Comprehensive Conservation and Management Plan

Appendix F. CHARACTERIZATION REPORT

A Study of the Status and Trends in the Inland Bays

FINAL DRAFT

Delaware Inland Bays Estuary Program Characterization Summary

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The Scientific and Technical Advisory Committee
of the Delaware Inland Bays Estuary Program

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Delaware's Inland Bays consist of three interconnected water bodies--Rehoboth, Indian River, and Little Assawoman Bays. Delaware's Inland Bays have a drainage area of about 300 square miles, a water surface area of 32 square miles, a marsh area of 9 square miles, a mean-low-water volume of 4 billion cubic feet, a tidal prism volume of 1.7 billion cubic feet for Indian River Bay and 700 million cubic feet for Rehoboth Bay, and a freshwater discharge of 300 cubic feet per second. Almost 30 square miles of the Inland Bays are classified as shellfish waters, of which 19 square miles are approved for shellfishing. There are about 126 people per square mile of watershed, and land is about 10 percent urban and 46 percent agriculture. The Inland Bays are tidally flushed, with flushing period estimates typically converging on 90-100 days for Indian River Bay and 80 days for Rehoboth Bay. No flushing estimates are available for Little Assawoman Bay.

The Bays are beset with a series of problems similar to other Mid-Atlantic estuaries. The Delaware Inland Bays Management Conference has identified several problems that require immediate attention. These include eutrophication (nutrient enrichment), habitat loss or modification, circulation and flushing, sedimentation, pathogens, and sea-level rise.

Overall, the Inland Bays are highly nutrient enriched (eutrophic), especially in the tidal creeks. For example, the characterization efforts in the Chesapeake Bay yielded a classification system for bay waters based upon total nitrogen and total phosphorous concentrations. With ambient total nitrogen concentrations generally in excess of 1 ppm, and total phosphorous concentrations generally in the range of 0.1 to 0.2 ppm, the Inland Bays would rank among the most enriched of the 32 sub-estuarine systems in the Chesapeake Bay. Based upon that classification system, the middle and upper segments of the Indian River estuary are more enriched than any segment of the Chesapeake Bay. Significant increases in tidal flushing rates over the past 20 years may have mitigated the progression of advancing eutrophic conditions, especially in the lower, higher salinity reaches of the system.

The circulation and flushing of the Inland Bays are strongly influenced by the coastal pumping effect. A short-term storm-induced rise in coastal sea level would pump water into the bays and vice versa. Coastal pumping may come in the form of tides or longer period sea-level fluctuations induced by remote wind forcing on the continental shelf. Furthermore, local wind forcing over the surface of the Bays may drive complicated horizontal circulation patterns within the Bays. Despite the small river discharge volume, there is a significant difference in salinity as one progresses from the mouth to the head of the Bays and their tributaries. This causes long-term residual currents in the bays which exhibit a two-layer pattern with a surface outflow and bottom inflow--a consequence of this phenomenon is that materials introduced into these Bays can be trapped by the upstream movement of the deeper salty layer of water.

In general, we find that Rehoboth Bay water quality is healthy to fair; Assawoman Bay and Indian River Bay water quality ranges from degraded to healthy, with the upstream two-thirds of Indian River Bay being the most degraded of the whole Inland Bays estuary. The Bays act as a nutrient trap, concentrating phosphorus and nitrogen from the inflowing natural waters, stormwater runoff, and wastewaters and thus stimulating phytoplankton biomass accumulation.

The primary sources of nutrient enrichment for the Inland Bays and their tributaries are somewhat different for nitrogen and phosphorus. By far, the majority of nitrogen loading comes from agricultural practices, followed by septic systems, and sewage treatment systems. On the other hand, the principal sources of phosphorus are agricultural practices, sewage treatment systems, and septic systems. Urban sources contribute about 10% of both phosphorus and nitrogen. The remainder of the nutrient sources are considered natural, including forests and rainfall. The relative importance of nutrient sources is summarized from Ritter (1991).

	Indian River Bay		Rehoboth Bay		Little Assawoman Bay	
Nutrient Sources	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Agriculture	44.6%	39.4%	33.0%	17.0%	54.7%	52.6%
Boating	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
Forest	11.0%	19.2%	7.4%	9.4%	6.7%	19.5%
Point Sources	12.5%	15.0%	27.3%	56.9%	0.0%	0.0%
Rainfall	6.2%	8.6%	8.8%	6.9%	12.8%	11.5%
Septic Tanks	16.0%	9.3%	11.2%	3.8%	14.6%	5.6%
Urban	9.8%	8.6%	11.7%	5.9%	11.2%	10.8%

For Indian River and Assawoman Bays, the principal source of both nitrogen and phosphorus is agriculture, through the application of inorganic fertilizers and manures. These practices, applied to the sandy, permeable soils of the watershed, have resulted in widespread contamination of groundwater by nitrates. For Rehoboth, agriculture is the principal source of nitrogen, but point sources are the major source of phosphorus. The principle point source is the Rehoboth wastewater treatment plant.

Groundwater is a highly significant component of freshwater flow into the Bays. About 70 to 80 percent of total freshwater stream flow is comprised of groundwater discharge. Groundwater also flows under the Bay shores and discharges directly into the Bays. Nearly all of this groundwater originates as precipitation that falls on the Inland Bays watershed.

Nitrate is the primary groundwater pollutant of concern to the health of the Bays and the people who live in the area. Nitrate contamination has been caused by a combination of land-use practices related to wastewater disposal and agriculture and the sandy soil and sediments that make up the aquifer. Nitrate concentrations in excess of the U.S. EPA maximum contaminant level occur in about 20 percent of over 1,200 wells sampled in the area. Nearly all of the nitrate-laden groundwater eventually enters the Bays.

Studies of nitrate and groundwater flow indicate that the nitrate problem will persist for several decades, even if all nitrate input were to stop today. This is due to the slow movement of groundwater and the long history of nitrate input to the aquifer.

Each of the Bays exhibits a fairly characteristic estuarine flora and fauna with some notable exceptions. The microscopic floating plants (phytoplankton) are most prolific (as measured by chlorophyll concentrations) in the portions of the estuary in closest proximity to nutrient sources (e.g., in the upper and middle portions of Indian River Bay), while Rehoboth Bay generally represents an intermediate level of ambient nutrients and chlorophyll concentrations, while the area nearest Indian River Inlet has the lowest concentrations of both. The same relationship is seen in the clarity (turbidity) of the water, with the upper portions of the tributaries having the most turbid water and the areas flushed near the Indian River Inlet having the least turbid water. Turbidity also changes seasonally, with clarity of the water generally improving after Labor Day and lasting until about Memorial Day. The most turbid water in all three bays is seen during the summer season and probably results from a combination of biological effects (increased phytoplankton and microbial growth) and physical effects (boat traffic). The combination of excessive nutrient levels and high turbidity appears to prohibit the growth of submerged aquatic vegetation (SAV) such as eel grass (*Zostera marina*) in the inland bays. This probably has significant ecological effects, because SAV is desirable habitat for a variety of finfish and shellfish and is food for certain types of waterfowl, although the habitat function may be provided, to some extent, by attached benthic algae (seaweeds). The seaweeds probably also play a role in sequestering excess nutrients during the summer, but we have evidence that extremely high levels of nutrients and turbidity have a degrading effect on the seaweeds as well.

Turbidity also limits benthic algae. Recent research is indicating that benthic microalgae, if allowed to grow naturally, forms a "cap" on the benthic sediments, thereby intercepting the groundwater nitrogen that seeps through benthic sediments and preventing the release of sediment-discharged phosphorus. By incorporating these nutrients into benthic microalgae biomass, available for grazing by marine animals and thus limiting further excessive phytoplankton production, turbidity within the bays is mitigated and a more natural balanced system results.

The invertebrate community is an important component of both aquatic and terrestrial living resources. It links autotrophic producers (plants and algae) that get their energy from the sun to heterotrophic consumers that get their energy by consuming other living things. It includes microscopic forms that require magnification to be seen clearly, such as zooplankton, and macroscopic forms such as blue crabs, shrimp, and clams. The larger organisms or macroinvertebrates generally prefer surfaces to which they can attach and hide from predators. The bottom is the dominant submerged surface in shallow, aquatic ecosystems such as the streams and small estuaries of Delaware's Inland Bays. In fresh water, the invertebrate community is dominated by aquatic insects, while in estuarine and marine waters, the community is dominated by worms, clams, and crabs. Macroinvertebrates are the primary food source for most fish species in both estuarine and fresh waters and, therefore, are critical to the survival of predatory fish such as largemouth bass, striped bass, flounder, and fish-eating birds such as osprey, cormorants, and eagles. The ecological importance of this community is easily overshadowed by the larger animals (including humans) that are dependent upon them. The following is a summary of the condition of the benthic macroinvertebrate community in the nontidal and tidal portions of the Inland Bays.

A 1991 statewide survey conducted by the Department of Natural Resources and Environmental Control provides a recent status of the condition of the benthic macroinvertebrate community in the nontidal streams of Kent and Sussex Counties. This study found that in Sussex County, 31 percent of perennial streams were in "good" condition, while 69 percent were either in "fair" or "poor" condition. The percentage in "good" condition would have been even lower if headwater intermittent streams had been included in the study. Habitat alteration to promote drainage was identified as the major cause of impairment within 84 percent of the "poor" sites exhibiting "poor" habitat conditions. In general, these habitat-limited sites are open ditches with little in-stream habitat, few pools, unstable stream banks, little or no shade, and/or little or no riparian vegetation.

Biological integrity, habitat quality, and water quality are inexorably linked. Thus, the "poor" condition of nontidal streams in the Inland Bays' watershed reflects not only their own "poor" condition, but also indicates that "poor" quality water is being delivered to the inland bays downstream. The extensive system of ditches and the dredging of tidal, freshwater habitats has served to more efficiently deliver contaminants to the bays.

No current comprehensive database is available by which to define the status of the benthic invertebrate community in the tidal portions of the Inland Bays. The last comprehensive survey of Rehoboth Bay and Indian River Bay was conducted over 20 years ago between 1968 and 1970. No comprehensive historical data exists for Little Assawoman Bay. Contemporary surveys of all three

Inland Bays are limited to no more than four stations in any one bay and, therefore, are inadequate to characterize current status or identify trends. The benthic community is an excellent indicator of the condition of living resource and its response to the changes in water quality and habitat. The absence of benthic invertebrate data is a significant gap in the Inland Bays' characterization.

Current and historical data exist to characterize the benthic invertebrate community within dead-end and poorly flushed manmade lagoons of the Inland Bays. In 1973, 1974, and 1991, water-quality and benthic-invertebrate data were collected in selected lagoons and compared to conditions in nearby tidal creeks and bays. The results showed that manmade, dead-end lagoons contained extremely impaired invertebrate communities compared to nearby creek and bay sites. In some lagoons, no animals were found. These conditions were due to poor flushing which caused extremely low dissolved oxygen (DO) levels (<2.0 mg/ℓ) during the summer months. While some recovery occurred during the remainder of the year, repeated summer low DO events result in a severely impaired invertebrate community throughout the year. Excessively low DO levels also serve to stimulate remobilization of phosphorus, sequestered in the benthic sediments, back into the water column thereby exacerbating an already critical nutrient overenrichment problem. The construction of new lagoons and the maintenance of existing lagoons should be carefully considered in light of these data.

