	100.0	35.2	56.0	67.2	80.8	17.3	25.5%	54
NH_3-NH_4-N	0.4	1.36	0.05	0.07	0.28	0.53	0.33	90.1%	63
NH_3 - All[2]	0.33	1.36	0.05	0.1	0.27	0.48	0.28	19.4%	101
NH_3 - Win[2]	0.67	1.36	0.28	0.47	0.58	0.90	0.30	44.5%	22
NO3-N	1.40	2.72	0.07	1.00	1.26	1.89	0.66	46.9%	53
Tot. N	2.25	3.62	0.78	1.78	2.19	2.73	0.62	27.65	53
BOD_5[3]	2.45	3.0	<2.4	<2.4	<2.4	<2.4	-	-	26
Total Phos-P	0.13	0.25	0.06	0.09	0.12	0.16	0.04	34.2%	53
Nonfil. Res.	13.4	45	0	8	13	16	8.3	61.5%	63
Chloro.-a	7.2	25.3	0	0.92	5.66	11.5	7.0	96.2%	26
pH (su)	7.5	8.6	6.7	7.3	7.4	7.7	0.45	6.0%	35
Turbid. (ftu)	7.6	30.0	1.0	4.0	5.7	10.0	5.7	74.6%	64
Fec. Col.[4]	300.3	4800	20	127	263	775	-	-	64
Tot. Col.[4]	5947.0	92000	490	2400	4900	16750	-	-	36

[1] All parameter units in mg/l unless otherwise noted.
[2] NH_3+NH_4-N from 1986 to 1990.
[3] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[4] Geometric mean of the data per 100 ml.

The mean DO concentration over the three-year period from 1988 to 1990 was 6.8 mg/l, with a minimum of 3.0 mg/l. The 50th percentile for the recent summer data is 5.2 mg/l, which is above the 24-hour DO standard of 3.5 mg/l. These results are in sharp contrast to the data from the entire period of record in which the minimum DO concentration was 0.1 mg/l and 50% of all measurements were below 1.5 mg/l.

The average ammonia concentration for the recent data is 0.4 mg/l compared to an average of 1.08 mg/l for the entire data set. It should be noted that the winter ammonia concentrations for the recent data appear to be higher than the summer values. The average ammonia concentration over the past five years for all of the data is 0.33 mg/l while the average winter concentration is 0.67 mg/l. Conversely, the average winter nitrate concentration for the same period is 1.03 mg/l and the summer average is 1.63 mg/l. Thus, much of the seasonal variability in ammonia concentrations may be related to the seasonal affects of nitrification in the Estuary. When recent Total Nitrogen data is considered (TKN + NO2-N + NO3-N), the summer average of 2.3 mg/l is somewhat higher than the winter average of 1.96 mg/l. The difference may also be related to the larger concentration of data points during the summer months.

TRENDS

Appendix C includes the graphs of water quality concentrations for selected parameters over time for this station. Review of the graphed data revealed apparent trends in most of the data parameters. Therefore, a series of test were conducted to determine if statistically signicant trends over time occurred at this station according to the methods outline in Section 4.3.2. Table 6.13 summarizes the results of those analyses. The table presents both the non-parametric Kendall's tau (τ) and the parametric Pearson correlation coefficient (r). The prob value for each results is also provided. A 5% level of significance was selected for these analyses. Therefore, because this is a two-tailed test, a significant positive (+) or negative (-) trend is represented by a prob value of 0.025 or less. A perfect correlation would be represented by a value of 1.0.

Table 6.13: Trend Analysis Results - Navy Yard, Phila.

Parameter	Kendall's Tau[1] τ	prob val.	Pearson Corr. Coeff.[2] r	prob val.	No. of Obs.
DO - All	0.171	0.0001	0.20	0.0001	1259
DO - Summer	0.391	0.0001	0.579	0.0001	500
DO Saturation	0.204	0.0001	0.290	0.0001	1256
NH_3+NH_4-N	-0.500	0.0001	-0.625	0.0001	1246
NO_3-N	0.449	0.0001	0.587	0.0001	1155
TKN	-0.502	0.0001	-0.689	0.0001	519
Tot. N	-0.220	0.0001	-0.3550	0.0001	505
BOD_5	-0.176	0.0001	-0.260	0.0001	1194
Tot. Phosphorus	-0.501	0.0001	-0.557	0.0001	552
Nonfilterable Res.	-0.012	0.0000	-0.300	0.0001	285
Turbidity (HLGE)	-0.265	0.0001	-0.223	0.0001	468
pH	0.1314	0.0001	0.2832	0.0001	1210
Fecal Coliform	-0.0830	0.0001	-	-	1083
Total Coliform	-0.00597	0.7950	-	-	849

1 τ=Kendall's tau; a prob value <0.025 represents a significant decreasing (-) or increasing (+) trend.

2 r=Pearson's correlation coefficient; a prob value <0.025 represents a significant decreasing (-) or increasing (+) trend.

Dissolved Oxygen - Review of the graph of DO concentration over time reveals an apparent increasing trend in DO concentration. The results of the correlation analysis for this parameter with time revealed a significant positive trend over time for all data ($r=.20$, $t=0.17$, $p=.0001$) and for summer DO ($r=0.58$, $t=0.39$, $p=0.0001$).

In addition to the overall trend in time, the extent and duration of low DO conditions is an important component of stream quality. Table 6.14 provides the minimum summer DO for each monitoring year and provides the percent of observations that violated the applicable summer DO standard of 3.5. Figure 6.2 graphs the minimum annual DO concentration over time.

From 1967 to 1980 both the DRBC and the Philadelphia WDPT collected water quality data at the Navy Yard station (see Figure 6.3). Thus, 20 to 40 data points were available from each summer. From 1984 to the present, 10 or fewer summer samples were collected. The difference in sample size, particularly the limited number of samples in recent years, should be considered in analyzing differences among years. However, the data are generally consistent and, point to a substantial increase in minimum DO concentrations over time. Again, the limited data points do not necessary represent the true DO minimum in any summer, but since they are collected at random are likely to represent common conditions.

From 1967 to 1981 the minimum summer DO level was less than 1 mg/l, generally in the range of 0.1 mg/l to 0.2 mg/l. Essentially, this represents anoxic conditions. In addition, over this period 90% to 100% of the measurements were below the 24-hour DO standard of 3.5 mg/l (with the exception of 1979 with 80%). It must be

Table 6.14: Minimum Summer DO Concentrations and Percent Violation - Navy Yard, Phila.

Year	Min. DO	% <1 mg/l	% < 3.5 mg/l*	% <5 mg/l	N
1964	0.1	61.1	94.4	100.0	18
1965	0.1	62.5	100.0	100.0	16
1966	0.1	72.7	100.0	100.0	11
1967	0.1	50.0	100.0	100.0	28
1968	0.1	35.0	90.0	95.0	40
1969	0.2	33.3	94.4	100.0	18
1970	0.1	40.5	97.3	100.0	37
1971	0.1	52.0	100.0	100.0	25
1972	0.1	43.5	78.3	87.0	23
1973	0.2	48.0	92.0	100.0	25
1974	0.2	33.3	95.0	100.0	24
1975	0.4	9.1	100.0	100.0	22
1976	0.2	13.0	100.0	100.0	23
1977	0.3	53.8	92.3	100.0	26
1978	0.3	30.0	100.0	100.0	20
1979	0.5	55.0	90.0	95.0	20
1980	0.8	9.5	90.5	100.0	21
1981	0.2	10.5	89.5	100.0	19
1982	1.4	0.0	92.3	100.0	13
1983	1.1	0.0	91.7	100.0	12
1984	1.9	0.0	77.8	77.8	9
1985	1.8	0.0	90.0	100.0	10
1986	2.7	0.0	37.5	62.5	8
1987	2.4	0.0	25.0	87.5	8
1988	3.3	0.0	12.5	75.0	8
1989	3.0	0.0	25	50.0	8
1990	4.5	0.0	0.0	12.5	8

* 24-hour DO Standard

noted that this standard is well below the 5.0 mg/l to 6.0 mg/l DO level required in other parts of the Estuary. With the exception of 1990, summer DO concentrations were below 5 mg/l over half of the time through the period of record. The 1990 measurements did not indicate any standard violations. Additional data will be needed to determine if this data represents a continuing improvement in DO concentrations at the Navy Yard Station.

The trend analysis results reveal a statistically significant increasing trend in DO at the 5% level ($p=0.0001$) for both the entire dataset and for the summer subset. Review of the graphs of DO data, including the minimum annual DO concentrations, reveals that the most dramatic improvement has come in the 1980s.

Nitrogen Series - Data over time for ammonia and nitrate is graphed in Appendix C. Visual inspection of the plots indicates a decreasing trend over time in ammonia and an increasing trend in nitrate. The scatter in the ammonia data appears to be greater in the early years of the sampling.

Trend analysis for NH_3+NH_4-N reveals a statistically significant decreasing trend at the 5% significance level. The non-parametric Kendall's tau is -0.5 ($p=0.0001$). The parametric equivalent, the Pearson Correlation coefficient, has the same p value. Total N also shows a significant decreasing trend.

As noted in the Status section for this station, above, there appears to be a difference between summer and winter ammonia concentrations, particularly in recent years. Review of the average concentrations over time divided into summer (June through September) and winter (December through March) subsets reveals that the annual average winter ammonia concentrations were higher than the annual average summer concentrations throughout the period of record. It must be noted that fewer data points are available for the winter data. By the late 1970s, both annual average winter and summer concentrations had declined and were within a few 0.1 mg/l of each other. During the 1980s, however, annual average summer ammonia concentrations continued to decline rapidly from about 0.71 mg/l in 1980 to 0.09 mg/l in 1990. Annual average winter ammonia concentrations increased in the early 1980s and then fluctuated, reaching a minimum of 0.33 mg/l in 1986, but increased back to 1.01 mg/l in 1989. The statistical significance of the differences were not tested. This seasonality is discussed further in Section 6.1.2.

Trend analysis for NO_3-N reveals a statistically significant increasing trend at the 5% significance level. The Kendall's tau is 0.45 with $p=0.0001$. The parametric correlation analysis also shows a statistically significant trend in nitrate data. The nitrate data also appear to have somewhat greater scatter in recent years, although to some extent this may be an artifact of decreased sampling density.

A subset of the data was created for the summer season (June through September). Trend analysis was conducted on this data with the same results as for the dataset as a whole for both ammonia and nitrate.

Total Phosphorus - As shown in Table 6.13, a statistically significant decreasing trend at the 5% level in total phosphorus concentrations was found. Review of the data plot for total phosphorus reveals a dramatic decline in concentrations in the late 1960s. Concentrations continued to decline during the 1970s and 1980s.

Coliforms - A statistically significant decreasing trend (5% level) was noted for fecal coliform counts. No statistically significant trend in total coliform counts was found at the 5% level. Review of the graphs of fecal coliform counts over time and of the annual geometric mean of the fecal coliform counts reveals a declining trend in the late 1970s, with a rapid decline in the last few years. The annual geometric mean coliform count dropped below the geometric mean standard of 770 only in the last three years.

Review of the graph of total coliform counts over time and of the annual geometric mean total coliform levels reveals no visible trend through the 1970s, a data gap in the mid-1980s and decreased counts in the last few years.

DATA SORTING

Various natural factors in the Estuary may influence water quality concentrations for certain parameters. This section describes analyses that were conducted at the Navy Yard Station to attempt to determine which of these possible factors are important.

Seasonal Sorting - As described earlier in this section, a summer subset of the data was created and statistical analyses conducted on that subset. The same statistically significant trends were identified from the results of that analyis as for the data set as a whole. Figure 6.4 provides a graph of the summer DO concentrations over time. Comparison of this figure with Figure 6.3 the graph of the overall DO concentrations over time, reveals much less scatter in the data, as well as significantly fewer data points. The overall increasing trend in DO concentrations is clearer.

Tidal Stage Sorting - Tide stage at the time of data collection is one factor which may influence concentrations of water quality constituents. The DRBC attempted to collect data at slack water, specifically at slack before flood tide (low-water slack), although the Philadelphia WDPT did not. Missing values for the tidal stage code are common in the early data, while Class 3 (slack before flood) predominates in the most recent data. However, Classes 1 and 3 are fairly well distributed throughout the data set.

Figure 6.4 graphs summer DO data over time in all tidal stage codes. The scatter in the data has been reduced when compared to the overall graph of DO data with time. However, further reduction in scatter may be possible by sorting the summer DO data by tidal stage. Figure 6.5 provides a graph of summer DO data collected only at slack before flood tide. This graph provides further reduction in scatter, but also dramatically reduced the number of data points. It is difficult to determine simply by viewing the graph if the reduced scatter would be worth the loss of data.

Freshwater inflow is another factor which may affect concentrations of water quality parameters. Figures 6.6 and 6.7 graph summer DO concentrations for wet and dry years respectively. On each graph, further data is lost. Review of the most recent years on Figure 6.6 seems to suggest higher DO concentrations than the most recent data on Figure 6.7. However, the last analysis year for the dry years was 1986 while the wet years include 1989 and 1990. There appears to have been an continued improved in water quality over the last few years. Thus, this last step in the sorting process would actually add bias to any analysis.

Thus, a technique is needed to determine if sorting provides enough reduction in variance to justify the elimination of data points. As described in Section 4.3.4, nonparametric Analysis of Variance techniques were employed for these purposes. An ANOVA test was conducted for DO data classified according to tide stage code, as provided in the STORET database. Section 4.2.2 provides details regarding the tide stage information from STORET. The ANOVA results for the entire data set revealed no significant difference in DO concentrations among the four tide codes at the 5% level using both the parametric ANOVA ($p=0.223$) and the nonparametric equivalent, the Kruskal-Wallis test ($p=0.603$). The data were not balanced but were fairly well distributed among the four tide stages as follows: 182 at high water slack; 273 at high-water mid-tide; 340 at low-water slack and 177 at low-water mid-tide. No significant difference was found for comparison of summer DO classified by tidal stage.

No significant difference in concentrations among tide stage classes were found for nitrate at the 5% level. Significant differences in concentration among classes were found for chloride and ammonia.

To reduce the variability in the data, a subset was created using the slack water data only (Classes 1 and 3). The non-parametric ANOVA tecnique, which in the case of only two levels is equivalent to the Wilcoxon Rank Sum Test, was used to test for differences. The result revealed no significant difference in concentrations at the 5% level between the two tide stages for all DO data ($p=0.909$), summer DO data ($p=0.814$), nitrate ($p=0.182$), or chlorides ($p=0.607$). A significant difference in ammonia concentration for all the data was noted ($p=0.007$) but no significant difference for these parameters were found when only the summer data were analyzed ($p=0.403$).

The results for the tidal sorting are inconclusive. Further analysis would be needed to fully understand these results.

Annual 90-Day Low Flow Sorting - As described in Section 4.2.3, the annual 90-day low flow value from the USGS monitoring station at Trenton was used as a surrogate measure of the relative wetness or dryness of each year. An ANOVA analysis was conducted to determine if there were significant differences among concentrations classified by 90-day low flow class. Figures 6.6 and 6.7 graph summer, slack before flood DO concentrations over time for wet years and dry years, respectively.

The results of this analyis revealed no significant difference at the 95% using both the ANOVA (p=0.05) and the Wilcoxon Rank Sum test (p=0.14). For the summer data, a significant difference in DO concentrations between flow classes was found using both tests at the 95% level. However, the results were unexpected. It would be expected that if the 90-day low flow classification were an important factor in DO concentration, concentrations in the classes representing the relatively dry years (1 and 2) would be more alike than those representing the relatively wet years (3 and 4). However, flow class 2, representing 90-day low flows that occurred in the second quartile was found to be significantly different than the other three classes, while the other three classes were not significantly different from each other. That is, DO concentrations in flow class 1, representing 90-day low flows that in the lowest quartile, were not significantly different than the DO concentrations from years in the highest quartile.

As discussed in detail in Section 4.2.3, several problems were recognized with the use of the annual 90-day low flow values to separate wet years from dry ones. A major factor is that the annual 90-day low flow classes were not evenly distributed over time. For example, most of the Class 2 years occur in the 1980s. Thus, the significant difference in the Class 2 values for DO concentrations is likely the result of the overall improving trend in DO over time and not a result of the flow classification. As dicussed in Section 4.2.3, it appears that this relatively simple parameter is of limited use in sorting the data for this study because of the distribution of wet and dry years.

Overall, the data for the Navy Yard station reveal dramatic improvements in DO concentrations and in other parameters over time. For DO, the improvement seems to be continuing.

6.1.4 Analysis for Station at Eddystone, PA (RK 135.12)

The Eddystone, PA Station is located at RK 135.12 (RM 83.98), near the seaward end of the Tidal River Zone. Data at this station were collected by both the Philadelphia Water Department and the DRBC. The period of record extends from 1963 to 1990. Table 6.15 summarizes the data for this station. Almost 1200 data points are available for certain parameters at this station.

STATUS

Data for the period from 1988 to 1990 are summarized in Table 6.16. Comparison of information in this table to that in Table 6.15 reveals that the minimum DO has improved from 0.1 mg/l for the entire data set to 2.1 mg/l in recent years. The average summer DO is now 7.4 mg/l compared to 2.3 mg/l for the entire data set. Average ammonia concentration for the recent data is 0.39 mg/l compared to 1.1 mg/l for the entire data set.

Table 6.15: Summary of Historic Data - Eddystone, PA

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO	4.7	13.1	0.1	1.9	4.0	7.4	3.2	68.7	1194
DO-Summer	2.3	7.4	0.1	1.2	2.0	3.2	1.5	64.4%	474
DO Sat. (%)	43.4	103.6	1.1	21.4	42.1	65.2	25.2	58.1%	1191
NH_3+NH_4-N	1.1	9.6	0.03	0.5	0.92	1.5	0.89	81.1%	1187
NO_3-N	1.28	4.73	0.0	0.82	1.15	1.6	0.64	50.1%	1148
TKN	1.61	4.2	0.0	0.9	1.5	2.2	0.9	55.0%	515
Tot N	3.16	8.09	1.15	2.4	2.97	3.65	1.03	32.7%	501
pH (su)	6.9	8.8	5.9	6.7	6.9	7.0	0.31	4.5%	1149Chlorides
	58.9	1290	6	16	22	37	133.3	226.1%	1188
BOD_5[2]	3.8	20.4	0.3	2.4	3.0	4.5	2.5	64.2%	1123
Turb. (hlge)	12.9	85	0	8	10	15	8.7	67.6%	469
Total Phos-P	0.24	2.8	0.02	0.13	0.20	0.26	0.20	82.2%	557
Chloro.-a	22.5	143.0	0	5.8	12	26.0	27.6	123.0%	338
Tot. Col.[3]	15115.7	7.7e05	0	7500	17000	33250	-	-	793
Fec. Col.[3]	833.2	59000	0.0	300	1100	3100	-	-	1031

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric mean of the data per 100 ml.

Table 6.16: Summary of Recent Data (1988-1990) - Eddystone, PA

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO	6.8	11.9	2.1	4.9	6.5	8.5	2.3	34.2%	53
DO-Summer	5.25	7.4	2.1	4.6	5.0	6.1	1.2	23.6%	24
DO Sat. (%)	68.8	100.0	26.6	57.2	67.7	80.0	16.3	23.7%	54
NH_3+NH_4-N	0.39	1.41	0.05	0.08	0.31	0.62	0.37	94.6%	63
NO_3-N	1.63	2.93	0.06	1.2	1.59	2.08	0.64	39.1%	53
TKN	0.74	2.0	0.2	0.6	0.7	0.9	0.32	43.1%	53
Tot. N	2.56	3.69	1.5	2.1	2.5	2.9	0.5	20.7%	53
BOD_5[2]	2.5	3.1	-	-	-	-	[illegible]	9.5%	26
Turb. (ftu)	10.0	38	2	5.5	9.5	10.0	6.6	66.6%	63
pH (su)	7.5	8.8	6.8	7.2	7.5	7.8	0.4	5.9%	35
Chlorides	28.6	126	9	17.3	23	31	20.5	71.6%	52
Total Phos-P	0.15	0.6	0.05	0.11	0.14	0.18	0.08	53.2%	53
Chloro.-a	8.5	54.8	0.0	0.6	5.66	11.5	12.4	146.7%	26
Fec. Col.[3]	80.6	5800	7.0	30	52.5	177.0	-	-	64
Tot. Col.[3]	2679.5	16e4	330.0	1100	2200	6600	-	-	36

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric mean of the data per 100 ml.

TRENDS

Appendix D provides the graphs of water quality concentrations for selected parameters over time for this station. Review of the graphed data revealed apparent trends in most of the data parameters. Therefore, a series of test were conducted to determine if statistically signicant trends over time occurred at this station according to the methods outline in Section 4.3.2. Table 6.17 summarizes the results of those analyses.

Table 6.17: **Trend Analysis Results - Eddystone, PA**

Parameter	Kendall's Tau[1] τ	prob val.	Pearson Corr. Coeff.[2] r	prob val.	n
DO	0.2378	0.0001	0.3577	0.0001	1194
DO - Summer	0.4541	0.0001	0.6910	0.0001	474
DO Saturation	0.2922	0.0001	0.4295	0.0001	560
NH_3+NH_4-N	-0.5133	0.0001	-0.6987	0.0001	1187
NO_3-N	0.3733	0.0001	0.5300	0.0001	1148
TKN	-0.3239	0.0001	-0.7335	0.0001	515
Tot. N	-0.2958	0.0001	-0.4376	0.0001	501
BOD_5	-0.2117	0.0001	-	-	1123
Tot. Phosphorus	-0.3831	0.0001	-0.4027	0.0001	557
Nonfilterable Res.	-0.1450	0.0001	-0.2110	0.0001	260
Turbidity (HLGE)	-0.1496	0.0001	-0.2141	0.0001	469
pH	0.2320	0.0001	0.4189	0.0001	1146
Chlorophyll-a	-0.3268	0.0001	-0.4747	0.0001	339
Chlorides	0.8809	0.0029	-0.1735	0.0001	1188
Fecal Coliform	-0.1412	0.0001	-	-	1031
Total Coliform	-0.0468	0.0494	-	-	793

1 τ=Kendall's tau; a prob value <0.025 represents a significant decreasing (-) or increasing (+) trend.

2 r=Pearson's correlation coefficient; a prob value <0.025 represents a significant decreasing (-) or increasing (+) trend.

Dissolved Oxygen - The results of the trend analysis reveal a statistically significant increasing trend in DO concentrations for the entire data set and the summer data set (p=0.0001).

In addition to the overall increasing trend in DO, the minimum summer DO concentrations and the extent of standard violations are important parameters in analysis of the DO regime of a water way. Table 6.18 provides the minimum summer DO concentrations the percentage of samples below the DO standard for each year.

Table 6.18: Minimum Summer DO Concentrations and Percent Violation - Eddystone, PA

Year	Min. DO	% <1 mg/l	% < 3.5 mg/l*	% <5 mg/l	N
1964	0.2	38.9	100	100	18
1965	0.1	13.3	86.7	100	15
1966	0.1	45.5	100	100	11
1967	0.4	20	93.3	100	30
1968	0.2	33.3	92.3	92.3	39
1969	1.0	0	100	100	17
1970	0.3	35.1	97.3	100	37
1971	0.1	44.0	100	100	25
1972	0.2	43.5	82.6	91.3	23
1973	0.4	12.0	96	100	25
1974	0.4	12.5	87.5	95.8	24
1975	0.9	4.5	90.9	100	22
1976	1.0	0	95.7	100	23
1977	0.7	11.5	96.2	100	26
1978	1.1	0	90.0	100	20
1979	1.8	0	77.8	88.9	9
1980	1.8	0	45.5	90.9	11
1981	1.9	0	37.5	100.0	16
1982	2.6	0	41.7	100	12
1983	1.3	0	25.0	100	12
1984	1.6	0	22.2	88.9	9
1985	2.9	0	20.0	70.0	10
1986	3.0	0	25.0	75.0	8
1987	2.2	0	25.0	75.0	8
1988	2.1	0	12.5	50.0	8
1989	3.4	0	12.5	62.5	8
1990	4.9	0	0	12.5	8

* 24-hour DO Standard

Based on the results in Table 6.18, minimum summer DO levels at the Eddystone station have increased dramatically over the past 27 years. In 1964, the first summer of sampling, the minimum measured DO concentration was 0.2 mg/l; by 1990 the minimum measured DO concentration was 4.9 mg/l. Throughout most of the 1960s and 1970s, over 90% of the measured DO concentrations violated the 3.5 mg/l standard. By 1978, however, the minimum measured summer DO concentration was above 1.0 mg/l. Up until the last few years the measured summer DO concentrations indicated standard violations about 25% of the time. In 1990, the minimum measured DO of 4.9 mg/l is well above the standard level. Future data will demonstrate whether future summer minimum levels will continue to improve.

Other Parameters - Statistically significant trends (at the 5% level) trends over time were found for all parameters. Increasing trends were found for DO, DO saturation, and nitrate. Decreasing trends were found for all other parameters. The results are similar to those found for the Navy Yard station. See Section 6.1.3 for a discussion of the concerns and implications of these trends for each paramter.

6.1.5 Summary and Synthesis for Tidal River Zone

Twenty-six monitoring stations are located in the Tidal River Zone where data were collected by the DRBC and the Philadelphia Water Department. Data collection at these stations was initiated in 1963 and has continued to the present at some of the stations.

The results provided in Chapter 5 and for the four stations analyzed herein have demonstrated that water quality conditons in this Zone have improved dramatically over the period of record. Table 6.19 summarizes current water quality conditions in the Tidal River Zone for the period 1988 to 1990.

Table 6.19: Summary Statistics for Tidal River Zone (1988-1990)

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	# of Obs.
Salinity (ppt)	0.11	0.35	0.04	0.09	0.10	0.12	0.035	604
Turbidity (ftu)	7.62	50	0.6	4	5	10	6.30	671
Temperature (°C)	16.2	31	0	10	17	22	7.73	663
pH (su)	7.59	9.5	6.7	7.3	7.6	7.8	0.46	371
BOD_5	2.46	4.6	<2.4	<2.4	<2.4	-	-	337
Total Phosphorus	0.12	0.60	0.02	0.09	0.11	0.15	0.054	604
Ammonia Nitrogen	0.26	1.41	0.05	0.10	0.17	0.34	0.257	664
Nitrate Nitrogen	1.27	2.93	0.01	0.93	1.16	1.60	0.545	604
DO	7.40	14.5	2.1	5.5	7.1	9.5	2.439	602
DO - Summer	5.59	6.7	2.1	4.5	5.7	6.7	1.39	272
Fecal Coliform[2]	176.9	54000	3	56	136	548	-	672

[1] mg/l unless otherwise specified
[2] geometric mean of data per 100 ml

The average salinity in this zone of 0.11 ppt is indicative of freshwater conditions, as expected. The average turbidity of 7.62 ftu is lower than in the other two zones. The average summer DO concentration of about 5.6 mg/l is above the maximum proscribed 24-hour DO standard in this zone which is 5 mg/l. However, the 25 percentile value of 4.5 mg/l and the minimum of 2.1 mg/l may be indicative of continuing depressed DO in this zone.

6.2 Transition Zone

The Transition Zone extends from about RK 128.7 (RM 78.07) to about RK 80.4 (RM 50). This zone marks the boundary between the saline Bay water and the fresh waters of the tidal river. The average salinity in this zone was about 0.96 ppt over the past three years. Turbidity peaks within the estuary in this zone with a 3-year average value of about 19.6 ftu.

Two stations in this zone were selected for detailed statistical analysis: New Castle, DE at RK 106.10 (RM 65.96) and Reedy Island, DE at RK 88.40 (RM 54.94). These stations represent the range of conditions found in the Transition Zone.

6.2.1 Analysis of Station at New Castle, DE (RK 106.1)

Appendix E provides graphs of water quality data over time for the station located on the Delaware River at New Castle, Delaware. This station is located within the Transition Zone at RK 106.1 (RM 65.96).

Data for the New Castle station were collected under the auspices of the DRBC. The period of recod for water qaulity data extends from 1967 to the present. Preliminary review of the data revealed one outlier for both chloride and conductivity (6000 ppm and 5000 ppm, respectively). These values were removed from the database. Table 6.20 summarizes the data for the station at New Castle.

Over 550 data points were available for the analysis of most parameters at this station. Dissolved oxygen concentrations varied from 0 mg/l to 12.5 mg/l, averaging 6 mg/l. Salinity averages 1.1 ppt.

Table 6.20: Summary of Historic Data - New Castle, DE

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO - All	6.0	12.5	0.0	4.1	5.9	7.6	2.5	41.5%	558
DO - Summer	4.32	7.8	0	3.2	4.5	5.6	1.61	37.36%	235
DO Sat. (%)	59.3	108.4	0.0	45.3	61.5	74.1	19.9	33.6	557
NH_3+NH_4-N	0.76	7.6	0.03	0.16	0.5	1.1	0.8	105.6%	572
NO_3-N	1.81	6.6	0.03	1.3	1.78	2.23	0.72	39.6%	545
TKN	1.5	5.2	0.04	0.8	1.2	2.1	0.9	63.0%	519
Tot. N	3.46	9.38	0.63	2.65	3.25	4.04	1.1	32.4%	504
BOD_5	2.8	12.0	<2.4	<2.4	<2.4	3.0	[illegible]	-	528
Total Phos-P	0.51	3.9	0.0	0.15	0.31	0.69	0.51	100.9%	558
pH (su)	7.09	9	5.75	6.8	7	7.4	0.42	5.97%	523
Nonfil. Res.	39.5	130	5	26	37	51	19.0	48.1	264
Salin. (ppt)	1.1	7.9	0.1	0.2	0.6	1.7	1.3	114.4%	471
Chloro.-a	18.7	103	0	5.8	12.0	26.0	19.2	102.6%	338
Fec. Col.[3]	141.0	11400	5	41	130	410	-	-	555
Tot. Col.[3]	3224.9	77000	100	1400	4150	9950	-	-	252

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric mean of the data per 100 ml.

STATUS

Table 6.21 provides a summary of the water quality status at the New Castle station for the period from 1988 through 1990. During this period, the minimum DO was 3.8 mg/l compared to 0.0 mg/l for the entire historic data collection period. The minimum DO is below the applicable 24-hour standard of 4.5 mg/l. The 25th summer percentile value of 5.1 mg/l is above the applicable standard and seemd to suggest that occassional violations of the standard might occur. It must be noted that the applicable 24-hour DO Standard is 6.0 mg/l about 10.4 km (6.46 mi) downstream of this station.

Table 6.21: Summary of Recent Data (1988-1990) - New Castle, DE

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO - All	7.2	11.5	3.8	5.5	7.0	8.9	2.1	29.0%	51
DO - Summer	5.6	7.6	3.8	5.1	5.6	6.3	1.01	18.0%	23
DO Sat. (%)	71.8	100.9	41.3	64.4	73.0	80.6	12.8	17.8%	53
NH_3+NH_4-N	0.38	1.33	0.05	0.1	0.19	0.61	0.40	100.1%	62
NO_3-N	1.8	2.8	0.03	1.5	1.9	2.1	0.6	30.7%	52
TKN	0.75	1.8	0.33	0.58	0.7	0.9	0.3	40.0%	52
Tot. N	2.69	3.96	0.63	2.41	2.66	3.08	0.54	20.1%	52
BOD_5	2.51	4.0	<2.4	<2.4	<2.4	<2.4	-	-	26
Total Phos-P	0.15	0.36	0.07	0.11	0.14	0.18	0.05	35.1%	52
pH (su)	7.65	9.0	6.8	7.3	7.5	7.9	0.49	6.4	33
Nonfil. Res.	42	122	5	29	36	55	21.5	51.3%	62
Salin. (ppt)	0.75	2.6	0.08	0.14	0.35	1.21	0.75	100.9%	52
Chloro.-a	8.9	33.2	0	3.4	8.2	12.6	7.7	85.9%	26
Fec. Col.[3]	46.3	350	5	24.2	44.5	82.2	70.5	103.6%	64
Tot. Col.[3]	855.5	16000	170	330	490	2200	3133.7	170.3%	36

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric mean of the data per 100 ml.

Recent salinity data averaged about 0.75 ppt, slightly lower than the historic average of 1.1 ppt. The geometric mean of the fecal coliform data for the last three years was below the applicable standard of a geometric mean of 770 per 100 ml and was below the 200 per 100 ml standard that is in effect at RK 95.7 (RM 59.5). The maximum fecal coliform count of 350 per 100 ml also was below the applicable standard.

TRENDS

Appendix E provides graphs of selected water quality paramters over time at the New Castle, DE station. Visual inspection of these graphs reveal possible trends over time for certain parameters. Trend analyses were conducted for various paramters according to the methods outlined in Section 4.3. Table 6.22 provides the results of the trend analysis for the paramters of interest. The table presents both the non-parametric Kendall's tau (τ) and the parametric Pearson correlation coefficient (r). The prob value for each test statistic also is provided. A 5% level of significance was selected for use in these analyses. Therefore, because this is a two-tailed test, a significant positive (+) or negative (-) trend is represented by a prob value of 0.025 or less. A perfect correlation would be represented by a value of 1.0.

Table 6.22: Trend Analysis Results - New Castle, DE

	Kendall's Tau		Pearson Corr. Coeff.		
Parameter	**t**	**p**	**r**	**p**	**n**
DO	0.272	0.0001	0.391	0.0001	558
DO - Summer	0.474	0.0001	0.656	0.0001	235
DO Sat.	0.394	0.0001	0.563	0.0001	557
NH_3+NH_4-N	-0.420	0.0001	-0.507	0.0001	572
NO_3-N	0.077	0.0072	0.027	0.5297	545
TKN	-0.492	0.0001	-0.618	0.0001	519
Tot. N	-0.405	0.0001	-0.613	0.0001	558
BOD_5	-0.184	0.0000	-0.326	0.0001	528
Tot. Phosphorus	-0.543	0.0001	-0.613	0.001	558
Nonfilterable Res.	0.046	0.2691	0.038	0.5371	264
Turbidity (HLGE)	-0.057	0.4165	0.024	0.8153	99
Chlorophyll-a	-0.390	0.0001	-0.563	0.0001	338
Fecal Coliform	-0.4202	0.0001	-	-	555
Total Coliform	-0.183	0.0000			252

1 τ=Kendall's tau; a prob value <0.025 represents a significant decreasing (-) or increasing (+) trend.

2 r=Pearson's correlation coefficient; a prob value <0.025 represents a significant decreasing (-) or increasing (+) trend.

DO - A statistically significant increasing trend in DO is noted for both the overall and the summer data. The DO standard for this portion of the river is a 24-hour average of 4.5 mg/l. Table 6.23 provides an analysis of annual minimum DO concentrations and the percent of time the standard was violated over time. About 10.4 km downstream of this station, the 24-hour DO standard increases to 6 mg/l. Thus, the percent of time date were below 6 mg/l also is shown. The minimum annual DO was less than 1.5 mg/l for each of the first five years of sampling. With the exception of 1981, the minimum DO increased to over 2 mg/l in the 1970s and had been over 3 mg/l since 1982. However, the minimum value was below the applicable standard in each of the last 5 years except for 1987. In the last five years, 12.5% to 25% of the reported DO values were below the applicable standard. It must be noted that this amounts to 1 to 2 of the 8 samples generally collected each summer. However, 50% to 86% of the samples were below 6 mg/l. Thus, DO appears to continue to be somewhat depressed near the New Castle station.

Nutrients and Other Parameters - Table 6.22 shows that a statistically significant decreasing trend was found in levels of ammonia, TKN, total N, BOD_5, total phosphorus, chlorophyll_a, fecal coliform and total coliform at New Castle. These results are generally consistent with the trends found at the upstream stations. However, a statistically significant increasing trend in nitrate was found using the Kendall method (p=0.0072), but not using the Pearson Correlation Method (p=0.5297). The trend toward increasing nitrate concentrations is not as marked at this station as it is farther upstream in the Delaware River.

Table 6.23: **Minimum Summer DO Concentrations and Percent Violation - New Castle, DE**

Year	Min. DO	% <3 mg/l	% <4.5 mg/l*	% <6 mg/l	N
1967	1.4	61.5%	76.9%	92.3%	13
1968	1.3	47.8%	82.6%	95.7%	23
1969	1.0	68.8%	93.8%	100.0%	16
1970	1.0	42.1%	94.7%	100.0%	19
1971	1.0	66.7%	100.0%	100.0%	9
1972	2.5	33.3%	50.0%	83.3%	6
1973	2.0	25.0%	75.0%	100.0%	8
1974	2.6	28.6%	71.4%	85.7%	7
1975	3.0	0	62.5%	100.0%	8
1976	2.6	12.5%	75.0%	100.0%	8
1977	4.4	0	12.5%	75.0%	8
1978	3.2	0	25.0%	87.5%	8
1979	2.8	11.1%	33.3%	100.0%	9
1980	5.1	0	0	22.2%	9
1981	0.0	12.5%	25.0%	62.5%	8
1982	3.2	10.0%	30.0%	80.0%	10
1983	4.0	0	12.5%	87.5%	8
1984	3.0	0	22.2%	55.6%	9
1985	4.9	0	0	70.0%	10
1986	3.6	0	12.5%	50.0%	8
1987	4.5	0	0	62.5%	8
1988	3.8	14.3%	14.3%	85.7%	7
1989	4.0	0	25.0%	75.0%	8
1990	4.0	0	12.5%	50.0%	8

*24-hour DO Standard

6.2.2 Analysis for Station at Reedy Island, DE (RK 88.4)

Appendix F provides graphs of the various water quality parameters over time for the Delaware River at Reedy Island. This station is located at RK 88.4 (RM 54.94), within Zone 2, the transition zone.

Data collection at this station was conducted by the DRBC and extends from 1967 to the present. Preliminary review of the data revealed occasional outliers. Two chloride concentrations greater than 20,000 mg/l and one conductivity value greater than 130,000 umhos were removed from the data set. In addition, a total phosphorus value of about 15 mg/l was deleted from the data set; all other values were less than 2 mg/l.

Table 6.24 provides an overall summary of the data for this station.

Table 6.24: Summary of Historic Data - Reedy Island, DE

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V. %	N
DO - Annual	7.4	13.4	0.9	6.0	7.2	8.9	2.1	28.2%	555
DO - Summer	5.9	8.9	0.9	5.2	6.1	6.8	1.2	21.2%	233
DO Sat. (%)	75.5	115.8	10.7	67.6	77.5	85.1	14.9	19.8	550
NH3+NH4-N	0.68	5.50	0.03	0.11	0.40	1.0	0.74	108.4%	568
NO3-N	1.59	4.7	0.04	1.28	1.59	1.90	0.52	32.6%	542
TKN	1.4	6.3	0.1	0.7	1.1	2.0	1.0	70.1%	536
Tot. N	3.08	7.9	0.8	2.3	2.8	3.7	1.1	35.5%	521
BOD_5[2]	2.6	9	<2.4	<2.4	<2.4	2.5	1.0	37.9%	518
Total Phos-P	0.2	4.89	0	0.1	0.15	0.23	0.26	127.0%	554
Salin. (ppt)	3.6	15.9	0.08	1.2	3.2	5.2	2.8	77.9%	469
Nonfil. Res.	53.1	193	6	33.75	44	66	29.3	55.2	262
pH (su)	7.3	8.6	5.7	7	7.3	7.6	0.4	6.1%	513
Turb-HLGE	26	130	0	15	20	33	17	67.5%	470
Chlor-a	22.4	370	0	5.8	12	28	31.7	141.2%	338
Fec. Col.[3]	51.3	63000	0.4	15.5	40.0	136.0	-	-	553
Tot. Col.[3]	642.9	11.7e5	3	200	560	2200	-	-	509

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric mean of the data per 100 ml.

STATUS

Table 6.25 provides a summary of the data collected at the Reedy Island Station from 1988 to 1990. The average DO over that period was 7.9 mg/l with a summer average of 6.7 mg/l. The minimum DO was 5.4 mg/l, which is below the applicable DO standard of 6 mg/l. The 25th percentile summer value of 6.3 mg/l indicates that while standard violations may occur they are probably not common.

Table 6.25: Summary of Recent Data (1988-1990) - Reedy Island, DE

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V. %	N
DO - Annual	7.9	12.2	5.4	6.8	7.4	8.4	1.7	21.2%	34
DO - Summer	6.7	7.7	5.4	6.3	6.7	7.0	0.53	7.9%	16
DO Sat. (%)	82.6	100.5	66.9	78.2	81.5	86.0	7.0	8.5%	36
NH3+NH4-N	0.25	1.07	0.05	0.05	0.145	0.435	0.25	102.4%	38
NO3-N	1.52	2	0.04	1.43	1.57	1.71	0.44	28.7%	34
TKN	0.72	1.38	0.2	0.49	0.66	1.0	0.34	46.9%	34
Tot. N	2.38	3.38	1.44	2.08	2.20	2.81	0.47	20.0%	34
BOD_5[2]	2.55	3..0	<2.4	<2.4	<2.4	2.85	-	-	8
Total Phos-P	0.17	0.4	0.08	0.11	0.16	0.21	0.07	40.2%	34
Salin. (ppt)	2.29	5.59	0.11	0.71	2.04	3.60	1.62	70.9%	34
Nonfil. Res.	63.42	173.	11.0	37.5	48.5	77.25	40.0	63.0%	38
pH (su)	7.8	8.6	6.9	7.5	7.85	8.0	0.41	5.2%	34
Turb (ftu)	28.2	60	6	19.25	25	35	13.1	46.7%	40
Chlor-a	14.4	35.3	0	3.2	13.2	24	35.3	85.4%	8
Fec. Col.[3]	21.0	73	3	14	20	37.5	17.5	66.4	40
Tot. Col.[3]	533.6	1600	79	350	445	1430	573.6	77.3%	12

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric mean of the data per 100 ml.

TRENDS

Appendix F provides graphs for selected water quality parameters over time at this station. Trend analyses were conducted for various parameters according to the methods described in Section 4.3. Table 6.26 provides the trend analysis results for this station.

Table 6.26: Trend Analysis Results - Reedy Island, DE

Parameter	Kendall's Tau t	Kendall's Tau p	Pearson Corr. Coeff. r	Pearson Corr. Coeff. p	n
DO	0.1397	0.0001	0.1998	0.0001	555
DO - Summer	0.3306	0.0001	0.4662	0.0001	233
DO Sat.	0.2796	0.0001	0.4059	0.0001	550
NH_3+NH_4-N	-0.4451	0.0001	-0.5428	0.0001	568
NO_3-N	0.0211	0.0001	-0.0433	0.3138	542
TKN	-0.4440	0.0001	-0.5669	0.0001	536
Tot. N	-0.3978	0.0001	-0.5495	0.0001	521
BOD_5	-0.0312	0.3261	-0.1930	0.0001	518
Tot. Phosphorus	-0.2059	0.0001	-0.1783	0.0001	554
Nonfilterable Res	0.0395	0.0001	0.0604	0.0001	262
Turbidity (HLGE)	-0.1223	0.0001	-0.1978	0.0001	470
Chlorophyll-a	-0.4195	0.0001	-0.5495	0.0001	337
Fecal Coliform	-0.3170	0.0001	-0.1146	0.0001	553
Total Coliform	-0.3079	0.0001	-0.0474	0.0001	509

DO - The DO standard for this portion of the river is a 24-hour average of 6 mg/l. Since 24-hour average data is not available, this figure is considered as the general standard level for this analysis. Table 6.27 provides the minimum DO concentration for each year and the percent of time DO was below certain levels.

Table 6.27: Minimum Summer DO Concentrations and Percent Violation - Reedy Island, DE

Year	Min. DO	% <3 mg/l	% <4 mg/l	% <5 mg/l	% <6 mg/l*	N
1967	4	0	0	50%	75%	12
1968	2.3	8.7%	30.4%	43.5%	73.9%	23
1969	1.0	25.0	25.0%	37.5%	68.0%	16
1970	4.3	0	0	15.0%	52.6%	19
1971	0.9	11.1%	11.1%	33.3%	77.8%	9
1972	4.1	0	0	33.3%	66.7%	6
1973	4.0	0	0	37.5%	100.0%	8
1974	4.6	0	0	14.3%	28.6%	8
1975	3.5	0	12.5%	37.5%	75.0%	8
1976	5.1	0	0	0	50.0%	8
1977	5.2	0	0	0	50.0%	8
1978	5.0	0	0	0	12.5%	8
1979	5.0	0	0	0	33.3	9
1980	6.5	0	0	0	0	9
1981	6.7	0	0	0	0	8
1982	4.8	0	0	12.5%	25.0%	8
1983	4.9	0	0	12.5%	50.0%	8
1984	4.3	0	0	33.3%	88.9%	9
1985	5.5	0	0	0	9.1%	11
1986	5.7	0	0	0	37.5%	8
1987	6.0	0	0	0	0	8
1988	6.2	0	0	0	0	7
1989	5.4	0	0	0	12.5%	8
1990	6.8	0	0	0	0	8

*24-hour DO Standard

As shown in both Figure 6.8 and Table 6.27, the minimum measured DO has increased over time to generally about 6.0 mg/l in recent years. The graph of summer DO concentrations in Appendix F also reveals such a trend. Because measurements were taken only once every two weeks or less frequently it is not possible to ensure that these samples represent the true minimum DO values for the year sampled. However, the average number of samples has not varied much since the early 1970s, and assuming a random selection of sampling days within each summer, it can be determined that the average minimum summer DO is higher during the past five years than it was in the period of 1967-1971. In addition, no DO concentrations below 4.0 mg/l have been recorded at this station since 1975.

DO saturation is another measure of the health of a waterway. Very high DO concentrations may be indicative of super-saturated conditions caused by high concentrations of algal causing excessive DO concentrations via photosynthesis during the day which may well become very depressed during nighttime respiration. During the period of record, DO was super-saturated on three occasions during the period from 1973 to 1984. Review of the graph of DO saturation over time reveals that during the last 6 summers DO saturation has consistently been in the range of 66%-102%. During the period from 1967-1972, DO saturation varied from a low of 10.7% to less than 90%.

A test for trend was conducted for DO using the parametric and nonparametric correlation analysis technique discussed in Section 3.3.4. The results indicated a positive correlation with time for DO (p=0.0001) using 233 values for summer DO using both the Pearson and Kendall correlation analyses. For all data, a positive trend was also noted (p=0.0001 for Pearson and p=0.0000 for Kendall's tau) for both tests with 555 data points.

The results of all of these analyses clearly indicate a positive trend in dissolved oxygen over time. As discussed previously, DO concentrations in a waterway depend on many factors. A number of analyses were conducted in a first-cut attempt to determine which factors are the essential factors in the change in DO concentration over time.

It must be remembered that these correlations simply show that DO varies with or against these factors and that no causative relationship can necessarily be assumed. For example, a significant negative correlation was noted between DO and total coliform. The reduction of coliform counts in the water in no way directly influences DO concentrations. They both are likely related to a third factor, improvement in the level of treatment of sewage entering the river.

With these factors in mind, a regression analysis was conducted for DO as the dependent variable using temperature, BOD_5, NH_3+NH_4-N, 90-day low flow, and date as the independent variables. The regression analysis was conducted in an exploratory mode with the possible limitations of the use of this method for water quality data in mind. Generally, the purpose was to determine which factors explained the greatest amount of variance in the DO data, not to generate a predictive equation.

A multiple regression model was constructed with DO as the dependent variable and various other parameters as independent variables. The data were first tested to determine which variables were significantly correlated with DO concentrations. This information was used to develop a model in which temperature, BOD_5, NH_3+NH_4, and chlorophyll-a were used as regressors. The BOD_5 data was restricted so that all values reported as less than 2.4 were set to 2.4. In addition, dummy variables were created for date, tide stage, and the 90-day low flow class.

As expected, when all of the DO data were used, the greatest proportion of the error was reduced when temperature was introduced as a regressor. Time explained the next largest portion of the error, followed by BOD_5, chlorophyll-a, and ammonia. Using all of these variables, an R^2 of about 0.66 was achieved. Using temperature alone, an R^2 of about 0.54 was found.

When only summer DO data were considered, temperature ceased to be an important regressor. In this case, time explained the greatest proportion of the error, followed by BOD_5, chlorophyll-a, and ammonia. The adjusted R^2 for the summer DO regression equation was about 0.25.

As expected, the data appeared to be autocorrelated. Therefore, more complex time series analysis methods would be needed to accurately model the DO data. Analyses of this type were beyond the scope of this project but could be informative if included in later studies.

Nutrients and Other Parameters - The results shown in Table 6.26 indicate a significant positive trend in nonfilterable residue using both the nonparametric seasonal Kendall test and the parametric Pearson Correlation analysis. A significant decreasing trend was found for all other parameters. These results are consistent with those obtained for many of the other stations in this study.

However, an statistically significant increasing trend in nitrate concentration was found only using the Kendall method. The Pearson test showed a insignificant decreasing trend in nitrate concentration. This result is consistent with the results obtained at the New Castle, DE station which is also located within the Transition Zone.

6.2.3 Summary and Synthesis for Transition Zone

Eight stations are located in Zone 2. Table 6.28 summarizes the recent data for this zone for the period from 1988 to 1990.

Salinity of the Transition Zone averaged 0.96 ppt and ranged from 0.076 ppt to 5.58 ppt from 1988 to 1990. Turbidity averaged 19.6 ftu, the highest average for any zone in the estuary and ranged from 2.5 ftu to 70 ftu. pH was somewhat basic, averaging 7.64 with a maximum of 9.2.

Summer DO levels averaged 5.8 mg/l, and ranged from 2.5 mg/l to 7.8 mg/l during that season. This indicates that violations of the 24-hour standard of 6 mg/l which applies to the lower portion of this Zone are possible. Fecal coliform levels are generally low, and the geometric mean over the past three years of 45.8 per 100 ml conforms to the applicable standard.

Trends in water quality for the Transition Zone are similar to those in the Tidal River Zone, with the exception of nitrate. DO showed an significant increasing trend for the overall and the summer datasets at both stations. Ammonia, total nitrogen, total phosphorus, BOD_5, and coliform counts showed significant decreasing trends. Analysis of the nitrate data revealed a significant increasing trend, but the trend was not as strong as in the Tidal River Zone. No significant trend in nitrate data was found using parametric correlation analysis.

Table 6.28: Summary Statistics for Transition Zone (1988-1990)

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	N
Salinity (ppt)	0.96	5.58	0.076	0.126	0.267	1.291	1.282	314
Turbidity (ftu)	19.6	70	2.5	10	17	25	11.7	382
Temperature (°C)	15.3	30	0	8.9	16	23	8.28	374
pH (su)	7.64	9.2	6.8	7.3	7.5	8.0	0.45	206
BOD_5	2.47	4.0	2.4	2.4	2.4	2.4	0.26	155
Total Phosphorus	0.14	0.40	0.02	0.11	0.14	0.17	0.05	314
Ammonia Nitrogen	0.34	1.39	0.05	0.06	0.18	0.51	0.35	373
Nitrate Nitrogen	1.74	3.00	0.02	1.50	1.76	2.02	0.55	314
Dissolved Oxygen	7.26	12.7	2.5	5.8	7.0	8.7	2.01	312
Dissolved Oxygen[2]	5.80	7.8	2.5	5.2	5.9	6.7	1.07	141
Fecal Coliform[3]	45.8	1266	3	22	40	90		382

[1] mg/l unless otherwise specified
[2] summer data only
[3] geometric mean of data per 100 ml

6.3 Bay Zone

The Bay Zone is located seaward of RK 77.55 (RM 48.2). Few stations are located in the Bay Zone for the data set analyzed in this study and the most seaward stationis located at RK 46.81. This probably reflects the fact that this zone has been the least degraded by anthropogenic influences and so less sampling is warranted.

6.3.1 Analysis of Station at the Mouth of the Smyrna River (RK 71.66)

The station at the mouth of the Smyrna River is located at RK 71.66 (RM 44.54) in Delaware Bay. Data has been collected at this station by DRBC from 1971 to the present. Review of initial plots of the data revealed that conductivity (at 25oC) typically was below 10,000 umho. However, one data point was well above this value and so was removed from the database.

Table 6.29 summarizes the database for the Smyrna Station. About 350 data points are available for most paramters.

STATUS

Table 6.30 summarizes the recent data for the Smyrna River Station. As shown in this table, the average DO over the last three years was 8.1 mg/l with a summer average of 6.8 mg/l. The minimum summer DO was 5.1 mg/l, while the summer 25 percentile was 6.5 mg/l. This indicates occassional violations of the 24-hour DO standard of 6.0 mg/l probably occur.

Coliform values are quite low and are in conformance with the applicable standards.

Table 6.29: Summary of Historic Data - Mouth of Smyrna River

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO - All	8.0	14.5	1.5	6.7	7.7	9.4	2.0	25.1%	353
DO - Summer	6.6	8.9	1.5	6.1	6.7	7.1	1.0	15.9%	151
DO Sat. (%)	84.6	194.9	19.5	77.7	84.9	91.8	15.8	18.6%	349
NH_3+NH_4-N	0.39	2.7	0.03	0.1	0.15	0.53	0.46	118.6%	368
NO_3-N	1.26	2.8	0.01	1.05	1.26	1.5	0.39	31.1%	354
TKN	0.88	3.5	0.0	0.48	0.7	1.1	0.62	70.5%	334
BOD5	<2.4	7.8	-	-	-	-	-	-	323
Total Phos-P	0.22	1.2	0.01	0.1	0.15	0.3	0.18	79.2%	353
pH (su)	7.53	8.5	5.7	7.4	7.6	7.8	0.37	4.9%	312
Nonfil. Res.	34.4	89	9	25	32	42	13.7	40.0%	209
Salin. (ppt)	8.2	17.2	0.75	5.0	7.8	10.5	6.1	74.4%	289
Chloro.-a	7.2	52	0	3.3	5.4	9.0	7.6	105.0%	194
Fec. Col.[3]	12.8	390	0	<10	<10	20	-	-	358
Tot. Col.[3]	50.0	7500	1	20	40	110	-	-	162

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric mean of the data per 100 ml.

Table 6.30: Summary of Recent Data (1988-1990) - Mouth of Smyrna River

Parameter	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO	8.1	12.4	3.5	6.8	7.5	9.4	1.8	22.4%	86
DO - Summer	6.8	8.0	5.1	6.5	6.8	7.2	0.62	9.2%	38
NH3+NH4-N	0.17	1.07	0.05	0.05	0.1	0.20	0.19	6.7%	100
NO3-N	1.26	2.00	0.05	1.07	1.3	1.45	0.39	30.7%	88
TKN	0.55	1.5	0.10	0.41	0.51	0.61	0.23	41.7%	88
BOD5	<2.4	All Values the Same						62	
Total Phos-P	0.11	0.43	0.03	0.09	0.1	0.12	0.05	46.1%	88
Salin. (ppt)	7.5	15.5	1.0	5.2	7.7	9.5	3.2	42.8%	88
pH (su)	7.7	8.5	5.7	7.5	7.7	7.9	0.5	6.2%	49
Fec. Col.[3]	9.0	110.0	1	6	9	14.5	-	-	101
Tot. Col.[3]	55.2	2200	1	21	47	170	-	-	73

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric mean of the data per 100 ml.

TRENDS

Data retrieved at the mouth of the Smyrna River is plotted in Appendix G. Tests for trends over time were conducted using the methods outlined in Section 4.3.

Dissolved Oxygen -Occasional violations of the 5 mg/l DO standard are noted. No trends in the dissolved oxygen data are apparent. Test for trends also revealed no significant trend in DO concentrations over time for all data or for the summer DO data.

Nutrients - A statistically significant decreasing trend in ammonia concentration was found for the entire data set ($p=0.0001$). This trend is consistent with the decreasing trends in ammonia concentrations found at the upstream stations. No statistically significant trend is found in the nitrate data at the 5% level ($p=0.5469$). An increasing trend in nitrate was found at most of the upstream stations.

A statistically significant decreasing trend in total phosphorus concentrations over time was found at the Smyrna station ($p=0.0001$). This is consistent with results at the upstream stations.

Coliform Bacteria - No violations of the fecal coliform standard were noted for the period of record using the annual geometric mean. Generally, the fecal coliform data were in the range of 10 per 100 ml to 100 per 100 ml. For the earlier data, coliform levels below 10 per 100 ml were reported as <10 per 100 ml. Since the late 1980s, a new technique has been employed and data are reported below 10 per 100 ml. This complicated the statistical analysis of trends in fecal coliform data. A statistically significant decreasing trend was found, however, review of the graphed data suggests that this is due to the change in the reporting technique.

Total coliform data is consistently reported from about 1980 to the present time. The limited data made it difficult to perform a trend analysis.

pH - No trend in pH is obvious from the graphed data. A gap in the pH measurements occurs in the late 1980s. The recent data generally appear to be higher than the earlier data. This observation is consistent with data from other stations. No statistically significant trend in pH was found.

BOD_5 - As at the other stations, BOD_5 values below 2.4 mg/l were occasionally reported at this station in the early to mid 1970s. After 1981, all BOD_5 concentrations were below the 2.4 mg/l detection limit.

DATA SORTING

Sorting by Tidal Phase Interval - The possible effect of tidal variation on constituent concentration was explored with the data from this station. The possible effects of freshwater inflow and tidal stage on concentrations of water quality constituents were explored at this station. Since fewer trends over time were found than for other stations, time should be less of a confounding factor in this analysis.

As described in Section 4.2.2, tidal sorting was conducted based on both the tide stage codes included in the STORET database and on the tidal current phase intervals calculated for this study. A comparison of the data classification by tide stage code and tidal current phase interval is provided in Table 6.31.

Table 6.31: Comparison of Tide Stage Code and Tidal Phase Interval Mouth of the Smyrna River

Class	Tide Stage Code (from STORET)	Tidal Phase Interval (Calculated)
Missing Value	23	48
Slack before Ebb (1)	108	69
Mid-Tide Ebb (2)	4	86
Slack before Flood (3)	242	140
Mid-Tide Flood (4)	1	35

Table 6.31 illustrates that the calculated values are quite different from the STORET tide stage code values. Overall, 206 differences were noted in the 378 observations. The calculated tidal phase interval classified more observations in the mid-tide classes and fewer during the slack-tide intervals.

Using the tidal phase interval as the classification variable, a statistically significant difference among salinity values was found (p=0.0001). As shown in Table 6.32, pairwise comparison of means using the Tukey method indicated that the average salinity measured during the slack before ebb tidal interval was significantly higher than the average measured during the slack before flood tidal interval. In fact, the data collected during the slack before ebb tidal interval had the highest average salinity and the data collected during the slack before flood interval had the lowest average salinity. Clearly, this is the expected result due to tidal incursion. A similar result was obtained using the tide stage codes found in the STORET database.

Table 6.32: Tidal Phase Interval ANOVA Results - Mouth of the Smyrna River

Parameter	Tidal Phase Interval	Mean	n	Significantly Diff. Tidal Phase Intervals
Salinity	SBE (1)	9.7	59	SBF (3)
	MTE (2)	7.9	72	-
	SBF (3)	6.8	114	MTF (4); SBE (1)
	MTF (4)	8.7	27	SBF (3)
NO_3-N	SBE (1)	1.12	68	SBF (3)
	MTE (2)	1.28	81	-
	SBF (3)	1.32	132	SBE (1)
	MTF (4)	1.18	33	-

No statistically significant differences among tidal phase intervals at the 5% level were found for ammonia, total phosphorus, or pH. A statistically significant difference among tidal phase intervals at the 5% level was found for nitrate. Results of the pairwise comparisons are provided in Table 6.32. The concentrations taken during the slack before ebb interval are significantly lower than those taken during the slack before flood interval.

A significant difference among tidal phase intervals was noted for DO when all of the data were considered. However, when only the summer data were analyzed, no significant differences were noted. Thus, the differences for the entire data set were considered to be of questionable value and pairwise comparisons were not conducted.

6.3.2 Analysis for Station at the Mouth of the Mahon River (RK 46.81)

The most seaward station in the study database was at the mouth of the Mahon River at RK 46.81 (RM 29.09). Data have been collected at this station from 1971 to the present; a summary of these data are presented in Table 6.33. Over 300 data points were available for many of the parameters sampled at this station.

STATUS

Table 6.34 provides a summary of data collected at the mouth of the Mahon River from 1988 to 1990. The table reveals an average summer DO concentration of 6.4 mg/l with a minimum value of 4.2 mg/l. The 25th percentile value of 5.5 mg/l is below the applicable 24 hour average of 6.0 mg/l. Thus, occasional DO violations occur at this station.

Fecal coliform values are very low. The recent maximum value was 8 per 100 ml.

Table 6.33: Summary of Historic Data - Mouth of Mahon River

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO - All	8.0	19.6	2.4	6.5	7.6	9.5	2.2	27.2	352
DO - Summer	6.5	10.1	2.7	5.7	6.6	7.3	1.2	17.8	150
DO Sat. (%)	86.2	177.7	24.6	76.5	88.2	96.1	16.6	19.3%	348
NH_3+NH_4-N	0.67	4.6	0.02	0.1	0.2	0.75	0.98	145.2%	350
NO_3-N	0.70	2.2	0.03	04.8	0.7	0.9	0.33	46.7%	349
TKN	1.45	9.5	0.07	0.7	1.0	1.8	1.21	83.2%	312
BOD_5	2.45	7.6	1.1	<2.4	<2.4	<2.4	-	-	316
Total Phos-P	0.28	2.0	0.02	0.11	0.2	0.4	0.24	86.5%	349
pH (su)	7.5	8.6	5.6	7.3	7.6	7.8	0.48	6.4%	308
Nonfil. Res.	81.2	210	2	51	74	104.2	43.5	53.6%	218
Salin. (ppt)	15.4	54.3	1.1	12.3	15.4	18.6	5.7	37.0%	284
Turb.-HLG	34.8	175	2	18	30	42	25.8	74.1%	265
Fec. Col.[3]	8.4	800	1	10	10	10	-	-	312
Tot. Col.[3]	13.0	1400	1	7	10	30	-	-	150

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric mean of the data per 100 ml.

Table 6.34: **Summary of Recent Data (1988-1990) - Mouth of the Mahon River**

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	C.V.	N
DO - All	7.6	12	4.2	6.0	7.5	8.6	1.8	24.3%	52
DO - Summer	6.4	8.6	4.2	5.5	6.4	7.3	1.2	18.3%	24
DO Sat. (%)	83.6	107.0	51.8	70.1	87.1	96.1	15.4	18.4%	54
NH_3+NH_4-N	0.16	2.05	0.05	0.05	0.06	0.11	0.3	207.4%	52
NO_3-N	0.67	1.2	0.03	0.43	0.70	0.93	0.30	46.5%	52
TKN	0.78	2.8	0.07	0.53	0.7	0.89	0.40	51.3%	52
BOD_5	2.4	3.1	<2.4	<2.4	<2.4	<2.4	-	-	26
Total Phos-P	0.11	0.21	0.04	0.08	0.1	0.14	0.04	38.5%	52
pH (su)	7.8	8.6	6.6	7.6	7.7	8.2	0.5	6.4%	34
Nonfil. Res.	55.9	175	10	33	47.5	69.75	33.1	59.1%	52
Salin. (ppt)	13.6	26.4	1.1	11.4	14.4	16.3	4.4	32.3%	52
Fec. Col.[3]	1.3	8	1	1	1	2	-	-	28
Tot. Col.[3]	5.5	350	2	2	3.5	8.75	-	-	26

[1] All parameter units in mg/l unless otherwise noted.
[2] Much of the BOD_5 data is reported as <2.4. Early data values below 2.4 are reported in some cases, thus the calculation of the mean is questionable.
[3] Geometric mean of the data per 100 ml.

TRENDS

Data retrieved for the station at the mouth of the Mahon River is presented in Appendix H. A trend analysis was conducted for the data from the Mahon River station. The results of this analysis are presented in Table 6.35.

DO - No significant trend is shown in DO concentrations for the overall data or for the summer data. This is also reflected in Table 6.36 which presents the minimum annual DO concentrations and the percent violation of the applicable DO standard of 6 mg/l. Generally, a few of the samples taken each summer violate the DO standard. In fact, both the trend analysis and Table 6.36 suggest the possibility that DO concentrations are declining at this station, although the trend analysis result is not statistically significant.

Nutrients and Other Parameters - Table 6.35 reveals a statistically significant declining trend in all other parameers, with the exceptions of BOD_5 which is increasing and turbidity which shows no trend. The results are generally consistent with the results from the Smyrna station.

Table 6.35: Trend Analysis Results - Mouth of the Mahon River

	Kendall's Tau		Pearson Corr. Coeff.		
Parameter	t	p	r	p	n
DO	-0.057	0.1144	-0.813	0.1281	352
DO - Summer	0.001	0.9896	0.002	0.9794	150
DO Sat.	0.033	0.3593	0.036	0.4977	348
NH_3+NH_4-N	-0.601	0.0001	-0.691	0.0001	350
NO_3-N	-0.178	0.0000	-0.273	0.0001	349
TKN	-0.411	0.0001	-0.528	0.0001	312
BOD_5	0.185	0.0000	0.173	0.0021	316
Tot. Phosphorus	-0.554	0.0001	-0.646	0.0001	349
Nonfilterable Res.	-0.245	0.0000	-0.290	0.0001	218
Turbidity (HLGE)	-0.084	0.0464	-0.174	0.0044	265
Fecal Coliform	-0.395	0.0001	-	-	312
Total Coliform	-0.390	0.0001	-	-	150

Table 6.36: Minimum Summer DO Concentrations and Percent Violation - Mouth of Mahon River

Year	Min. DO	% <4 mg/l	% <6 mg/l*	N
1972	6.2	0	0	6
1973	5.5	0	50%	8
1974	6.6	0	0	1
1975	2.7	37.5%	87.5%	8
1976	6.3	0	0	8
1977	5.6	0	37.5%	8
1978	5.1	0	50.0%	8
1979	4.2	0	22.2%	9
1980	5.9	0	11.1%	9
1981	5.5	0	12.5%	8
1982	5.1	0	22.2%	9
1983	5.2	0	62.5%	8
1984	4.5	0	55.6%	9
1985	4.7	0	18.2%	11
1986	5.8	0	25.0%	8
1987	4.5	0	12.5%	8
1988	5.3	0	25.0%	8
1989	4.6	0	25.0%	8
1990	4.2	0	50.0%	8

*24-hour DO Standard

6.3.3 Summary and Synthesis for the Bay Zone

The Bay Zone includes three water quality monitoring stations. A summary of recent data for the period from 1988 to 1990 at these stations is provided in Table 6.37.

Salinity in the Bay Zone averages 8.36 ppt and turbidity averages 14.8 ftu. This zone has relatively good DO concentrtions with a minimum of 4.2 mg/l. Occasional violations of the DO standard of 6.0 mg/l could be expected. Fecal coliform levels are quite low at the monitored sites and conform to all standards. Average nutrient levels include total phosphorus at 0.12 mg/l of P, ammonia at 0.18 mg/l of N, and nitrate at 1.14 mg/l of N.

Trends in water quality parameters in the Bay Zone differed somewhat from those in the other two zone. DO showed no significant trend in the Bay Zone, while improving dramatically in the other two zones. No trends in nitrate were found. Statistically significant decreasing trends were observed in ammonia, total nitrogen, total phosphorus, and coliform levels.

Table 6.37: Summary Statistics for Bay Zone (1988-1990)

Parameter[1]	Mean	Max.	Min.	Q25	Q50	Q75	Std. Dev.	N
Salinity (ppt)	8.38	26.4	0.16	4.54	7.87	12.0	4.86	209
Turbidity (ftu)	14.8	57	3	9	11	20	9.33	245
Temperature (°C)	15.94	29	0	9	18	23	8.23	239
pH (su)	7.76	8.6	6.6	7.5	7.7	8.0	0.41	137
BOD_5	2.41	3.1	2.4	2.4	2.4	2.4	0.08	104
Total Phosphorus	0.12	0.43	0.02	0.08	0.10	0.14	0.054	209
Ammonia Nitrogen	0.18	2.05	0.05	0.05	0.09	0.17	0.25	239
Nitrate Nitrogen	1.14	2.5	0.01	0.77	1.2	1.49	0.52	209
Dissolved Oxygen	7.91	12.5	4.2	6.8	7.6	8.9	1.77	207
Dissolved Oxygen[2]	6.69	8.6	4.2	6.2	6.8	7.4	0.87	94
Fecal Coliform[3]	5.59	63	0	2	6	13		182

[1] mg/l unless otherwise specified
[2] summer data only
[3] geometric mean of data per 100 ml

6.4 Comparison of Estuarine Zones

STATUS

Table 6.38 provides a comparison of average water quality levels for selected parameters in each of the three zones for the period from 1988 to 1990. The table shows the extreme variation in salinity among the zones, ranging from 8.38 ppt in the Bay Zone to 0.11 ppt in the Tidal River Zone. Turbidity is at a maximum in the Transition Zone, averaging 19.6 ftu. Average turbidity is the Tidal River Zone is about half of that in the Bay Zone. Temperature and pH vary slightly among the zones, with slightly lower temperatures and slightly more basic conditions in the seaward direction. Nutrient and BOD_5 levels also appear to peak in the Transition Zone.

Average summer DO levels are almost 1 mg/l higher in the Bay Zone than in the Tidal River Zone, with intermediate levels in the Transition Zone. Fecal coliform counts are about 2 orders of magnitude lower in the Bay Zone than in the Tidal River Zone. It should be noted that DO levels are higher and coliforms counts are lower in the upper portion of the Tidal River Zone, upstream of the major dischargers.

The recent data demonstrates the interaction of natural processes in the estuary with anthropogenic influences, primarily in the Tidal River Zone. The point and non-point source discharges of pollutants appear to have the least impact on the Bay Zone because of the large amount of dilution and mixing that is occuring in that Zone and because of the distance separating the Bay Zone and the major dischargers.

When compared to the results of the graphical analysis in Chapter 5, the statistics for concentrations of water quality parameters in the Tidal River Zone, particularly for ammonia and dissolved oxygen may be somewhat misleading. Although these are accurate averages for the entire zone, there is a wide variation in water quality between the downstream and upstream ends of that zone. This can not be reflected in a one-number average for a zone.

Table 6.38: **Comparison of Data for Delaware River Estuary Zones - Average of Data for 1988-1990**

Parameter[1]	Tidal River Zone	Transition Zone	Bay Zone
Salinity (ppt)	0.11	0.96	8.38
Turbidity (ftu)	7.62	19.6	14.8
Temperature (°C)	16.2	15.3	15.9
pH (su)	7.59	7.64	7.76
BOD_5	2.46	2.47	2.41
Total Phosphorus	0.12	0.14	0.12
Ammonia Nitrogen	0.26	0.34	0.18
Nitrate Nitrogen	1.27	1.74	1.14
Dissolved Oxygen	7.40	7.26	7.91
Dissolved Oxygen[2]	5.59	5.80	6.69
Fecal Coliforms[3]	176.9	45.8	5.59

[1] mg/l unless otherwise specified
[2] summer data only
[3] geometric mean of data per 100 ml

TRENDS

Table 6.39 summarizes the results of the trend analyses for each zone. DO levels have improved dramatically over time in the lower Tidal River Zone and the Transition Zone, but have shown no statistically significant trend in the upper Tidal River Zone or in the Bay Zone. The Bay Zone appears to contain sufficient dilution volume and/or flushing action to any waters with low DO levels that may flow into it from upstream. The upper portion of the Tidal River Zone also showed no significant trends in DO concentrations. This area is the portion of the Tidal River Zone upstream of most of the major point source dischargers. Thus, upgrades of these discharges, which improved DO levels in the lower portion of the Tidal River Zone, had little effect on DO in upper Tidal River Zone.

BOD_5 showed little overall trend, primarily because of the method of data reporting. It appears clear that maximum BOD_5 levels have dropped in most portions of the Delaware Estuary.

Ammonia concentrations showed a statistically significant declining trend throughout the estuary and bay. Correspondingly, nitrate levels have risen in the Tidal River Zone. Nitrate levels also showed a statistically significant increasing trend in the transition zone, although the results were not as strong. In the Bay Zone, no conclusive trend in nitrate levels could be discerned. TKN levels showed statistically significant declining trends in all three zones, as did total nitrogen levels. Total phosphorus levels also demonstrated a statistically significant declining trend. Fecal coliform levels declined in the Tidal River and Transition Zone, but showed no trend in the Upper Bay Zone.

Table 6.39: Comparison of Historic Water Quailty Trends Among Estuarine Zones

	TIDAL RIVER ZONE Upper	TIDAL RIVER ZONE Lower	TRANSITION ZONE	UPPER DEL. BAY ZONE
DO	—	↑	↑	—
BOD_5	—	↓	—	—
NH_3+NH_4	↓	↓	↓	↓
NO_3	↑	↑	↑	—
TKN	↓	↓	↓	↓
TP	↓	↓	↓	↓
TURB.	↓	↓	↓	↓
FC	↓	↓	↓	—

7. SUMMARY AND CONCLUSIONS

This study was initiated with the objective of reviewing and evaluating our present understanding of general water quality conditions in the Delaware Estuary. Towards this objective, an inventory and analysis of pertinent historic water quality data sets was performed. This analysis defined the current water quality status of the Delaware Estuary, and described both longitudinal and temporal trends in corresponding water quality data. In addition, this study examined the possible confounding effects of various external factors such as seasonality, tidal forcing, and freshwater inflow. The results of this study include: (a) an annotated bibliography of historic water quality data reports for the Delaware Estuary (Volume II); and (b) a study report of the Status and Trends in water quality of the Estuary (this volume).

7.1 Summary

The Delaware Estuary can be classified as a drowned river valley coastal plain estuary. It can be divided into three distinct regions based on general patterns of salinity, turbidity and biological productivity. These have been defined as: the Tidal River Zone (RK 214.6 - RK 128.7); the Transition Zone (RK 128.7 - RK 86.9); and the Bay Zone (RK 86.9 - RK 0).

The Delaware Estuary has a long history of pollution related to loadings from both point and non-point sources. Most of the major point source dischargers are located in the lower Tidal River Zone. Over the past thirty years, significant effort and money has been expended to improve the level of treatment at the major point source dischargers to the Estuary. Most of the major treatment plants now discharge effluent treated to secondary level.

7.1.1 Methods of Data Compilation and Analysis

The initial task in this study was to gather all of the accessible water quality data that was pertinent to this study. This was accomplished by searching a myriad of possible sources, including university and agency libraries and computerized bibliographic databases. Also, federal, state and local agencies with authority over the water quality in the Delaware Estuary were contacted for any available data. In addition, the USEPA STORET computerized database also was accessed for data. This search revealed a vast array of Delaware Estuary water quality data. The possible data sources were then reviewed and analyzed to determine their **applicability** to this and other studies. Relevant documents were reviewed and the pertinent information was entered into the Annotated Bibliography.

The most consistent, long-term computerized database found was that maintained by the Delaware River Basin Commission (DRBC) on the USEPA STORET computer. These data, including those collected in the 1960s and 1970s by the Philadelphia Water Department, were retrieved and used for the Status and Trends Analysis. The data were entered into the project database using the Statistical Analysis System (SAS) software on the Najarian Associates VAX Computer Network. The use of SAS allowed one program to be used for data organization, analysis and plotting.

The retrieved database contains data collected from 1963 to 1990 at 45 stations within the estuary. Currently, sampling continues at 18 stations. The station locations ranged from the upper Bay Zone to the head of tide at Trenton, N.J. The greatest concentration of sampling stations are located in the Tidal River Zone. Data from seven pairs of stations were combined because they were at the same location but sampled by two different agencies. Overall, the combined database contains over 24,000 water quality observations.

Water quality parameters in the database include: DO, temperature, DO saturation, BOD_5, ammonia, nitrate, nitrite, total kjeldahl nitrogen (TKN), pH, total phosphorus, chlorides, turbidity, fecal coliforms, total coliforms, acidity, and conductivity. The retrieved data were used to calculate certain other parameters, including salinity and total nitrogen, which are included in the database.

Long-term trends in estuarine water quality data may be masked by natural short-term estuarine variability induced by both natural and anthropogenic factors. Therefore, surrogate measures were defined for several of the major natural factors, including season, tidal current interval, and freshwater inflow. The influence of these factors on water quality conditions in the Estuary were examined.

For example, the dissolved oxygen concentration in a water body is strongly dependent on temperature. All dissolved oxygen analyses were conducted on both the overall dataset and on a "summer-only" subset, where summer was defined as the period from June through September, inclusive. Freshwater inflow also may influence water quality conditions in an estuary, particularly during sustained periods of drought or above-normal flow. The annual 90-day low flow at Trenton, N.J. was employed as a surrogate measure of freshwater conditions. Four classes were defined to classify each year varying from very dry to very wet. This effort was not entirely successful, primarily because the four classes were not evenly distributed over time. Thus, it was not possible to separate the effect of sustained freshwater inflow levels on water quality independently of other effects.

The tidal regime also may confound analysis of trends in water quality. The data retrieved from the STORET database often included a code indicating the Tide Stage at the time of sampling. To test the accuracy of these codes and to fill in for the missing data, a method was developed to determine the tidal current phase interval for each data point. This was accomplished by exercising a tidal elevation prediction model and processing the results to classify water quality data into one of four separate quarter intervals of a tidal cycles. The computed intervals were checked against available tidal current phase data in the NOS Tidal Current Tables. This analysis revealed that the method properly partitions the data in all but a few isolated cases.

7.1.2 Estuarine-Wide Trend Analysis Results

The status of and trends in the water quality data were examined in two basic ways. First, an estuarine wide analysis was conducted using graphical techniques. This allowed for a qualitative assessment of the current status of estuarine water quality and of trends over time and space. Second, statistical methods were used to examine the current status and trends over time of water quality at specific stations within each defined estuarine zone. The second method allowed the actual data at a station to be examined without the smoothing effects which occur when data are averaged over time or space.

The estuarine-wide study included three separate analyses. First, historic trends in estuarine-wide water quality were examined by graphing constituent concentrations averaged over three separate three-year intervals: 1968-1970; 1978-1980; and 1988-1990. The profiles reveal decreasing trends in BOD_5, total phosphorus, ammonia, and total nitrogen. Ammonia also demonstrates a persistent spatial trend. The source of elevated ammonia levels appeared to be in the Tidal River Zone near Philadelphia and Camden, although the elevated concentrations in this area have been reduced over time. A long-term increase in nitrate concentrations was clear in the Tidal River Zone.

Dissolved oxygen showed dramatic improvement over time, particularly between the 1978-1980 profile and the 1988-1990 profiles. The noticeable DO deficit of about 4 mg/l which encompassed about 64 km of the Delaware Estuary in the 1978-1980 period was reduced in magnitude to about 1.5 mg/l, and in size to about 16 km, in the 1988-1990 profile. Fecal coliform concentrations have also dropped dramatically, although elevated concentrations remain in the Philadelphia-Camden area.

The second estuarine-wide analysis considered the effect of sorting the data for various possible confounding effects. First, 90-day intervals were studied in three separate years to examine the difference between high freshwater flow years and low freshwater flow years on water quality conditions. The analysis determined that any effects attributable to freshwater inflow were far less pronounced than those related to improvement in treatment plant loadings to the estuary. Again, the strong trends in water quality parameters over time in the estuary and the distribution of wet and dry years limited the study of the possible effects of freshwater inflow on water quality.

Tidal variations were examined by subdividing the data for one of the 90-day low-flow periods into those collected at slack-before-flood tide and those collected at slack-before-ebb tide using the tide stage codes in the STORET system. Tidal variation was quite noticeable for most parameters. Profiles of DO, nitrate, organic nitrogen, total phosphorus, and fecal coliform appeared to be displaced towards the head of the estuary for the slack-before-ebb data. The profile displacement is consistent with the 10-20 km tidal excursion reported in previous hydrodynamic studies of the Delaware Estuary. Also, this result suggests that tidal advection causes significant short-term variability in local estuarine water quality.

The third component of the estuarine-wide study was a review of current estuarine status. This was conducted by graphing average winter and summer constituent concentrations for the period from 1988 to 1990. The results of this analysis are summarized for each estuarine zone later in this chapter.

7.3.1 Results of Quantitative Trend Analysis by Estuarine Zone

The status and trends in water quality data of the Delaware Estuary were also studied at selected stations within each estuarine zone. Nonparametric statistical analysis methods, primarily Kendall's Rank Correlation method, were used to test for the statistical significance of trends in water quality. Table 6.39 summarizes these results. Statistically significant decreasing trends for ammonia, TKN and total phosphorus were found throughout the estuary. Increasing trends for nitrate were found in the Tidal River Zone and to some extent in the Transition Zone, but not in the Bay Zone. Fecal coliform levels showed a statistically significant decline in the Tidal River Zone and Transition Zone, but no significant trends were found in the Bay Zone.

A statistically significant improvement in dissolved oxygen concentrations was found in both the Lower Tidal River Zone and in the Transition Zone. No statistically significant trends were found in the Upper Tidal River Zone or in the Bay Zone, although there were some indication (statistically insignficant trends) of possibly declining dissolved oxygen levels in those regions.

The effects of confounding factors including tidal stage and freshwater inflow also were examined at selected stations. An Analysis of Variance was conducted at several stations to determine if any significant difference could be discerned for various parameters classified by tidal stage using either the tide stage code in STORET or the calculated tidal current interval. At the stations in the Tidal River

Zone, the results did not suggest that subdividing the data by tidal stage would substantially reduce the variance in the data set. In the Bay Zone, a statistically significant difference was discerned among salinity data collected at various tidal stages. However, no statistically significant differences were found for the water quality parameters, with the exception of nitrate. Thus, the results suggest that subdividing the data by tidal interval would not explain much of the variance.

A multiple regression analysis was conducted in an exploratory mode at one of the stations using dissolved oxygen as the independent variable. When all of the DO data was used, the introduction of temperature as a regressor reduced the error to the greatest extent, followed by time, BOD_5, chlorophyll-a and ammonia. When summer DO data only were used temperature ceased to be an important regressor and time explained the greatest proportion of the error. The adjusted R^2 in the later case was 0.25. The data appear to be autocorrelated, as would be expected. Therefore, more complex methods, beyond the scope of this study, are needed to develop an adequate regression model.

7.1.4 Water Quality Status

The current status of water quality in the Delaware Estuary was examined in a qualitative manner using graphical analysis techniques for the entire estuary and in a more quantitative manner for selected stations within each estuarine zone. The following paragraphs summarize the current status in each estuarine zone. It must be noted that the zones are all of different sizes and that the greatest concentration of stations is located in the Tidal River Zone.

The freshwater Tidal River Zone can be subdivided into an upstream and a downstream portion. The upper portion of the Tidal River Zone is located upstream of the major point source discharges. The average summer DO level in this zone was about 5.6 mg/l. The average DO concentrations throughout this zone are above the applicable standards. However, review of all of the summer data does suggest occasional violations of the applicable standards. Average summer DO levels are about 1 mg/l lower in this zone than in the Bay Zone.

The geometric mean fecal coliform count per 100 ml in this zone is below the applicable standards; the data suggest violations of this standard may occur. Turbidity is lowest in this zone. Average total phosphorus concentrations are about the same as the Bay Zone average and slightly lower than in the Transition Zone. However, ammonia and nitrate levels are higher than in the Bay Zone.

The Transition Zone is characterized by average salinity of about 0.96 ppt over the past three years. Turbidity is at a maximum in this zone, reaching 19.6 ftu compared to 7.6 ftu in the Tidal River Zone and 14.8 ftu in the Bay Zone. Nutrient concentrations, including total phosphorus, ammonia, and nitrate, are also highest in this zone. The average summer DO concentration is intermediate between the values found in the Tidal River Zone and the Bay Zone, as is the geometric mean fecal coliform count. Both of these values conform to the applicable standard but the overall data suggest possible violations of these standards at certain time within this zone.

The data available for this study extend only into the upper portion of the Bay Zone. Clearly, salinity is at a maximum in this zone. pH also appears to be at maximum levels in this zone, while ammonia and nitrate concentrations are at minimum levels. Average summer DO levels are above the applicable standard, although occasional standard violations appear to occur. Fecal coliform values are quite low at the available stations.

7.2 Overall Study Conclusions

This study has demonstrated that water quality in the Delaware Estuary has improved dramatically over the past 27 years. Minimum summer DO levels which approached 0.1 mg/l in the 1970s in some parts of the estuary were over 4 mg/l for 1990, and were over 3 mg/l for each of the last three years. Although average summer DO concentrations meet the applicable standards throughout the estuary, DO levels are still somewhat depressed in the lower Tidal River Zone where the current standard is 3.5 mg/l compared to 5 to 6 mg/l in the other portions of the estuary. Data for the last few years suggest continued improvement in the Tidal River Zone. Future data must be examined to determine if this trend will continue.

Total ammonia concentrations have declined throughout the estuary. Nitrate levels have increased in the Tidal River Zone and possibly in the Transition Zone, but have not changed in the Bay Zone. Overall, however, total nitrogen levels have declined over time throughout most of the estuary. Fecal coliform levels have declined throughout most of the estuary but remain somewhat elevated in a small reach of the Tidal River Zone.

The improving water quality has occurred over the period of time when treatment levels have been upgraded at many of the major STPs discharging to the subject estuary. Although no cause and effect relationship has been demonstrated in this study, it is clear that DO levels have risen dramatically and nutrient levels have dropped during this period of improvement in discharge effluent quality. Indeed, a continuing trend toward improved DO concentrations has been found for the last few years in the Tidal River Zone as upgrades of some major treatment plants have been completed. This suggests that the upgrade process has had the desired effect.

The data also point towards the need for continuing improvement in water quality in some portions of the estuary. Judicious improvement alternatives must be formulated and tested using state-of-the-art models to ensure that maximum enhancements in water quality of the Delaware Estuary is achieved with the least future expenditure. This objective must be pursued through future studies.

7.3 Suggestions for Future Study

This study has examined the status and trends in general water quality parameters in the Delaware Estuary. The results of this study suggest that improvements in water quality conditions are related to the reduced loadings from sewage treatment plants. This is substantiated by the continued improvement in water quality as additional plant upgrades came on-line. However, the data were not available to correlate actual loadings to the Estuary with water quality trends. The analysis of data from 90 major sewage treatment plants and 300 combined sewage overflows which discharge to the estuary is clearly a project in itself. It is entirely possible that the necessary data do not exist; however, this is an important avenue for possible future research.

Further review of certain features of individual parameters may also be warranted. For example, there is still no good explanation for the dramatic decline in phosphorus levels seen during the earliest years of this study. In addition, the USGS hourly water quality data should be digitized, processed and studied to analyze any diurnal DO patterns. The DO levels found in this study may not be indicative of the true minimum DO concentrations that could occur during algal respiration in the early morning hours.

This report also examined the possible effects of various external factors on concentrations of water quality parameters in the Delaware Eestuary. These factors deserve further study to determine their importance in data analysis and in the design of sampling studies. The use of other surrogate measures for freshwater inflows should be explored. The analysis of data classified by tidal current interval should be extended to other stations. The accuracy of the tidal stage codes in the STORET database should be reviewed. In addition, field experiments should be designed to study the effect of tidal current conditions on water quality data.

Further statistical analysis of the data could be conducted to better define the water quality trends and to try to discern which parameters have had the greatest impact on the improved DO concentrations. Such studies could focus on selected time periods and locations in the database, possibly related to specific treatment plant upgrades, to further define the effect of treatment levels.

Most important, however, is a continuation of the trend analysis to future data. The Delaware Estuary does not appear to have reached an equilibrium condition. Further improvement in water quality is certainly possible in many portions of the Estuary. It is essential to continue the study to determine whether water quality continues to improve. This information would be invaluable in planning future water quality management strategies.

REFERENCES

REFERENCES

REFERENCES

Albert, R.C., 1982. "Cleaning Up the Delaware River, A Status and Progress Report Prepared Under the Auspices of Section 305(b) of the Federal Clean Water Act". Delaware River Basin Commission.

Albert, R.C., 1988. "The Historic Context of Water Quality Management for the Delaware Estuary". *Estuaries*, 11:99-107.

Albert, R.C., 1991. Supervising Engineer. Water Quality and Planning Section, Delaware River Basin Commission. Letter to Tavit O. Najarian, Sc.D, Najarian Associates, L.P. dated March 5, 1991.

Bauer, K.M., Glauz, W.D., and A.D. McElroy, 1984. "Guidance - 1984 State Section 305(b) Reports, Methodologies for Determining Trends in Water Quality Data". U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington D.C., 20460.

Biggs, R.B., 1978. "Coastal Bays" p.69-99 in R.A. Davis (ed.), Coastal Sedimentary Environments. Springer-Verlag, New York.

Bryant, T.L., and J.R. Pennock, 1988. The Delaware Estuary: Rediscovering a Forgotten Resource. University of Delaware Sea Grant College Program, Newark, Delaware, 144pp.

Culberson, C.H., Sharp, J.H., Church, T.M., and Lee, B.W., 1987. "Data from the SALSX Cruises, May 1978 - July 1980. University of Delaware, Delaware Sea Grant College Program.

Delaware River Basin Commission, 1986. "Administrative Manual - Part III, Water Quality Regulations".

Delaware River Basin Commission, 1988. "The Delaware River Basin Stream Mileage System". Staff Paper 105.

Delaware River Basin Commission, 1990a. "Delaware River and Bay Water Quality Assessment, 1988-1989 305(b) Report". March 1990.

Delaware River Basin Commission, 1990b. "Current Status of Allocations, Delaware Estuary".

Gibbs, J., 1990. US Geological Survey Water Resources District Office - Trenton, NJ. Telephone Conversation. December, 1990.

Gross, Seymour 11/29/90. Delaware River Basin Commission, Personal Communication.

Hirsch, R.M., Slack, J.R., and Smith, R.A., 1982. "Techniques of Trend Analysis for Monthly Water Quality Data". *Water Resources Research*, 18:107-121.

Hirsch, R.M., and J.R. Slack, 1984. "A Nonparametric Trend Test for Seasonal Data with Serial Dependence". *Water Resources Research*, 20:727-732.

Interstate Commission on the Delaware River Basin, 1962. "Preliminary Report - Water Quality Survey, Delaware River Estuary. INCODEL. Philadelphia, PA.

Kawabe, M., Sharp, J.H., Wong, K.C., and Lebo, M.E., 1990. "Oceanographic Data Report Number 8: Density Profiles from the Delaware Estuary, October 1986 - September 1988". University of Delaware, Delaware Sea Grant College Program.

Kolva, J., USGS Water Resource Divsion Office, Pennsylvania, Personal Communication, April 12, 1991.

Kubik, K., USEPA - Edison. Telephone Conversation. December, 1990.

Najarian, T.O., Thatcher, M.L., and D.R.F. Harleman, 1980. "C&D Canal Effect on Salinity of Delaware Estuary". *ASCE, Journal of the Waterway Port and Coastal Ocean Division*, 106:1-17.

Osborne, J., 1990. New Jersey Department of Environmental Protection. Telephone Conversation. December 1990.

Otto, H., 1990. Delaware Department of Natural Resources and Environmental Conservation. Telephone Conversation. December 1990.

Polis, D.F. (ed.), 1973. Delaware Bay Report Series, 10 v., Univ. of Delaware, College of Marine Studies.

Pennock, J.R., 1985. "Chlorophyll Distribution in the Delaware Estuary: Regulation by Light Limitation". *Estuarine, Coastal and Shelf Science*, 21:711-725.

Ryan, R., 1990. Pennsylvania Department of Environmental Resources. Telephone Conversation. December 1990.

Sharp, J.H., Cifuentes, L.A., Coffin, R.B., Pennock, J.R., and K.-C Wong, 1986. "The Influence of River Variability on the Circulation, Chemistry, and Microbiology of the Delaware Estuary". *Estuaries*, 9:261-269.

Sharp, J.H., Culberson, C.H., and T.M. Church, 1982. "The Chemistry of the Delaware Estuary. General Considerations". *Limnology and Oceanography*, 27:1015-1028.

Tarr, J.A. and J. McCurley, 1984. "Pollution Trends in Five Estuaries, 1988-1990. Unpublished Report. Carnegie Mellon University, Pittsburg, PA.

Thatcher, M.L., Najarian, T.O., and P.-S. Huang, 1981. "Fifty Year Analysis of Salinity Intrusion and the Associated Average Annual Costs to Water Users in the Delaware Estuary". Report prepared for U.S. Army Corps of Engineers, Philadelphia, Pennsylvania, under contract DACW61-81-C-0032, by Najarian, Thatcher, & Associates, Inc., Closter, New Jersey, 158pp.

Thatcher, M.L., and T.O. Najarian, 1980. "Salt Intrusion in the Delaware Estuary under the influence of C&D Canal Flows". Report prepared for U.S. Army Corps of Engineers, Philadelphia, Pennsylvania, under contract DACW61-80-C-0080, by Najarian, Thatcher, & Associates, Inc., Closter, New Jersey.

Thatcher, M.L., and D.R.F. Harleman, 1978. "Development and Application of a Deterministic Time-Varying Salinity Intrusion Model of the Delaware Estuary". Report prepared for the Delaware River Basin Commission, Trenton, New Jersey, 232 pp.

U.S. Geological Survey Water-Data Report, 1987. "Water Resources Data, New Jersey Water Year 1987, Vol. 2. Delaware River Basin and Tributaries to Delaware Bay".

Wofsy, S., McElroy, M.B., and J.W. Wilkins, 1981. "Transformation of Nitrogen in a Polluted Estuary: Nonlinearities in the Demand for Oxygen at Low Flow." *Science*, 213: 754-757.

Wong, K.-C., and R.W. Garvine, 1984. "Observations of Wind-Induced, Subtidal Variability in the Delaware Estuary". *Journal of Geophysical Research*, 89:10,589-10,597.

FIGURES

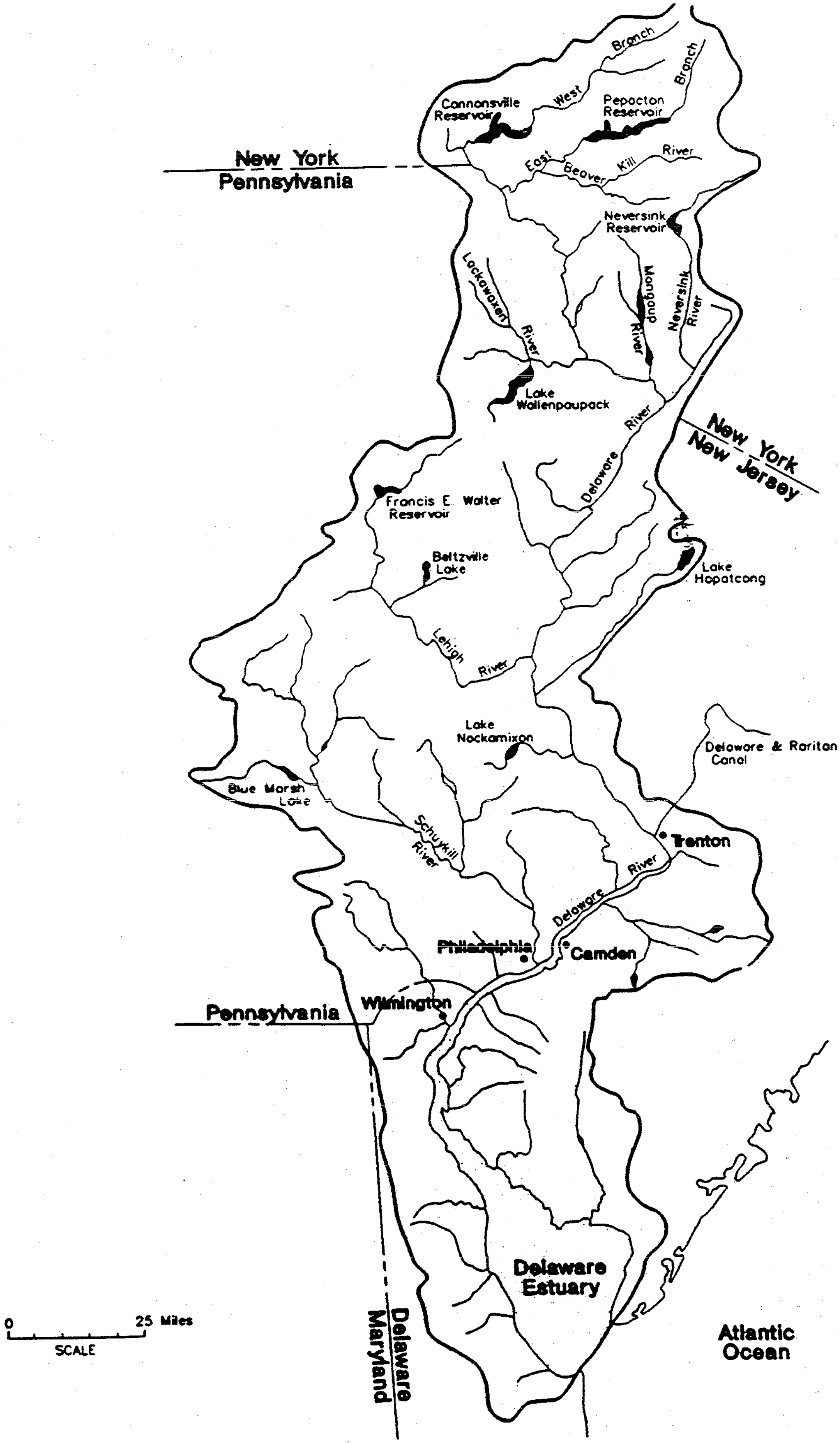


FIGURE 2.1: Delaware Estuary Drainage Basin

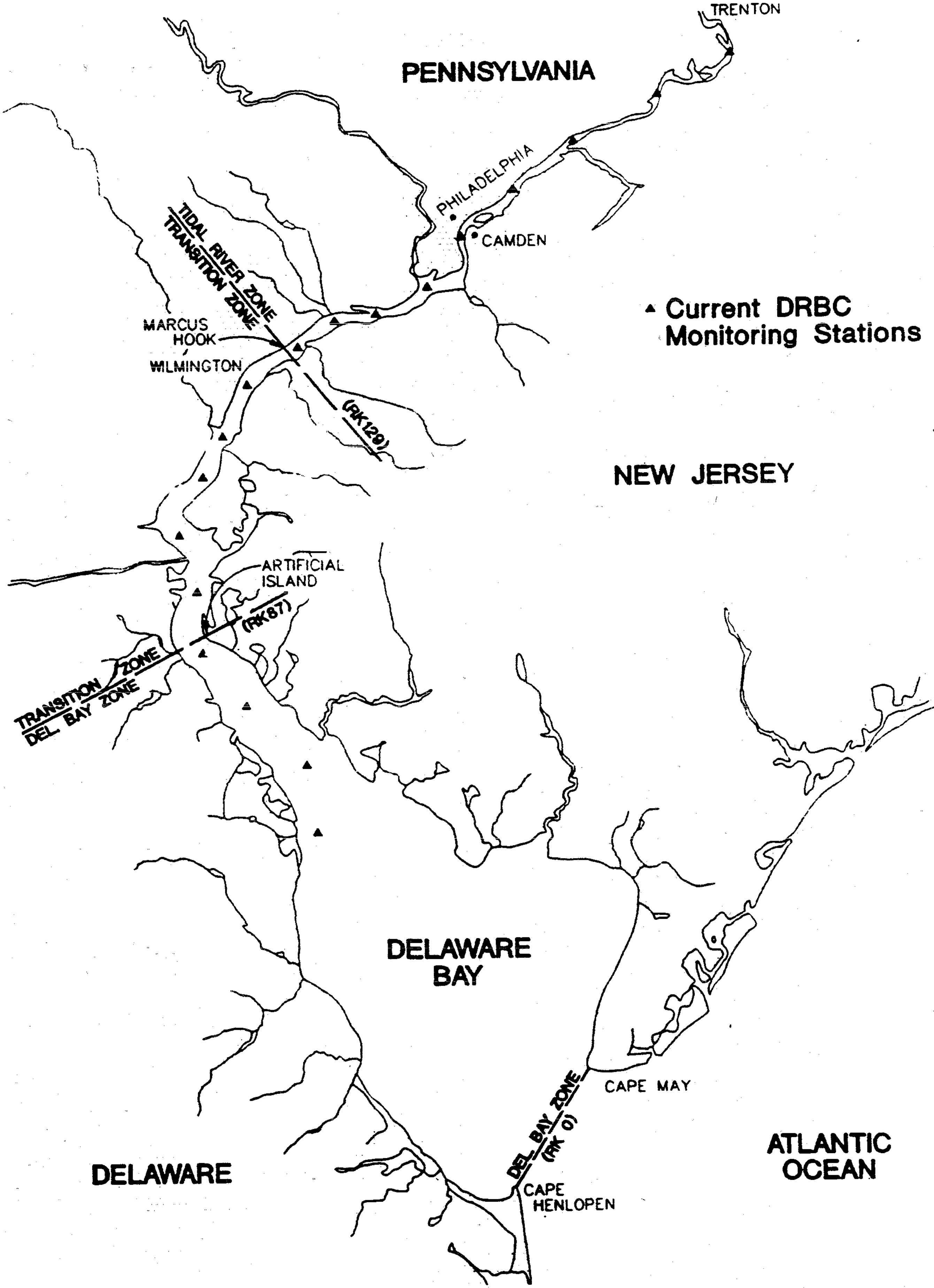


FIGURE 2.2: Delaware Estuary Zones

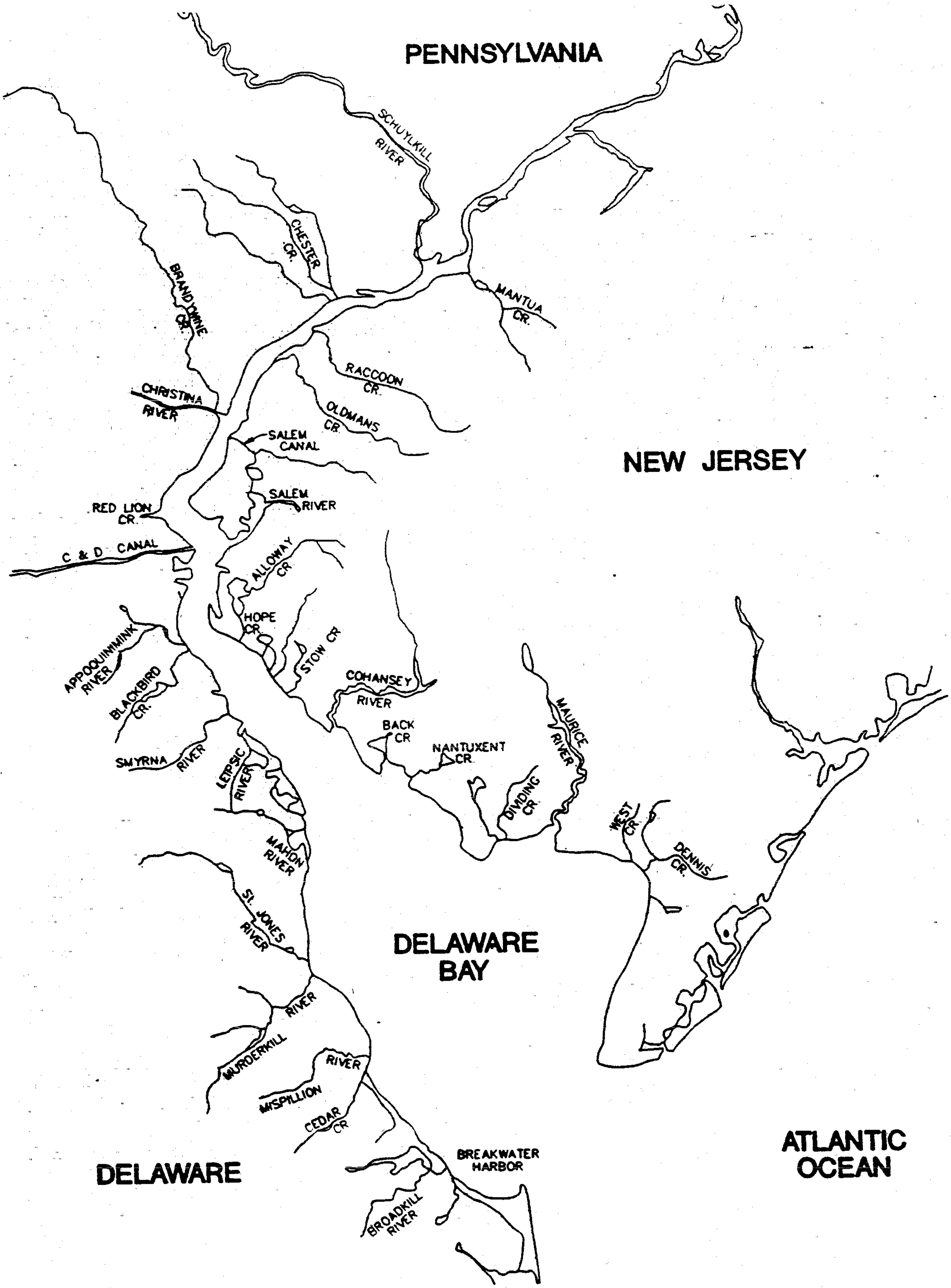


FIGURE 2.3: TRIBUTARIES of the DELAWARE ESTUARY

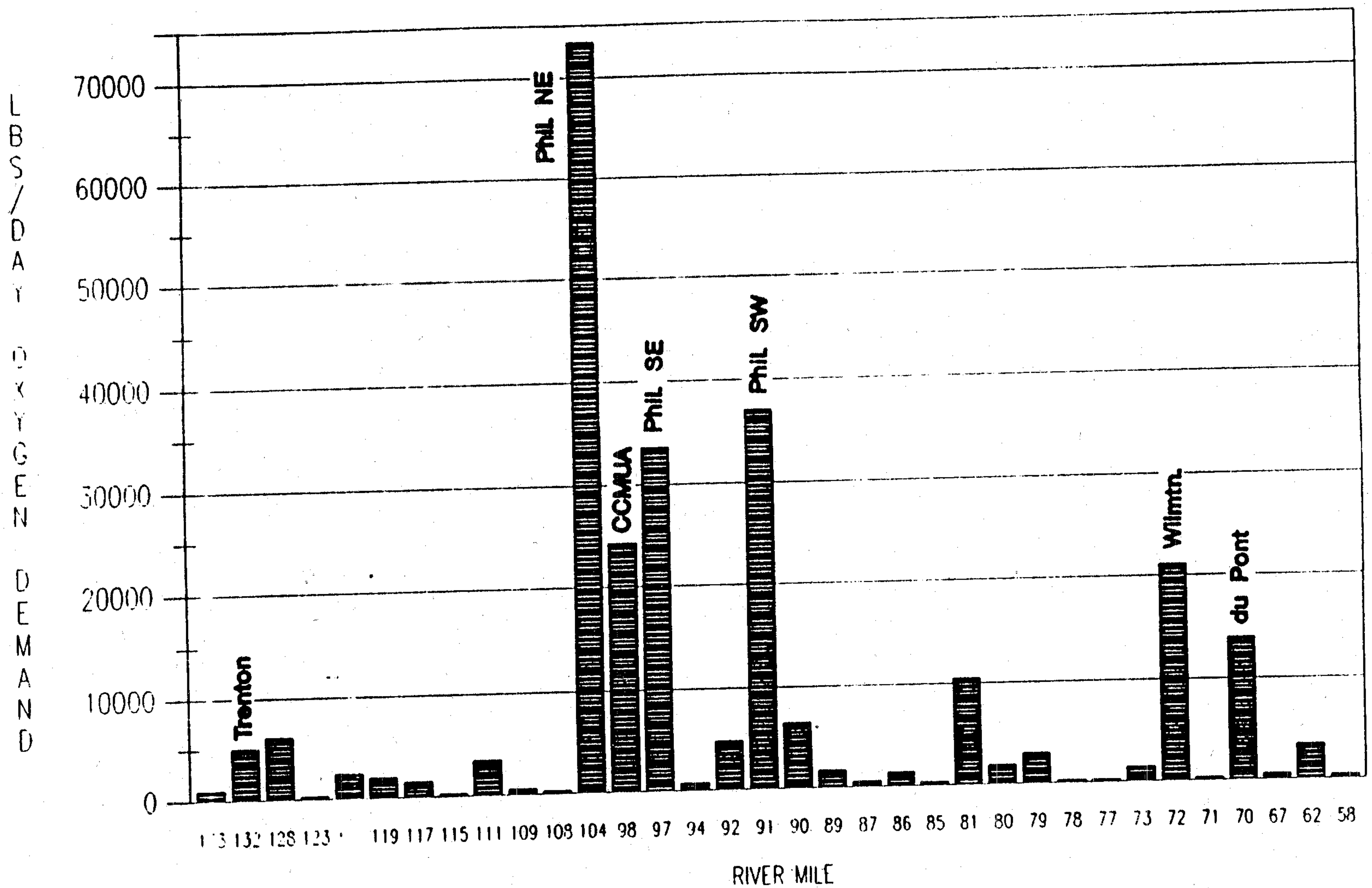
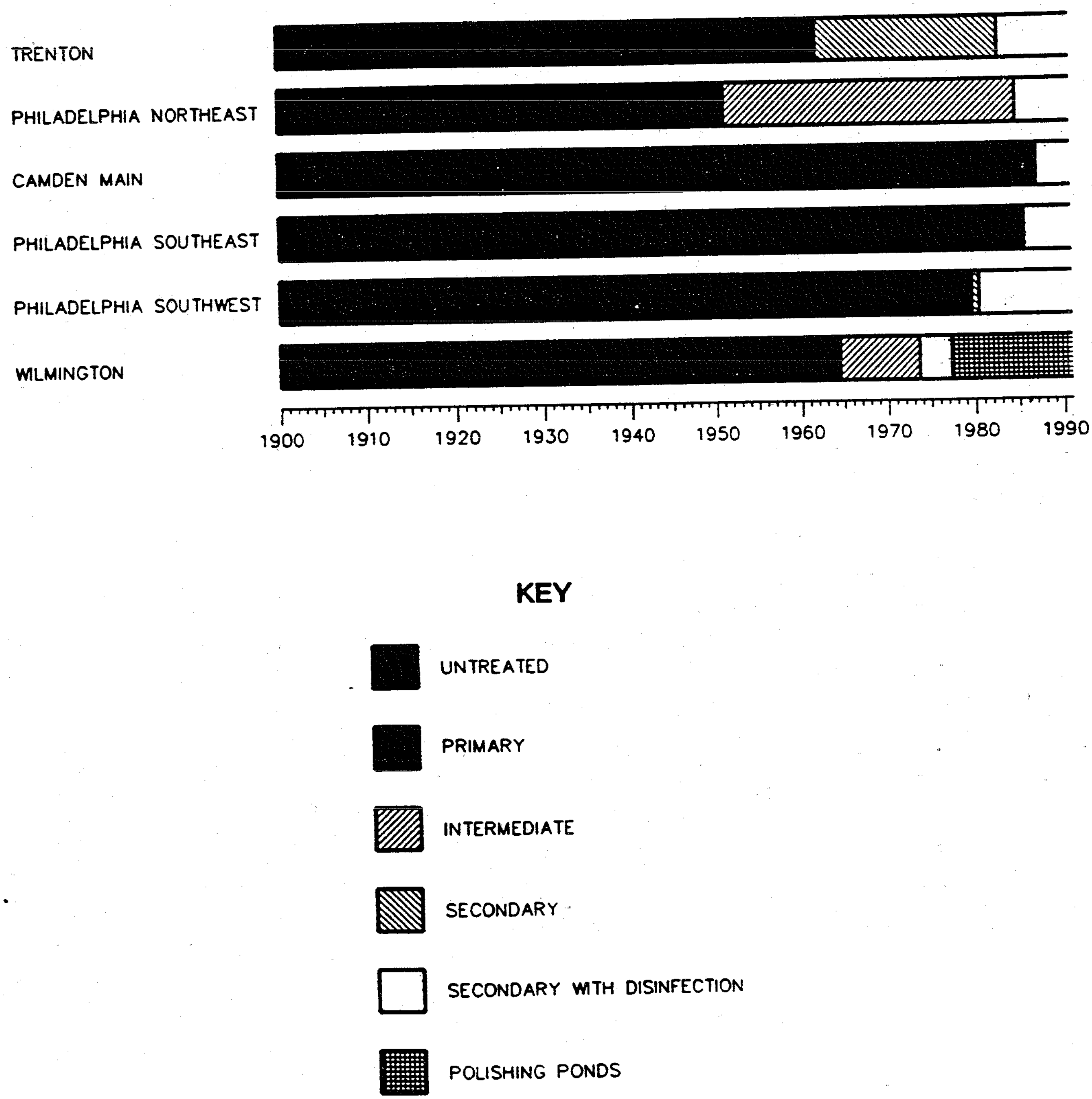


FIGURE 2.4: DRBC's Delaware Estuary BOD Allocations for 1990

FIGURE 2.5: HISTORY of UPGRADES at MAJOR MUNICIPAL TREATMENT PLANTS

(AFTER BRYANT AND PENNOCK, 1988)



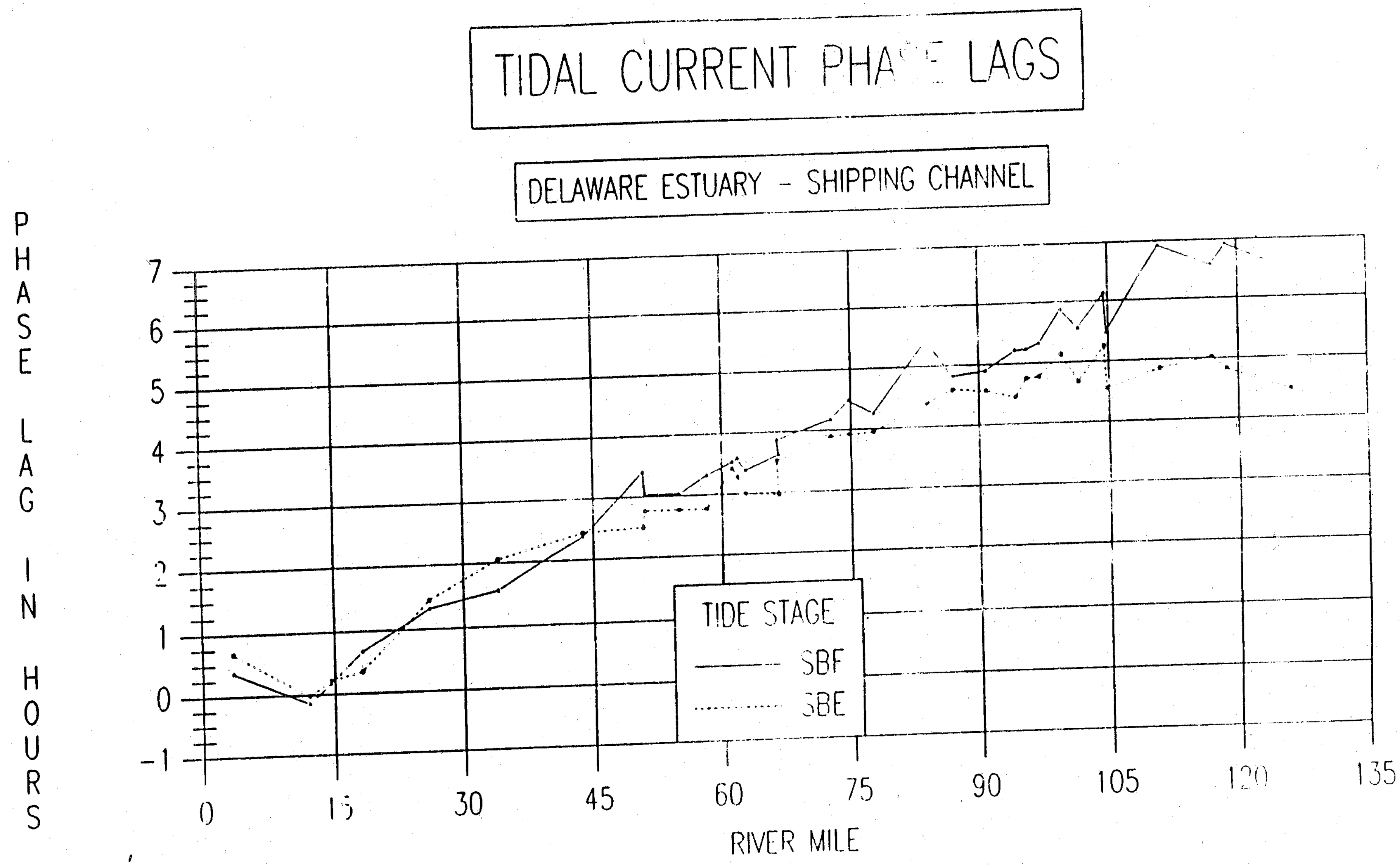


FIGURE 4.1 **Tidal current phase lags along the main shipping channel of the Delaware Estuary**

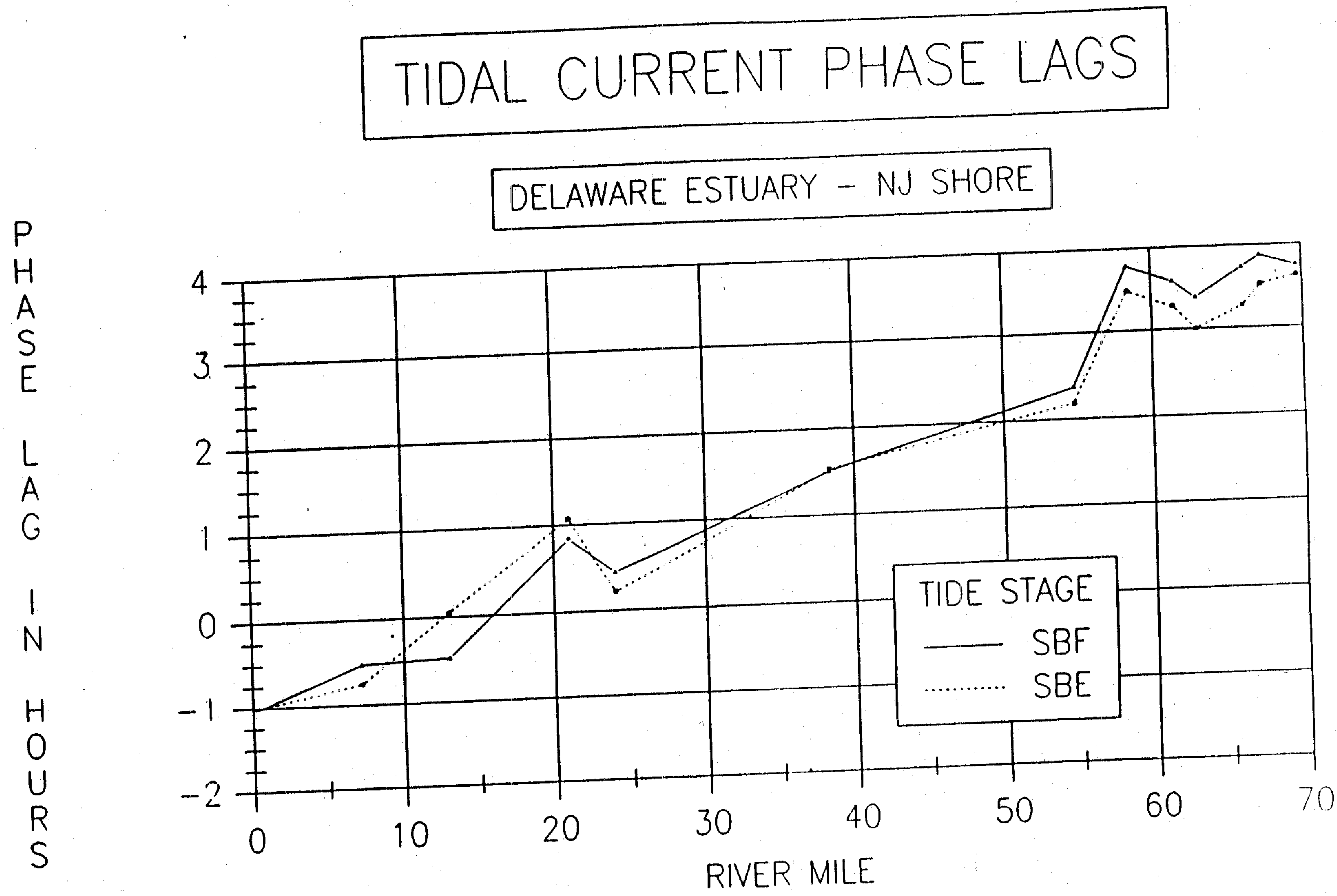


FIGURE 4.2 **Tidal current phase lags along the New Jersey Shore of the Delaware Estuary.**

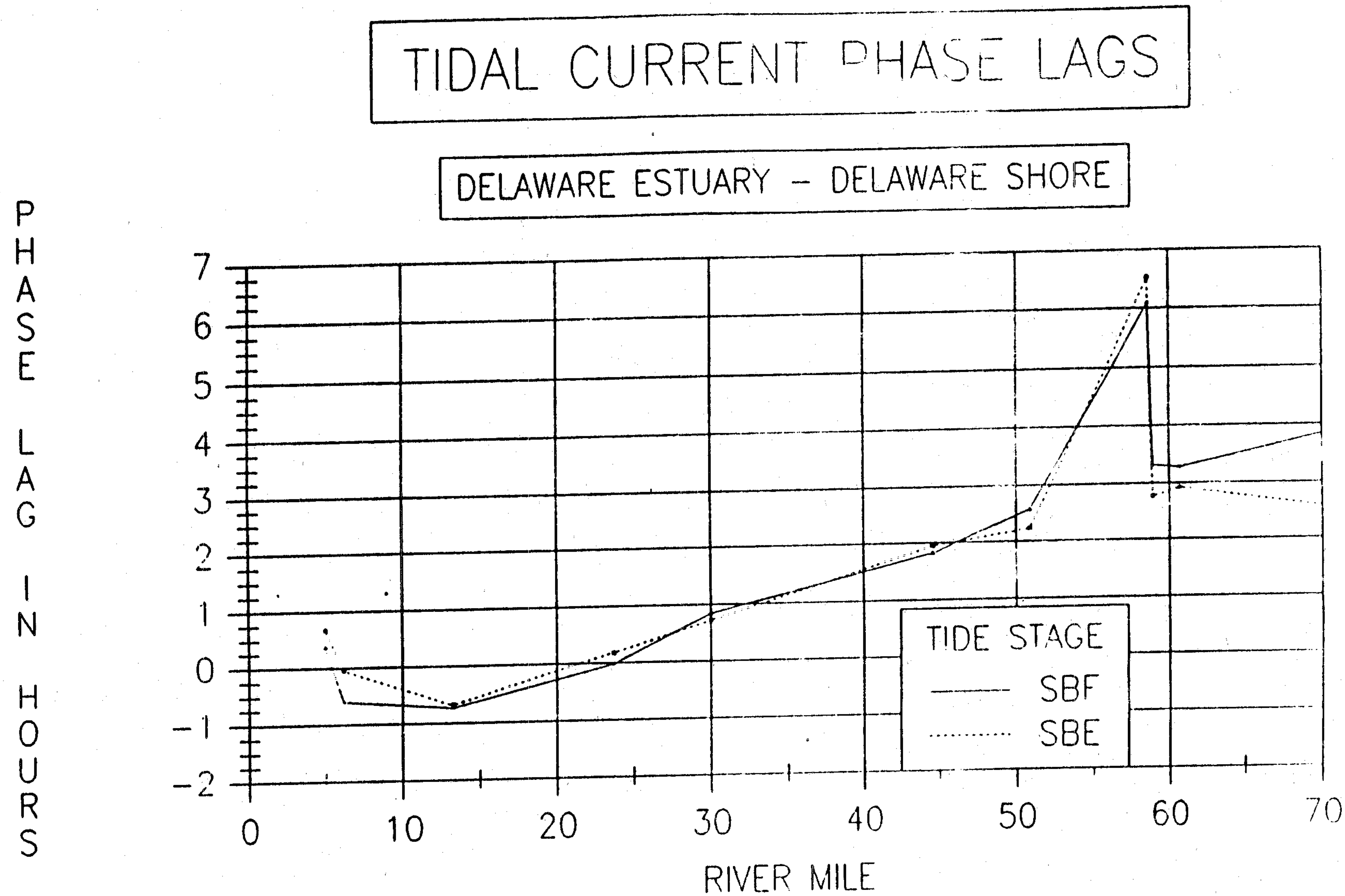


FIGURE 4.3 **Tidal current phase lags along the Delaware Shore of the Delaware Estuary.**

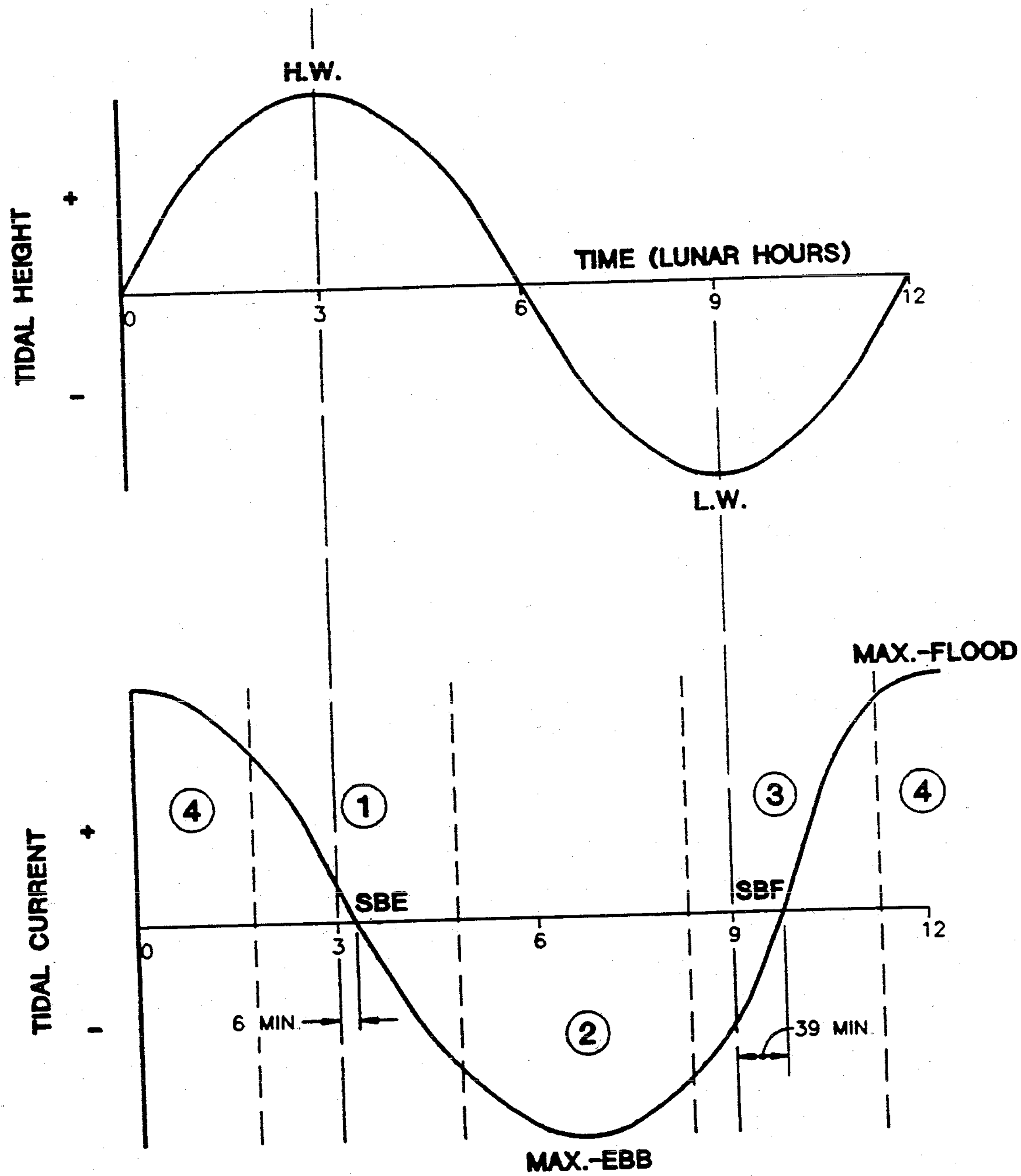
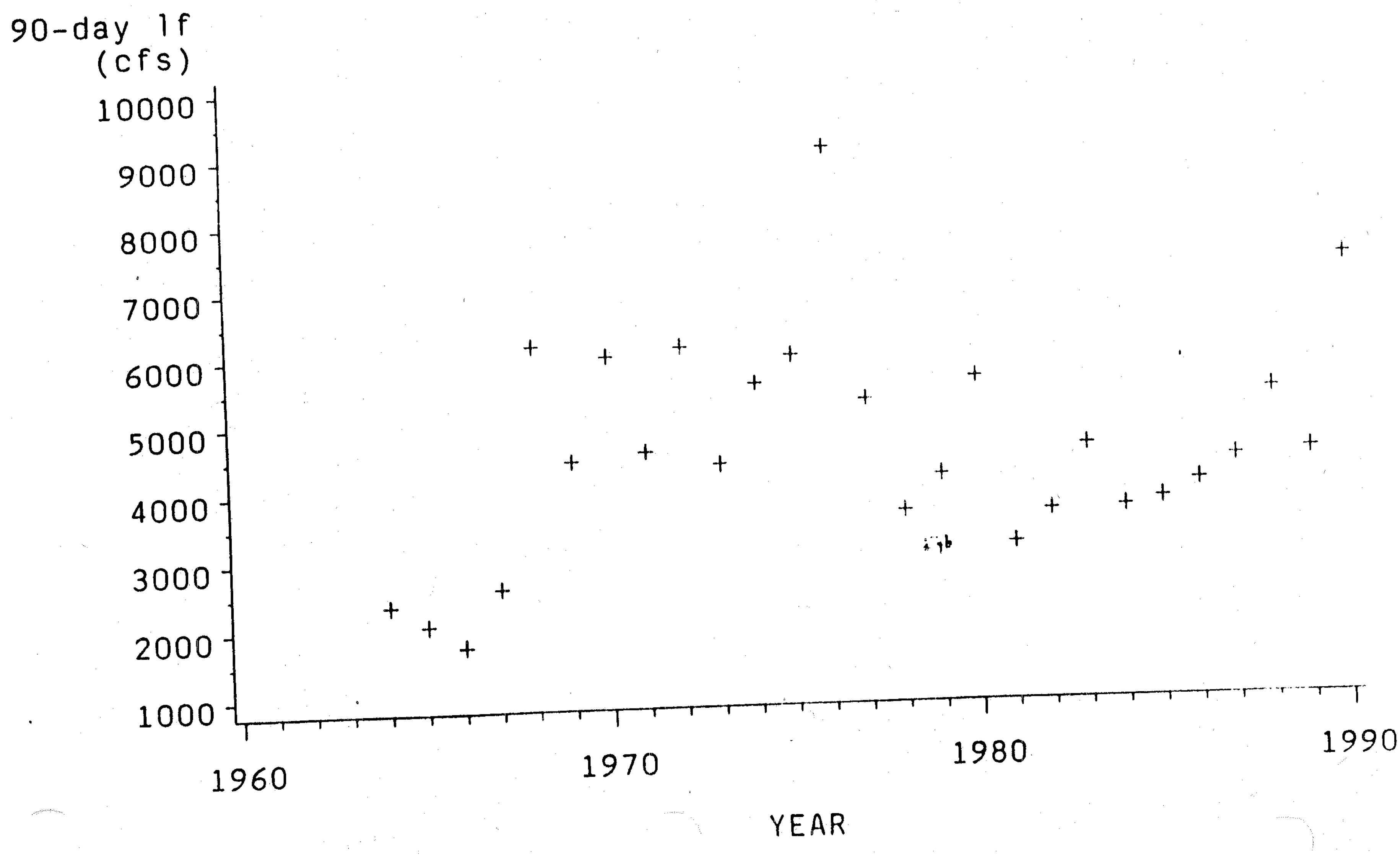


FIGURE 4.4: Illustration of quarter-interval for tidal current cycle.

Delaware River at Trenton, NJ

Historic Data Analysis - Annual 90-Day Low Flow (cfs)
Agency= USGS Station=01463500



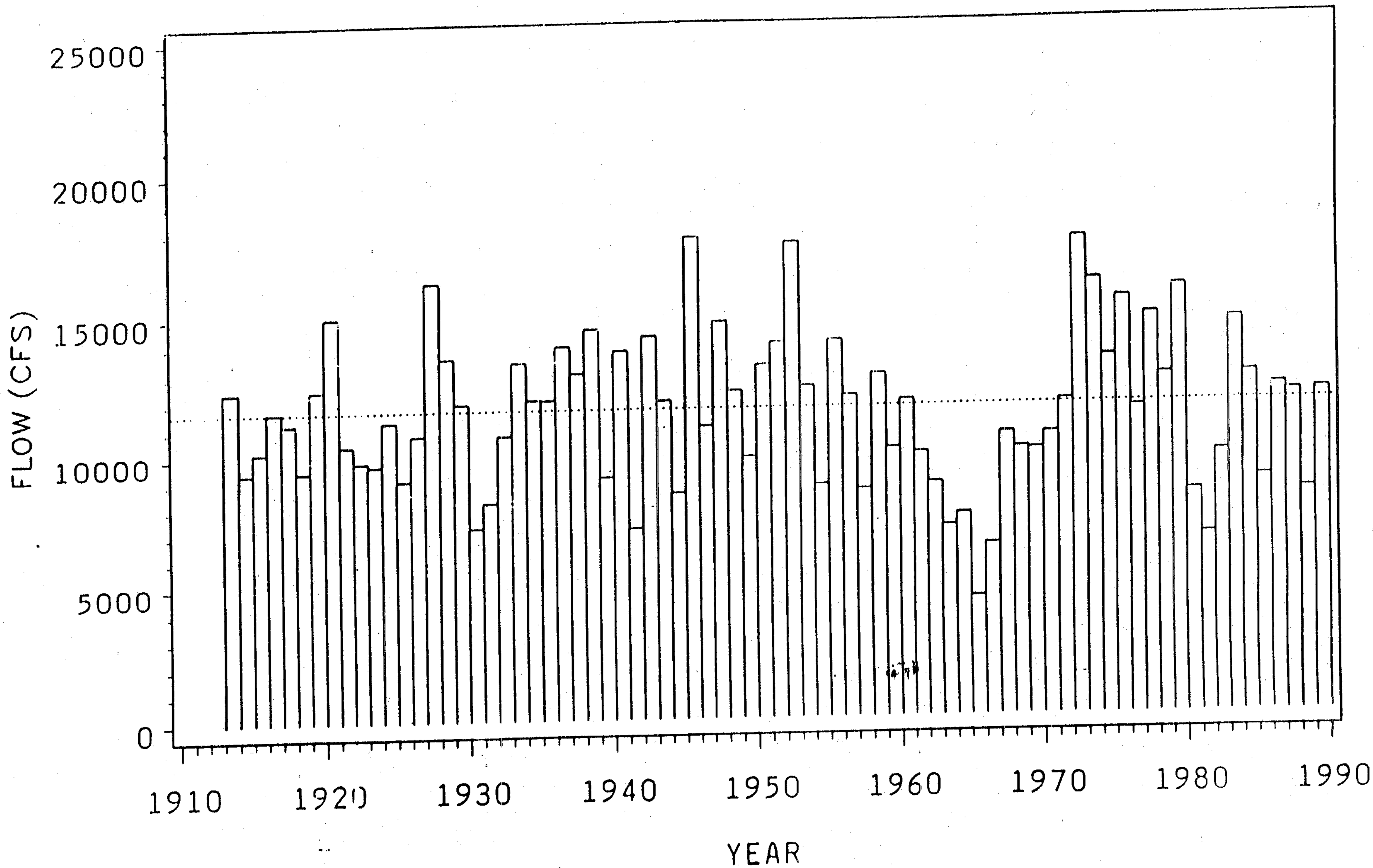


FIGURE 4.6: **Annual Average Streamflows at Trenton, New Jersey**

FIGURE 5.1

Historic Water Quality Conditions

Mean of Data for 1968–1970, 1978–1980, and 1988–1990

Salinity Profiles

FIGURE 5.2

Historic Water Quality Conditions

Mean of Data for 1968–1970, 1978–1980, and 1988–1990

Temperature Profiles

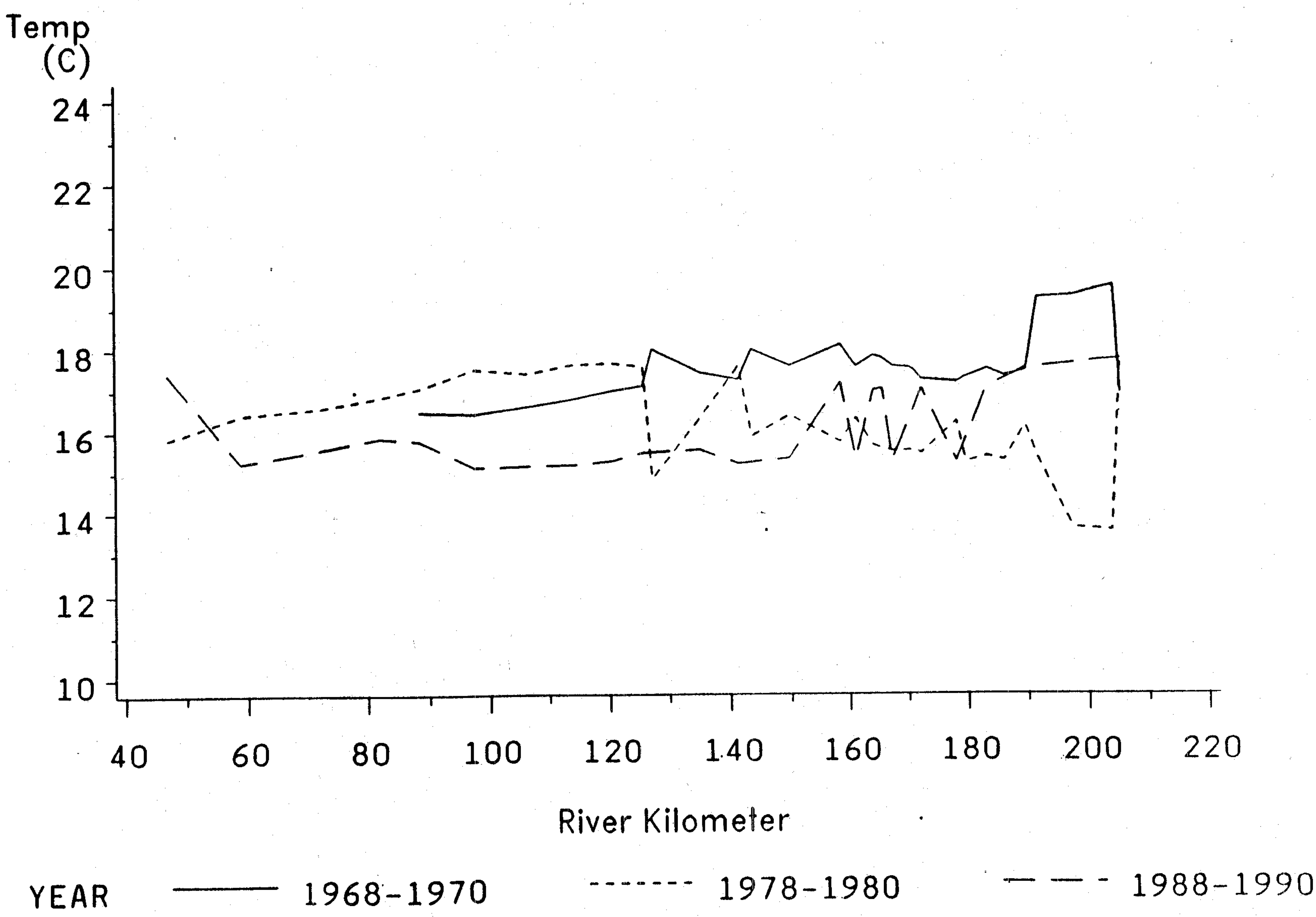


FIGURE 5.3

Historic Water Quality Conditions

Mean of Data for 1968–1970, 1978–1980, and 1988–1990

pH Profiles

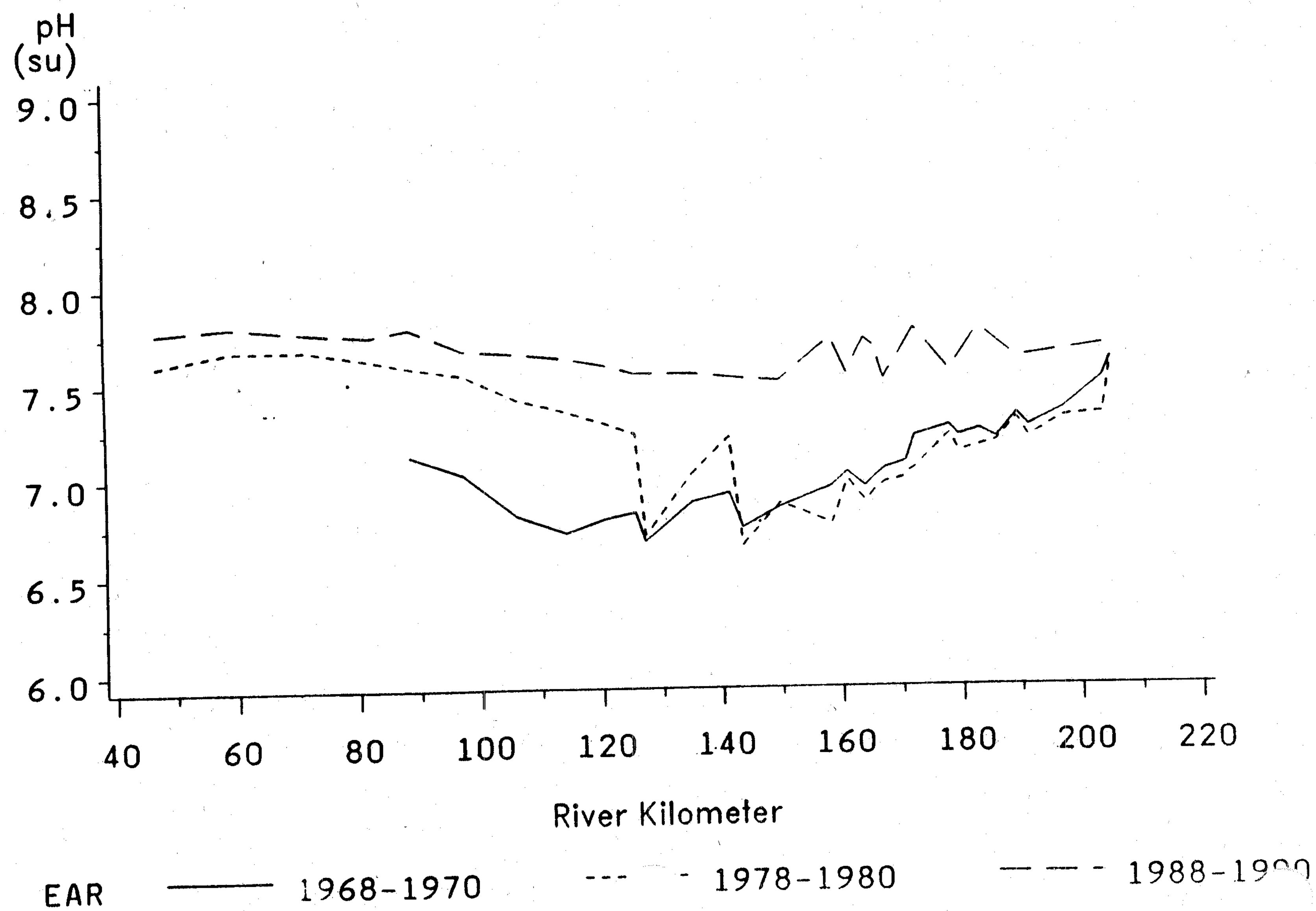


FIGURE 5.4

Historic Water Quality Conditions

Mean of Data for 1968–1970, 1978–1980, and 1988–1990

BOD5 Profiles

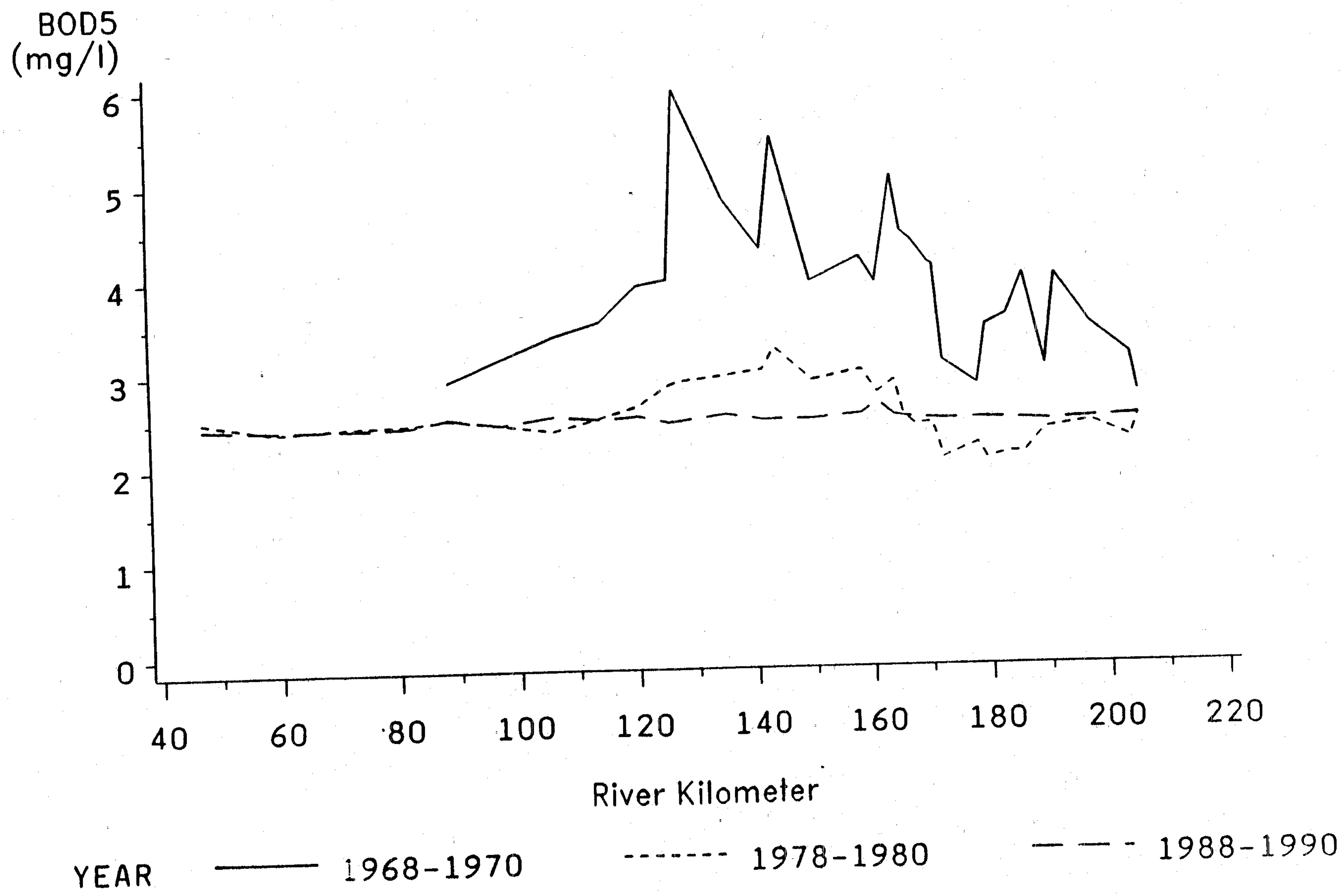


FIGURE 5.5

Historic Water Quality Conditions

Mean of Data for 1968–1970, 1978–1980, and 1988–1990

Total Phosphorus Profiles

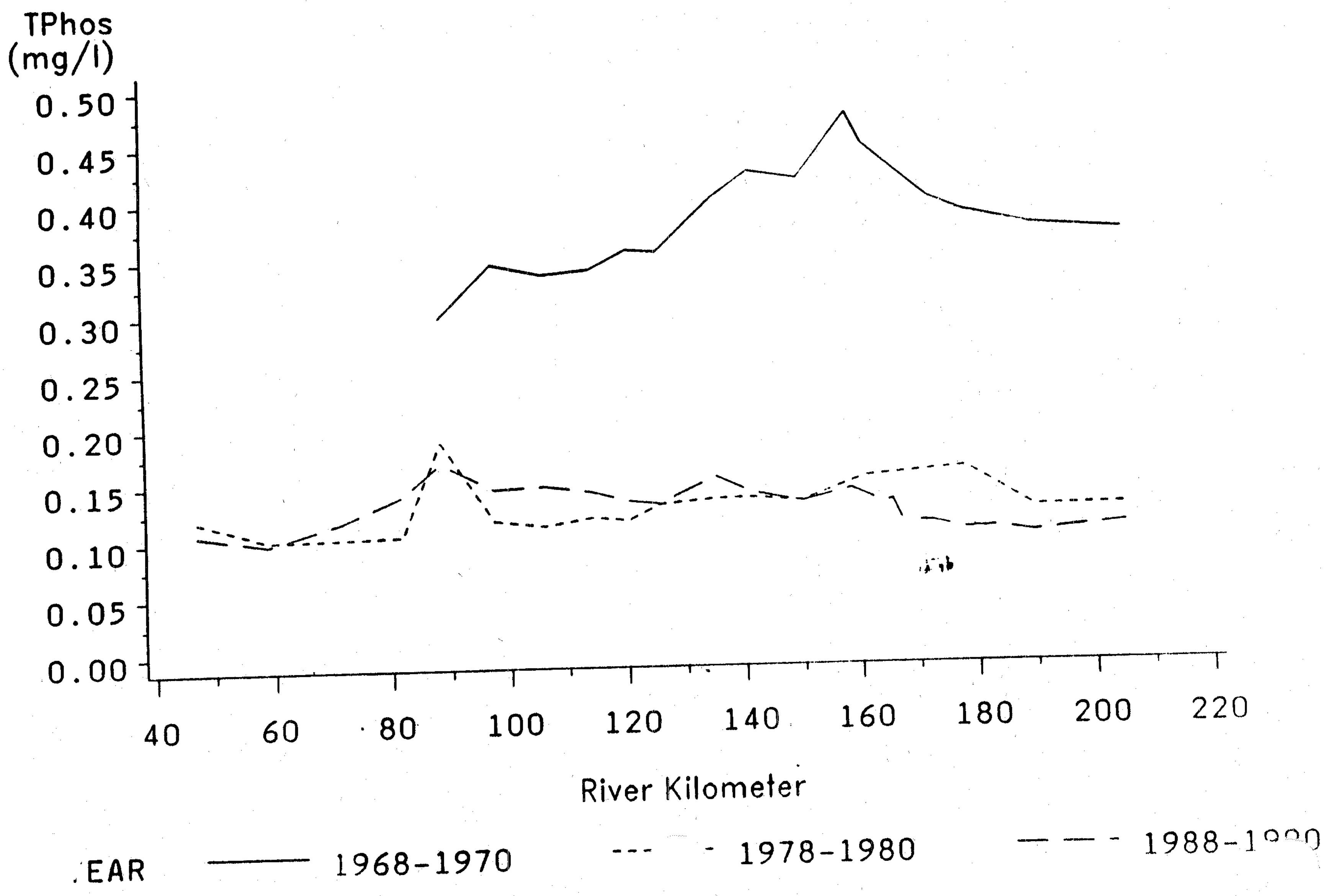


FIGURE 5.6

Historic Water Quality Conditions

Mean of Data for 1968–1970, 1978–1980, and 1988–1990
Ammonia Nitrogen Profiles

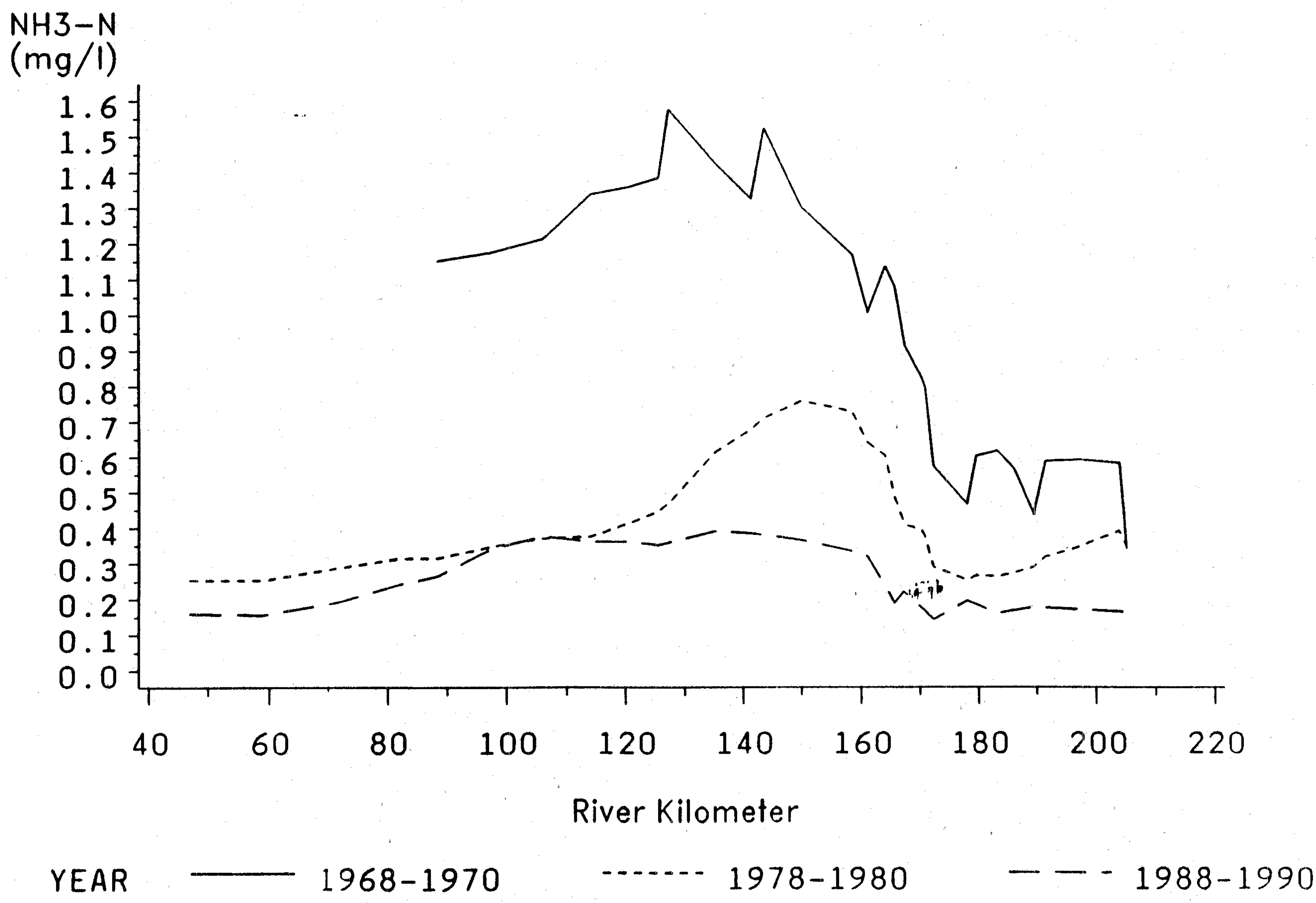


FIGURE 5.7

Historic Water Quality Conditions

Mean of Data for 1968–1970, 1978–1980, and 1988–1990
Nitrate Nitrogen Profiles

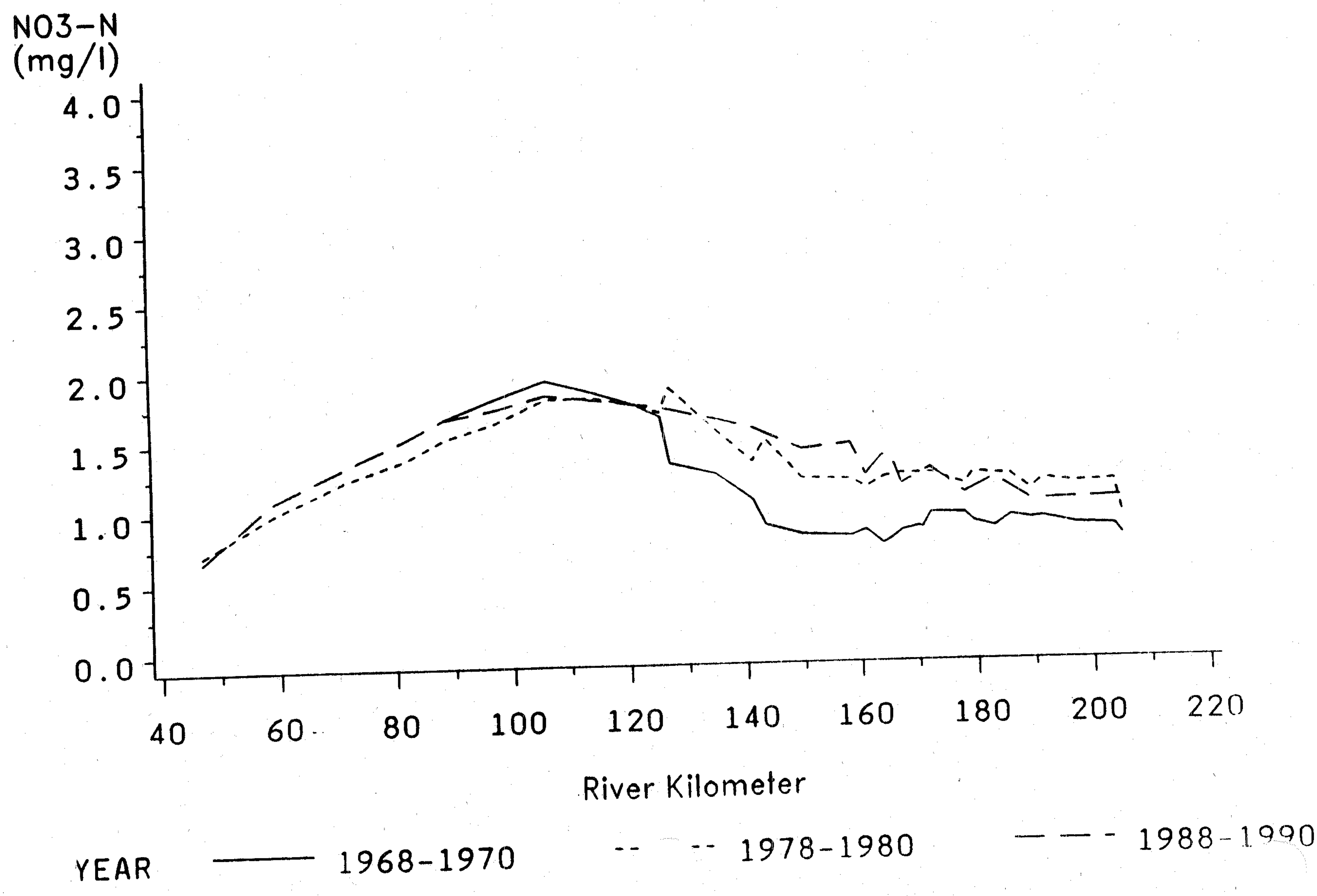


FIGURE 5.8

Historic Water Quality Conditions

Mean of Data for 1968–1970, 1978–1980, and 1988–1990

Total Nitrogen Profiles

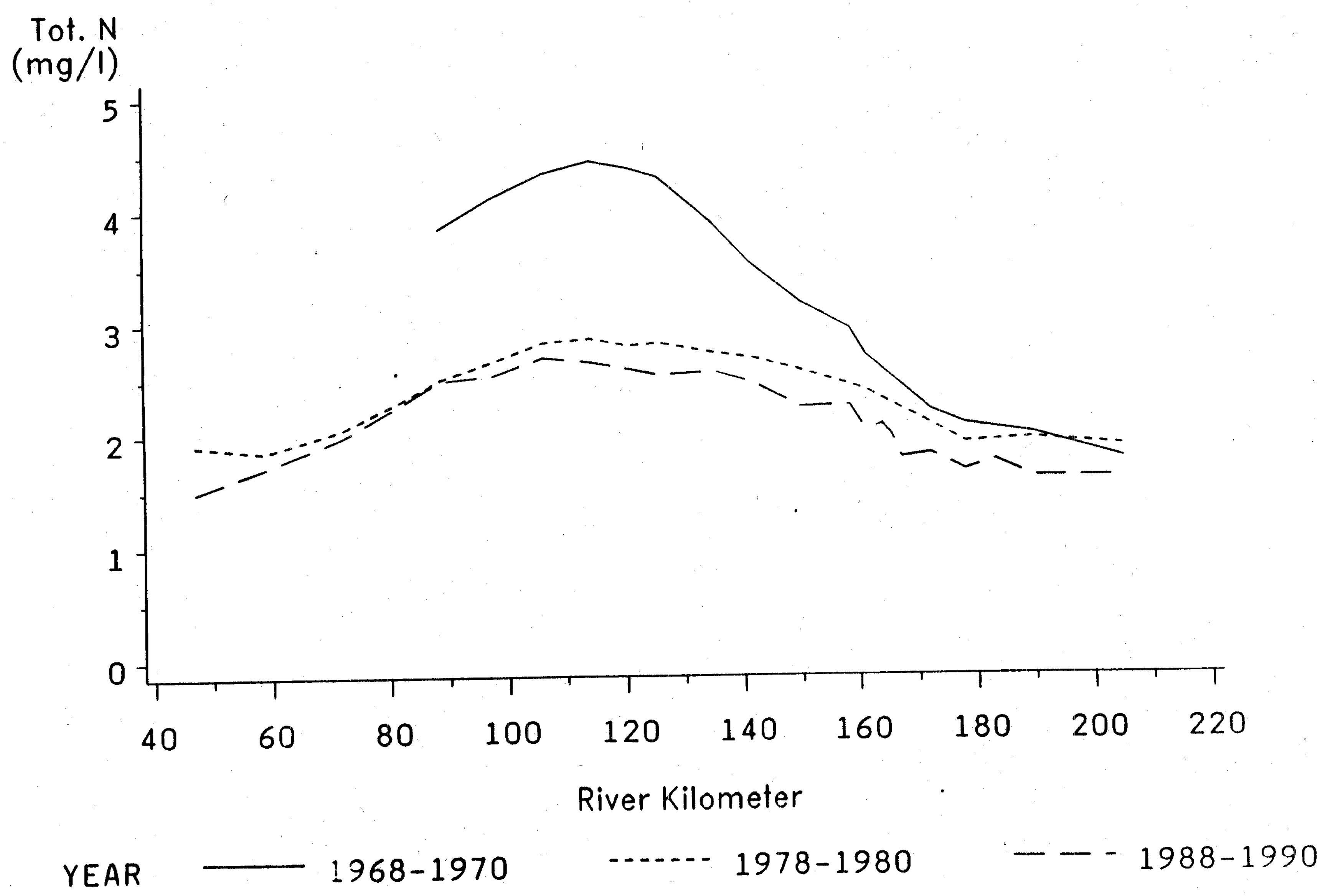


FIGURE 5.9

Historic Water Quality Conditions

Mean of Data for 1968–1970, 1978–1980, and 1988–1990
Summer Dissolved Oxygen Profiles

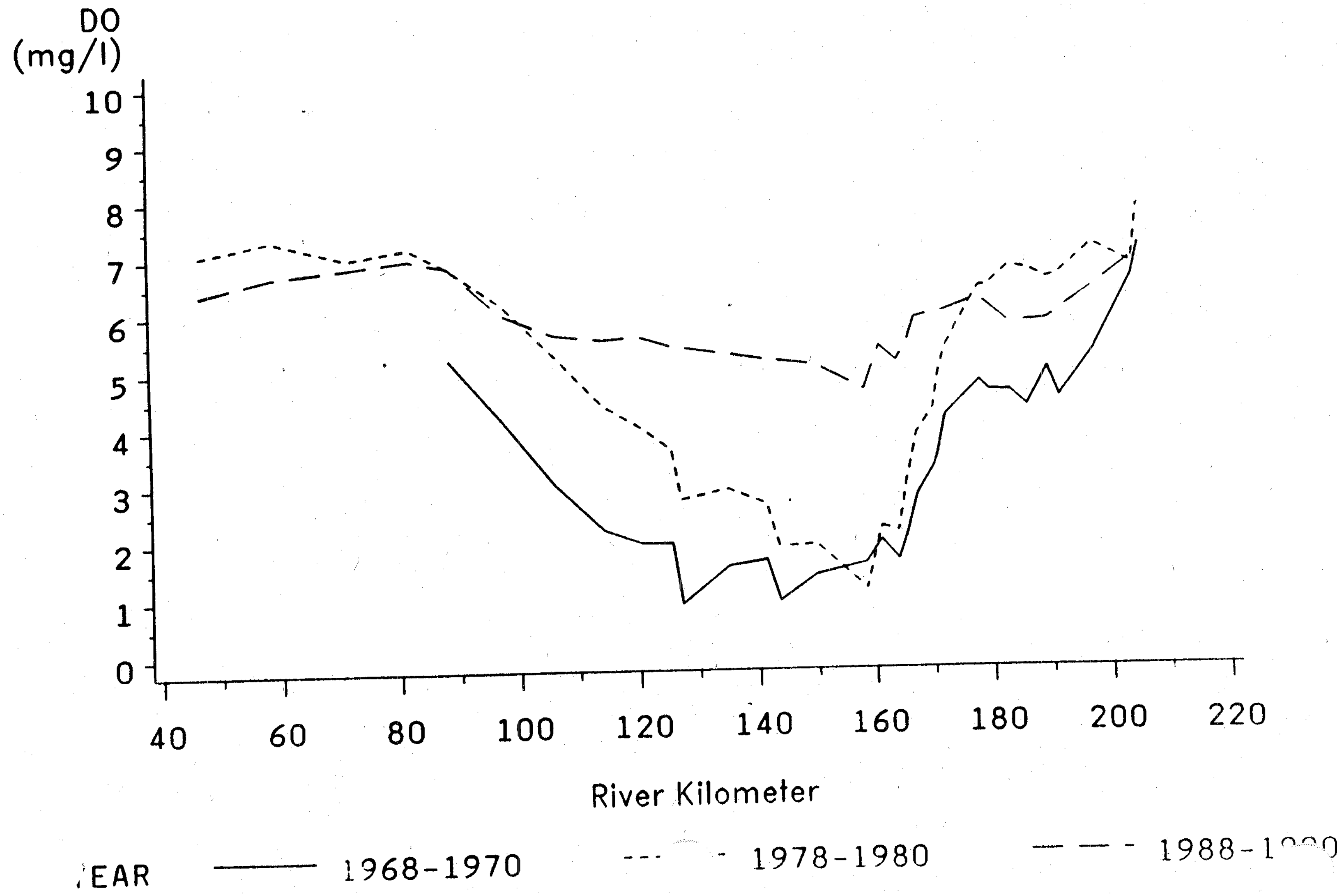


FIGURE 5.10

Historic Water Quality Conditions

Geometric Mean of Data for 1968–1970, 1978–1980, and 1988–1990

Fecal Coliform Profiles

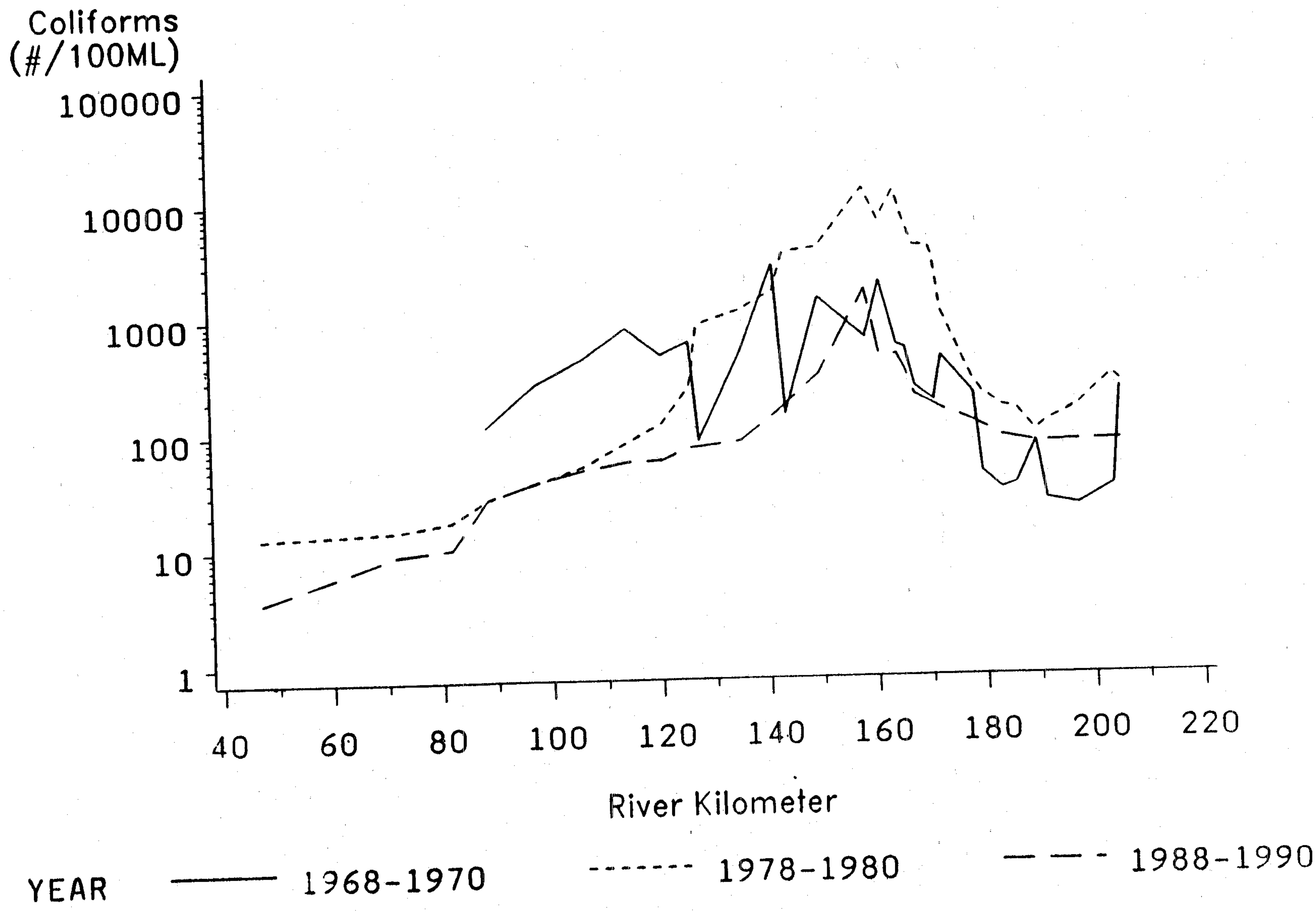


FIGURE 5.11

Water Quality Status Comparison during Different Flow Years

Mean of Data for 1981, 1985, and 1986
June-August Ammonia Nitrogen Profiles

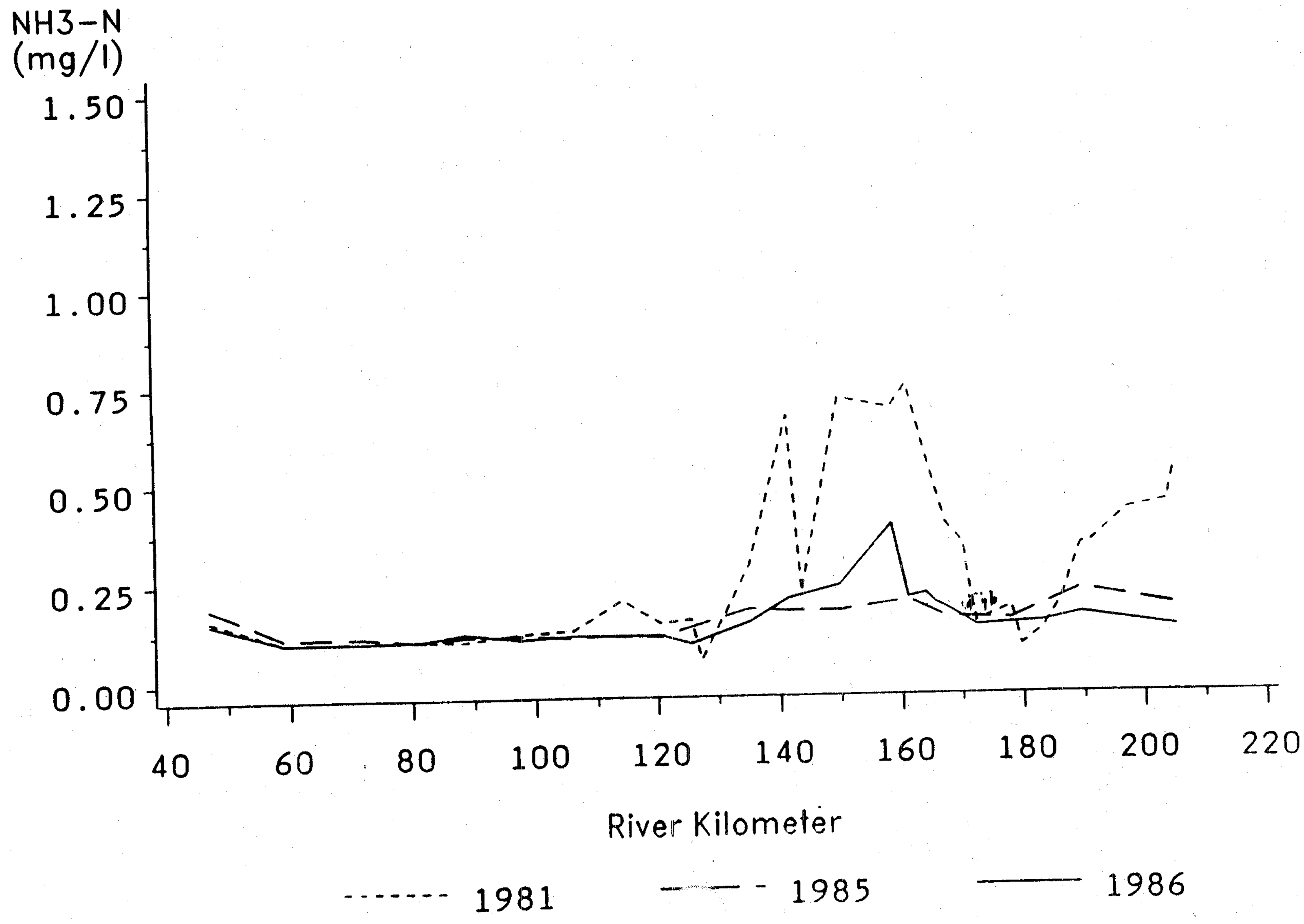


FIGURE 5.12

Water Quality Status Comparison during Different Flow Years

Mean of Data for 1981, 1985, and 1986
June-August Nitrate Nitrogen Profiles

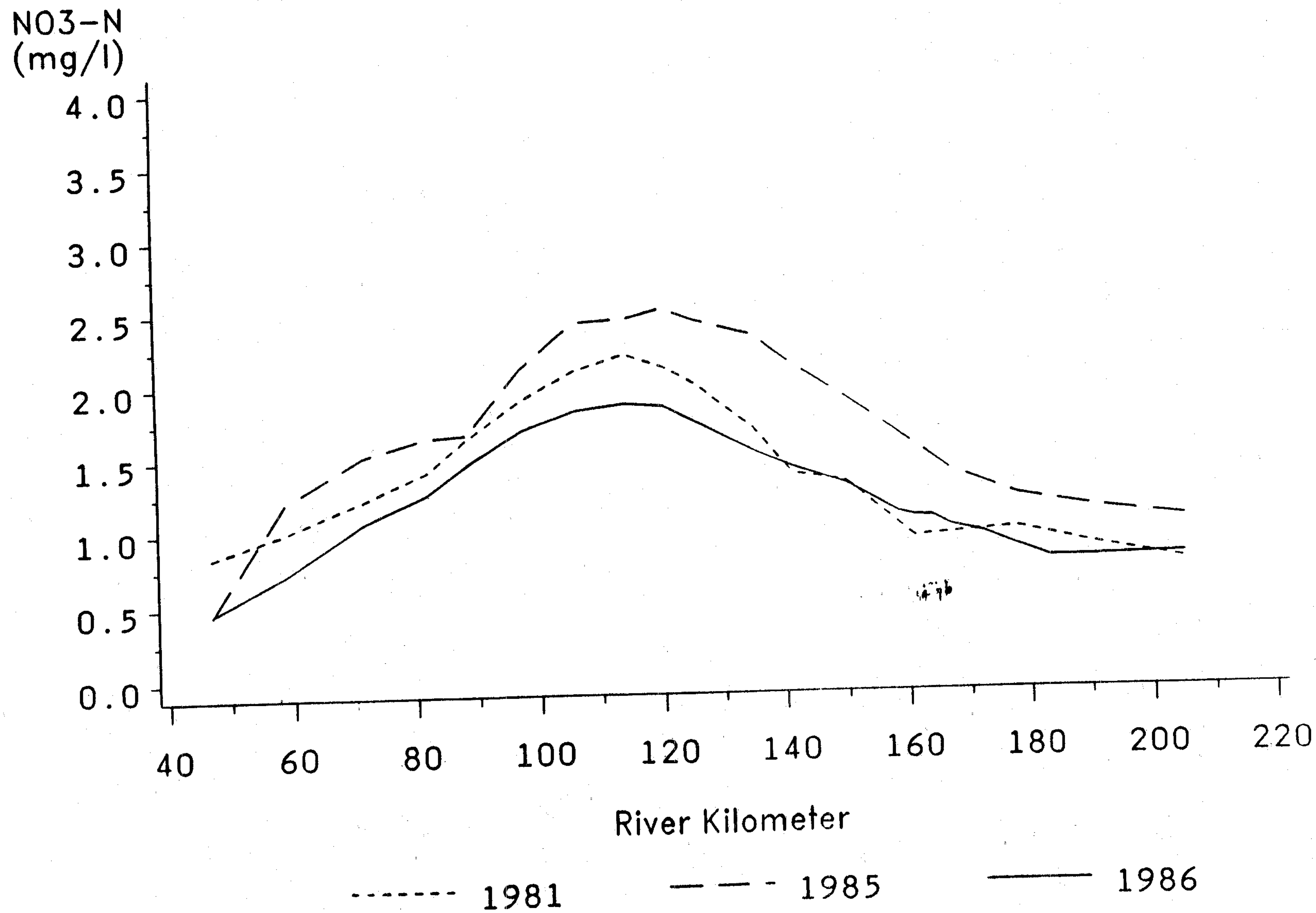


FIGURE 5.13

Water Quality Status Comparison during Different Flow Years

Mean of Data for 1981, 1985, and 1986
June-August Total Nitrogen Profiles

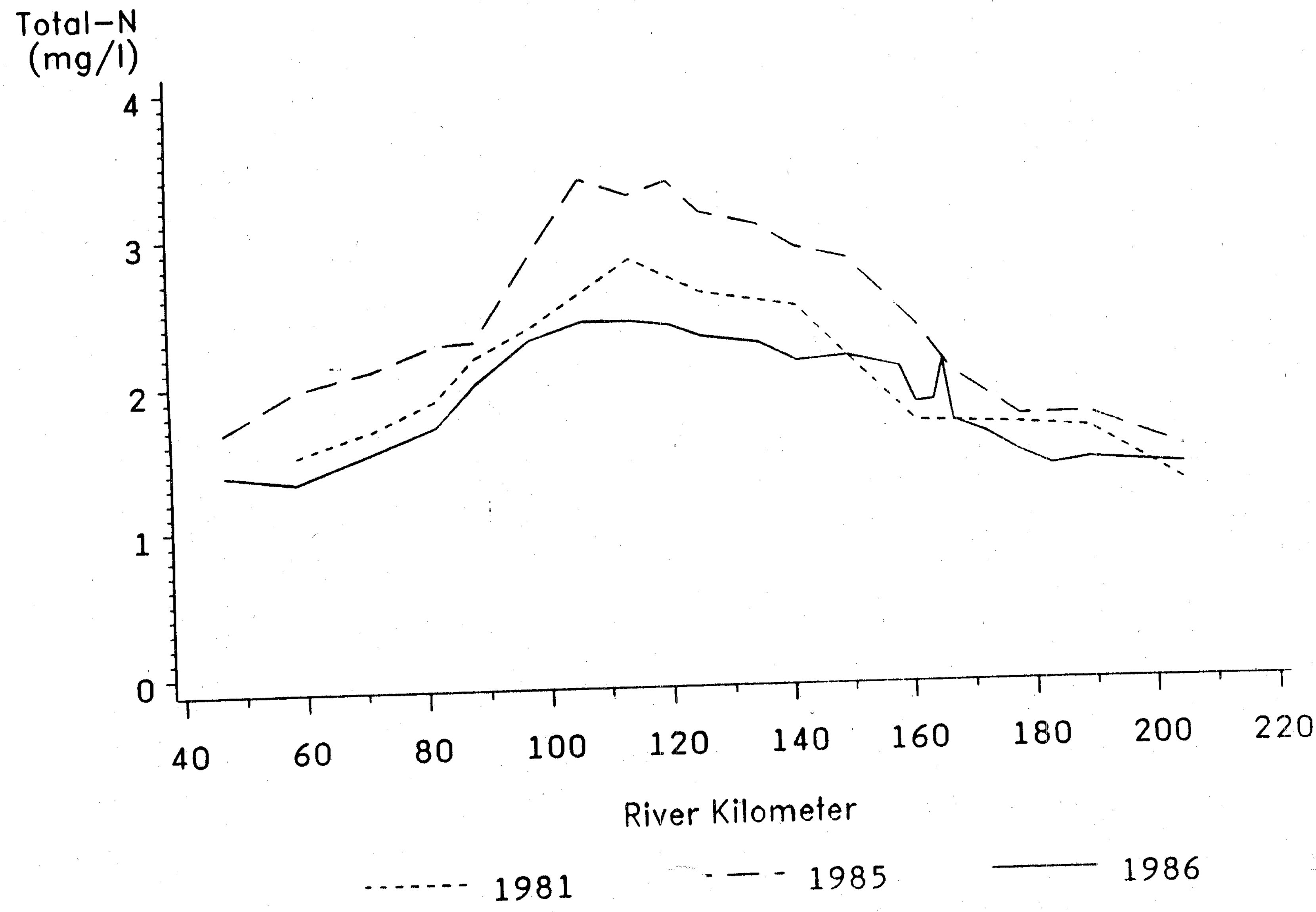


FIGURE 5.14

Water Quality Status Comparison during Different Flow Years

Mean of Data for 1981, 1985, and 1986
June-August Total Phosphorus Profiles

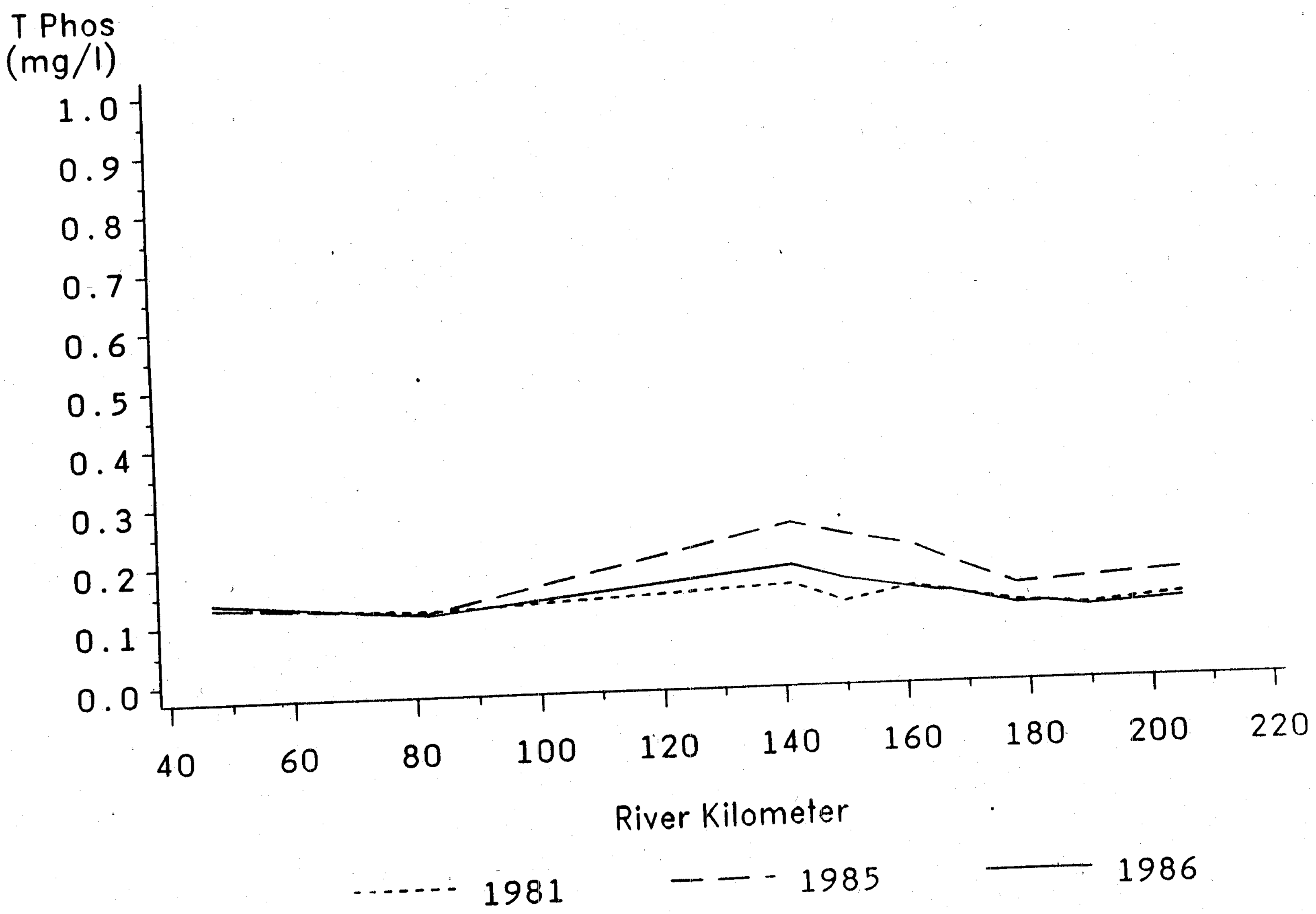


FIGURE 5.15

Water Quality Status Comparison during Different Flow Years

Mean of Data for 1981, 1985, and 1986
June-August pH Profiles

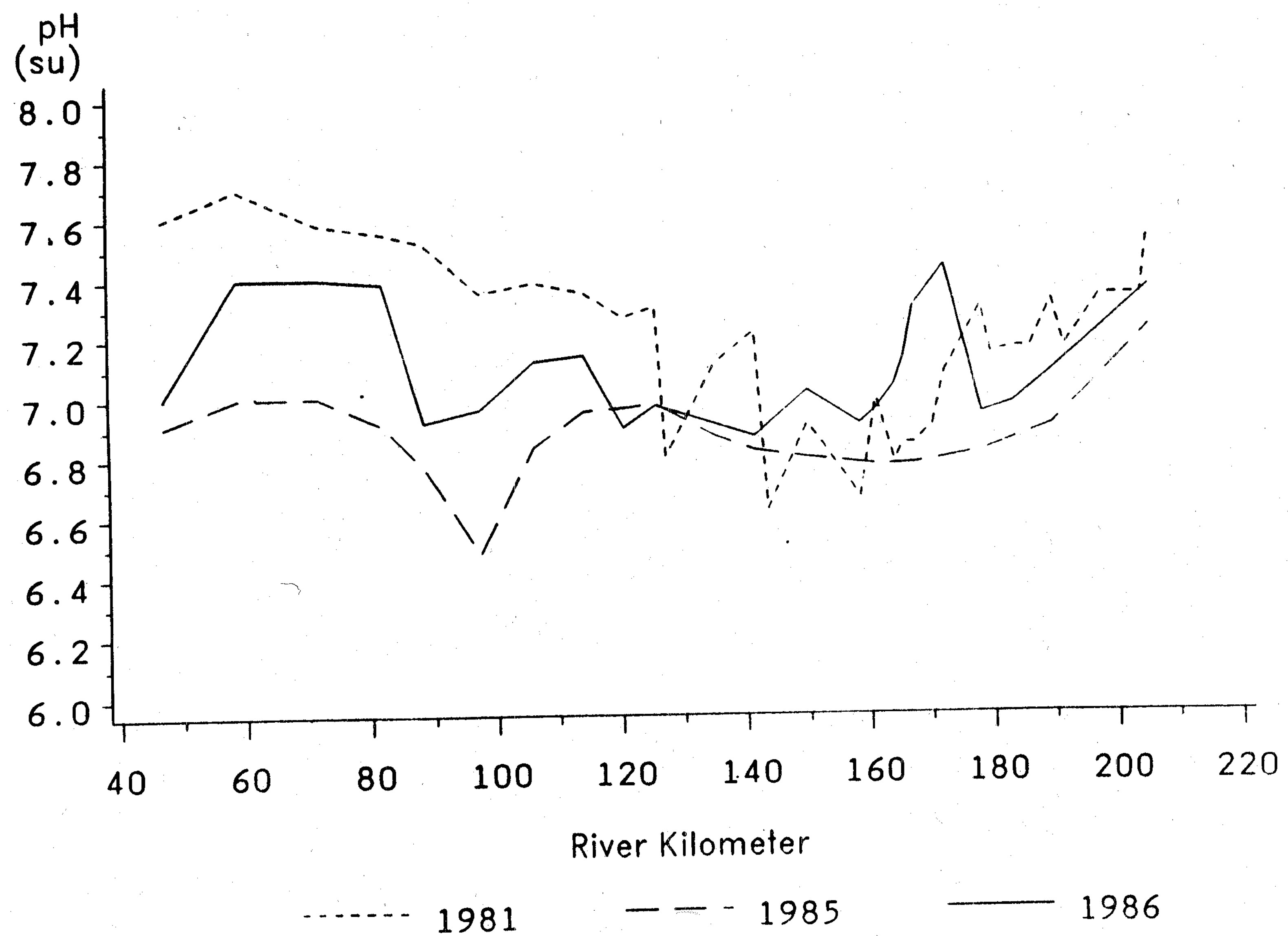


FIGURE 5.16

Water Quality Status Comparison during Different Flow Years

Mean of Data for 1981, 1985, and 1986
June-August BOD5 Profiles

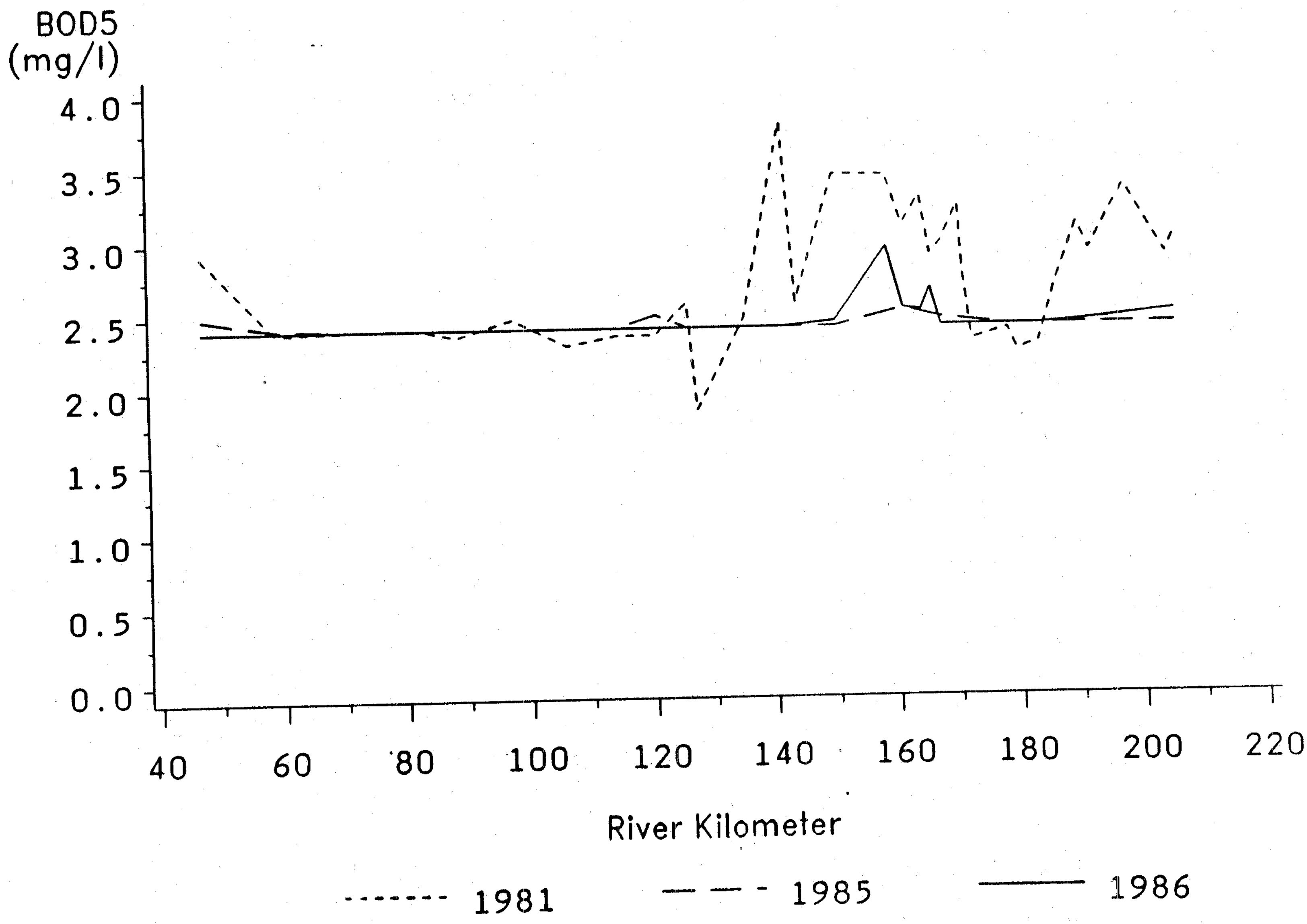


FIGURE 5.17

Water Quality Status Comparison during Different Flow Years

Mean of Data for 1981, 1985, and 1986
June-August Dissolved Oxygen Profiles

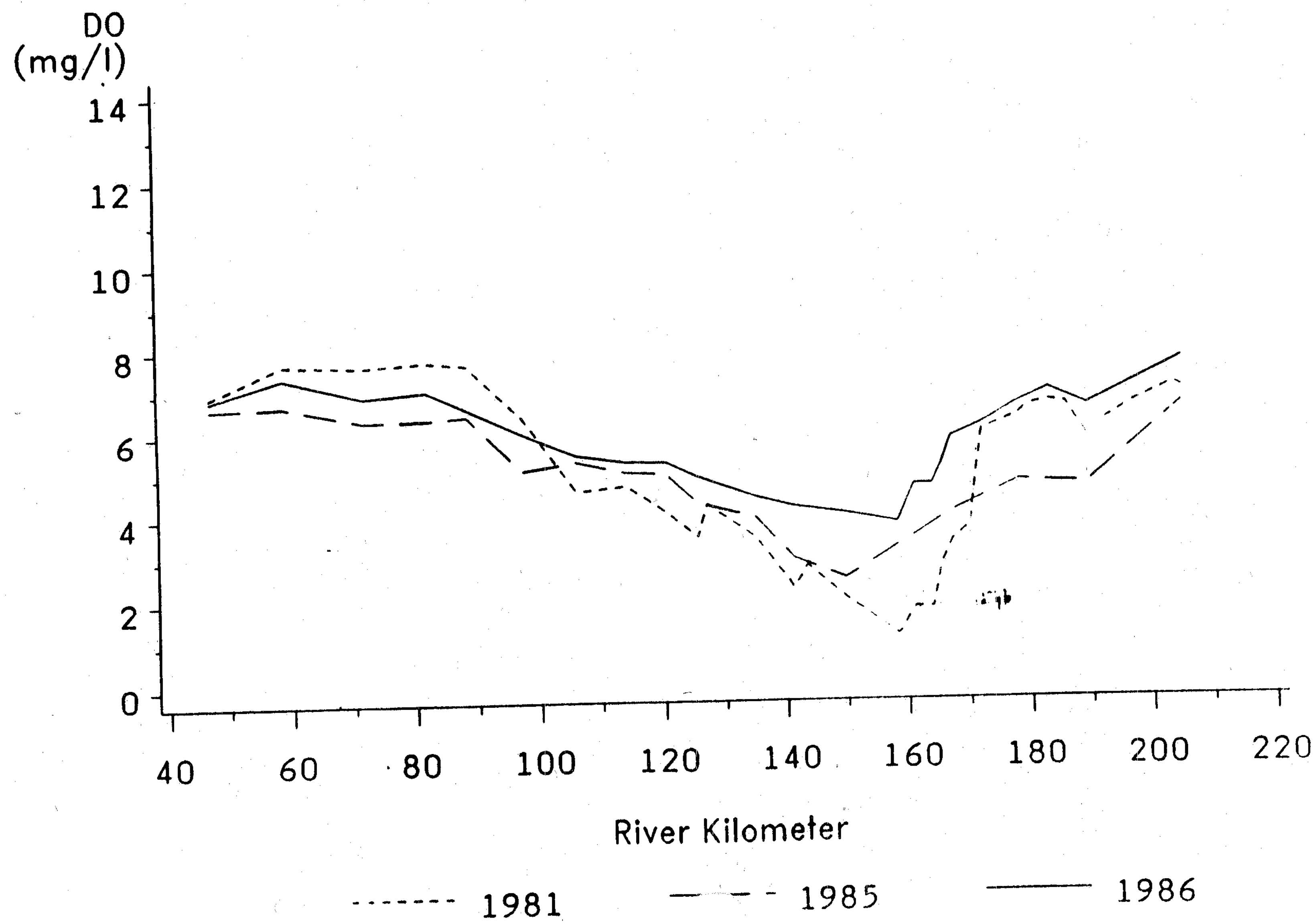


FIGURE 5.18

Water Quality Status Comparison during Different Flow Years

Geometric Mean of Data for 1981, 1985, and 1986
June-August Fecal Coliform Profiles