The Inland Bays historically have provided nursery areas and habitat for a large variety of shellfish, finfish, and other wildlife and their food species. Over the past century, many of these desirable species have declined in numbers due to loss of suitable habitat and availability of appropriate food. For example, more than 2,000 acres of tidal wetlands have been lost, primarily due to dredging and filling in the Inland Bays areas, representing more than 24 percent of the previously existing habitat. Previously existing oyster, soft-clam, and bay-scallop fisheries are essentially extinct. The hard clam and the blue-crab are currently the only shellfish species of commercial or recreational importance in the Inland Bays. Although apparently holding their own, these fisheries are potentially susceptible to over-fishing, declines in the water quality (especially as these declines affect food availability), bacterial contamination of growing areas, oxygen concentrations in the bays, and contamination by toxic materials such as boat bottom paints.

Significant modification to the aquatic habitats of the Inland Bays has occurred over the last few hundreds years. The most significant impacts have occurred as a result of the stabilization and deepening of the Indian River Inlet resulting in a change of the make-up and complexion of the Inland Bays. Since the early 1930s, the bays have progressed from an almost totally fresh water, landlocked system to a marine-dominated estuary, all within 60 years. The most dramatic change has occurred since the early 1970s when the inlet depth eroded from 20 feet to depths in excess of 90 feet. The resultant increase in the volume of highly saline ocean that was allowed to pass with each tidal cycle, and the accompanying increase in tidal range, has had a profound impact on the resources of the Inland Bays.

Of particular importance is the reduction (almost total loss) of the tidal fresh portion of the Inland Bays. The establishment of dammed mill ponds, dredging the upper portions of tidal tributaries, thus allowing the extended upstream progression of the saline tidal wedge, coupled with the increased salinity of the bays, has virtually eliminated breeding and nursery habitat for species of anadromous fish once common to the Inland Bays. Healthy populations of striped bass, shad, and various herring, to name a few, once thrived in the bays, but these species have virtually disappeared due to major losses of this high-value tidal fresh habitat required for the perpetuation of these particular species and many more not mentioned but still trophically important. Many of those few upper tributary areas that could still function as spawning and nursery fisheries habitat have been cleared of coarse woody habitat, through stream clear and snag operations, for the purpose of water-drainage, channelization, and small-boat navigation yielding streams sterile of habitat structure necessary for protective cover.

Extensive areas of inland fresh-water wetlands have and are still continuing to be lost in the Inland Bays watershed. As much as 62 percent (higher in the south Indian River watershed) of the palustrine wetlands have been lost due to channelization and ditching from 1950 to present. Particularly in the south Indian River watershed, vast acreage of nontidal, forested wetlands have had extensive ditching and draining for agricultural purposes and, more recently, have been further converted to rural, residential development. This watershed has more than three times the amount of ditches/streams per area than the rest of Sussex County.

Loss of habitat within the Inland Bays, increased human disturbance, and poor water quality have negatively affected water-dependent, resident wildlife populations. The habitat elements and representative species affected by habitat degradation include loss of feeding cover such as submerged aquatic vegetation and small tidal ponds (waterfowl, otters); loss of nesting cover including dunes and backwash areas (piping plovers, least terns, skimmers, diamond-backed terrapin); salt-marsh grasses (Forster's terns, rails, black ducks); islands (pelicans, common terns); large trees (bald eagles, herons, egrets); and loss of brood-rearing cover; e.g., salt marsh and freshwater wetlands (black ducks, clapper rails).

Annual waterfowl counts show declines in diving ducks, Atlantic brant, and Canada geese; however, annual fluctuations are driven more by northern breeding conditions than wintering habitat. Bald eagle and osprey production have increased. Aquatic furbearer populations such as river otter, muskrat, and beaver are stable.

Several shorebird populations (sanderlings, red knots, ruddy turnstones, semi-palmated plovers) depend on horseshoe crab eggs to quickly replenish fat burned during migration. Neotropic avian migrants' numbers are declining, presumably due to poor wintering habitat conditions to the south.

The Inland Bays have been filling with sediment at the rate of five to ten inches during the past 50 years, while the rate of sea-level rise has been about four inches over the same period. In addition to shoaling of the Bays due to sedimentation, the tidal amplitude has also been modified. The cross-sectional area of the inlet has increased by four times since 1939. As the cross-sectional area increased over time, the tidal wave passing through the inlet increased and was propagated through the bays causing higher high tides and lower low tides. This means that spring low-tide elevations are lower (9 inches for Rehoboth and 12 inches for Indian River Bay) than they were 50 years ago. In such systems, where the mean depth is only three feet, such changes in tidal range can dramatically affect whether one is "afloat or aground."

Shoreline modifications have been extensive throughout the bays. Miles of shoreline have been structurally reinforced in the name of shoreline erosion control by the use of vertical bulkheads. Dead-end lagoons proliferate around the bays. Recently tallied, dead-end lagoons covered over 495 acres with a shoreline length of over 47 miles. Due to their physical configuration and high aspect (length:width) ratio, circulation and flushing by the tides severely limit water quality and the benthic community with most lagoons not supporting even the most tolerant benthic species. While not much can be done to improve existing dead-end lagoons, the creation of new lagoons can certainly be avoided. Recent changes in public perception, accomplished through education, have resulted in the extensive utilization of rip-rap and vegetative shoreline stabilization methods as preferred alternatives to bulkheading.

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SECTION 1

INTRODUCTION

1.1 THE PROCESS OF CHARACTERIZATION

Characterization is the integrated system-wide assessment of the problems of the Inland Bays. The problems, identified by the Management Committee, include:

Habitat Loss and Modification (1)	Eutrophication (1)
Pathogens (2)	Toxicity (no priority)
Water Use Impacts (6)	Circulation/Flushing (5)
Sedimentation (4)	Sea Level Rise (3)
Atmospheric Deposition (no priority)	

The assessment addresses historical trends and present conditions. The results are used to substantiate environmental problems, evaluate their causes, recommend remedial or management strategies, and develop long-term monitoring plans. It is important to recognize that the process is not rigorously scientific. Most of the data sets have been taken by different means for various purposes. Net sizes and analytical methods may vary significantly, and it is likely that the scientific community will be (at least) vaguely uneasy with the analyses (Flemer, et al., 1987).

1.2 SEGMENTATION

We divided the Bays into segments based on salinity patterns, circulation and geomorphology. We assume that comparable physical and geological structure can support comparable resources and that major differences could form the basis for hypotheses regarding human intervention. After presenting a draft plan to the Scientific and Technical Advisory Committee, modifications were suggested, and a final segmentation scheme was developed.

1.3 DATA BASE ASSEMBLY

We identified major data bases to be used in the analysis, prioritized them for inclusion and obtained STAC concurrence on their use. We considered all relevant data for inclusion to minimize the possibility that important historical information would be discovered after data analysis and that re-analysis would be required.

1.4 HISTORICAL PERSPECTIVE

It is critical that we understand the profound changes that have occurred in the Bays since the settlers first arrived. Forests have been replaced by fields. The supply of nutrients has increased with the invention of inorganic fertilizers. Pesticides targeted for particular organisms are transported to the Bays and affect non-target organisms. The shape of the Bays, the location of the inlet, and circulation of their waters are different now than they were even 40 years ago. Consider then that the first Bay-wide surveys did not occur until the 1960's.

1.5 CHARACTERIZATION INTEGRATION

After each bay-wide problem has been addressed individually, we attempted to assess the inter-relations between problems and management strategies. Can we relate water quality and habitat or circulation and eutrophication? Because we cannot uniquely define the Inland Bays or any of their components, we will never finish characterization. There will always be another data set to discover or another extreme event that modifies the system. The best that we can achieve is to determine the "mood of the system" and then develop a monitoring system to track future change.

1.6 REFERENCES

Flemer, D.A., R.B. Biggs, V.K. Tippie, K.S. Price and W. Nehlsen, 1987. "Characterizing the Chesapeake Ecosystem" in *Estuarine and Coastal Management Proceedings 10th Coastal Society Symposium*, p . 153-177.

DELAWARE INLAND BAYS CHARACTERIZATION

SECTION 2

WATER QUALITY

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2.1 SYSTEM DESCRIPTION AND SEGMENTATION

Delaware's Inland Bays consist of three interconnected waterbodies, Rehoboth, Indian River, and Little Assawoman Bays. These are also connected to Delaware Bay, the Atlantic Ocean and Assawoman Bay, respectively. They and their watersheds are all located within the state of Delaware and comprise the State's entire Atlantic coastal interface (Figure 2.1). The surface area of open water for the Inland Bays is approximately 86.2 square kilometers (33.3 square miles), and the volume is about 110 million cubic meters (3.9 billion cubic feet). In addition, there are 32.7 square kilometers (12.5 square miles) of intertidal salt marshes fringing the Inland Bays.

The astronomically produced prevailing tides in the Inland Bays are semidiurnal, with a higher and lower high tide and a higher and lower low tide occurring each lunar day (24.8 hours). Tides at Indian River Inlet exhibit a typical range between mean low water and mean high water of 1.25m (4.2 ft). The tidal wave is strongly attenuated as it passes from Indian River Bay into Rehoboth Bay so that the tidal range at the Masseys Ditch entrance to Rehoboth Bay is 0.36m (1.2 ft). The present day higher-high occurrence (of the semidiurnal) flood-tidal prism volume flux through Indian River inlet has been estimated by researchers (Raney, Doughty and Livings 1990) for the U.S. Army Corps of Engineers (COE) as approximately 51 million cubic meters (1.8 billion cubic feet). Similarly, the tidal prism flux through Masseys Ditch to Rehoboth Bay has been estimated as approximately 18.4 million cubic meters (650 million cubic feet). Several methods have been used to estimate the flushing time for the Inland Bays. The estimates typically converge on 90-100 days for Indian River Bay and 80 days for Rehoboth Bay. No flushing estimates are available for Little Assawoman Bay.

The Corps' Tidal Prism Model Investigation (Raney, Doughty and Livings 1990) estimated that the flux of the semidiurnal higher-high tidal prism through the Indian River Inlet has increased approximately 260% since about 1970. Similarly, they estimate that the tidal prism of Rehoboth Bay has increased by approximately 200% during the same period. Clearly, both systems are flushed much more effectively now than they were about 20 years ago. The flushing characteristics of the Indian River estuary probably have been further exaggerated by the dredging of a channel along the length of the tidal estuary in 1951, no doubt improving the hydraulic connection between the lower high salinity reaches and the upper reaches below the Millsboro dam.

Rehoboth Bay exhibits a polyhaline salinity (see Figure 2-4 for Venice classification) throughout the year. The Bay receives fresh water from two tributaries, Love and Herring Creeks. In addition, there are salt water exchanges between the Bay and the Lewes and Rehoboth Canal (to the north) and the Bay and Masseys Ditch (to the south). Four NPDES facilities are permitted to discharge 2.8 MGD into the Lewes and Rehoboth Canal. Rehoboth Bay is shallow with a maximum depth of about 2 meters. The eastern third, near to the barrier island, is less than 1m deep. Bottom sediments consist of sands and muddy sands derived from the presence of old, closed inlets and storm washovers. Bottom sediments in the deeper portions of the Bay and the tributaries consist of muds and sandy muds.