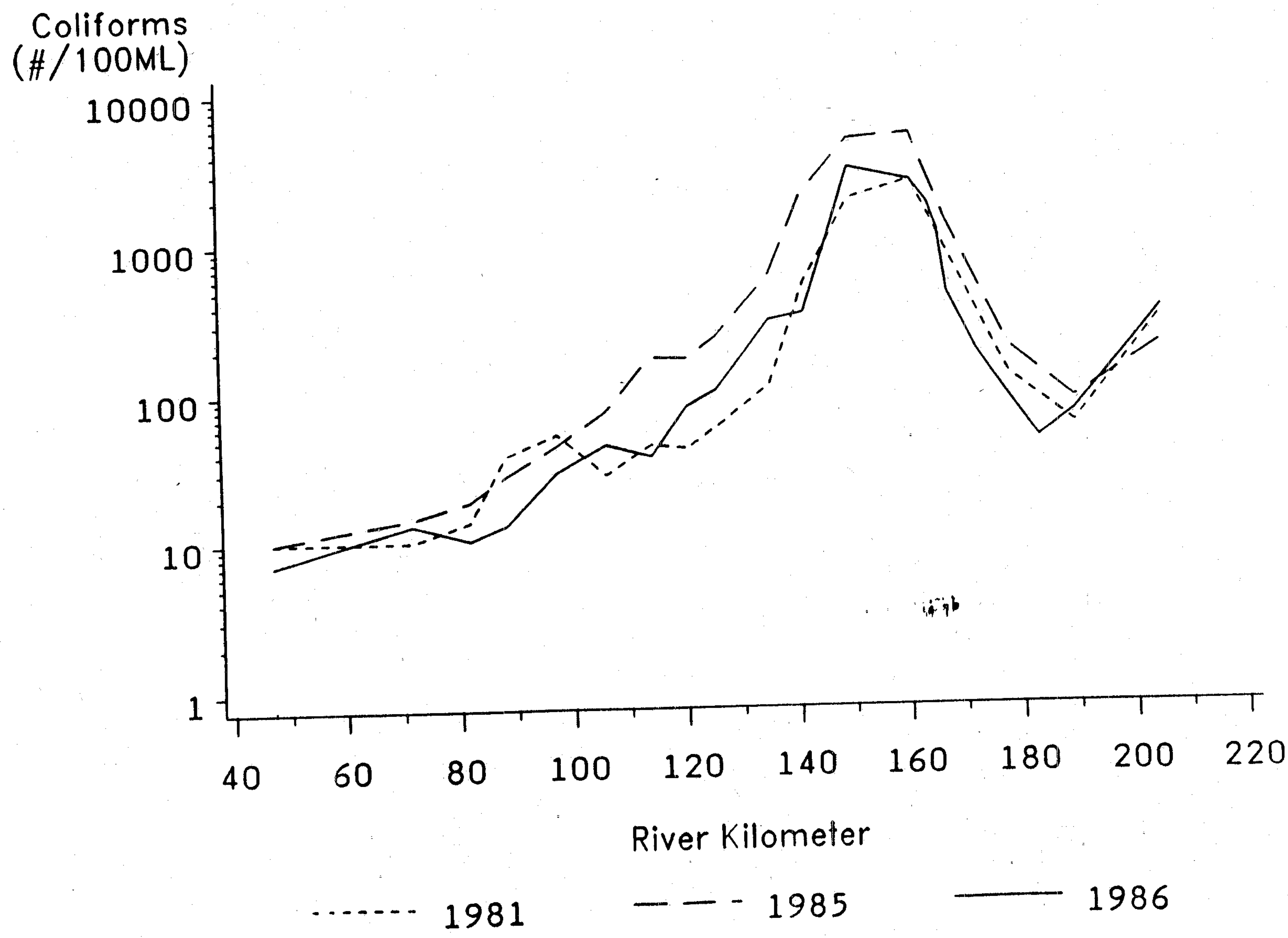


FIGURE 5.19

Water Quality Status at Different Tide Stages

Mean of Data for 1985
June-August Ammonia Nitrogen Profiles

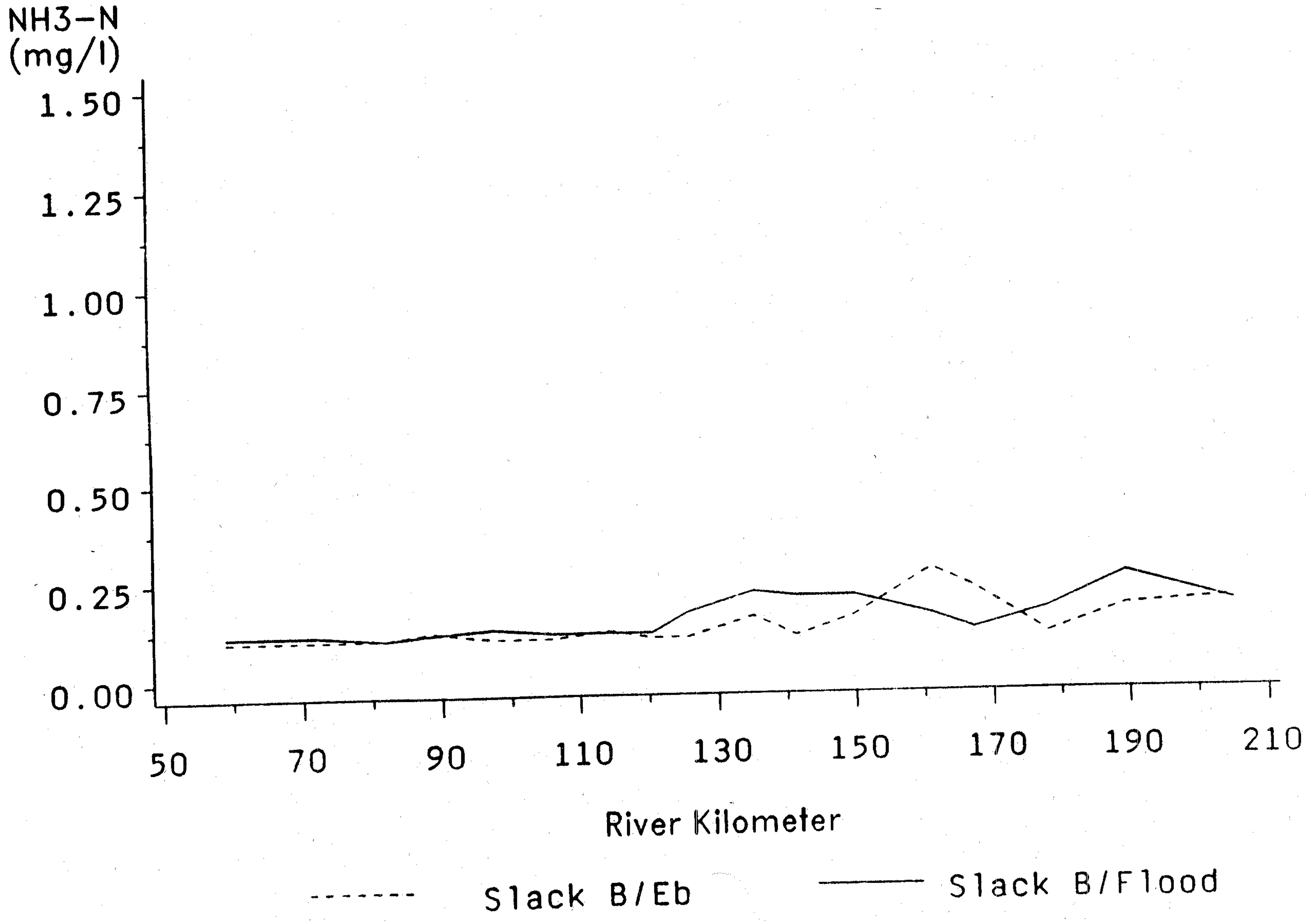


FIGURE 5.20

Water Quality Status at Different Tide Stages

Mean of Data for 1985
June-August Nitrate Nitrogen Profiles

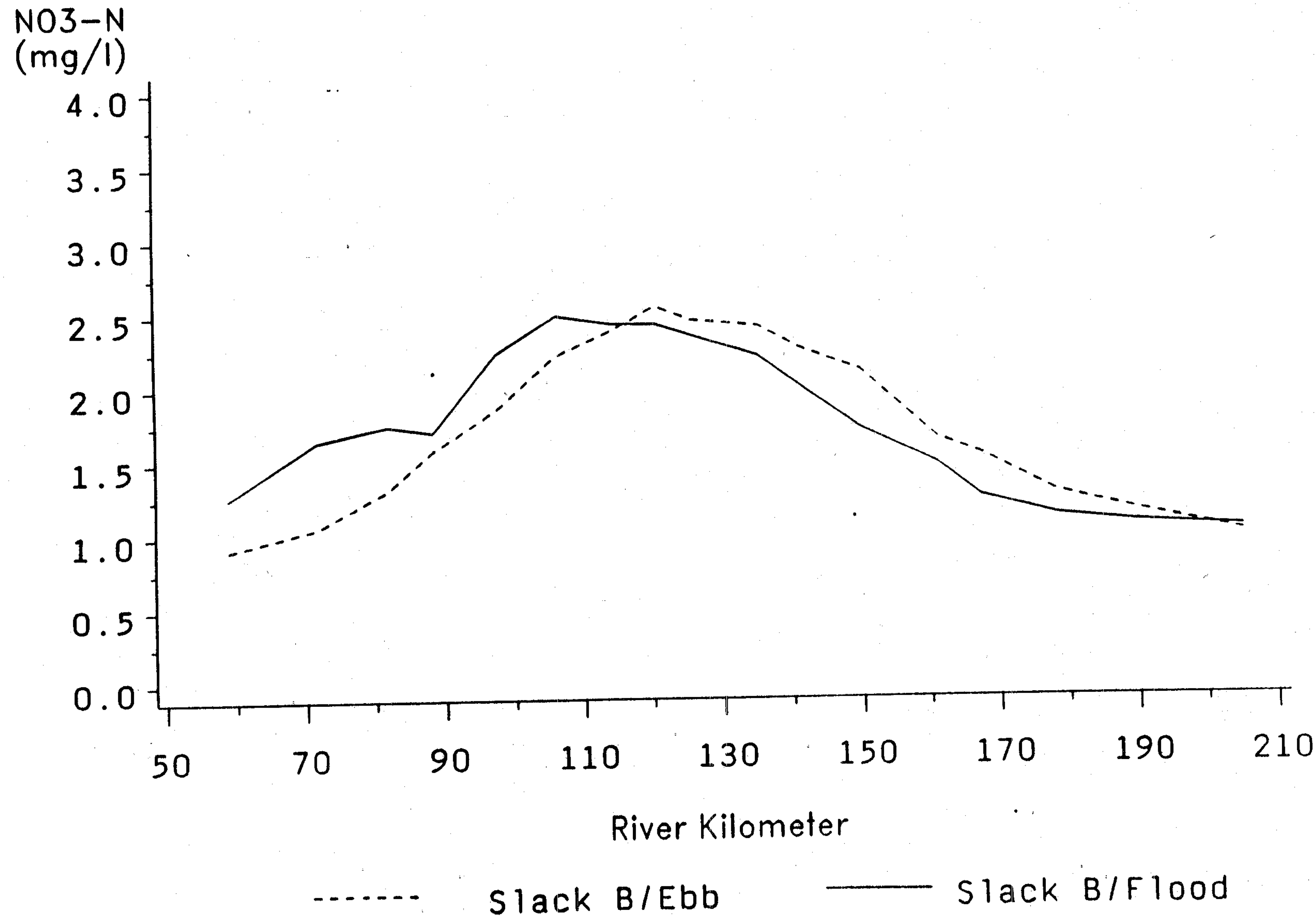


FIGURE 5.21

Water Quality Status at Different Tide Stages

Mean of Data for 1985
June-August Total Nitrogen Profiles

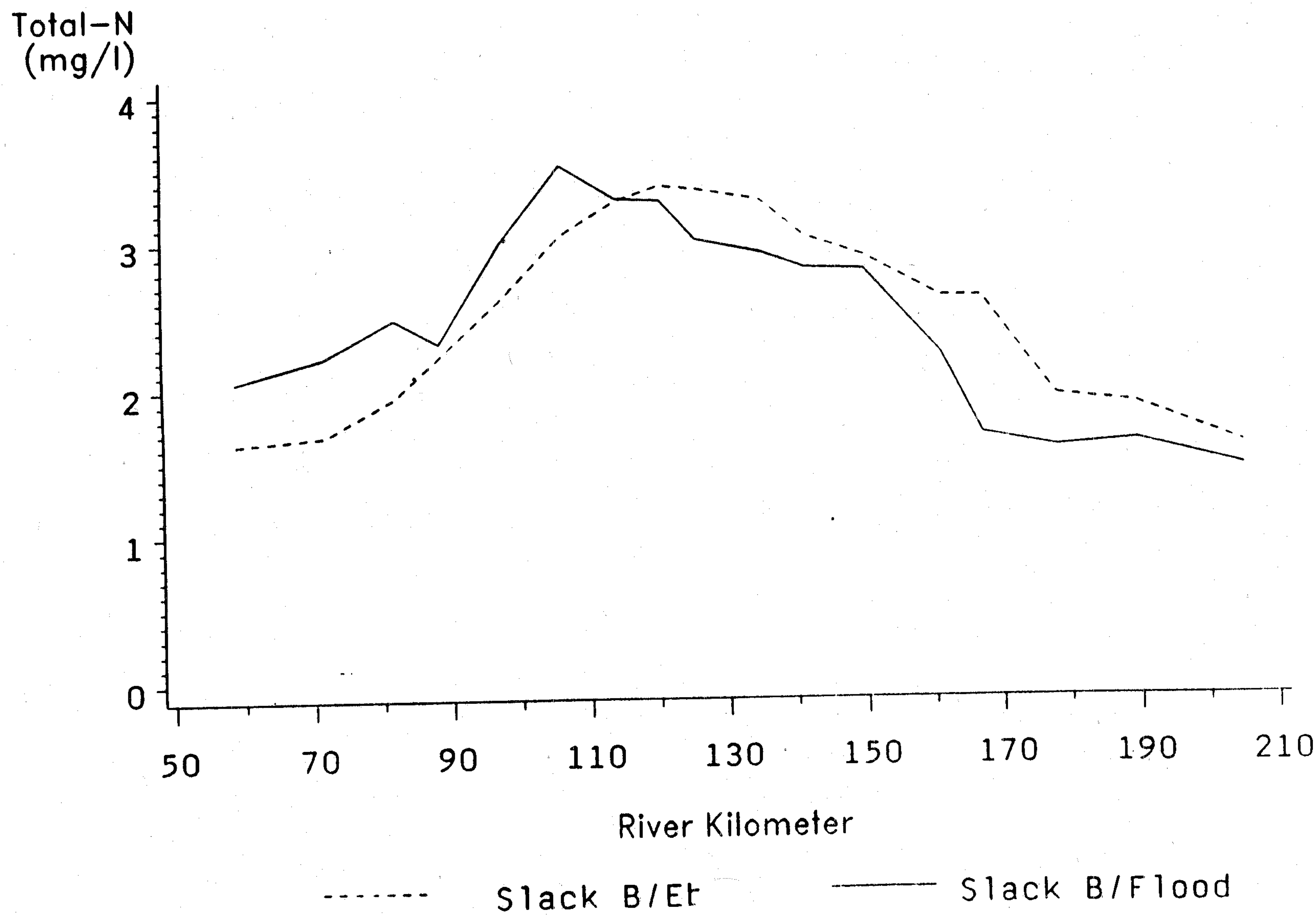


FIGURE 5.22

Water Quality Status at Different Tide Stages

Mean of Data for 1985
June-August Total Phosphorus Profiles

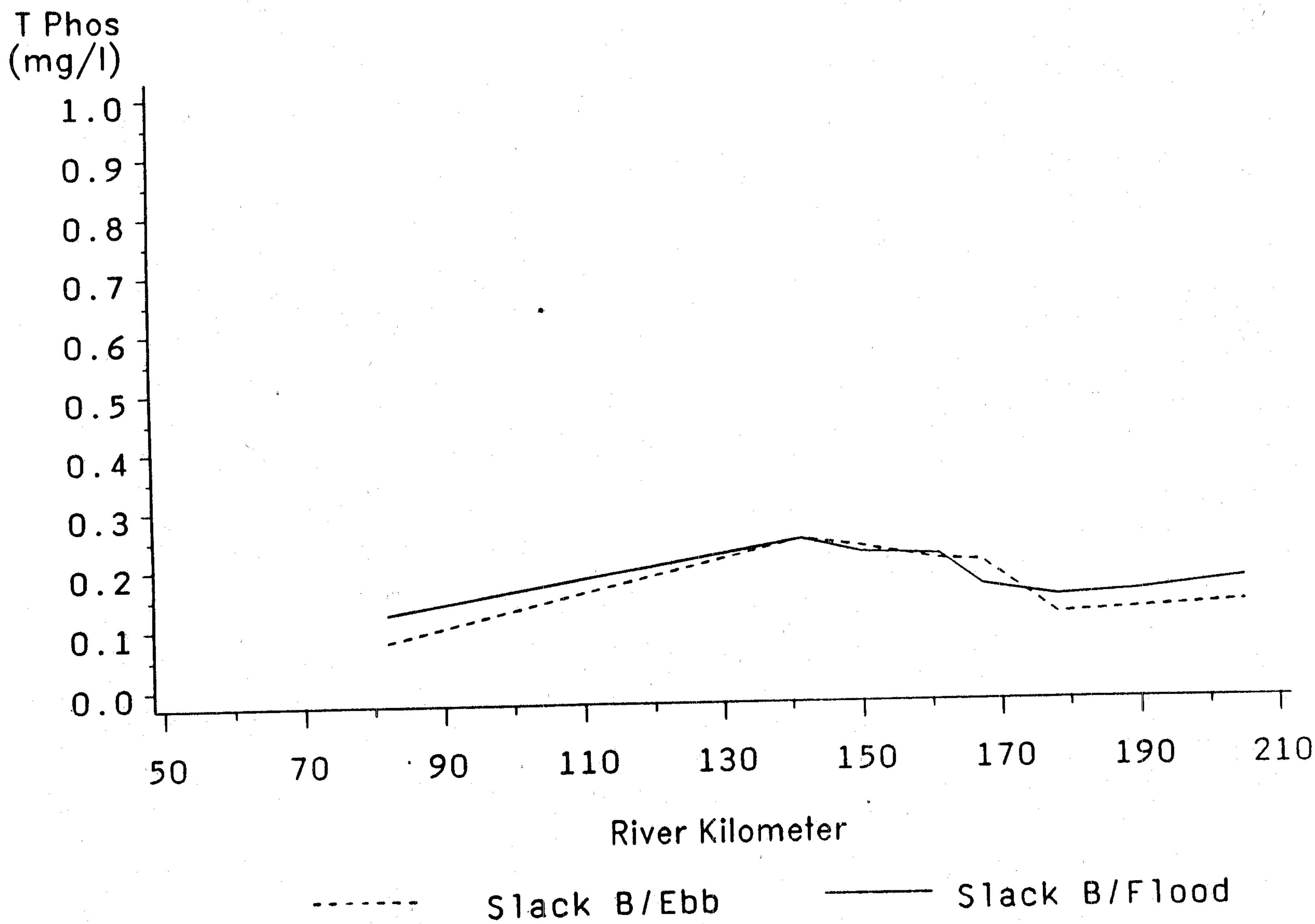
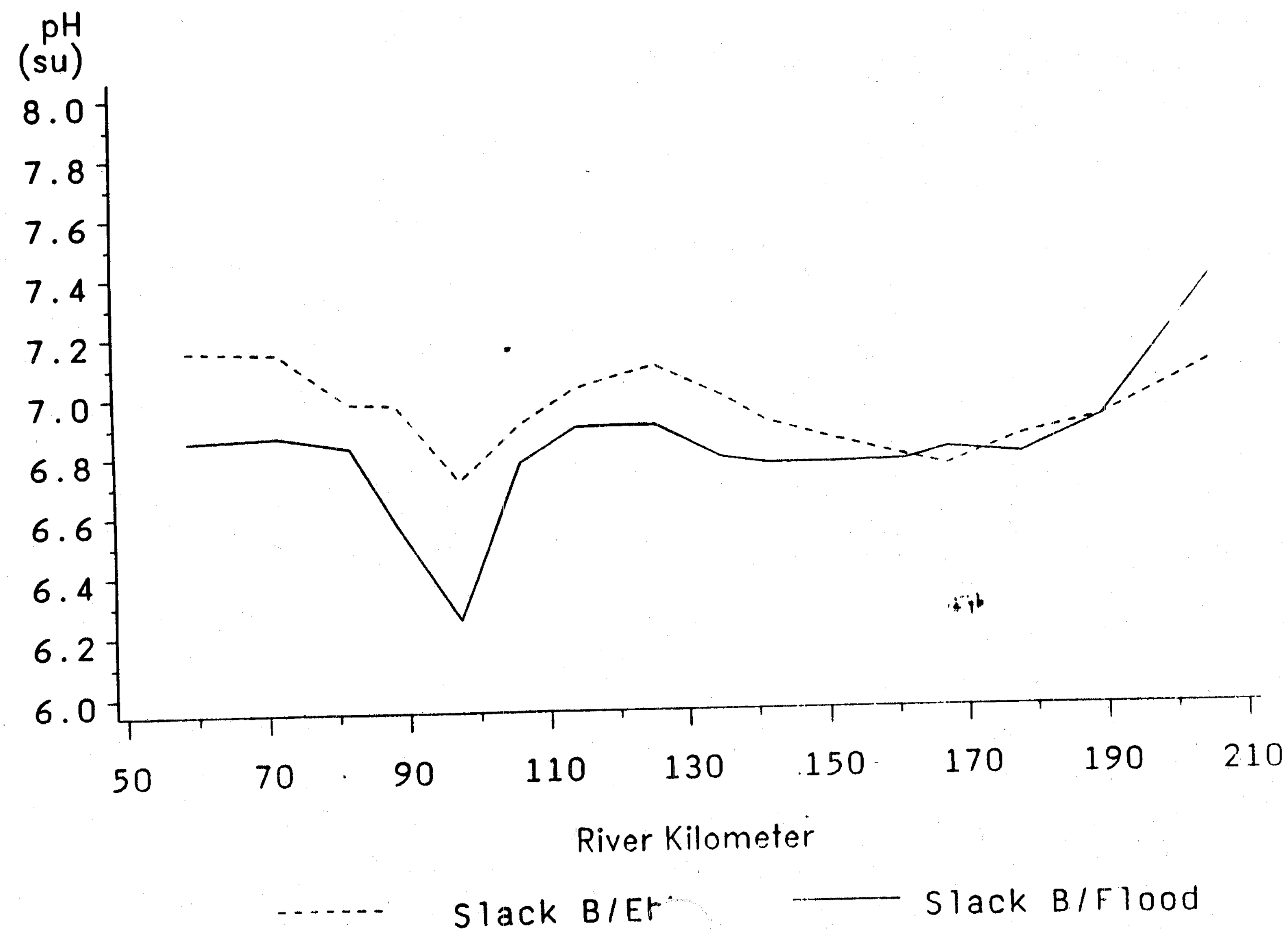


FIGURE 5.23

Water Quality Status at Different Tide Stages

Mean of Data for 1985
June-August pH Profiles



IGURE 5.24

Water Quality Status at Different Tide Stages

Mean of Data for 1985
June-August Salinity Profiles

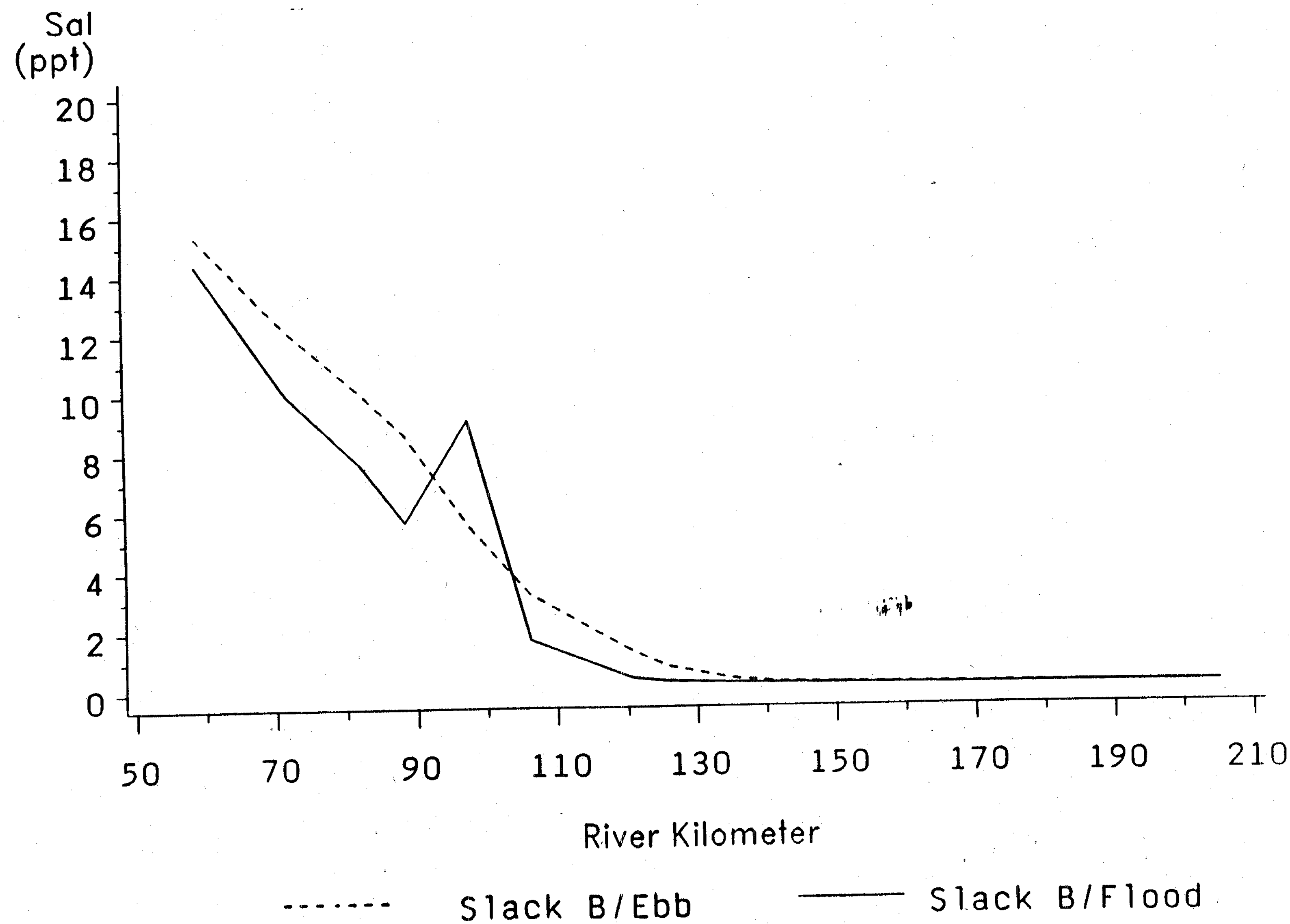


FIGURE 5.25

Water Quality Status at Different Tide Stages

Mean of Data for 1985

June-August Temperature Profiles

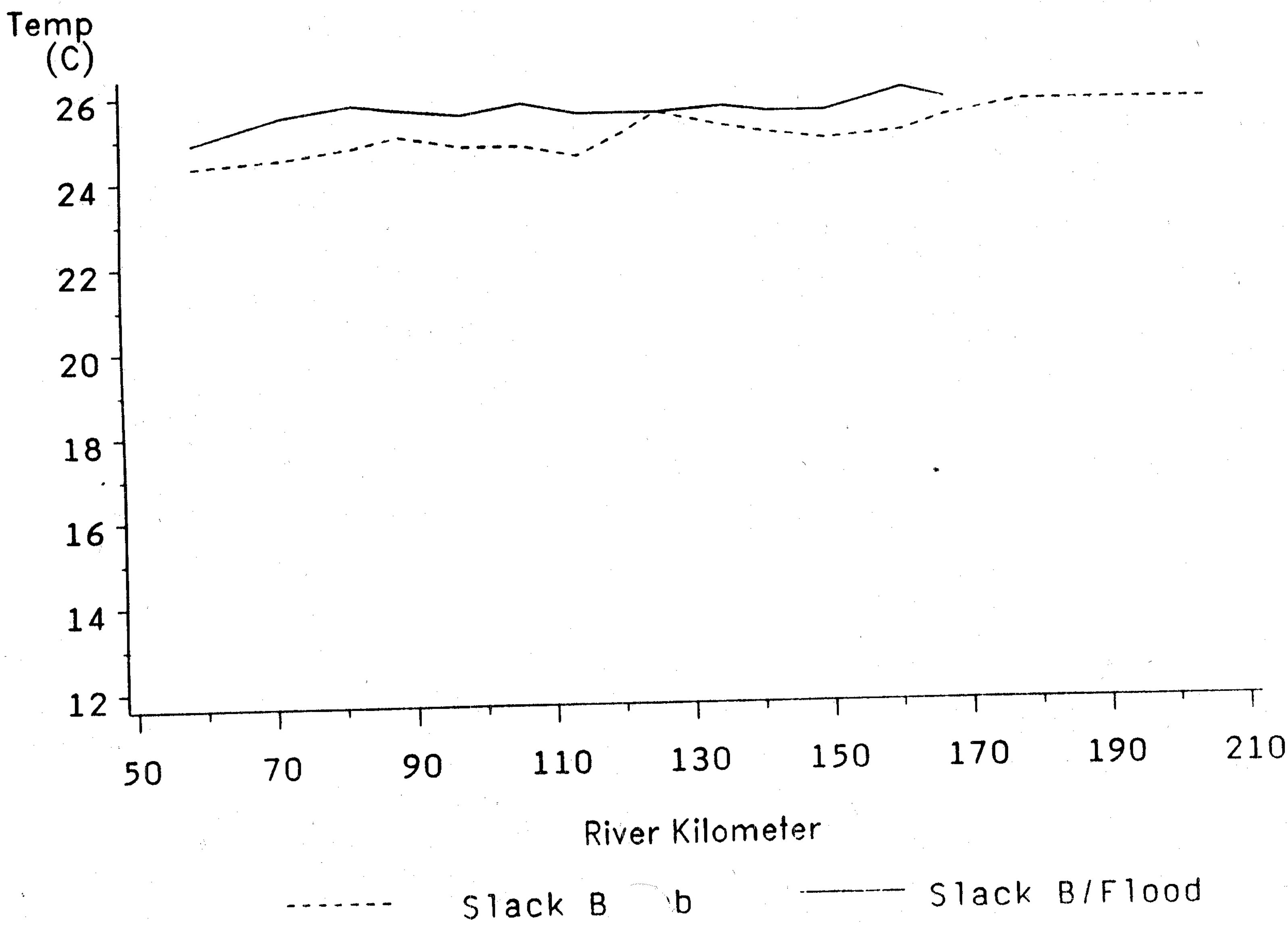


FIGURE 5.26

Water Quality Status at Different Tide Stages

Mean of Data for 1985
June-August BOD5 Profiles

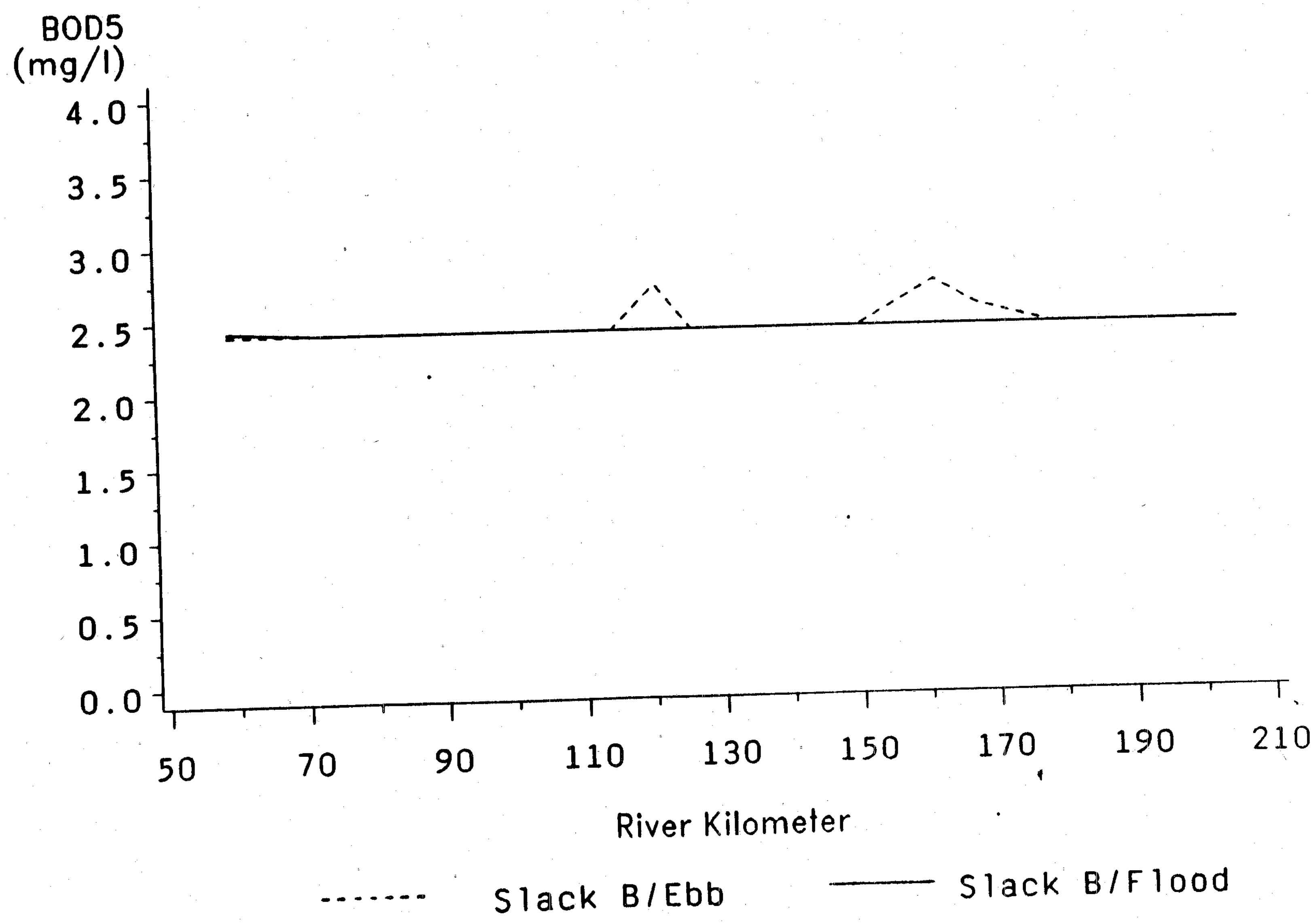


FIGURE 5.27

Water Quality Status at Different Tide Stages

Mean of Data for 1985
June-August Dissolved Oxygen Profiles

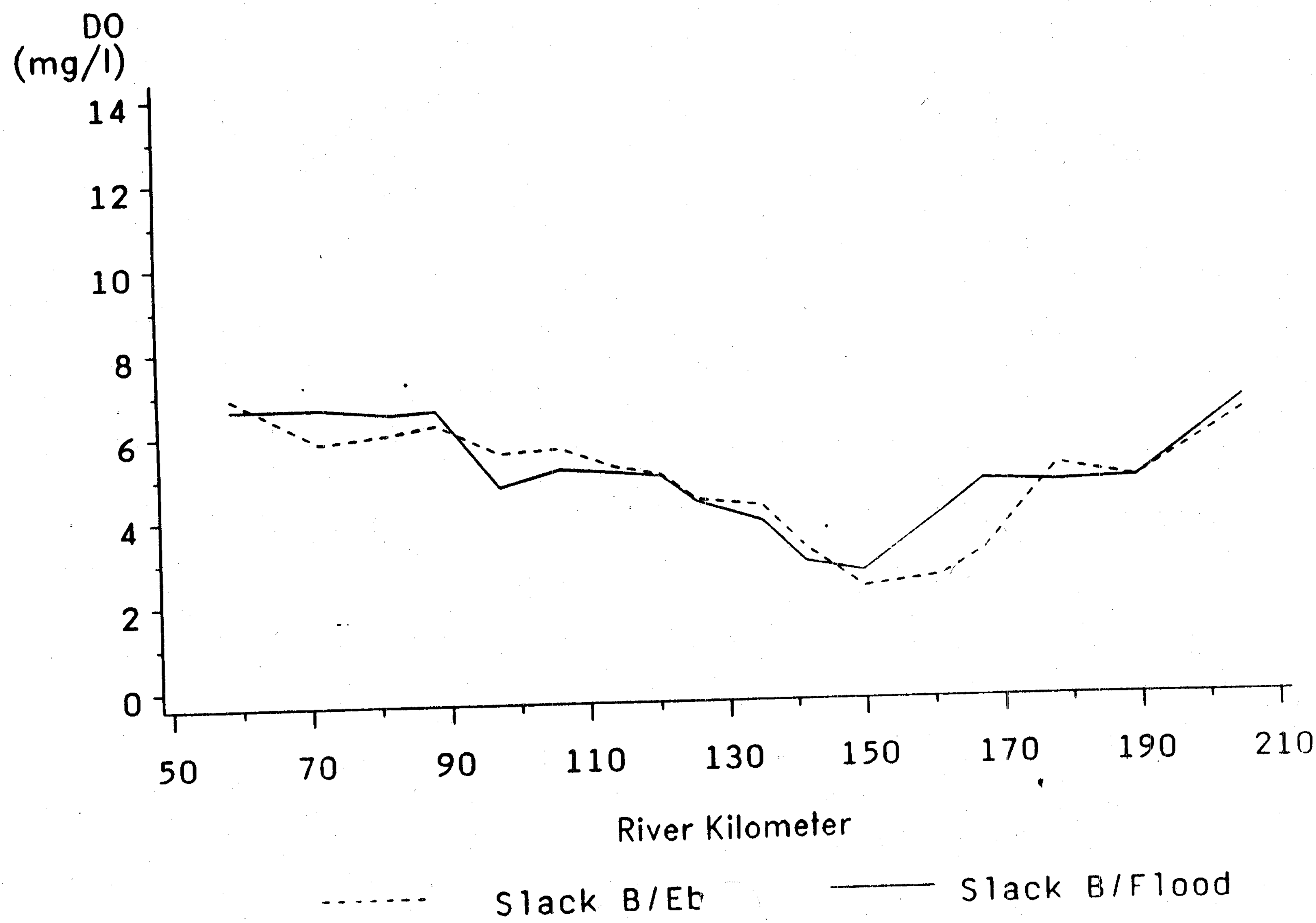


FIGURE 5.28

Water Quality Status at Different Tide Stages

Geometric Mean of Data for 1985
June-August Fecal Coliform Profiles

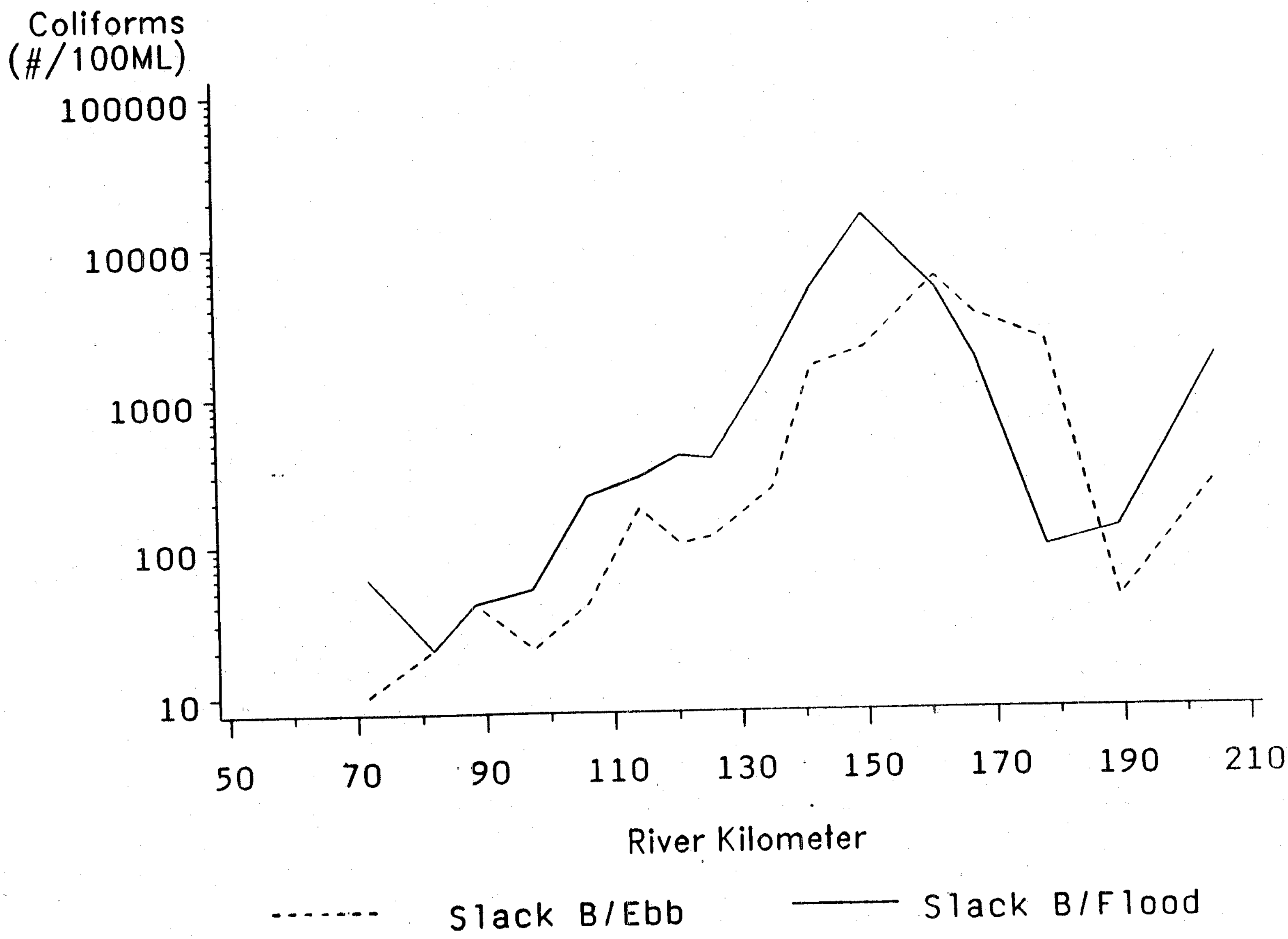


FIGURE 5.29

1988–1990 Water Quality Status

Mean of Data for Summer and Winter Seasons
Salinity Profiles

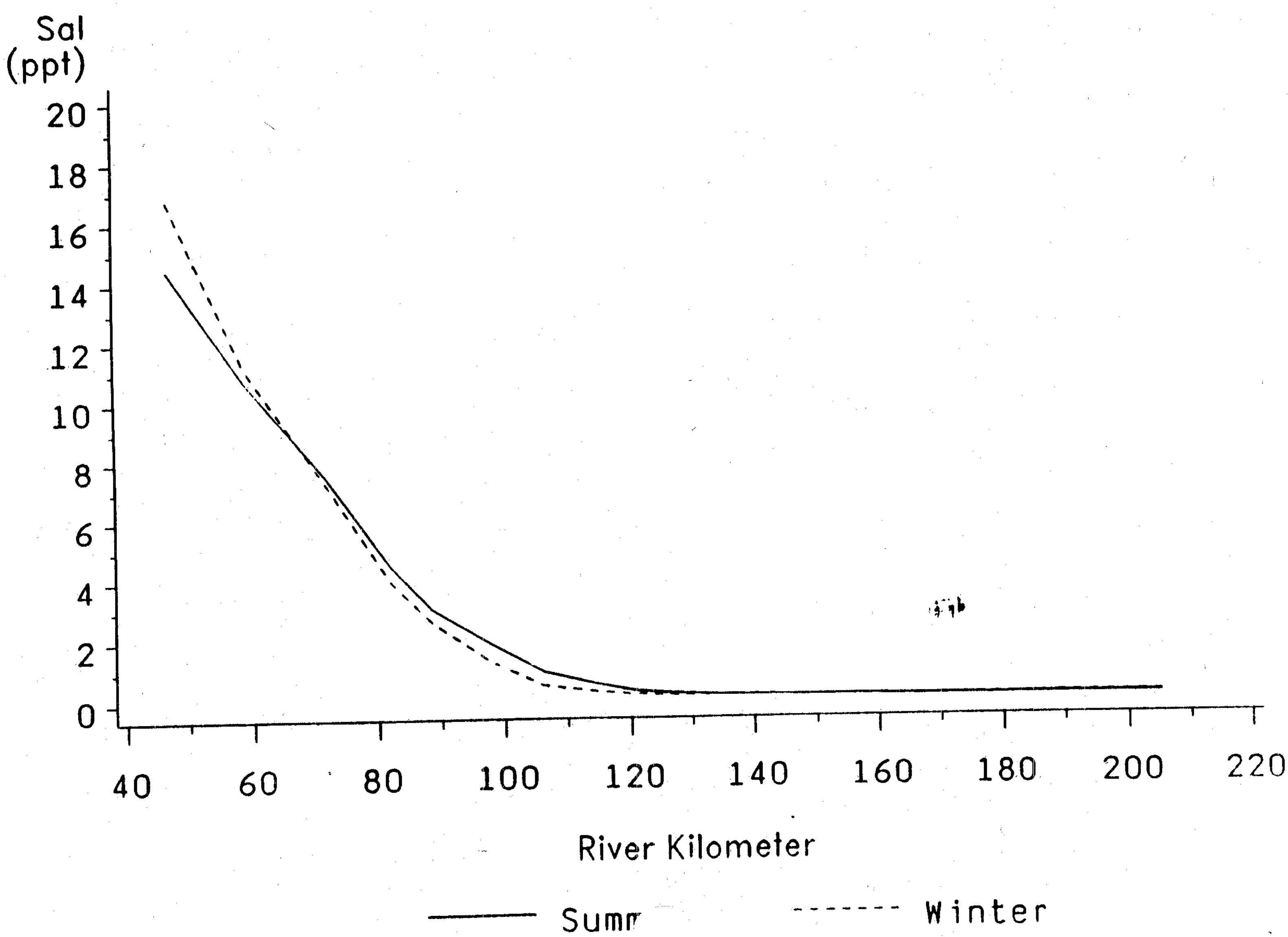


FIGURE 5.30

1988–1990 Water Quality Status

Mean of Data for Summer and Winter Seasons
Turbidity Profiles

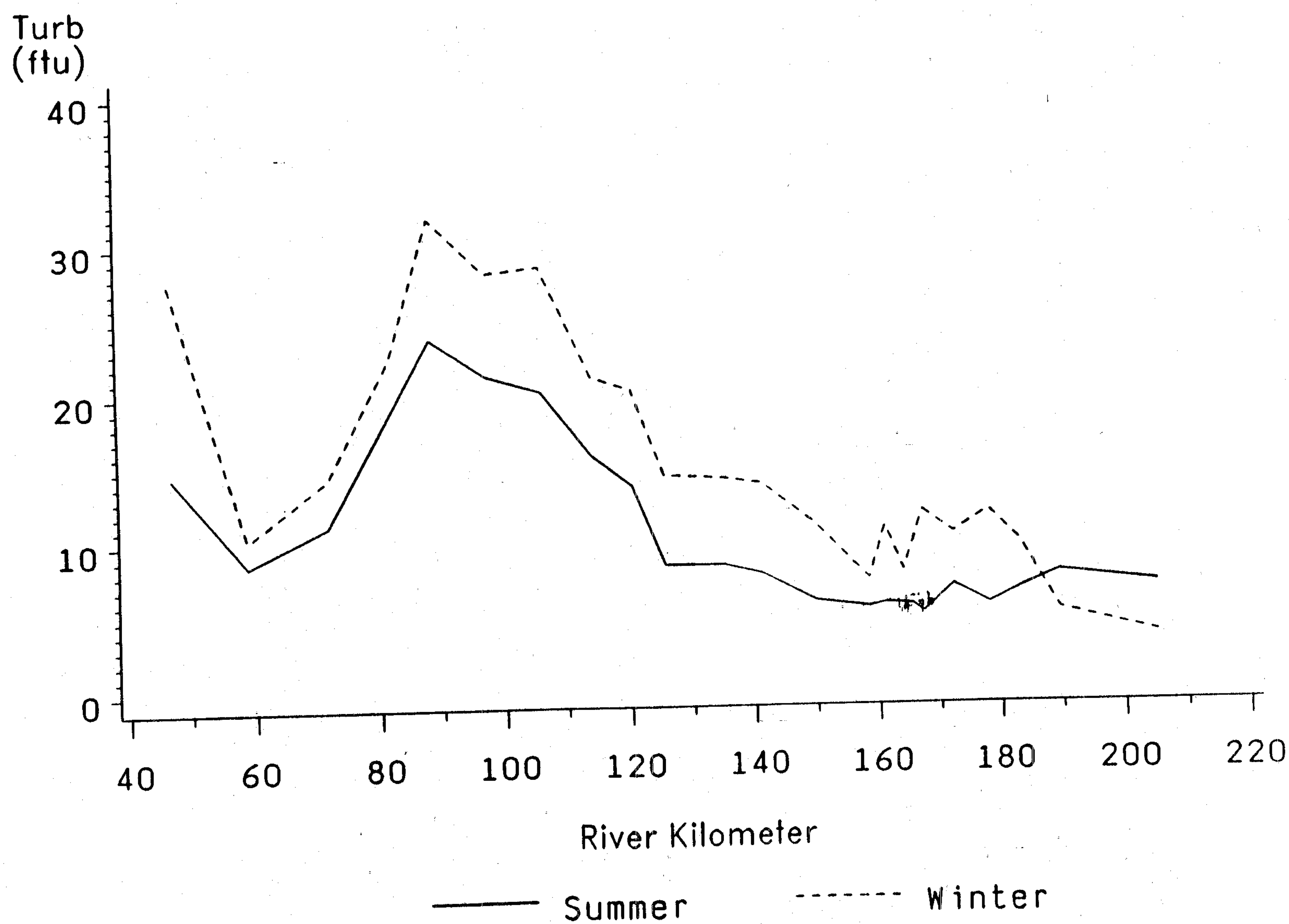


FIGURE 5.31

1988–1990 Water Quality Status

Mean of Data for Summer and Winter Seasons
Temperature Profiles

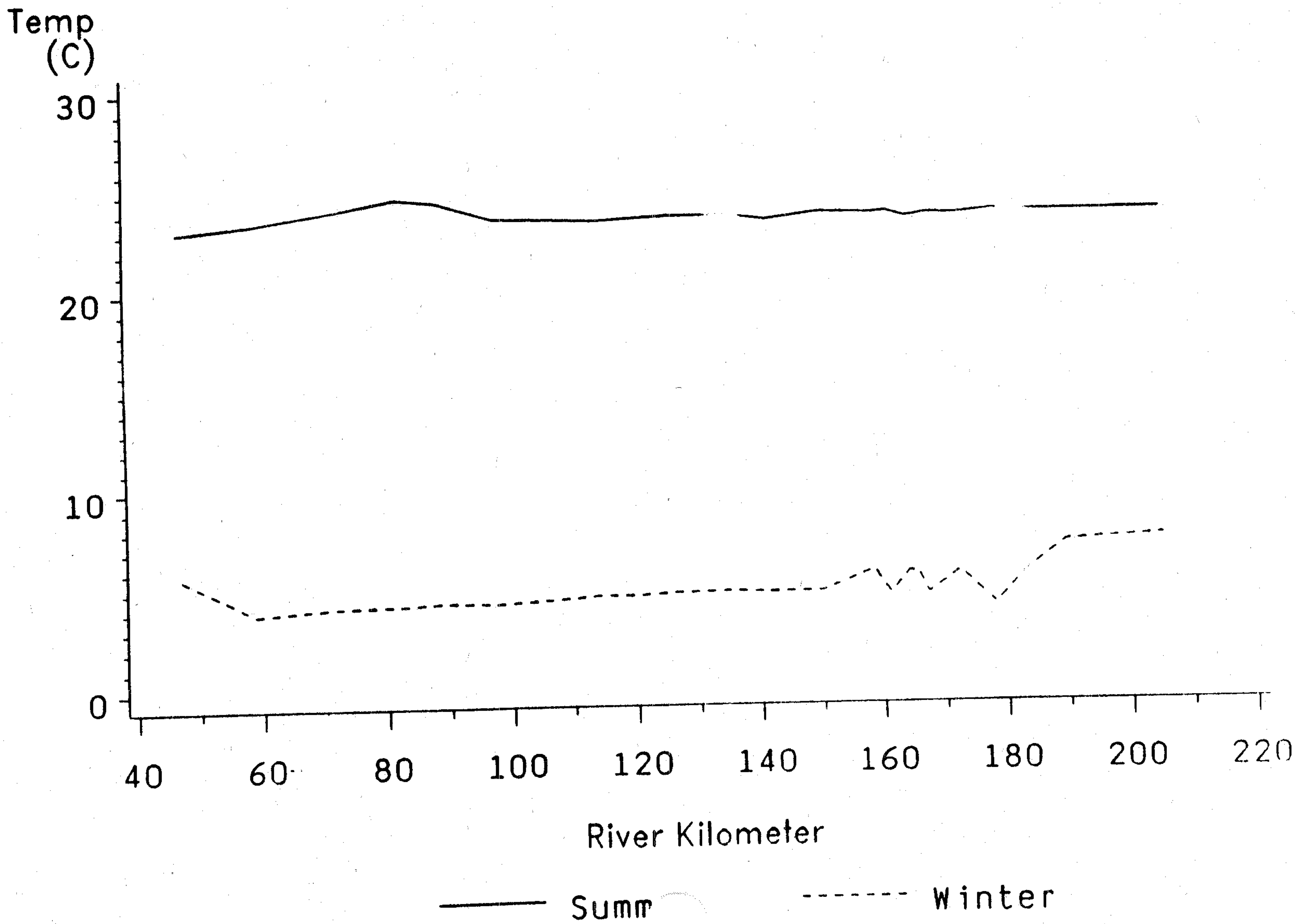


FIGURE 5.32

1988–1990 Water Quality Status

Mean of Data for Summer and Winter Seasons
pH Profiles

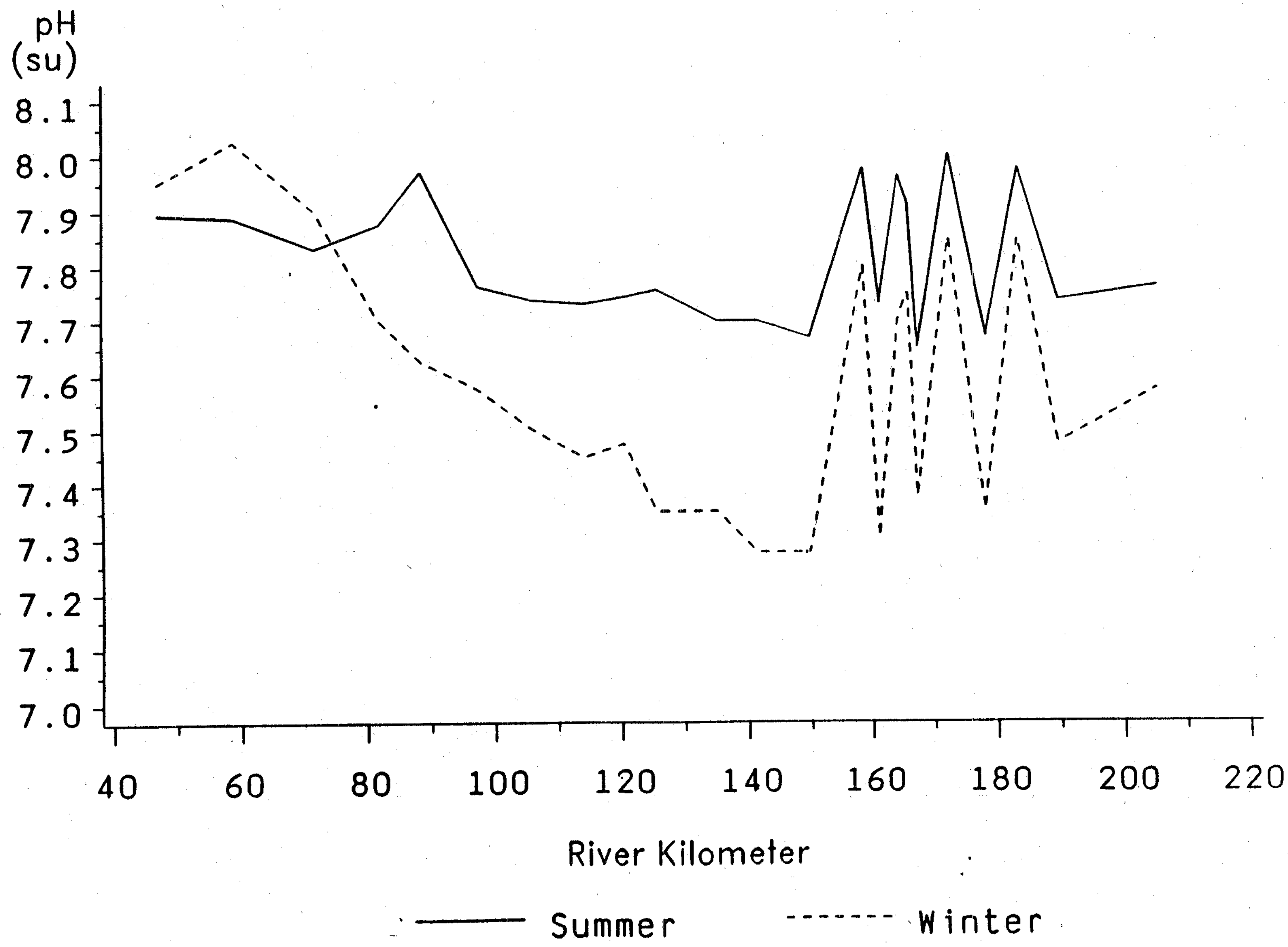


FIGURE 5.33

1988–1990 Water Quality Status

Mean of Data for Summer and Winter Seasons
BOD5 Profiles

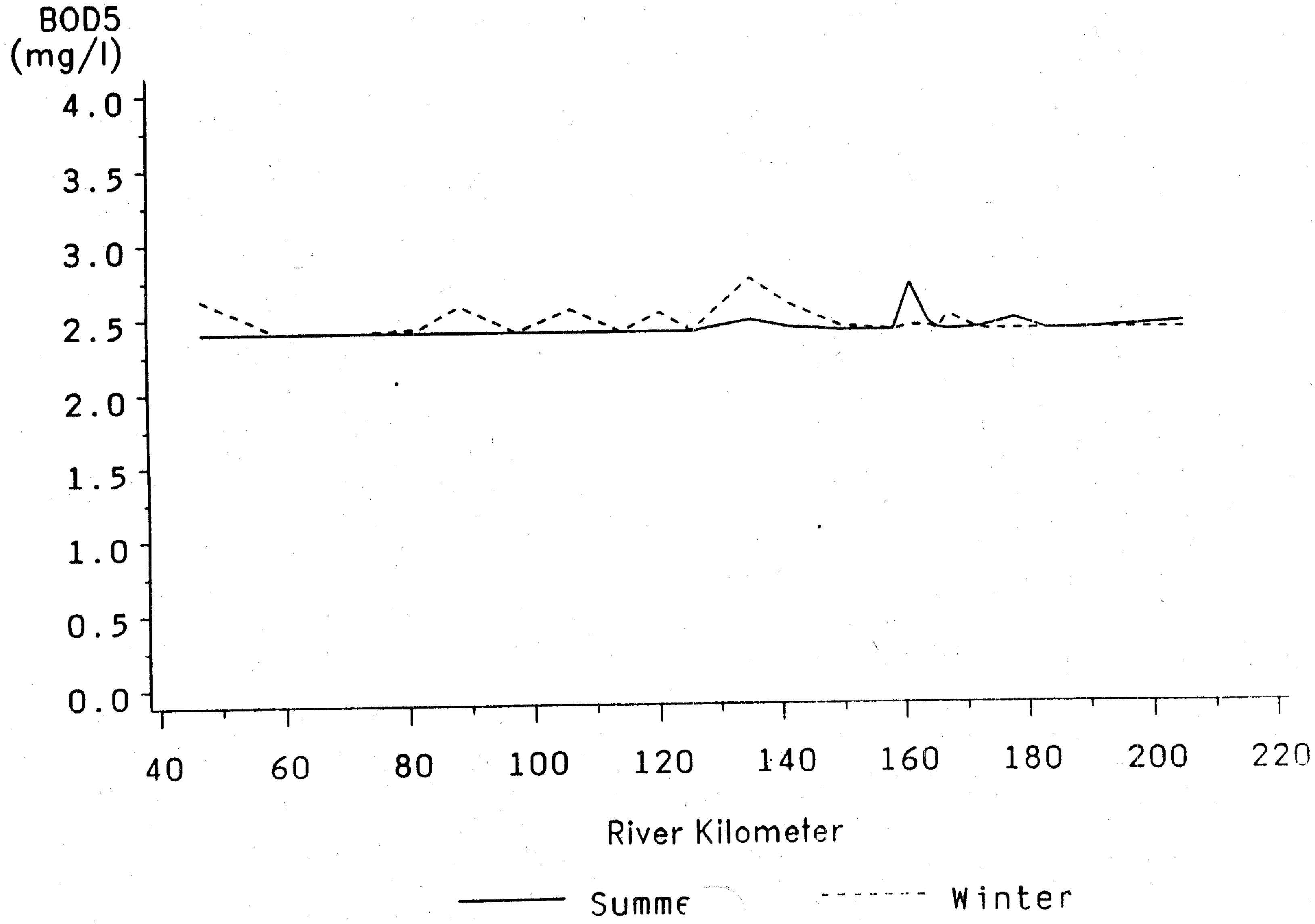


FIGURE 5.34

1988–1990 Water Quality Status

Mean of Data for Summer and Winter Seasons
Total Phosphorus Profiles

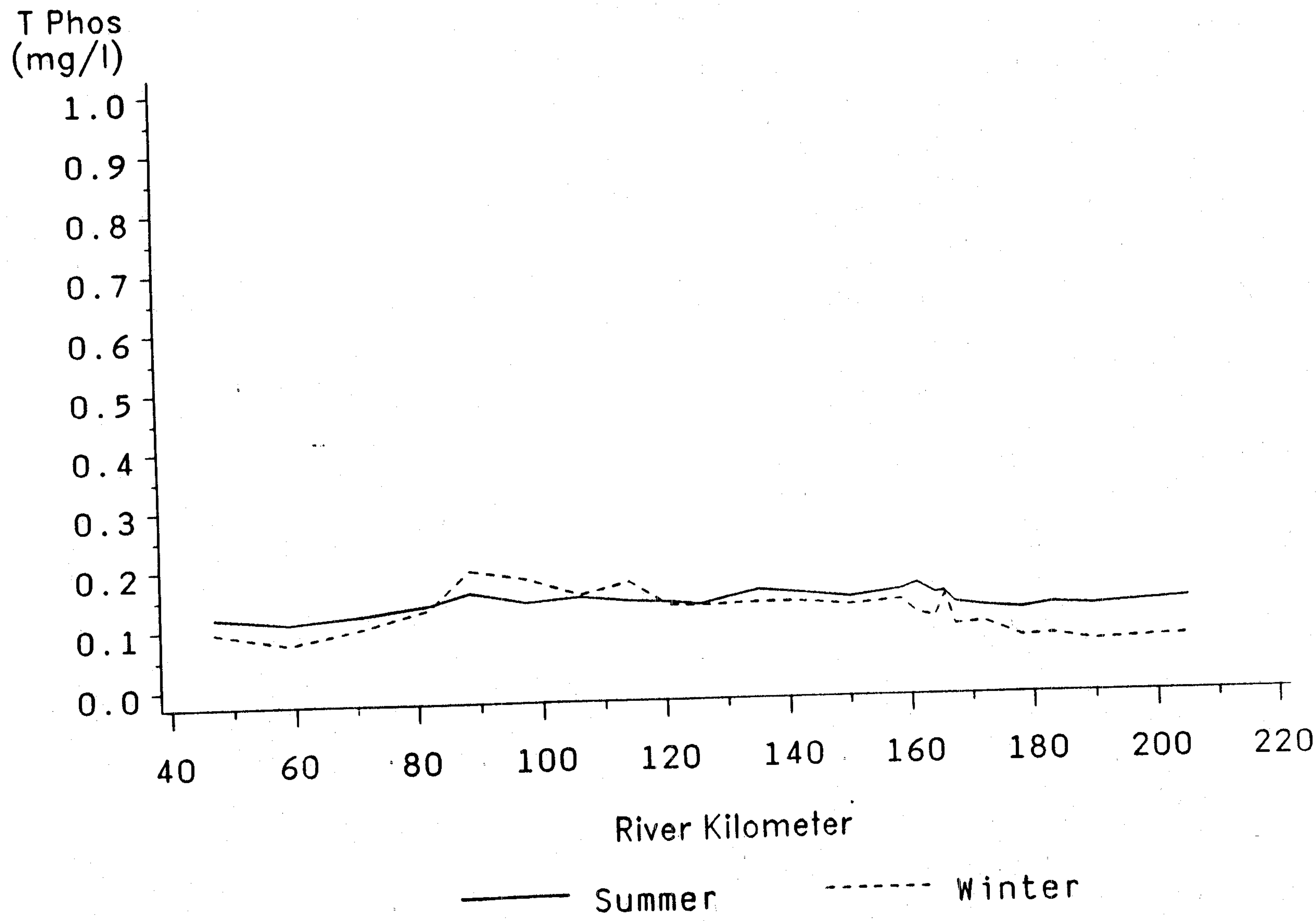


FIGURE 5.35

1988–1990 Water Quality Status

Mean of Data for Summer and Winter Seasons
Ammonia Nitrogen Profiles

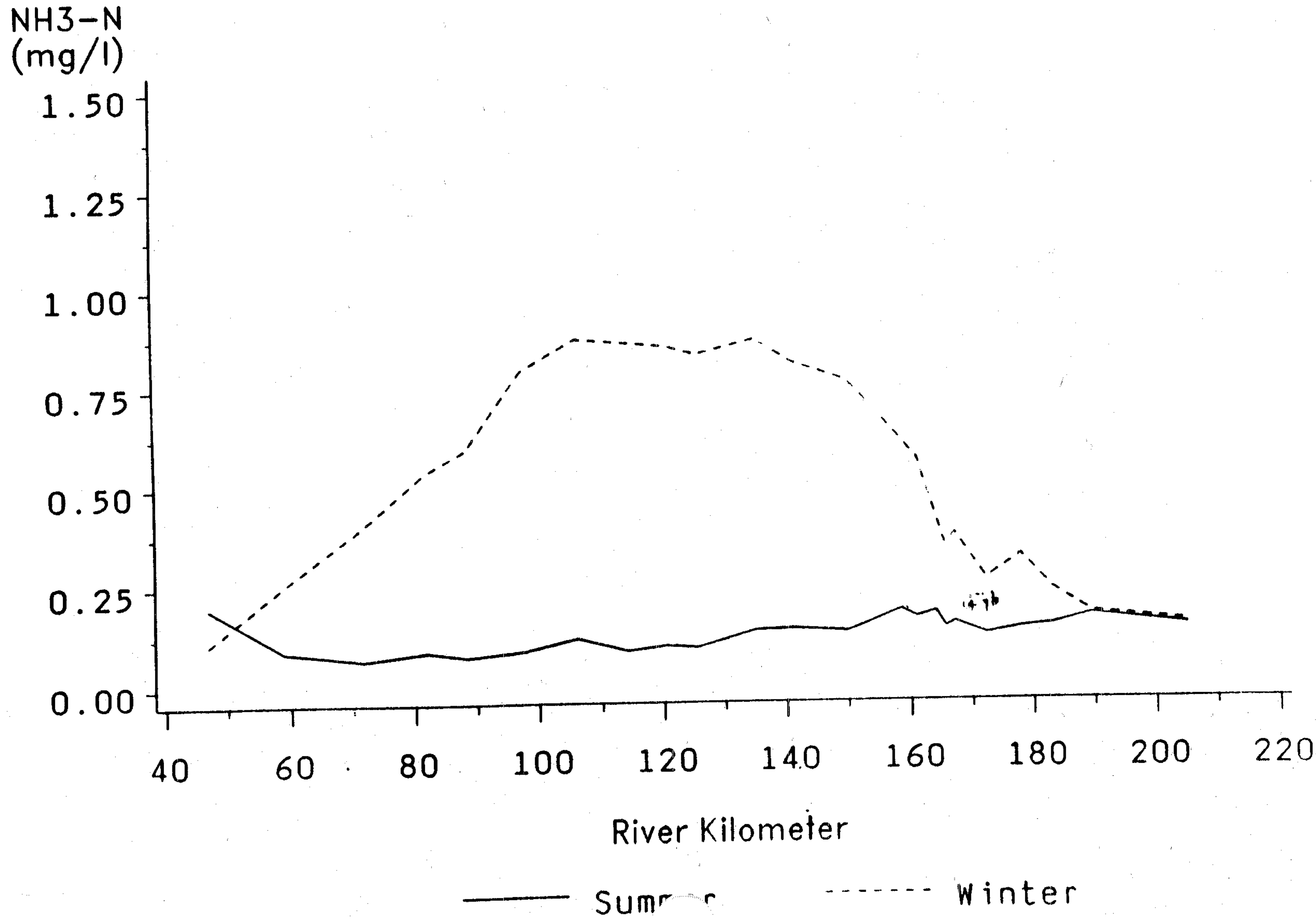


FIGURE 5.36

1988–1990 Water Quality Status

Mean of Data for Summer and Winter Seasons
Nitrate Nitrogen Profiles

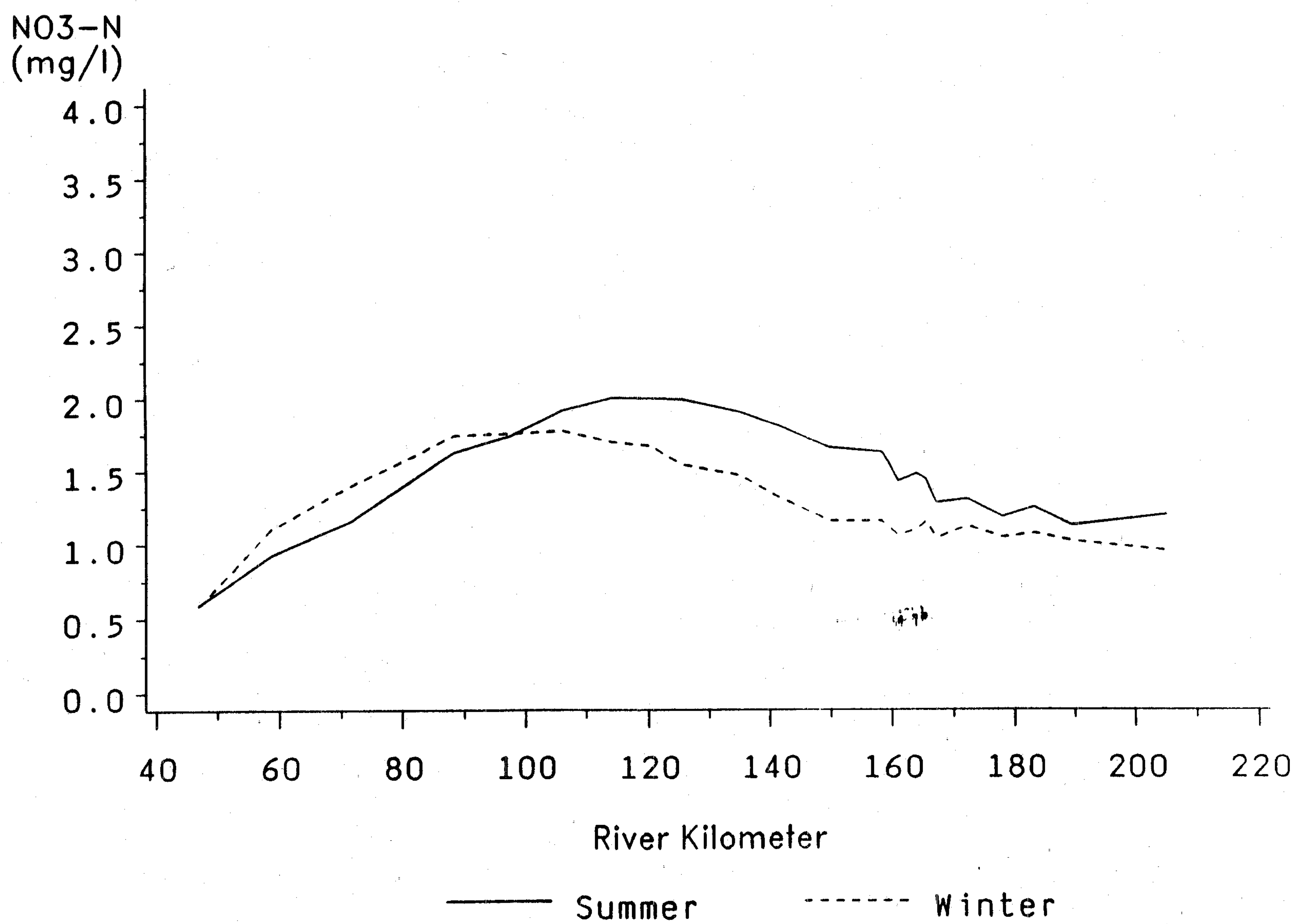


FIGURE 5.37

1988–1990 Water Quality Status

Mean of Data for Summer and Winter Seasons
Total Nitrogen Profiles

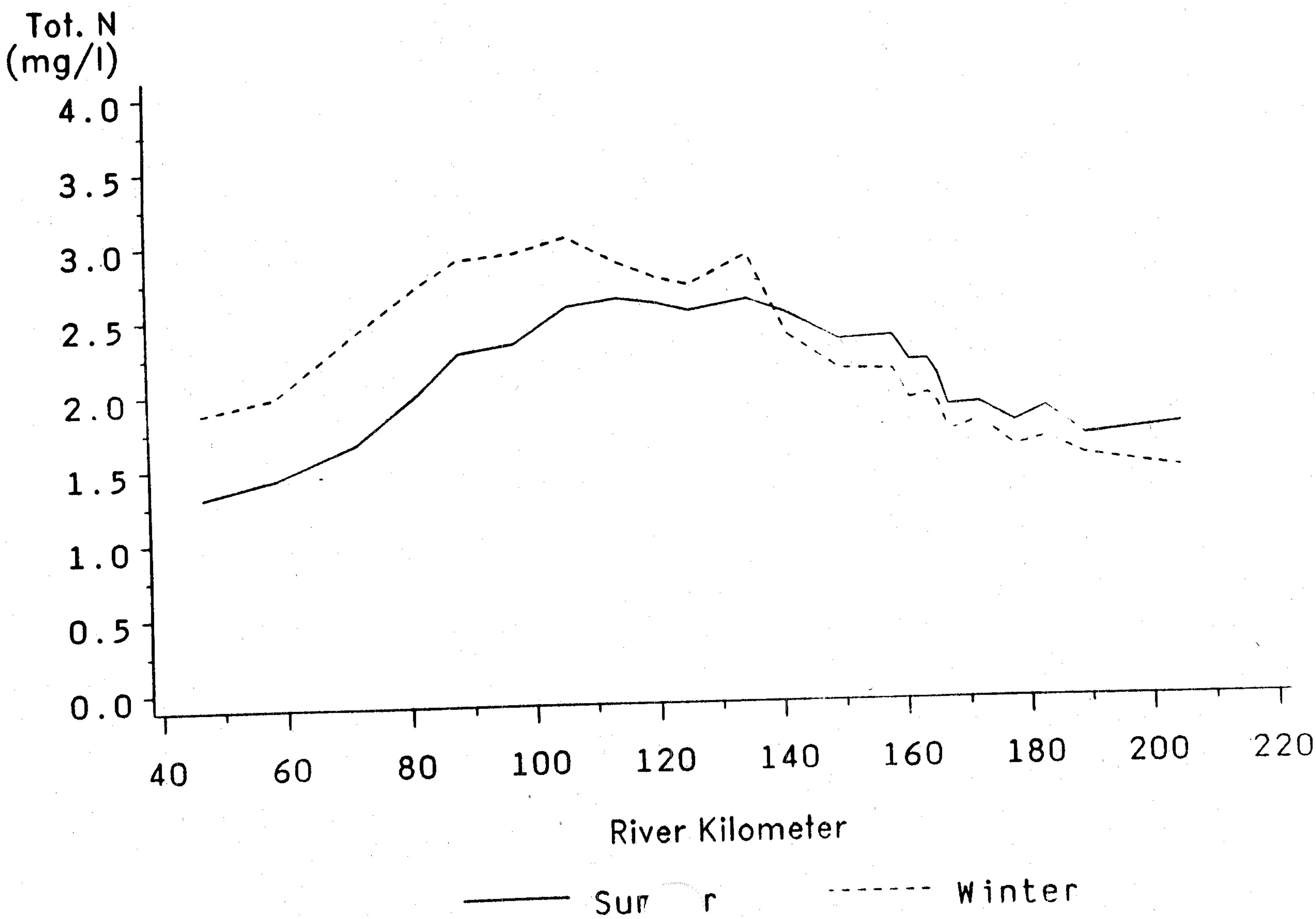


FIGURE 5.38

1988–1990 Water Quality Status

Mean of Data for Summer and Winter Seasons
Dissolved Oxygen Profiles

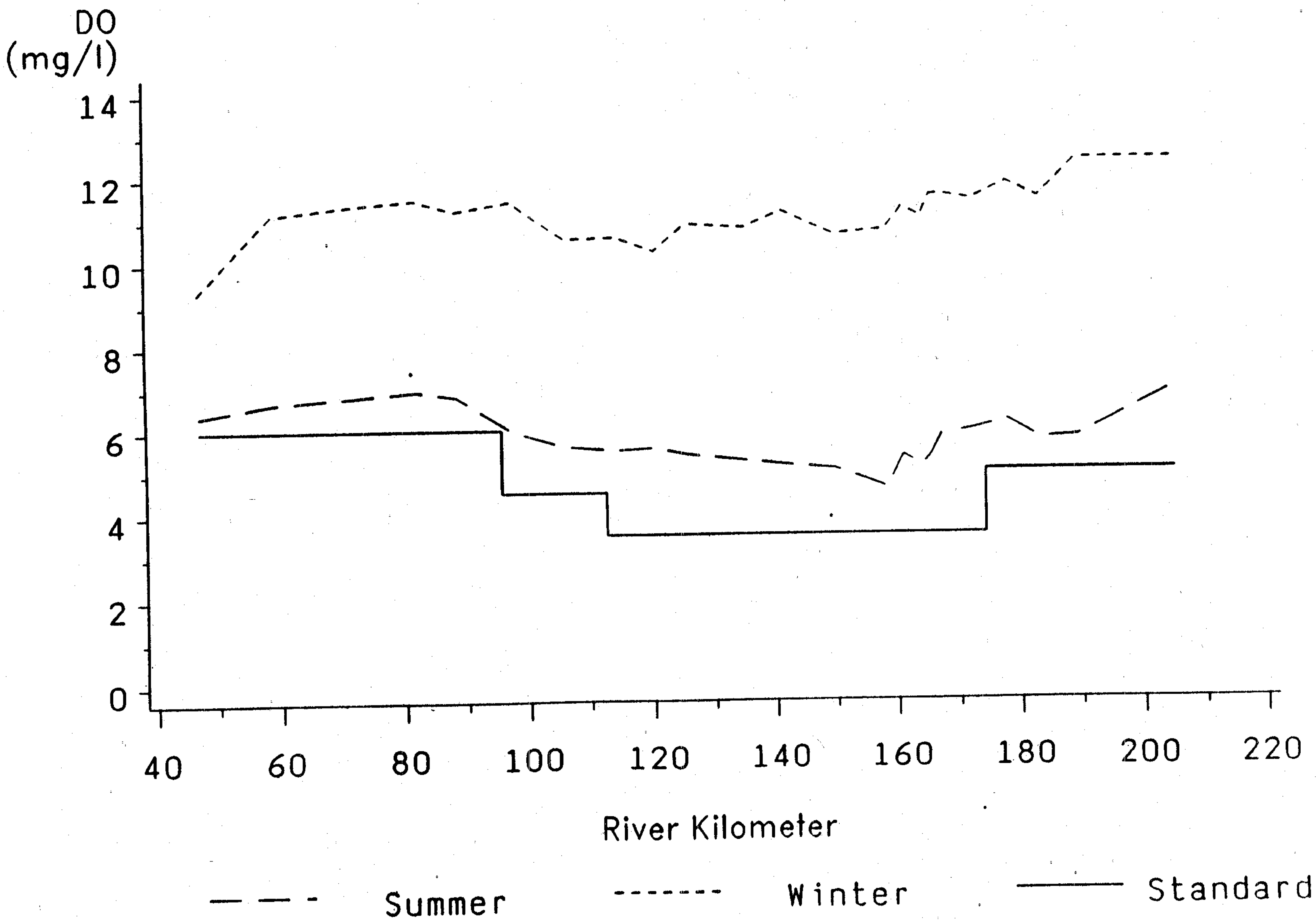


FIGURE 5.39

1988-1990 Water Quality Status

Geometric Mean of Data for Summer and Winter Seasons
Fecal Coliform Profiles

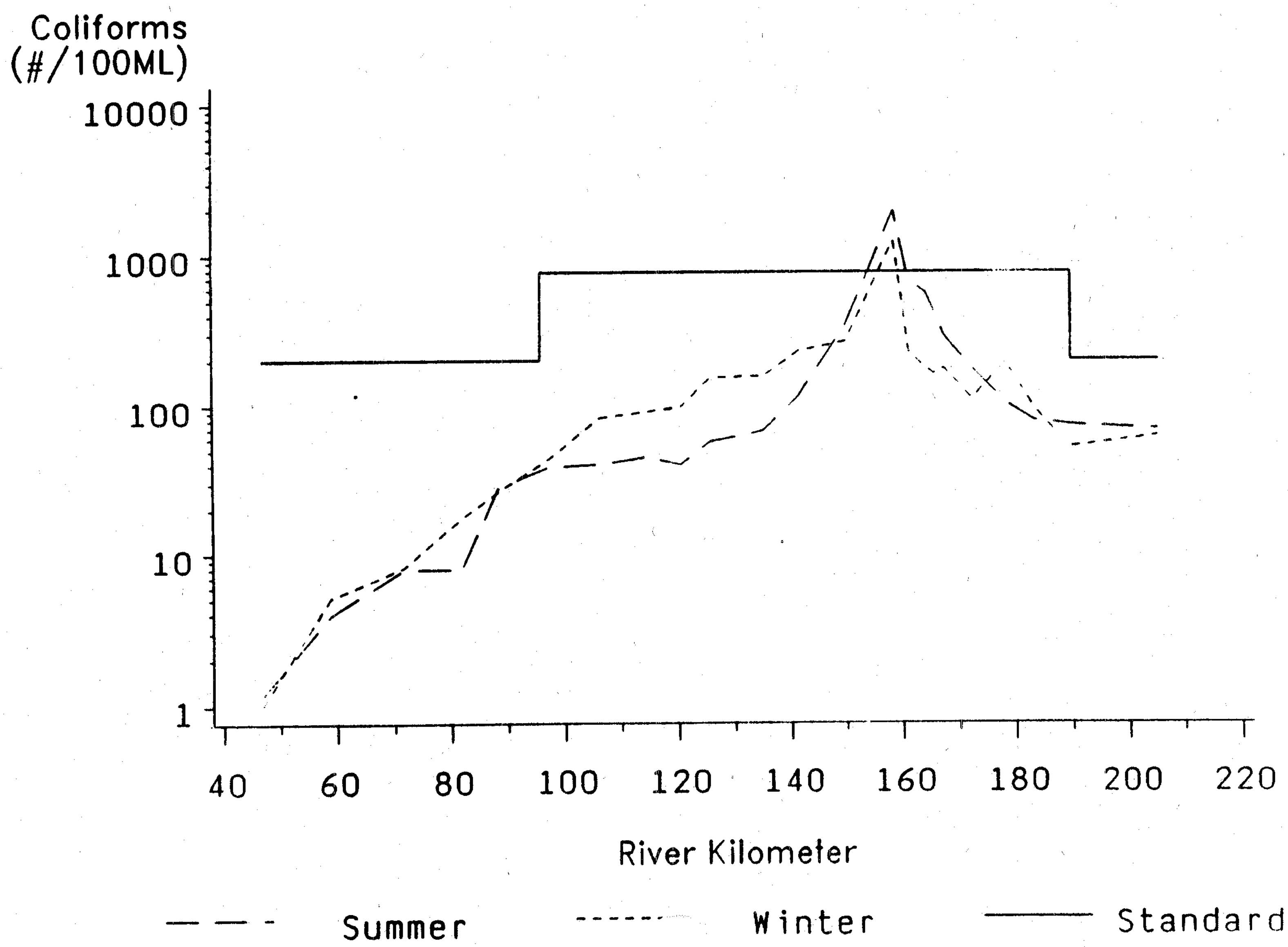


FIGURE 6.1

Delaware River at Torresdale, PA (RK 178.12)

Historic Data Analysis - Dissolved Oxygen
Minimum Annual DO Concentrations

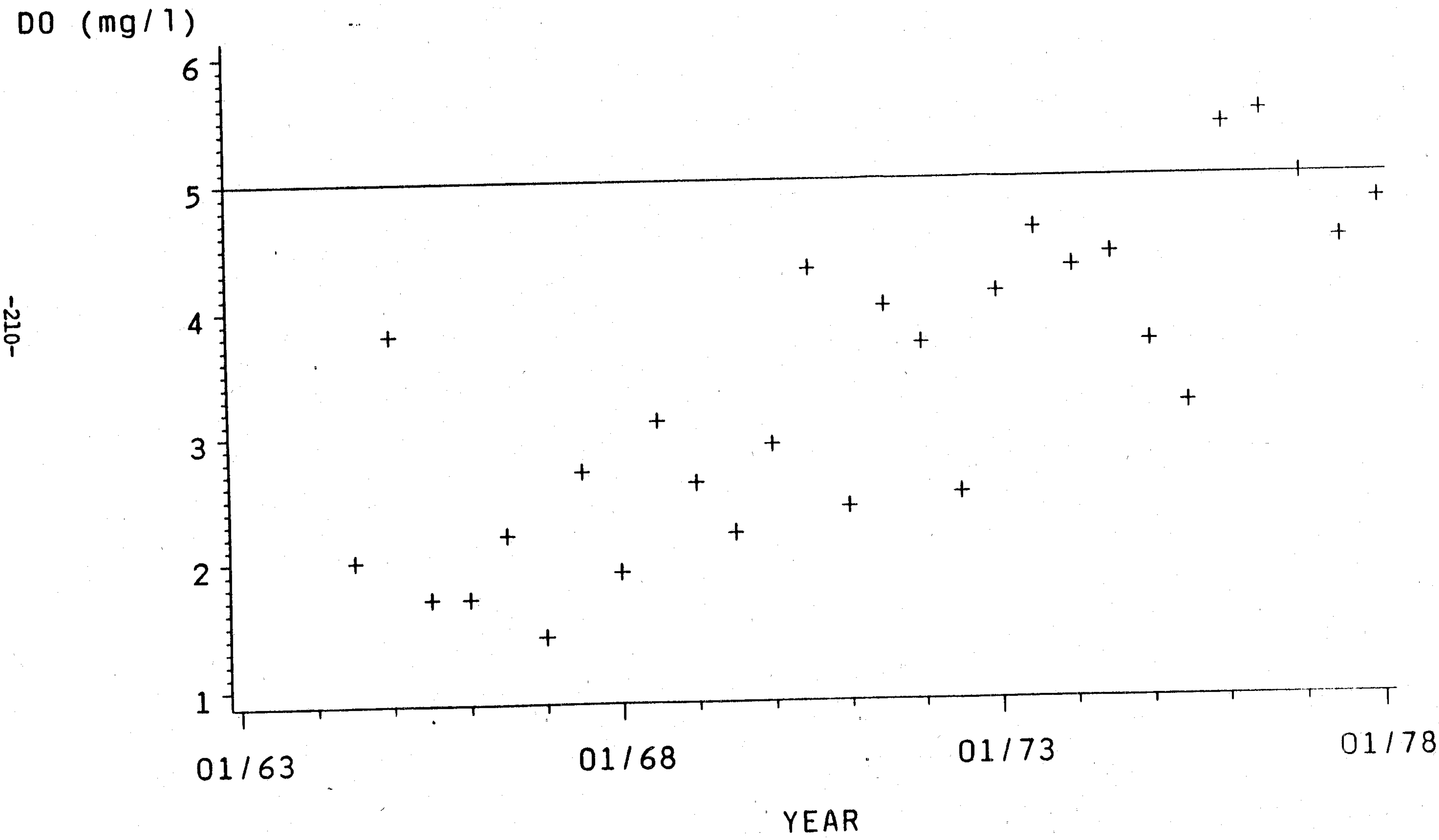


FIGURE 6.2

Delaware River at Navy Yard, Phila. (RK 149.93)