A Lewes Rehoboth Canal
B Love Creek
C Herring Creek
D Guinea Creek
E Lingo Creek
F Swan Creek
G Stockley Branch
H Millsboro Pond
I Betts Ingrams Pond
J Iron Branch
K Pepper Creek
L Vines Creek
M Blackwater Creek
N White Creek/Assawoman Canal
O Miller Creek
P Dirickson Creek

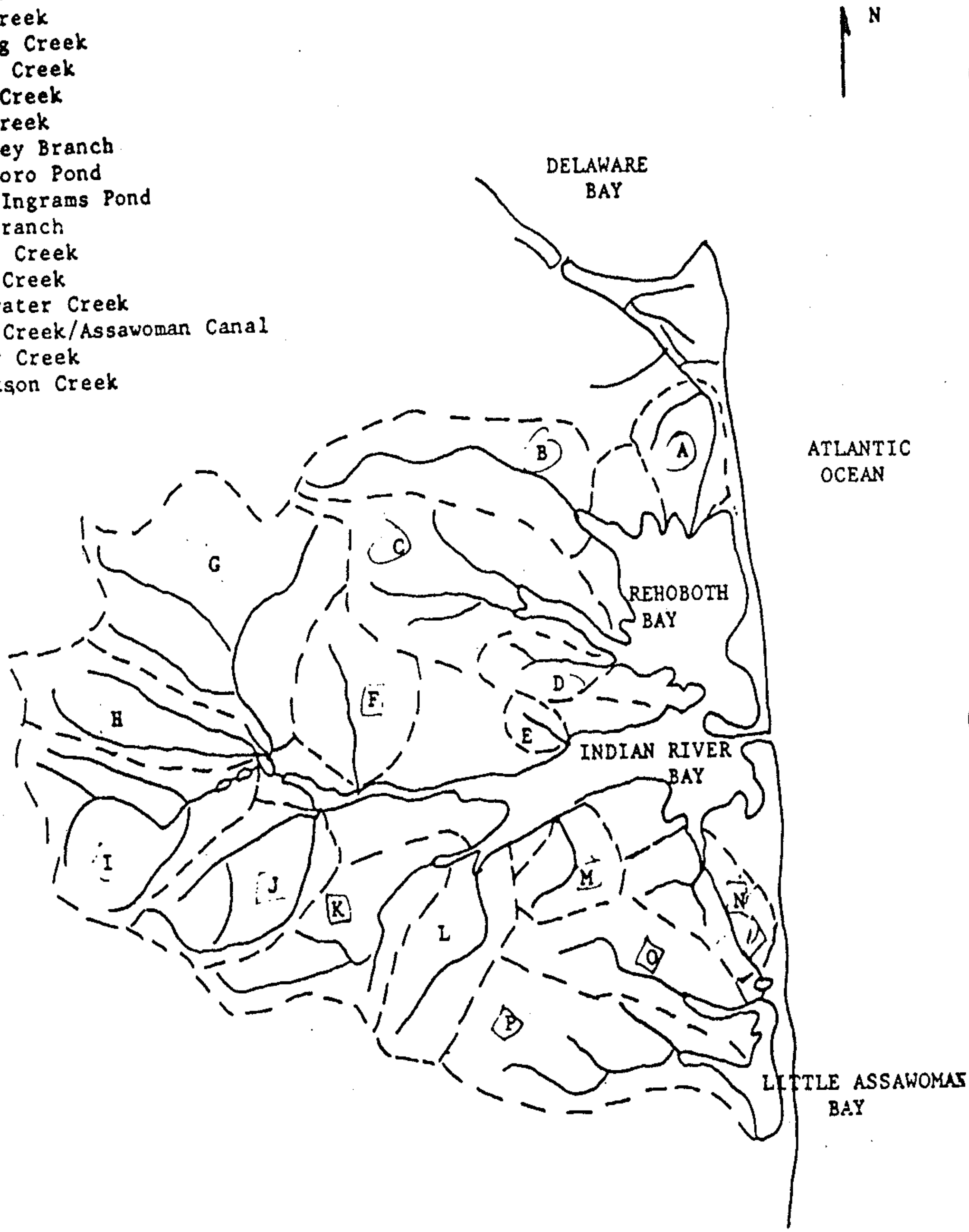

Figure 2.1 Map of Drainage Basins in Inland Bays

Indian River Bay exhibits a complete range of salinity from euryhaline at Indian River Inlet to oligohaline at Millsboro (the head of tide). Several major freshwater tributaries, including Stockley Branch, Horsepond Ditch, Pepper Creek and the Betts/Ingram Pond System, discharge into the Bay. The Bay is also connected to Rehoboth Bay through Masseys Ditch, to Little Assawoman Bay through the Assawoman Canal and to the Atlantic through Indian River Inlet. Nine NPDES facilities discharge into the Bay, principally upstream of Pepper Creek. Indian River Bay is shallow (less than 2m) except near the inlet where shifting tidal channels may exceed 7m. The bottom sediments are sands and muddy sands near the inlet grading to muds and sandy muds in the upper estuary and tributary creeks. Sandy sediments border the Bay where upland intersects the shoreline.

Little Assawoman Bay is a polyhaline waterbody. It receives modest freshwater flow from Dirickson and Miller Creeks and is connected to Indian River Bay on the north by the 4 mile long Assawoman Canal. It is connected to Assawoman Bay (Maryland) to the south through the Ditch. No NPDES permits have been issued for Little Assawoman Bay. Little Assawoman Bay is shallow (generally less than 1m deep). Bottom sediments consist of muds and muddy sands.

Data on land use in the watersheds around each of the Inland Bays are presented in Table 2.1. At the present (1986 data) the Inland Bays watersheds consist of 10% urban, 38% agricultural, 36% forested, 5% wetlands, and 11% water areas. Substantial land use differences occur between the watersheds of Indian River, Rehoboth, and Little Assawoman Bays. Little Assawoman has the highest percentage of land in agriculture (49%) and the lowest percentage in forest (24%), while Indian River has the highest percentage in forest (41%) and Rehoboth has the lowest percentage of land in agriculture (35%). Smaller percentage differences occur in urban, wetlands, and water areas between the three basins.

The first settlement in Sussex County was founded at Lewes in 1658. The area surrounding the Inland Bays was probably not largely affected until around 1750, at which time lumber was the leading export of Sussex County (Beasley, 1987). The main subsistence crops were wheat, corn and buckwheat. The four main industries at the turn of the century were milling (saw-mills and grist-mills), exportation of lumber, shipbuilding and the production of bog iron. Small local industries included tanneries, sea-salt production, coopers, wheel-wrights, distilleries, barrel-makers and blacksmiths. Charcoal was produced in large quantities to fire the local iron furnaces and for export (Carter, 1976).

Sometime after 1750 agriculture began to play an important part in the economy of Sussex County but by 1800 farms began to decline because of soil exhaustion due to poor farming practices and farming was again reduced to a subsistence level. The earliest fertilizer consisted of lime from burned oyster shells and the remains of menhaden. There are records of the land around Georgetown being drained for cultivation and manured in 1830 (Carter, 1976). By 1850 most of the land suitable for agriculture had been identified and cleared for cultivation. Crops had shifted from subsistence crops to vegetable farms and orchards. The northeastern and middle Atlantic states were the first region to use chemical fertilizer in the United States (Cotnoir, 1982) in 1855. Fertilizer use in Delaware has steadily increased in the last forty years. Total tonnage of fertilizer sold and presumably used has increased from 37,267 in 1942 to a high of 169,038

Table 2.1.A Land Use Areas for Indian River Bay Watershed. (modified from Ritter, 1986)
Hectares (x 2.47 = Acres)

	Drainage Area (46,285 ha)										
Land Use	Pepper Creek	Vines Creek	Blackwater Creek	White Creek Assawoman Canal	Indian River Direct Drainage	Iron Branch	Swan Creek	Lingo Creek	Betts–Ingram Pond	Millsboro Pond	Stockley Branch
Urban (Sewered)	0	0	0	57	750	40	0	0	0	51	0
Urban (Nonsewered)	151	99	76	489	894	245	148	73	215	44	391
Agriculture	1557	1254	1201	831	1760	2299	1527	124	2576	1931	1395
Confined Feeding/Pasture	139	109	43	23	20	16	21	0	101	73	87
Forest	794	1078	730	386	1882	1982	2398	207	2696	1801	2750
Wetlands	68	64	102	109	751	18	36	0	39	23	65
Water	48	26	0	93	3725	0	0	0	31	70	0
Total	2757	2630	2152	1988	9782	4600	4130	404	5658	3993	4688

Table 2.1.B Land Use Areas for Rehoboth Bay Watershed

	Drainage Area (19,411 ha)				
Land Use	Herring Creek	Guinea Creek	Love Creek	Lewes–Rehoboth Canal	Direct Drainage
Urban (Sewered)	0	0	0	298	120
Urban (Unsewered)	233	308	182	625	708
Agriculture	2360	586	2143	637	860
Confined Feeding/Pasture	71	0	197	0	0
Forest	1921	1096	1559	521	898
Wetlands	204	52	48	181	613
Water	103	0	48	18	2821
Total	4892	2042	4177	2280	6020

Table 2.1.C Land Use for Little Assawoman Bay Watershed

Drainage Area (9951 ha)		
Dirickson Creek	Miller Creek	Little Assawoman Direct
0	0	350
193	113	292
3033	1181	310
70	3	28
1309	616	354
116	52	352
103	68	911
4824	2033	2597

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in 1980. The tons of actual nutrients have increased from 8,087 to 42,298 and these nutrients have been applied to approximately the same area of agricultural land. The crops grown have shifted to grains, principally in support of a rapidly developing poultry industry (Cotnoir, 1982).

Significant areas of palustrine wetlands (seasonally flooded forested wetlands) existed early in the history of the Inland Bays. These swamps were drained, timbered and converted to agriculture throughout the development of the watershed. Dahl (1990) has estimated that 54% of Delaware's palustrine wetlands have been drained and Timer (1985) computed a loss of 62% of Sussex County's palustrine wetlands in the last 30 years, though it is not known how much of the loss occurred in the Inland Bays and the Pocomoke watersheds. We do know that, beginning in 1816, public drainageways (tax ditches) were dug to drain the palustrine wetlands. There are currently 225 miles of ditches affecting 35000 acres of Inland Bays watersheds, particularly in the southern Inland Bay area.

Since the early 1900's, one of the major industries in Sussex County has been the production of broiling chickens (broilers). The number of broilers raised has increased from about 900,000 in 1924 to 156 million in 1982 (Census of Agriculture, 1925 - 1982). Presently, Delaware produces 18% of the broilers in the United States and most of this production is located in Sussex County (Ritter, personal communication). Broiler production can cause environmental problems because poultry manure has the highest percentage of nitrogen and phosphorous of any typical farm manure (Ensminger, 1976). The water wells with the highest nitrate contamination in the county are in areas of poultry production and poultry manure is thought to be the leading cause of nitrate groundwater contamination in Sussex County (Ritter and Chirnside, 1982).

The population of Sussex County rapidly increased from 1750 residents in the year 1728 to 20,488 in 1790, then slowly increased to 40,000 by 1930. Between 1930 and 1980 the population has more than doubled. Population stands at 115,000 (1991) and is projected to increase to 150,000 by 2010. These figures are for permanent population, and do not address the summer tourist population which can double the resident population.

2.1.1 Segmentation Concepts

The goal of segmentation of the Inland Bays is to reduce the number of sites which must be studied in order to characterize all portions of the system. Typically a system is segmented and similar segments grouped into classes. Ideally, for any given class of segments, the individual segments should be alike in physical, chemical and biological characteristics. However, if too stringent a requirement of similarity is made, the number of classes will be very large and many segments would be in classes with only one member. With this in mind, it should be noted that the biotic community is a result of the abiotic driving forces, or in other words, the physical-chemical environment determines the nature of the biological community inhabiting that environment. Presumably, then, if several segments of a coastal environment had similar physical and chemical properties, the biological communities in those segments would be very much alike as well.

However, man complicates matters by altering the physical-chemical environment by activities such as dredging, nutrient loading, thermal loading and so on. He, thereby, also modifies the biota in those regions. In fact, it is just these modifications of the biological community due to present loadings which must be identified and measured to allow for predictions of the effects of future loadings. Therefore, the criteria for segmenting a coastal system should be physical characteristics which principally are exclusive of the chemical inputs from man. In other words, the philosophy for segmentation is to choose criteria which will group coastal segments into classes of similar physical characteristics, so that the differences in the biological communities among similar segments can be related to the man-made alterations, especially chemical additions. As a guide to defining the spatial scale of segments, it is important to recognize that they may be used as the basic geographic unit to:

- assess trends in water quality, living and other natural resources, and uses of near coastal waters;
- collect, characterize and assess data on toxics, nutrients, and natural resources to identify the nature, causes, extent and opportunities for control of environmental problems in near coastal waters;
- develop the relationship between pollutant loadings and potential uses of near coastal waters;
- management strategies to assure that designated uses of near coastal waters are protected.

2.1.2 Segmentation Rationale

It typically is desirable in segmenting an estuarine system to use a mix of a number of spatial oceanographic parameters, like temperature and salinity. However, segments are often chosen simply on a geographic basis either for management or data availability reasons. In fact, both of these methods, a spatial parameter basis and a geographic basis, were used to segment each of the three tidal systems of the Inland Bays (i.e., Rehoboth Bay, Indian River Bay, and Little Assawoman Bay). Observations of the geography, morphometry, hydrography, and the locations of available historic water quality sampling stations in the Inland Bays, lead to a natural scheme for separating the system into 13 segments. Rehoboth Bay, Indian River Bay and Little Assawoman Bay form the basis of segmentation as these 3 entities are morphologically and hydrographically distinct.

Rehoboth Bay has been segmented along an east-west axis. These segments were determined strictly on geographic and temporal bases in an attempt to assign an equal distribution of both the locations of available water quality sampling stations and the number and frequency of observations available at those stations. The location of the Lewes and Rehoboth Canal and the Rehoboth sewage treatment plant at the northern end of Rehoboth Bay and the close proximity to the coastal ocean through Masseys Ditch at the southern end of the Bay provided a speculative reason to differentiate among segments along a north-south axis. Initially, a north-south segmentation based upon the variation of the bottom materials (i.e., higher sand fraction in the sediments on the eastern side of the Bay) was considered but examination of the available data revealed that there was insufficient data to support such a division. As a result Rehoboth Bay was initially divided into three (3) segments, a northern one (RBN), a central or middle segment (RBM), and a southern segment (RBS). The two major tributaries were also included as separate segments, Herring Creek (HCT) and Love Creek (LCT). The Rehoboth Bay segments are shown in Figure 2.2

Similarly, Little Assawoman Bay was assigned three (3) north-south segments, north (LAN), central or middle (LAM), and southern (LAS). However, it was recognized early-on that the only temporally significant distribution of data exists for a single DNREC station located in the southern segment. A speculative reason for a north-south division for Little Assawoman is that it is connected through the Assawoman Canal to the lower Indian River Bay to the north and to the larger Assawoman Bay to the south, two potentially significantly differing influences. A recent spatially-comprehensive data collection effort for Little Assawoman Bay may provide a basis for another segmentation scheme but those data were not included in this analysis (Ullman, et al. 1992).

In contrast to the geographic and data availability approach used to delineate segments for the two systems discussed above, the spatial differentiation of an oceanographic parameter, salinity, was used for the segmentation of Indian River Bay. Salinity observations made between 1970 and 1990 at ten DNREC sampling stations located at navigational buoys along the Indian River Bay channel, from the inlet at the ocean to the vicinity of the Millsboro Pond dam, were used as the basis on the segmentation. Figure 2.3 is a schematic of the information displayed on a

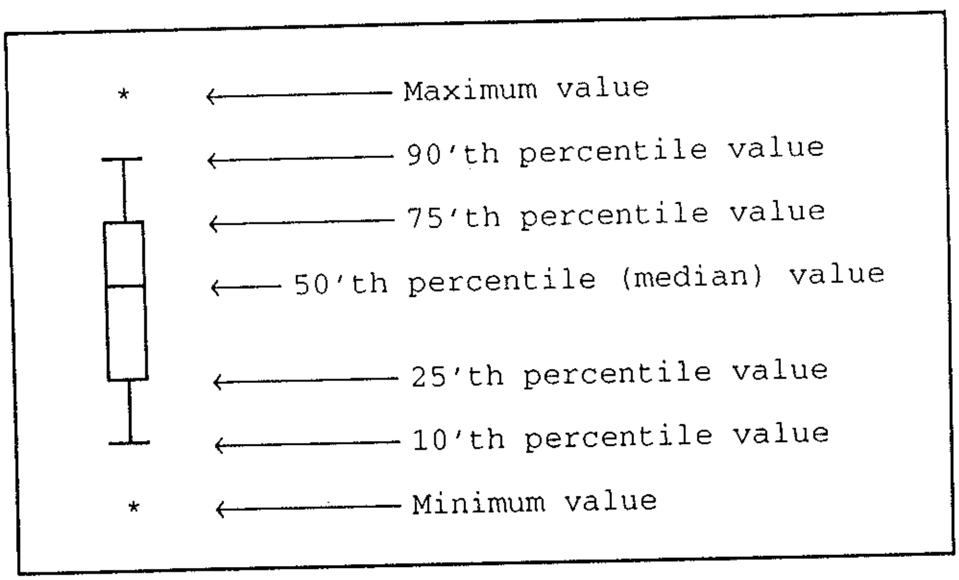

Fig. 2.3 Schematic of Tukey Box Graph.

Tukey box graph which has been modified from that described by Cleveland (1985). Figure 2.4 is a modified Tukey box graph of ensemble statistics for all of the observations of salinity at each

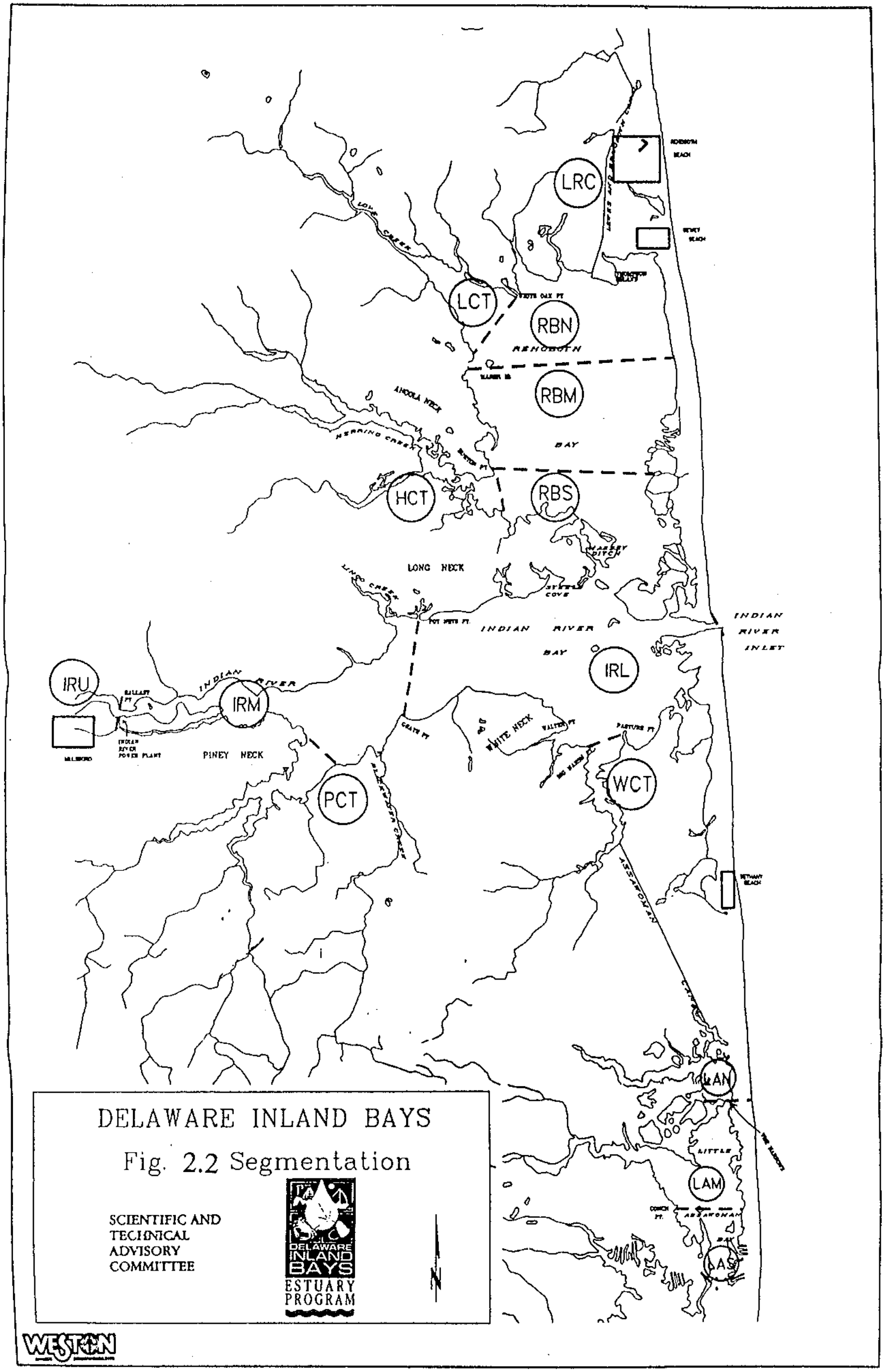

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Fig. 2.2 Segmentation

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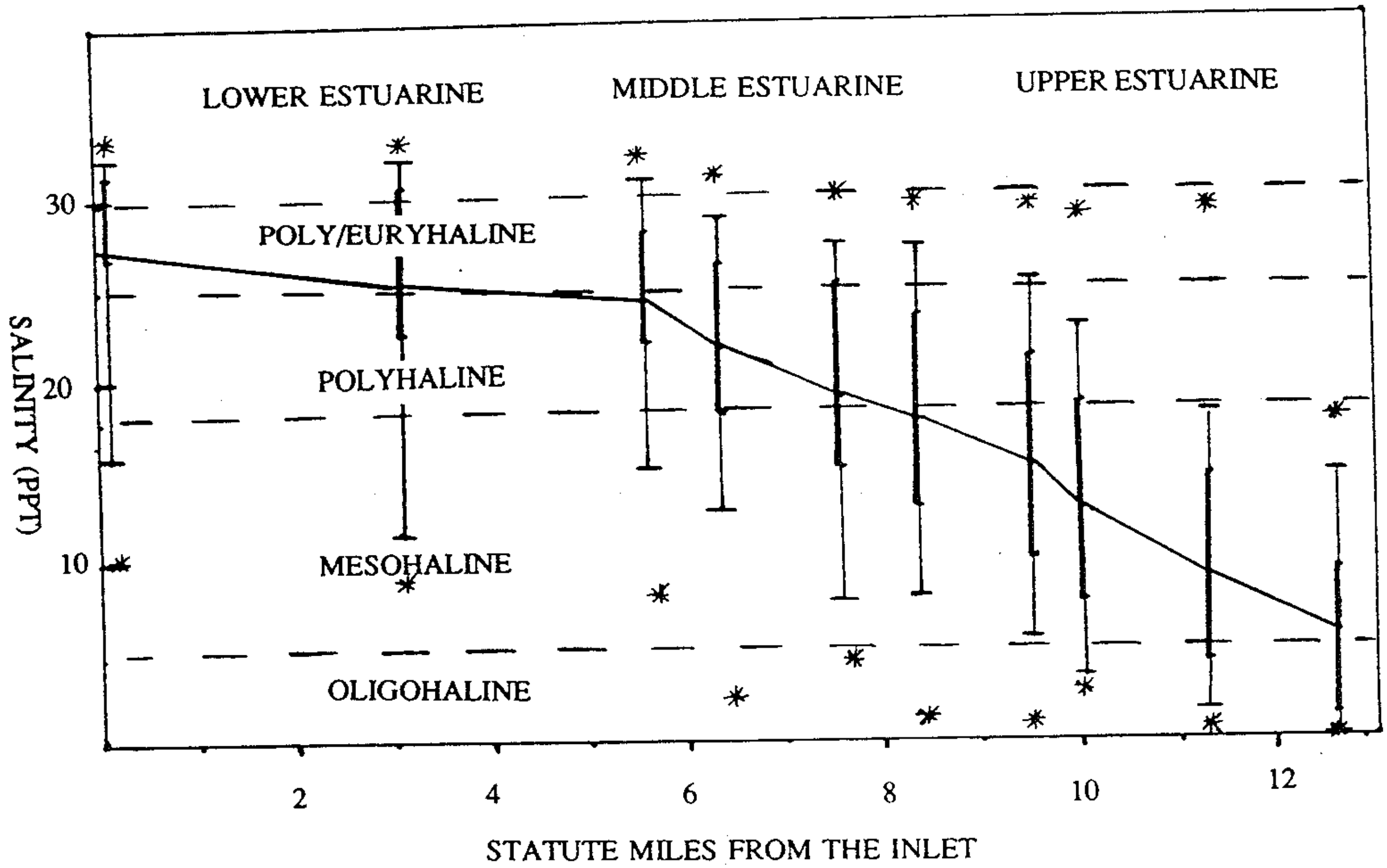
SALINITY SUMMARY: INDIAN RIVER, 1970-90
(MODIFIED TUKEY BOX GRAPH)