Historic Data Analysis - Dissolved Oxygen
Minimum Annual DO Concentrations

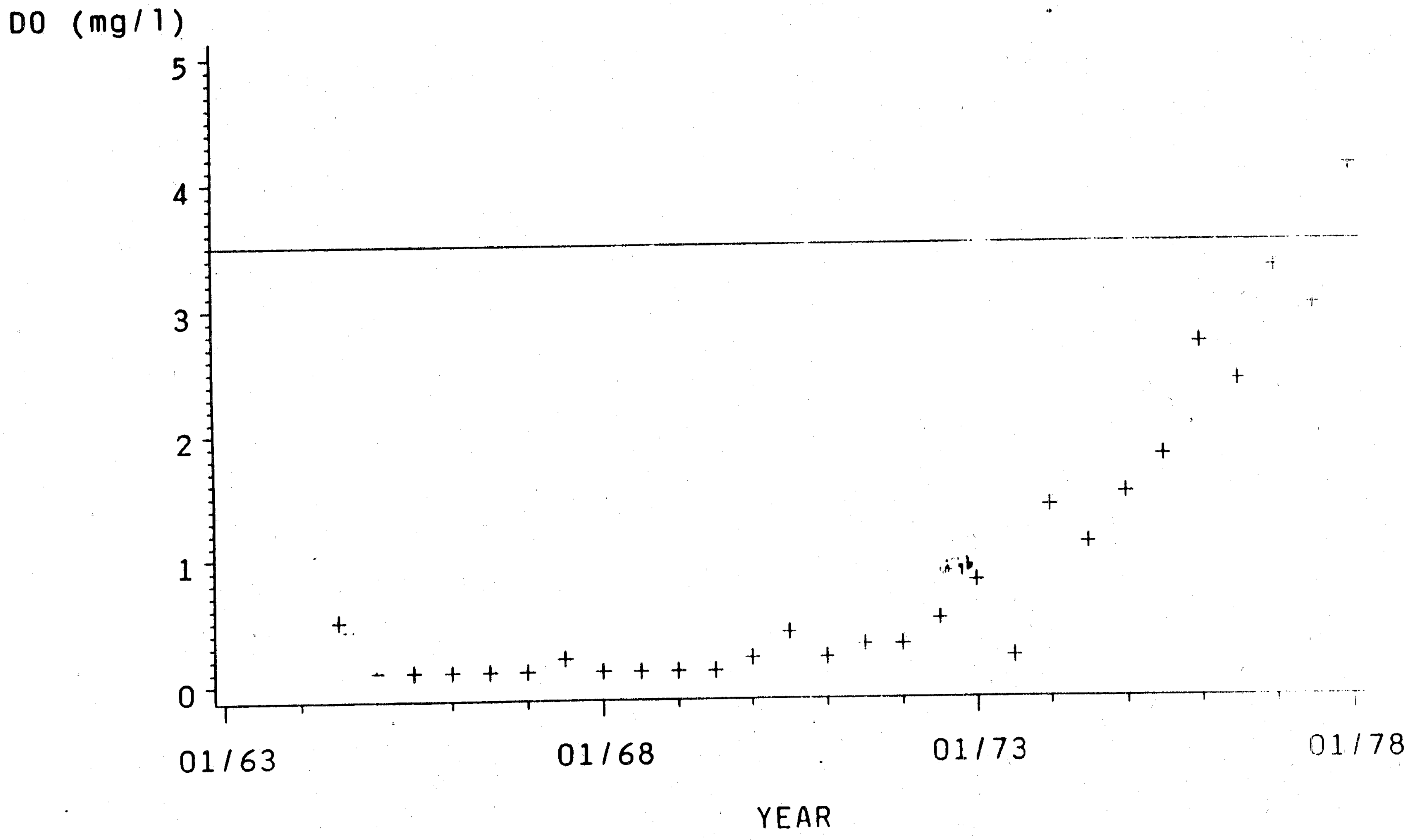


FIGURE 6.3

Delaware River at Navy Yard, Phila. (RK 149.93)

Historic Data Analysis - Dissolved Oxygen
Agency=DRBC Station=892065 AND
Agency=PHILWDPT Station=Del- 4

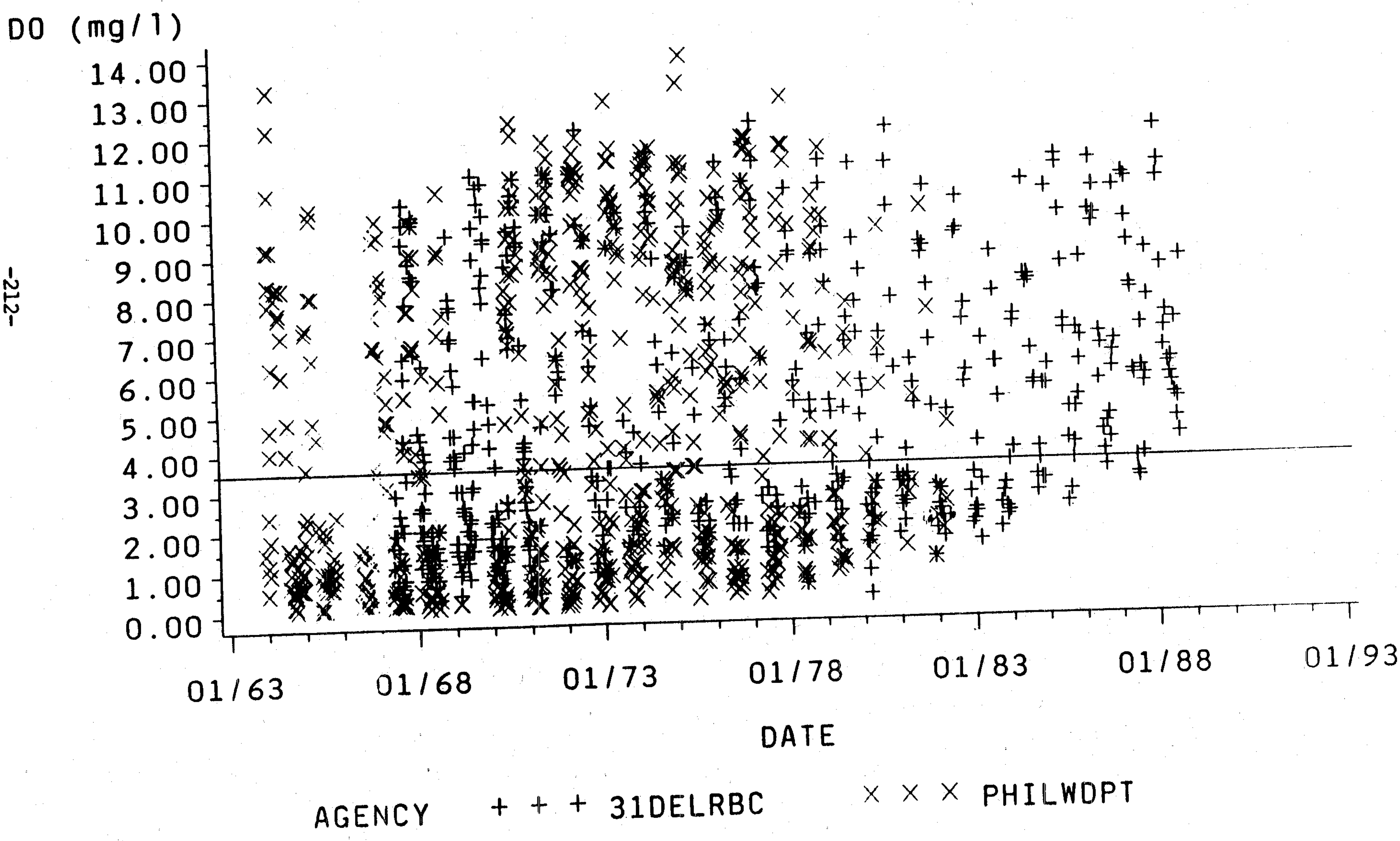


FIGURE 6.4

Delaware River at Navy Yar‹. ᴾʰila. (RK 149.93)

Historic Data Analysis - Dissolved Oxyge - Summer Data
Agency=DRBC Station=892065 AN
Agency=PHILWDPT Station=Del- 4

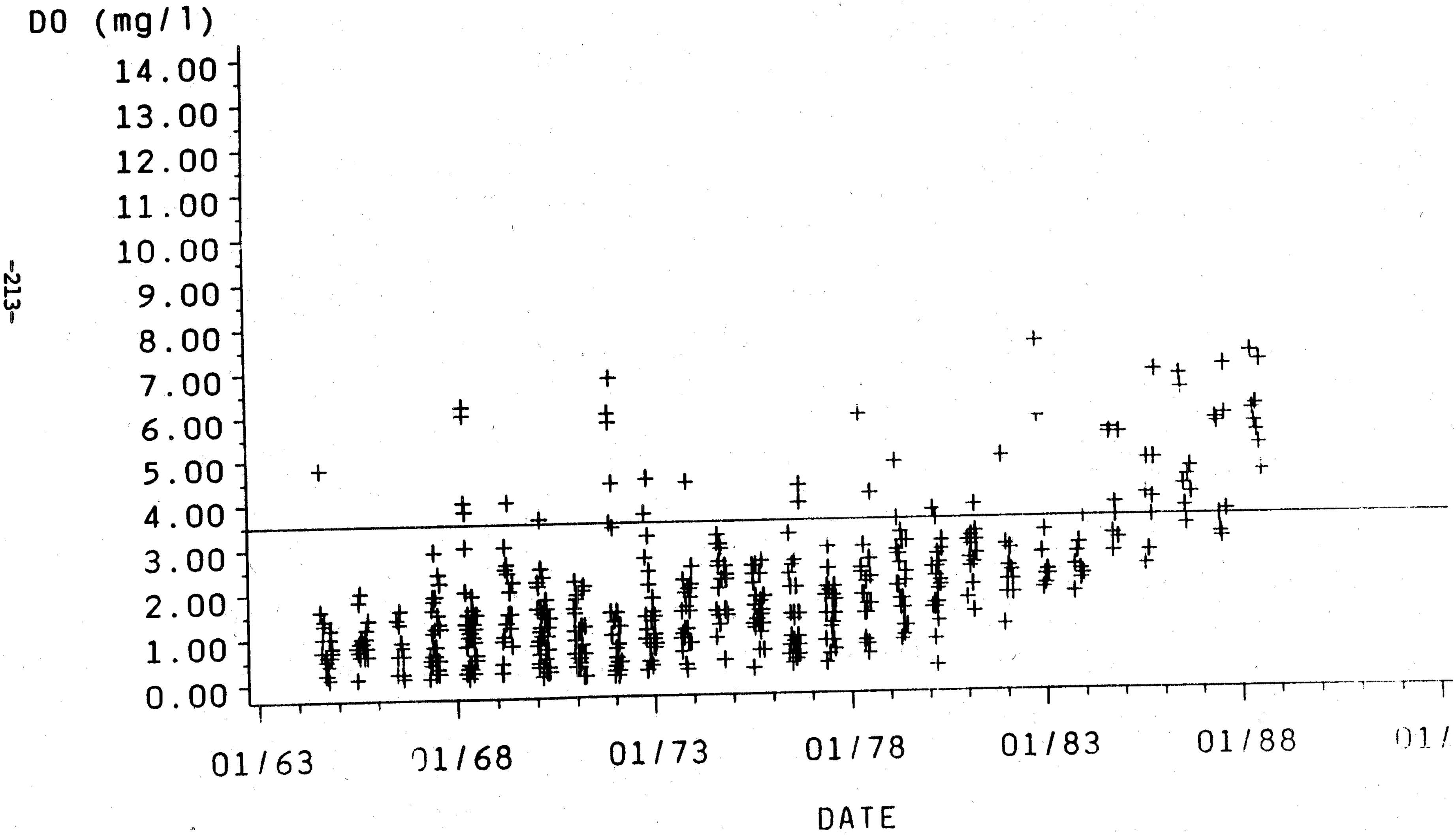


FIGURE 6.5

Delaware River at Navy Yard, Phila. (RK 149.93)

Historic Data Analysis - DO - Summer and Slack Before Flood Data

Agency=DRBC Station=892065 AND
Agency=PHILWDPT Station=Del- 4

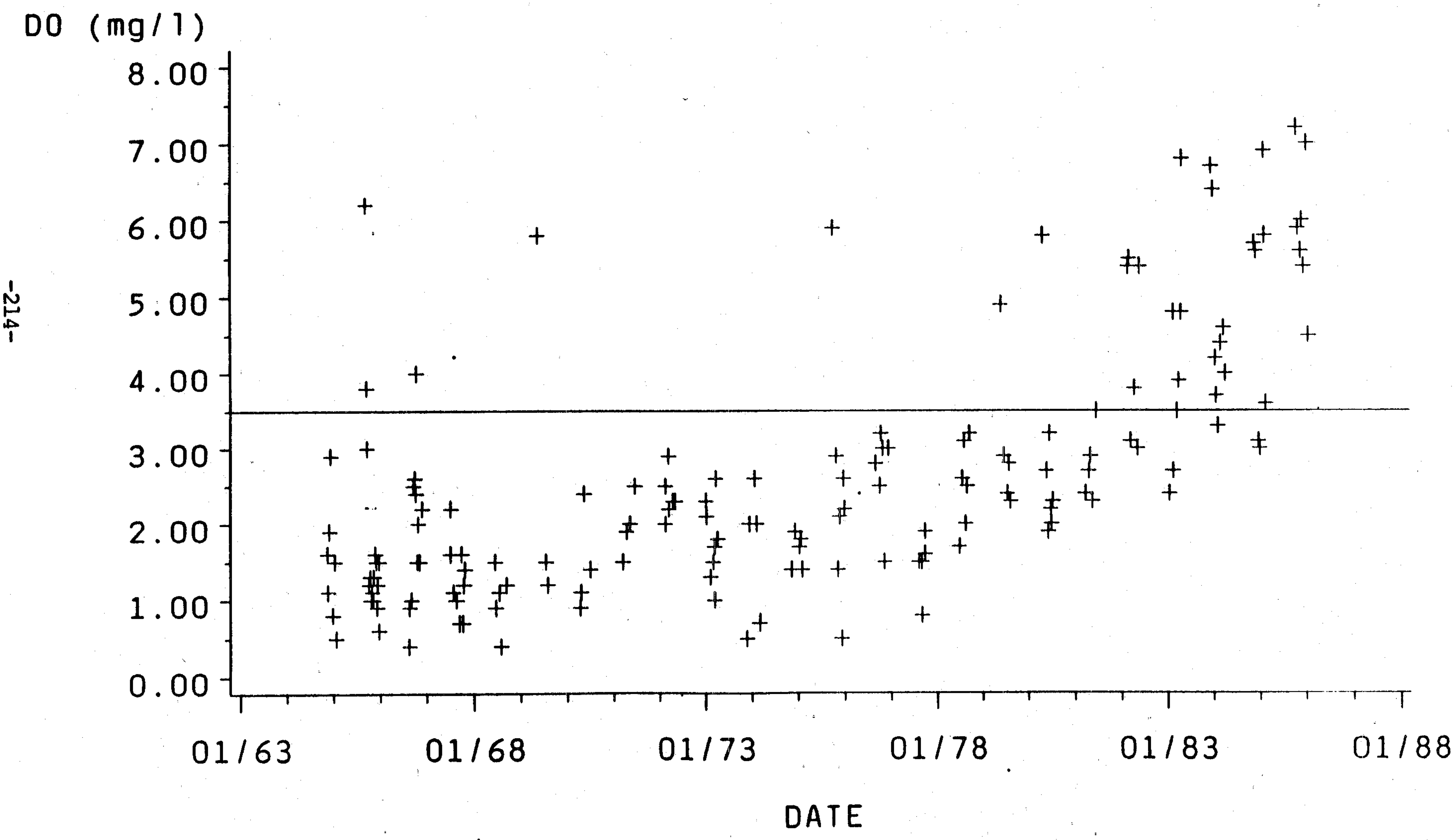


FIGURE 6.6

Delaware River at Navy Yard, Phila (RK 149.93)

Historic Data - DO - Summer, Slack before Flood, Wet Years (>50%)
Agency=DRBC Station=892065 AND
Agency=PHILWDPT Station=Del- 4

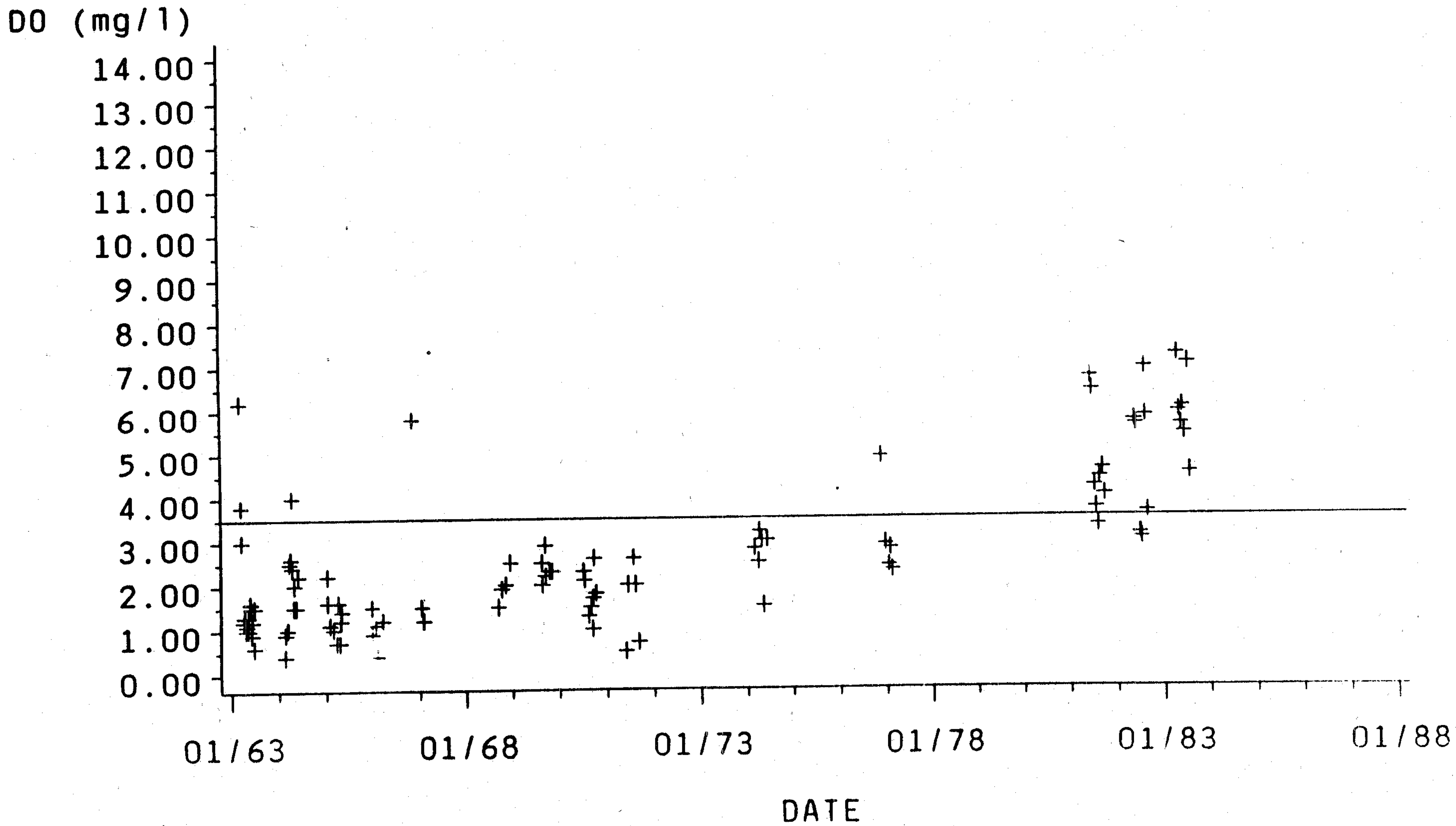


FIGURE 6.7

Delaware River at Navy Yard, Phila. (RK 149.93)

Historic Data - DO - Summer, Slack before Flood, Dry Years (<50%)
Agency=DRBC Station=892065 AND
Agency=PHILWDPT Station=Del- 4

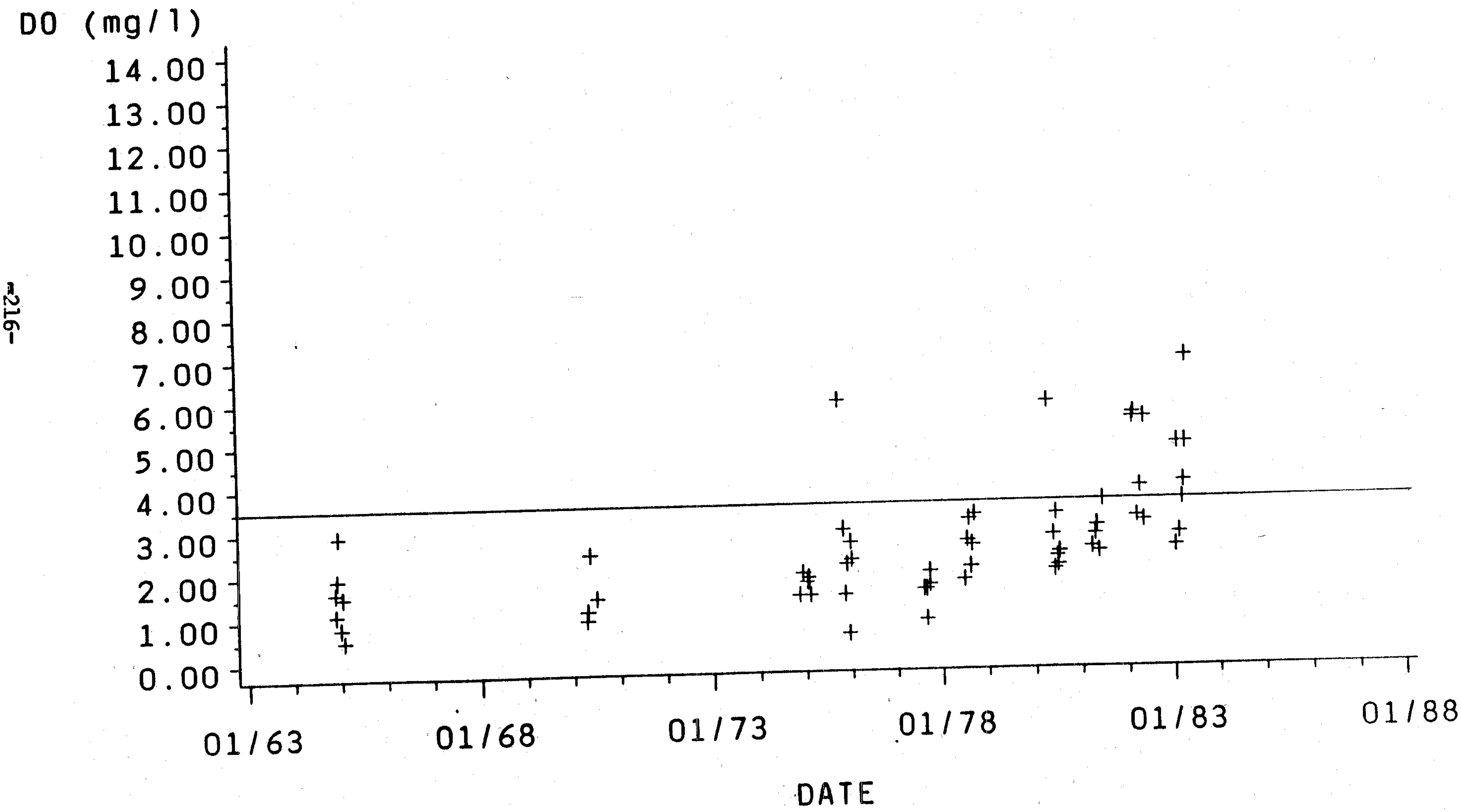
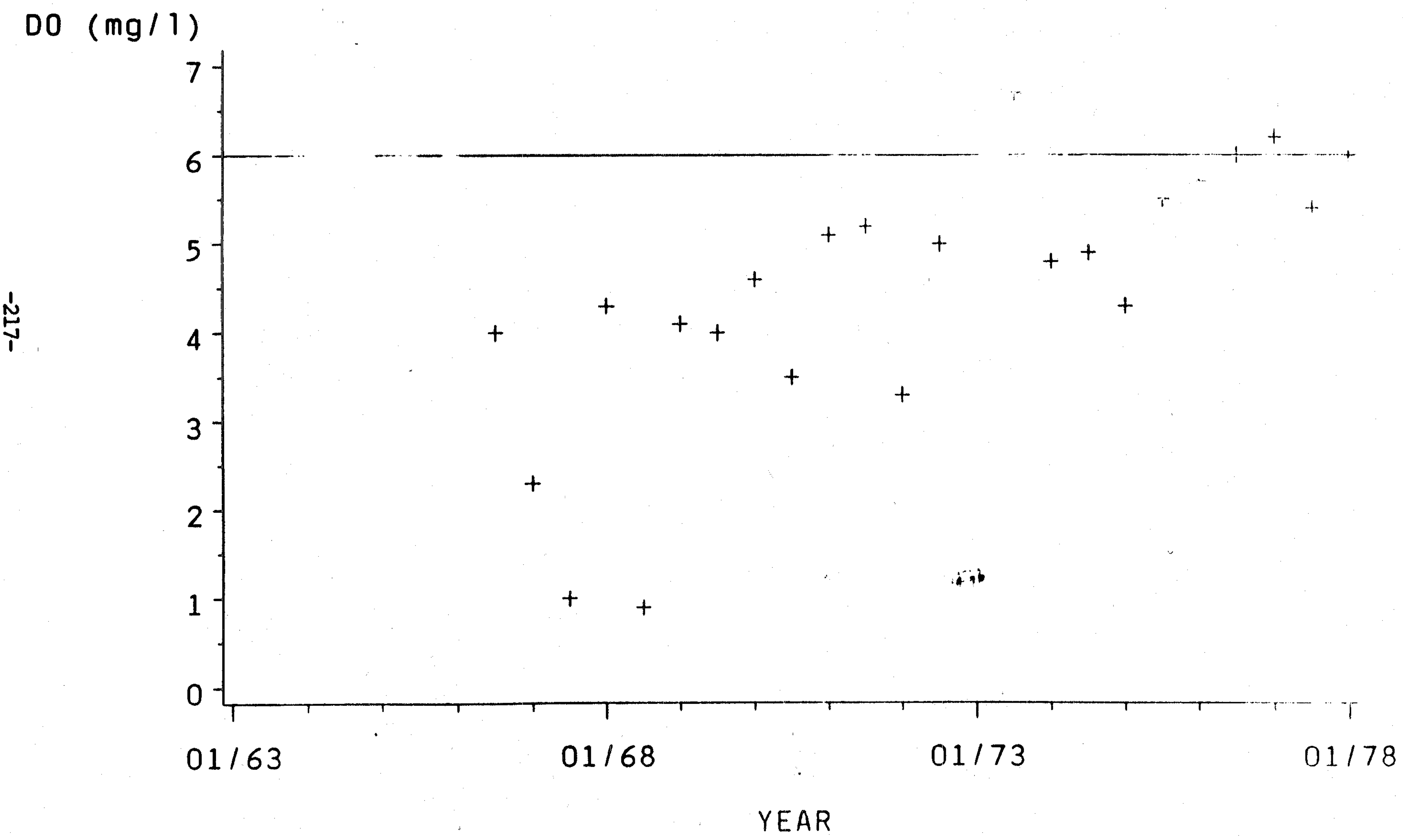


FIGURE 6.8

Delaware River at Reedy Island DE (RK 88.40)

Historic Data Analysis - Dissolved Oxygen
Minimum Annual DO Concentrations



APPENDIX A

DELAWARE RIVER AT FIELDSBORO, NJ (RK 205.11)

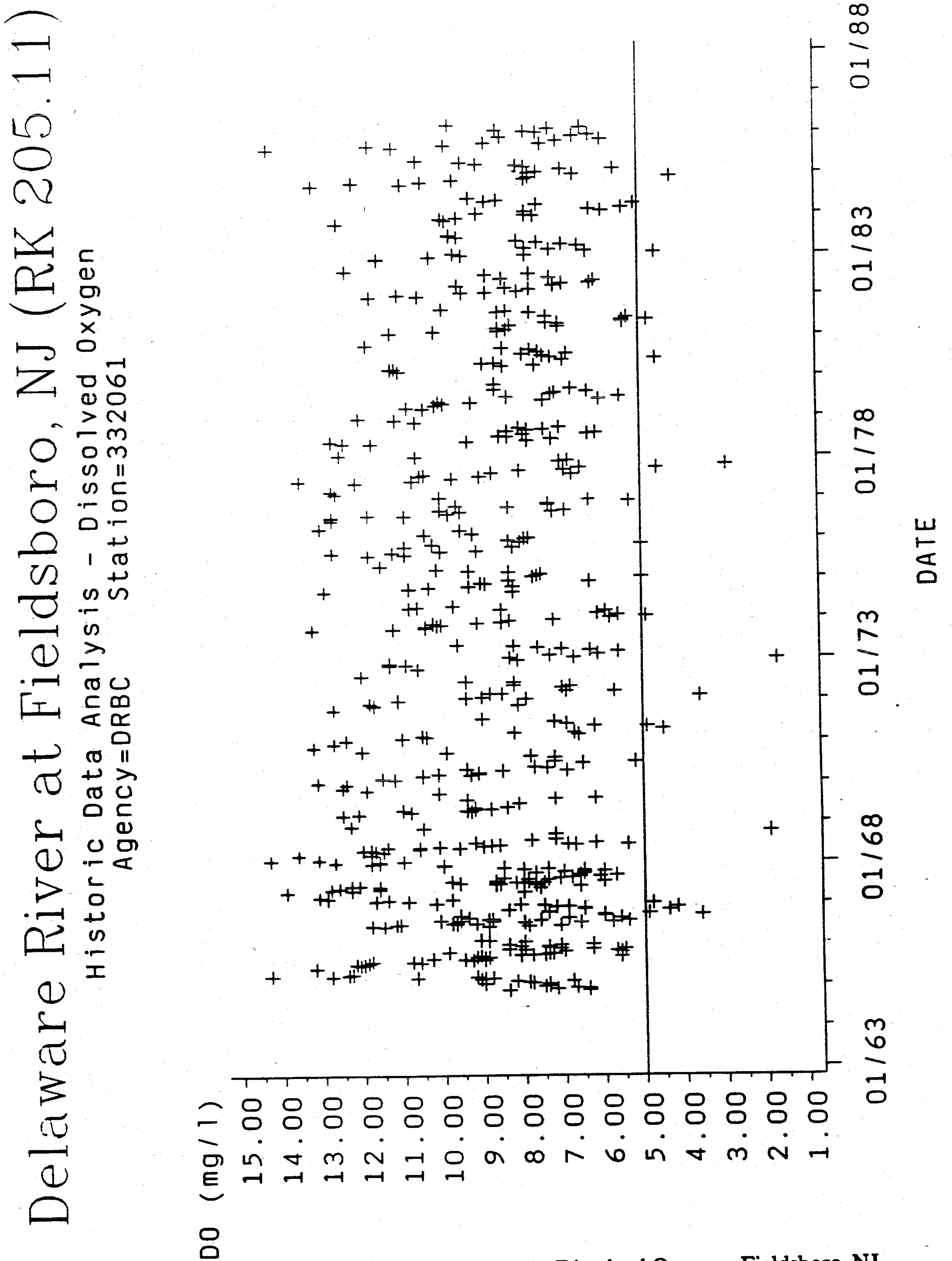


Figure A.1: Dissolved Oxygen - Fieldsboro, NJ

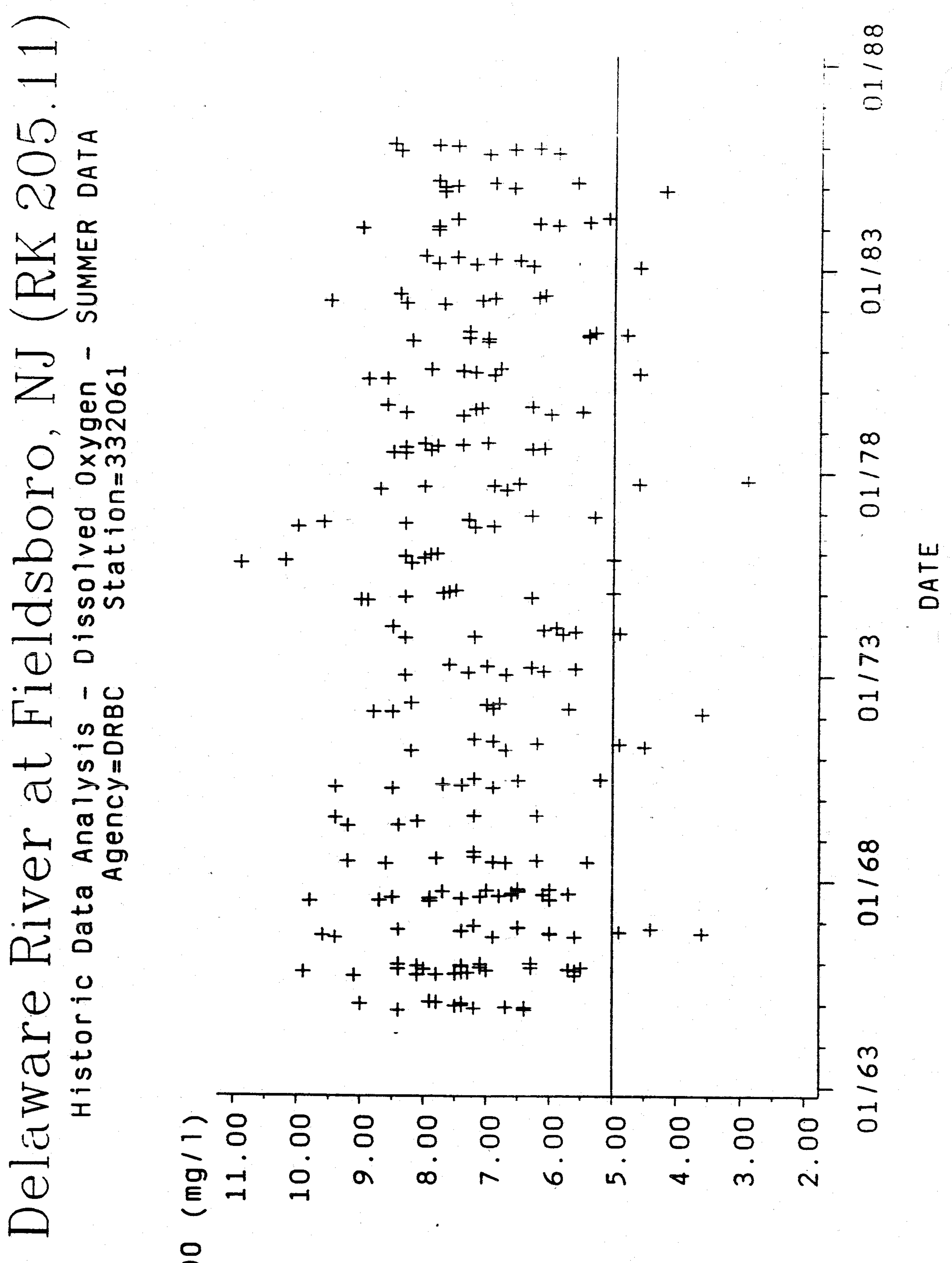


Figure A.2: Summer Dissolved Oxygen - Fieldsboro, NJ

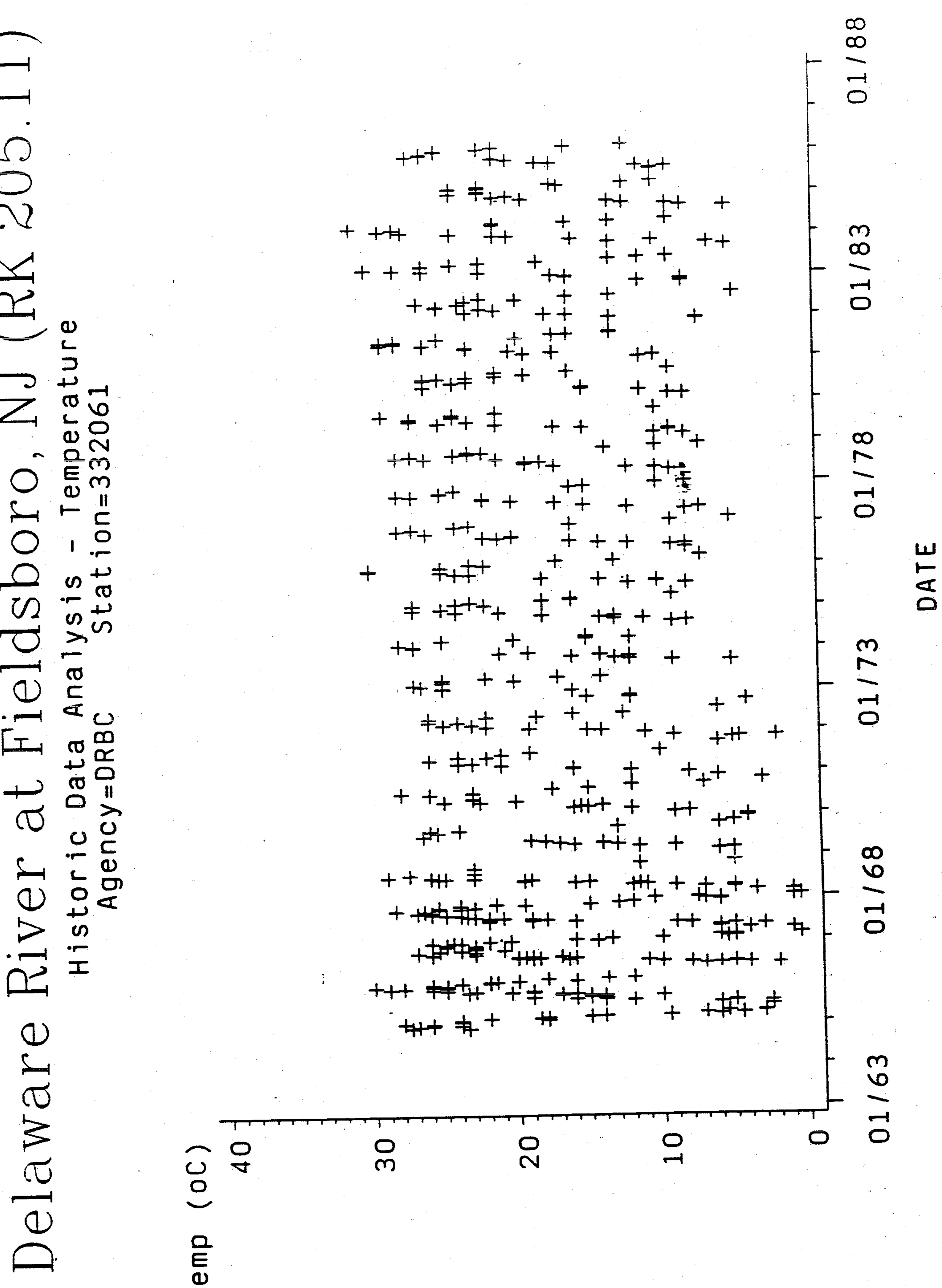


Figure A.3: Temperature - Fieldsboro, NJ

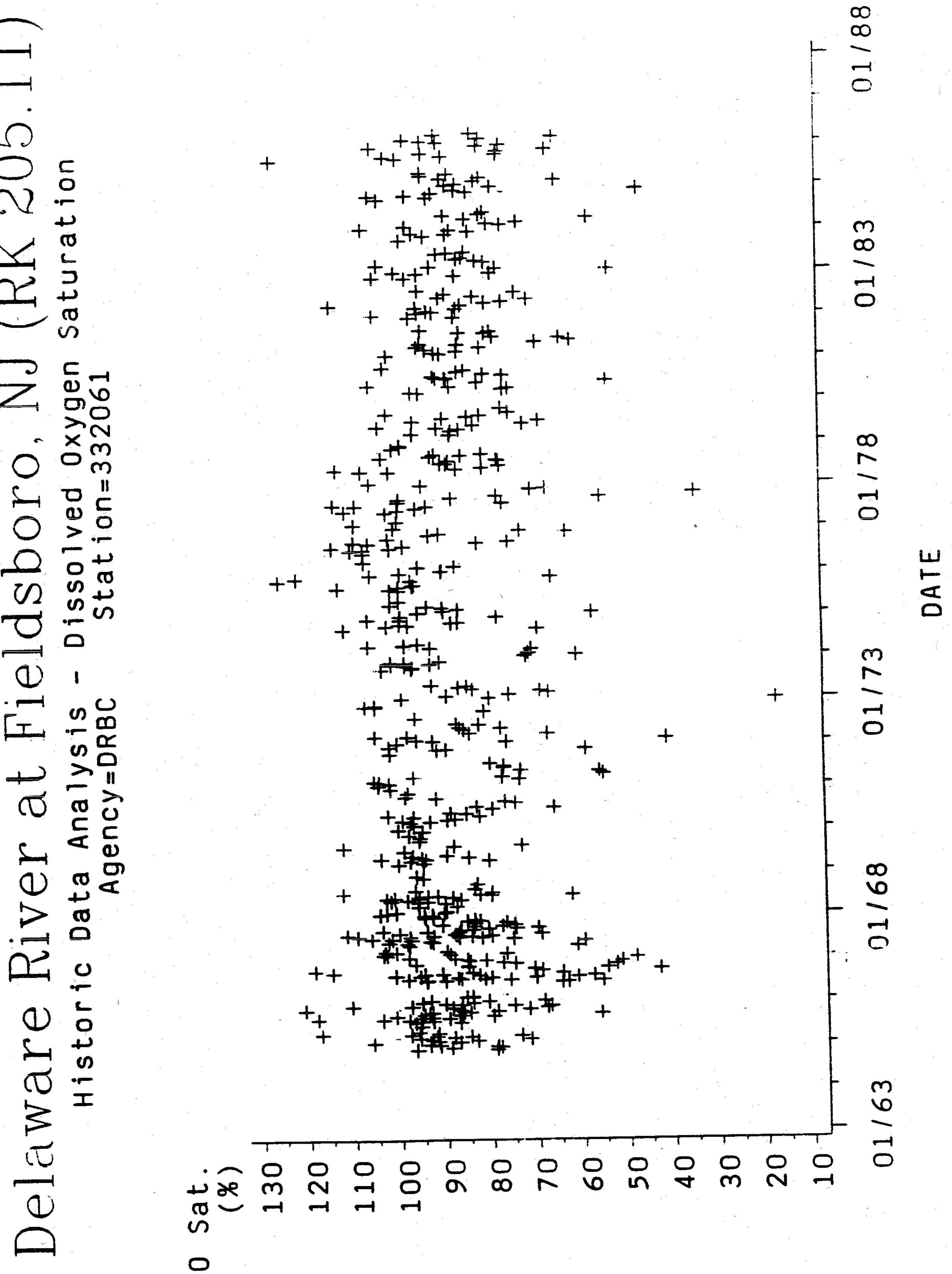


Figure A.4: DO Percent Saturation - Fieldsboro, NJ

4

Delaware River at Fieldsboro, NJ (RK 205.11)

Historic Data Analysis - Chlorides
Agency=DRBC Station=332061

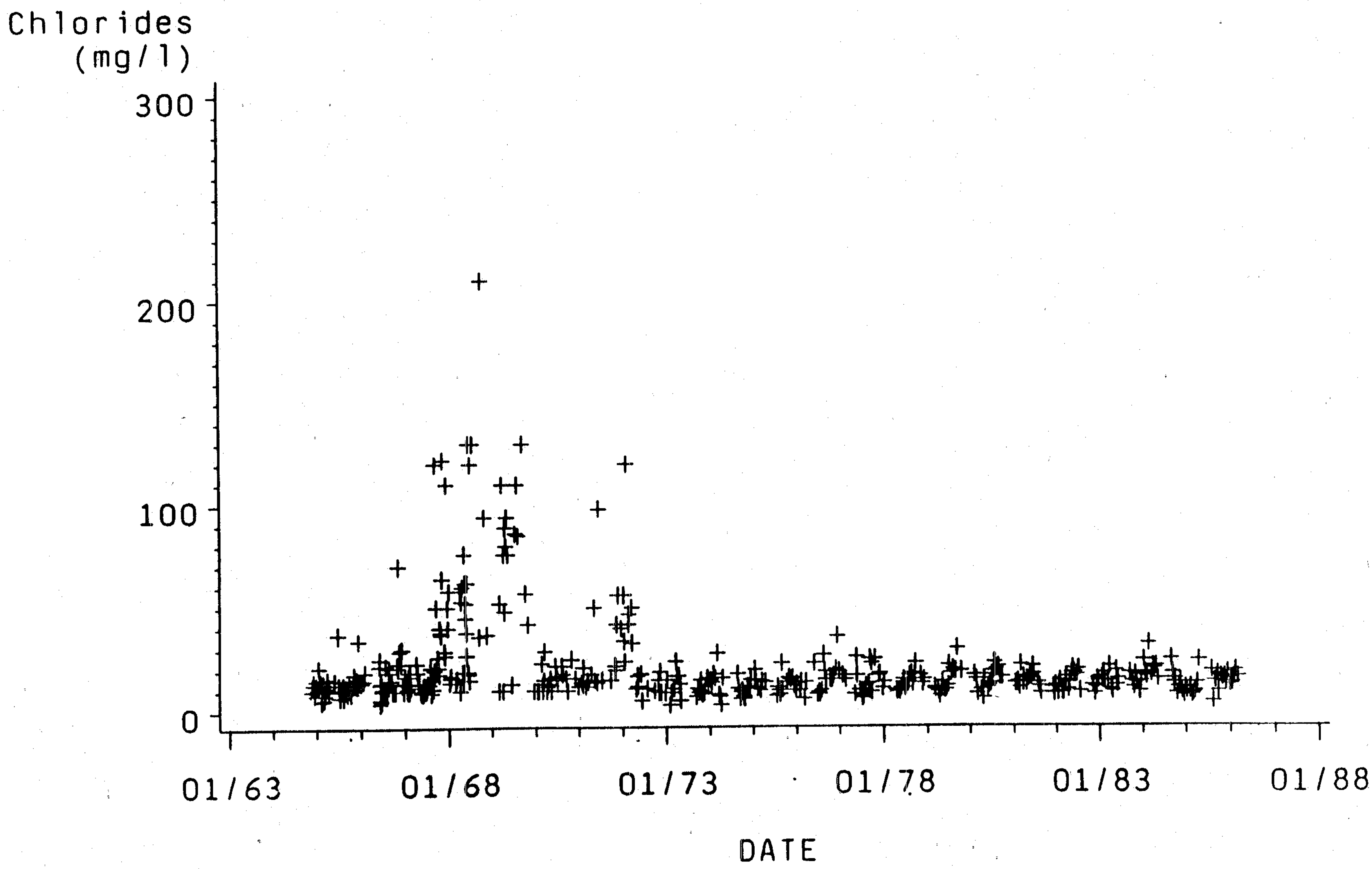


Figure A.5: Chlorides - Fieldsboro, NJ

5

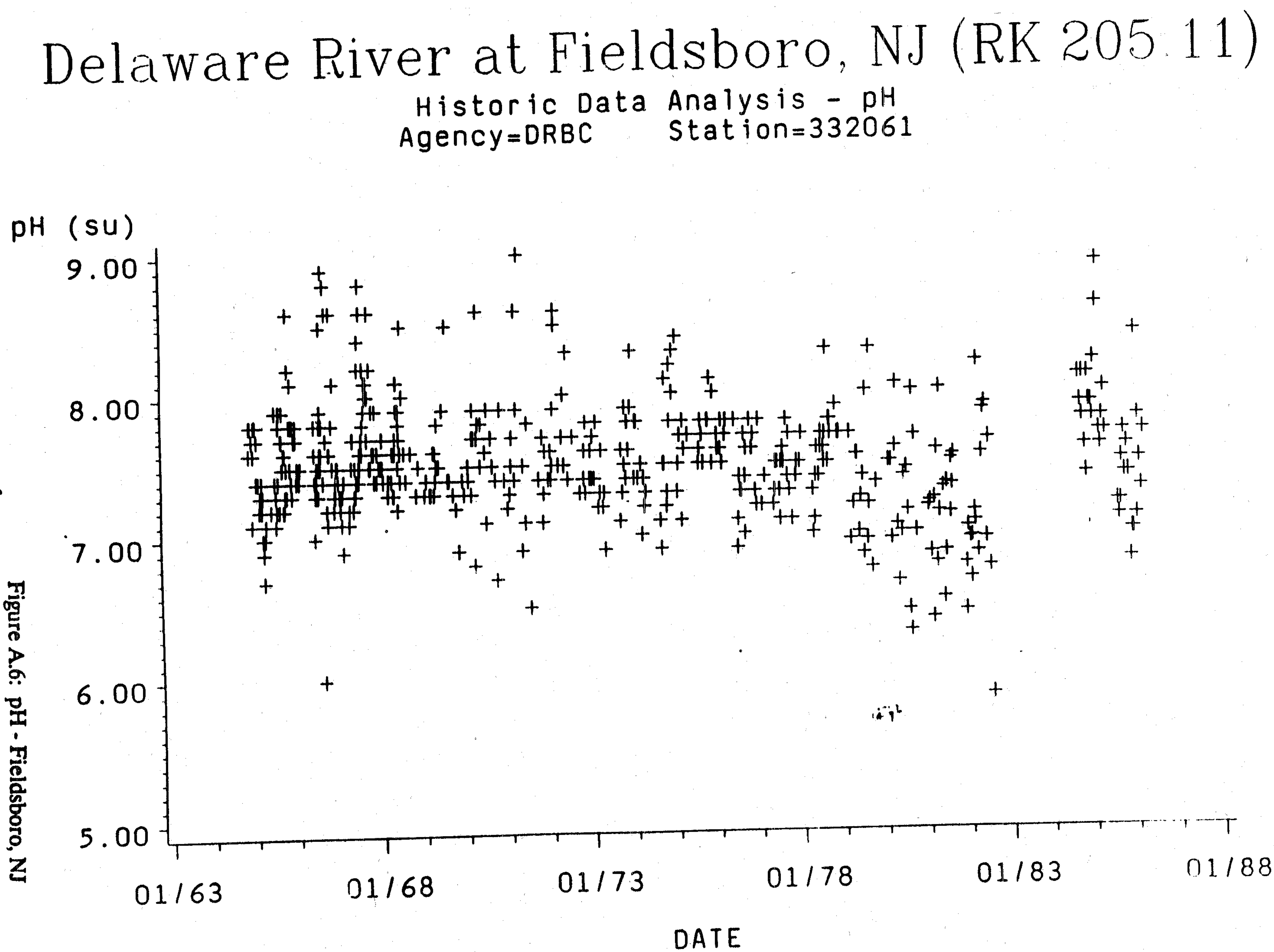


Figure A.6: pH - Fieldsboro, NJ

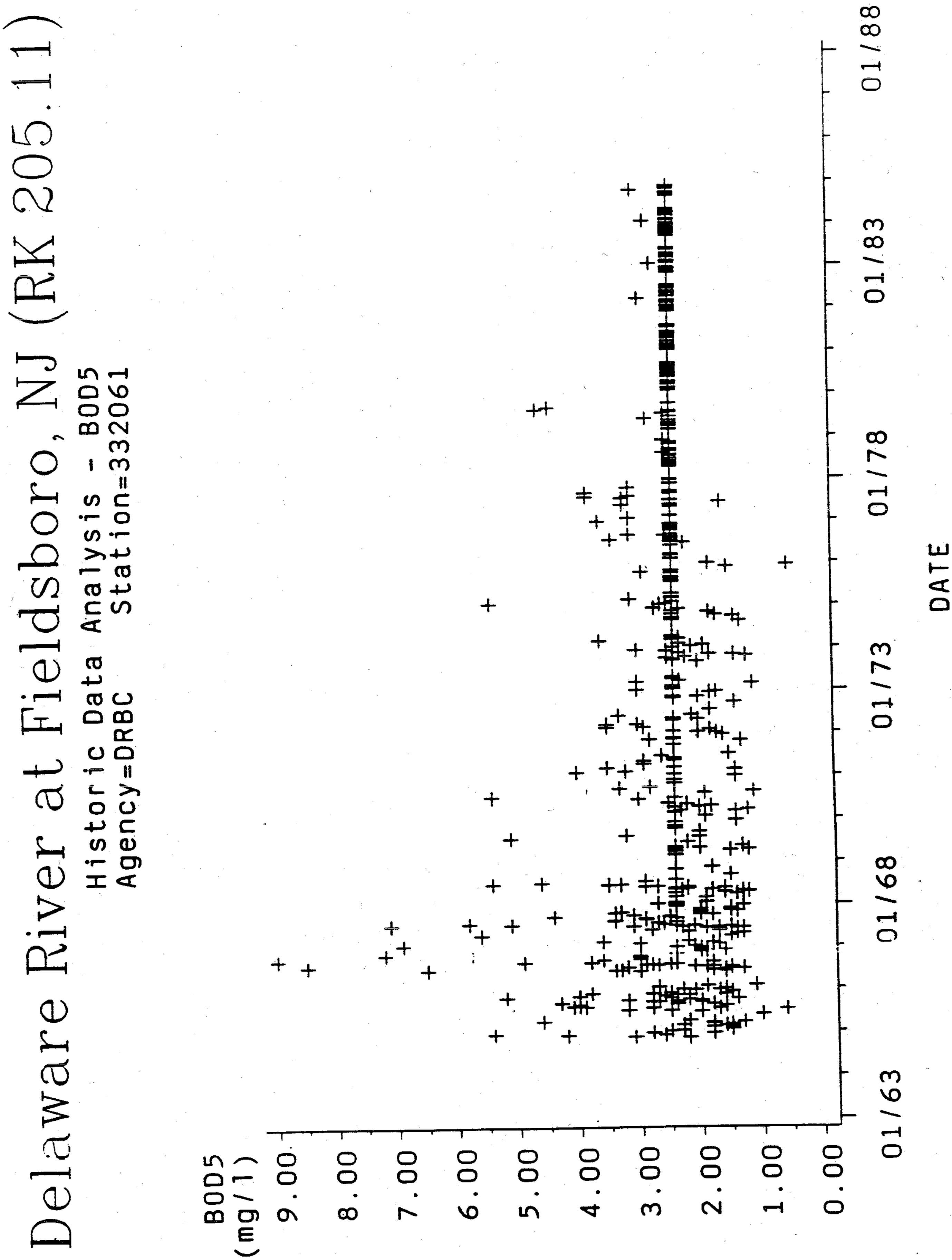


Figure A.7: BOD_5 - Fieldsboro, NJ

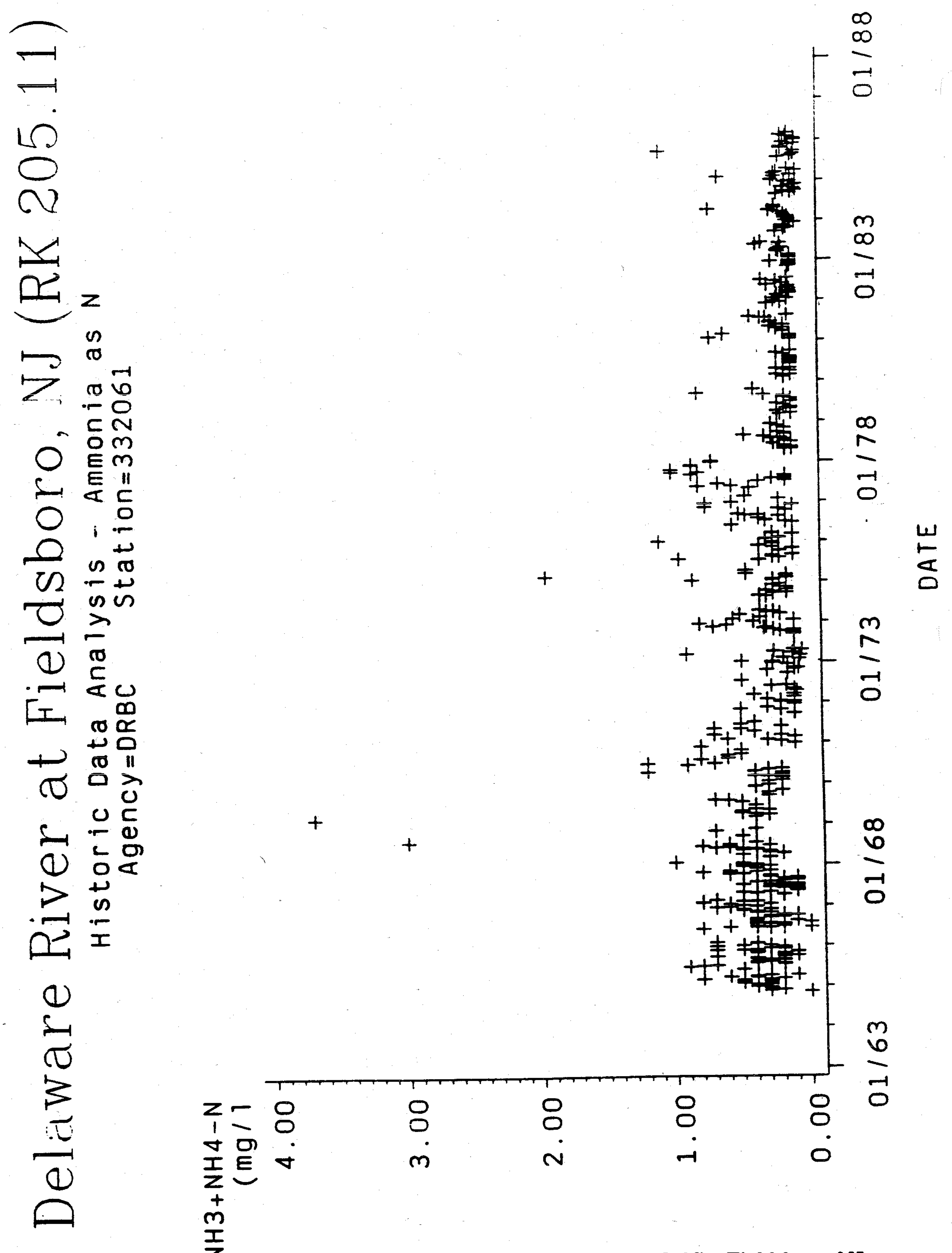


Figure A.8: Ammonia (NH_3-N) - Fieldsboro, NJ

8

Delaware River at Fieldsboro, NJ (RK 205.11)

Historic Data Analysis - Nitrate as N
Agency=DRBC Station=332061

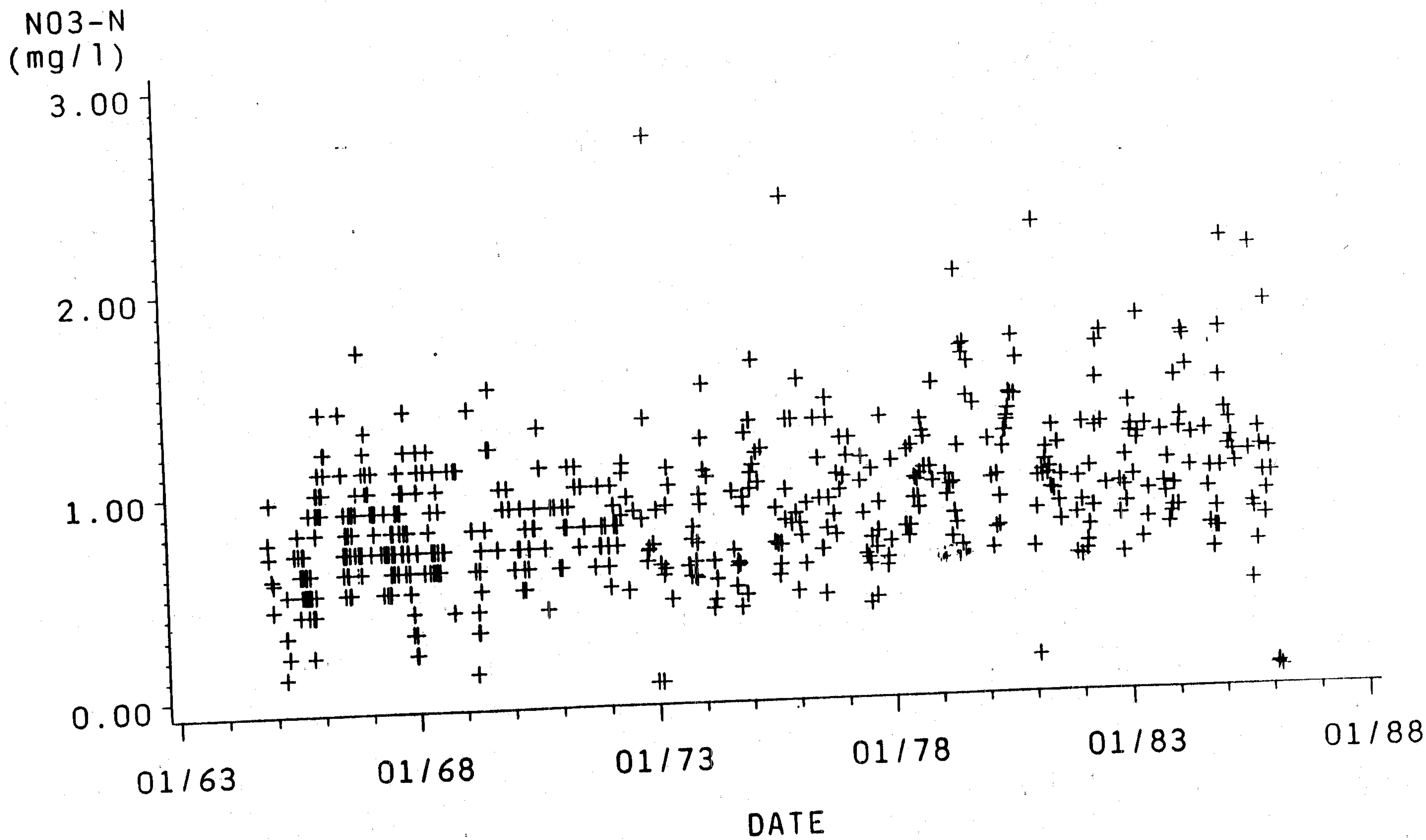


Figure A.9: Nitrate (NO_3-N) - Fieldsboro, NJ

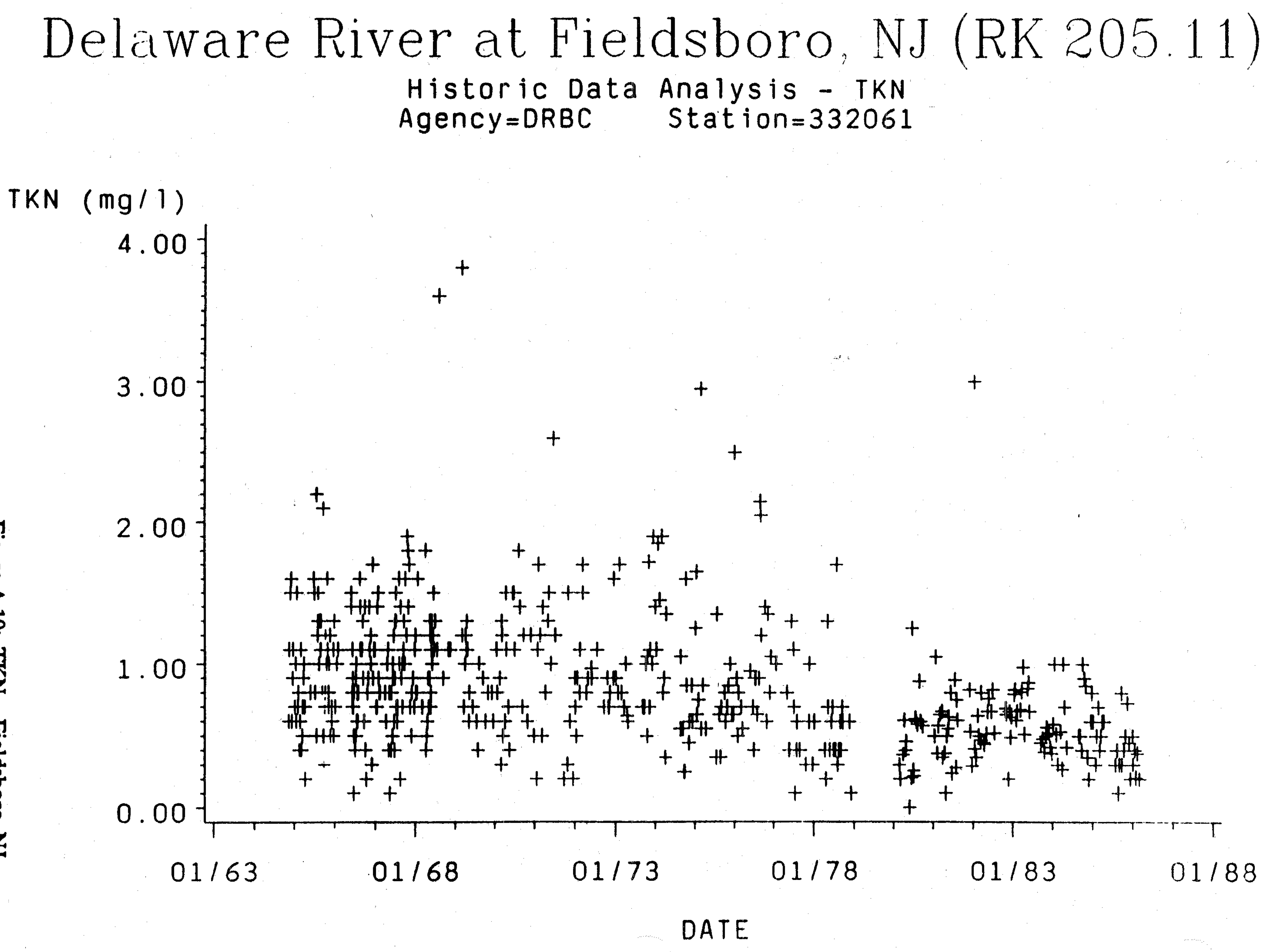


Figure A.10: TKN - Fieldsboro, NJ

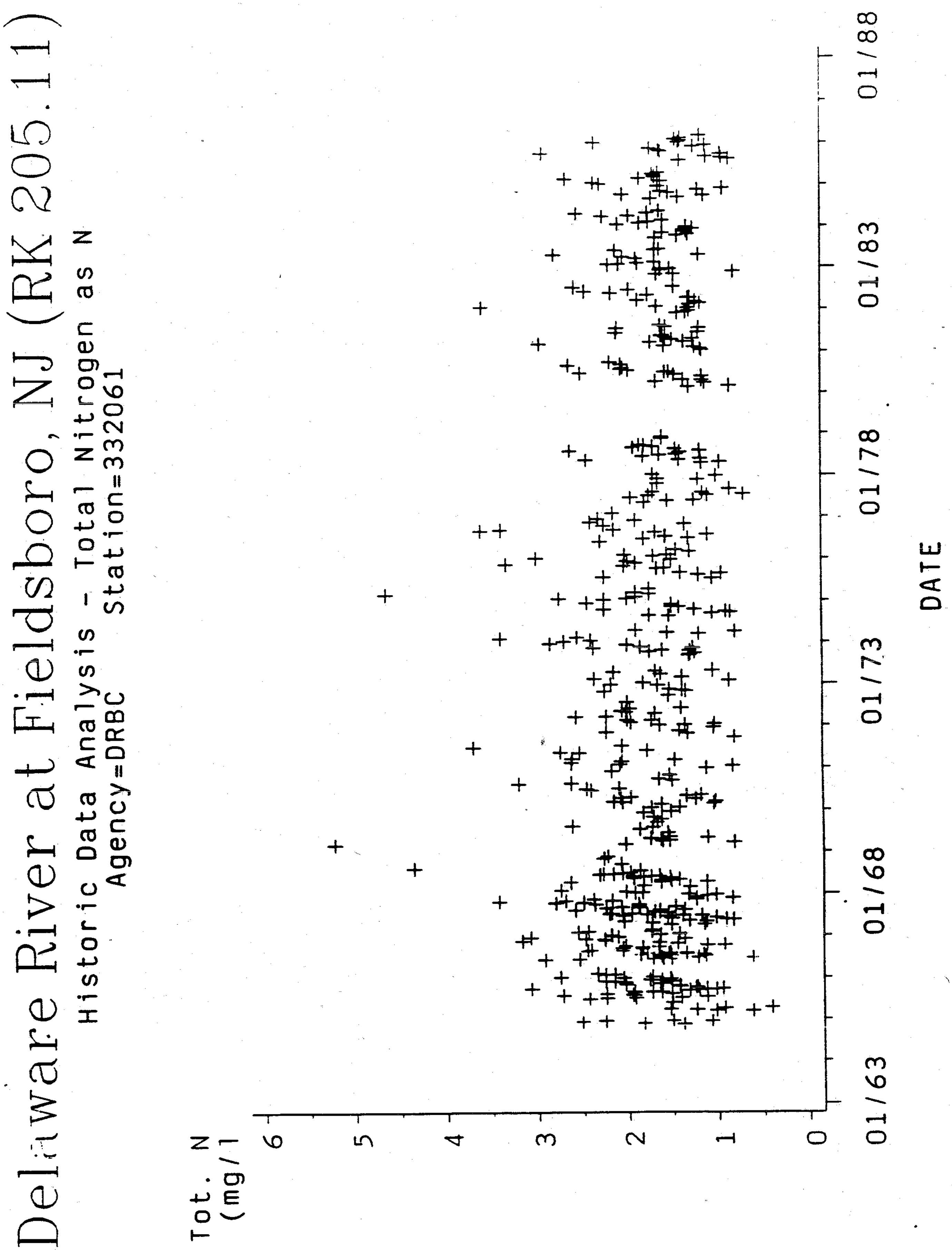


Figure A.11: Total Nitrogen - Fieldsboro, NJ

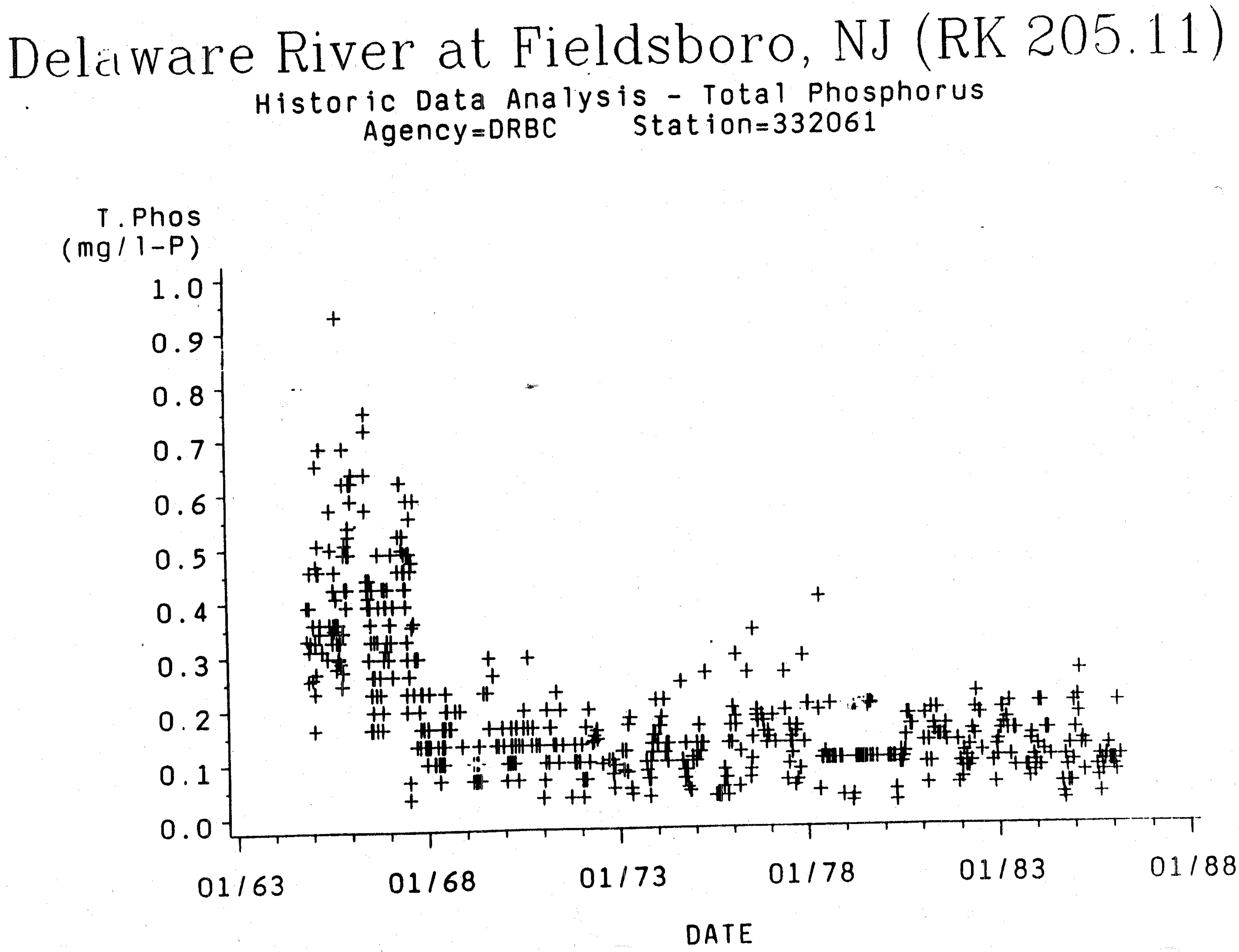


Figure A.12: Total Phosphorus - Fieldsboro, NJ

Delaware River at Fieldsboro, NJ (RK 205.11)

Historic Data Analysis - Turbidity HLGE
Agency=DRBC Station=332061

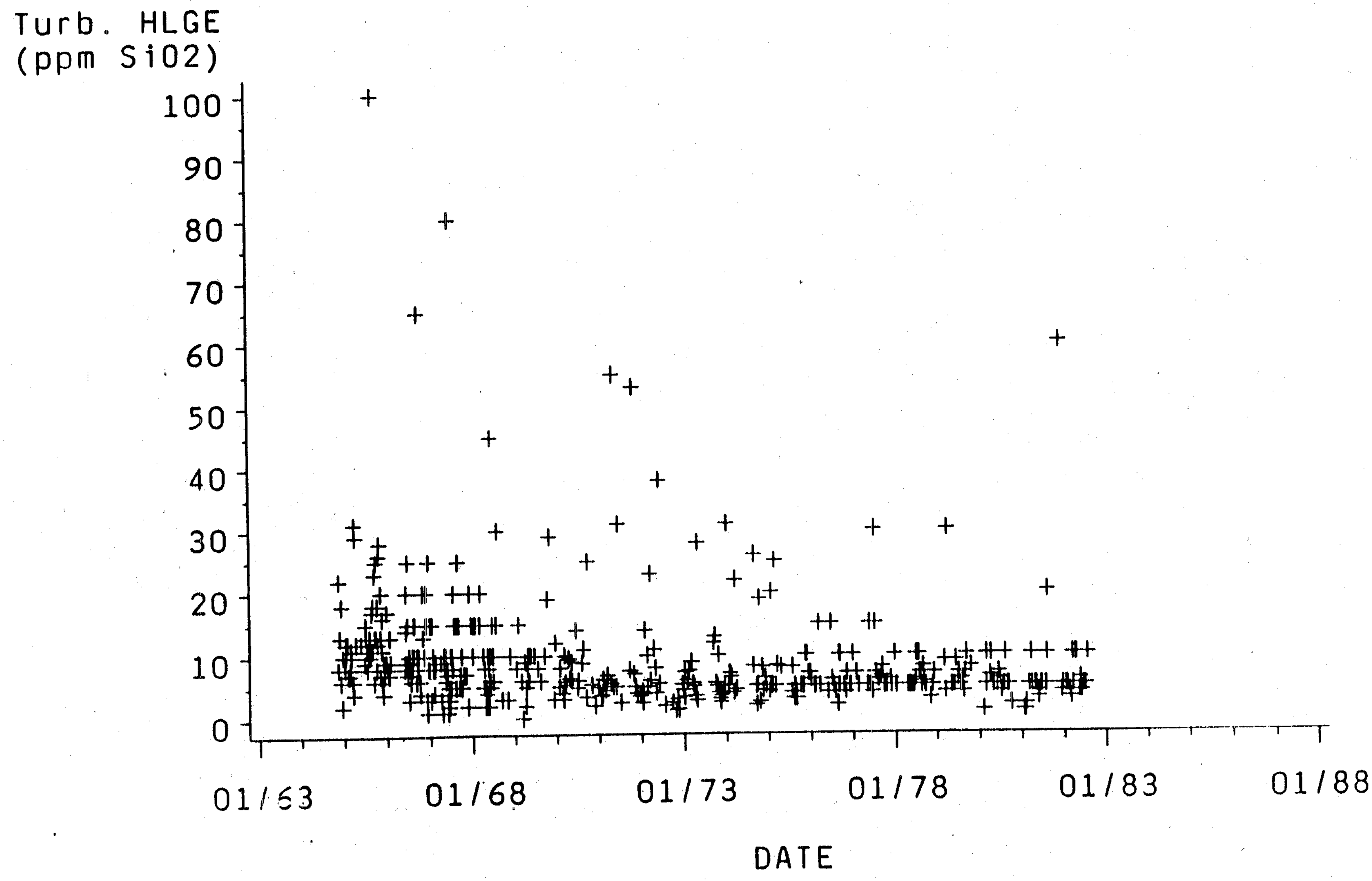


Figure A.13: Turbidity - Fieldsboro, NJ

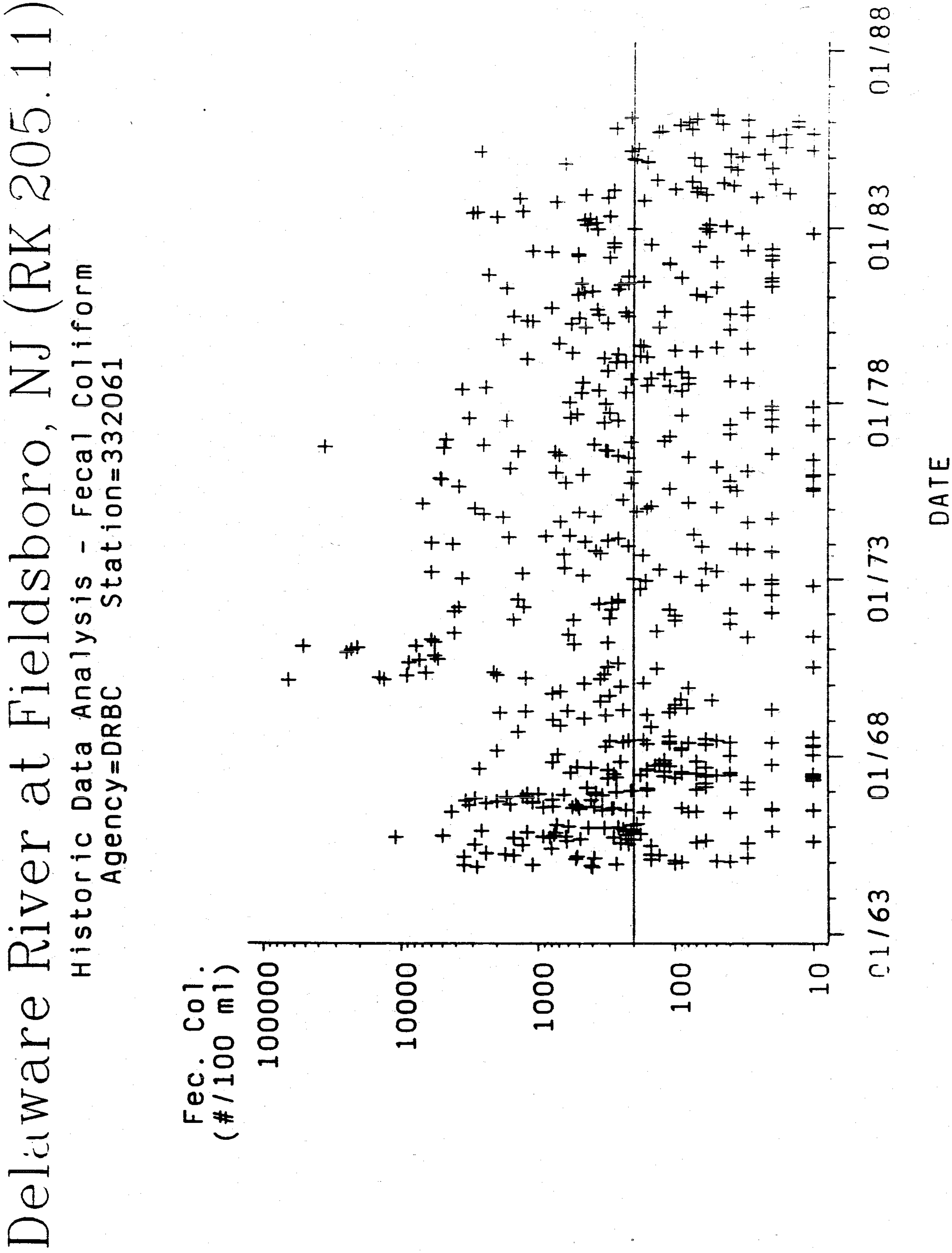


Figure A.14: Fecal Coliform - Fieldsboro, NJ

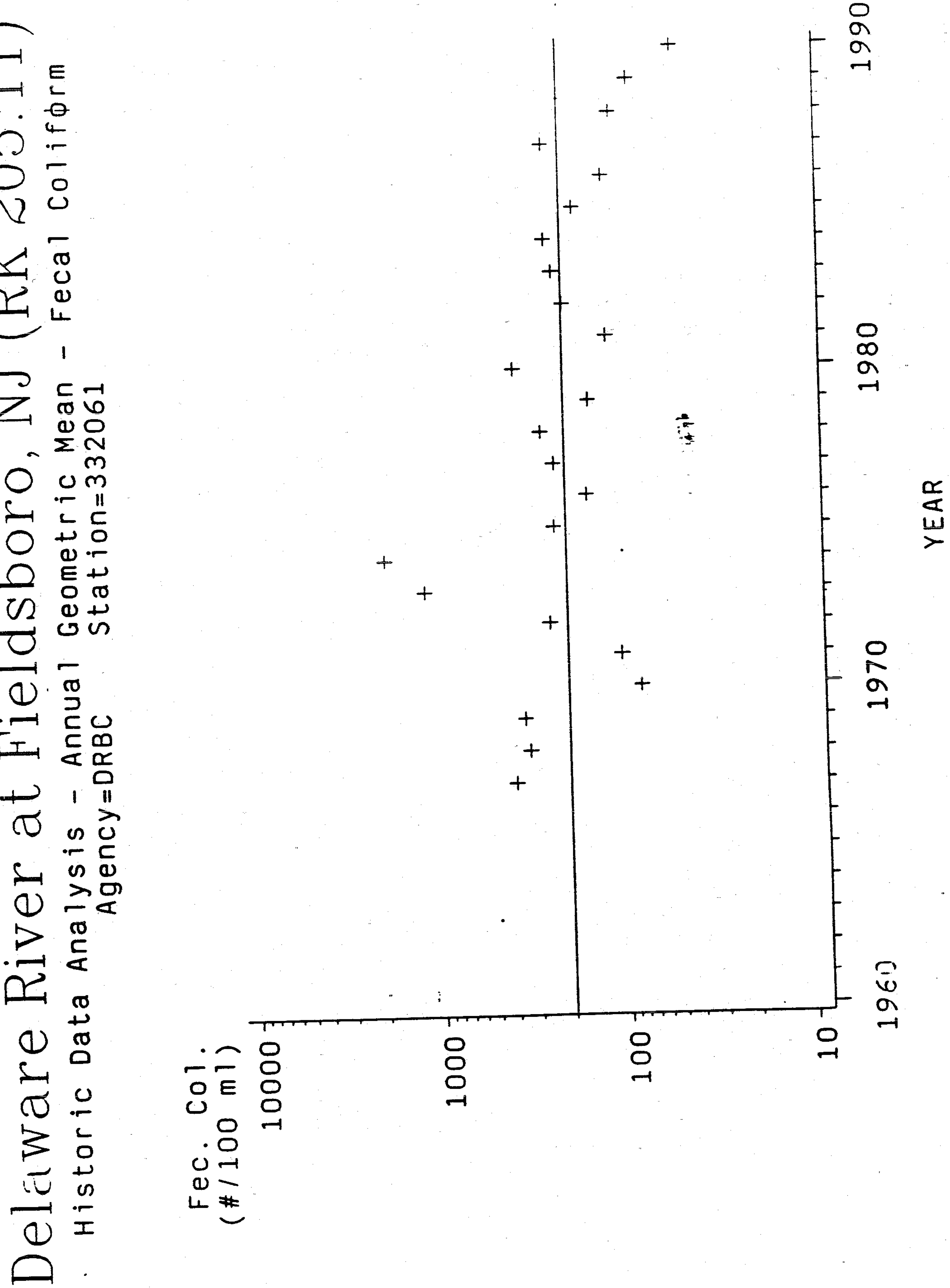


Figure A.15: Annual Geometric Mean FC - Fieldsboro, NJ

APPENDIX B

DELAWARE RIVER AT TORRESDALE, PA (RK 178.12)

Delaware River at Torresdale, PA (RK 178.12)

Historic Data Analysis - Dissolved Oxygen
Agency=DRBC Station=892077 AND
Agency=PHILWDPT Station=DEL-14

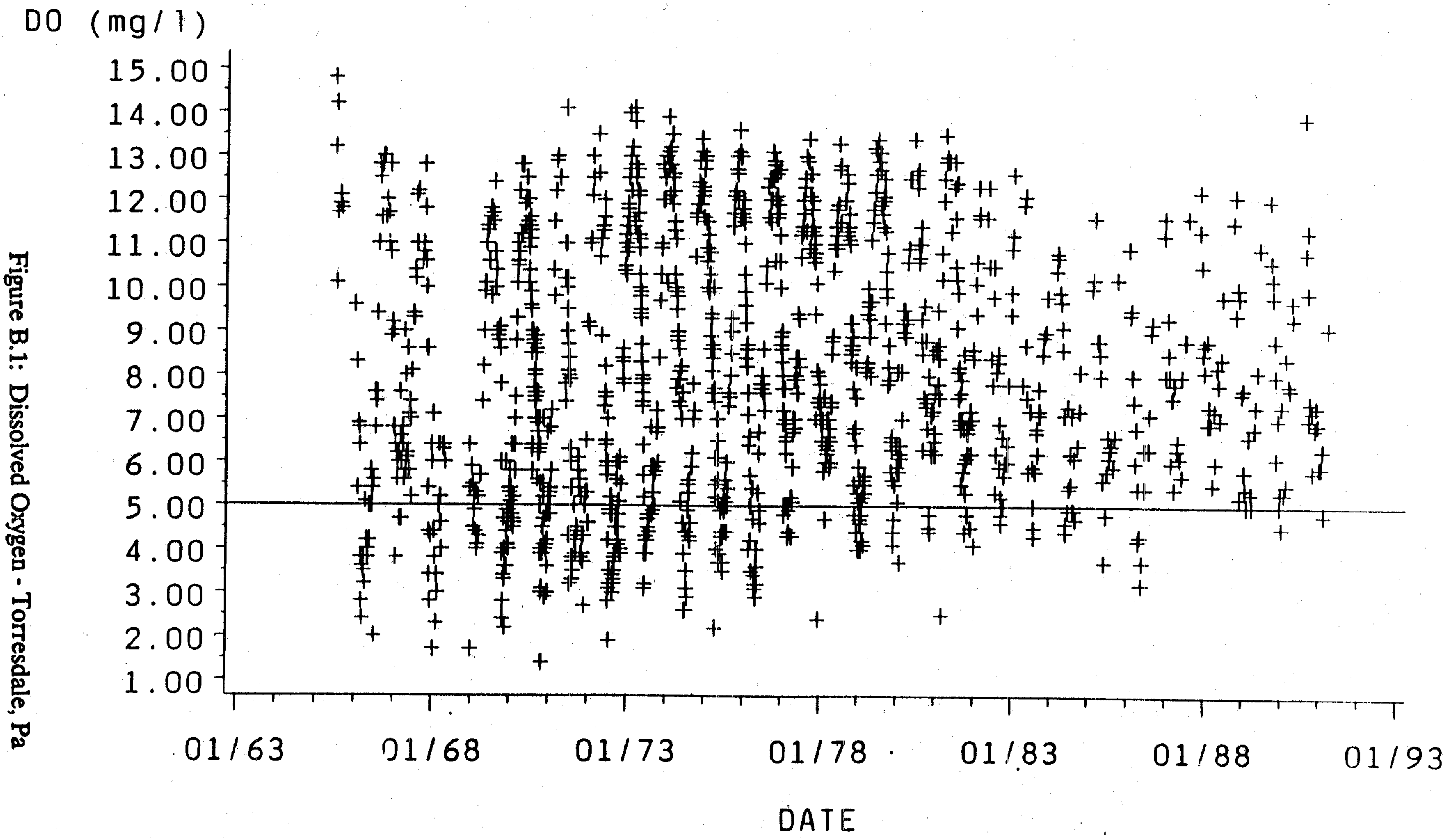


Figure B.1: Dissolved Oxygen - Torresdale, Pa

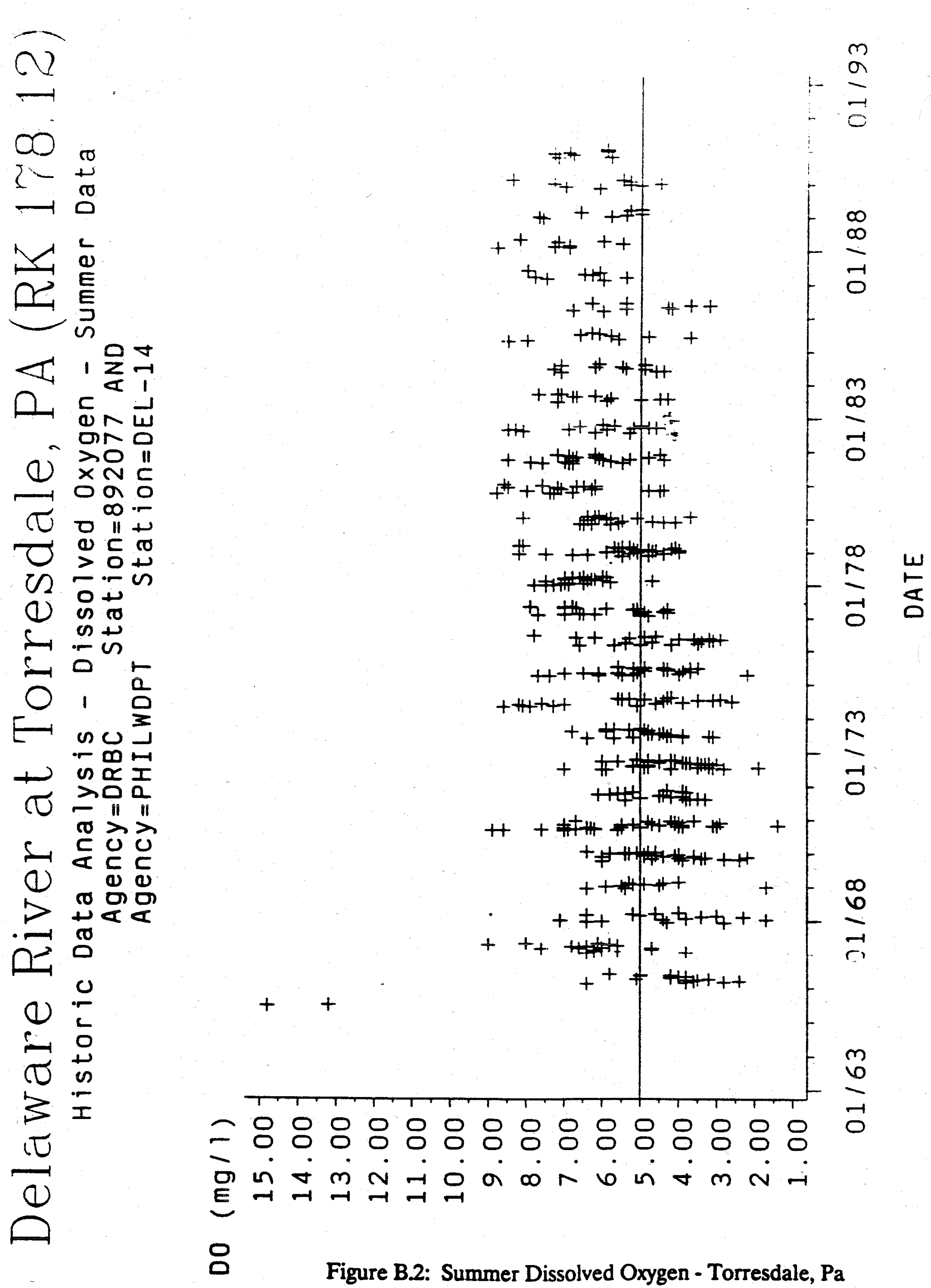


Figure B.2: Summer Dissolved Oxygen - Torresdale, Pa

Delaware River at Torresdale, PA (RK 178.12)