Horizontal lines indicate Venice system salinity ranges
0-5 - limnetic 0.5 to 5 ppt - oligohaline 5-18 ppt - mesohaline
18-25 ppt polyhaline 25-30 ppt polyhaline/euryhaline

Fig. 2.4 Tukey box graph of salinity along Indian River.

buoy station. For reference purposes, horizontal dashed lines have been placed at the levels that delineate the Venice System of approximate ranges of salinities in coastal waters, including euryhaline, polyhaline, mesohaline, oligohaline, and limnetic (Carriker 1967). Based upon salinity alone, three segments have been chosen for Indian River Bay, including: the upper system (IRU) that is roughly oligohaline to mesohaline; the middle Bay (IRM) that is roughly polyhaline; and, the lower Bay (IRL) that is roughly transitional from polyhaline/euryhaline to fully euryhaline (oceanic). Two tributaries, White Creek (WCT) and Pepper Creek (PCT) are also assigned segments. These segments are shown in Figure 2.2.

2.1.3 Description of the Segments

Rehoboth Bay North (RBN) The segment extends across the east-west extent of the Bay and is bounded to the north by the Lewes Rehoboth Canal and to the south by a latitudinal line at 38°40′10″ through Marsh Island and just south of the mouth of Love Creek.

Central Rehoboth Bay (Middle) (RBM) The segment extends across the east-west extent of the Bay and is bounded on the north by a latitudinal line at 38°40′10″ through Marsh Island and to the south by a latitudinal line north of Burton Point and buoy C"11" at 38°38′45″

Rehoboth Bay South (RBS) The segment extends across the east-west extent of the Bay and is bounded on the north by a latitudinal line north of Burton Point and buoy C"11" at 38°38′45″ and to the south near Middle Island.

Love Creek Tributary (LCT) All of that estuary west of a line from Bookhammer Landing to White Oak Point and northwestward to the head of tide. The segment is bounded on the east by (RBN).

Herring Creek Tributary (HCT) From a line drawn due south of Burton Point to Long Neck and enclosing all of the estuary west of that line to the head of tide at Guinea Creek, Hopkins Prong, and Burton Prong. The segment is bounded on the east by (RBS).

Indian River Lower (IRL) The polyhaline to euryhaline portion of Indian River Bay, extending from the seaward end of Indian River Inlet westward to a line drawn from Pot Nets Point to Grays Point.

Indian River Middle (IRM) The mesohaline to polyhaline portion of Indian River Bay extending from IRL westward to a north-south line drawn at Ballast Point near the Delmarva Power and Light Company Indian River power station.

Indian River Upper (IRU) The oligohaline to mesohaline portion of Indian River extending from IRM westward to the Millsboro Pond dam, just east of Millsboro.

White Creek Tributary (WCT) From a line drawn from Big Marsh Point eastward to Pasture Point, then southward to the head of tide at Ocean View. The segment is bounded on the north by IRL and connects to the Assawoman Canal on the southeast.

Pepper Creek Tributary (PCT) From a line drawn from Rock Point southeastward to Aydelotte Point, then along Vines and Pepper Creeks to the head of tide. The segment is bounded to the north by IRM.

Little Assawoman Bay North (LAN) Extending from the intersection of White Creek and the Assawoman Canal south - eastward along the canal to the south end of Little Bay at The Narrows.

Central Little Assawoman Bay (Middle) (LAM) Extending from southern end of LAN at The Narrows southward to a latitudinal line through Conch Point and the northern end of Point of Cedars Island at 38°44'30" and westward along Dirickson Creek to the head of tide.

Little Assawoman Bay South (LAS) Extending from the southern end of LAM southward through the Bay to The Ditch at the Route 58 Bridge.

2.2 DATA BASE USED FOR THE CHARACTERIZATION

2.2.1 Data Sources

Many data sets were identified and reviewed for available water quality data. These were listed, ranked in order of perceived importance, and presented to the STAC early in the course of the study. It became immediately clear that the principal source of information used for this water quality characterization would be the data collected by the State of Delaware Department of Natural Resources and Environmental Control (DNREC) and maintained on the USEPA STORET system. In most cases, since the DNREC data set was so extensive, the availability of other data was reviewed against the state data set to see if spatial or temporal gaps could be identified.

Values for the period of record for physical and chemical parameters were retrieved from STORET, along with their respective remark codes, and placed in SAS personal computer data sets. Three separate retrievals were performed by the STORET polygonal method, capturing all stations within each major sub-basin (i.e., Rehoboth, Indian River and Little Assawoman drainages). Where remark codes indicated that values were at or below a specified detection limit, the value was taken as equal to the stated detection limit. When values were indicated as at a detection limit but the value was given as zero or a detection limit was not specified, the observation was treated as a missing value in the SAS data set. In all, over 3,866 observations of as many as 147 physical, chemical, and informational variables were retrieved from STORET, including 2,644 observations for stations located in tidal waters and 1,222 observations from fresh water stations located within the watersheds.

Summaries of the spatial and temporal extent of the DNREC data were performed using SAS. These summaries proved useful in determining the need to add additional data to the data base. As a result, in addition to the DNREC information discussed above, data was also obtained from 8 other sources, including the published works of: S.M. Warlen 1964; W.K. Derickson 1970; E.M. Humphries 1970; E.W. Radle 1971; P.K. Orris 1972; L. Watling 1976; K. Brookins 1984; and the Philadelphia Academy of Natural Sciences 1988. All of these additional data were collected in tidal waters. Locations of the sampling stations of the DNREC and other data sets located in the tidal portions of the Inland Bays are shown in Figure 2.5. The final tidal waters data set included over 3200 observations over time of as many as 152 locational, temporal, physical, chemical, and condition code variables.

Other data in addition to water quality data were added to the SAS data base. Mean daily fresh water discharge data was retrieved from STORET for the periods of record at USGS gaging stations located both within the basin (Stockley Branch at Stockley 4/43-4/91; Millsboro Pond Outlet 5/86-9/88; Vines Creek near Omar 1/85-9/88) and in directly adjacent or nearby basins (Pocomoke River near Willards 12/49-9/90; Nanticoke River near Bridgeville 4/43-6/91; Sow Bridge Creek 10/56-9/78).

Finally, time series of information relating to permitted point source discharges were entered into the SAS data base for the Inland Bays.

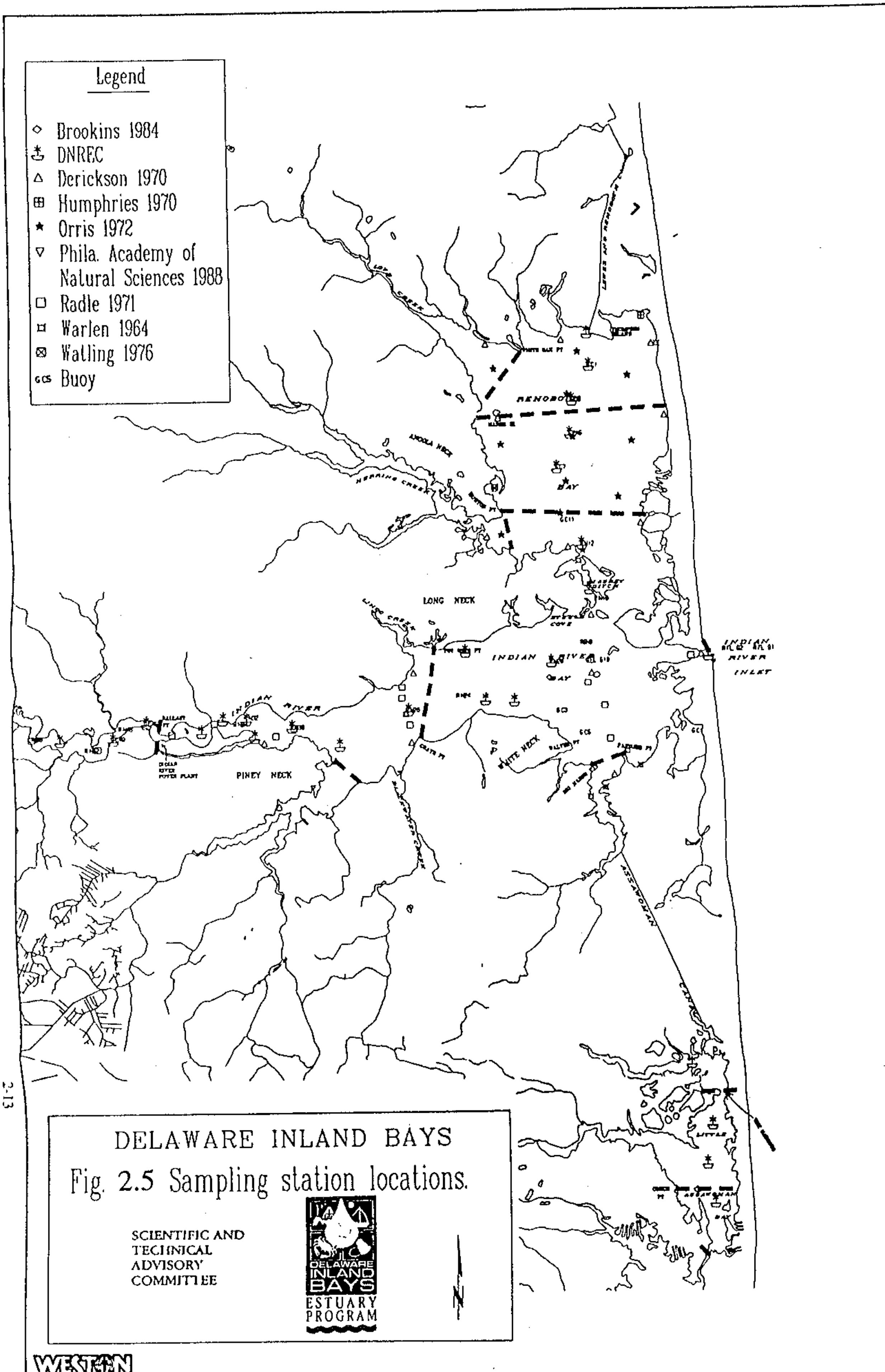


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Fig. 2.5 Sampling station locations.

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2.2.2 Data Quality Assurance

The sources of the selected data sets and the data itself were reviewed to ensure integrity and validity. Data of questionable reliability was filtered out. Particular attention was paid to the sources, collection procedures, and analytical techniques of the candidate data. Criteria for acceptance of data included a number of requirements that lent themselves to numerical detection. For instance, observations of parameters collected within each season for each segment were compared to the system-wide means of those parameters for the same season and outliers were graphically identified for further investigation. Total nutrients values were checked against the reported constituent values. Dissolved oxygen deficits were computed and compared to those reported. The DNREC laboratory was contacted when specific questions regarding analytical techniques arose. Questionable data or data collected by questionable techniques were flagged and investigated for potential remediation. Any data that we concluded was of questionable reliability was removed from the analysis.

Analytical procedures for all STORET parameters are well documented in EPA publications. Procedures for the other data sets are documented in the original publications. Only those data for samples analyzed by like or comparable lab or field techniques were included in the final data base.

2.2.3 Data Analysis Tools

As mentioned above, the basic data base management and statistical analysis tool used in the study was the SAS package running on personal computers. Graphical-based analyses and presentation graphics were produced using SAS-Graph and PC- and workstation versions of ARC/INFO. The digital-format data actually used for the characterization effort will be provided to DNREC in a form and format compatible with the state's ORACLE data base management system. ARC/INFO coverages are stored and are transferrable in DFX format.

2.2.4 Adequacy of Data Base for Characterization

Estuarine characterization requires adequate spatial and temporal coverage of data to allow for the detection of trends and the determination of current status. The results of the search for available data were described above. During the course of the analyses of these data, the results of which are described in later sections of this chapter, it became evident that there were significant deficiencies in the coverage of the available data. For instance, although the coverage of the main stems of Rehoboth and Indian River bays is fairly good for the years 1970 through 1991, relatively little historic data exists for Little Assawoman Bay. Similarly, only a very modest amount of data was located for the tidal tributaries to the Inland Bays (Herring Creek, Love Creek, etc.). Although it might be expected that these areas are among the more heavily impacted waters, not enough historic data was found to reasonably determine or infer the conditions of these areas. Similarly, the data search did not yield enough observations of water quality in the fresh water portions of the system to allow reliable estimates loadings of nutrients or other water quality parameters.

Finally, insufficient data were found to allow for either a trend analysis or a status determination of metals or other potential toxicants.

2.3 FRESH WATER INFLOWS

Two long-term series of mean monthly fresh water discharge, one for the Indian River basin and one for the Rehoboth basin, were inferred by combining the historic water balance calculations of Mather (1969) from 1897 to 1943, and combinations of observations of streamflow from gages located both within and outside of the basin from 1943 through 1990. The resulting synthesized time series for the Indian River and Rehoboth basins are summed as inches of runoff for annual, spring (March-June), and summer (July-September) series and are listed in Appendix 2.1 (INDIINYR, REHOINYR, INDIINSE, and REHOINSE, respectively) along with the annual and seasonal cumulative relative frequencies of occurrences (QRANK and QSRANK). The synthesized monthly runoff time series for Indian River is plotted in Figure 2.6.

Runoff versus cumulative frequency plots for the long-term basinwide seasonal estimates synthesized for Indian River are shown as right-continuous empirical cumulative distributions in Figures 2.7 and 2.8. These graphs are equivalent to cumulative frequency distributions with ordinates expressed in terms of cumulative relative frequencies and with abscissa values expressed as the fraction (x100 = percent) of time the flow value is greater than or equal to the indicated value. Computed seasonal runoff values for several recent years are included on the graphs as illustrations of their use. For instance, the estimated Indian River basin runoff for the spring of 1989 is 10.2 inches (25.9 cm) and is shown on Figure 2.7 as a spring value that probably may be expected to be exceeded only 14.9 % of the time (i.e., only 14.9% of the springs between the years 1897 and 1990 exhibited greater runoff amounts than the spring of 1989).

Because data were available from gages located directly in the Indian River basin above the Millsboro Pond (Stockley Branch and Millsboro Pond Outlet), it was possible to synthesize what is considered to be an accurate enough (i.e., not dependant on out-of-basin information) representation of the discharge of the 66 square mile (172 square kilometer) Indian River watershed discharge at Millsboro Pond to provide daily flow estimates. These estimates (as cfs/sq mi) and their corresponding cumulative relative frequencies of occurrence are also listed in Appendix 2.1 as annual and spring discharge at Millsboro between 1943 and 1991. The annual mean of these daily flow estimates are 1.3 cfs/sq mi (0.014 cu m/sq km) while the mean of the daily values for the spring seasons (March-June) is 1.7 cfs/sq mi (0.019 cu m/sq km). Figures 2.9 and 2.10 show 7-day and 28-day running means of the daily estimates at Millsboro between 1970 and 1991 (i.e., trailing box-car averages of 7 and 28 day lengths, respectively). The availability of this time series facilitated the analyses of salinity intrusion in Indian River estuary that are discussed later in this report.

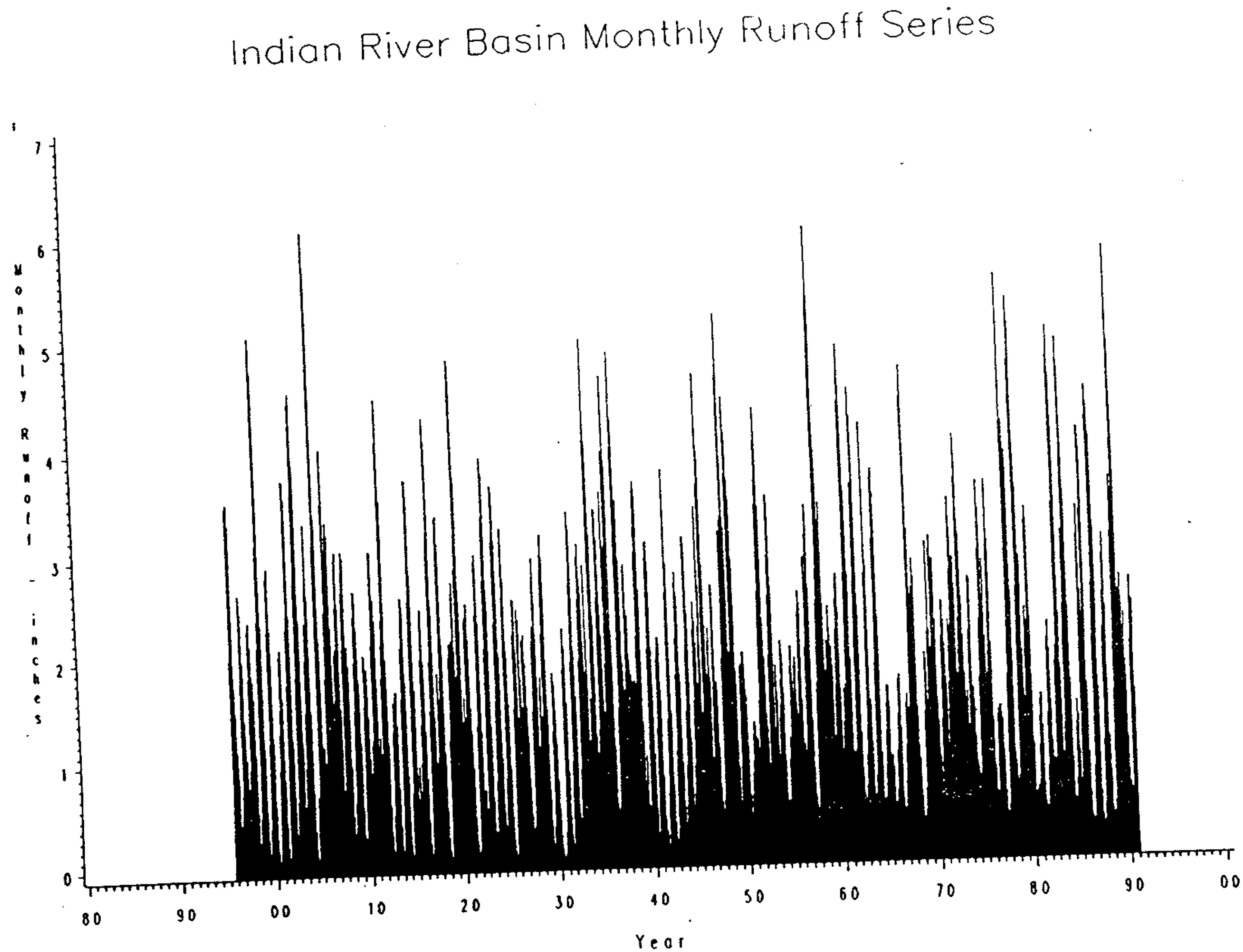

Fig. 2.6. Monthly runoff (inches) Indian River Basin, 1897-1990.

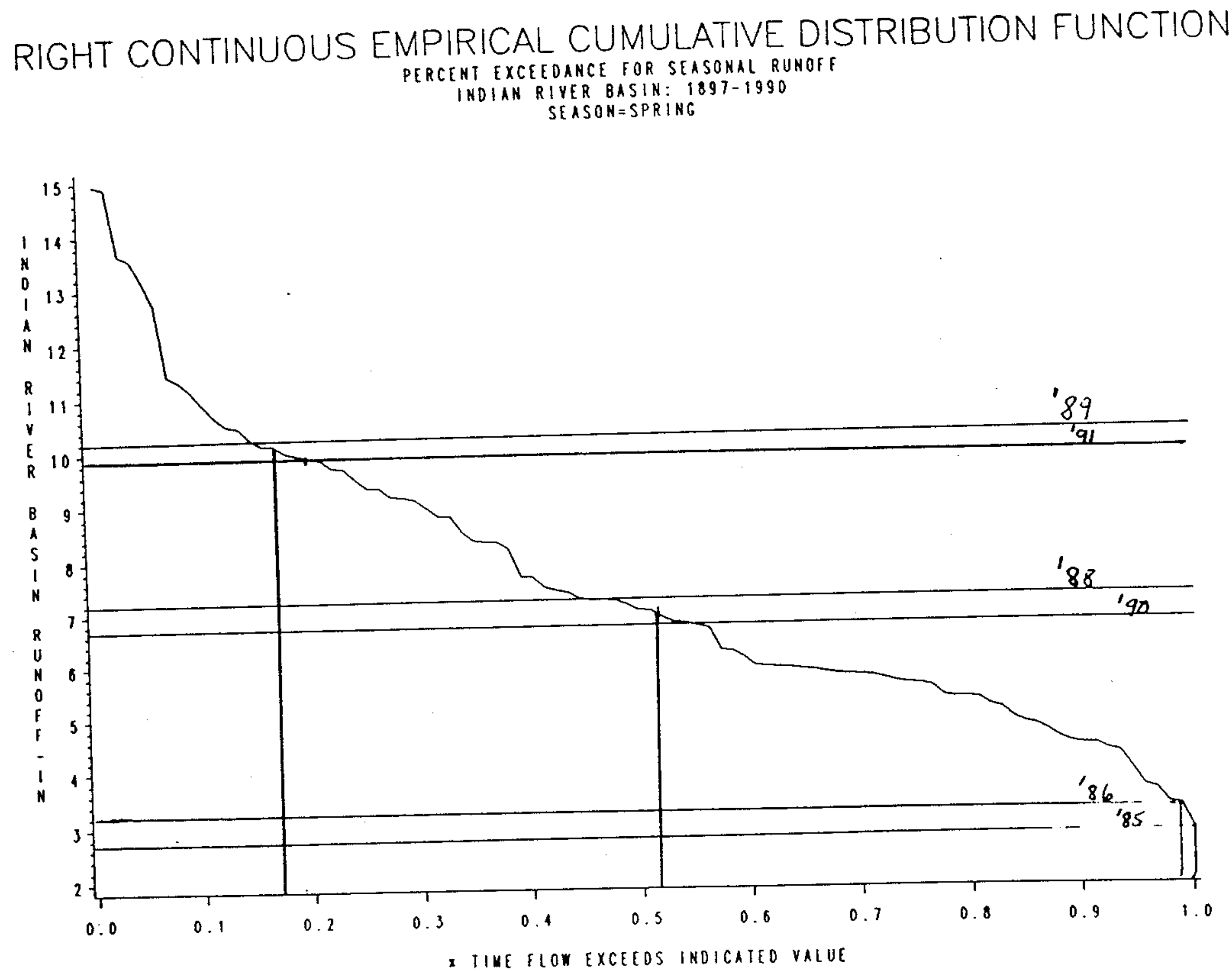

Fig. 2.7 Spring runoff (inches) versus cumulative frequency.