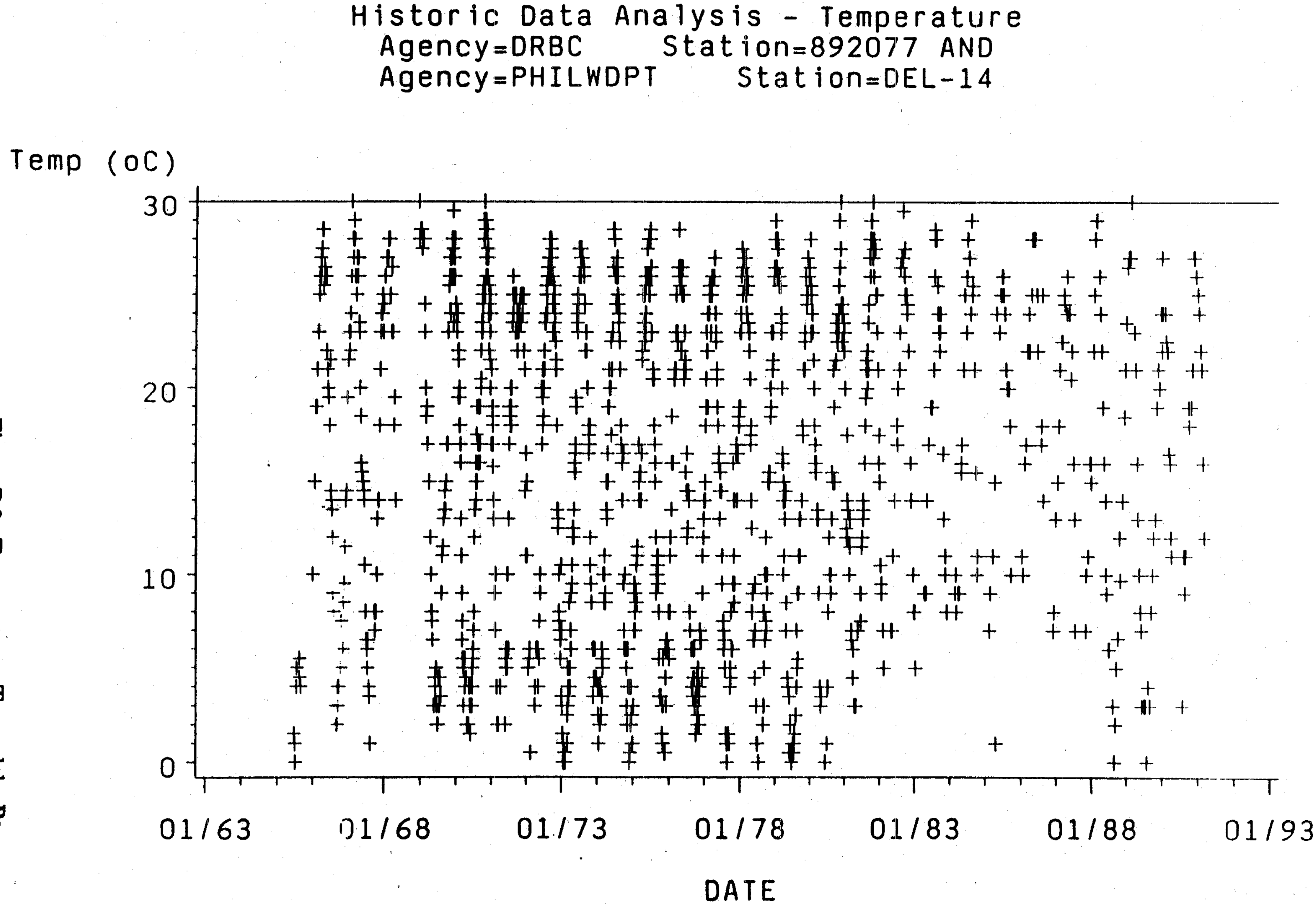


Figure B.3: Temperature - Torresdale, Pa

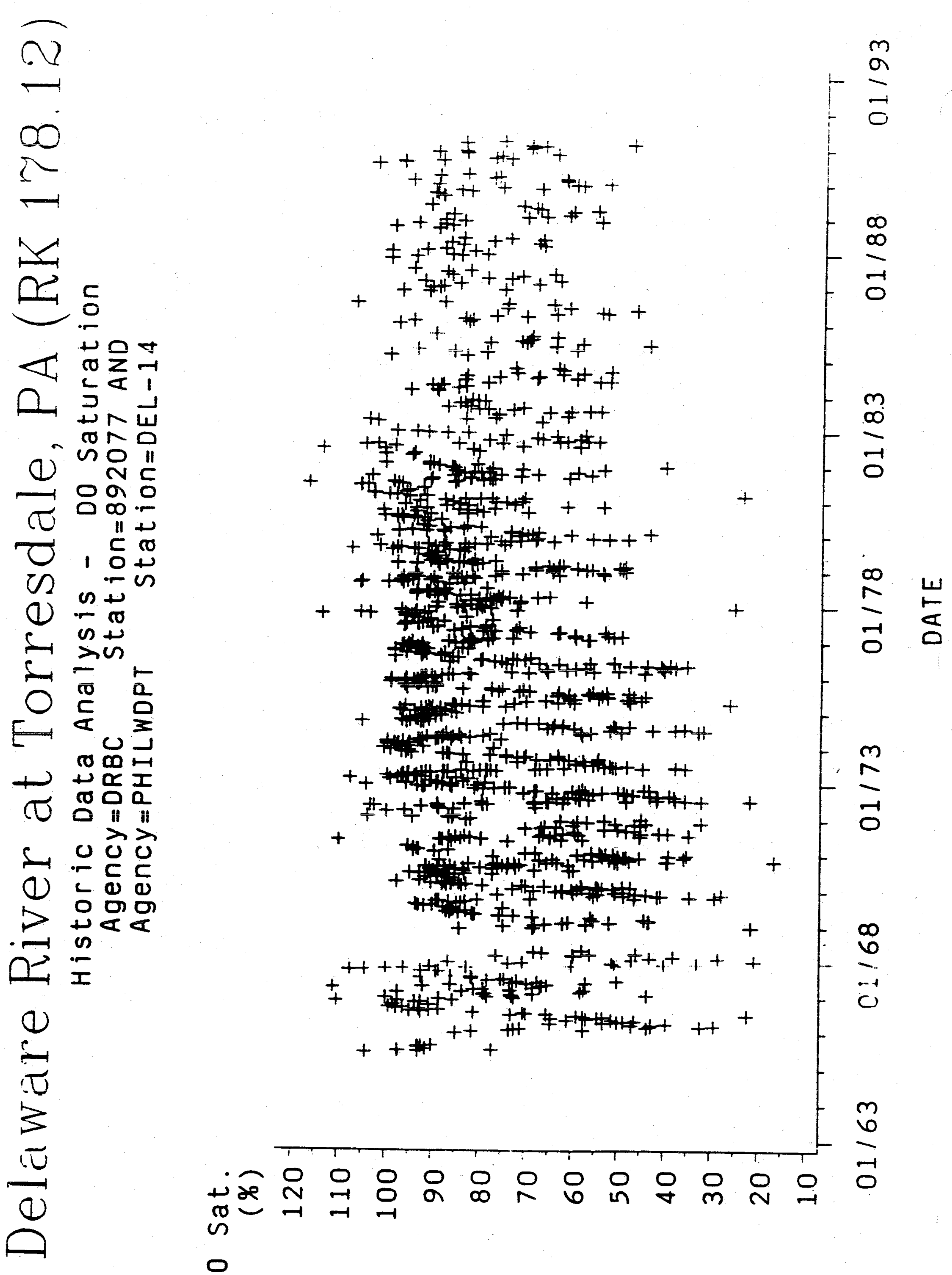


Figure B.4: DO Percent Saturation - Torresdale, Pa

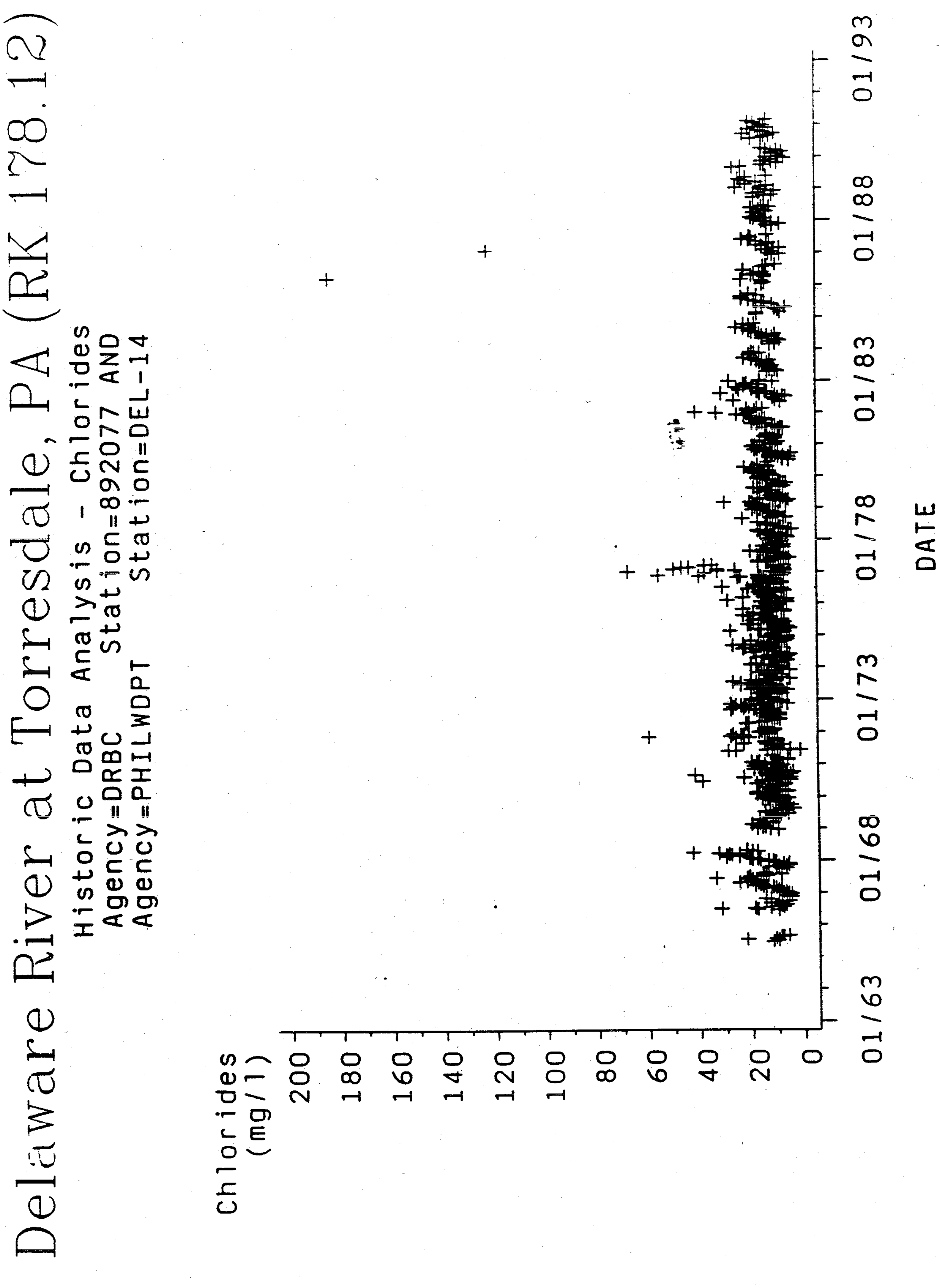


Figure B.5: Chlorides - Torresdale, Pa

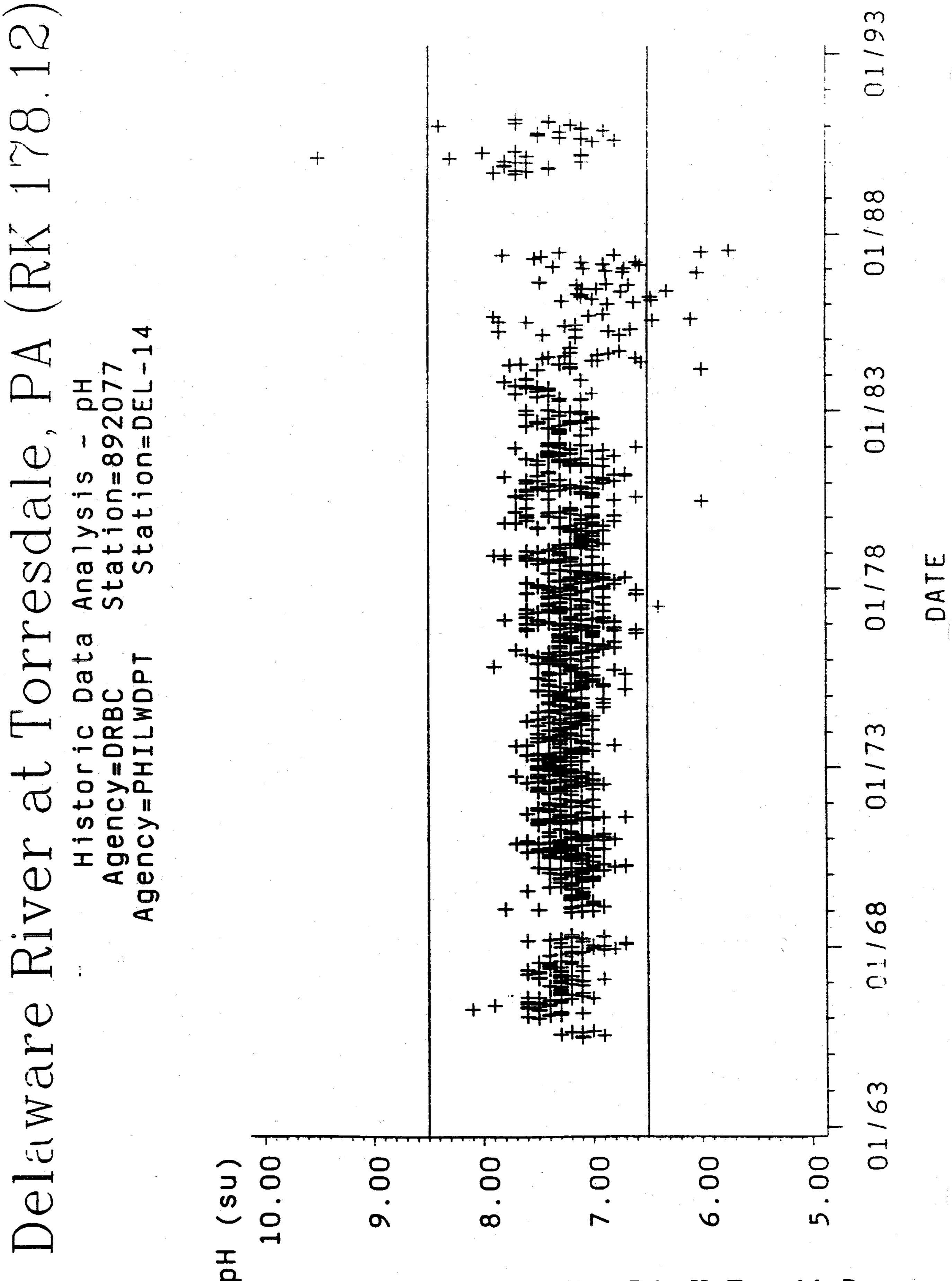


Figure B.6: pH - Torresdale, Pa

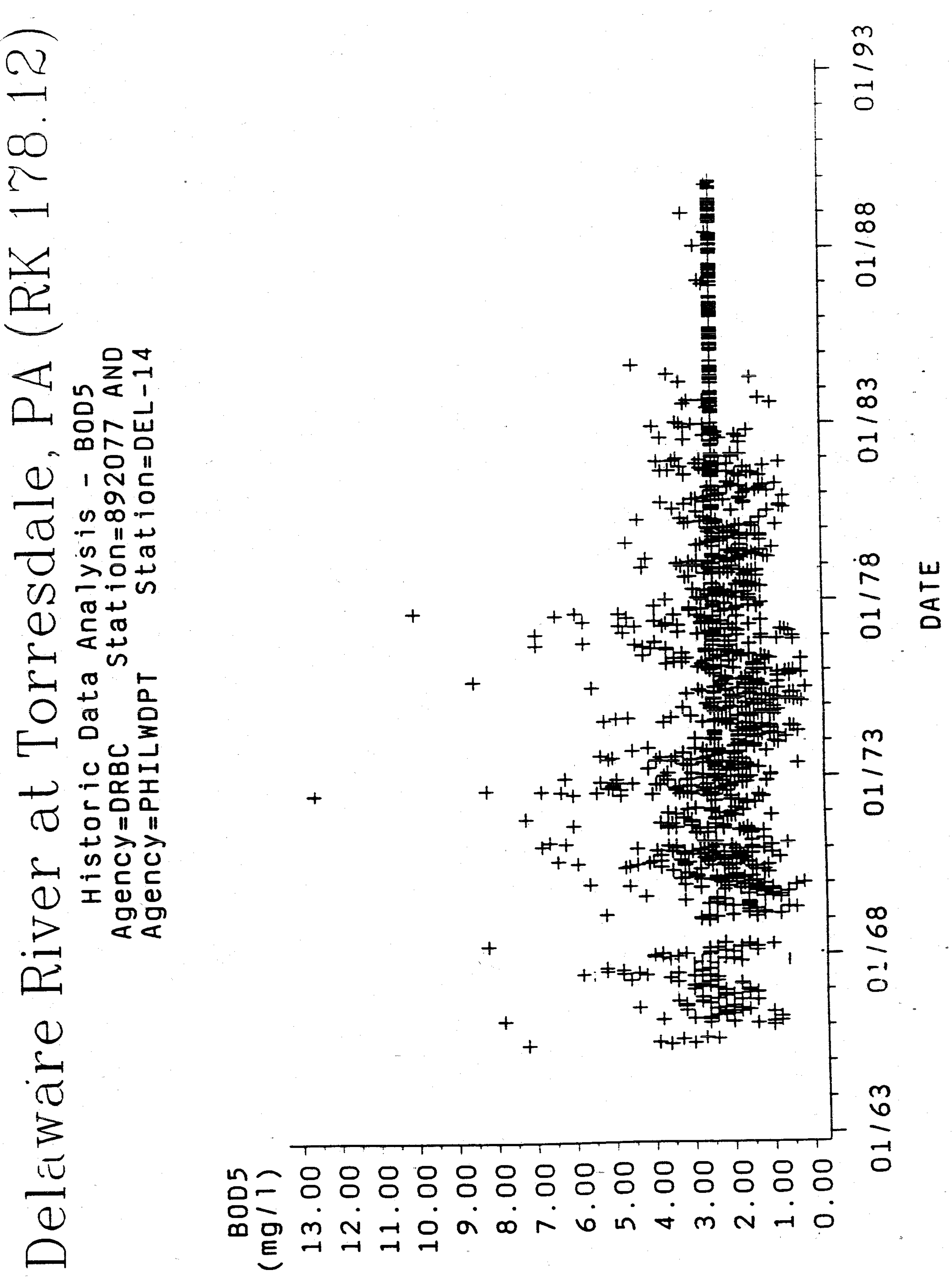


Figure B.7: BOD_5 - Torresdale, Pa

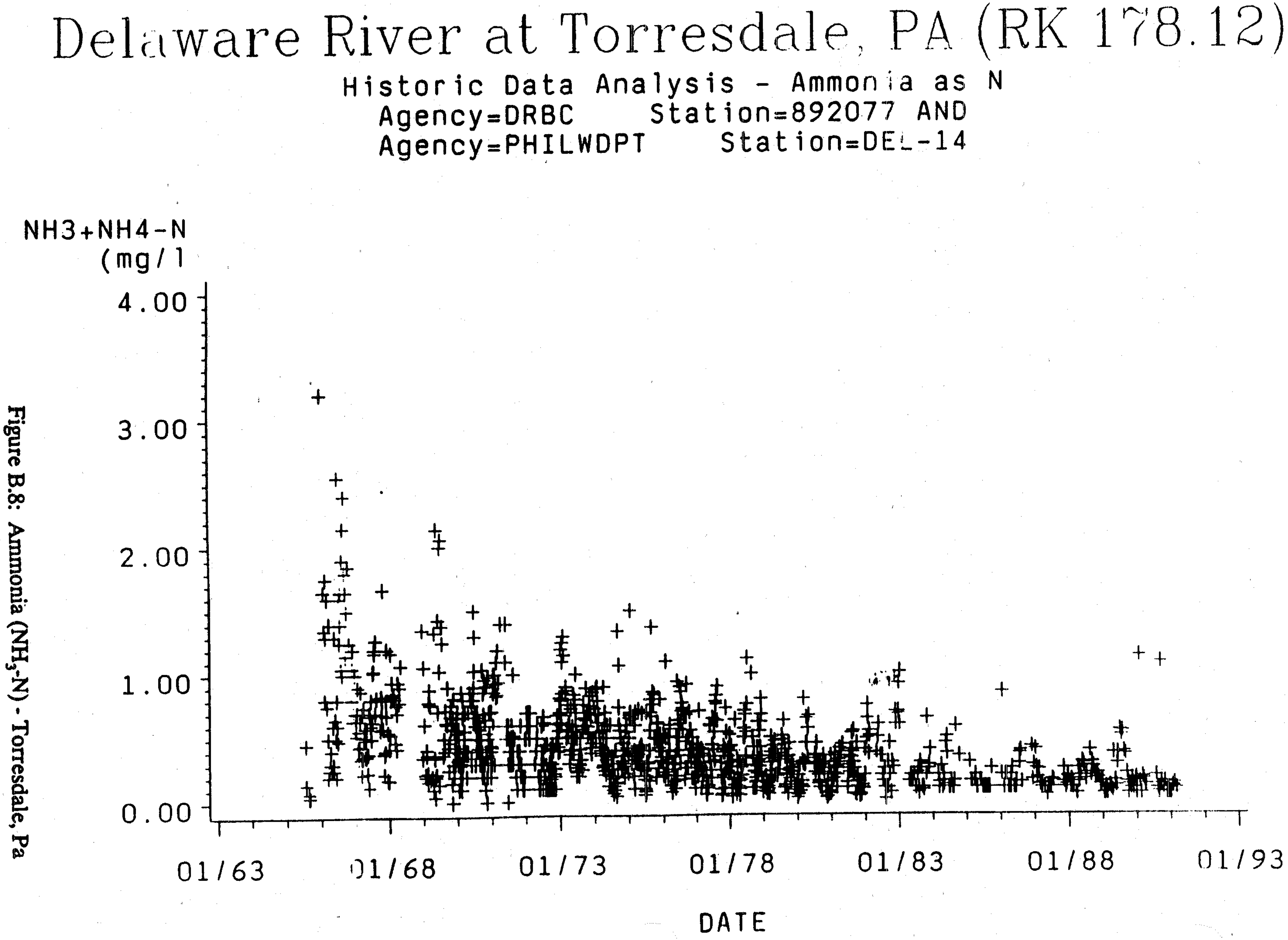


Figure B.8: Ammonia (NH_3-N) - Torresdale, Pa

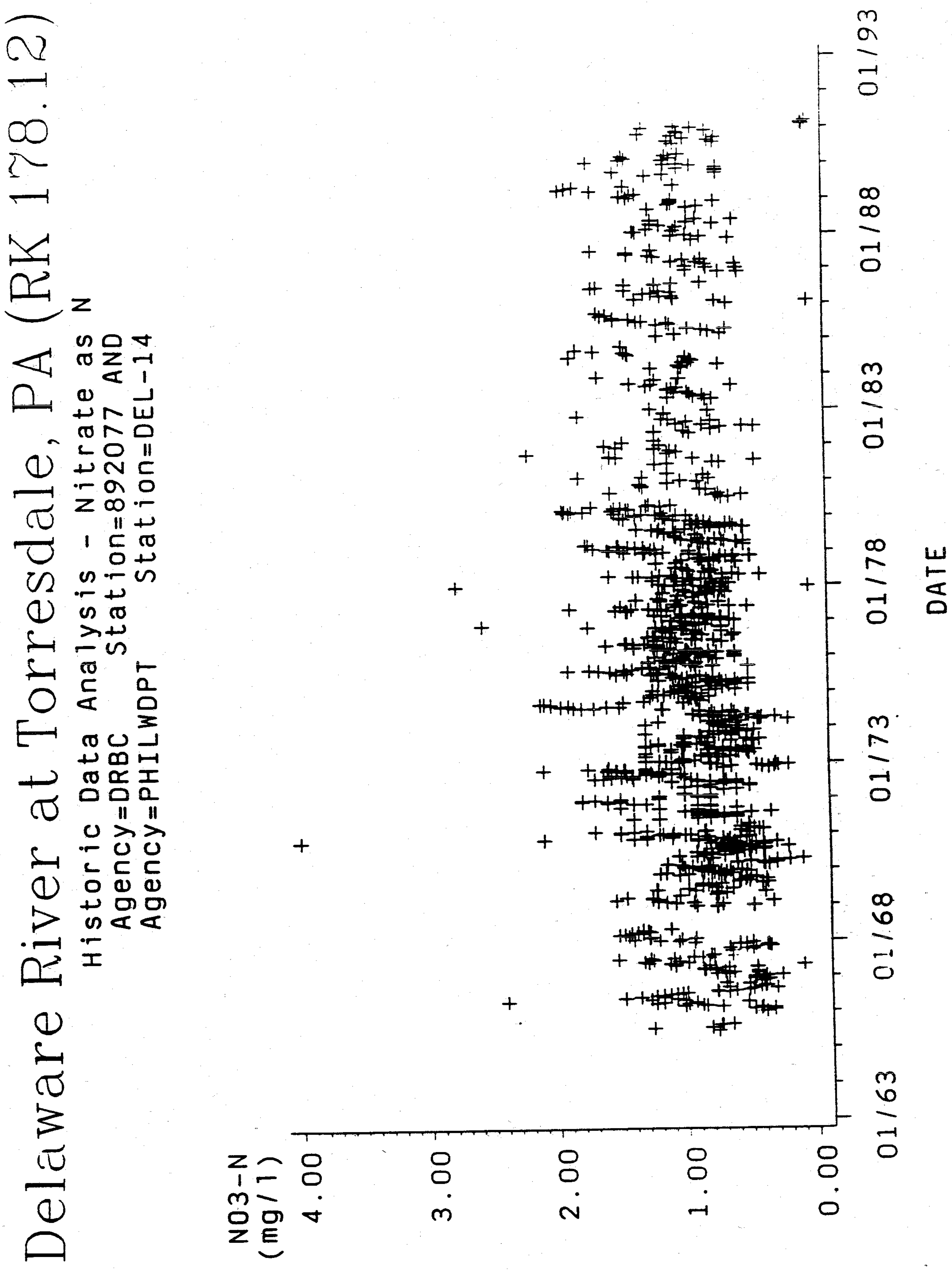


Figure B.9: Nitrate (NO_3-N) - Torresdale, Pa

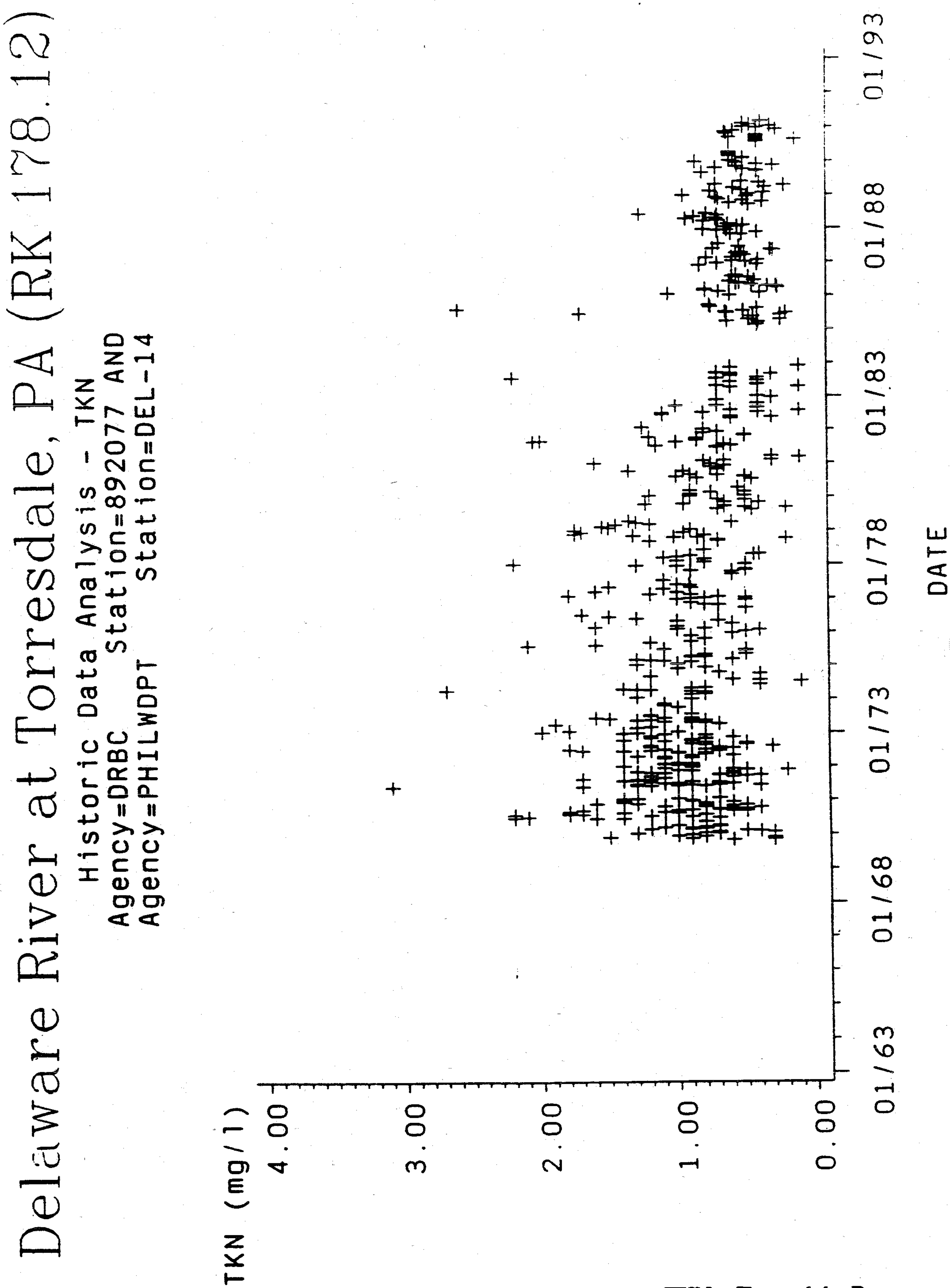


Figure B.10: TKN - Torresdale, Pa

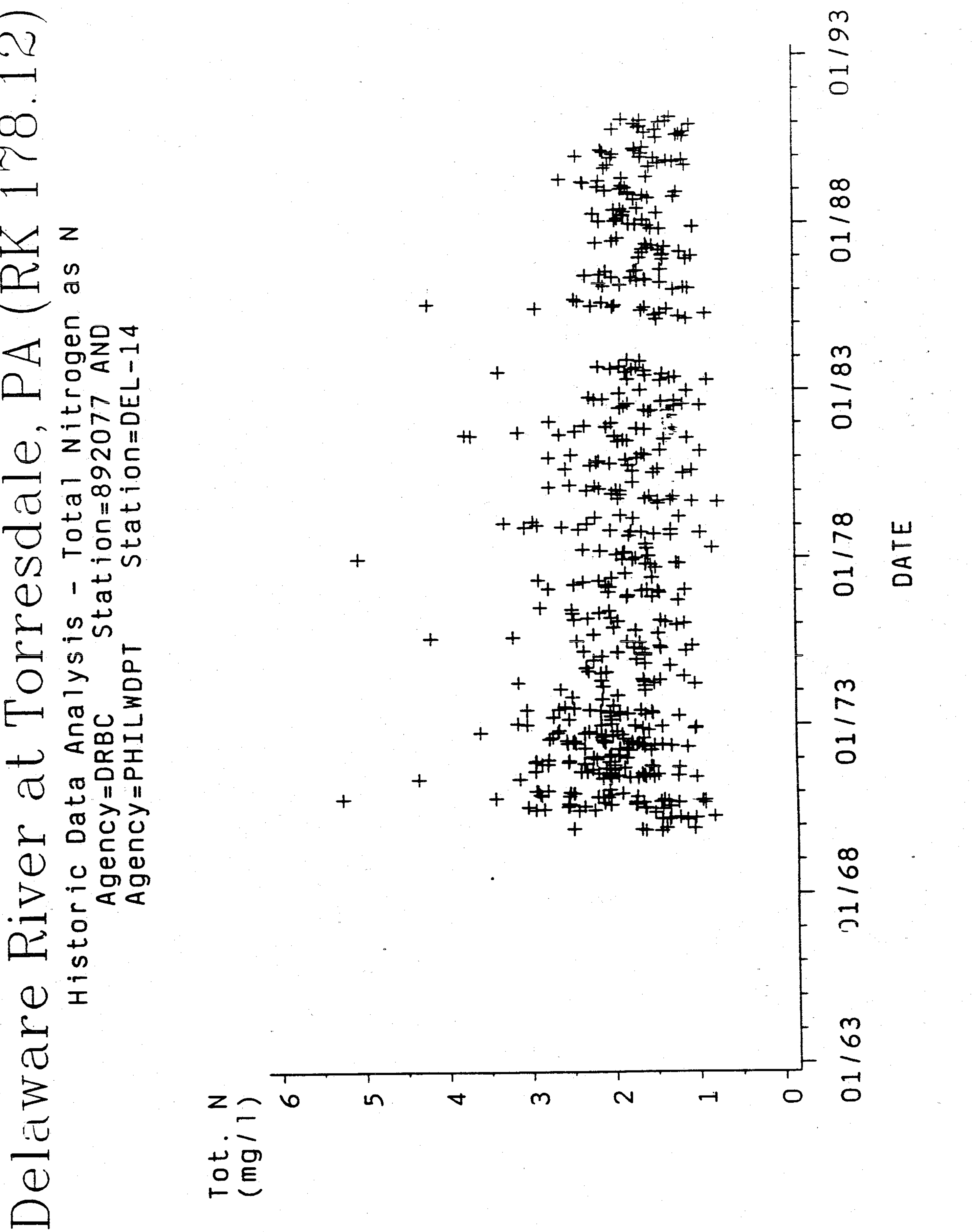


Figure B.11: Total Nitrogen - Torresdale, Pa

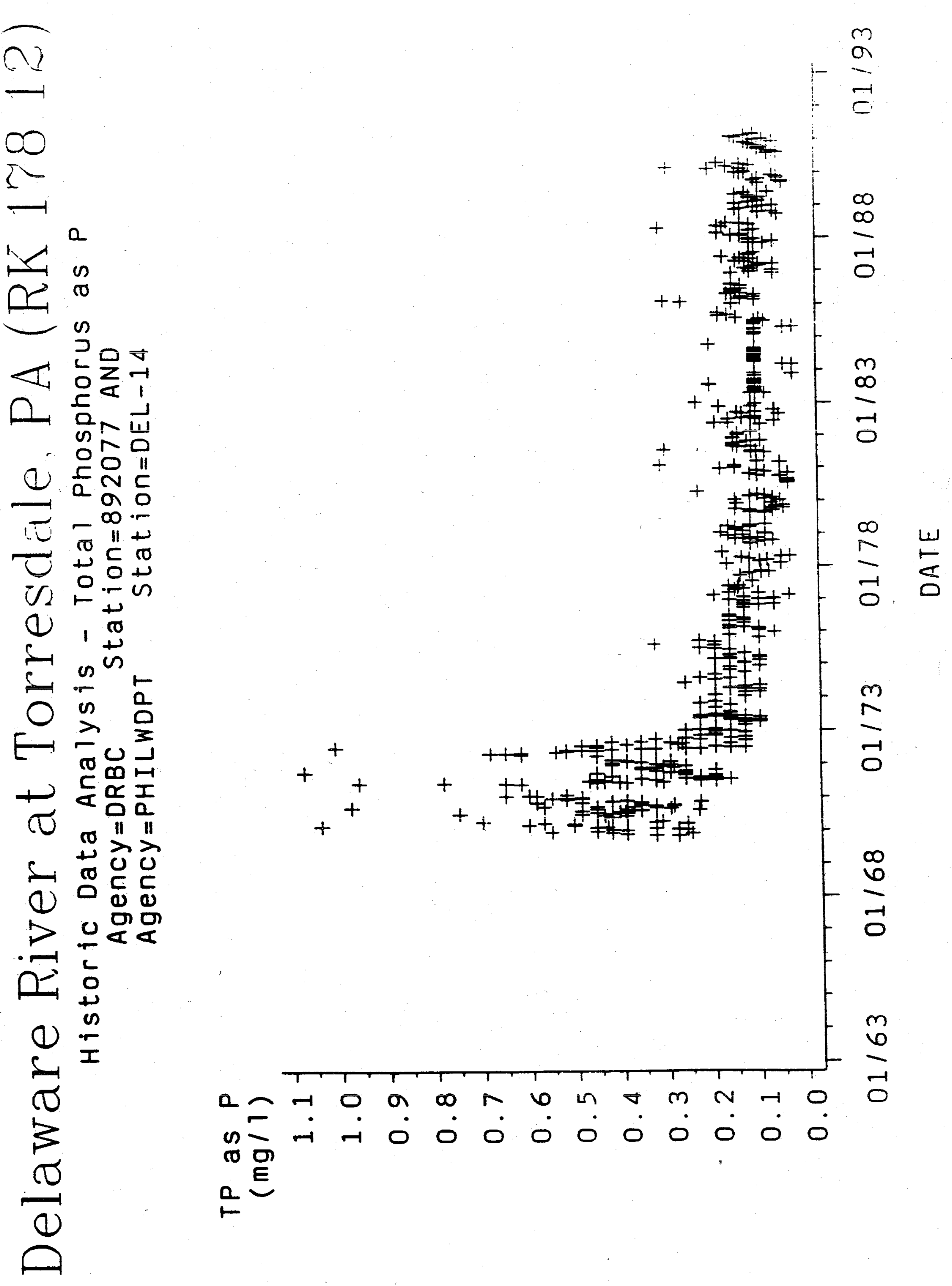


Figure B.12: Total Phosphorus - Torresdale, Pa

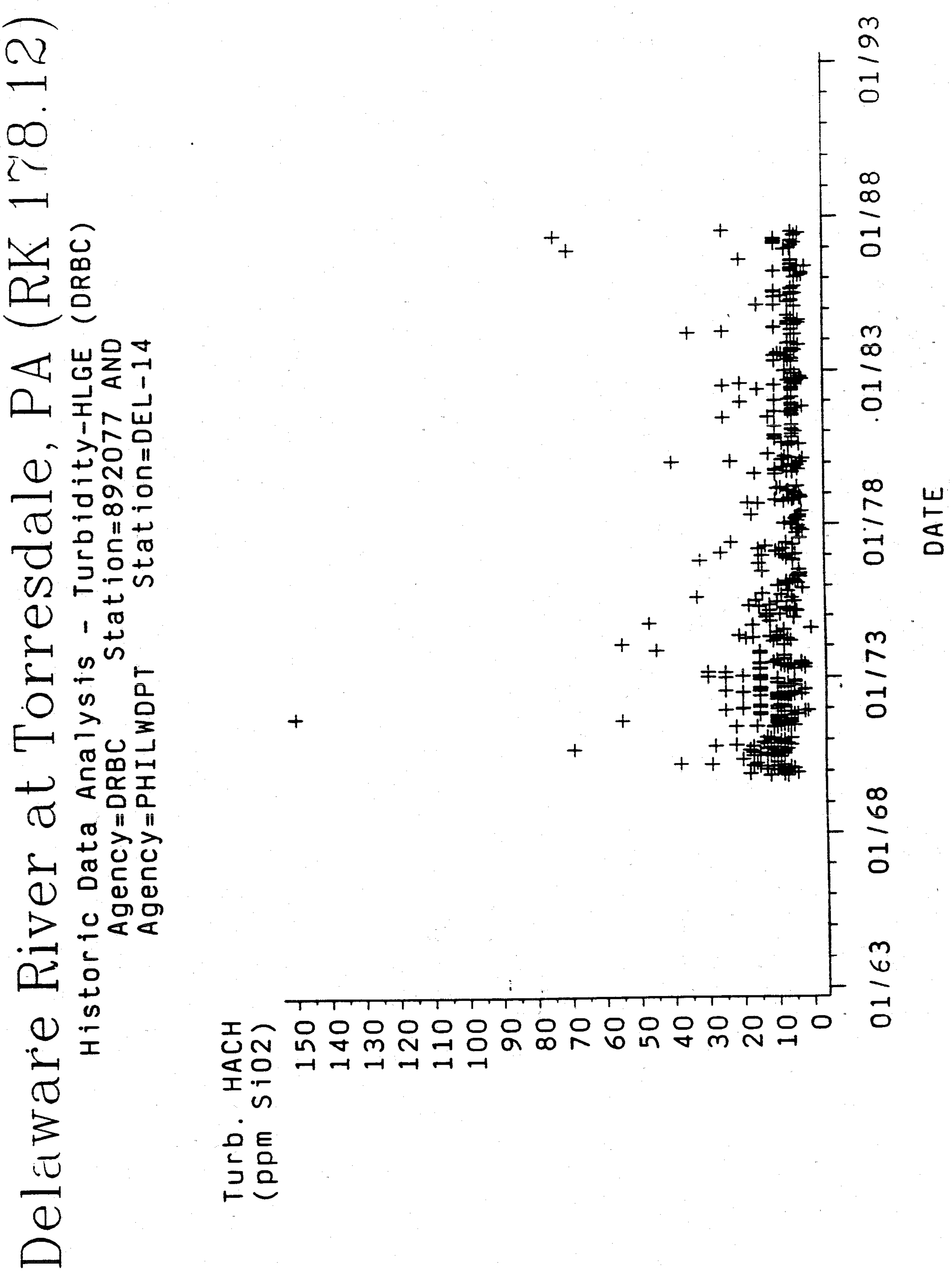


Figure B.13: Turbidity - Torresdale, Pa

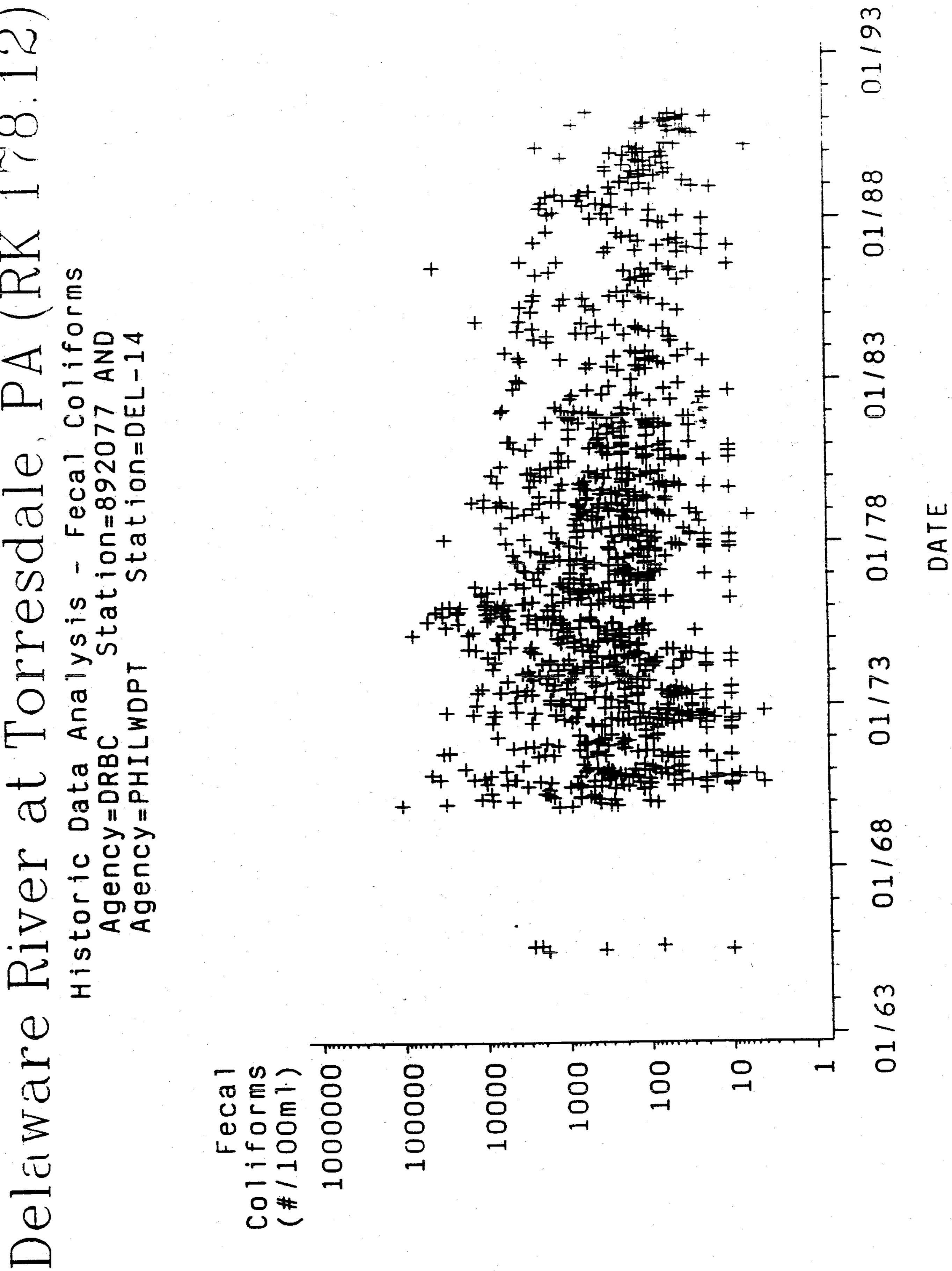


Figure B.14: Fecal Coliform - Torresdale, Pa

30

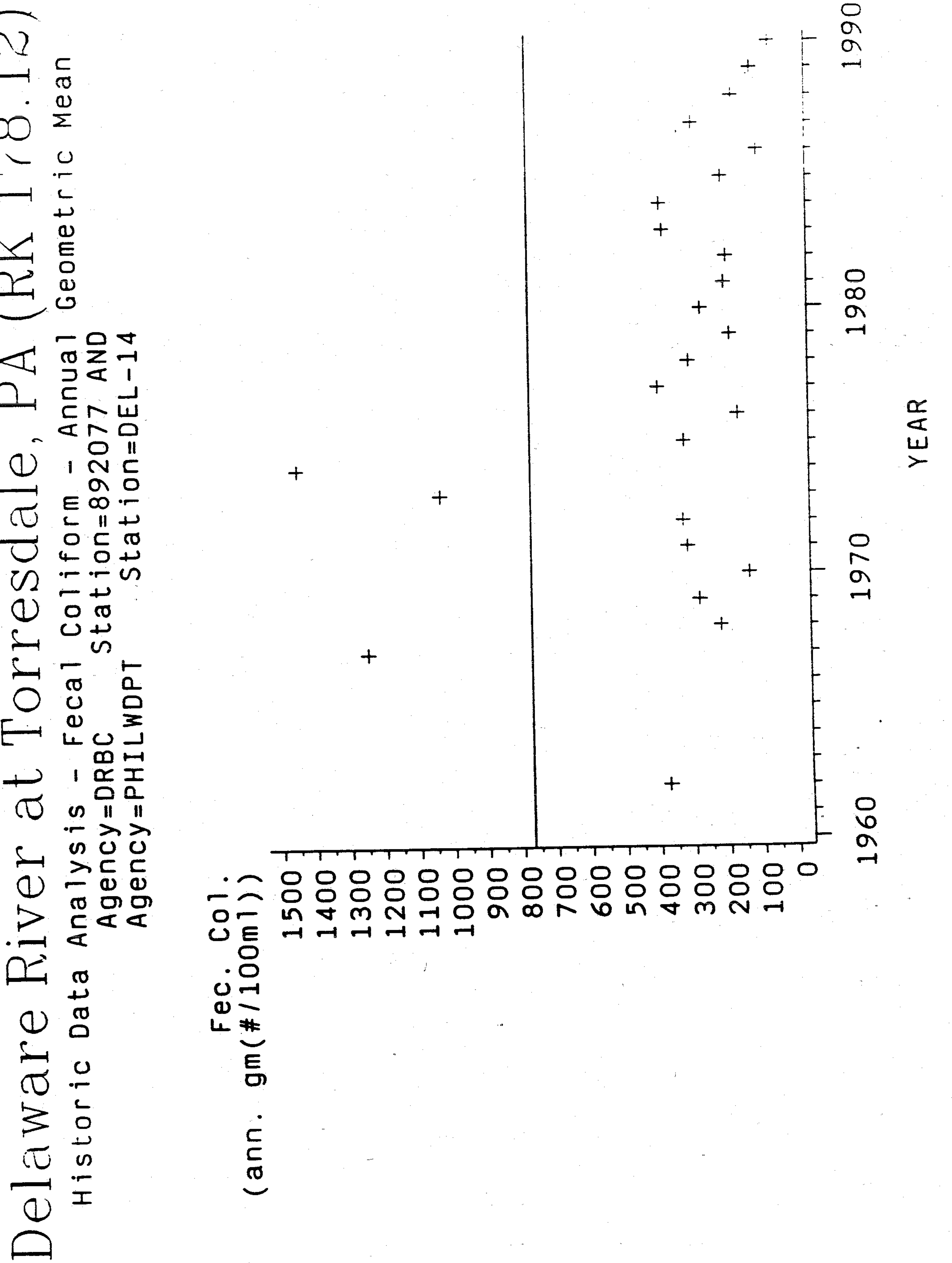


Figure B.15: Annual Geometric Mean FC - Torresdale, Pa

APPENDIX C

DELAWARE RIVER AT NAVY YARD, PHILA. (RK 149.93)

Delaware River at Navy Yard, Phila. (RK 149.93)

Historic Data Analysis - Dissolved Oxygen
Agency=DRBC Station=892065 AND
Agency=PHILWDPT Station=DEL- 4

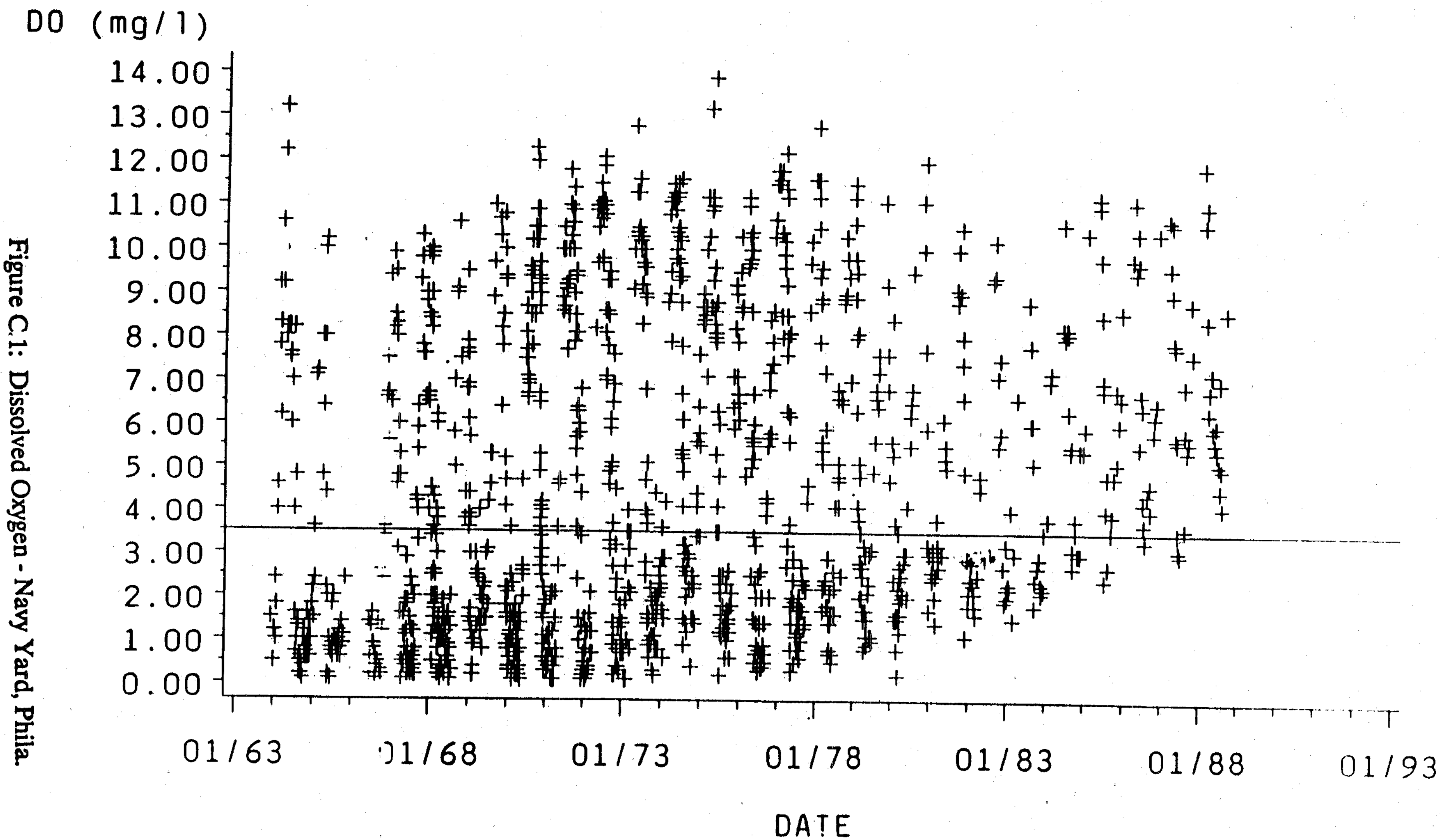


Figure C.1: Dissolved Oxygen - Navy Yard, Phila.

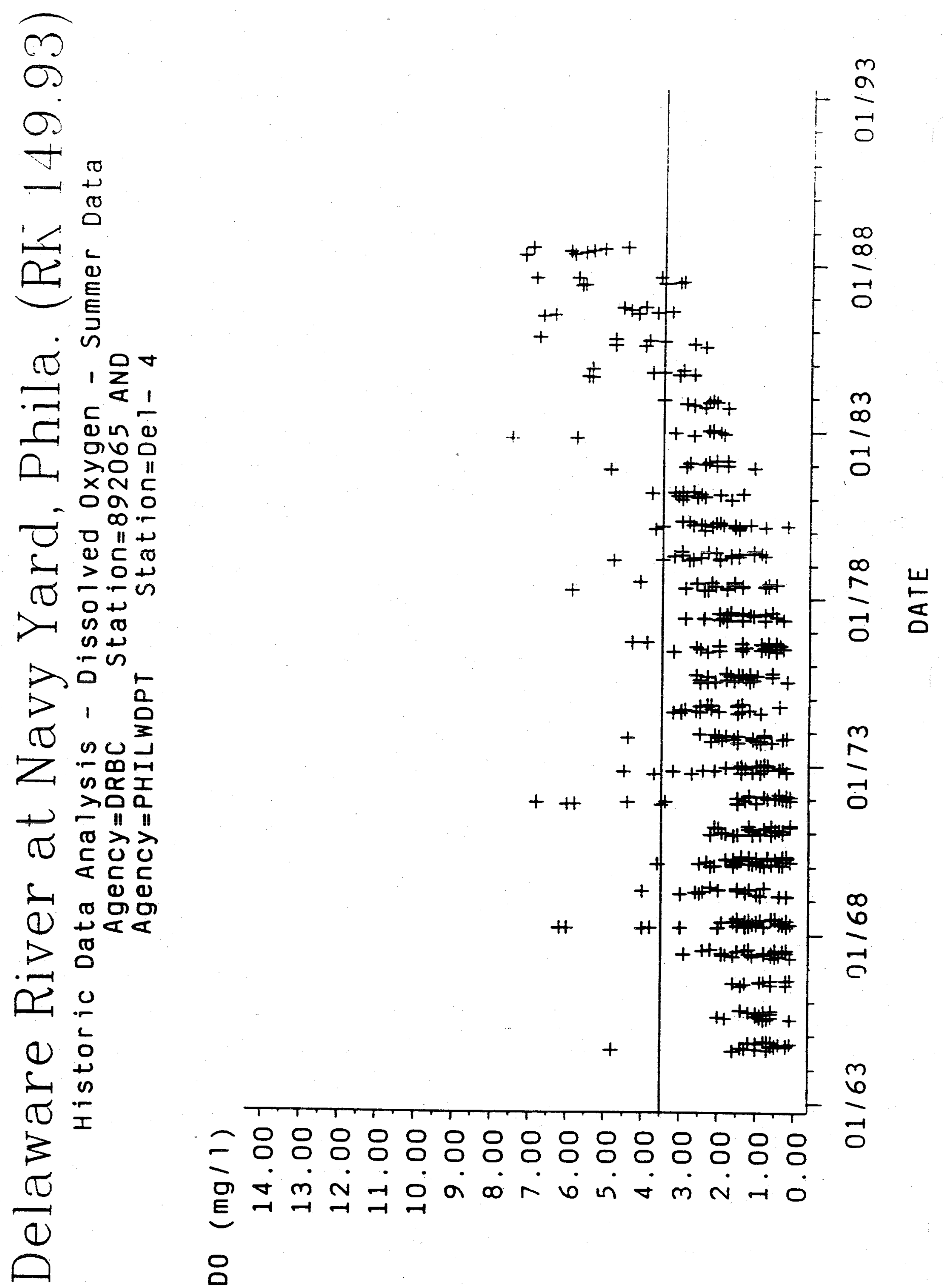


Figure C.2: Summer Dissolved Oxygen - Navy Yard, Phila.

Delaware River at Navy Yard, Phila. (RK 149.93)

Historic Data Analysis - Temperature
Agency=DRBC Station=892065 AND
Agency=PHILWDPT Station=Del- 4

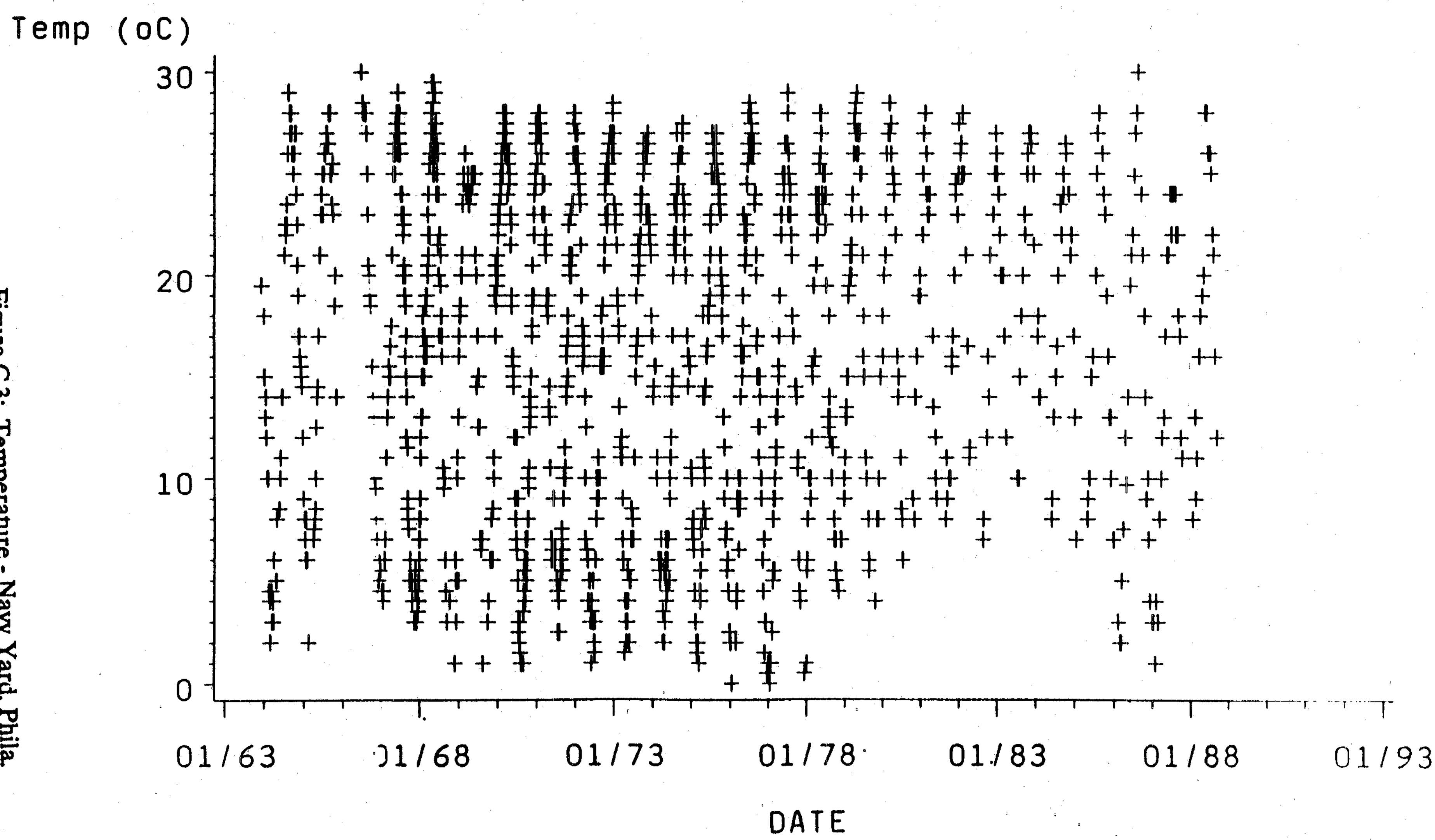


Figure C.3: Temperature - Navy Yard, Phila.

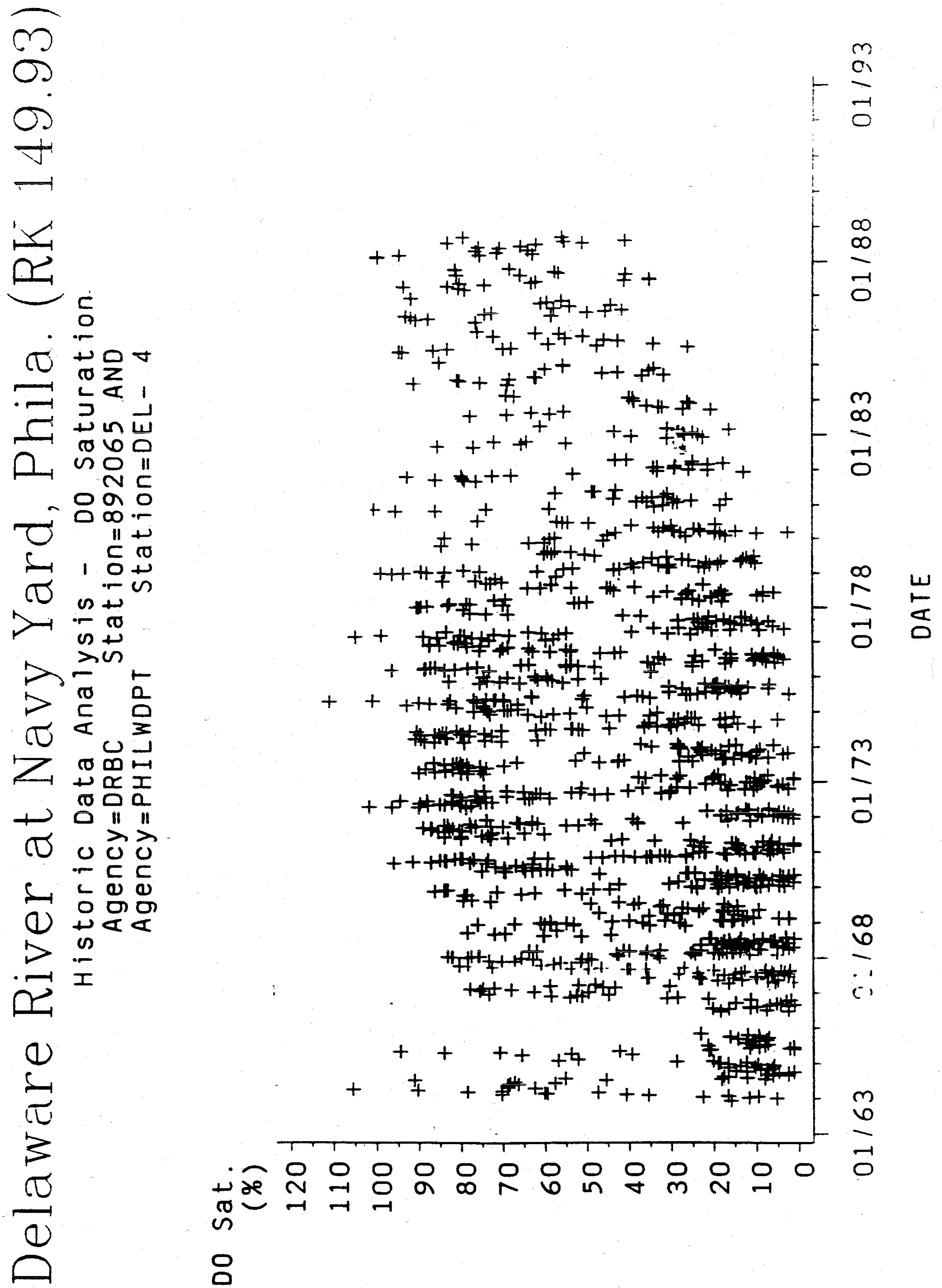


Figure C.4: DO Percent Saturation - Navy Yard, Phila.

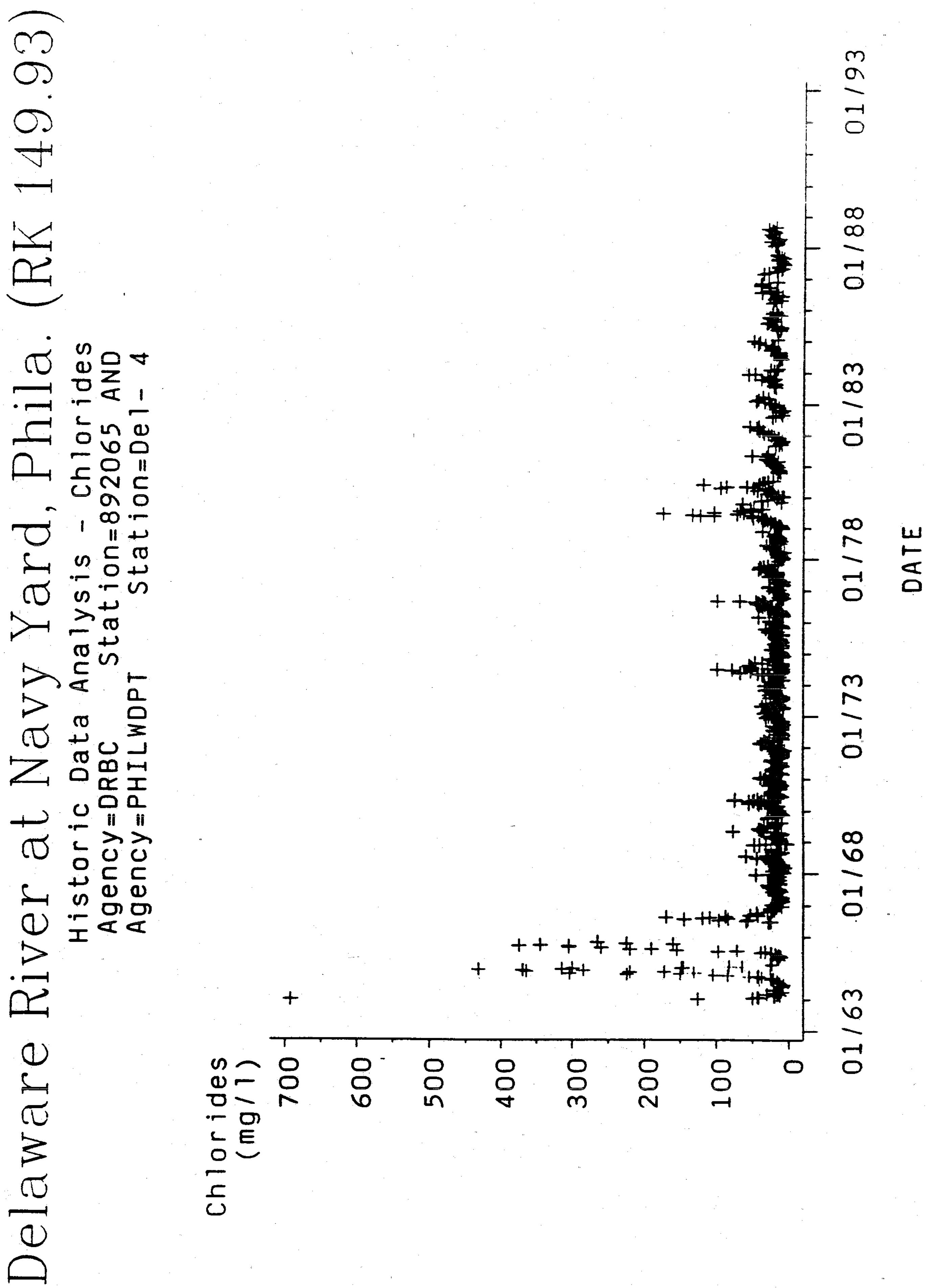


Figure C.5: Chlorides - Navy Yard, Phila.

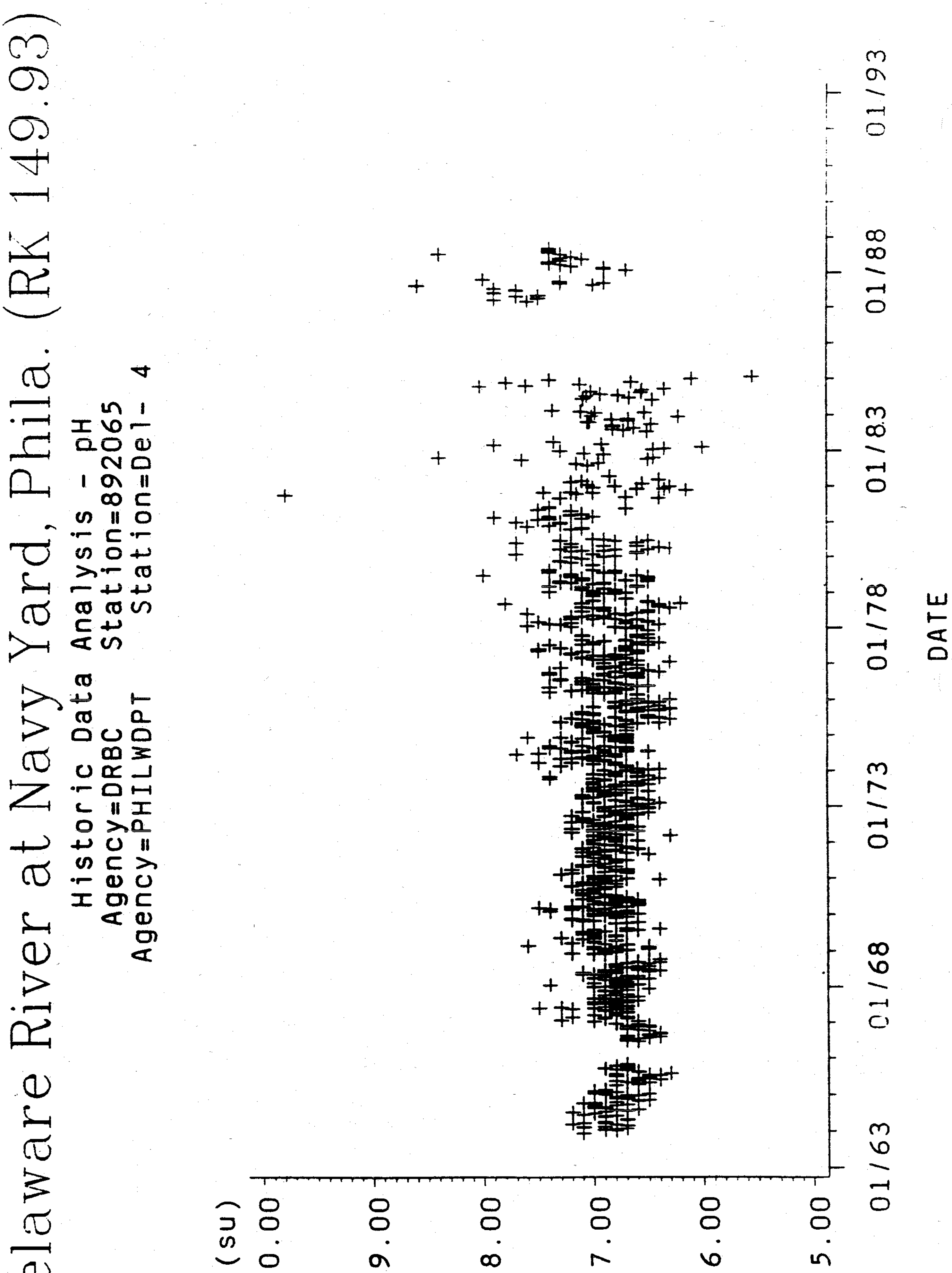


Figure C.6: pH - Navy Yard, Phila.

Delaware River at Navy Yard, Phila. (RK 149.93)

Historic Data Analysis - BOD5
Agency=DRBC Station=892065 AND
Agency=PHILWDPT Station=Del- 4

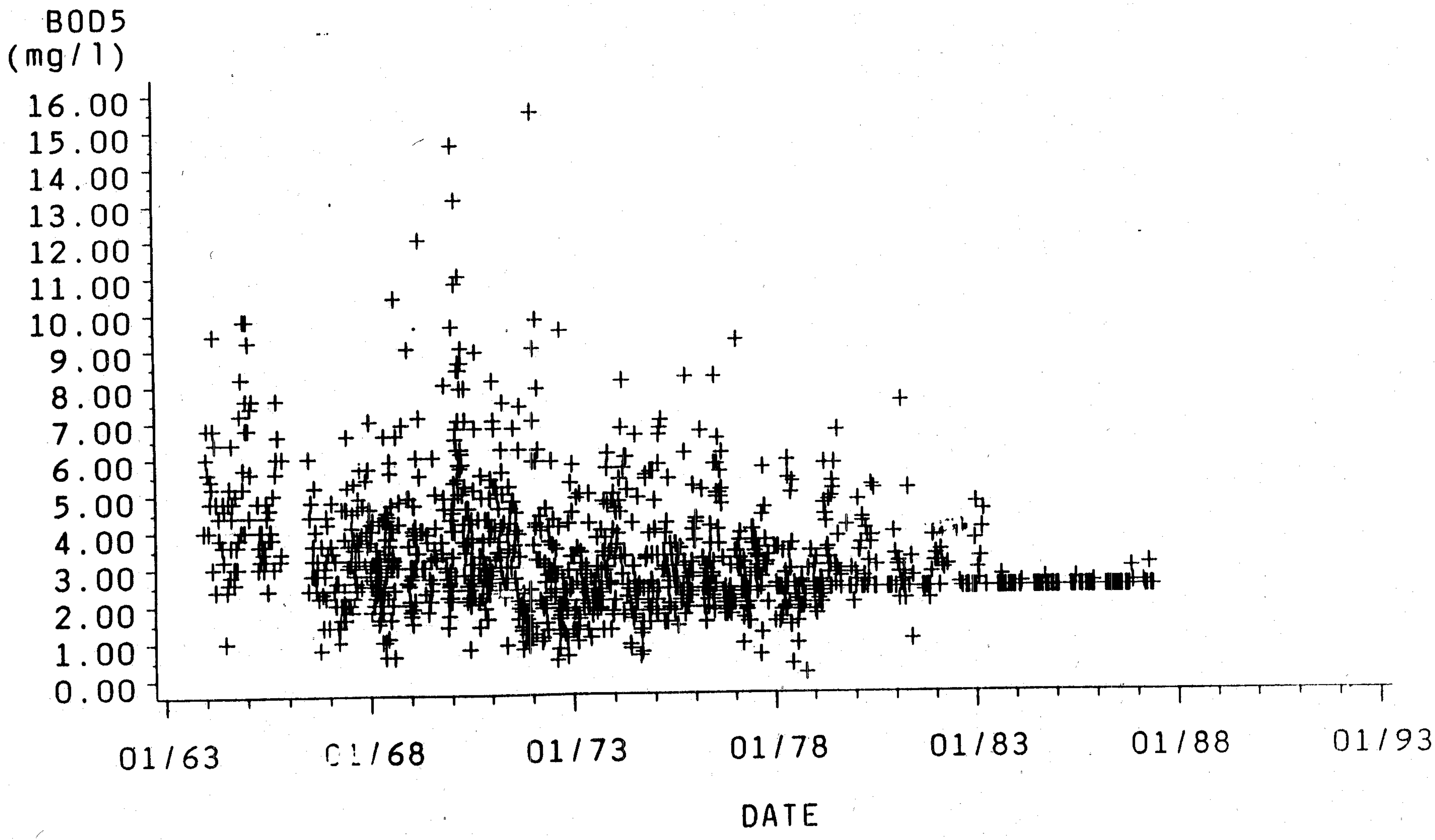


Figure C.7: BOD_5 - Navy Yard, Phila.

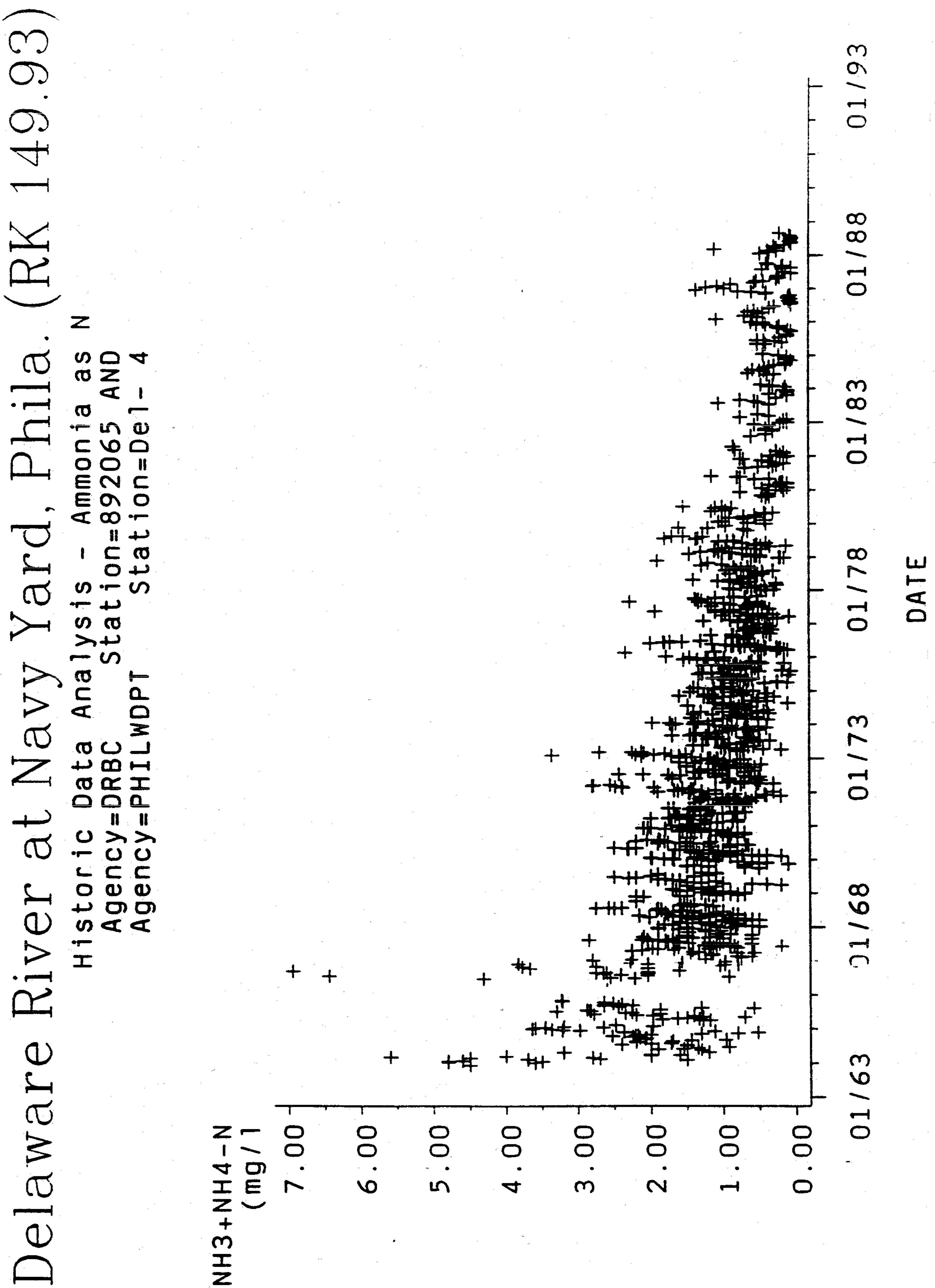


Figure C.8: Ammonia (NH_3-N) - Navy Yard, Phila.

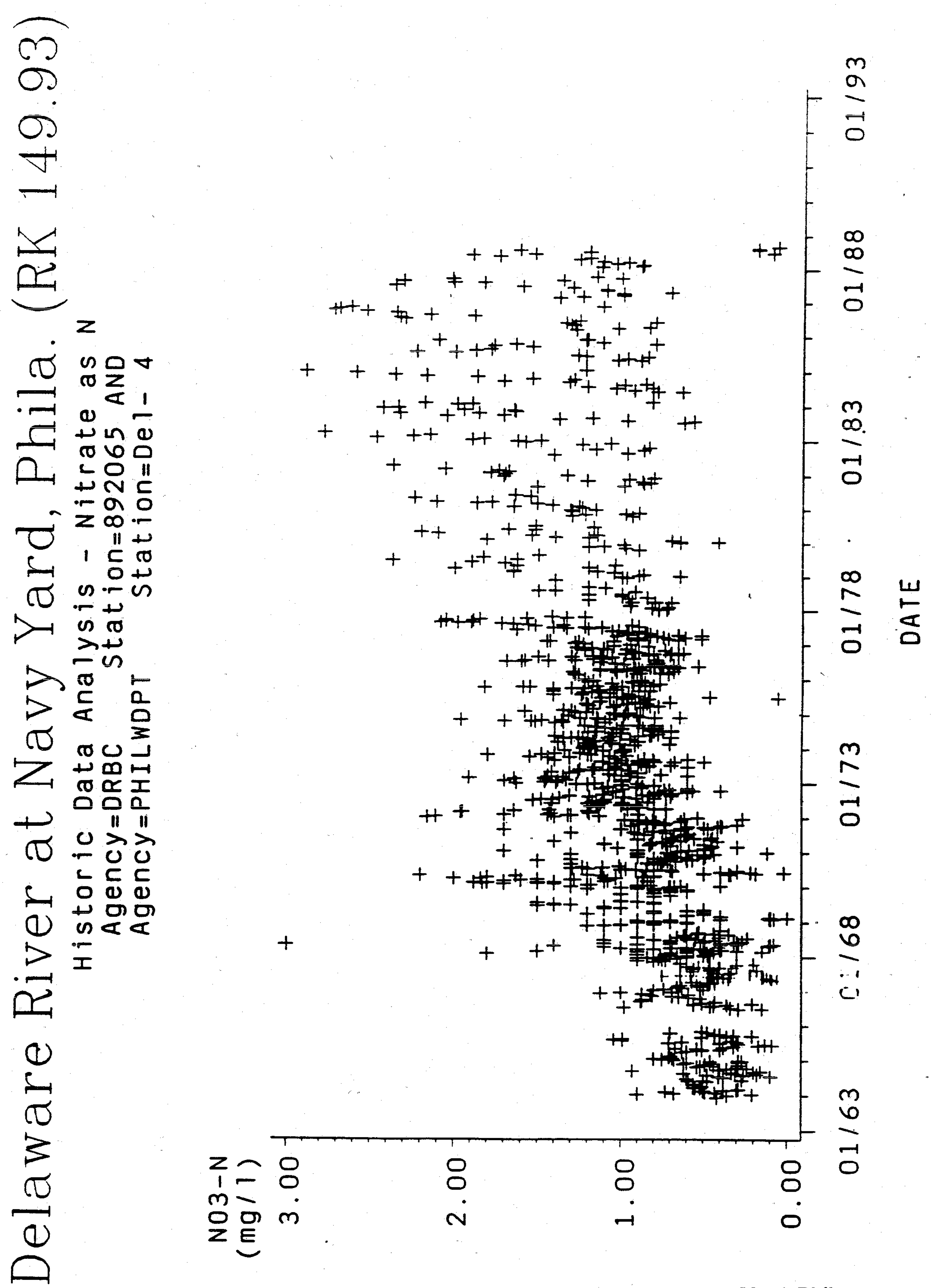


Figure C.9: Nitrate (NO_3-N) - Navy Yard, Phila.

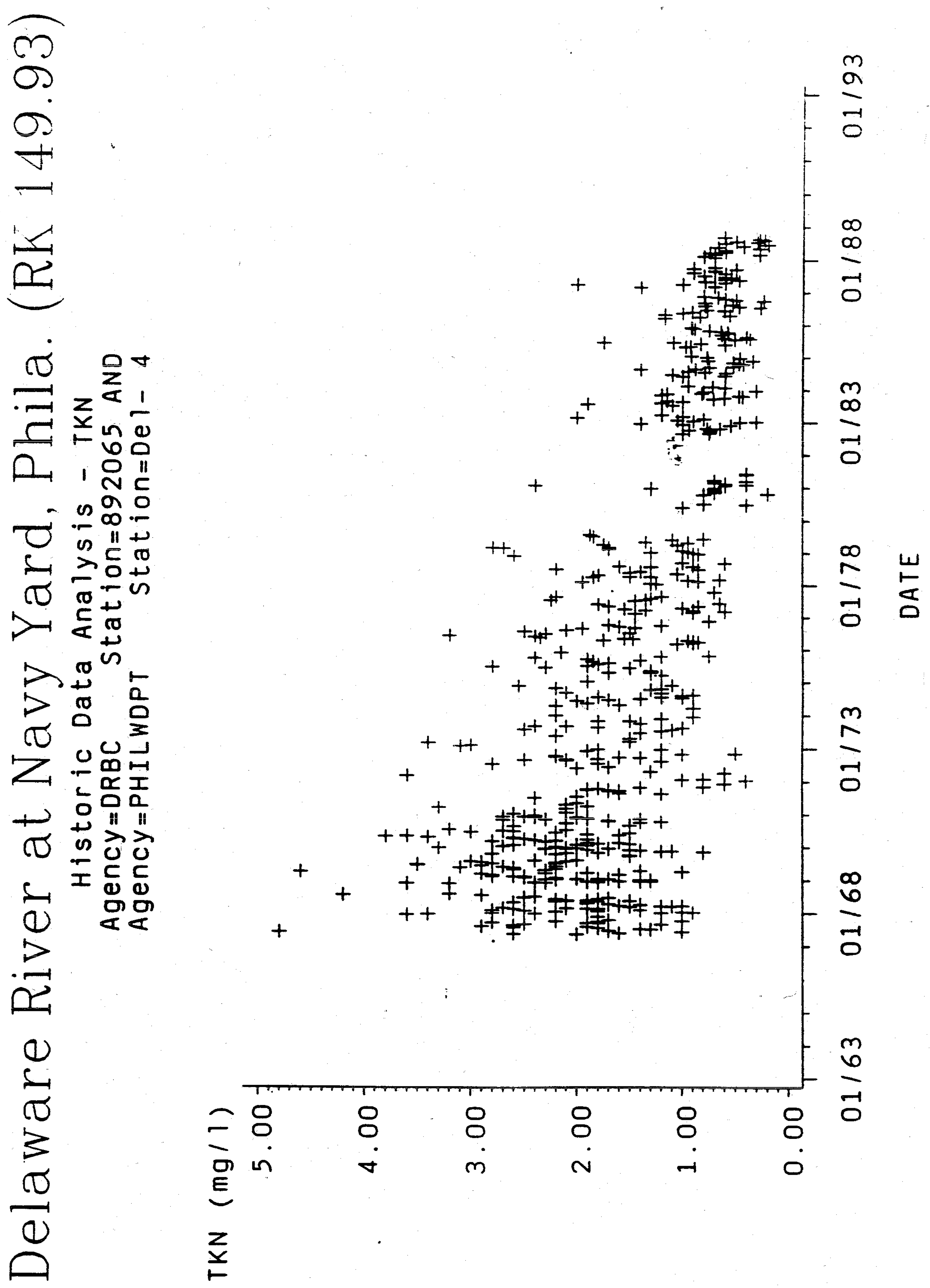


Figure C.10: TKN - Navy Yard, Phila.

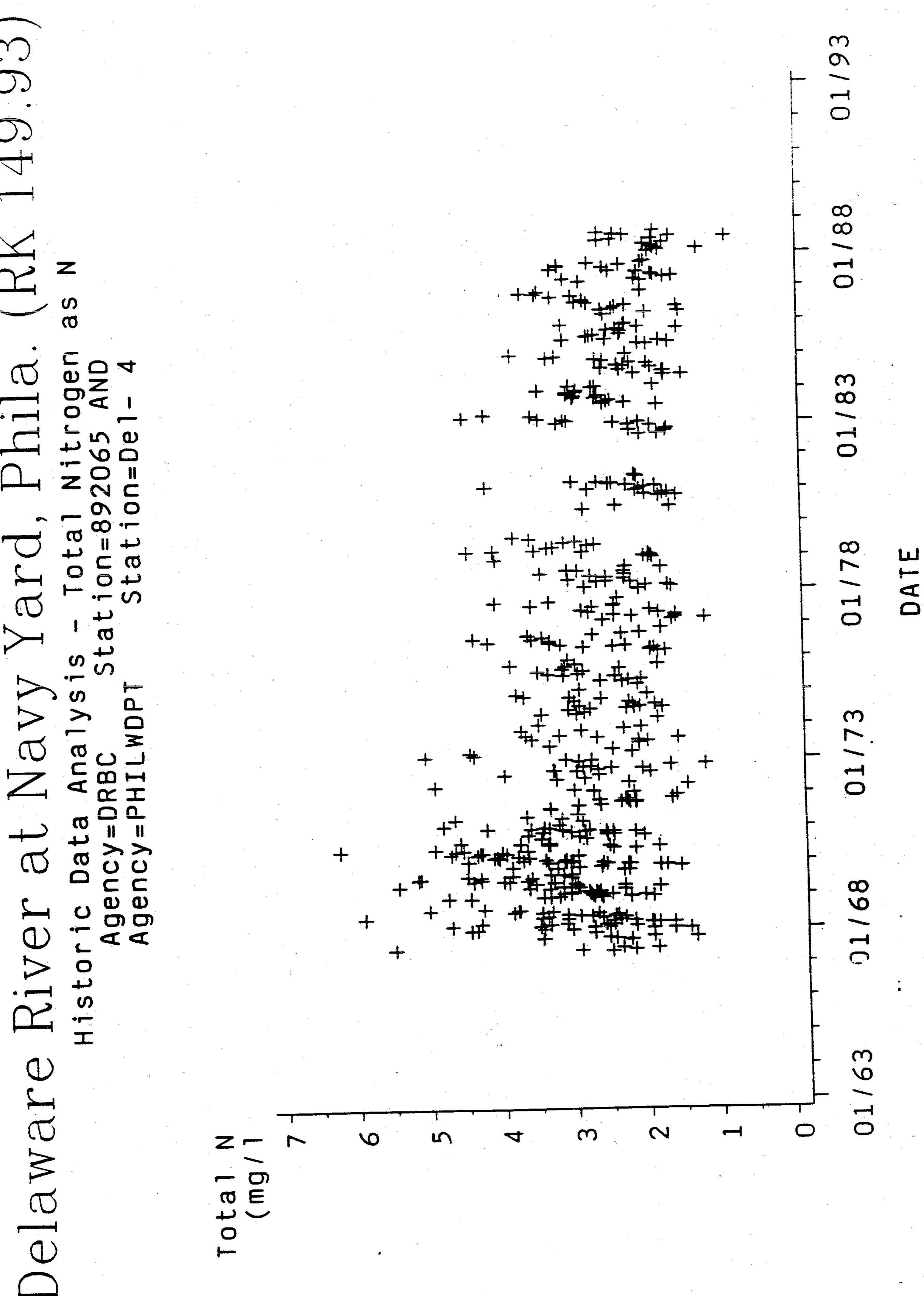


Figure C.11: Total Nitrogen - Navy Yard, Phila.

Delaware River at Navy Yard, Phila. (RK 149.93)

Historic Data Analysis - Total Phosphorus as P
Agency=DRBC Station=892065 AND
Agency=PHILWDPT Station=Del- 4

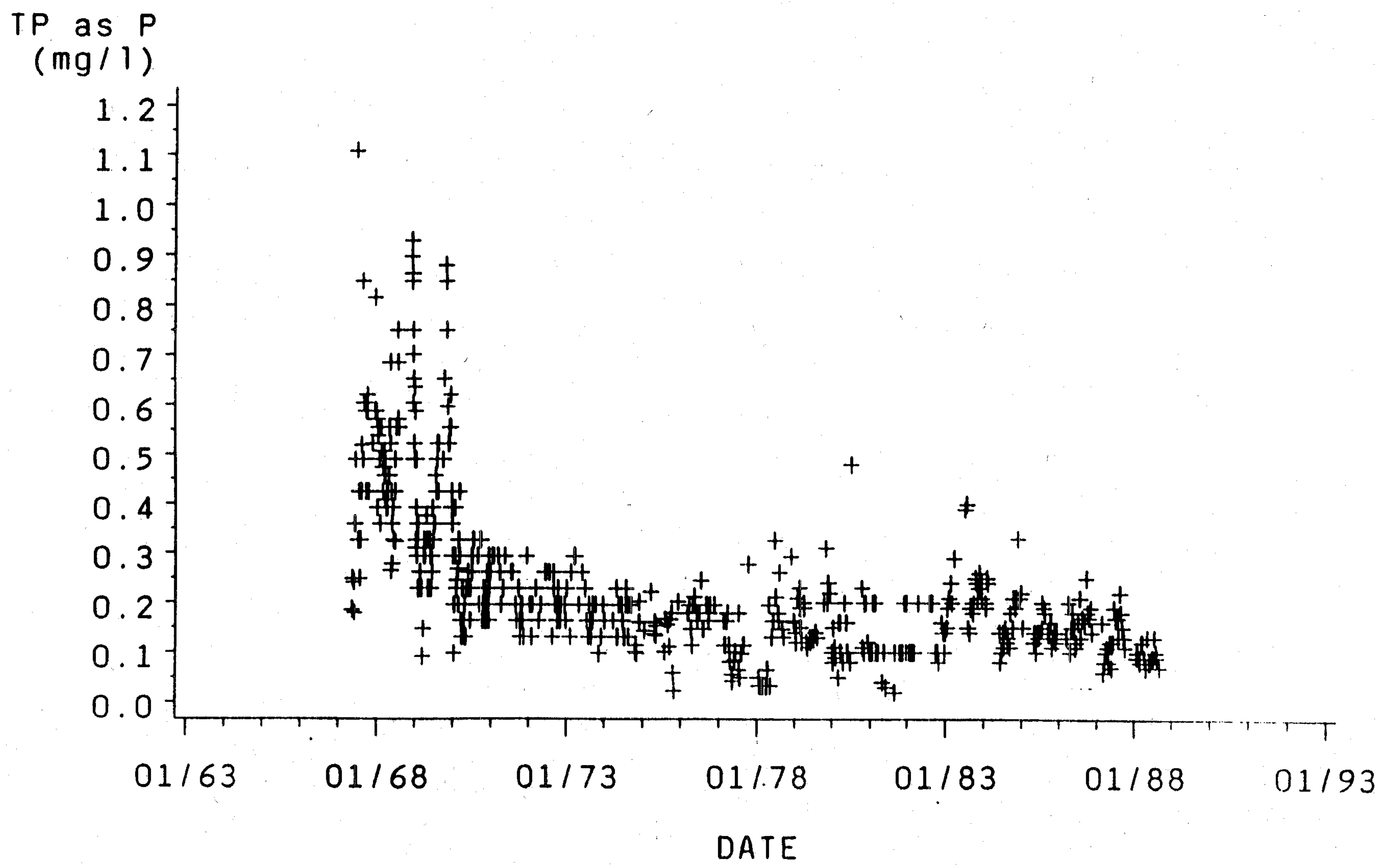


Figure C.12: Total Phosphorus - Navy Yard, Phila.