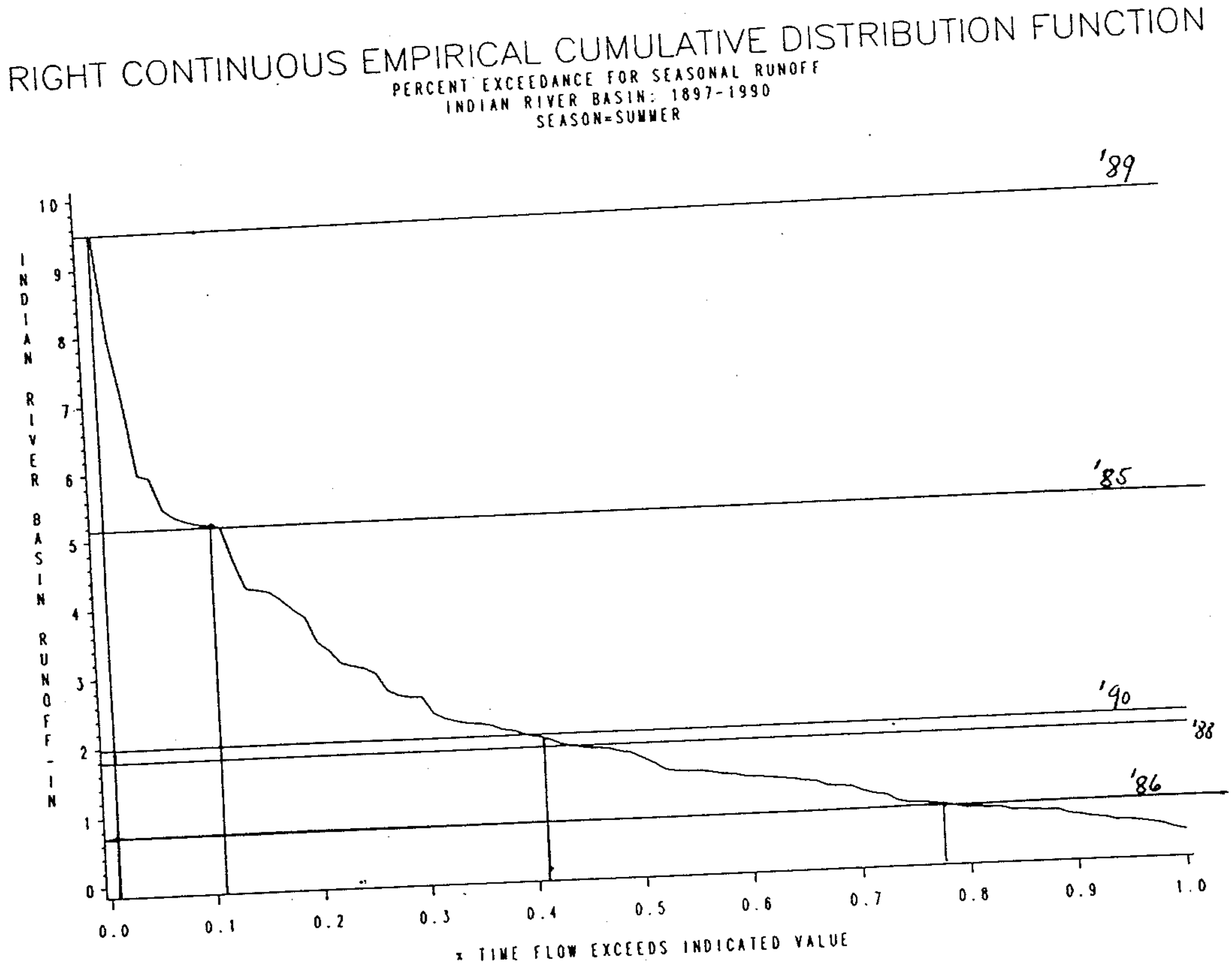

Fig. 2.8 Summer runoff (inches) versus cumulative frequency.

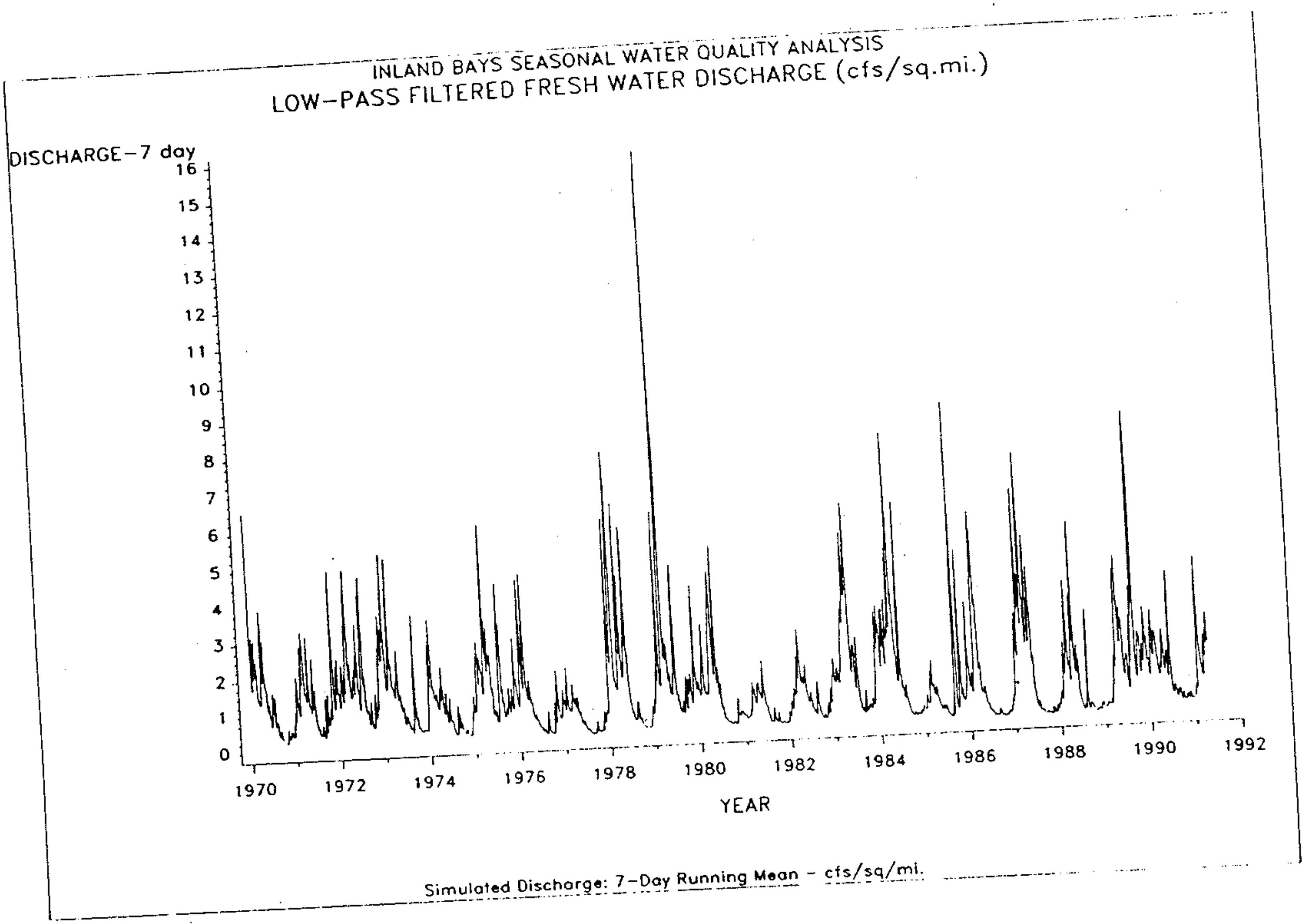

Fig. 2.9 7-day running mean discharge estimates at Millsboro.

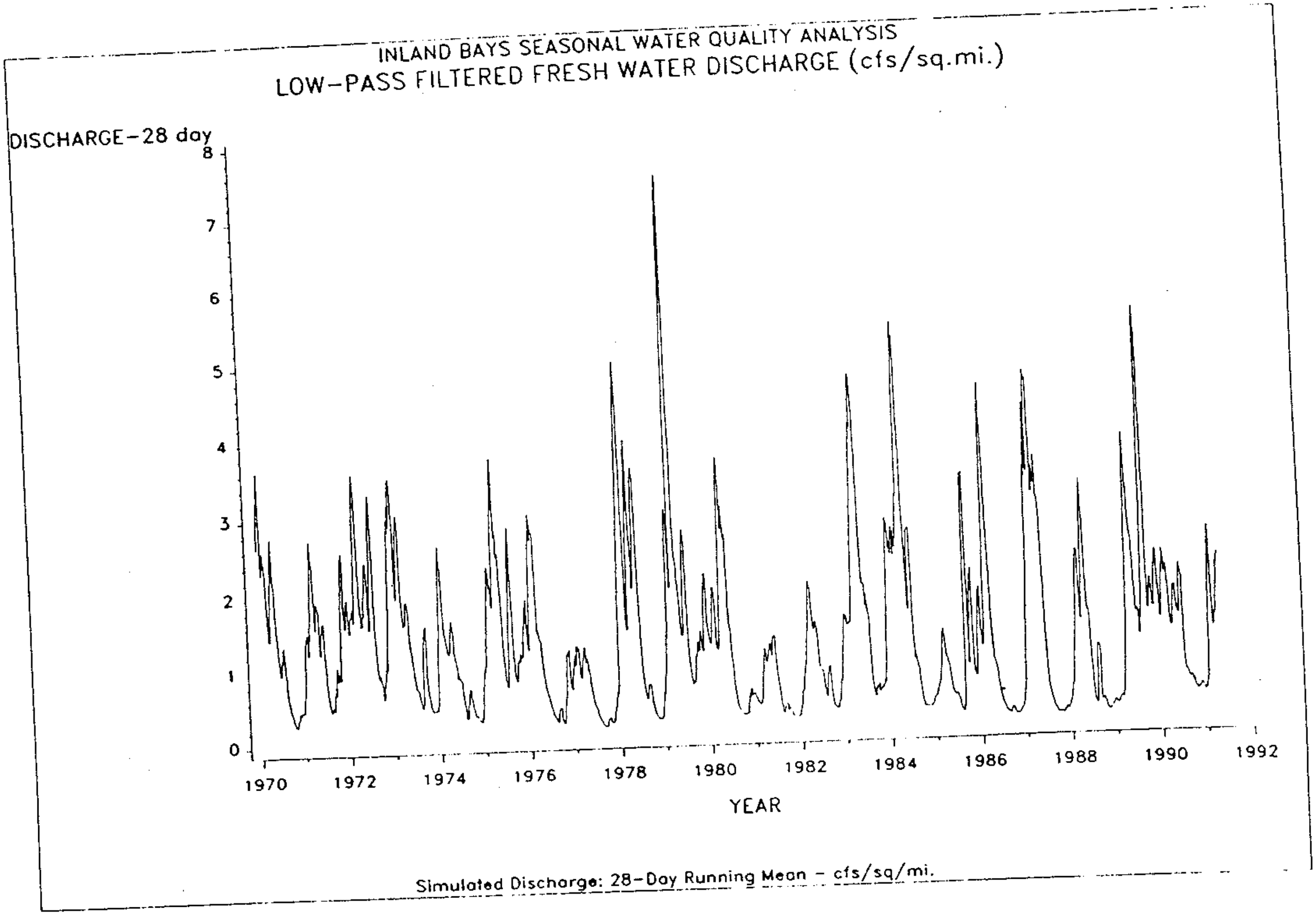

Fig. 2.10 28-day running mean discharge estimates at Millsboro.