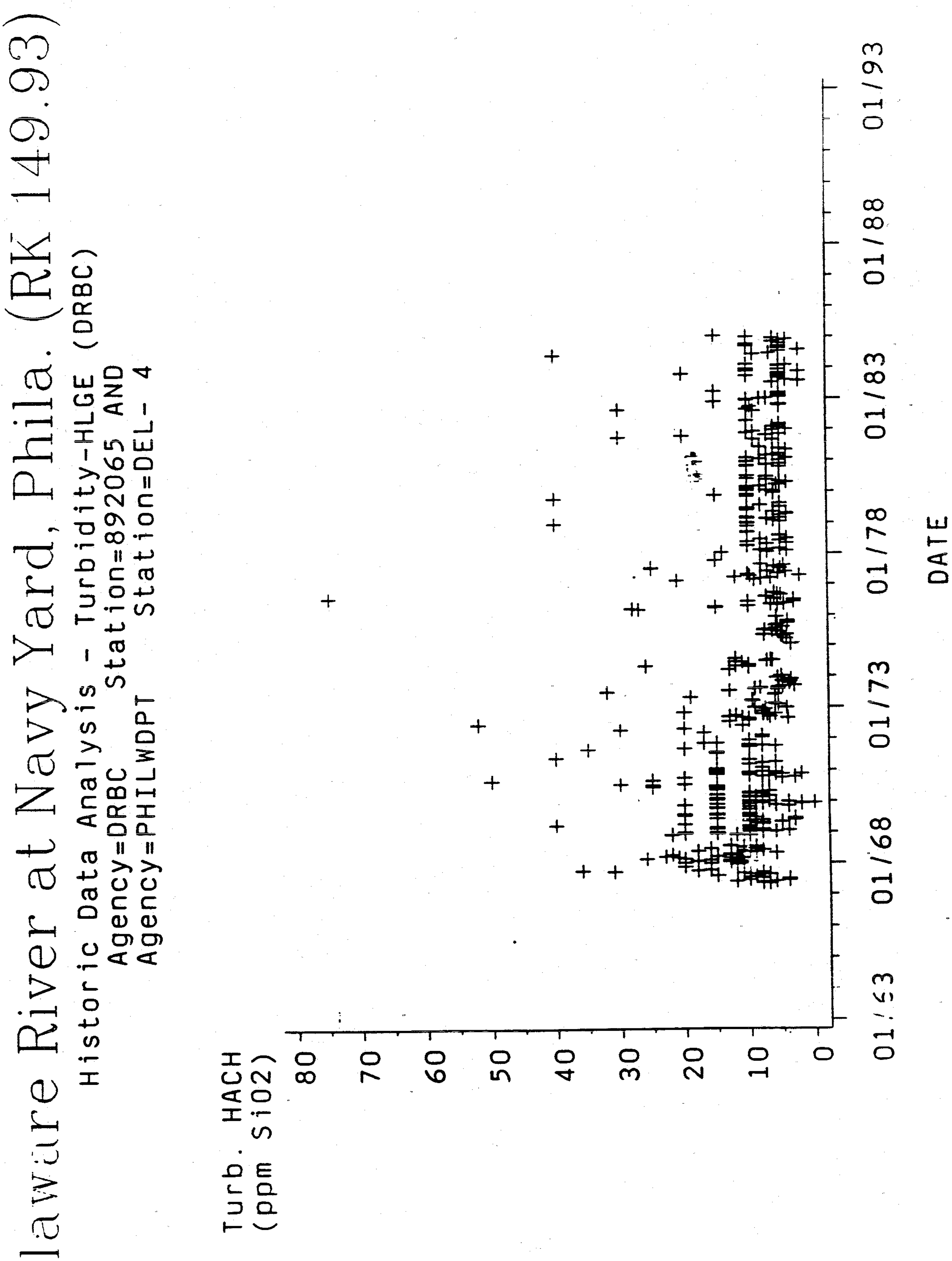


Figure C.13: Turbidity - Navy Yard, Phila.

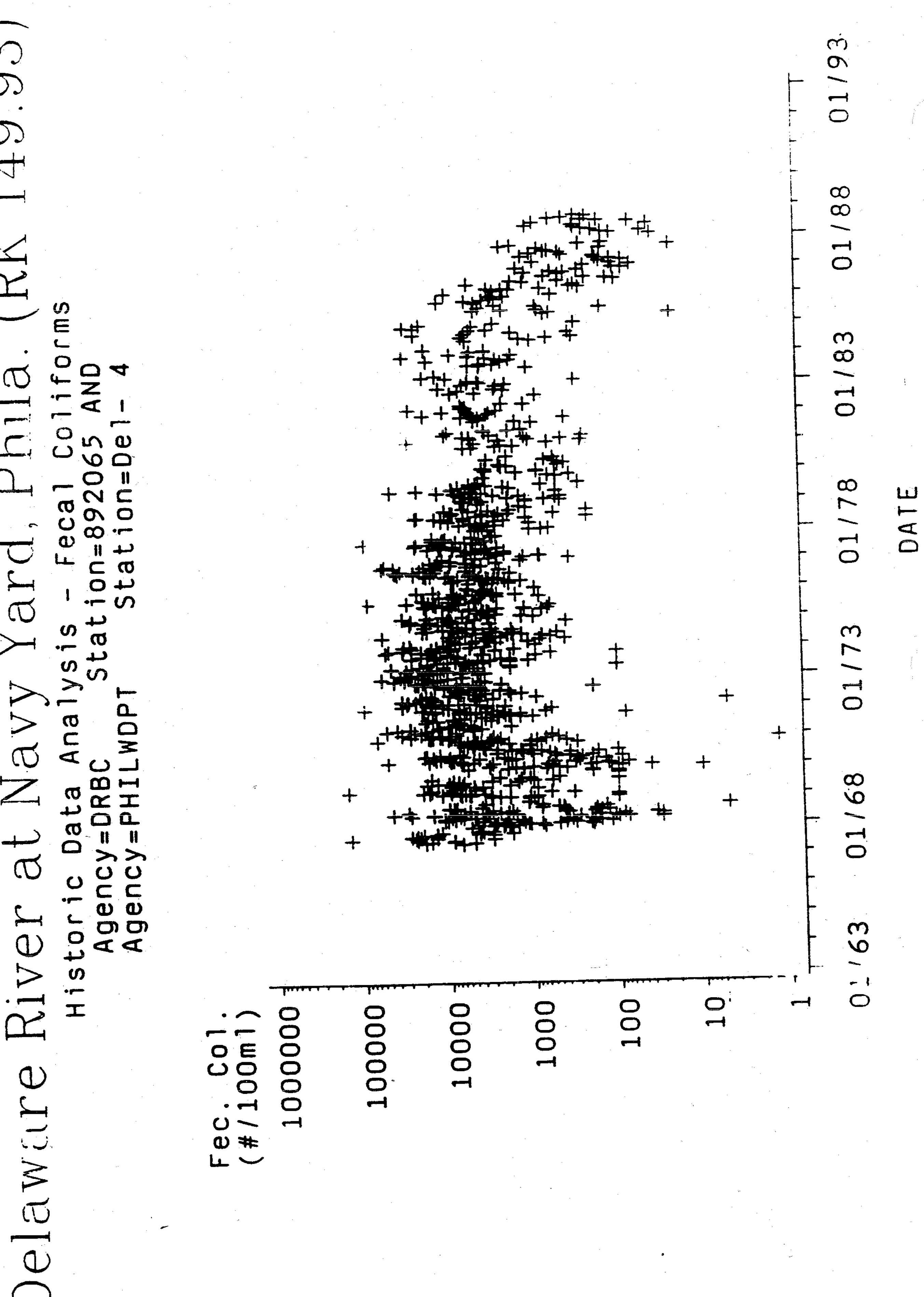


Figure C.14: Fecal Coliform - Navy Yard, Phila.

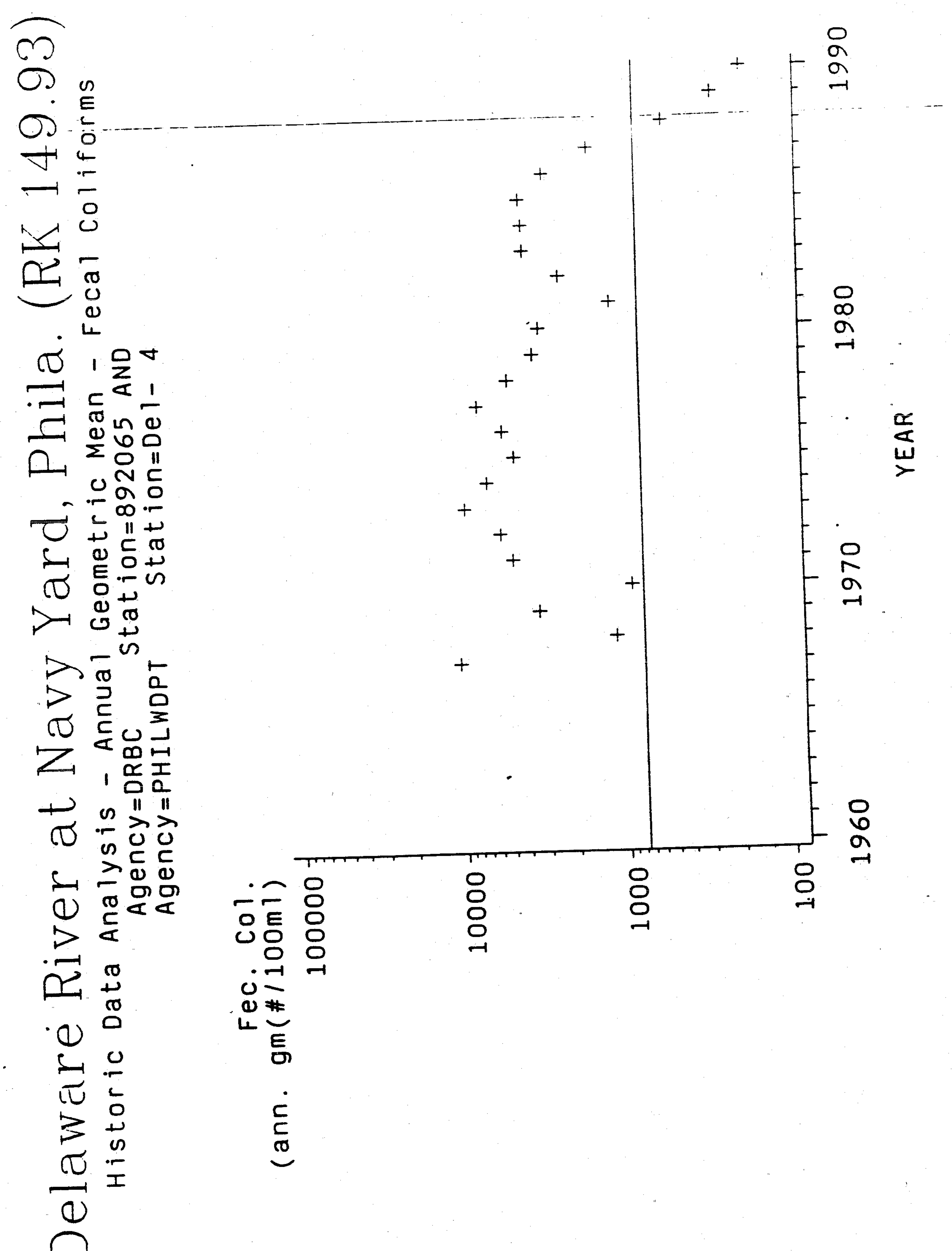


Figure C.15: Annual Geometric Mean FC - Navy Yard, Phila.

APPENDIX D

DELAWARE RIVER AT EDDYSTONE, PA (RK)

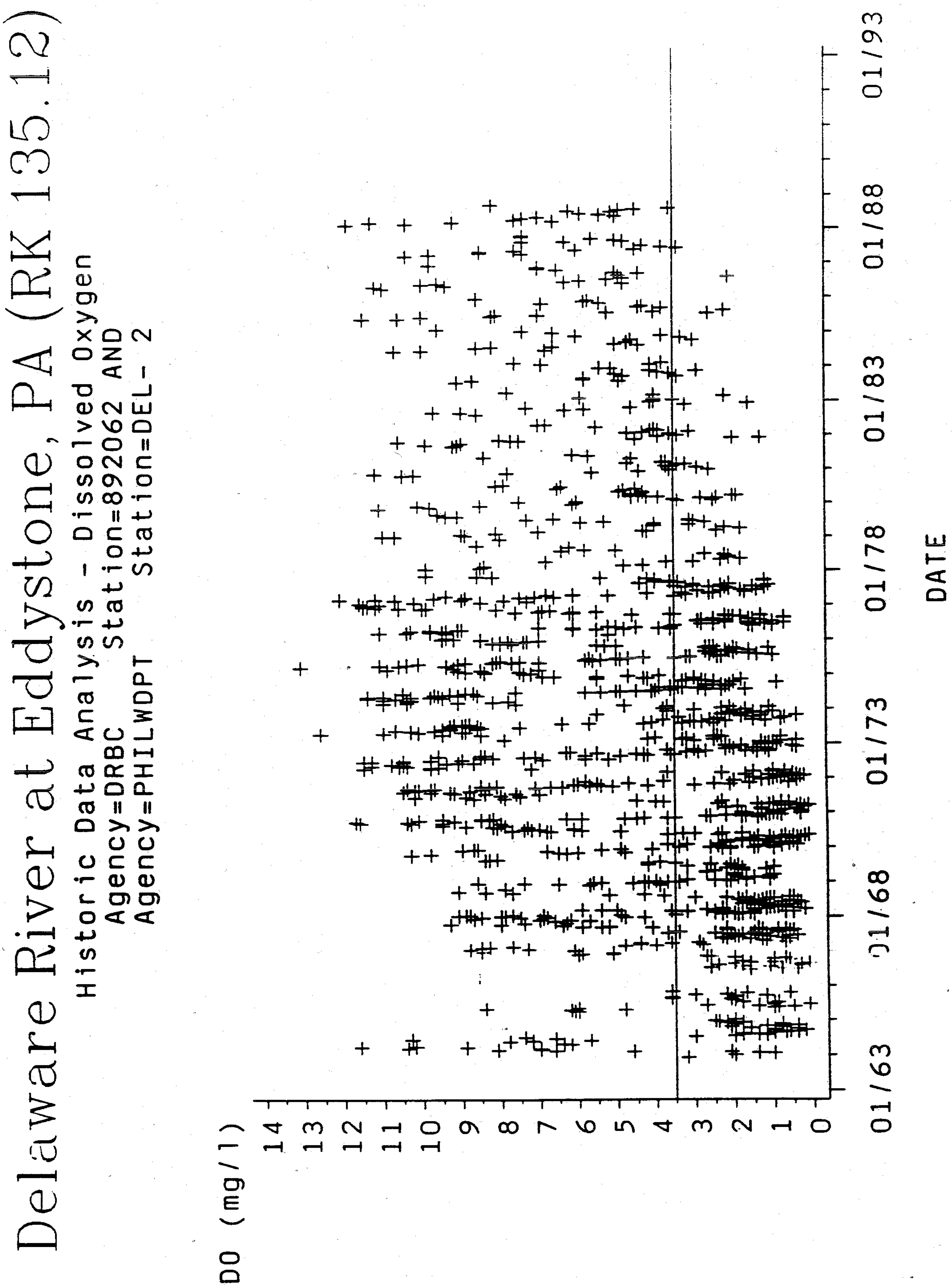


Figure D.1: Dissolved Oxygen - Eddystone, PA

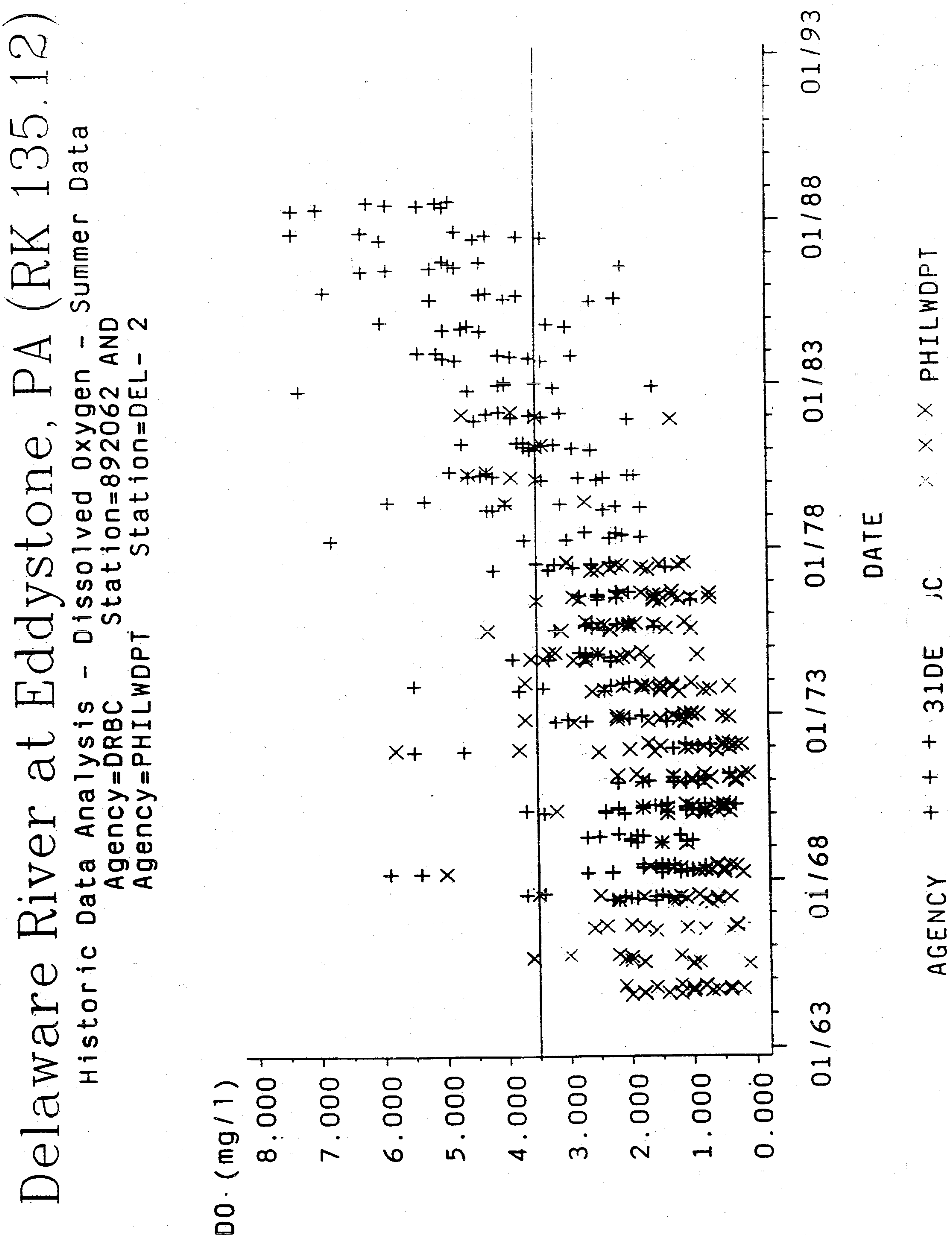


Figure D.2: Summer Dissolved Oxygen - Eddystone, PA

Delaware River at Eddystone, PA (RK 135.12)

Historic Data Analysis - Temperature
Agency=DRBC Station=892062 AND
Agency=PHILWDPT Station=DEL- 2

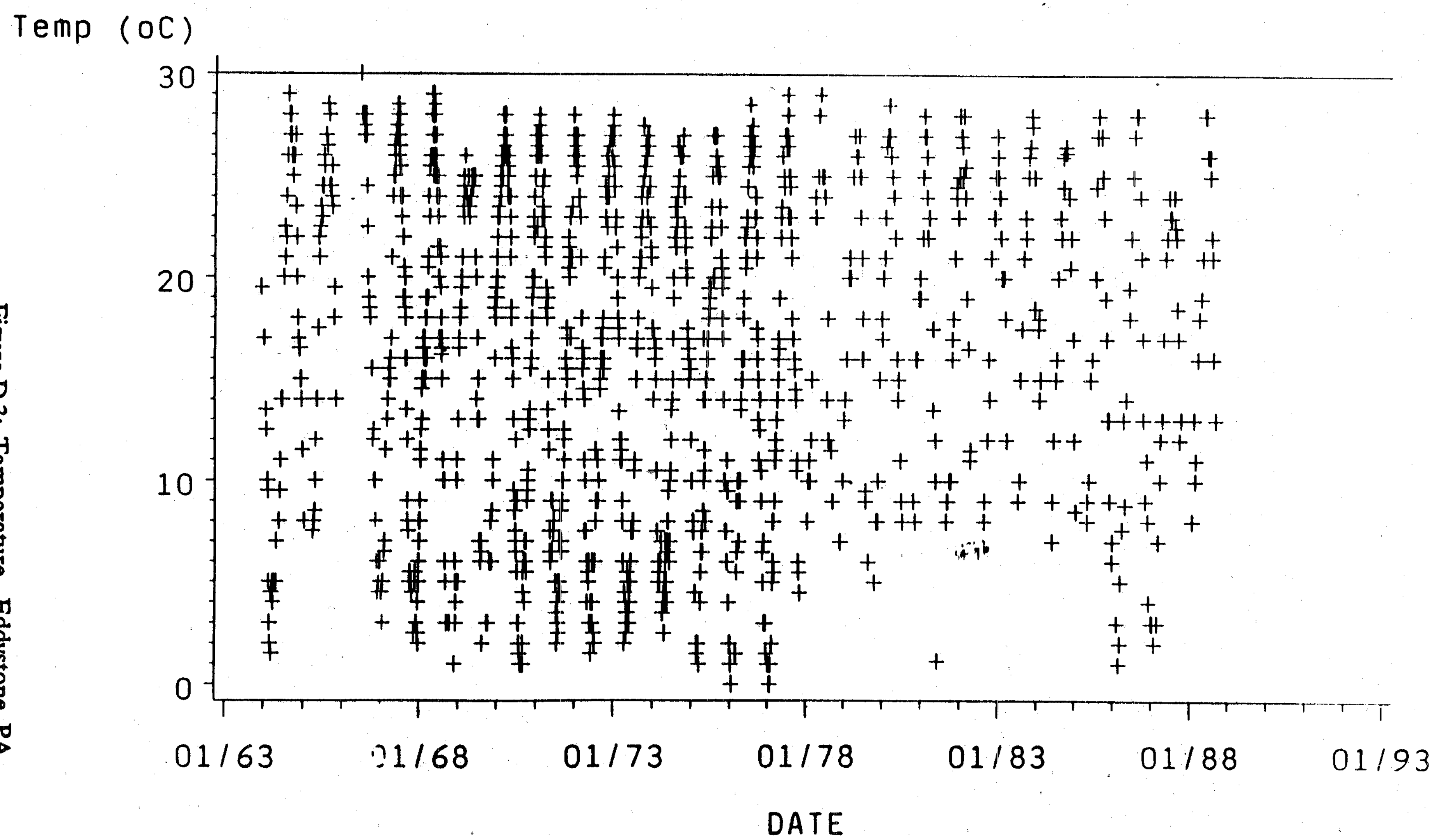


Figure D.3: Temperature - Eddystone, PA

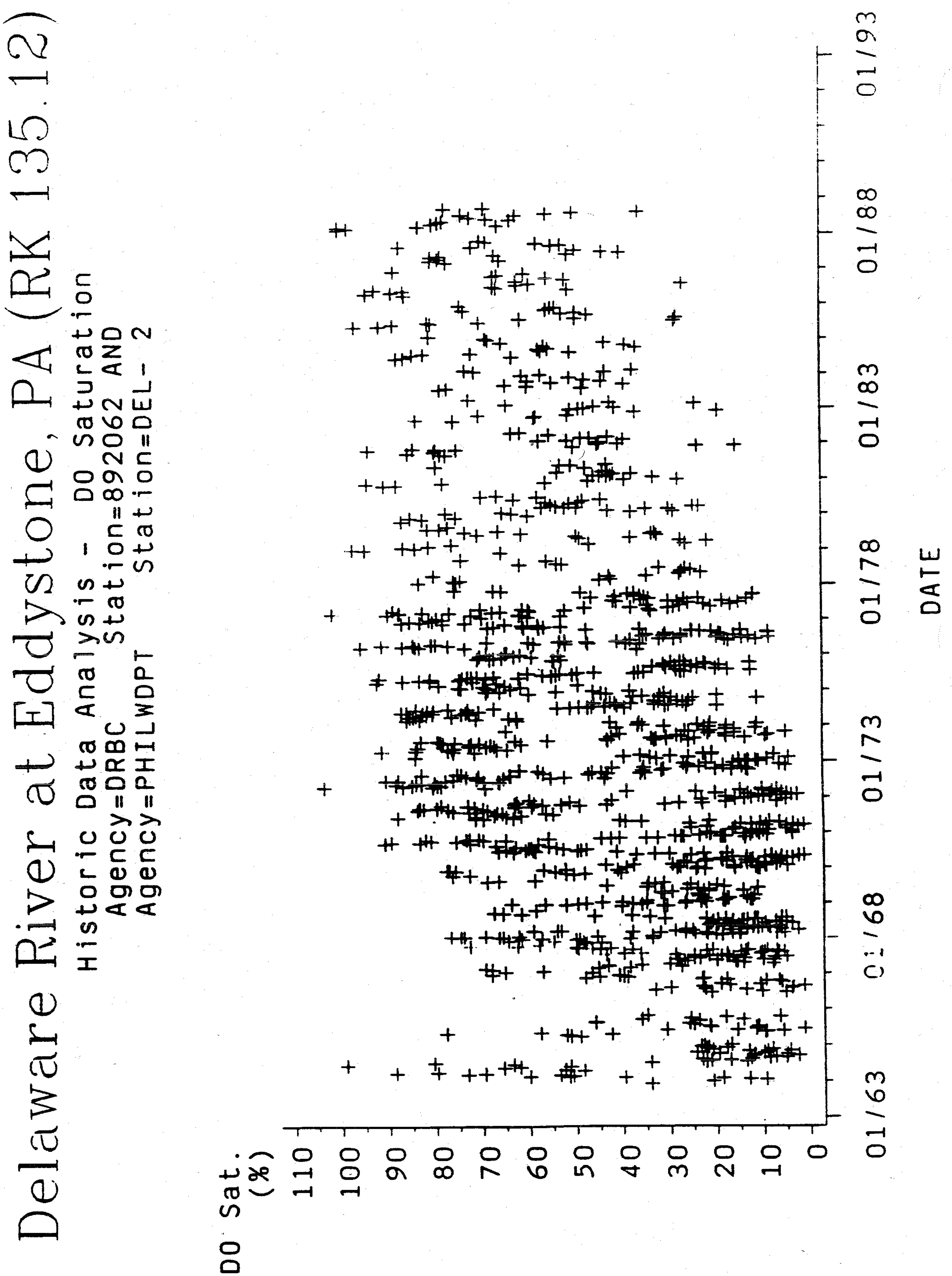


Figure D.4: DO Percent Saturation - Eddystone, PA

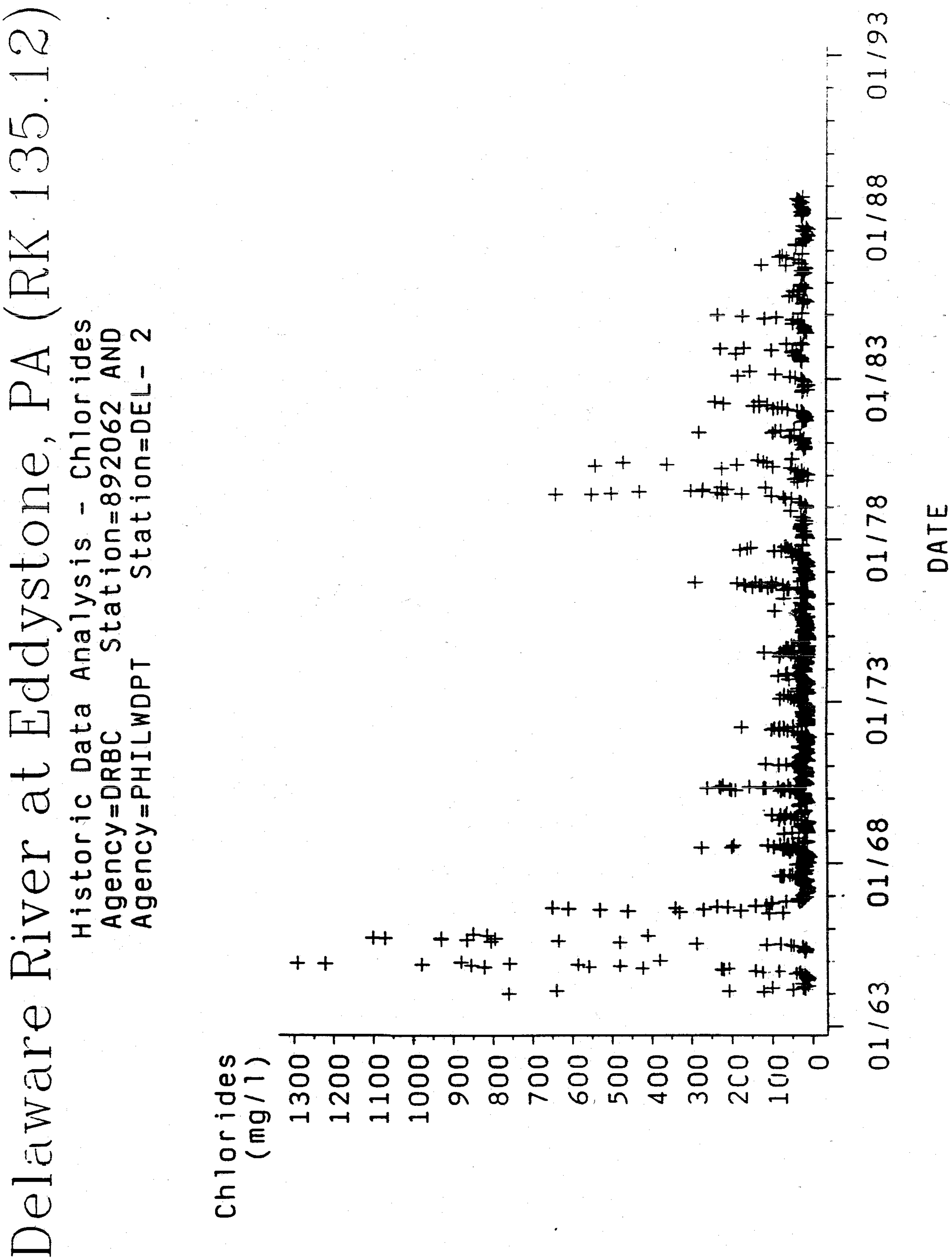


Figure D.5: Chlorides - Eddystone, PA

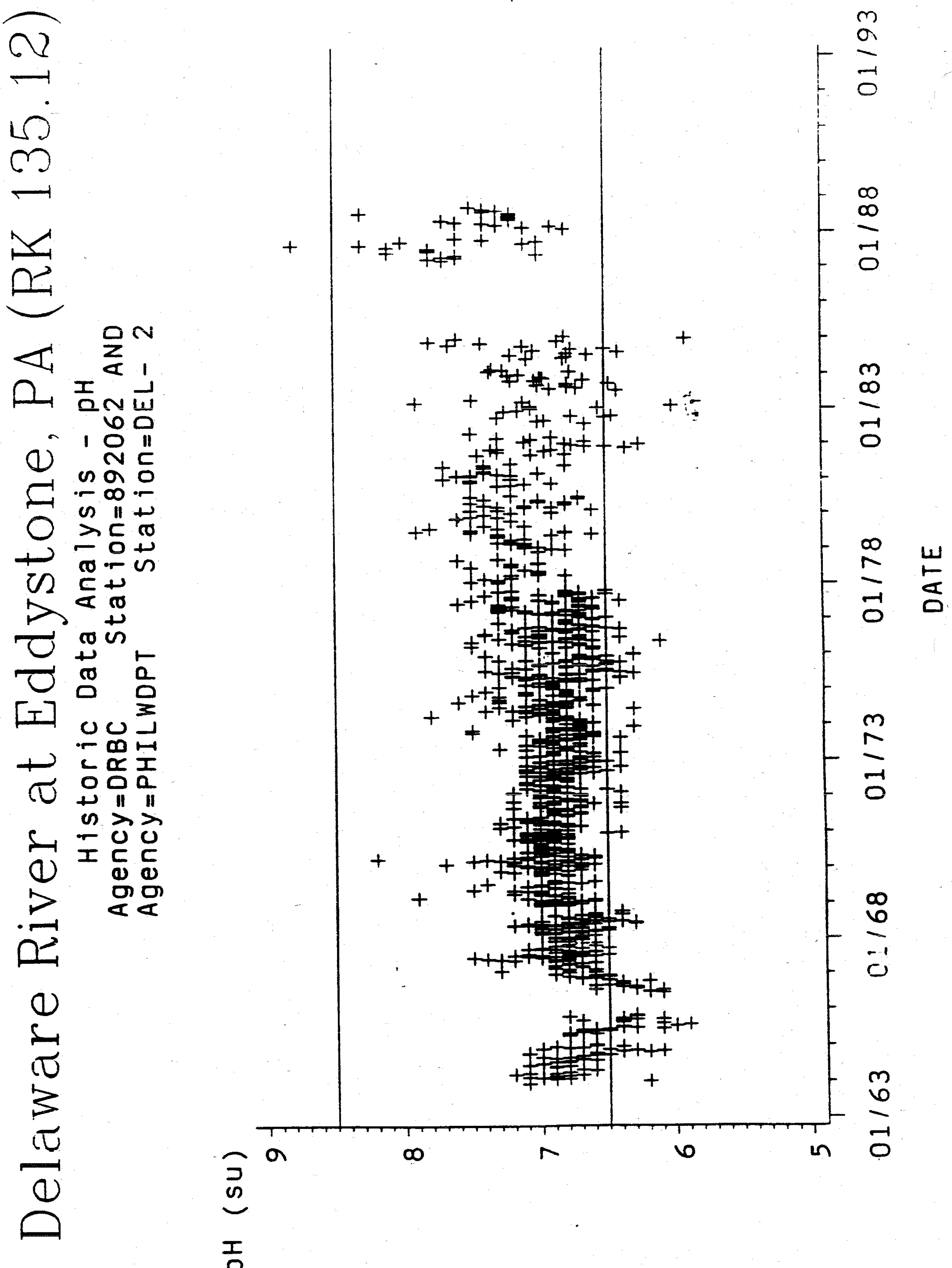


Figure D.6: pH - Eddystone, PA

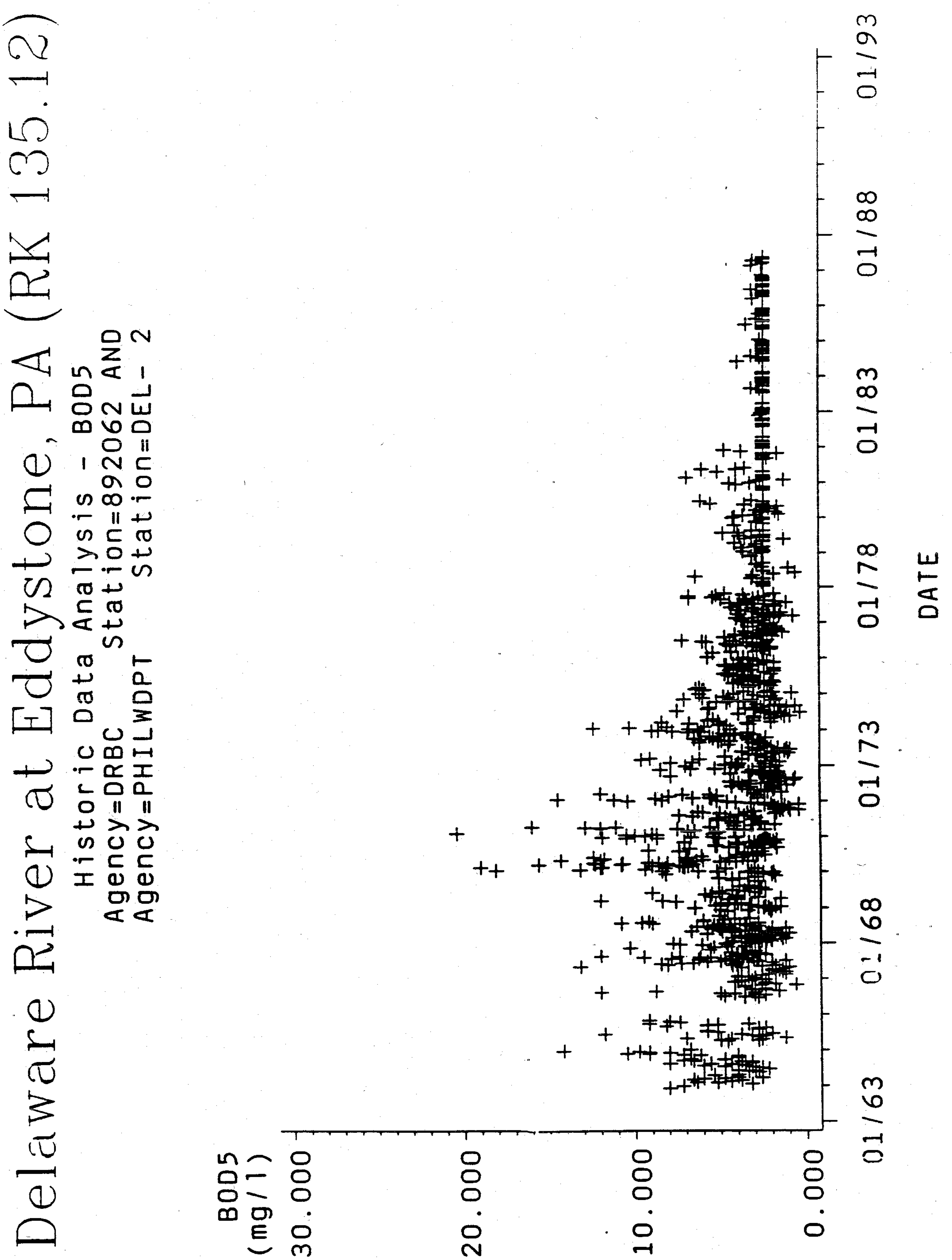


Figure D.7: BOD_5 - Eddystone, PA

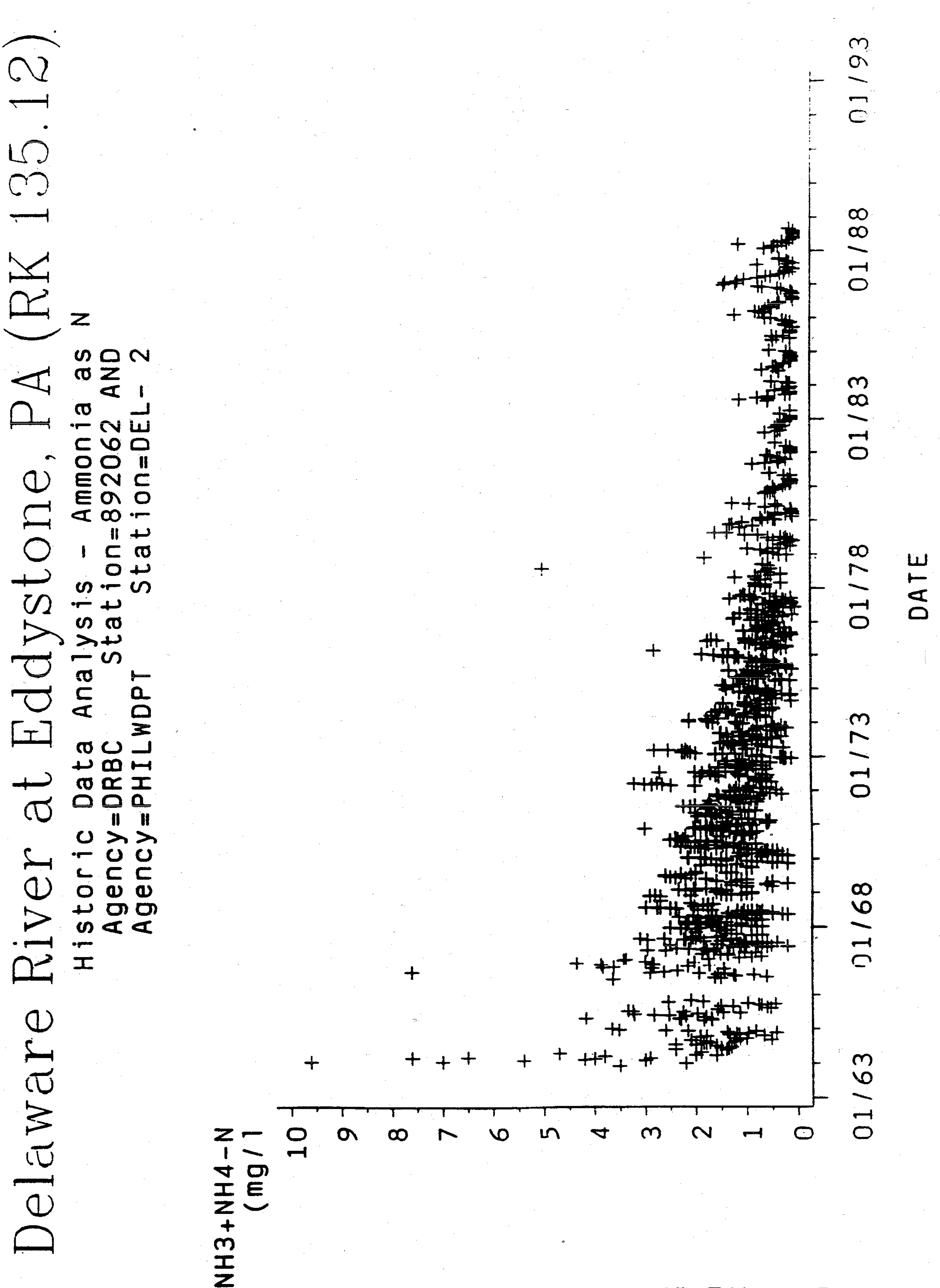


Figure D.8: Ammonia (NH_3-N) - Eddystone, PA

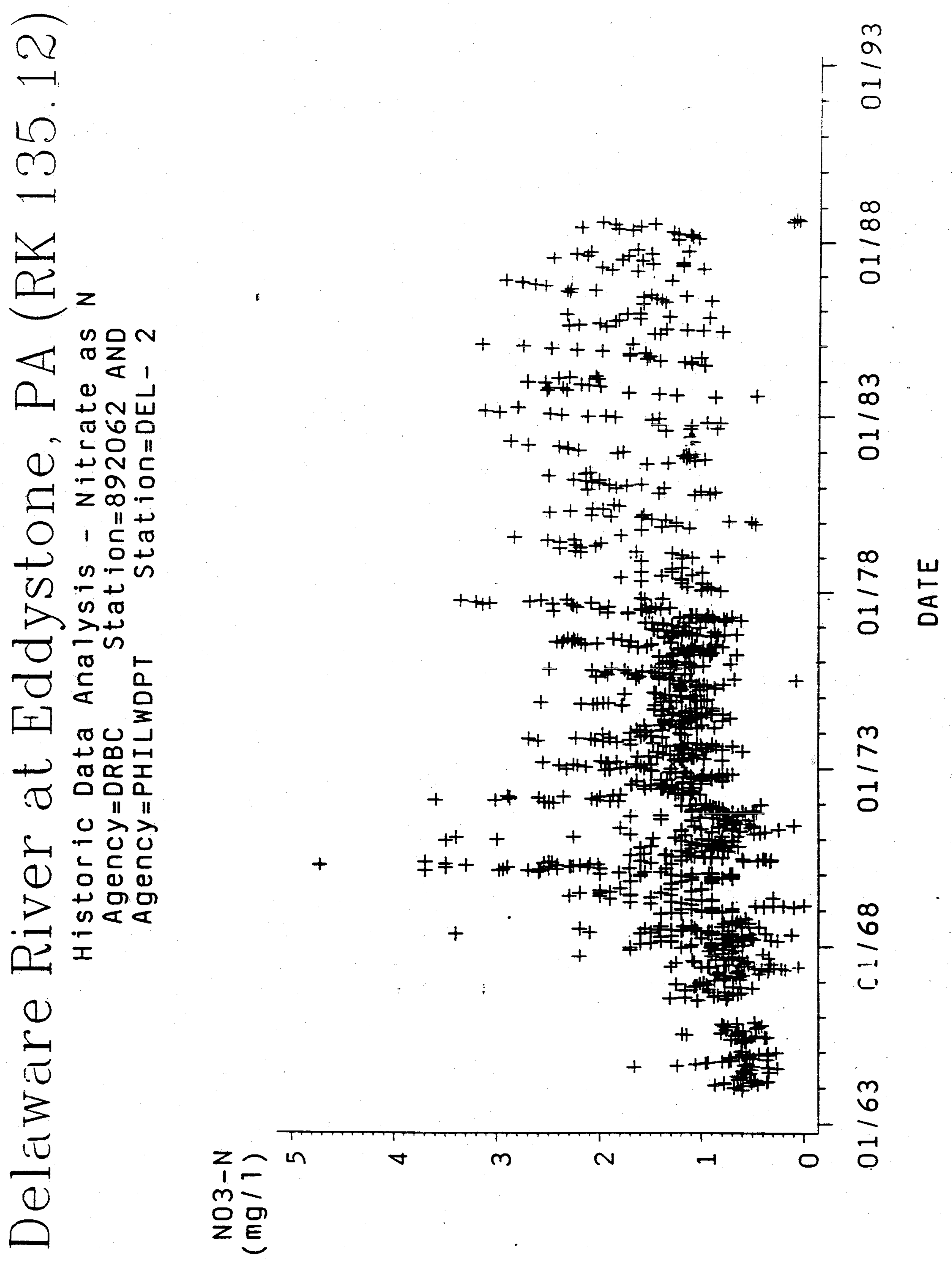


Figure D.9: Nitrate (NO_3-N) - Eddystone, PA

Delaware River at Eddystone, PA (RK 135.12)

Historic Data Analysis - TKN
Agency=DRBC Station=892062 AND
Agency=PHILWDPT Station=DEL- 2

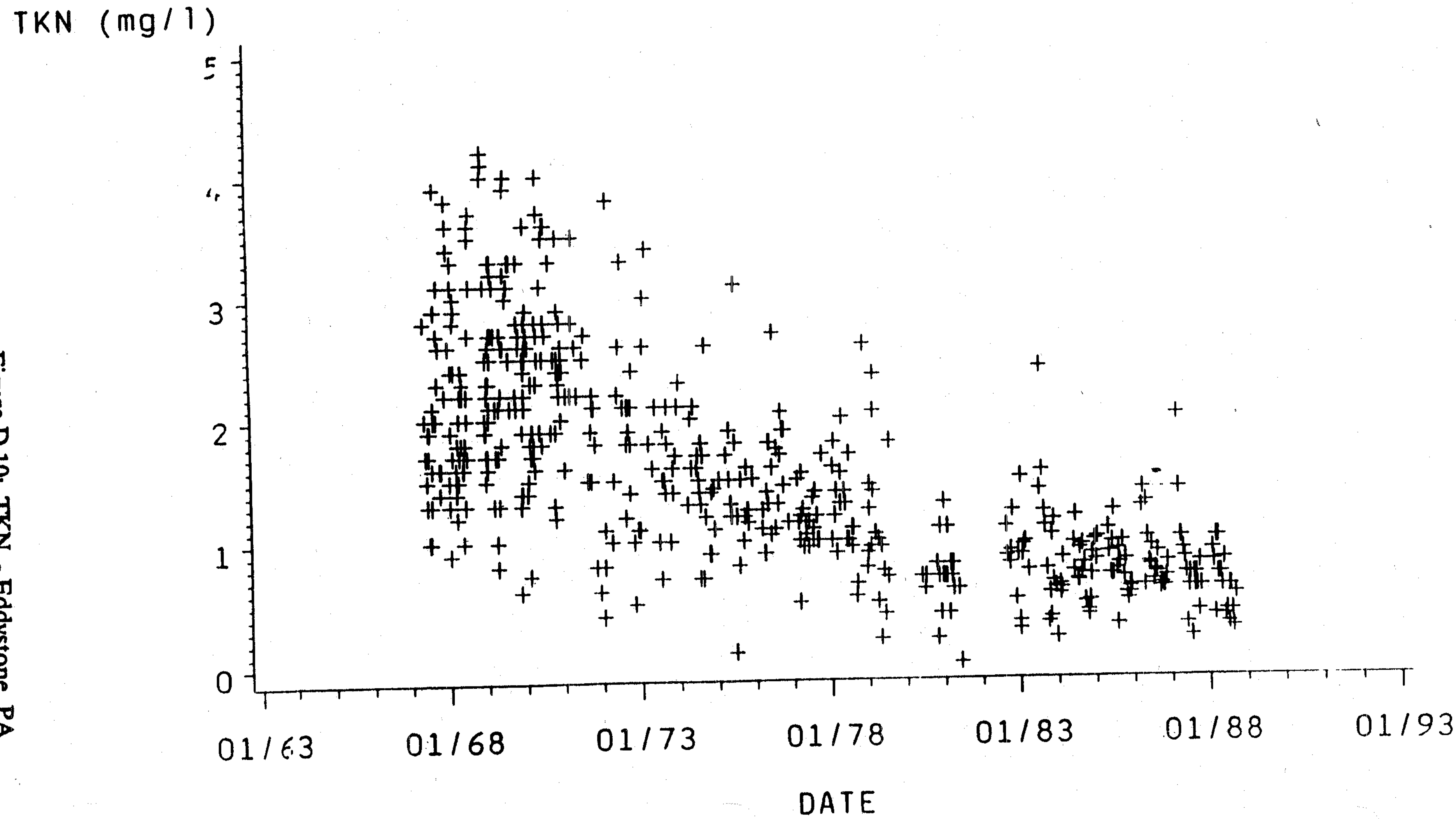


Figure D.10: TKN - Eddystone, PA

Delaware River at Eddystone, PA (RK 135.12)

Historic Data Analysis - Total Nitrogen
Agency=DRBC Station=892062 AND
Agency=PHILWDPT Station=DEL- 2

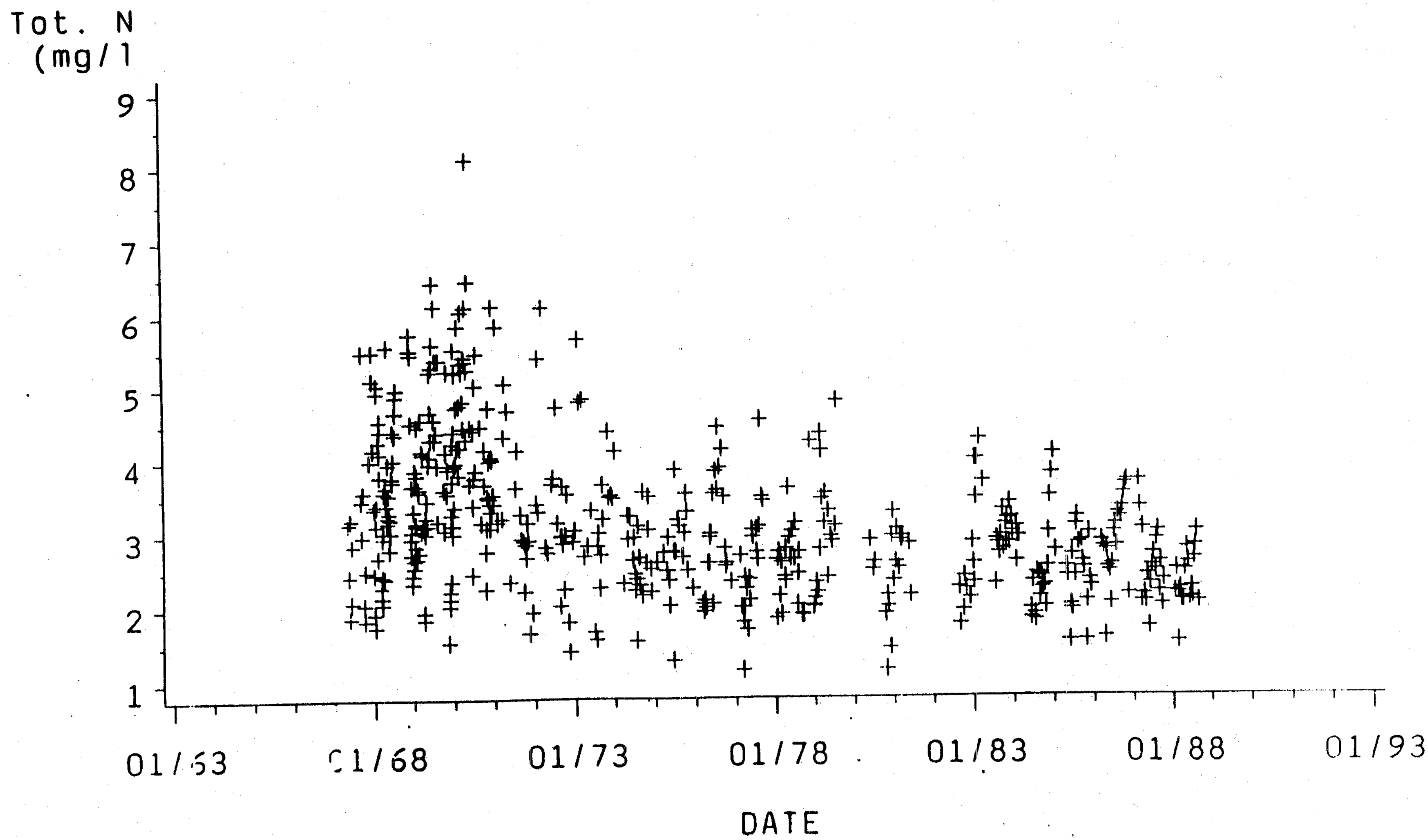


Figure D.11: Total Nitrogen - Eddystone, PA

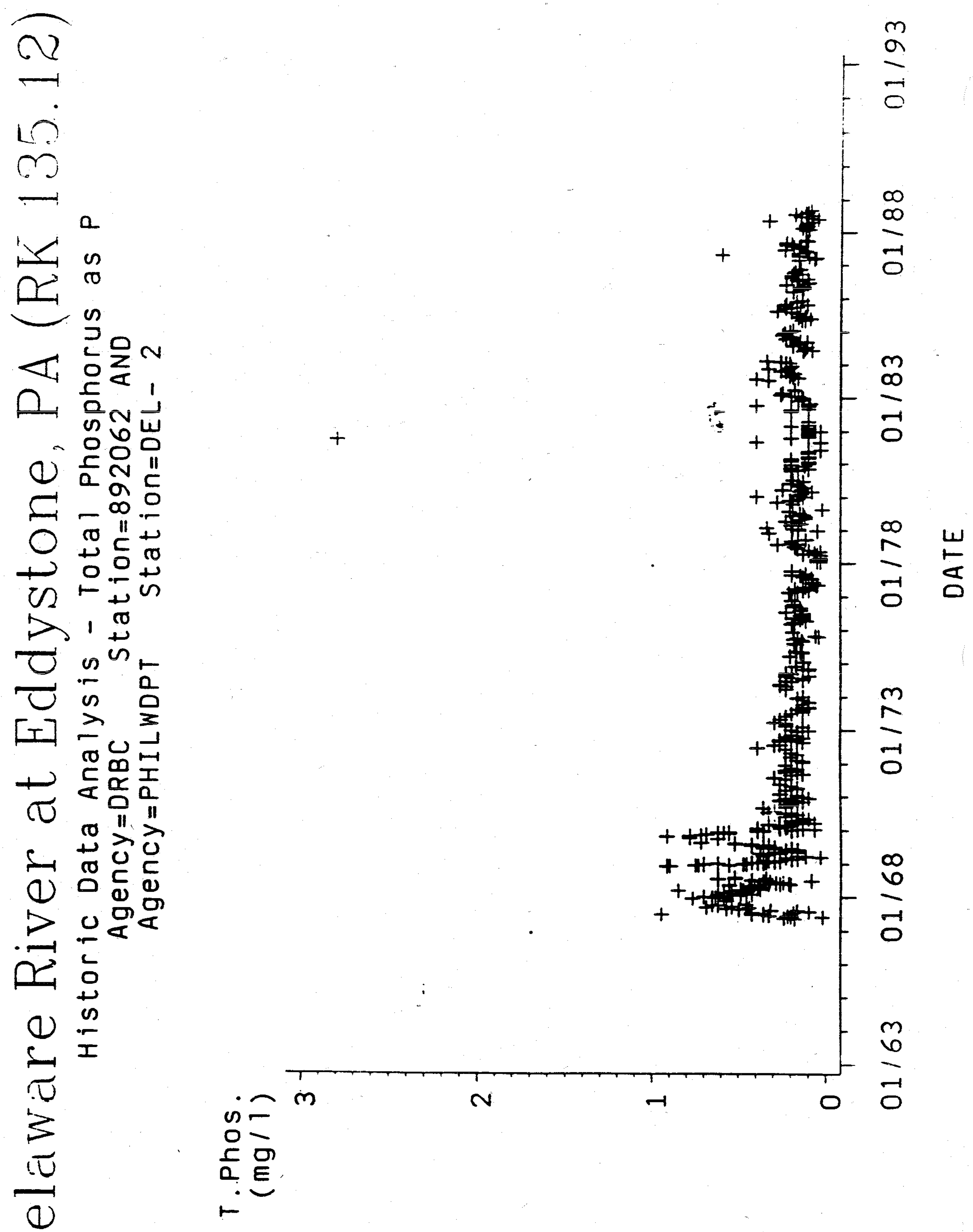


Figure D.12: Total Phosphorus - Eddystone, PA

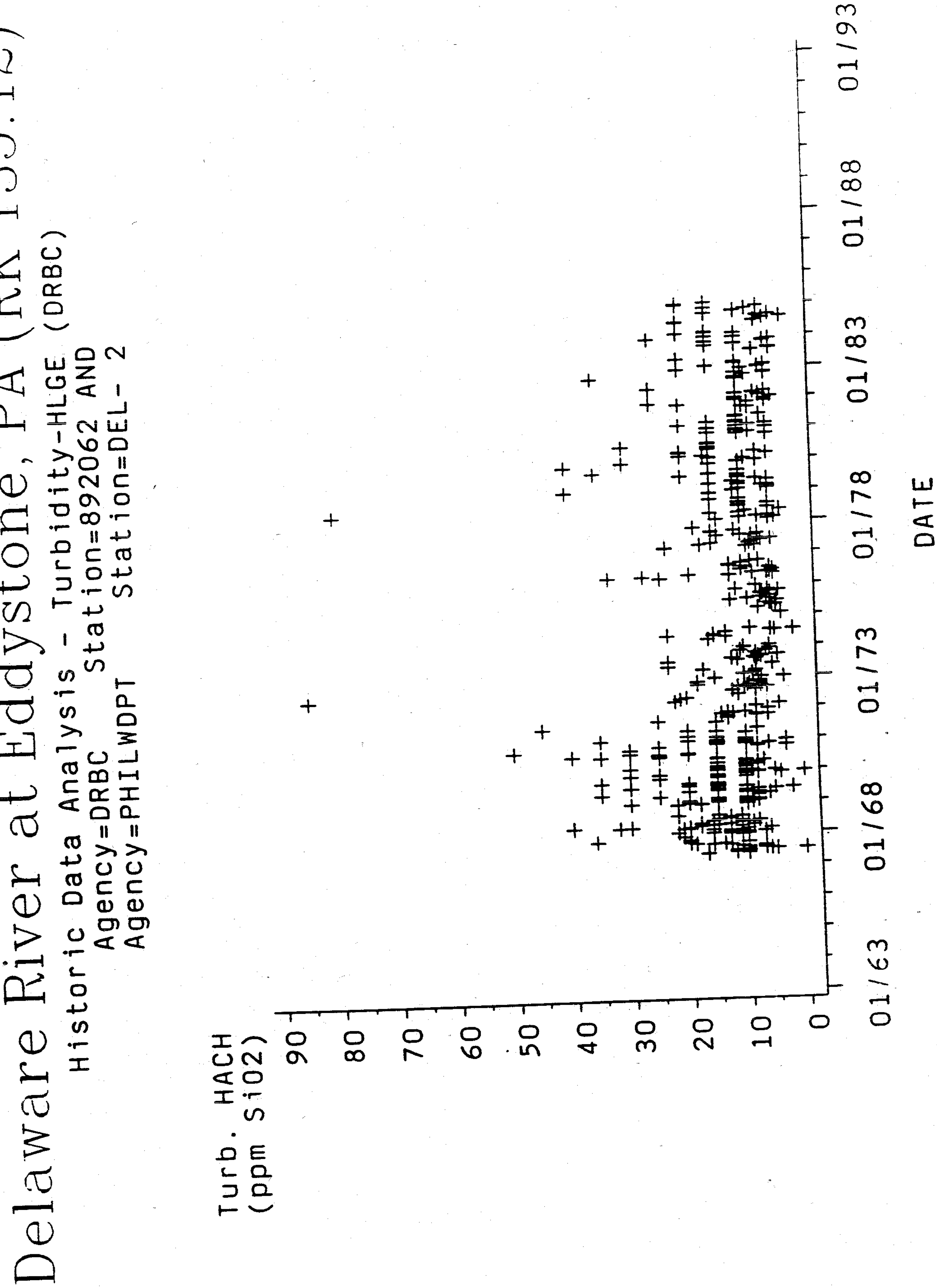


Figure D.13: Turbidity - Eddystone, PA

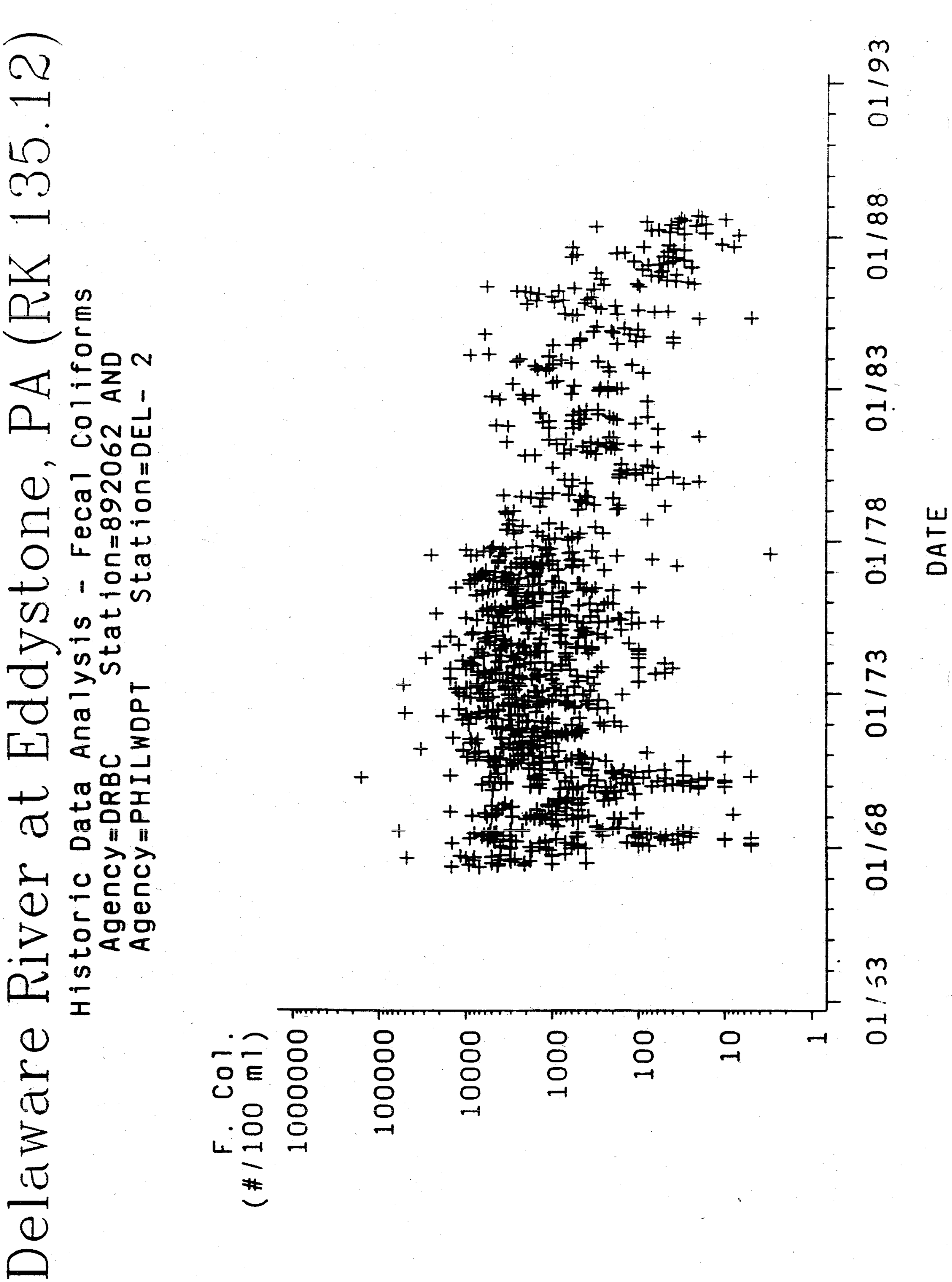


Figure D.14: Fecal Coliform - Eddystone, PA

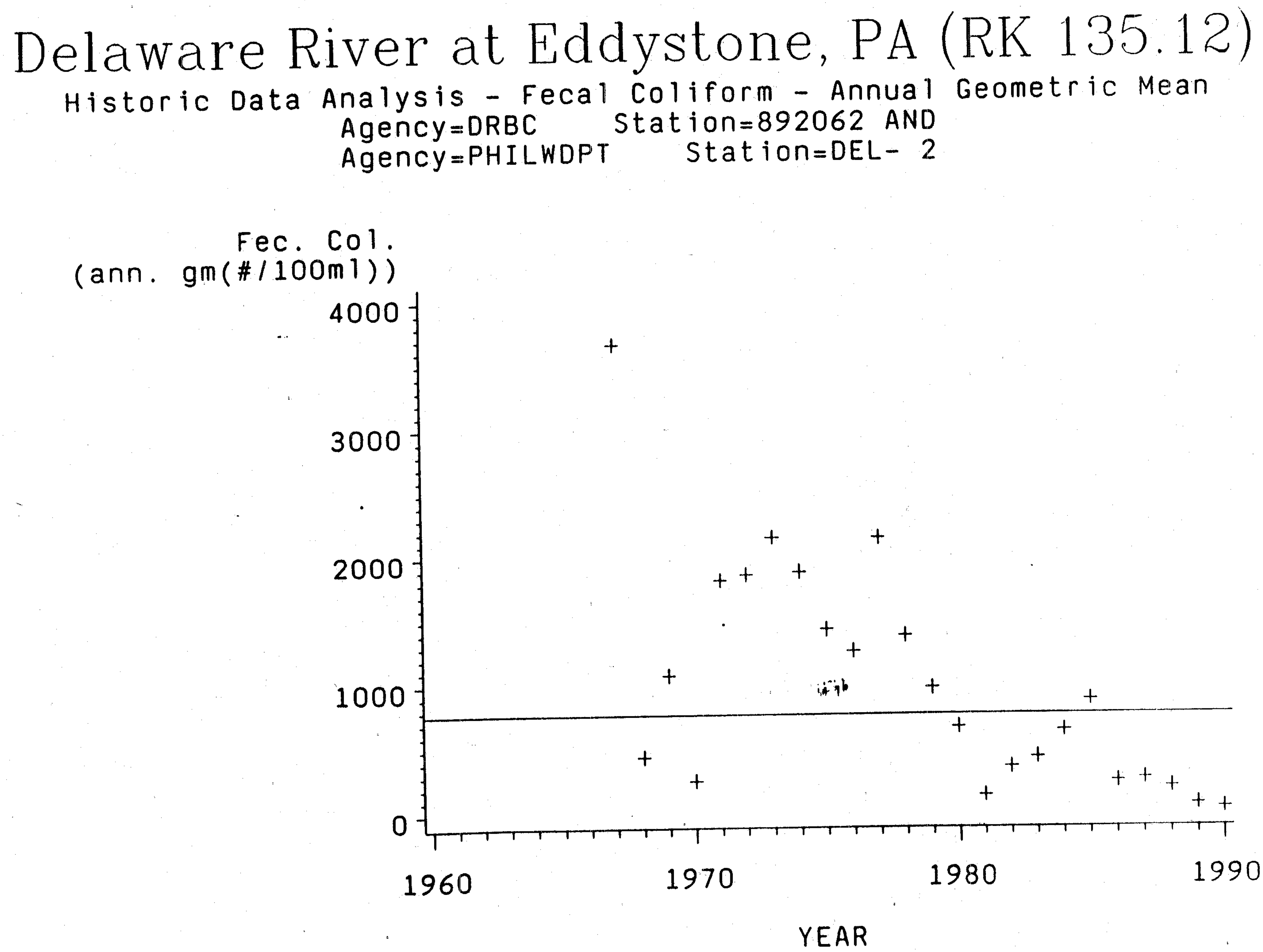


Figure D.15: Annual Geometric Mean FC - Eddystone, PA

APPENDIX E

DELAWARE RIVER AT NEW CASTLE, DE (RK 106.10)

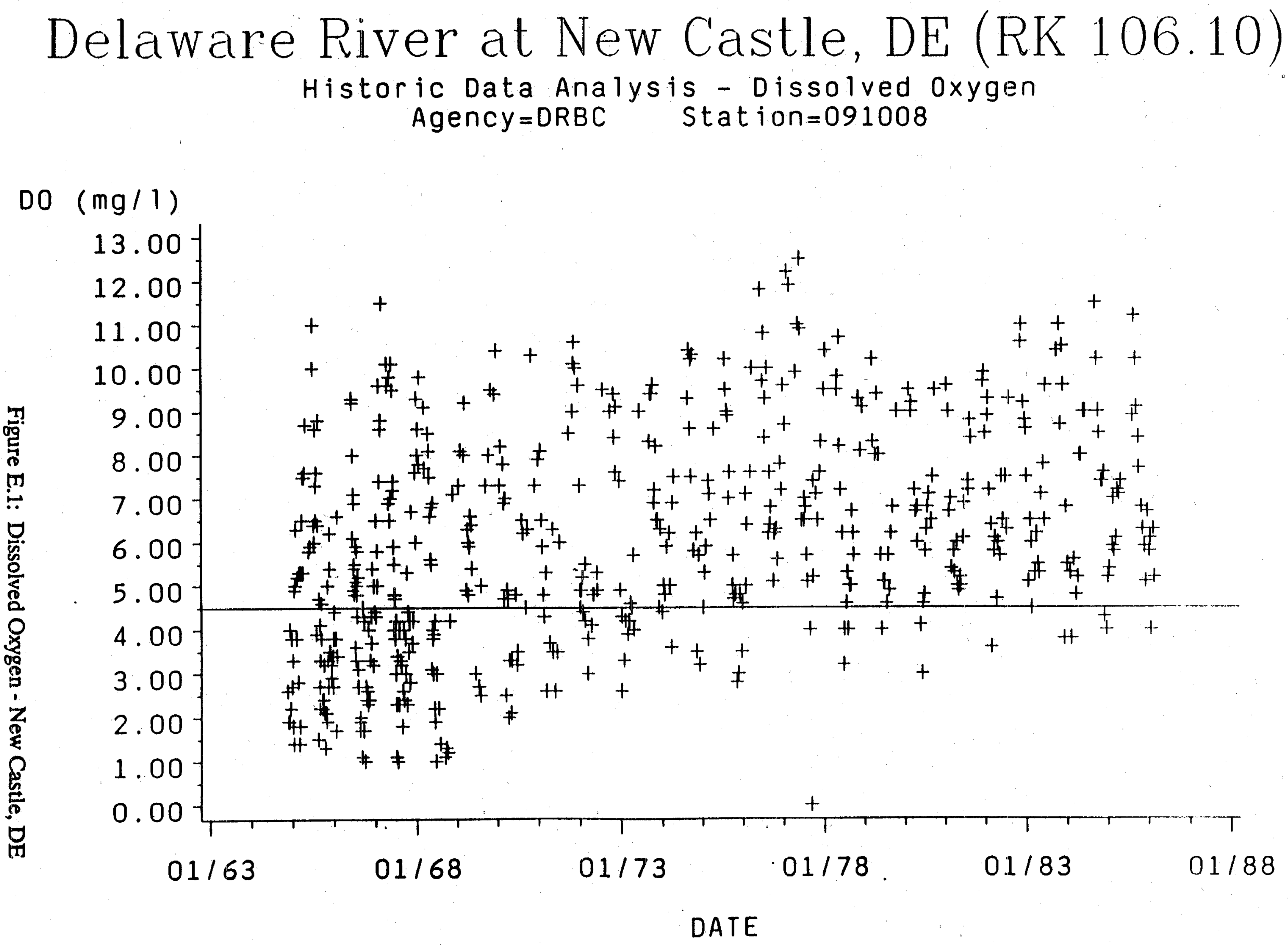


Figure E.1: Dissolved Oxygen - New Castle, DE

Delaware River at New Castle, DE (RK 106.10)

Historic Data Analysis - Dissolved Oxygen -SUMMER DATA
Agency=DRBC Station=091008

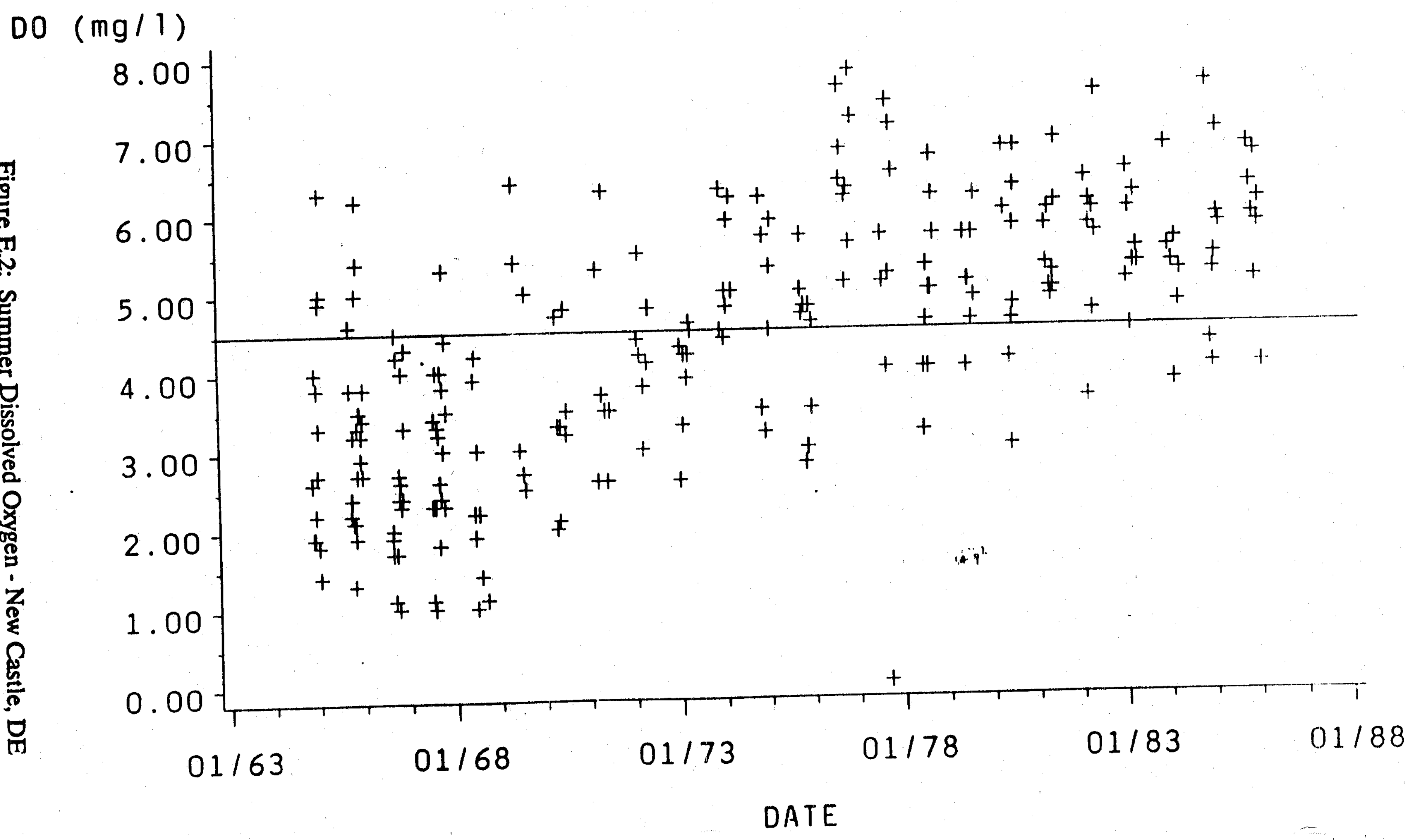


Figure E.2: Summer Dissolved Oxygen - New Castle, DE

Delaware River at New Castle, DE (RK 106.10)

Historic Data Analysis - Temperature
Agency=DRBC Station=091008

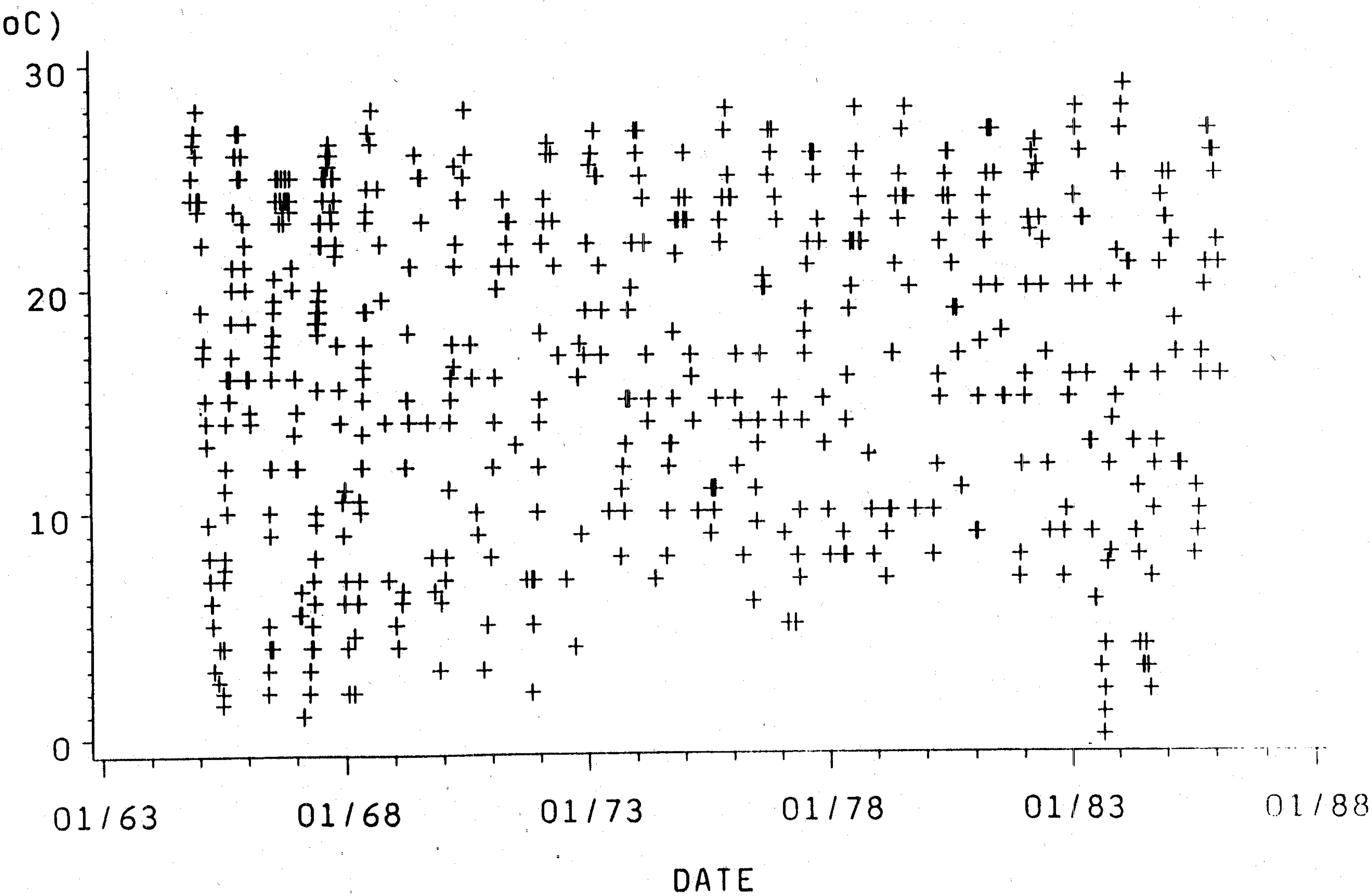


Figure E.3: Temperature - New Castle, DE

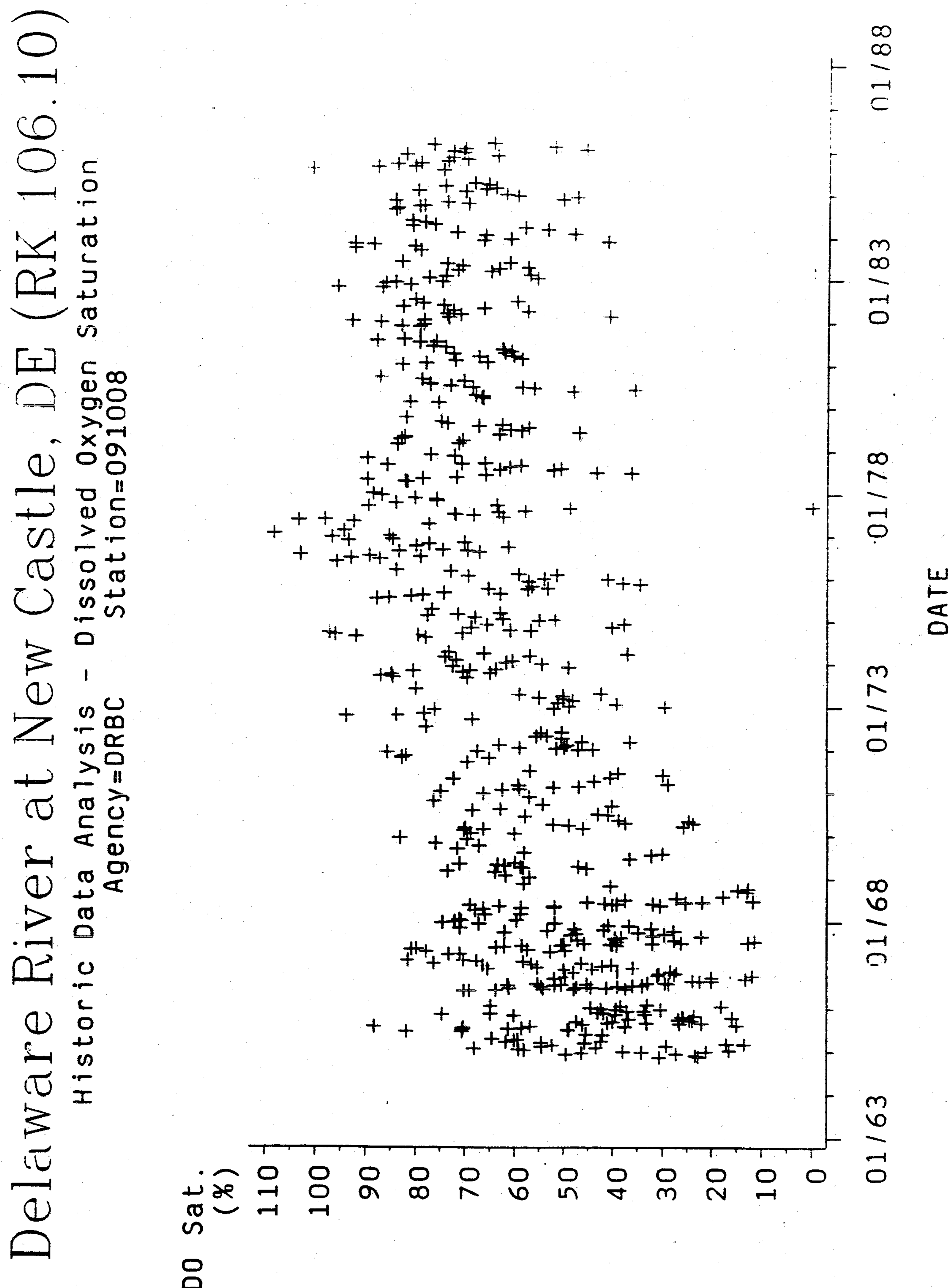


Figure E.4: DO Percent Saturation - New Castle, DE

Delaware River at New Castle, DE (RM 65.96)

Historic Data Analysis - Salinity
Agency=DRBC Station=091008

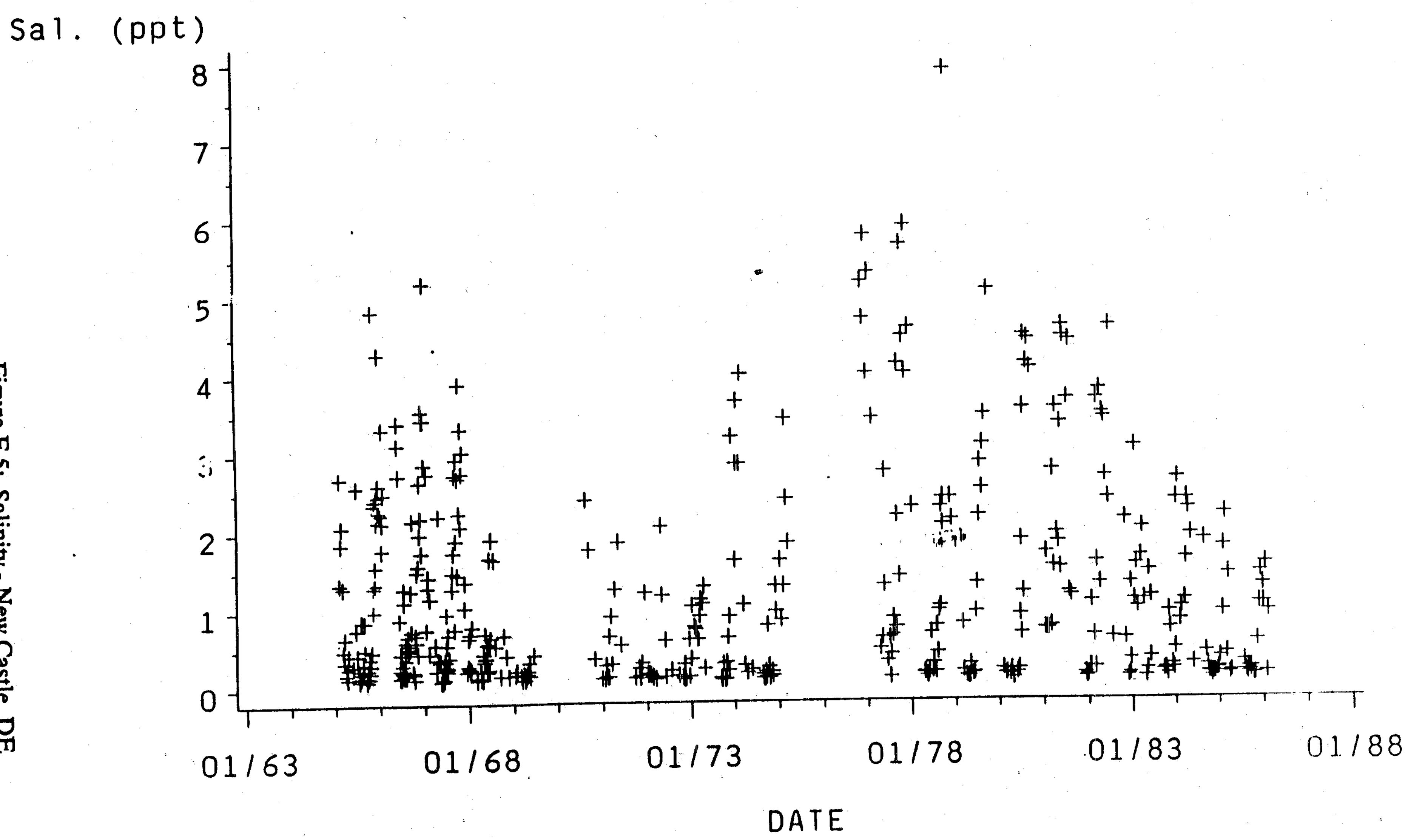


Figure E.5: Salinity - New Castle, DE

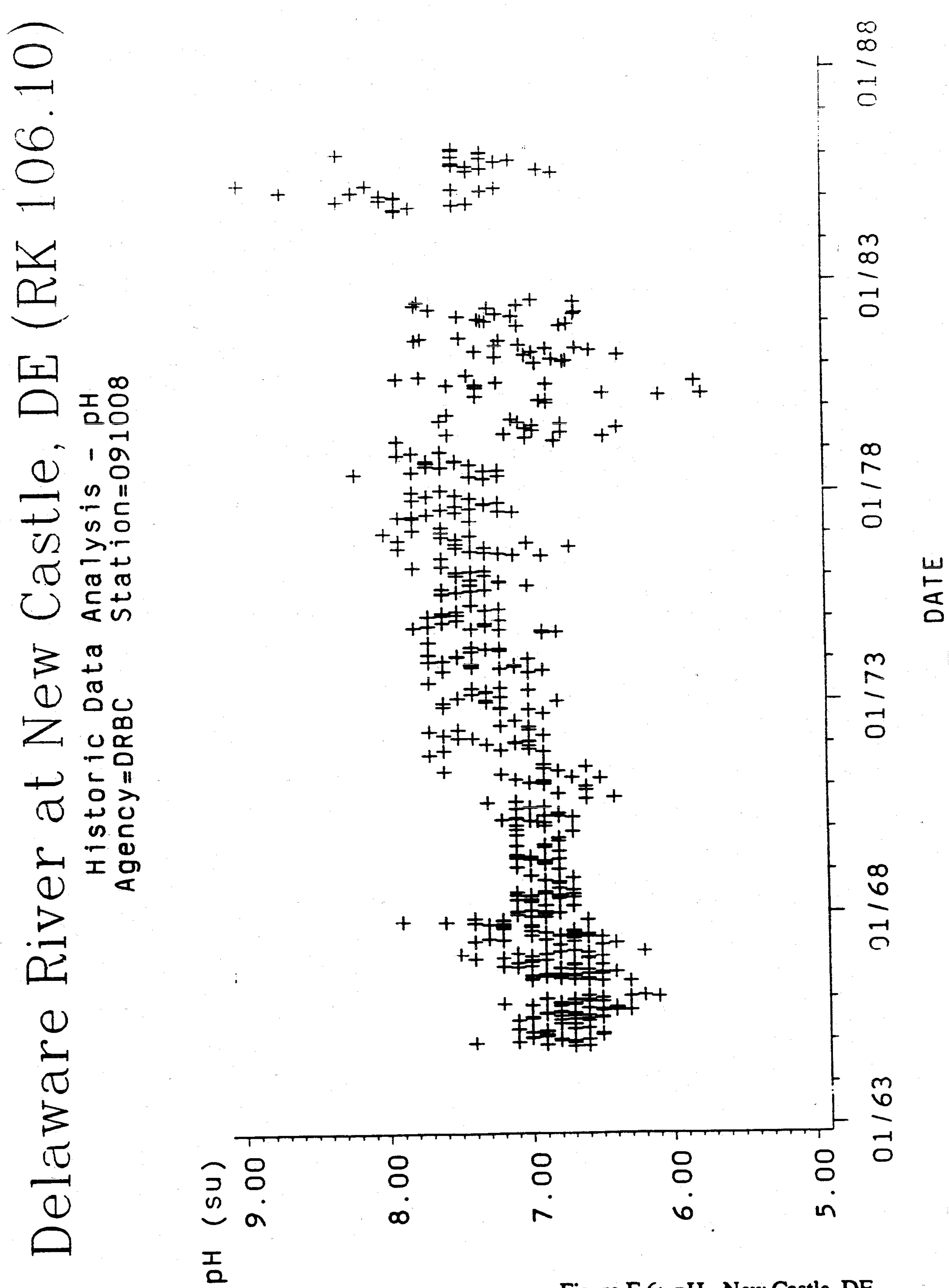


Figure E.6: pH - New Castle, DE

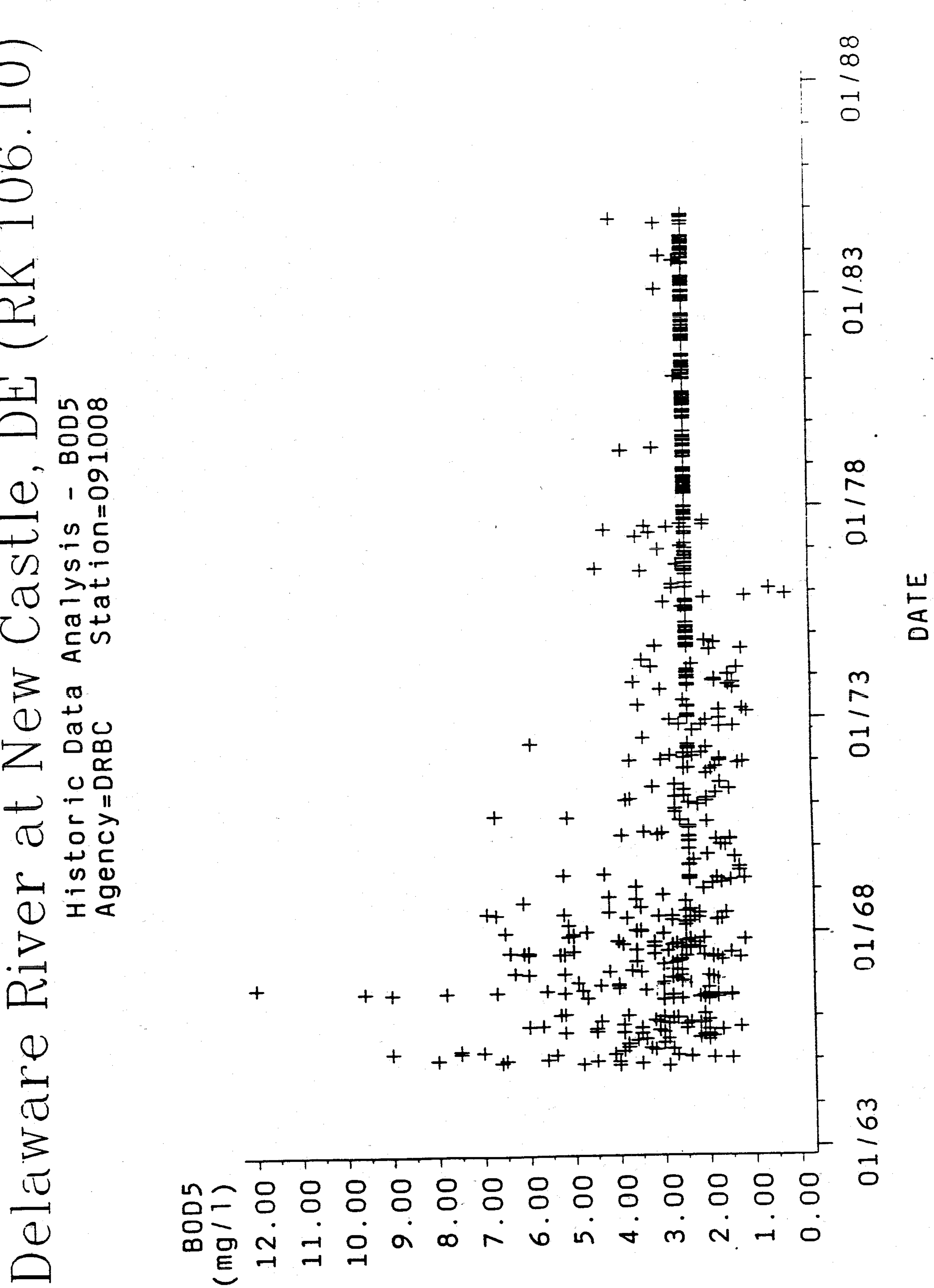


Figure E.7: BOD_5 - New Castle, DE

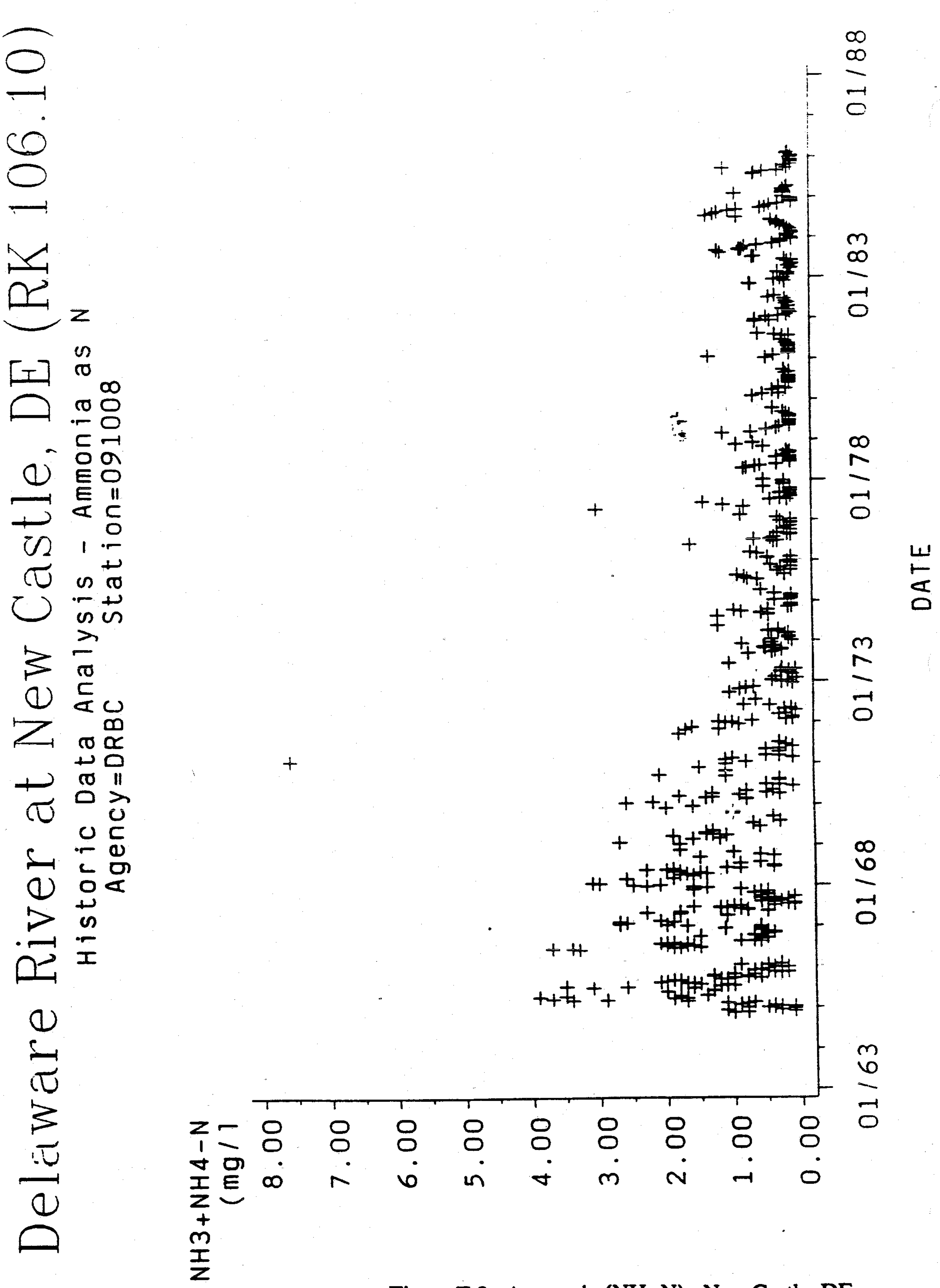


Figure E.8: Ammonia (NH_3-N) - New Castle, DE

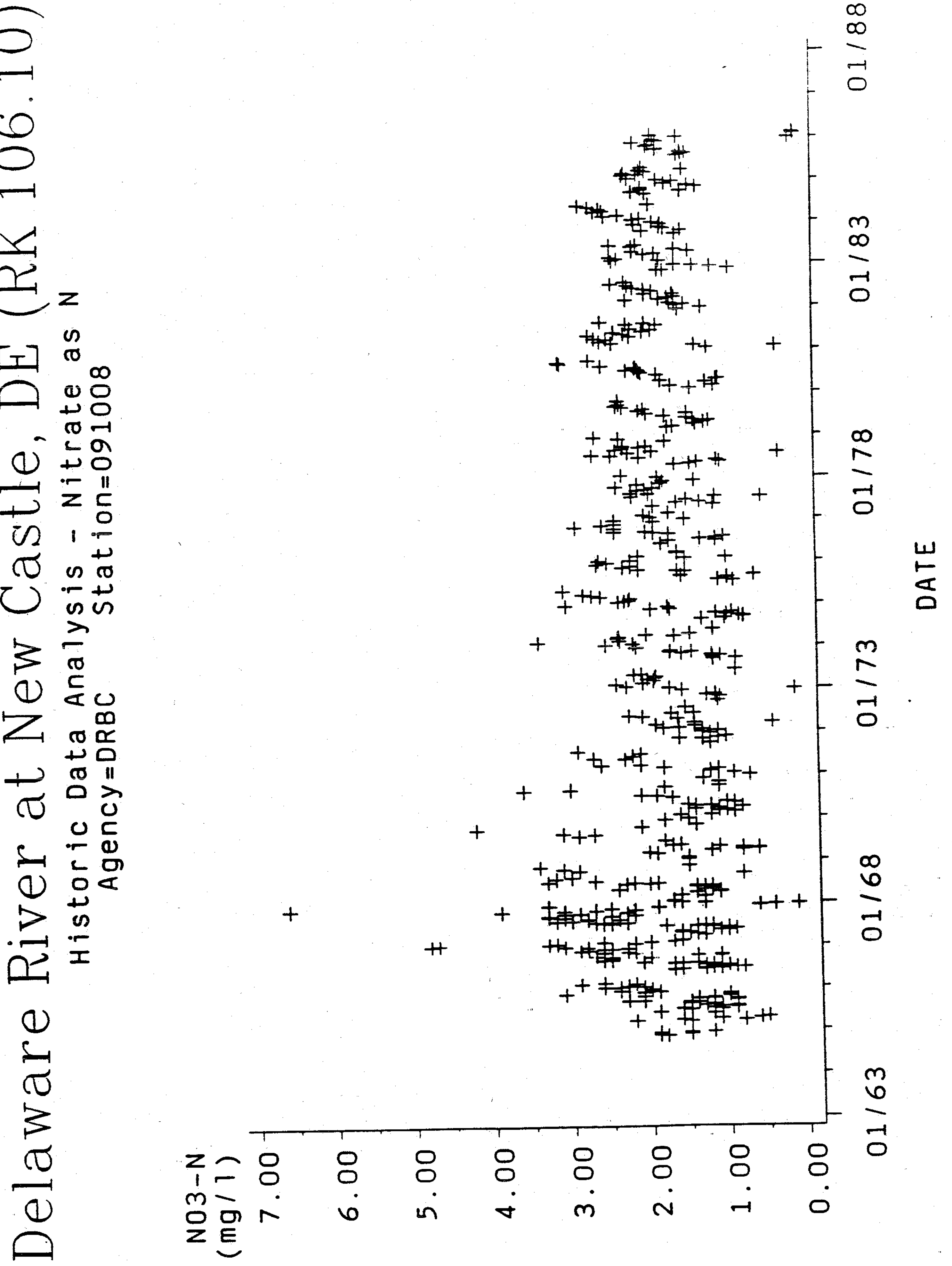


Figure E.9: Nitrate (NO_3-N) - New Castle, DE

Delaware River at New Castle, DE (RK 106.10)

Historic Data Analysis - TKN
Agency=DRBC Station=091008

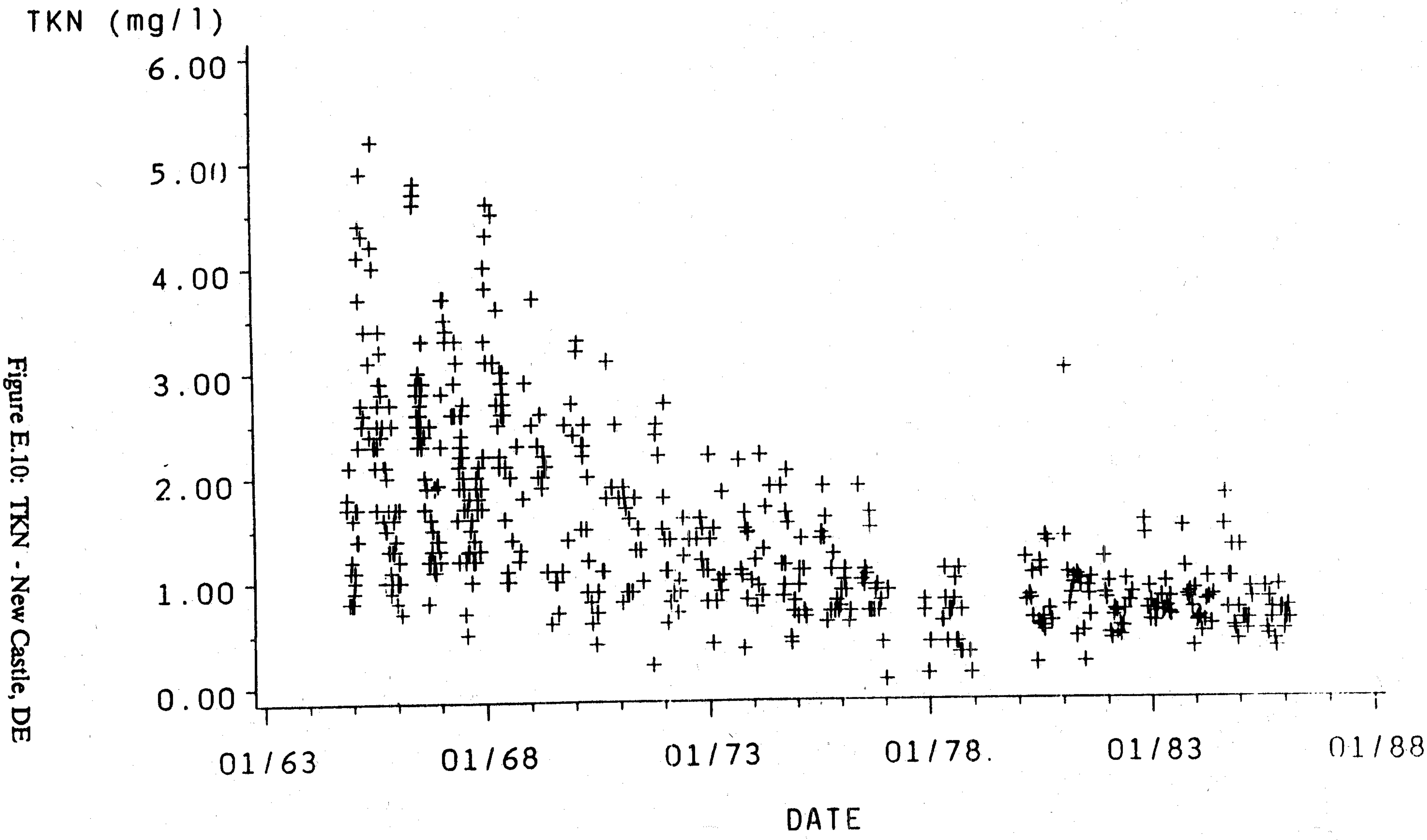


Figure E.10: TKN - New Castle, DE

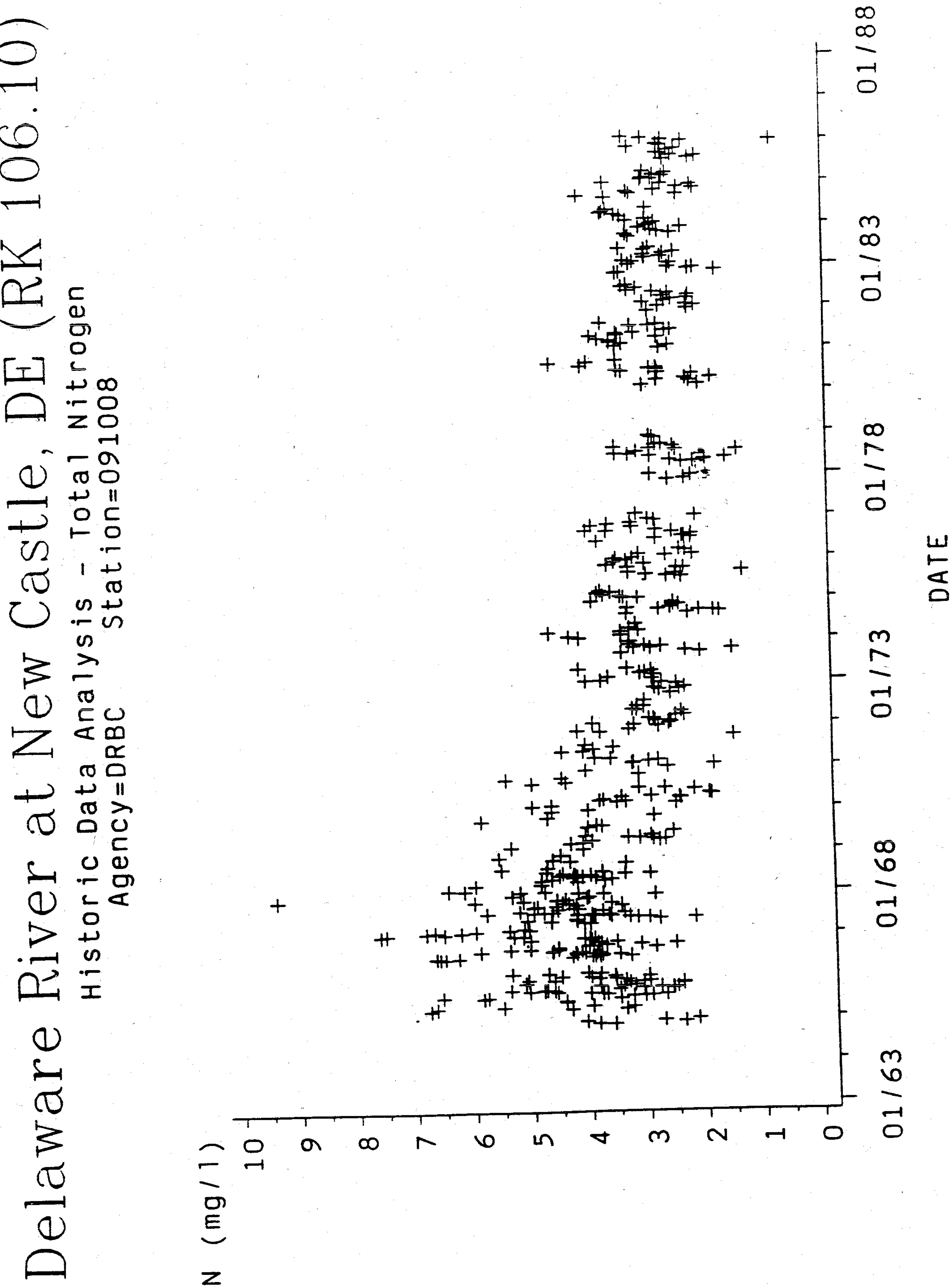


Figure E.11: Total Nitrogen - New Castle, DE

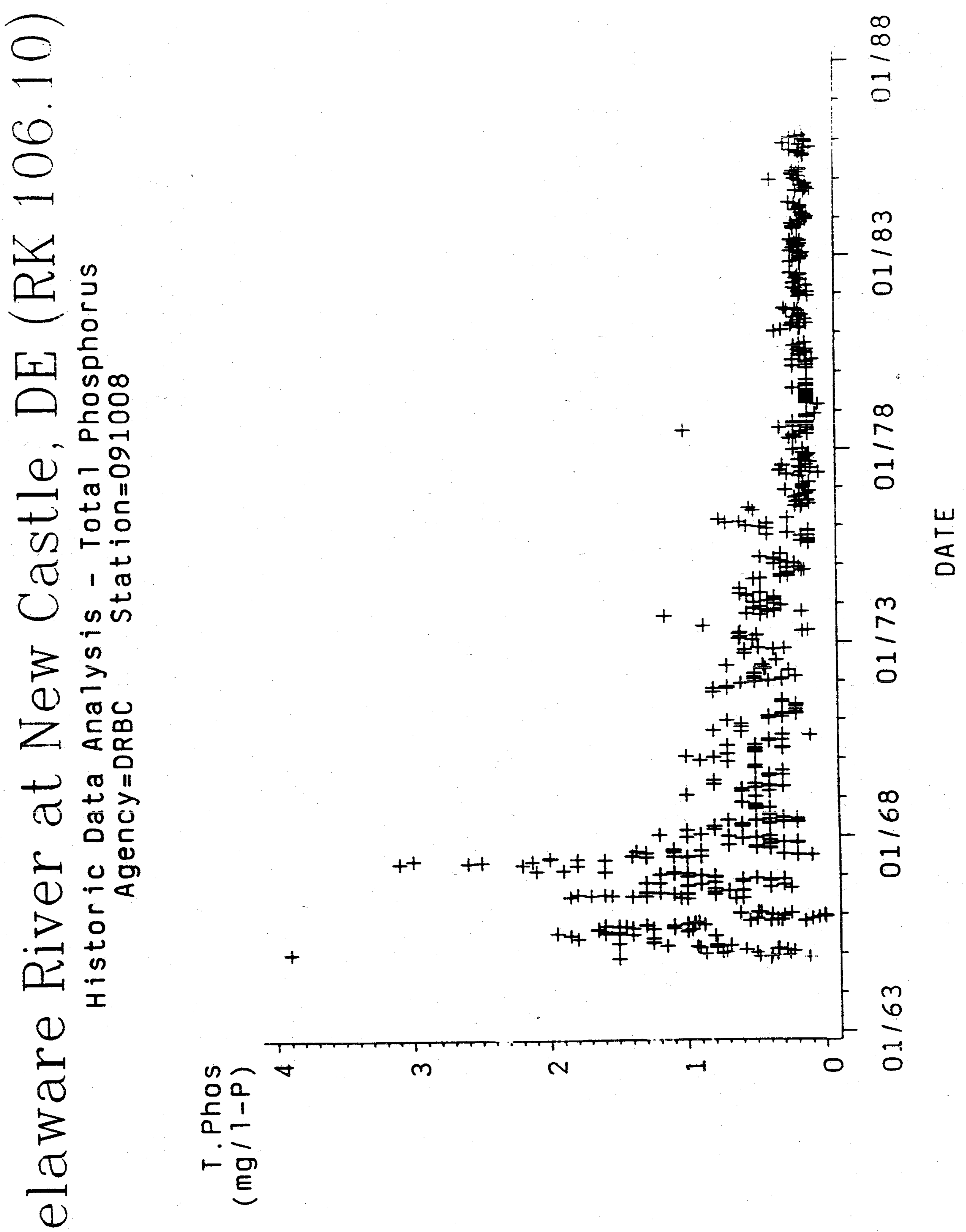


Figure E.12: Total Phosphorus - New Castle, DE

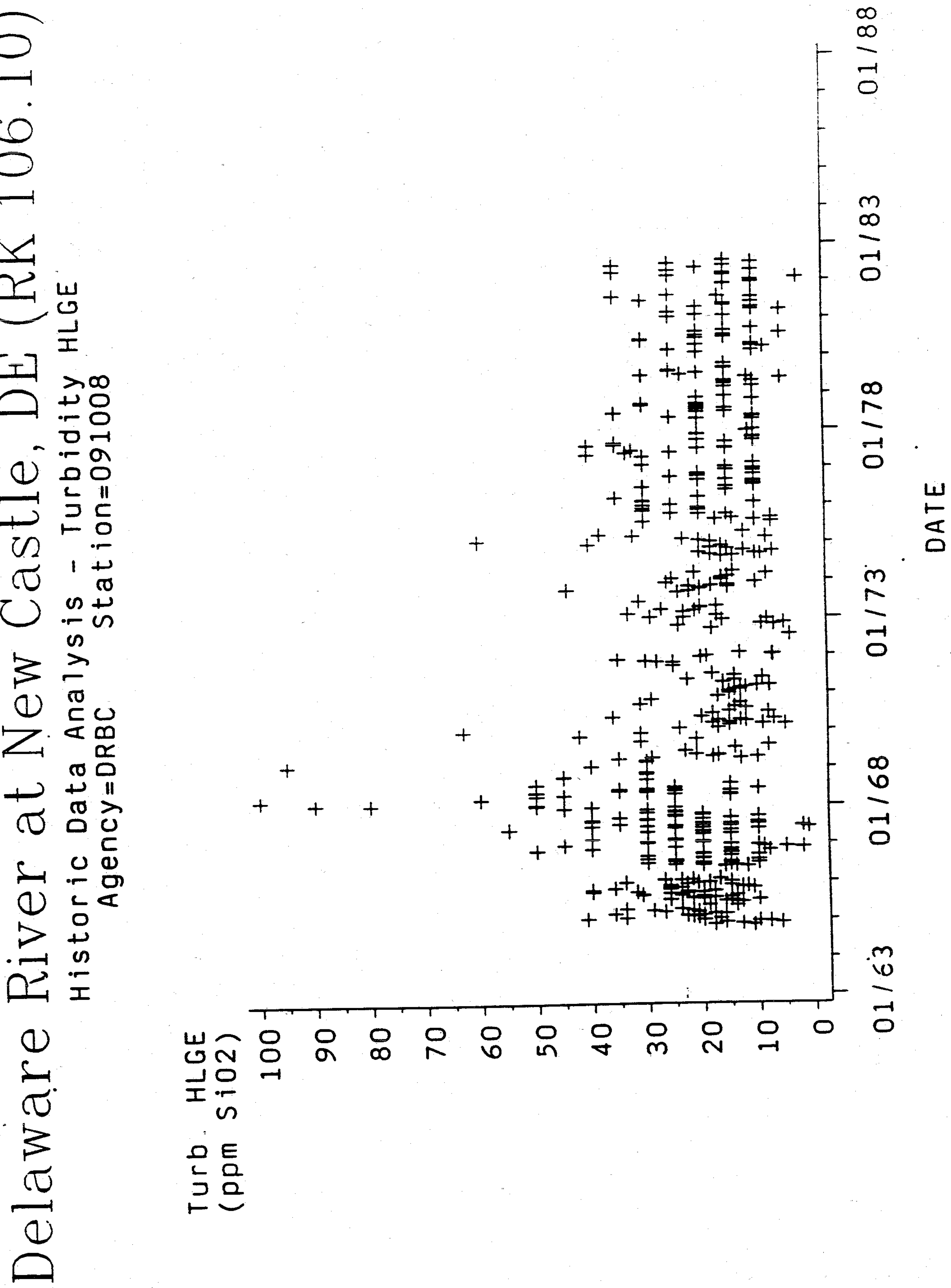


Figure E.13: Turbidity - New Castle, DE

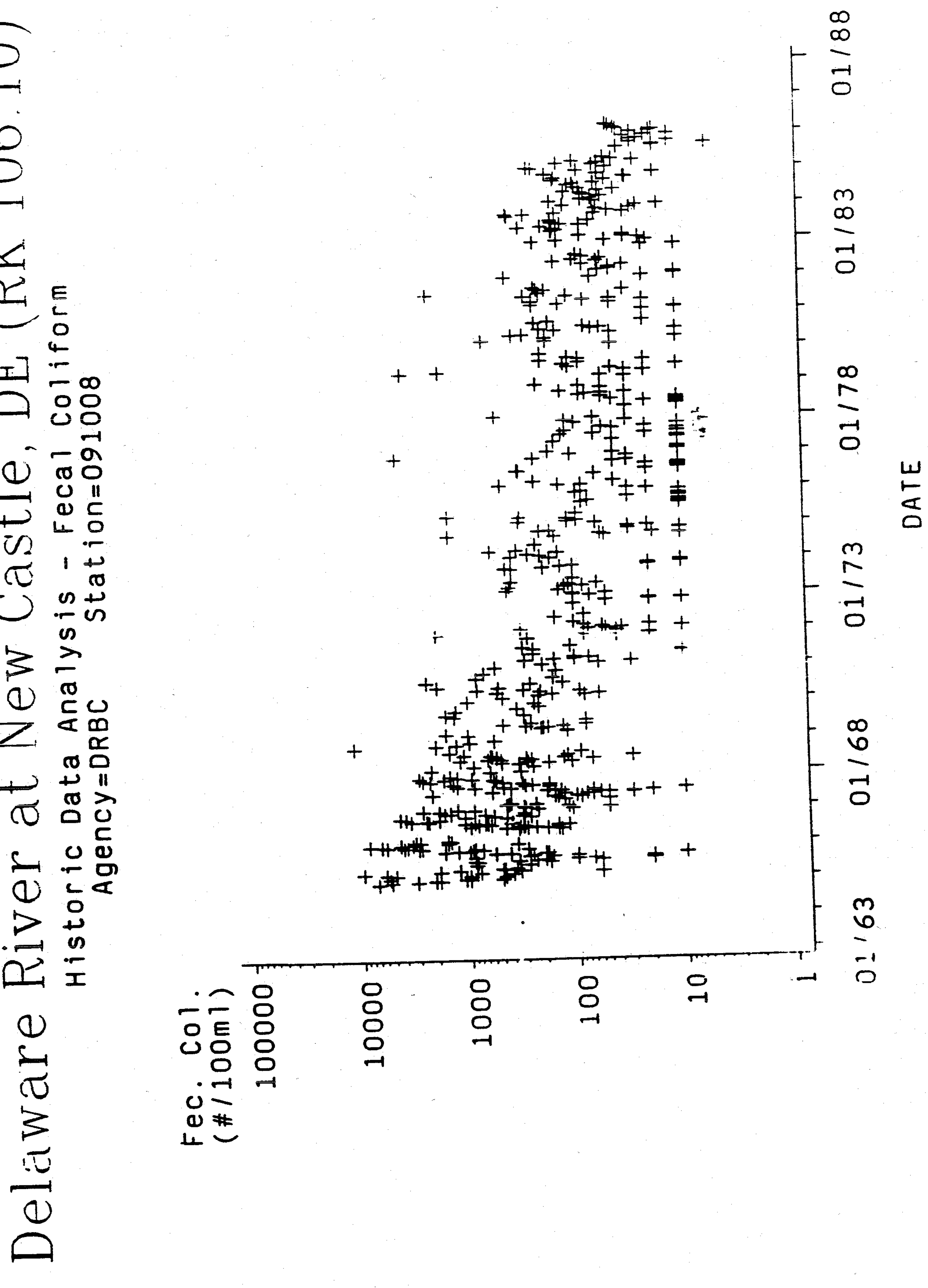


Figure E.14: Fecal Coliform - New Castle, DE

APPENDIX F

DELAWARE RIVER AT REEDY ISLAND, DE (RK 88.40)

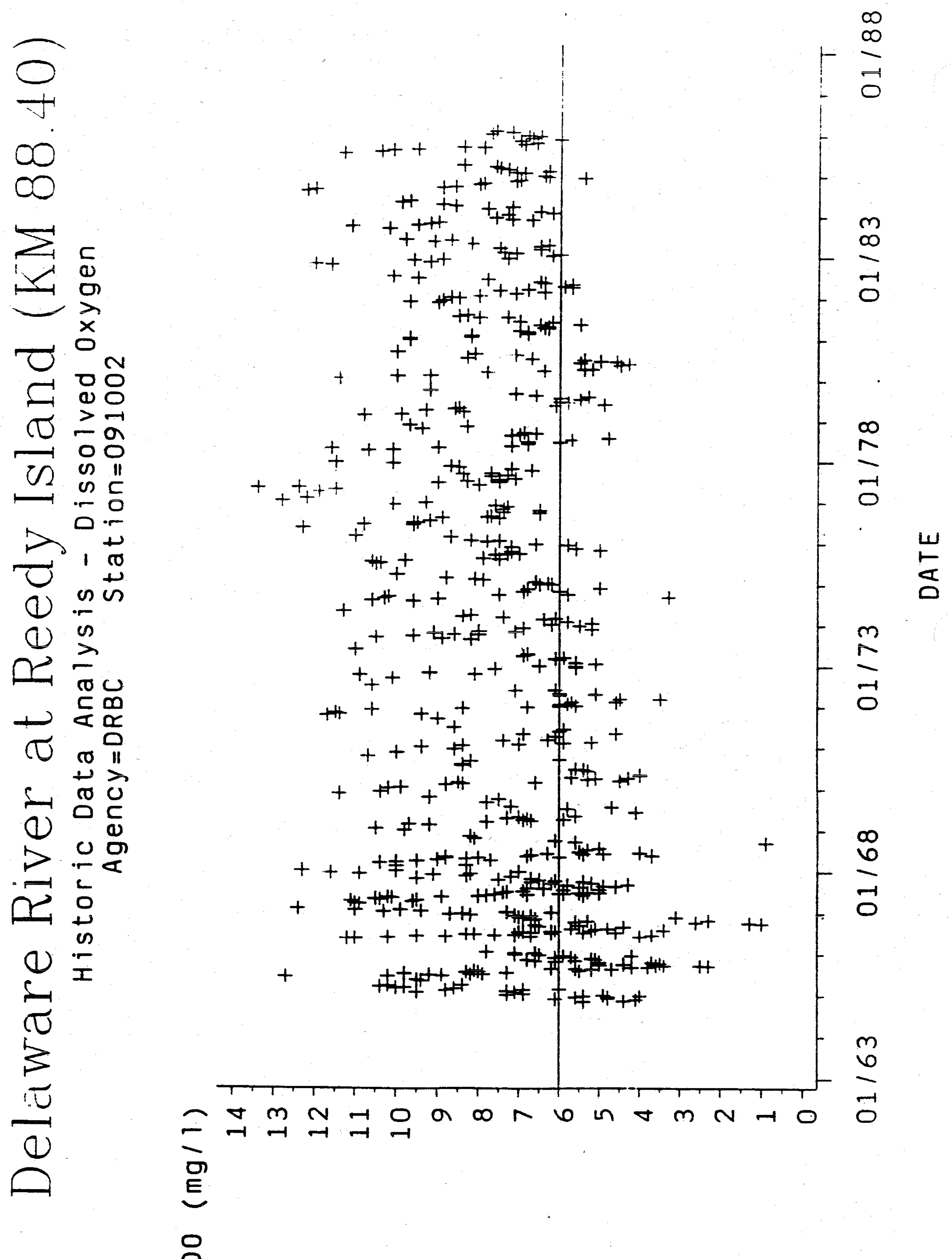


Figure F.1: Dissolved Oxygen - Reedy Island, DE

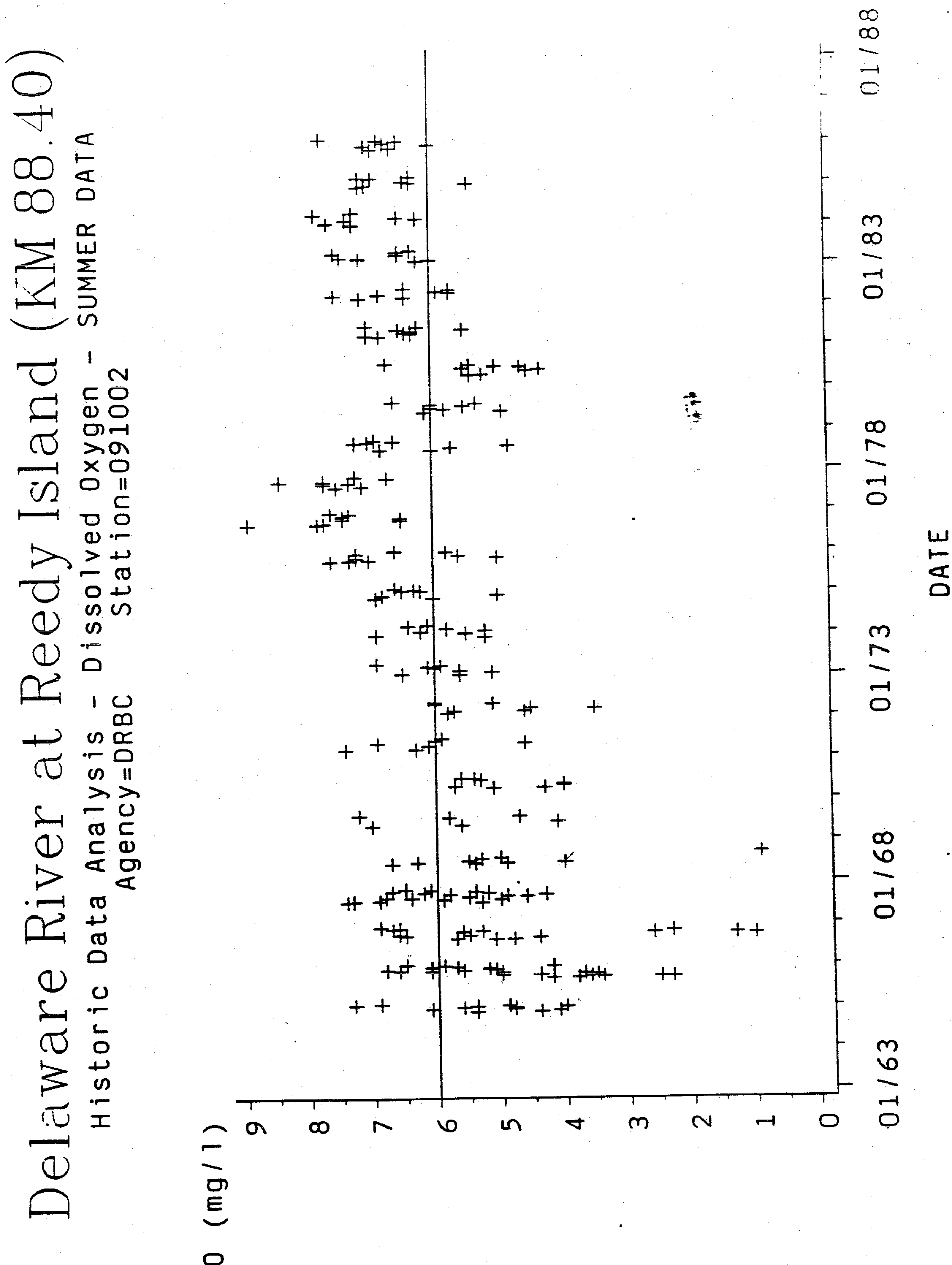


Figure F.2: Summer Dissolved Oxygen - Reedy Island, DE

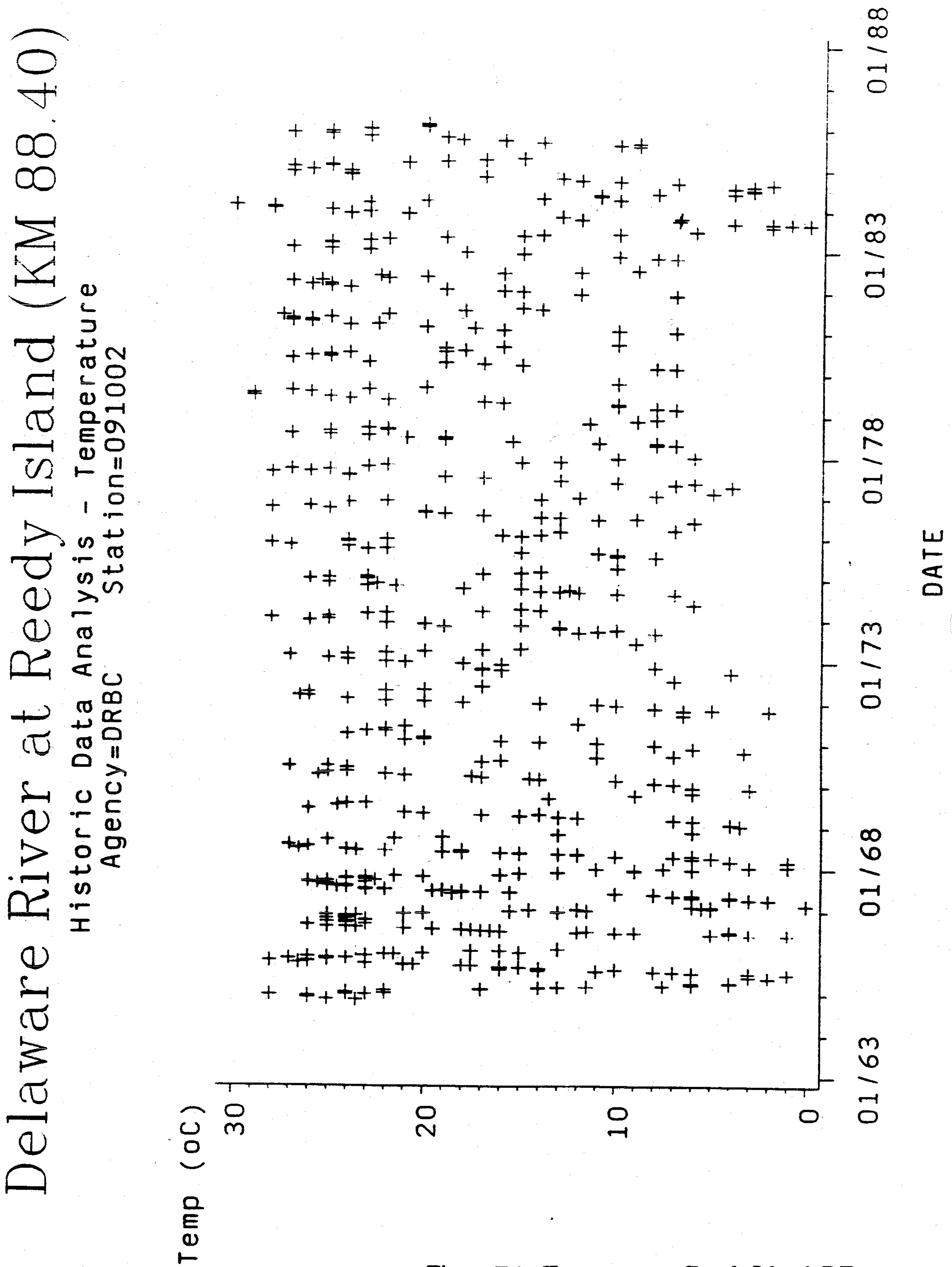


Figure F.3: Temperature - Reedy Island, DE

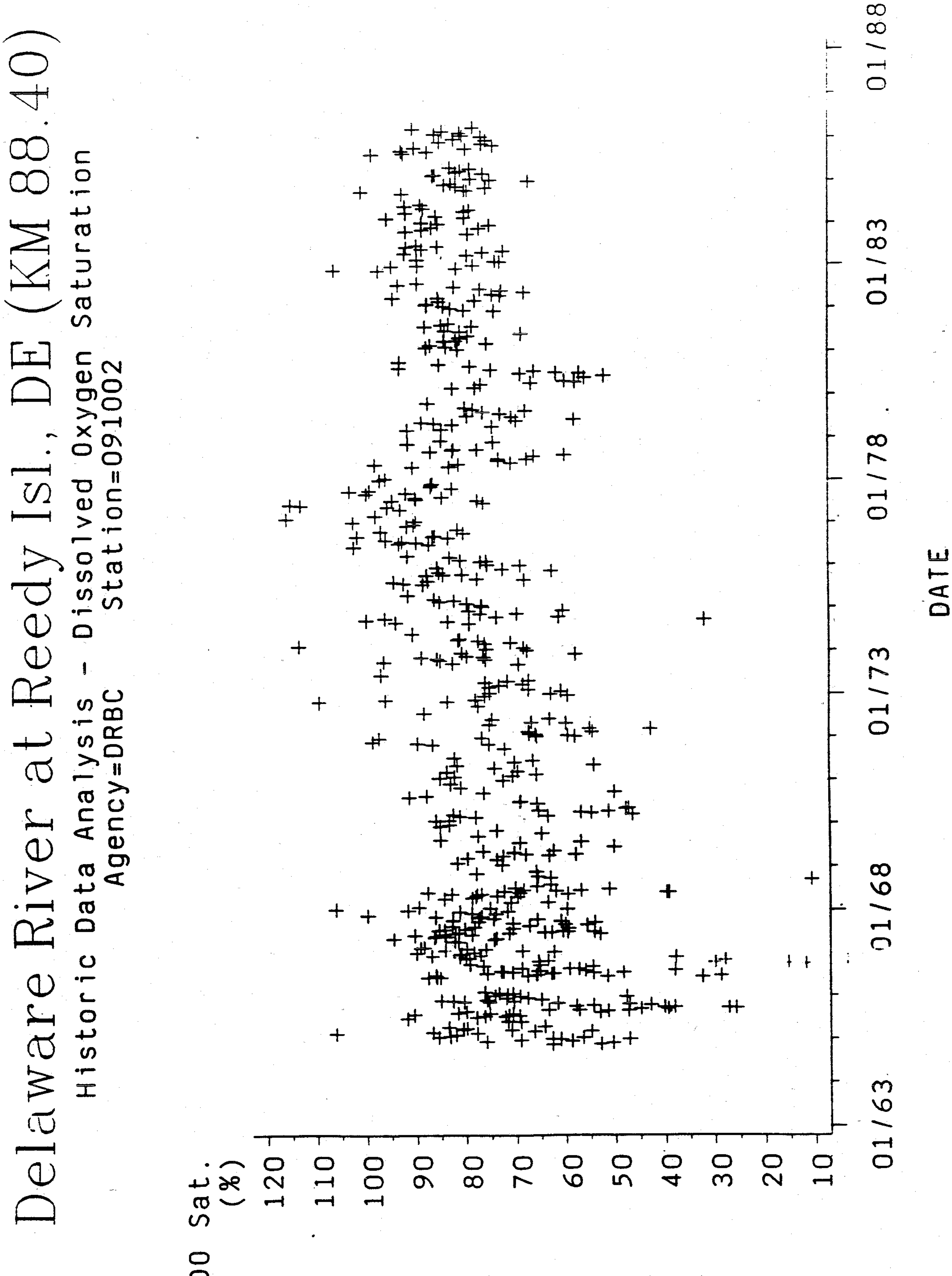


Figure F.4: DO Percent Saturation - Reedy Island, DE

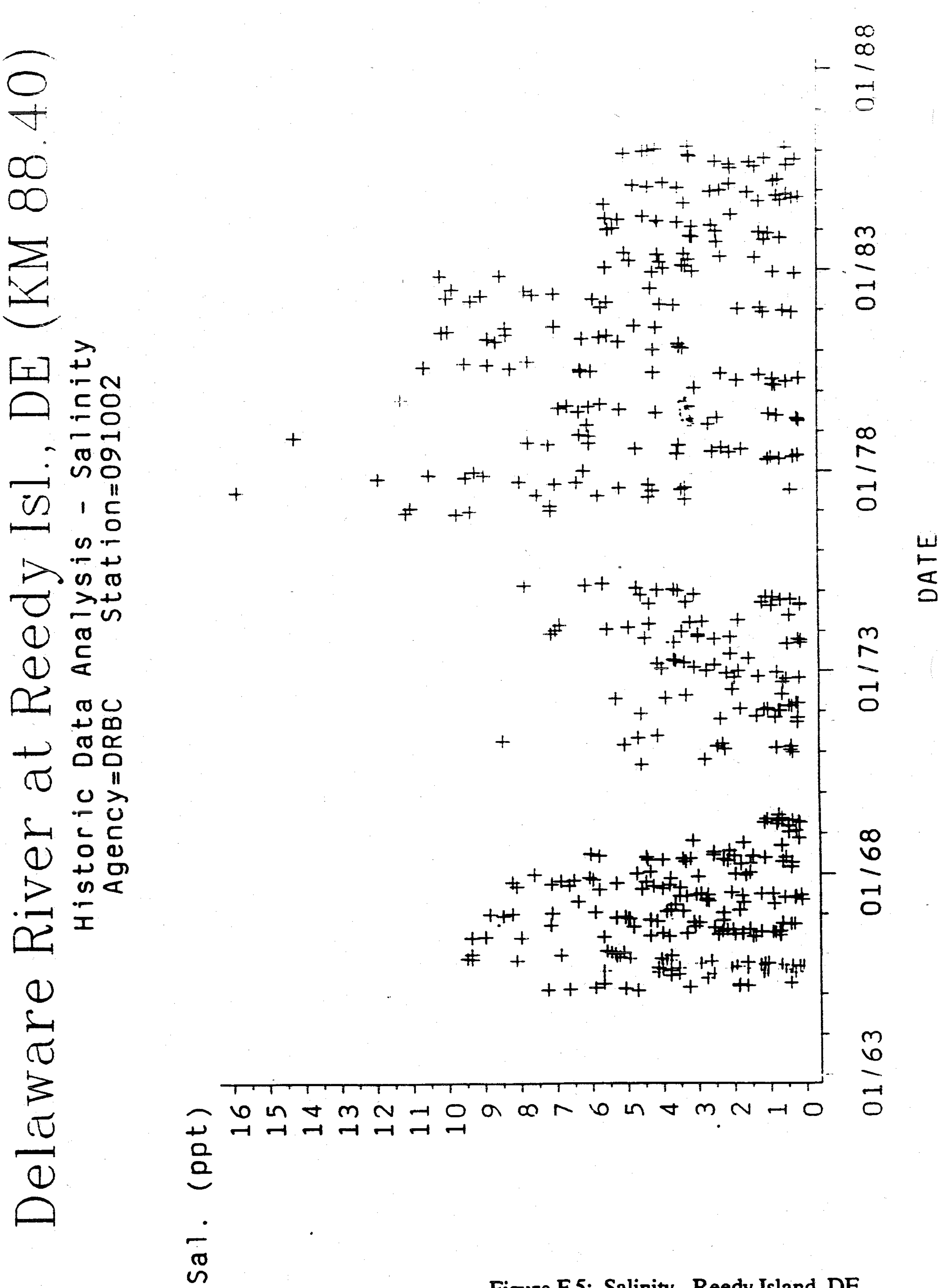


Figure F.5: Salinity - Reedy Island, DE

Delaware River at Reedy Island (KM 88.40)

Historic Data Analysis - pH
Agency=DRBC Station=091002

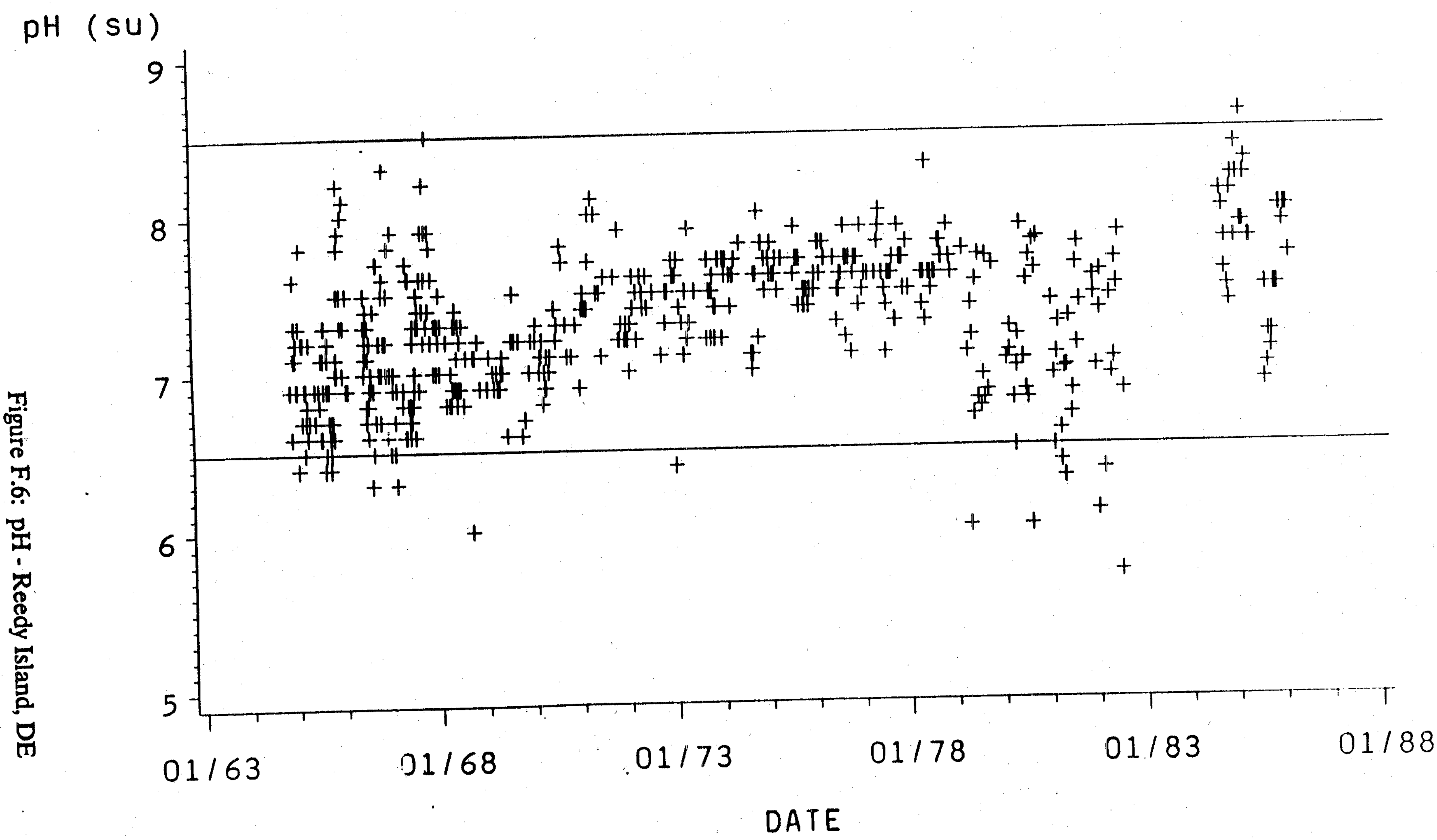


Figure F.6: pH - Reedy Island, DE

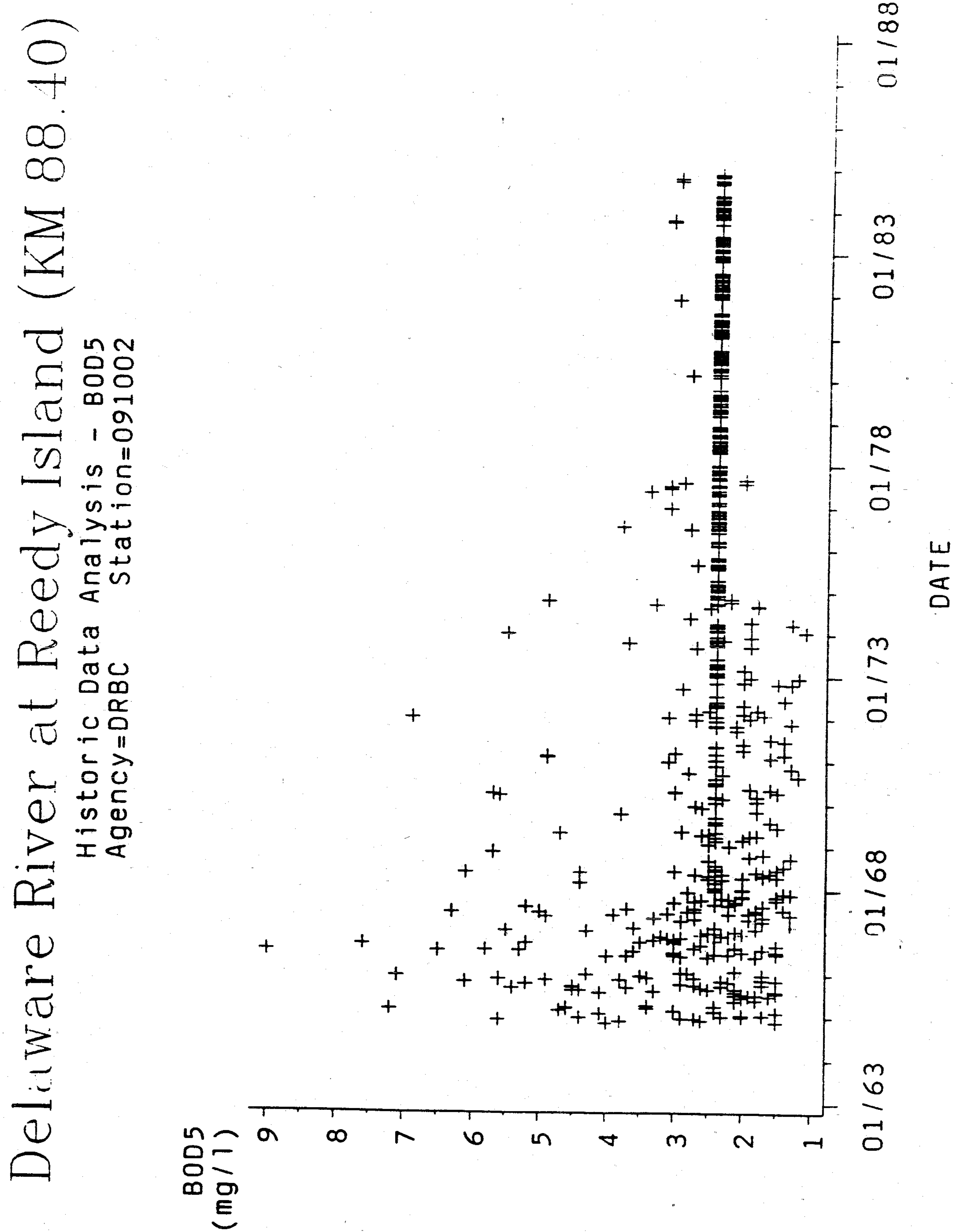


Figure F.7: BOD_5 - Reedy Island, DE

Delaware River at Reedy Island (KM 88.40)

Historic Data Analysis - Ammonia as N
Agency=DRBC Station=091002

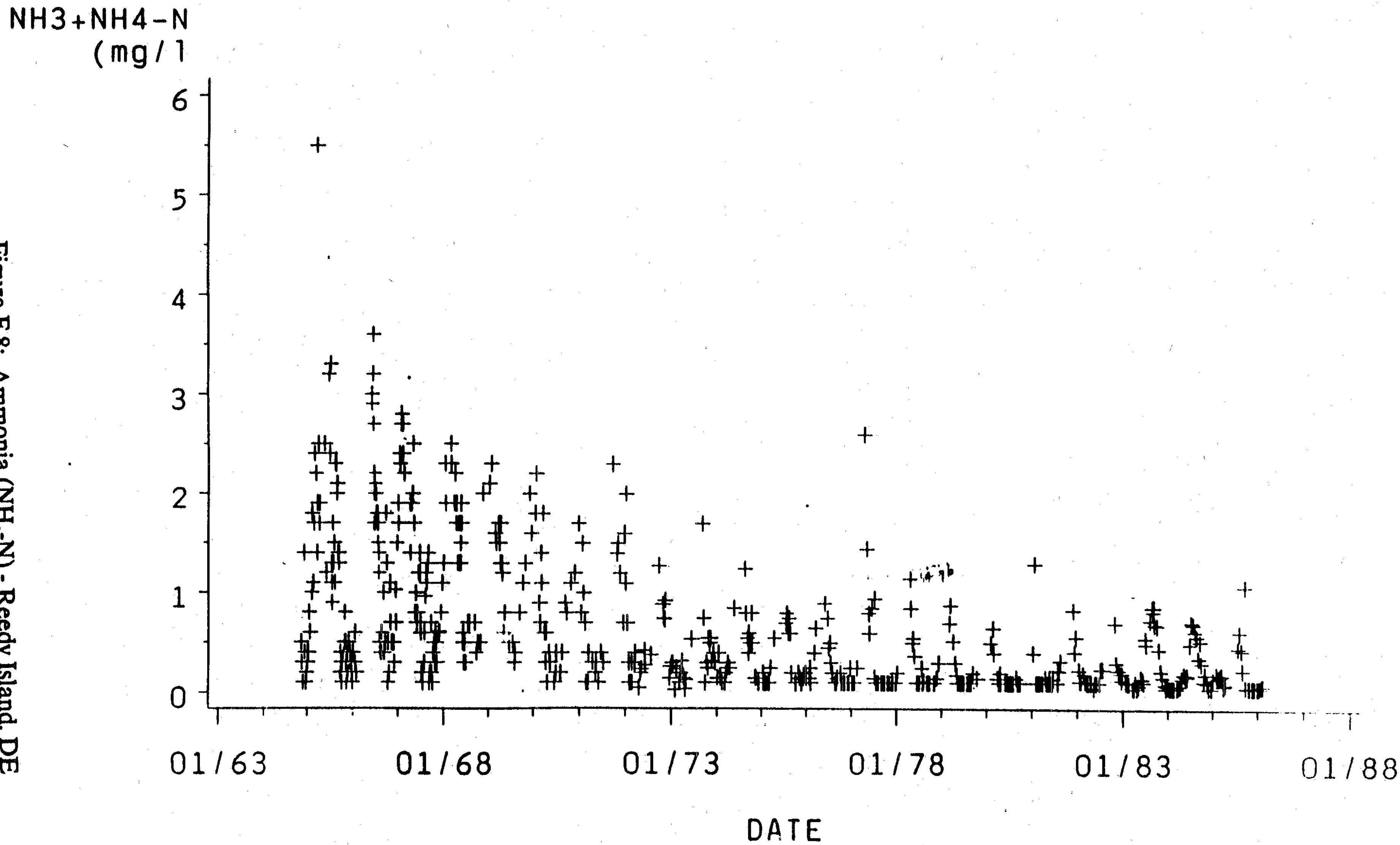


Figure F.8: Ammonia (NH_3-N) - Reedy Island, DE

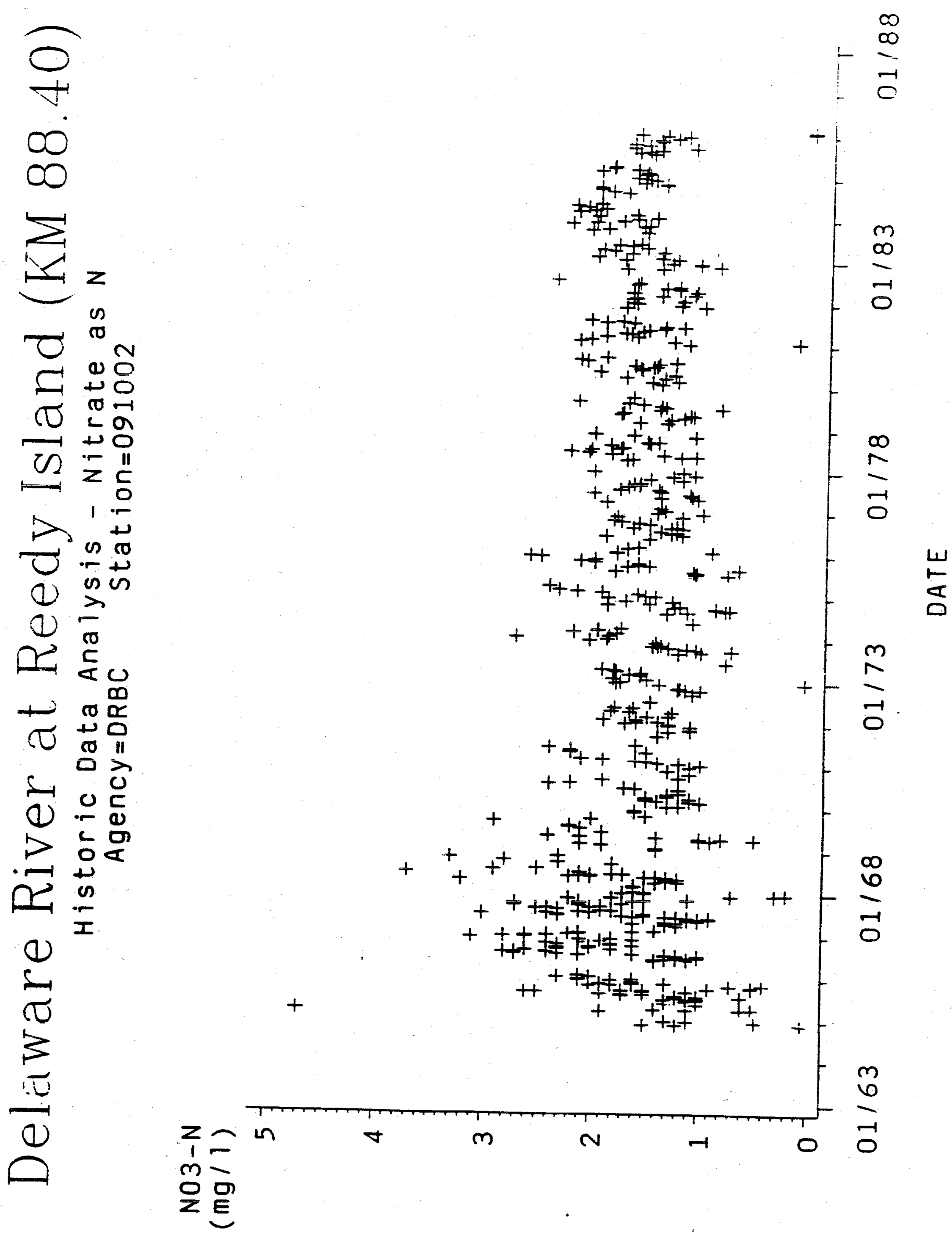


Figure F.9: Nitrate (NO_3-N) - Reedy Island, DE

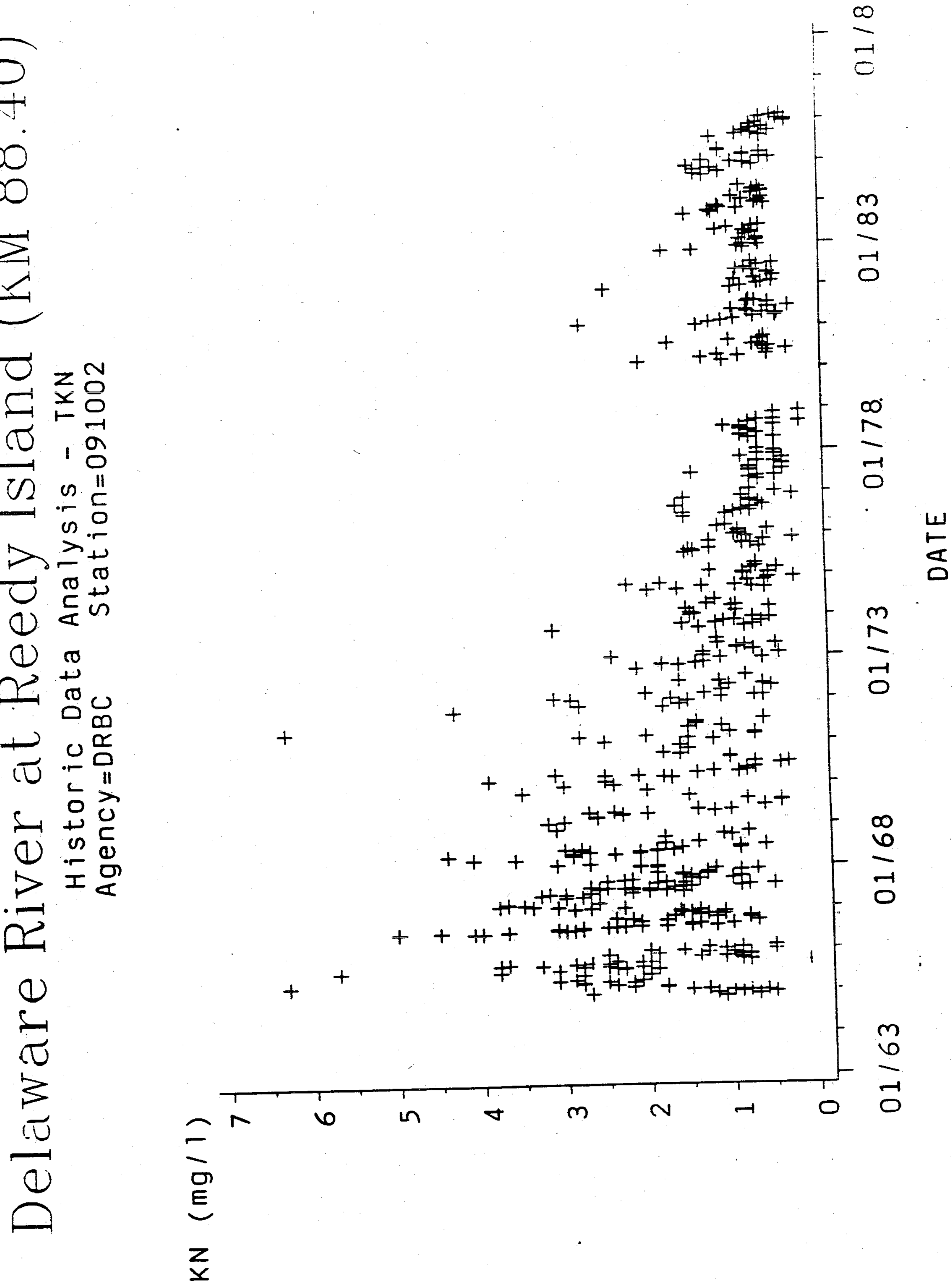


Figure F.10: TKN - Reedy Island, DE

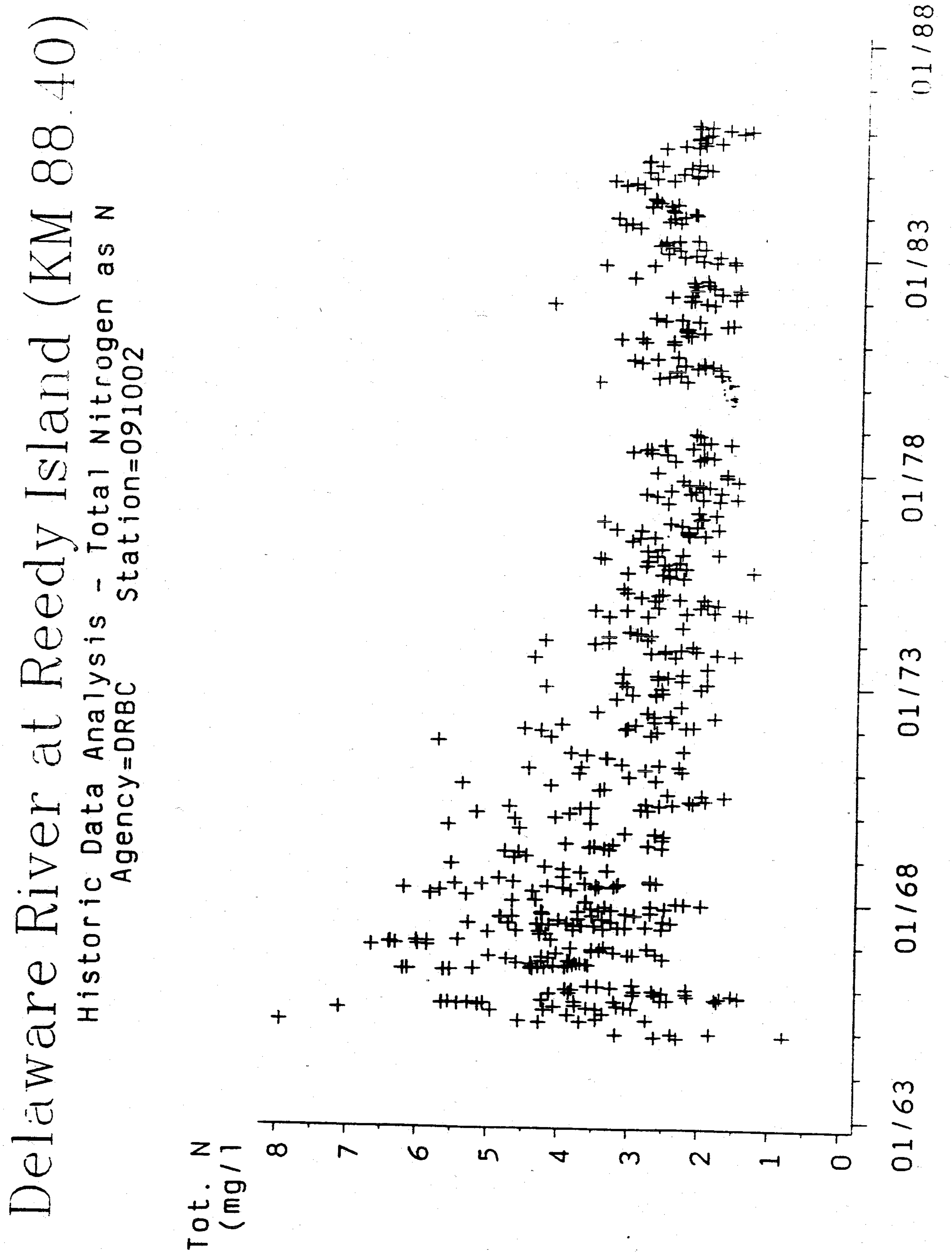


Figure F.11: Total Nitrogen - Reedy Island, DE

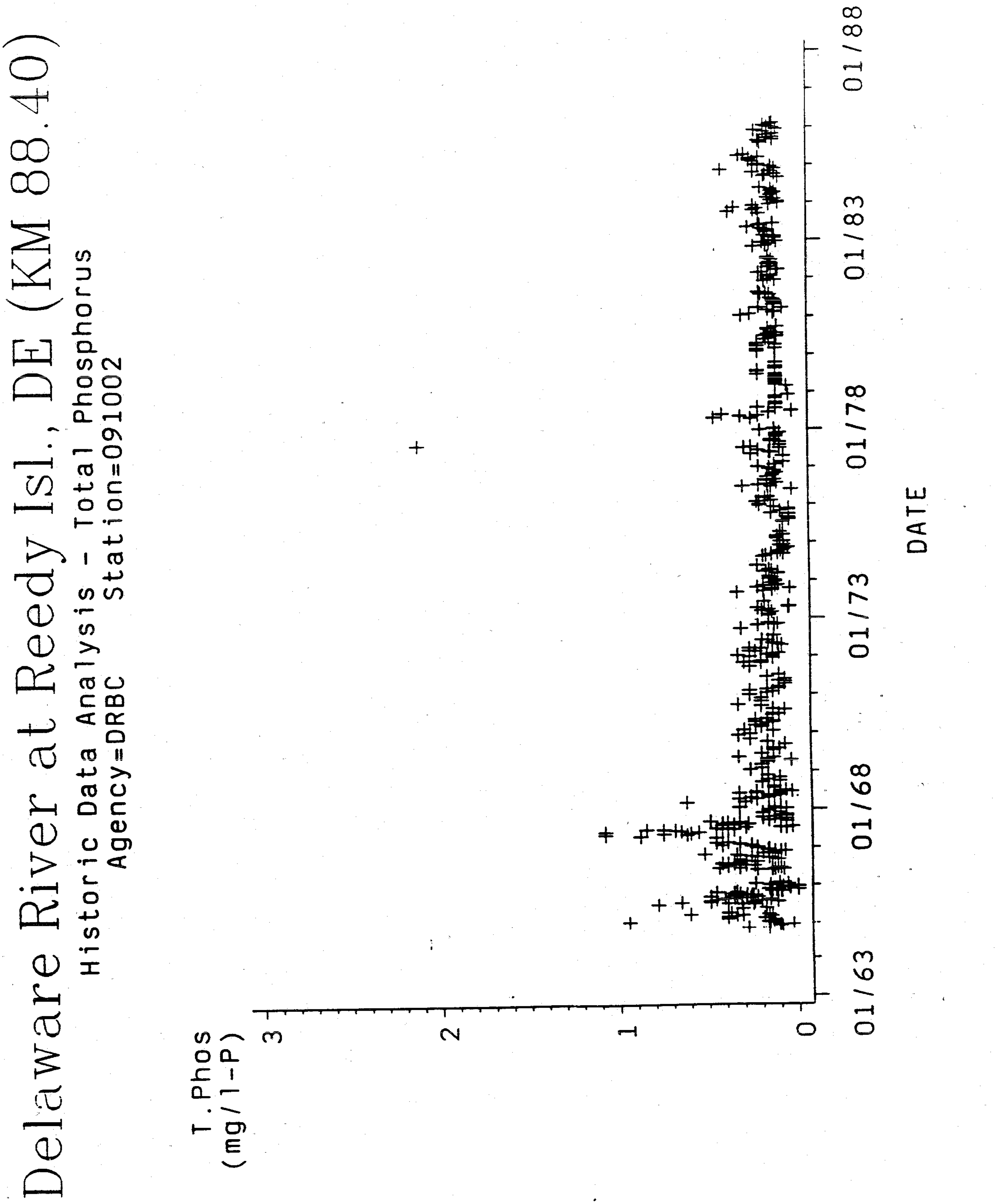


Figure F.12: Total Phosphorus - Reedy Island, DE

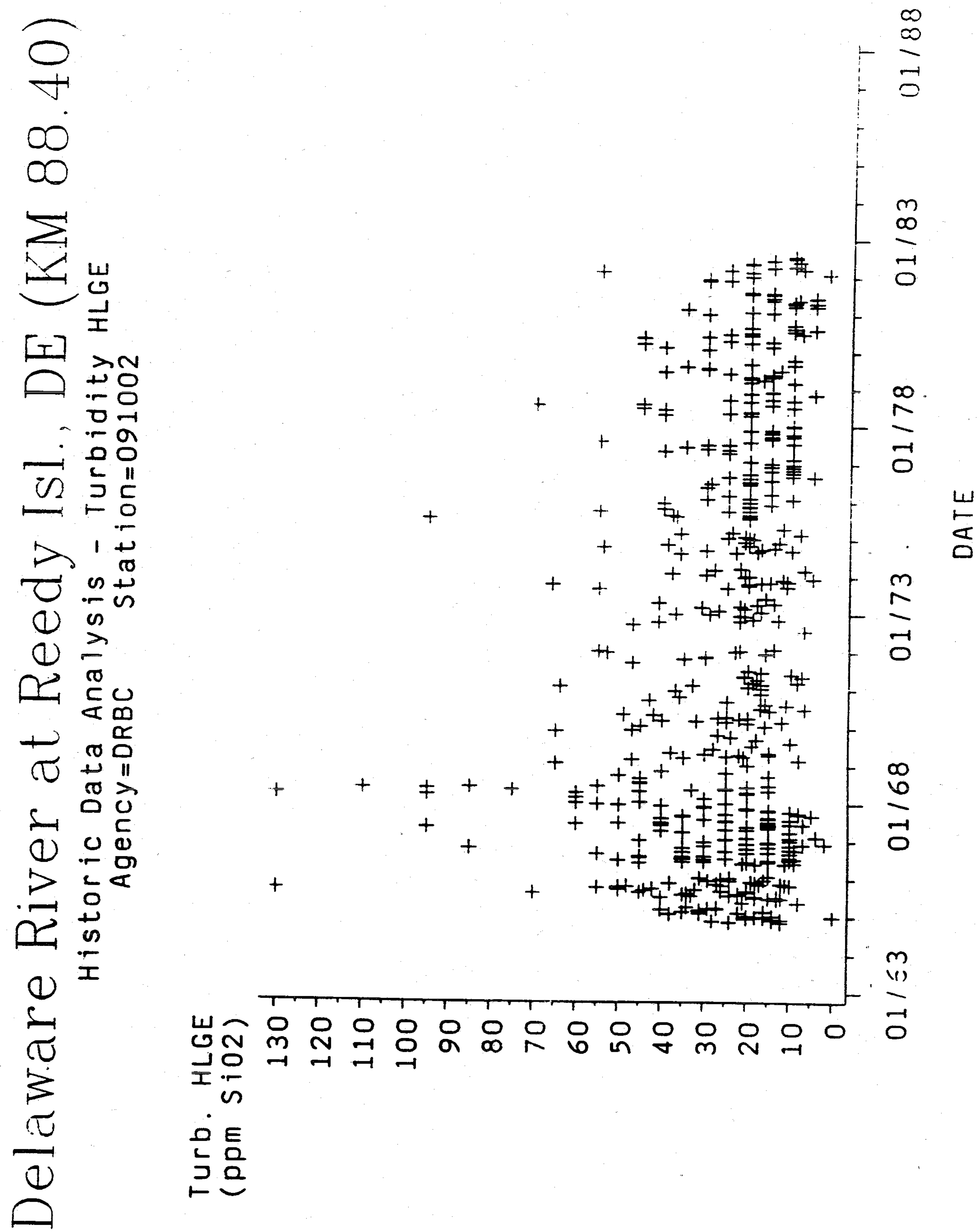


Figure F.13: Turbidity - Reedy Island, DE

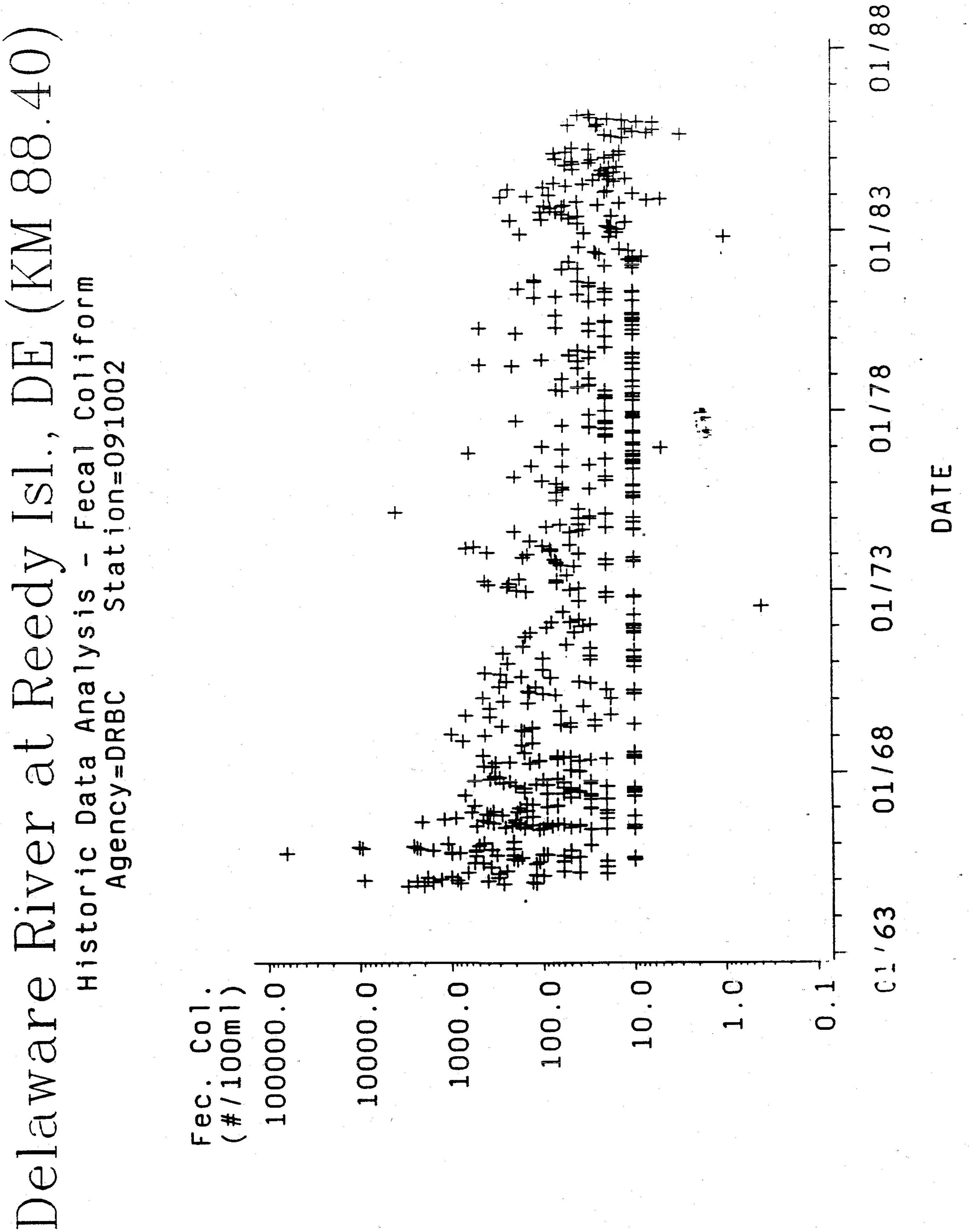


Figure F.14: Fecal Colifor.n - Reedy Island, DE

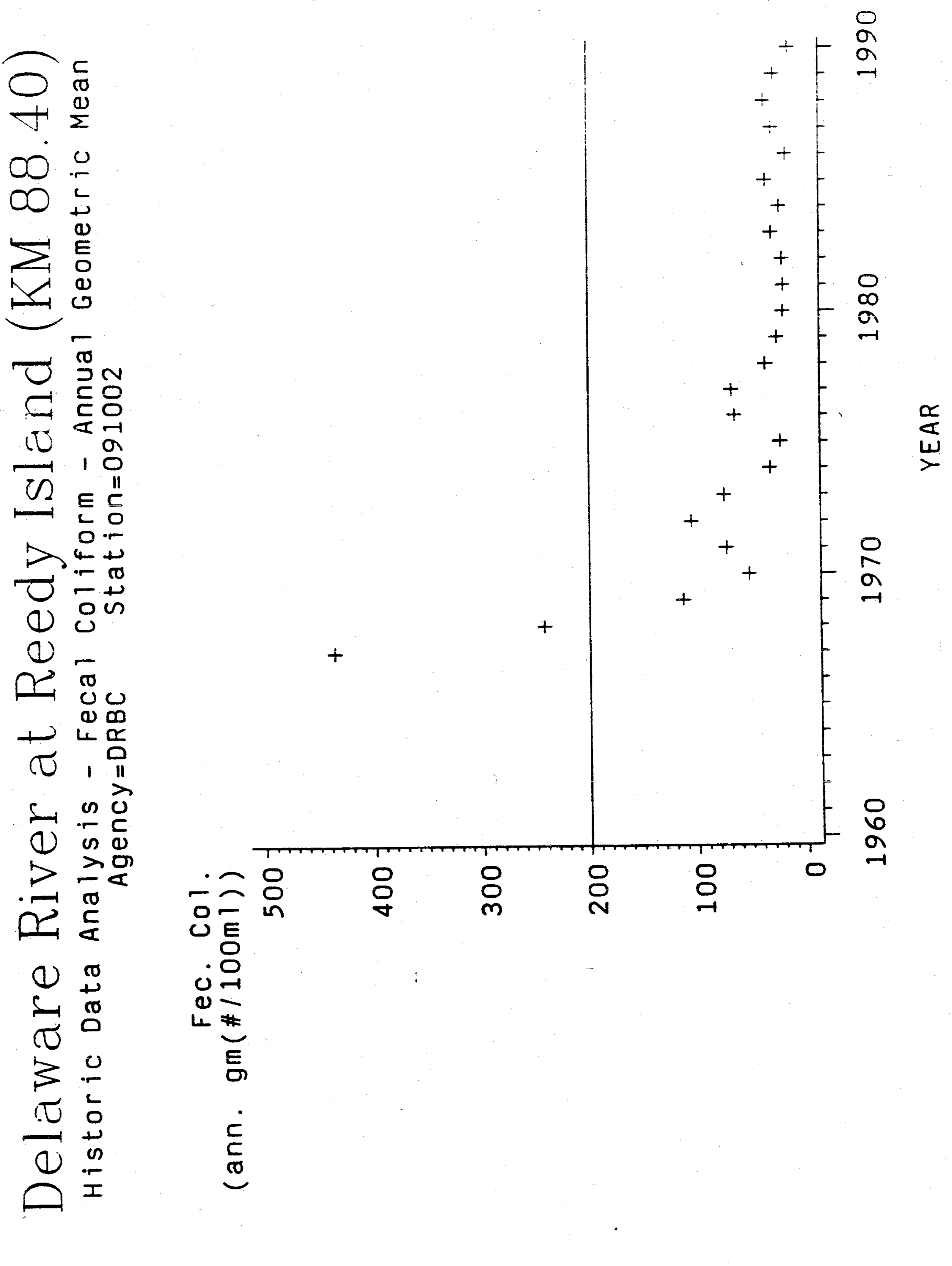


Figure F.15: Annual Geometric Mean FC - Reedy Island, DE

APPENDIX G

DELAWARE RIVER AT MOUTH OF THE SMYRNA RIVER (RK 71.66)

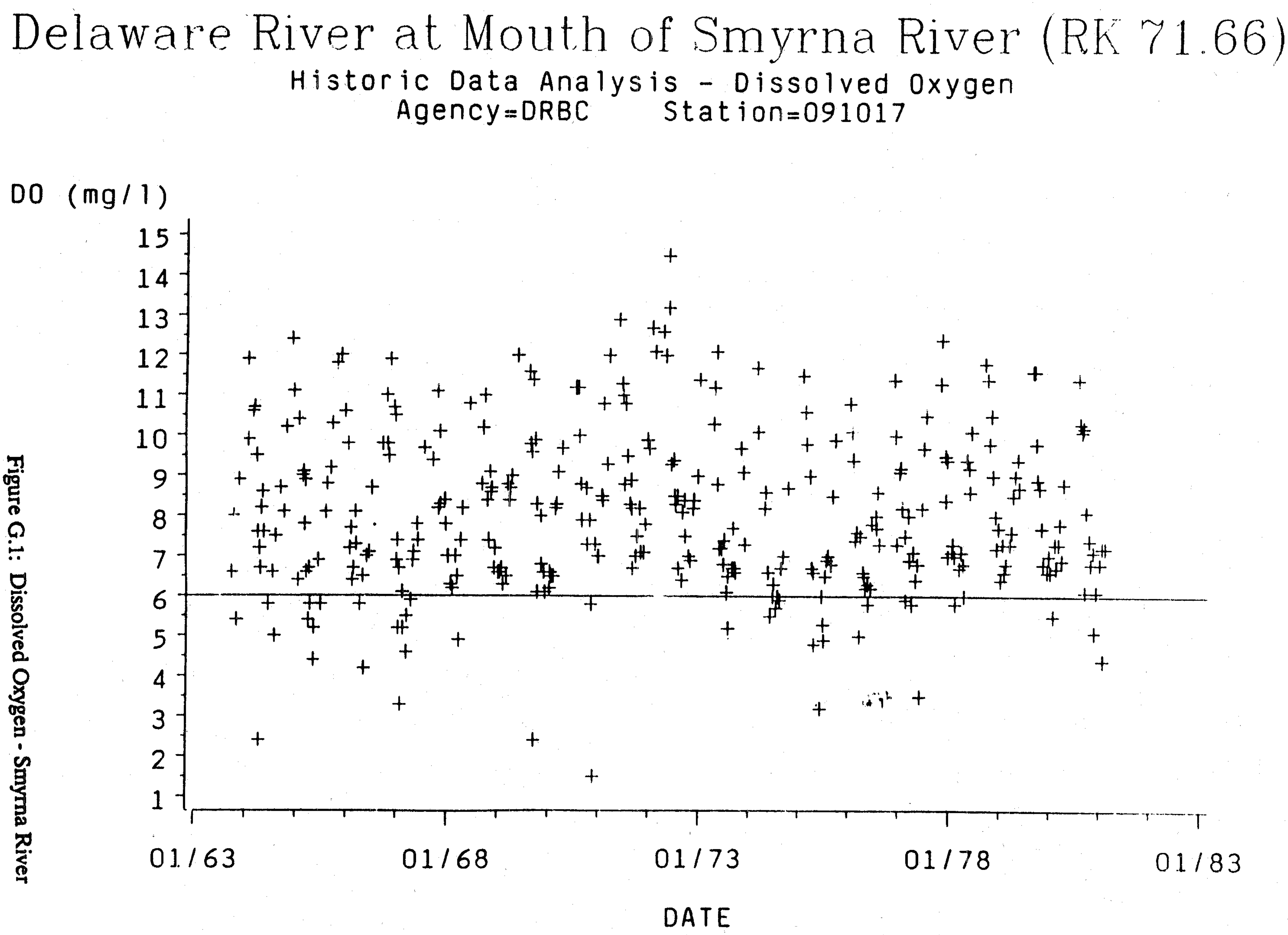


Figure G.1: Dissolved Oxygen - Smyrna River

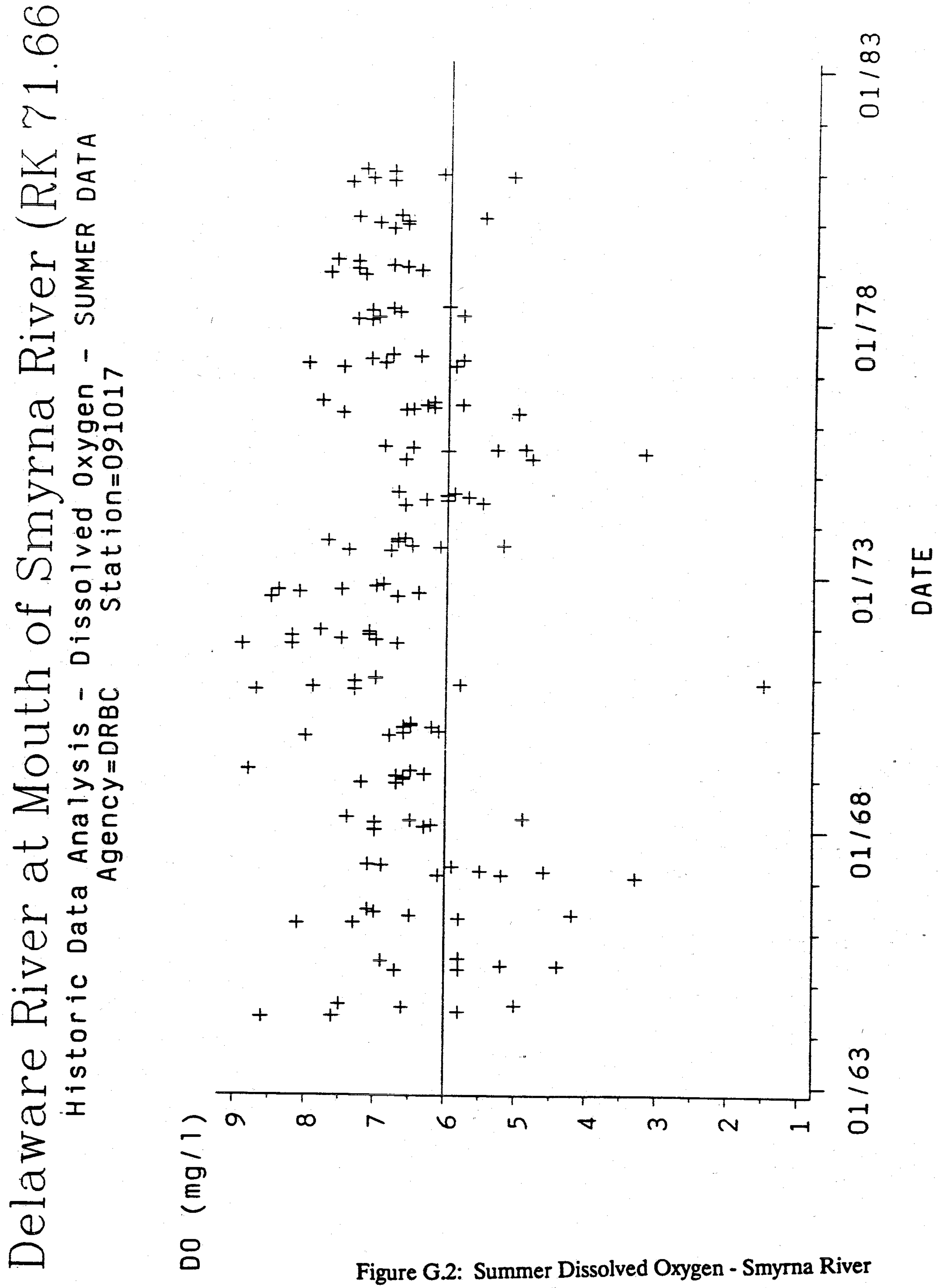


Figure G.2: Summer Dissolved Oxygen - Smyrna River

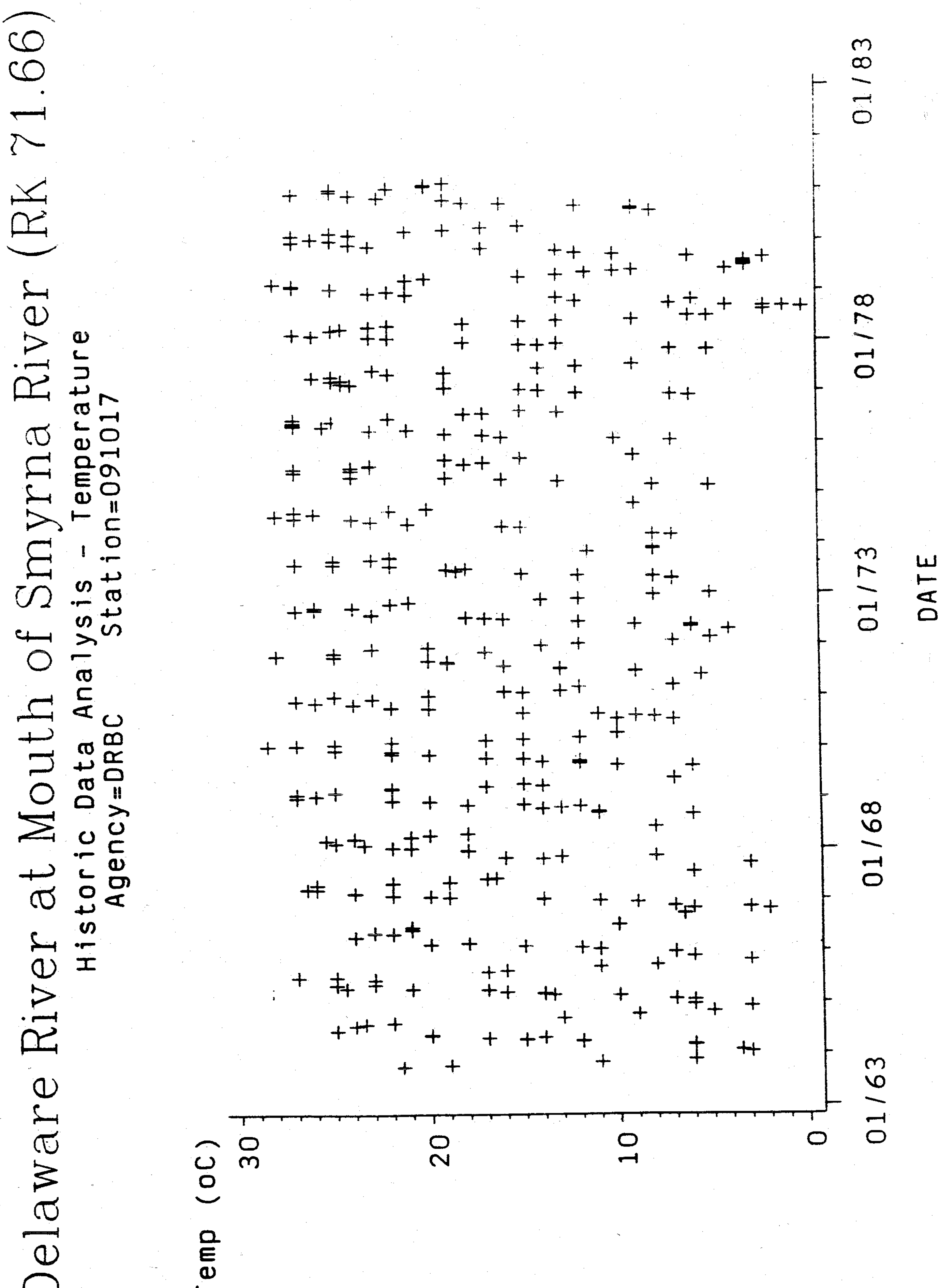


Figure G.3: Temperature - Smyrna River

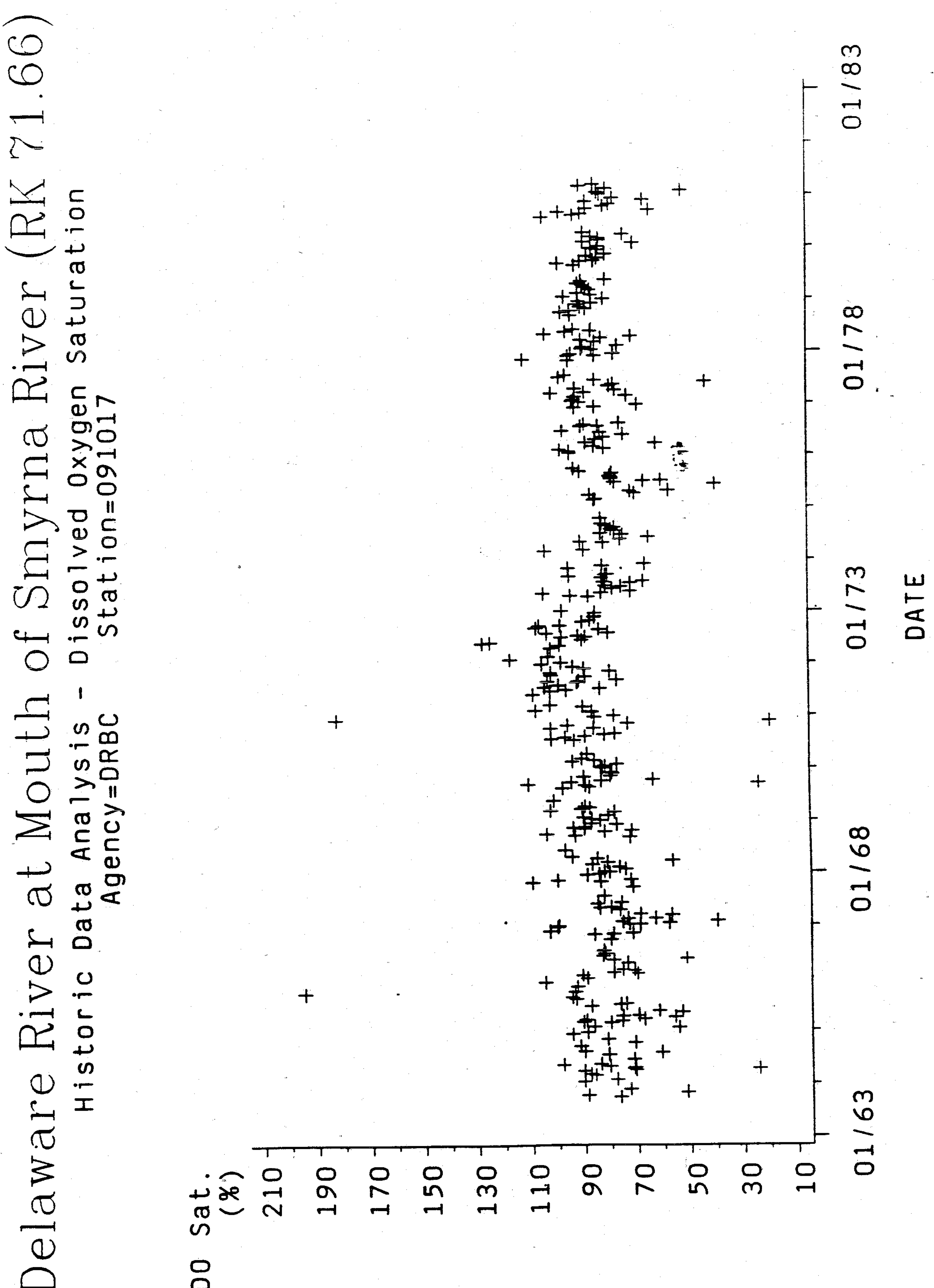


Figure G.4: DO Percent Saturation - Smyrna River

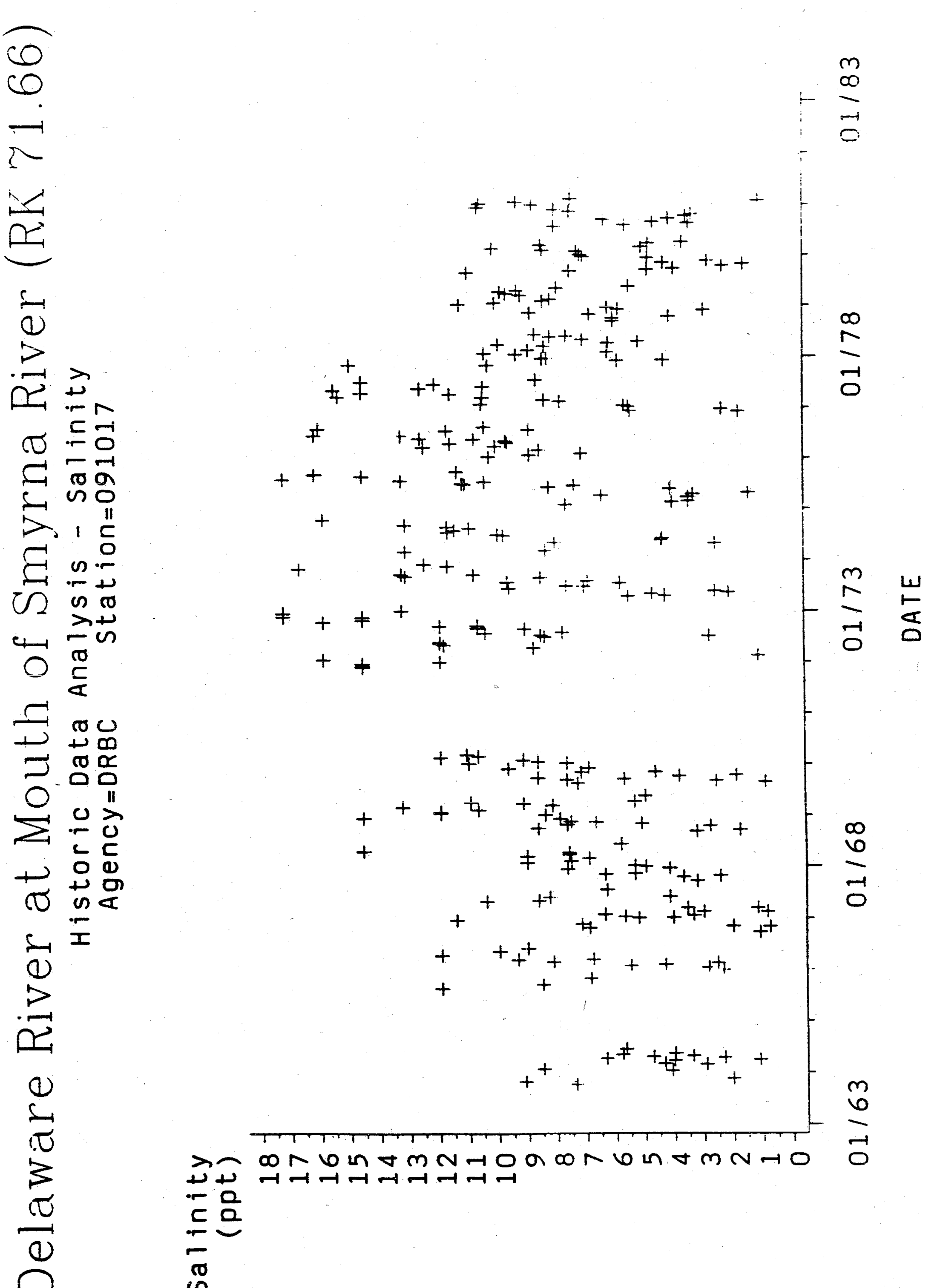


Figure G.5: Salinity - Smyrna River

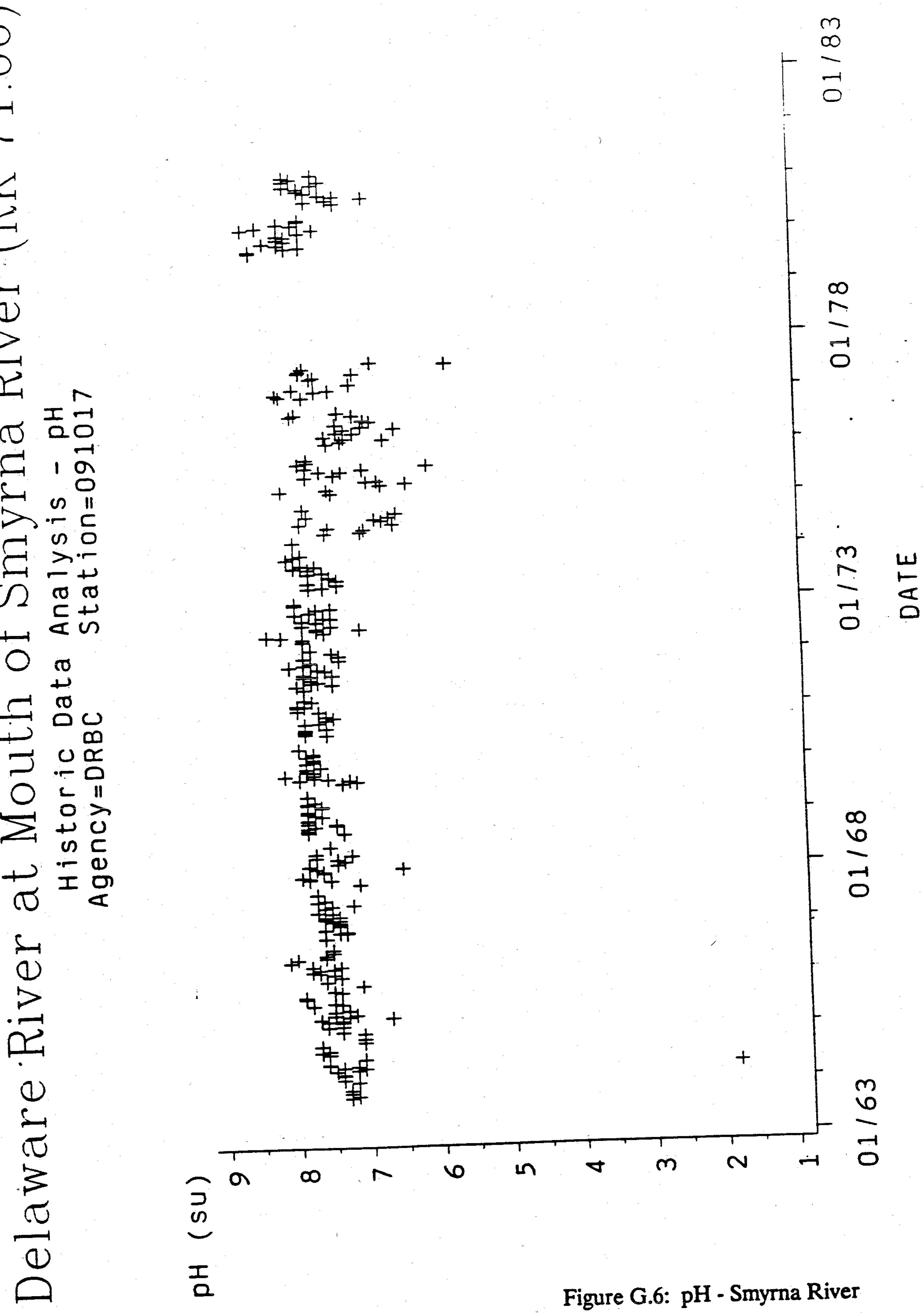


Figure G.6: pH - Smyrna River

Delaware River at Mouth of Smyrna River (RK 71.66)

Historic Data Analysis - BOD5
Agency=DRBC Station=091017

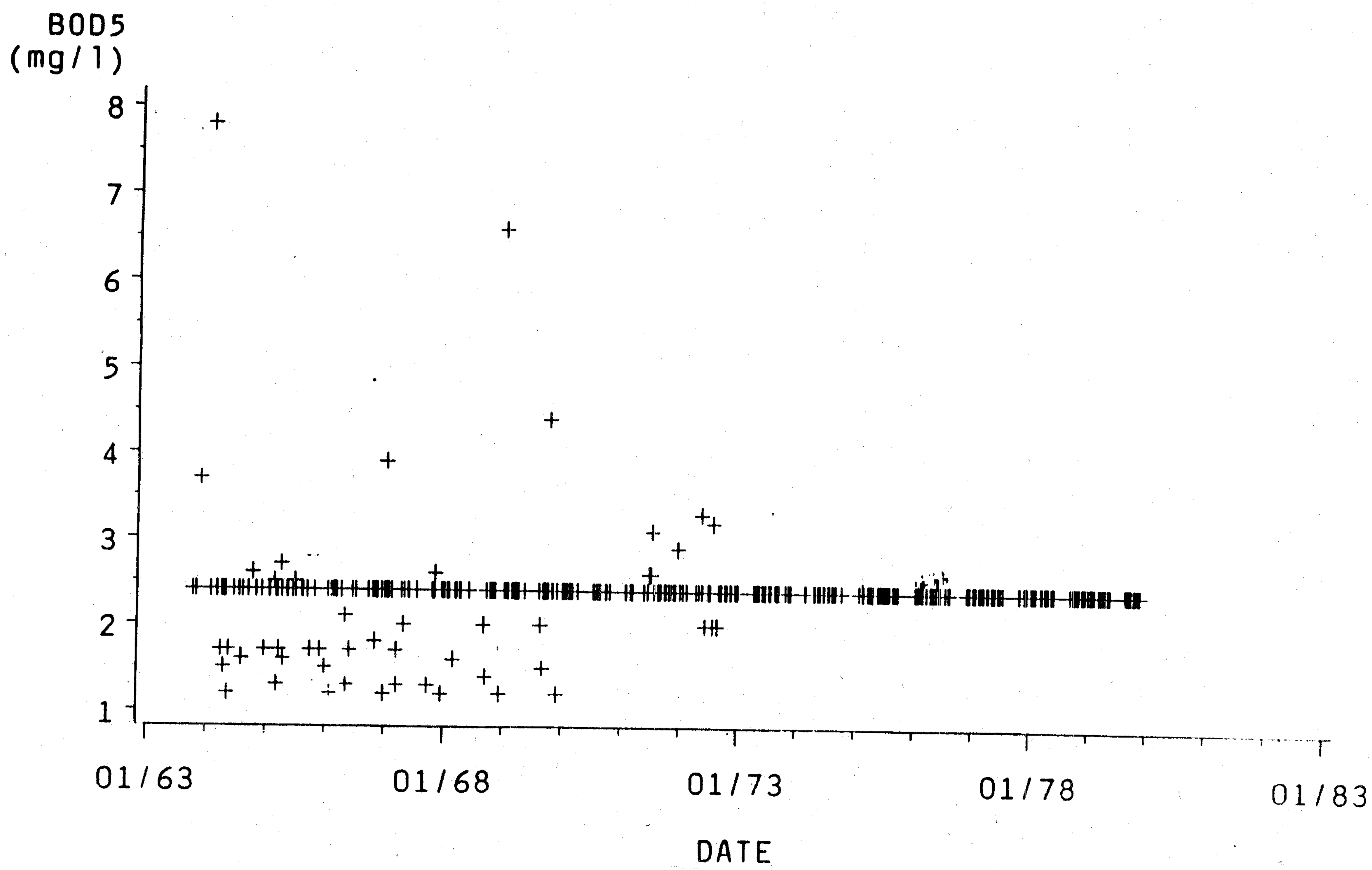


Figure G.7: BOD_5 - Smyrna River

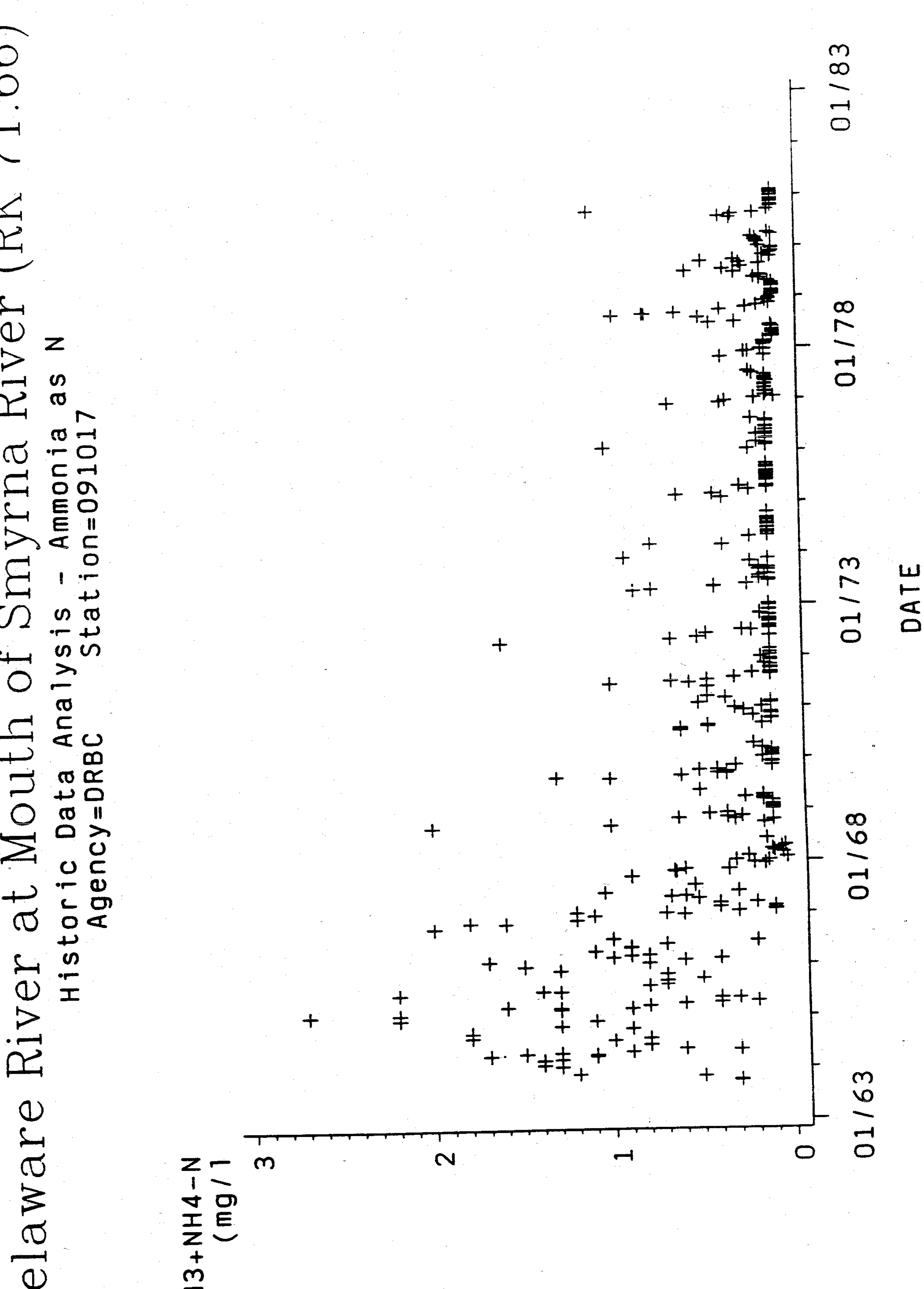


Figure G.8: Ammonia (NH_3-N) - Smyrna River

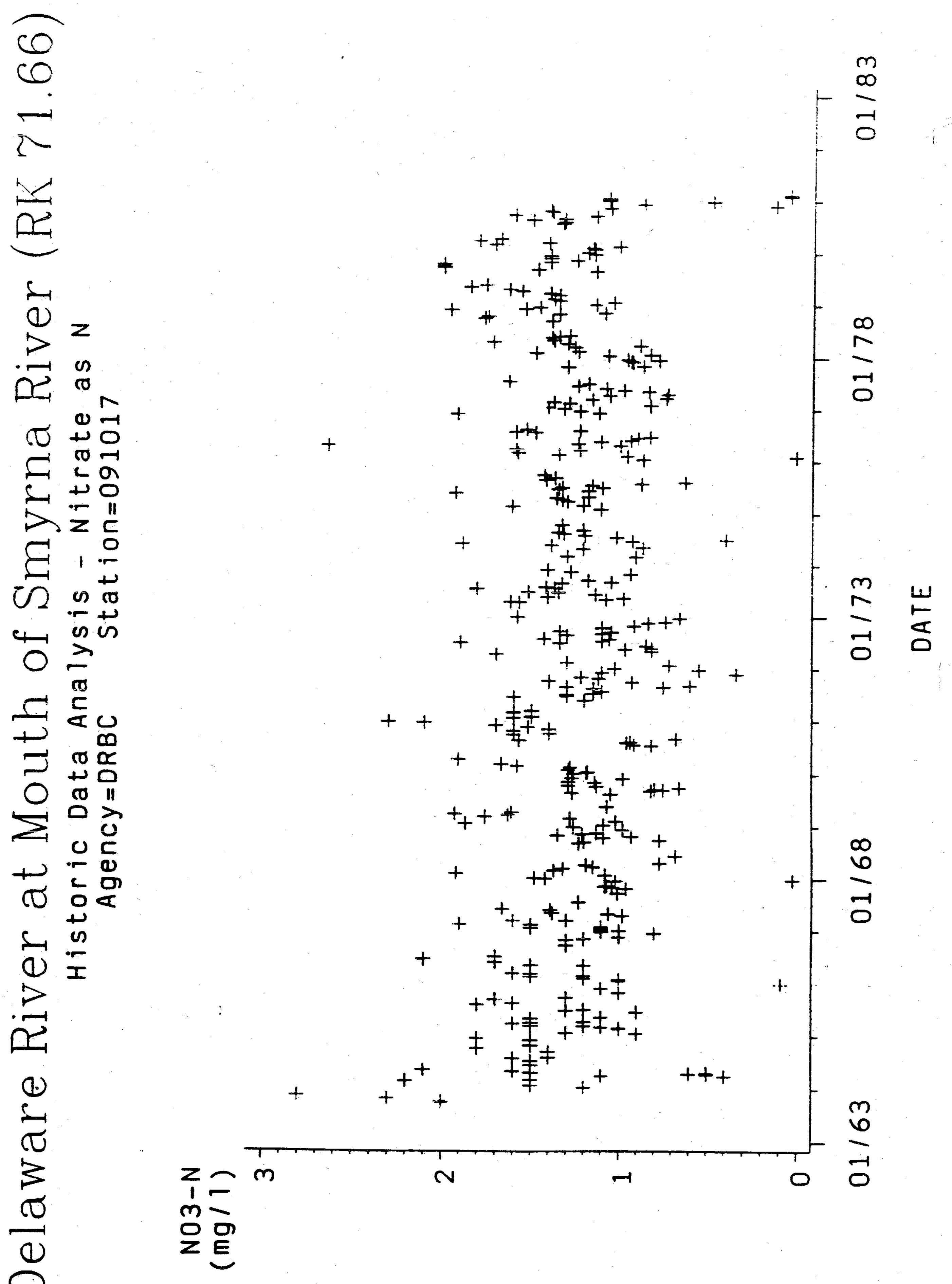


Figure G.9: Nitrate (NO_3-N) - Smyrna River

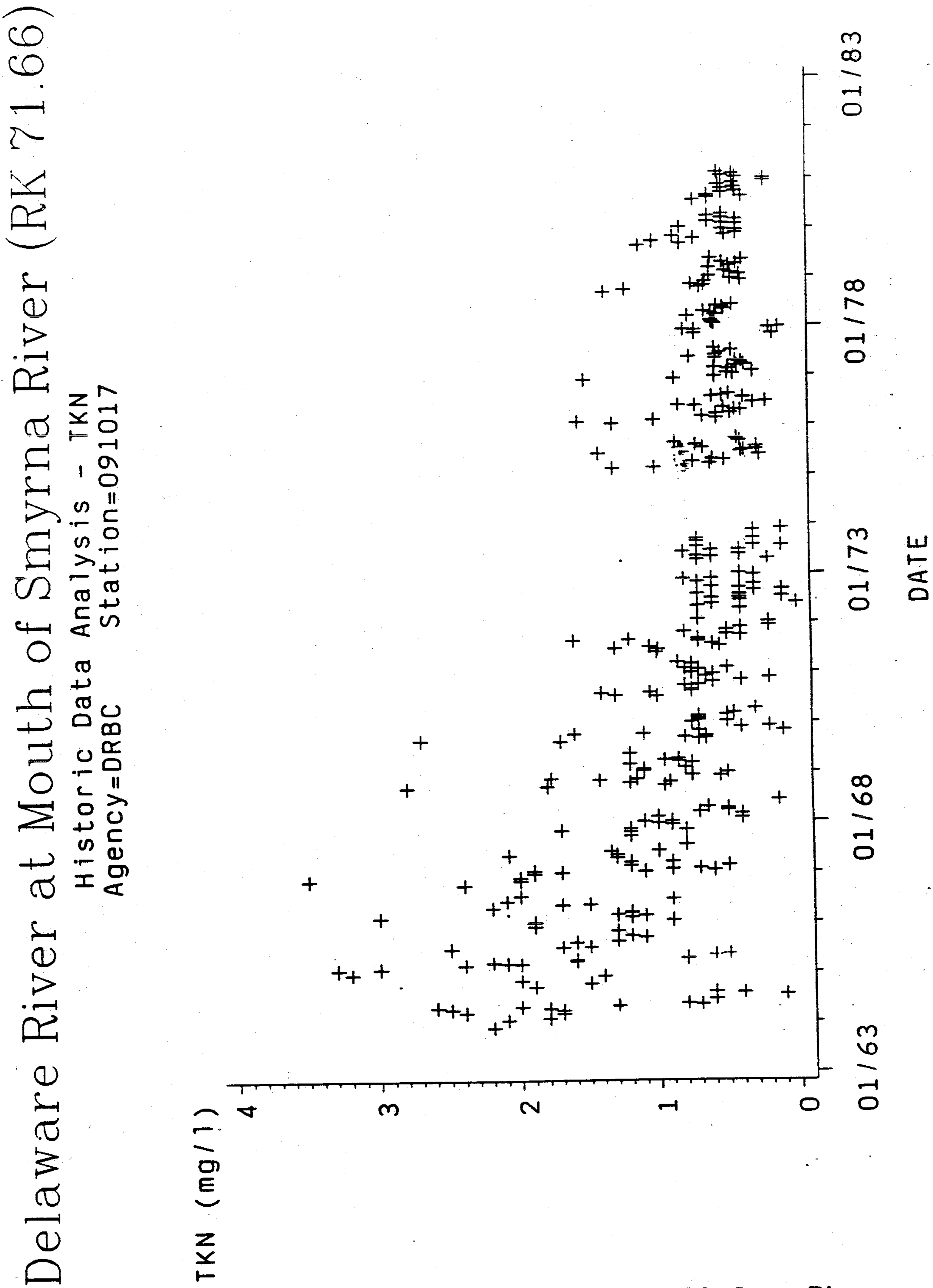


Figure G.10: TKN - Smyrna River

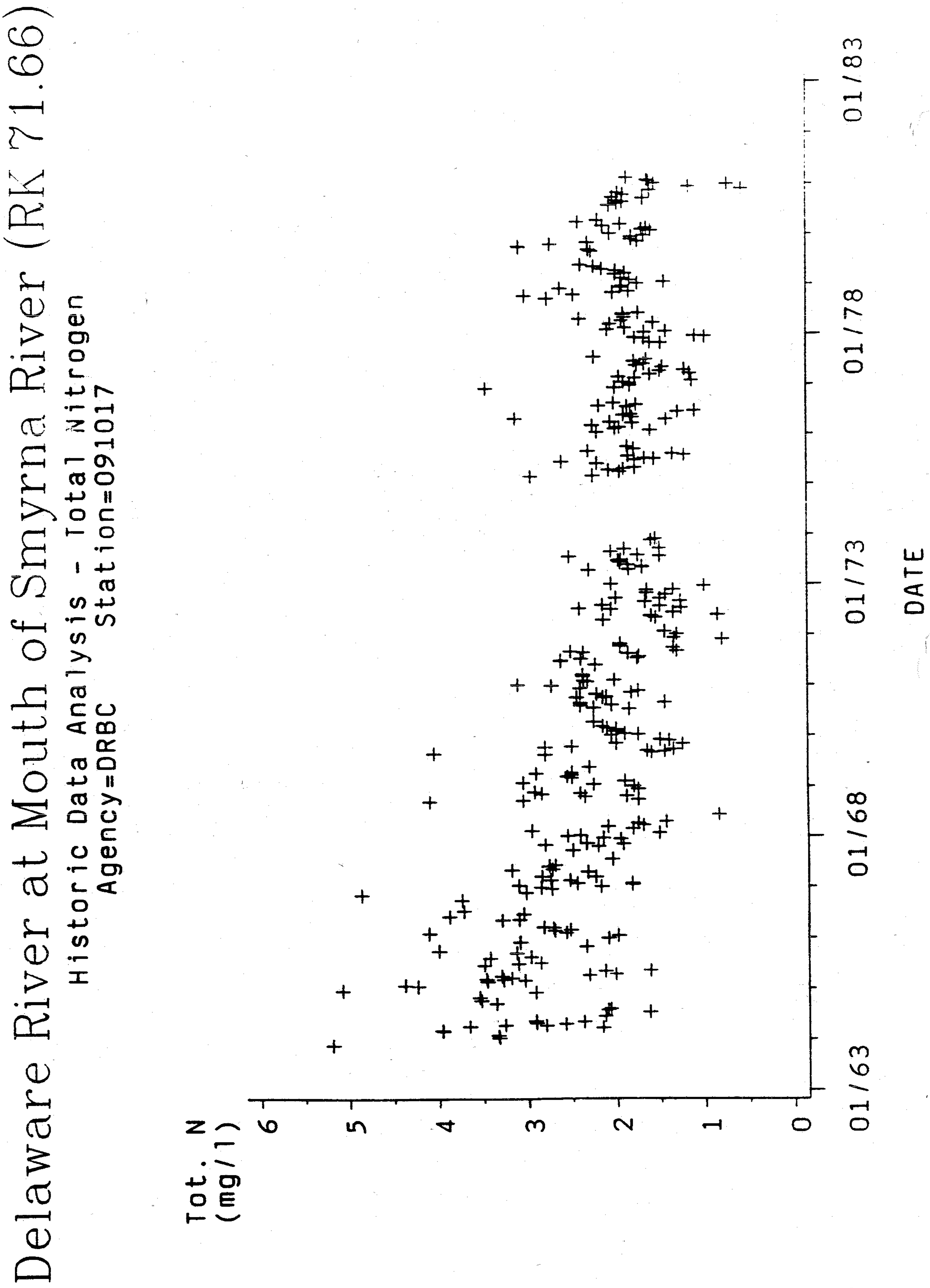


Figure G.11: Total Nitrogen - Smyrna River

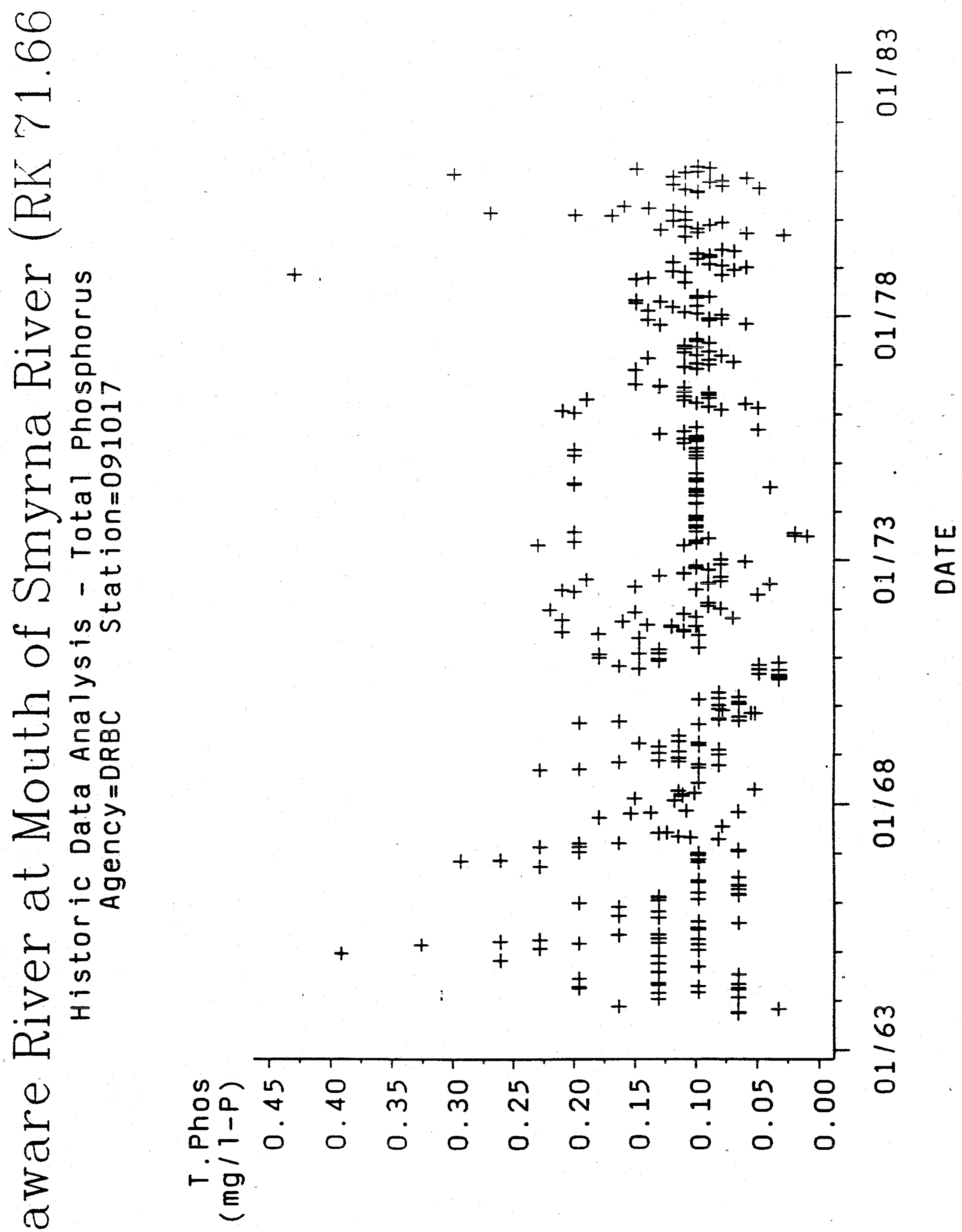


Figure G.12: Total Phosphorus - Smyrna River

Delaware River at Mouth of Smyrna River (RK 71.66)

Historic Data Analysis - Turbidity HLGE
Agency=DRBC Station=091017

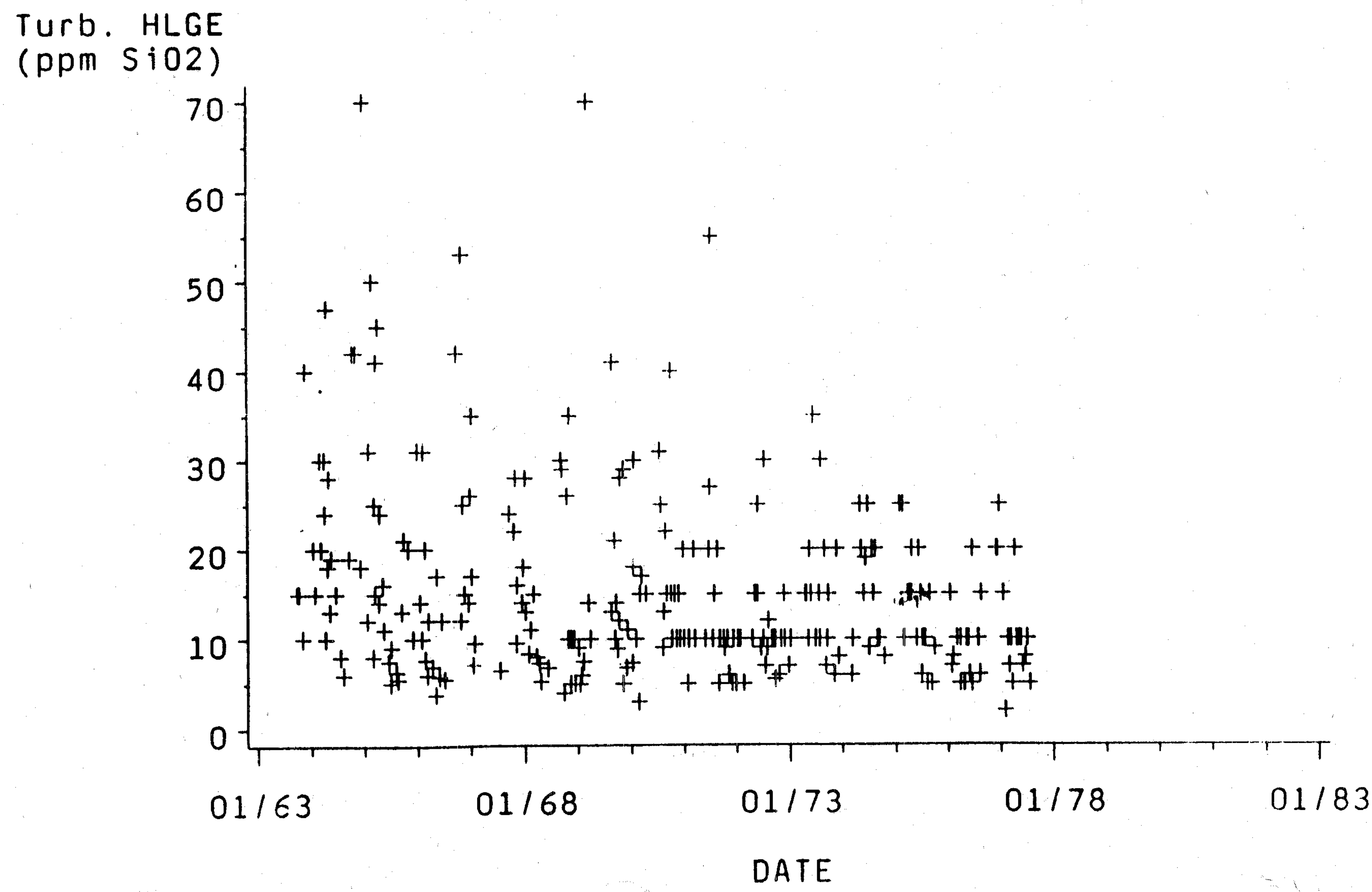


Figure G.13: Turbidity - Smyrna River

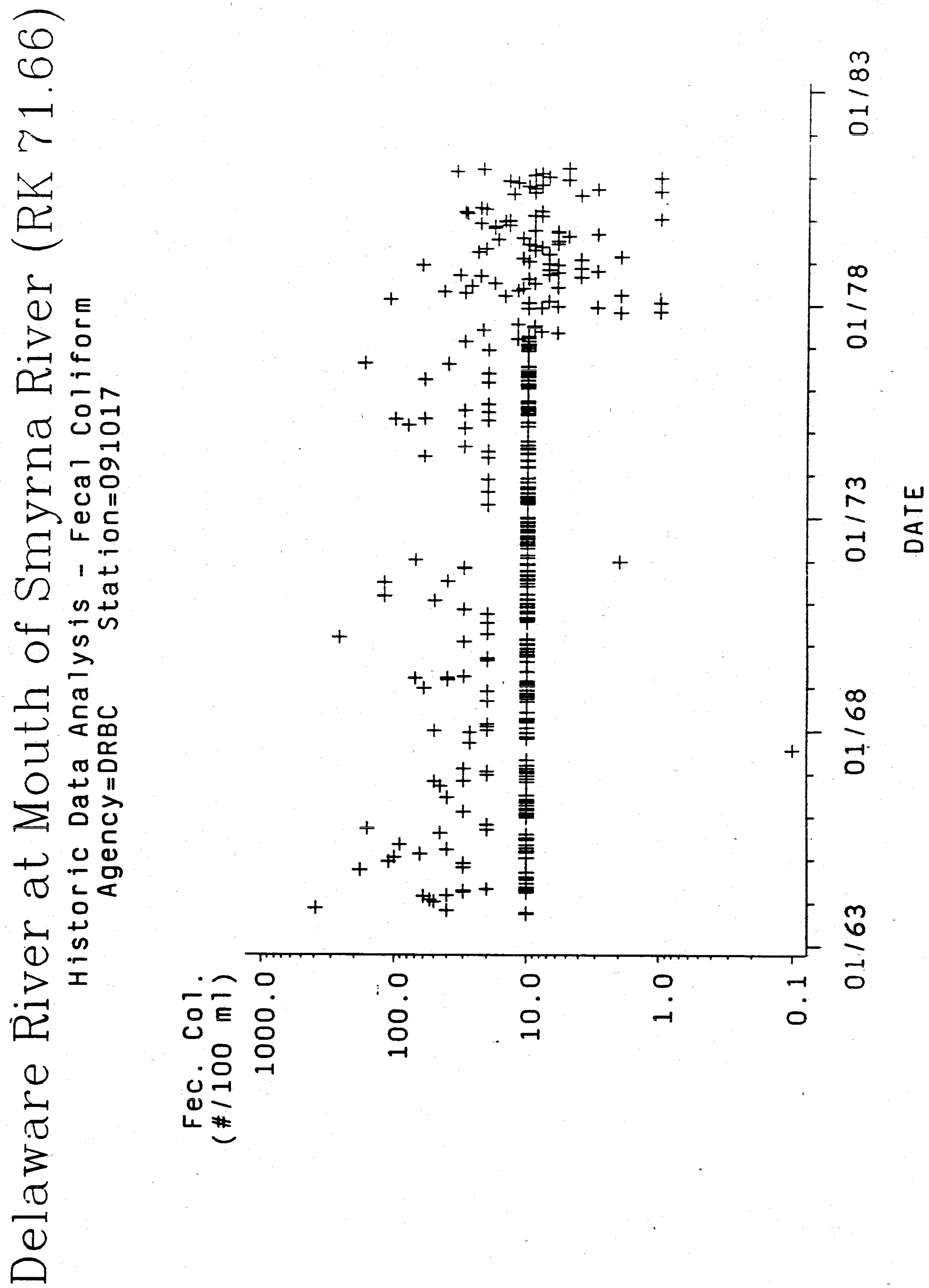


Figure G.14: Fecal Coliform - Smyrna River

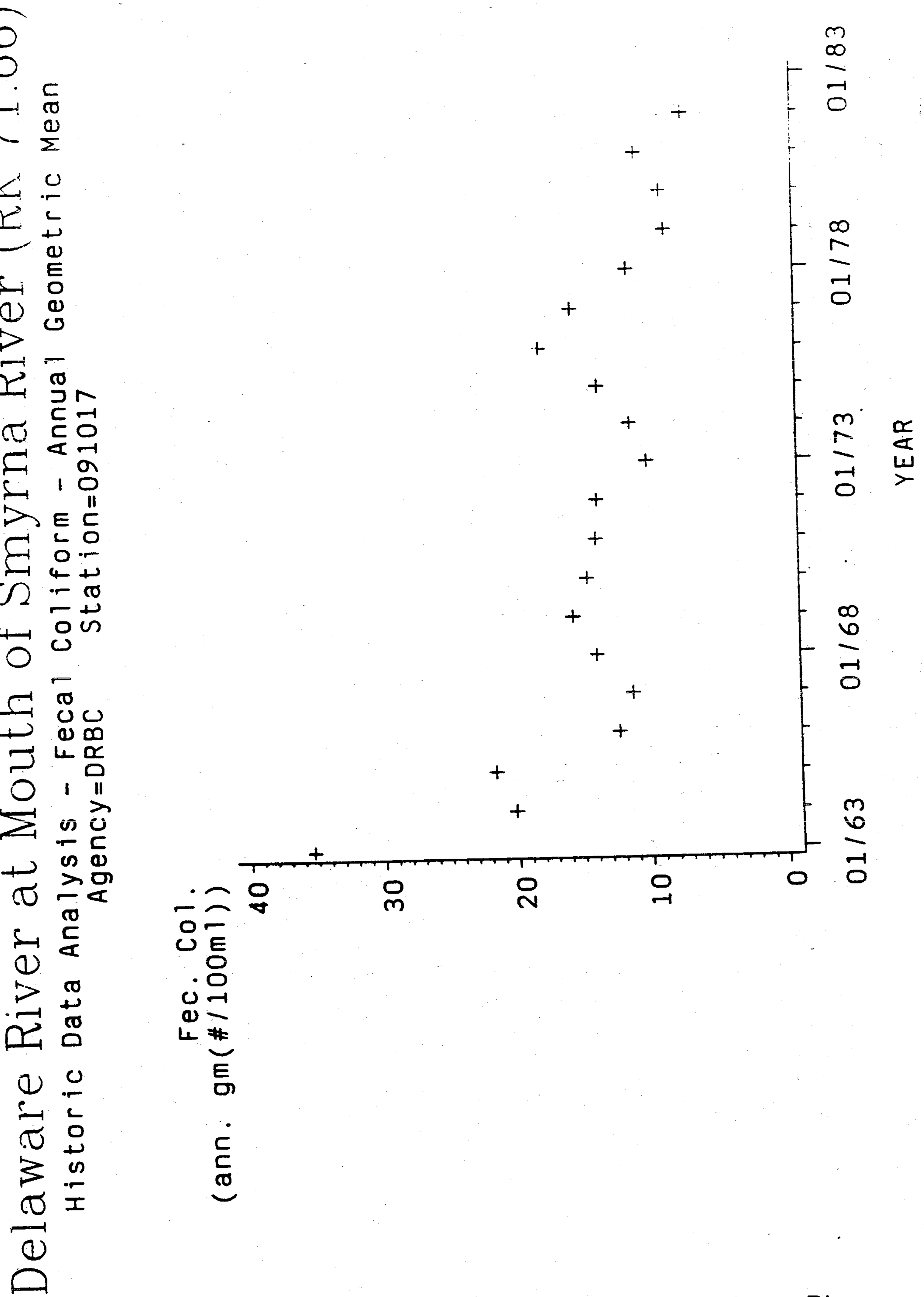


Figure G.15: Annual Geometric Mean FC - Smyrna River

APPENDIX H

DELAWARE RIVER AT MOUTH OF THE MAHON RIVER (46.81)

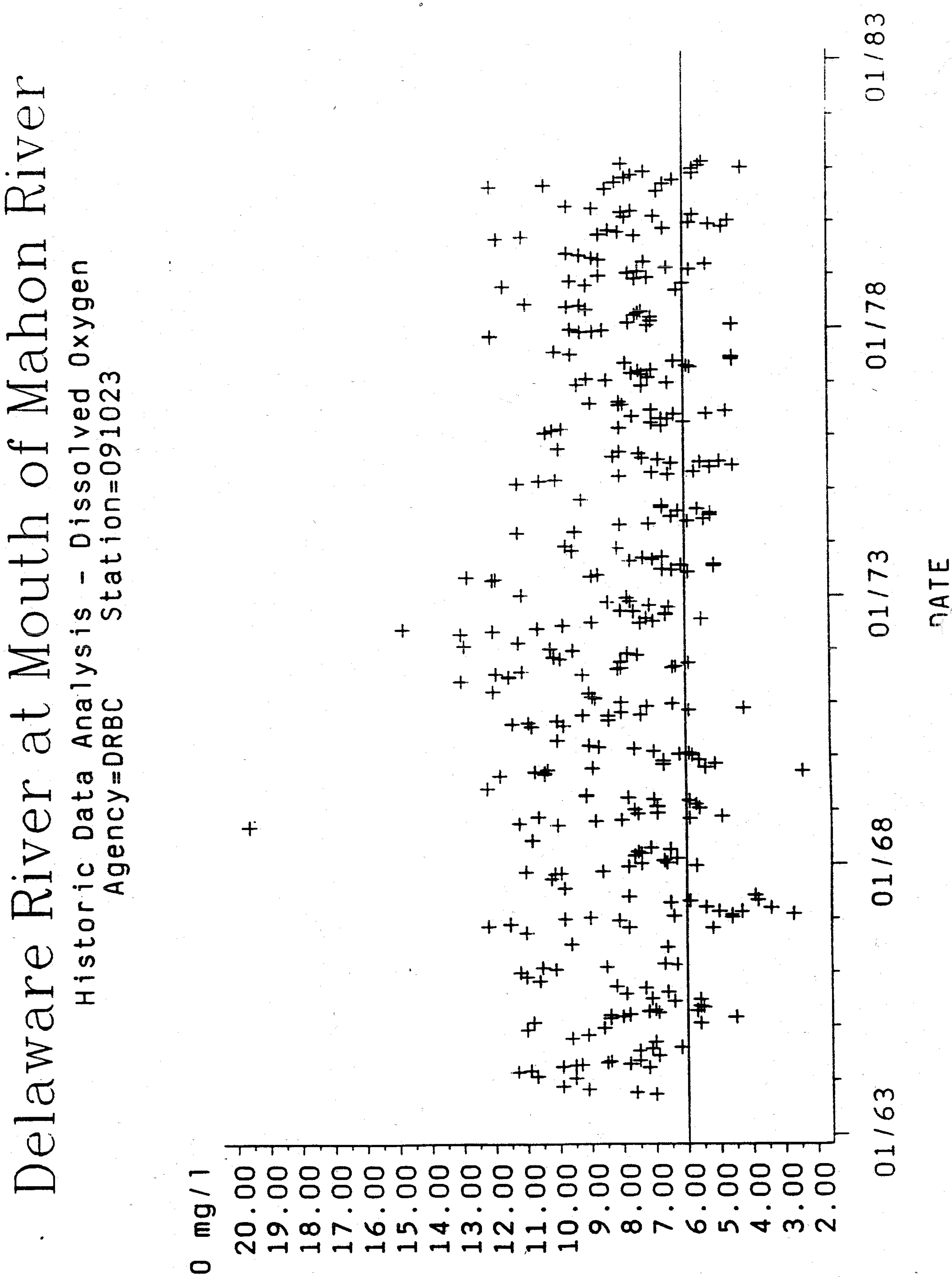


Figure H.1: Dissolved Oxygen - Mahon River

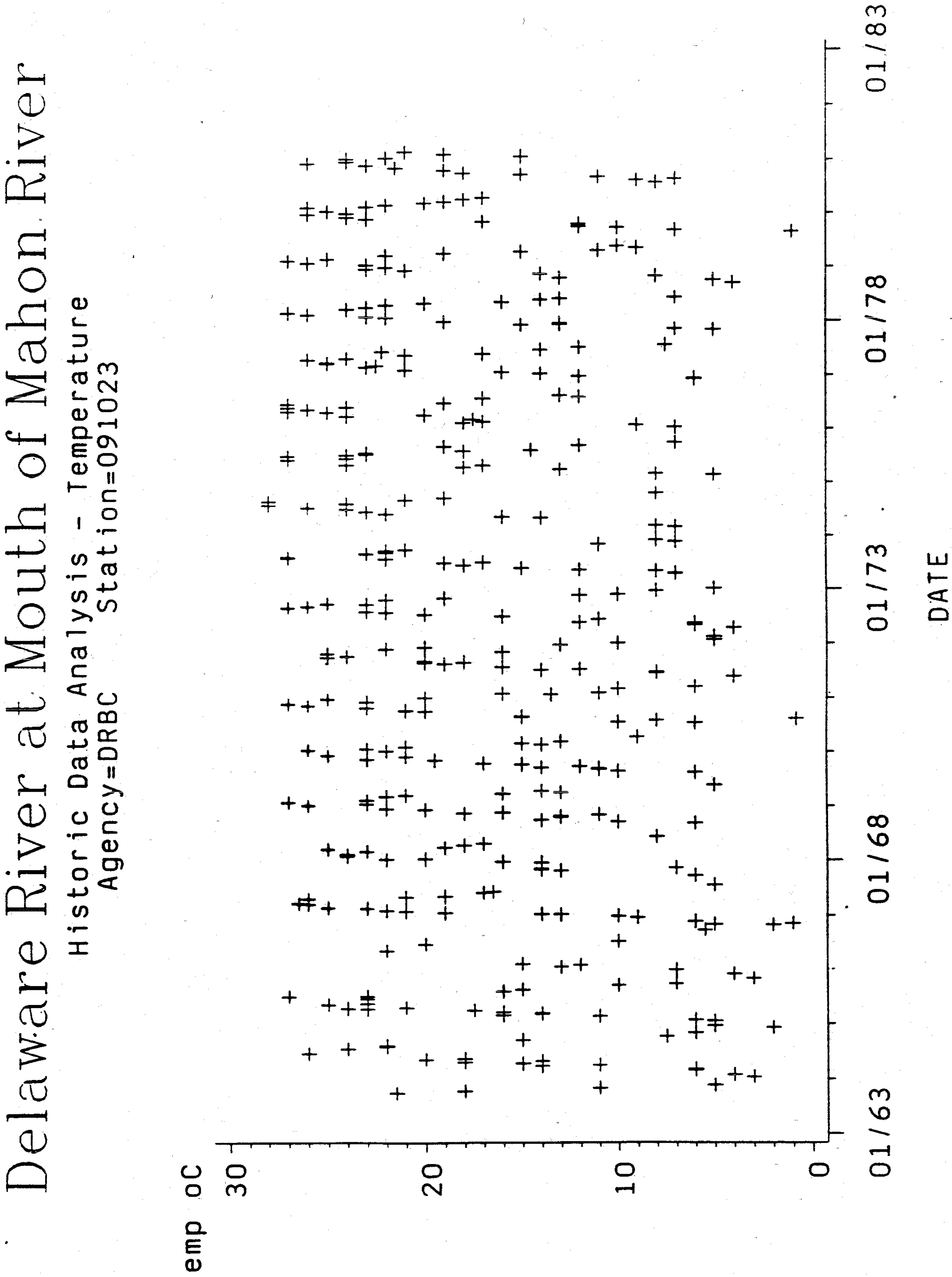


Figure H.2: Temperature - Mahon River

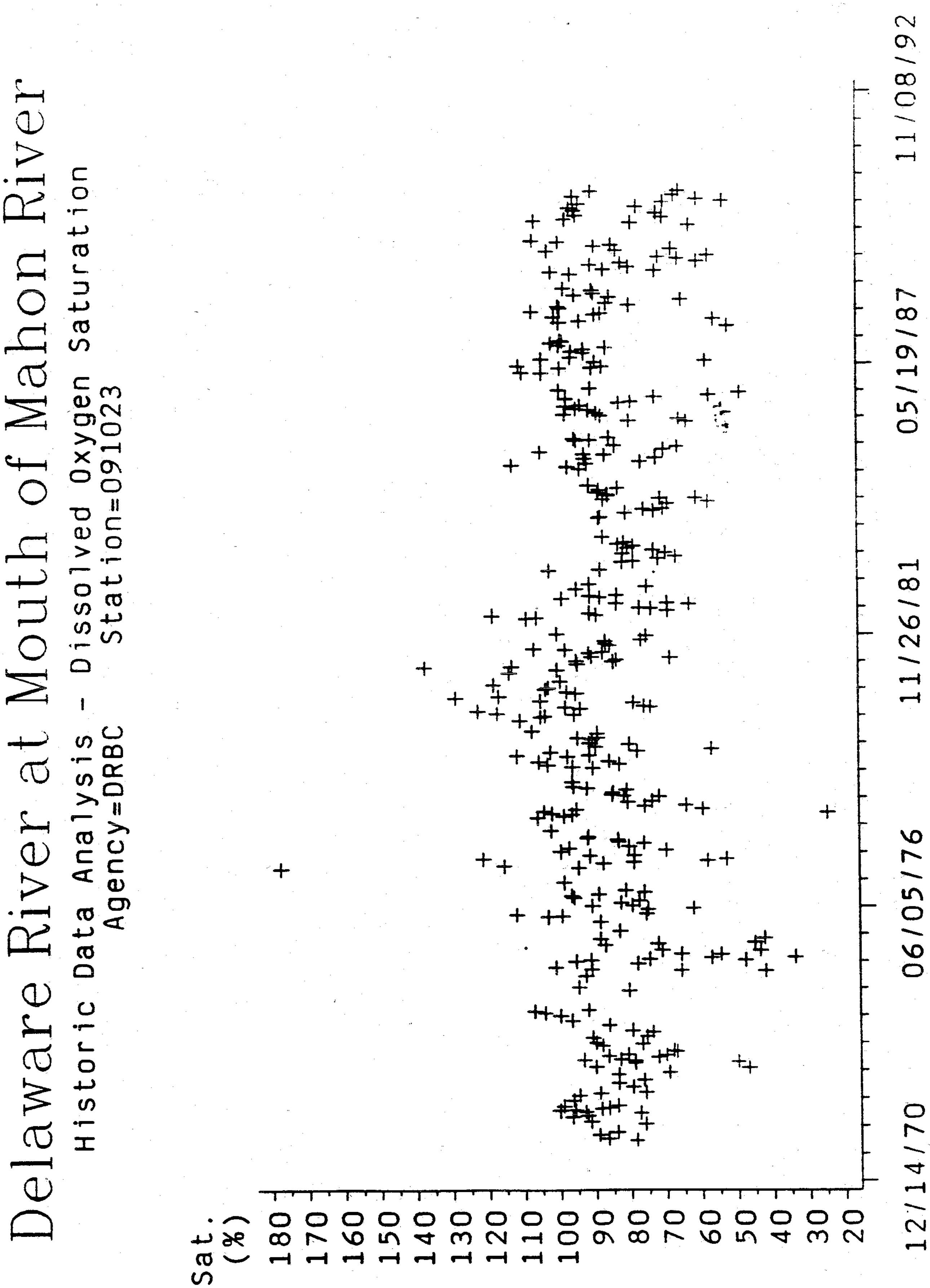


Figure H.3: DO Percent Saturation - Mahon River

Delaware River at Mouth of Mahon River

Historic Data Analysis - Salinity
Agency=DRBC Station=091023

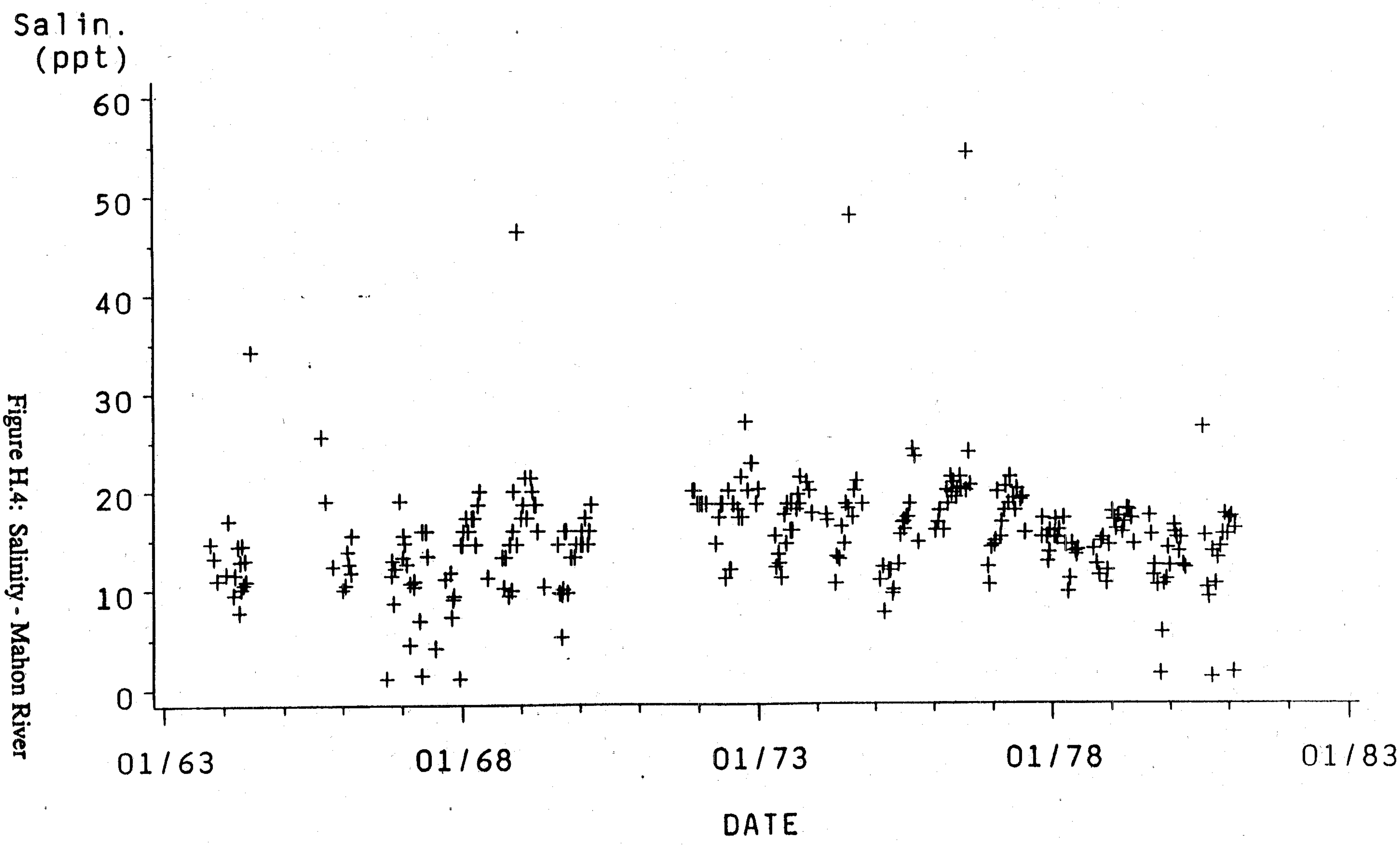


Figure H.4: Salinity - Mahon River

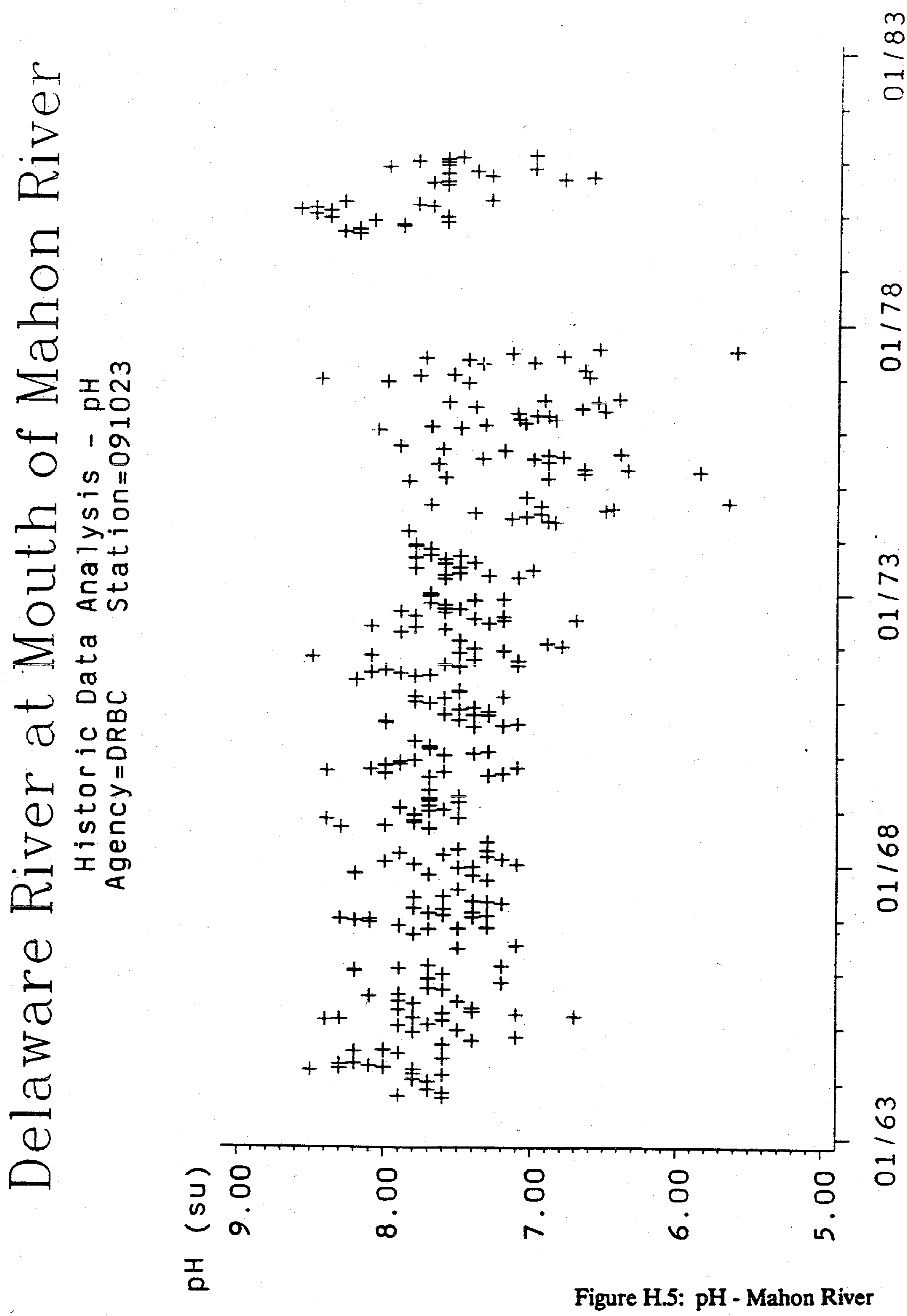


Figure H.5: pH - Mahon River

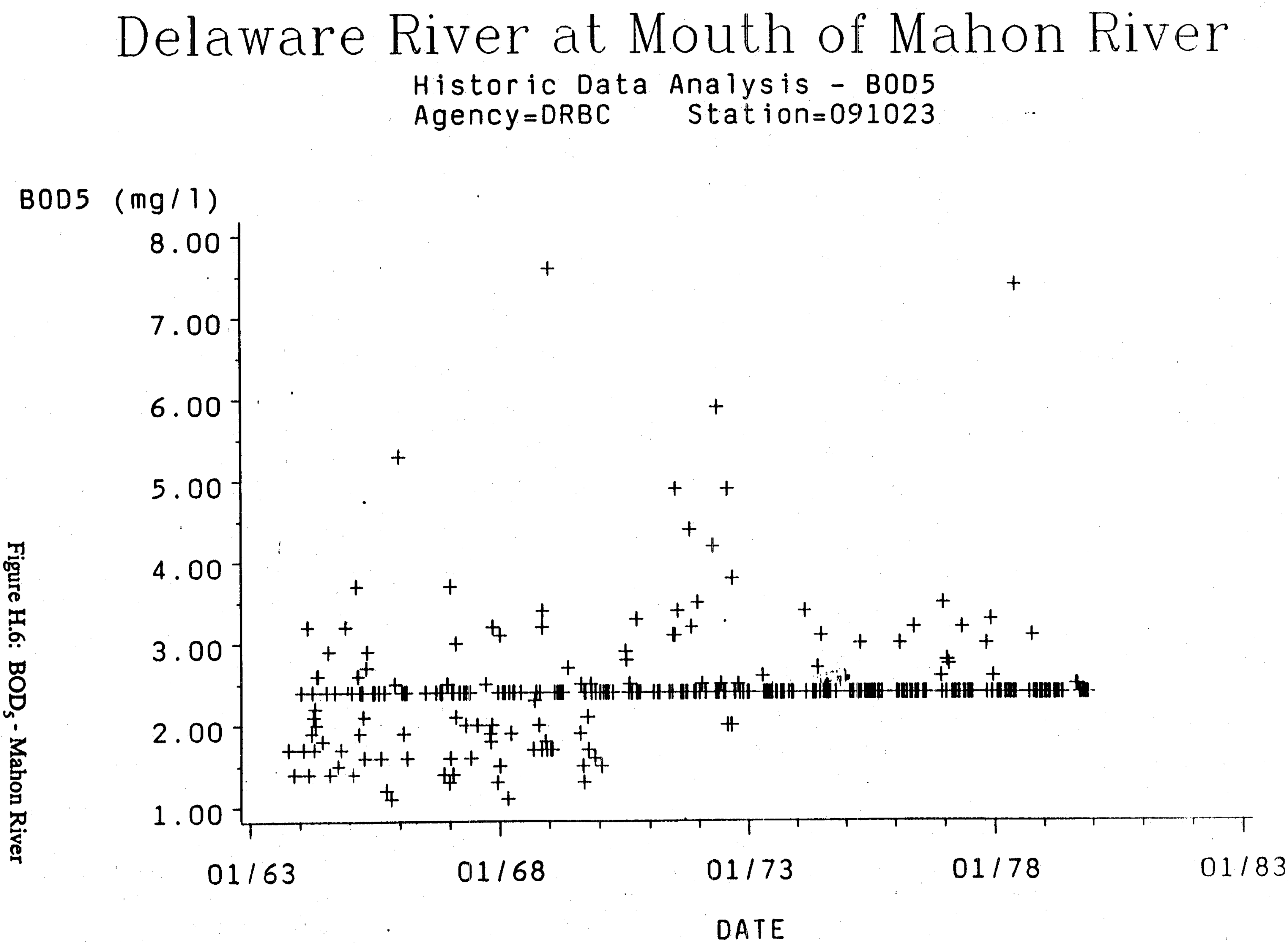


Figure H.6: BOD_5 - Mahon River

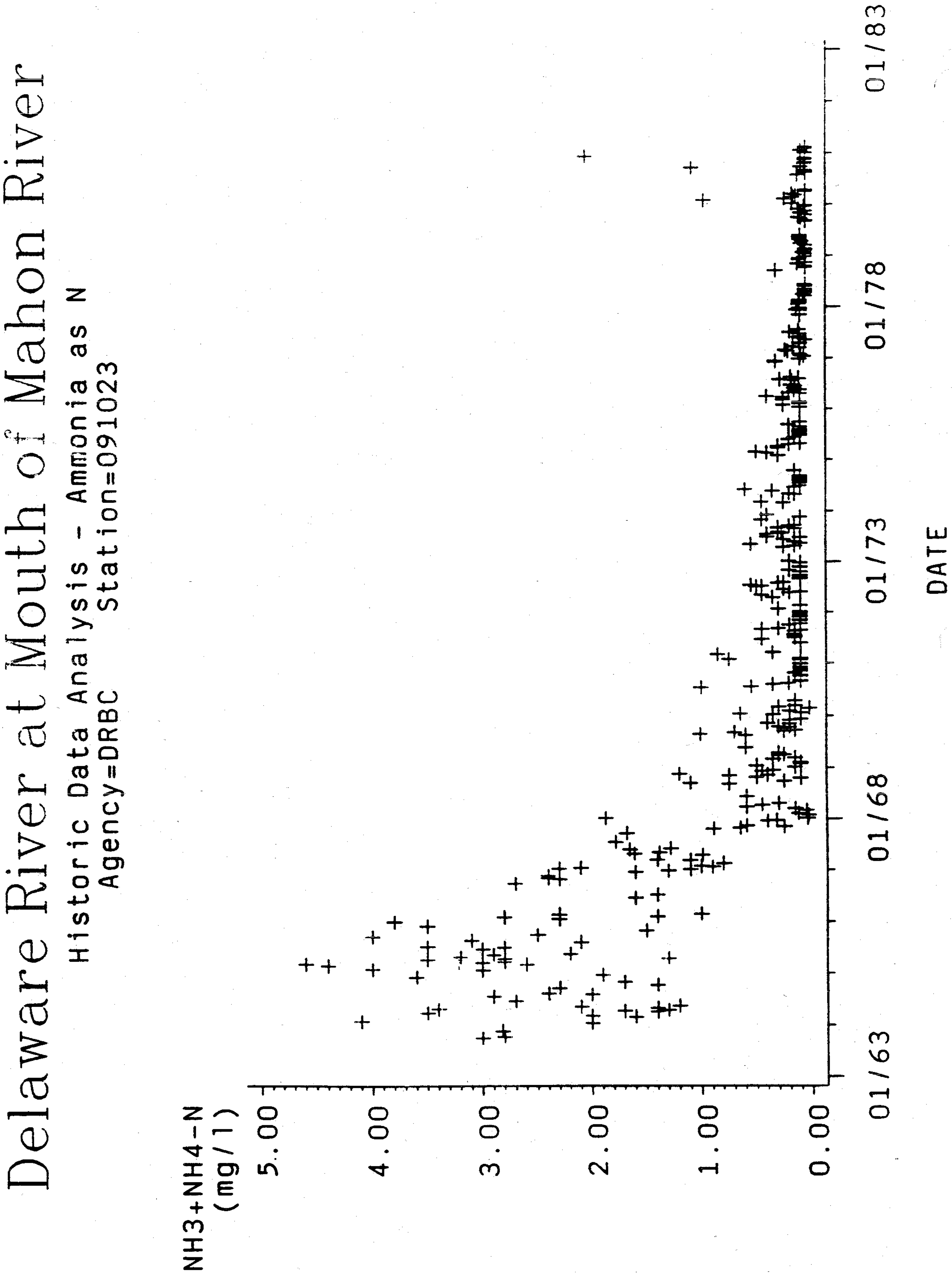


Figure H.7: Ammonia (NH_3-N) - Mahon River

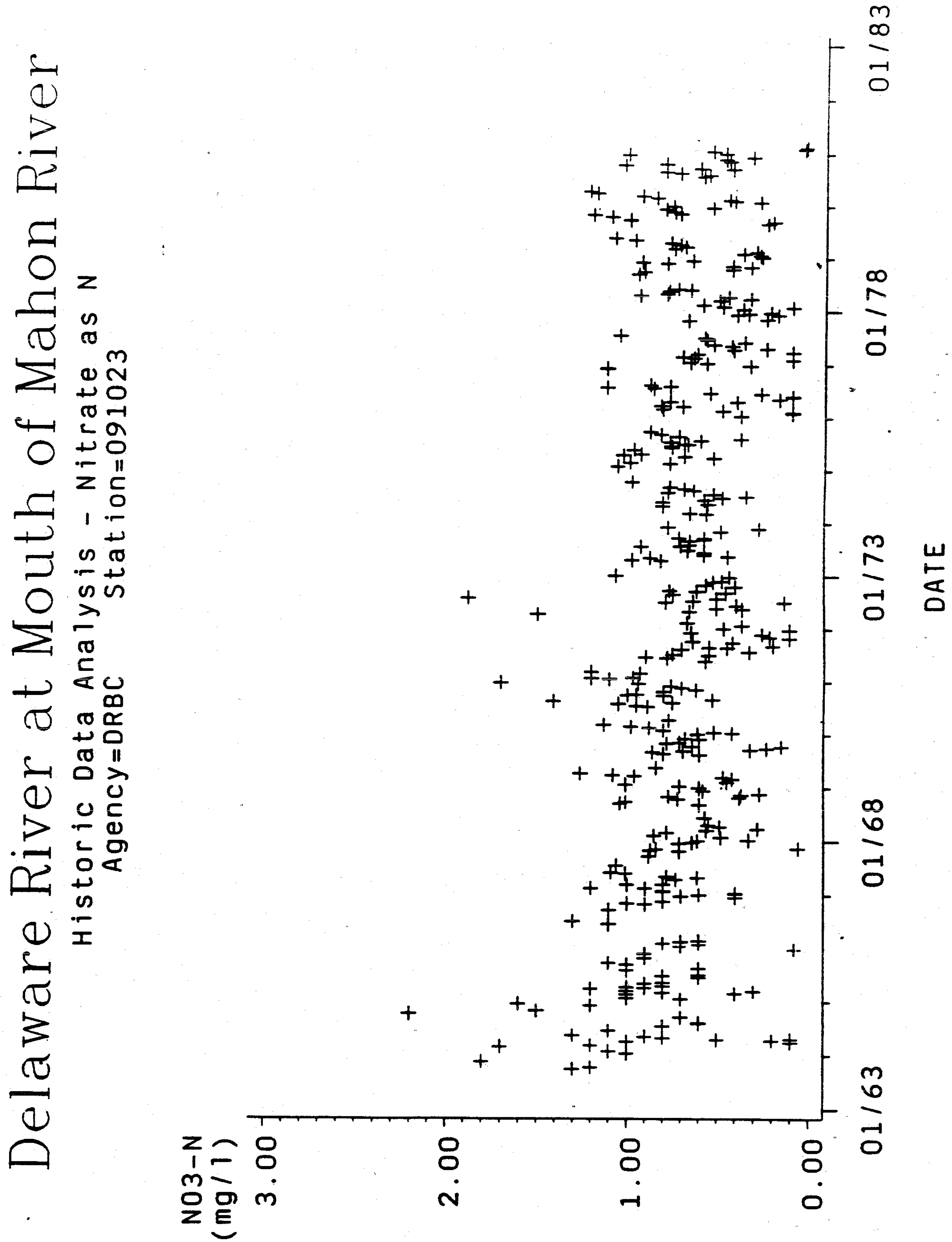


Figure H.8: Nitrate (NO_3-N) - Mahon River

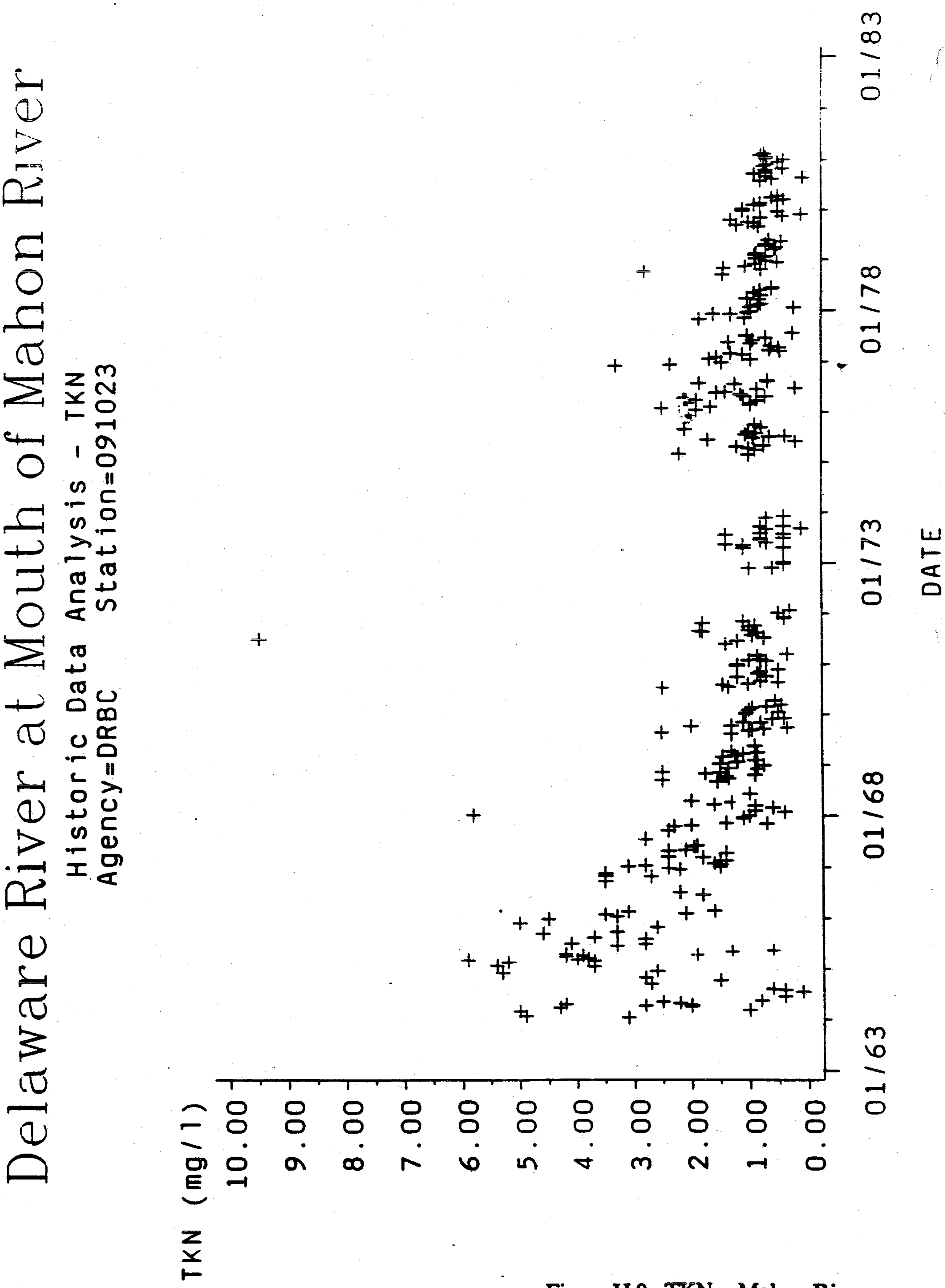


Figure H.9: TKN - Mahon River

120

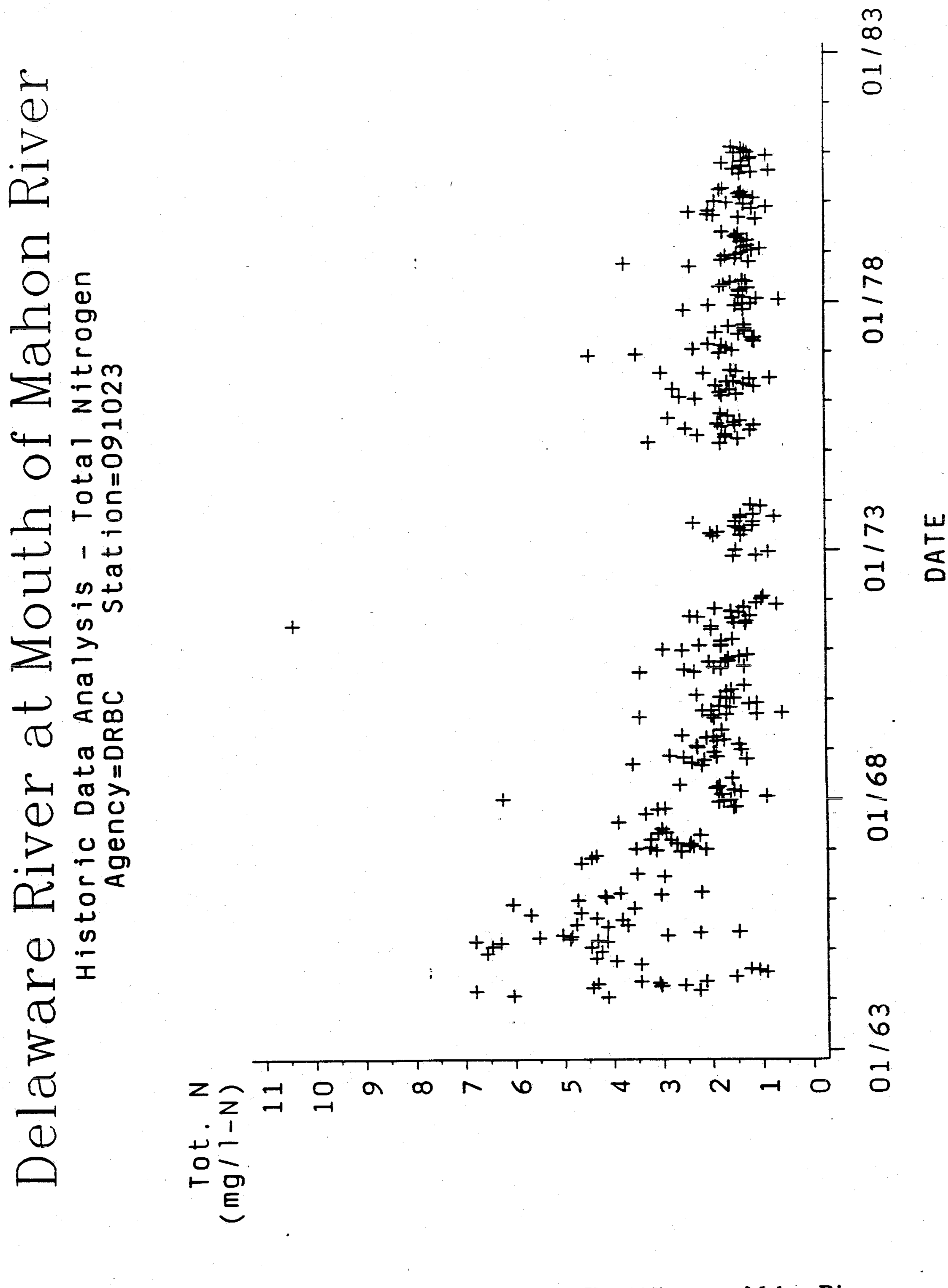


Figure H.10: Total Nitrogen - Mahon River

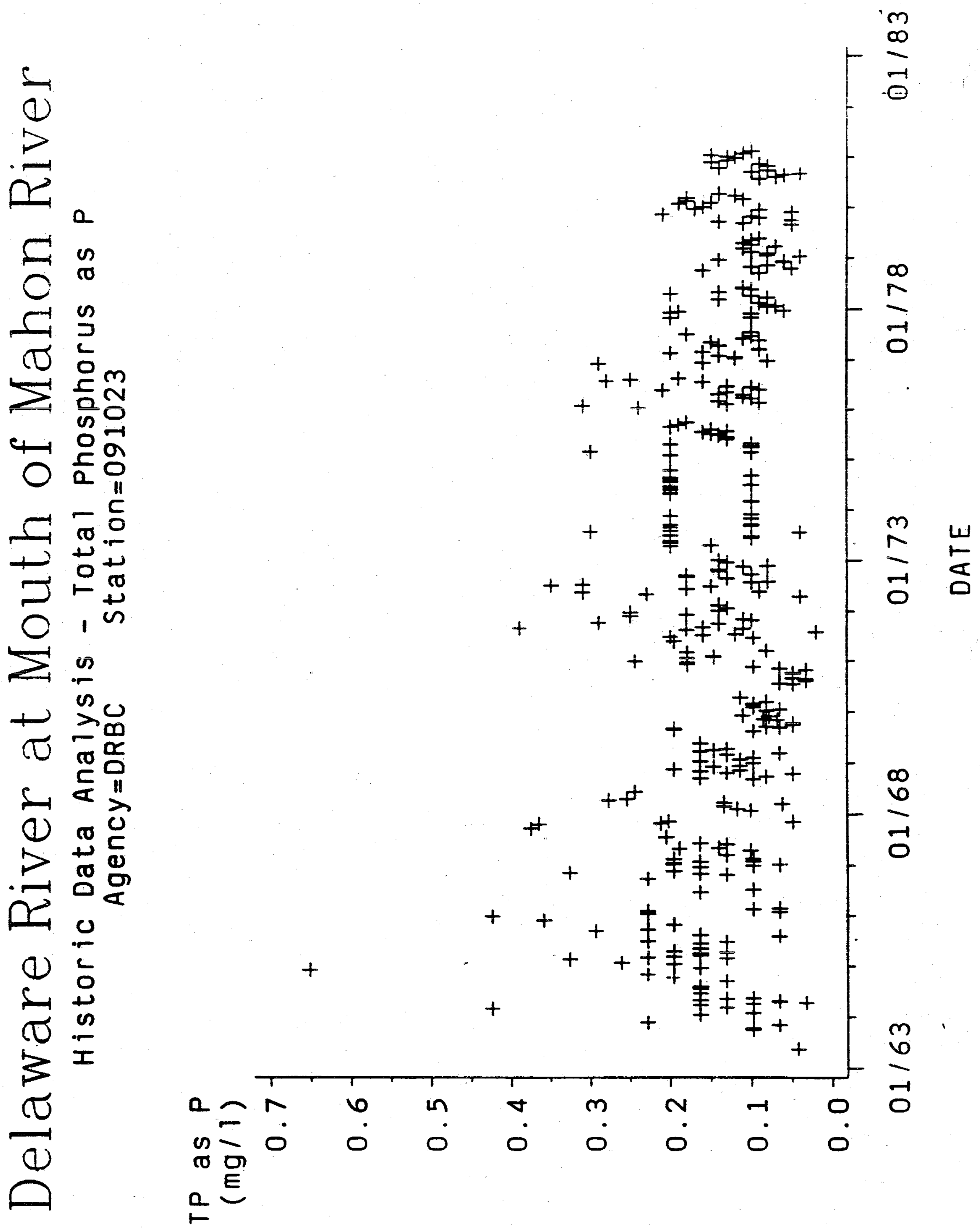


Figure H.11: Total Phosphorus - Mahon River

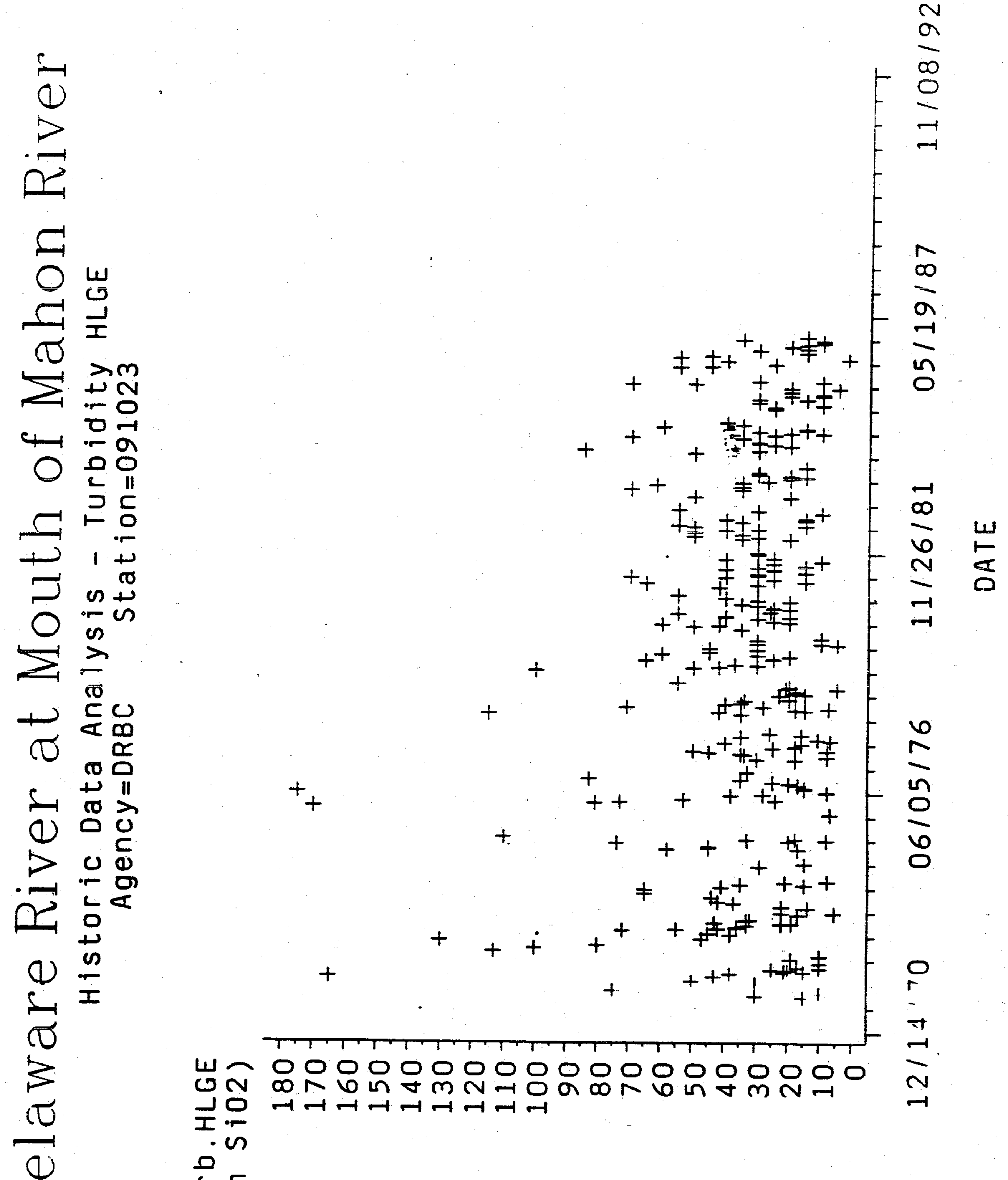


Figure H.12: Turbidity - Mahon River

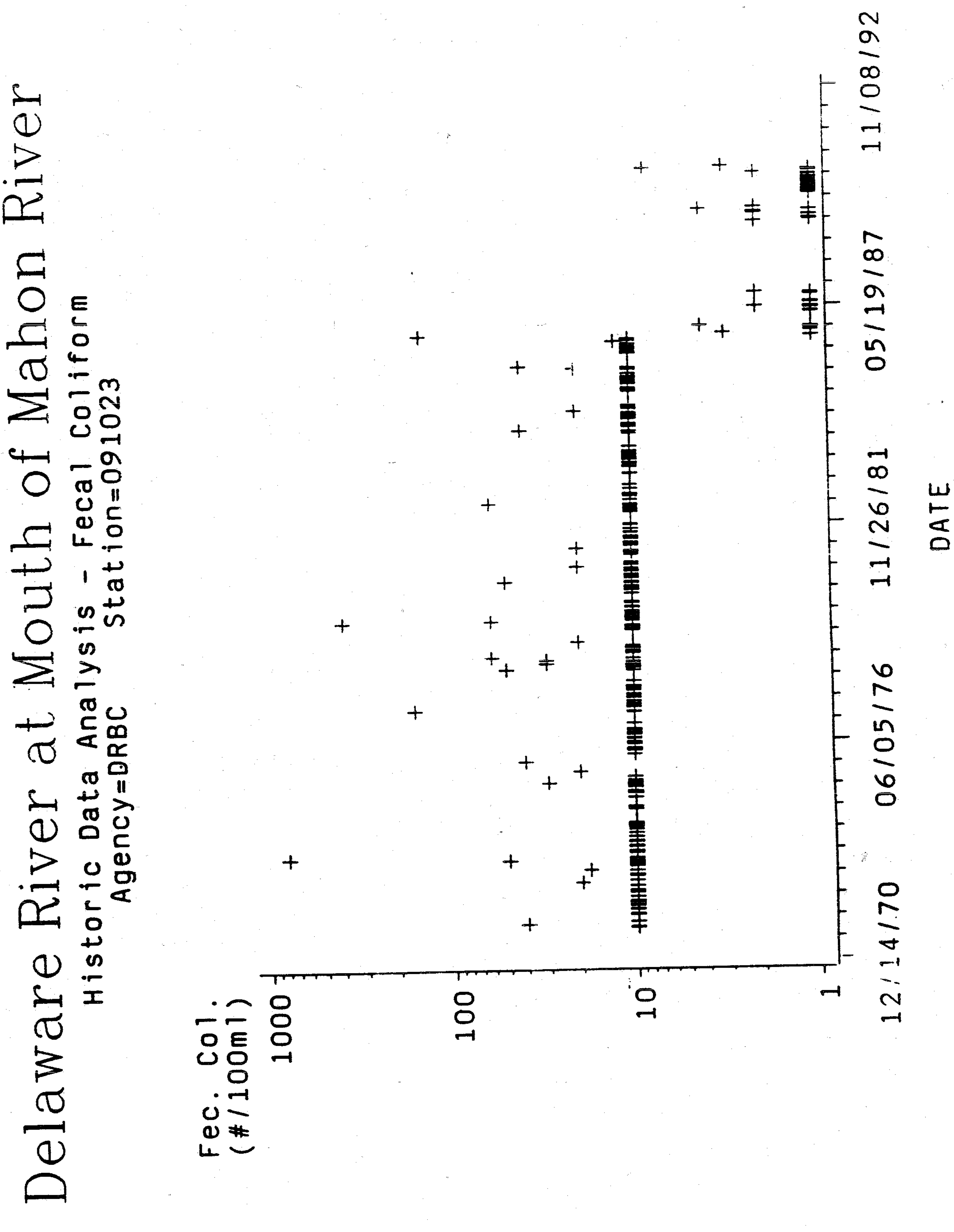


Figure H.13: Fecal Coliform - Mahon River