2.4 SALINITY

2.4.1 Basin-Wide Salinity Conditions

Plots of the ranges of salinities observed in segments annually and seasonally for each year between 1970 and 1991 are included in Appendix 2.2. A typical example is shown in Figure 2.11. Vertical lines connect the minimum and maximum observed value for each year. The seasons are defined as: Winter, December of the previous year through the end of February of the specified year; Spring, March 1 through June 15; Summer, June 16 through September 30; and Autumn, October 1 through November 30. Note that, if the available data for any segment/season combination were judged to be too sparse, the plot for that combination has been omitted. For instance there is virtually no coverage of most water quality parameters for most years and seasons for either the northern or middle segments of Little Assawoman Bay and therefore the reader will seldom find plots included for these (LAN and LAM) segments.

Further, we see no interannual variability in the salinity data for the more highly saline areas of the Inland Bays. An increase in salinity would have verified the predicted increase in flushing due to changes in inlet dimensions. The plots show that on an annual basis, for years that have an adequate frequency of observations (say at least 5 or more), there has been little or no consistent difference among the salinity concentrations of the three Rehoboth Bay segments (RBN, RBM, RBS), the Masseys Ditch (MD) segment, and the lower Indian River estuarine (IRL) segment between 1970 and the present. The southern segment of Little Assawoman Bay (LAS) appears, under most conditions, to be fresher by several parts per thousand (i.e., less salty) than RBN, RBM, RBS, MD, or the IRL segments. These observations generally hold for the seasonal cases but the reduced number and uneven frequency of observations for each case (year) for the seasonal plots cause considerably more scatter among the segments. As expected and as discussed previously, Indian River shows a range of salinities from oceanic at the seaward end to near fresh at the head of tide at the Millsboro Pond. The annual plots largely confirm the selection of the Indian River segments with IRU oligohaline to mesohaline, IRM polyhaline, and IRL transitional from polyhaline/euryhaline to fully euryhaline (oceanic). An unexpected observation, however, is how seldom the uppermost segment of the Indian River estuary (IRU) experiences truly limnetic (fresh water) conditions. This apparently high salinity condition in IRU and its implications for biological habitat prompted further investigation as discussed below.

2.4.2 The Salinity Conditions of the Upper Indian River Estuary

To better characterize the salinity conditions of the upper Indian River estuary, the single DNREC station nearest the Millsboro Pond outlet was isolated in a separate data set. Observations collected between May of 1970 and July of 1988 at navigational buoy "64" about 2000 feet (600 m) below the dam were used for this analysis. A modified Tukey box plot (see Section 2.2 and Figure 2.4) of monthly salinity observations collected over the period of record at this station is included in Appendix 2.3. Note that the salinity is non-zero at the 25th percentile of all observations taken in the months of March to June at this most upstream of the regularly sampled tidal stations. The remaining plots included in Appendix 2.3 show all of the

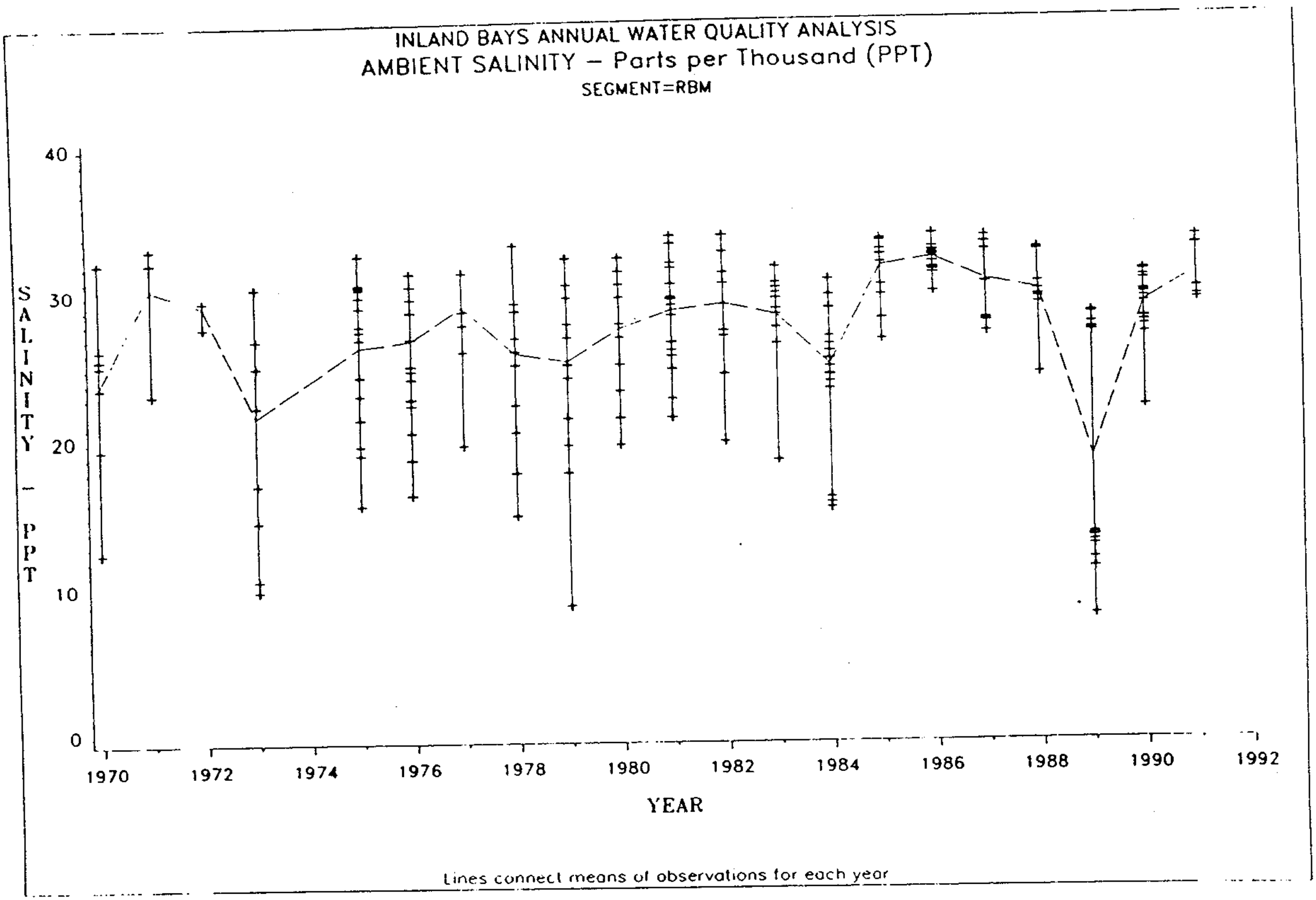

Fig. 2.11 Typical salinity graph.

observed spring season (March 1 through June 15) salinity observations for each year on the left axis and the mean spring discharge (March through June) or various co-occurring running means of the daily fresh water discharge series at Millsboro on the right axis. Note that for the 18 years in which spring salinities were observed, only 6 years had springs with at least one zero salinity observation.

A general rule of thumb that may be derived from these graphs is that the salinity at buoy "64" in the springtime approaches one part per thousand or less when the mean of the freshwater discharge from Millsboro Pond for the previous 3 or 7 days is at or above about 150 cfs (4.5 cu m/s). The mean daily discharge at Millsboro in the spring is only 112 cfs (3.4 cms). A cumulative frequency analysis of the 3-day and 7-day average daily discharge time series revealed that both the 3-day and 7-day discharge exceeded 150 cfs only about 21% of all the spring days occurring between 1943 and 1991. Based on this analysis, it is reasonable to expect the salinity in the tidal waters below the Millsboro Pond outlet to reach limnetic conditions only on about 20% of the days between March 1 and June 30 each year. In other words one might expect to find oligohaline conditions existing below Millsboro about 80% of the days in the spring season.

2.5 WATER TEMPERATURE

Graphs of ranges of water temperature observed in segments annually and seasonally for each year between 1970 and 1991 are included in Appendix 2.4. Vertical lines connect the minimum and maximum value observed for each year. The seasons are defined as described in Section 2.4.1.

The annual and most seasonal series show that RBN, RBM, RBS, MD, IRL and LAS typically exhibit similar temperature conditions. The annual series graphs show that almost universally the temperature of these tidal waters has risen between 1975 and 1992 by approximately 2 to 5 degrees centigrade. To further investigate this apparent phenomenon, seasonal Tukey box plots were developed for each of the three systems (Indian River, Rehoboth, and Little Assawoman) in their entirety (Appendix 2.4). These plots show that most of the annual temperature increase is accounted for by spring, and to a lesser extent, fall seasonal increases. Summer water temperatures do not appear to have changed significantly over this period of time. These apparent seasonal trends are supported by the individual seasonal plots of Appendix 2.4.

The temperature graphs for the Indian River segments indicate that IRU and IRM are often significantly warmer that the temperature of the fresh water entering the system (graphed as IRF). This difference is at times as much as 10° C. Temperatures are typically lower in IRL, most likely due to the influence of the ocean on flood tides and flows through Masseys Ditch and the Little Assawoman Canal on ebb tides. Solar heating of the shallower, more turbid upstream waters, combined with the addition of the heated water discharge of the Indian River power generating station located between IRU and IRM, may account for the observed temperature elevation of the waters of these segments above that of the lower system. Jensen (1974) found similar temperature elevations through this reach in a number of surface water surveys conducted in 1970 and 1971.

2.6 DISSOLVED OXYGEN

Dissolved oxygen (DO) is the parameter with perhaps the most widely ranging array of differing analytical techniques that were allowed to enter the data base. Techniques allowed include field and lab determinations by the azide modified Winkler iodometric procedure and field determinations by a variety of electronic DO probes and meters.

It is often difficult to detect and interpret trends in DO because of the varying temperature-related diurnal and seasonal patterns of oxygen saturation and the widely varying light-related diurnal patterns of photosynthetic oxygen production and respiratory oxygen utilization. To help minimize this variability, part of the data screening process included eliminating any DO observations for which there was no time of day, temperature, or salinity reported.

Plots of all DO observations collected within each segment for each of three seasons (excluding winter) for years between 1970 and 1991 are shown in Appendix 2.5. A typical example is shown in Figure 2.12. A dashed line has been drawn at the 5 ppm level, the State water quality standard. Saturation values were calculated for concurrently measured temperature and salinity values using Carpenter's (1968) method. Dissolved oxygen deficit, defined for this analysis as the observed DO value minus the computed saturation value, is also plotted on these graphs on the right vertical axis. A solid line is drawn at the zero deficit level. The DO deficit plot, in combination with the DO plot, provides a direct graphical mechanism to elucidate the DO behavior in contrast with the effects of temperature. To aid in understanding the light-related effects on the DO, each plot is accompanied by a duplicate plot where the DO plotting character has been replaced by an indicator of the time of day when the observation was obtained.

The DO graphs indicate that, except for several years of elevated dissolved oxygen concentrations surrounding 1980, there are many observations of DO occurring below 5 ppm in the springs and summers between 1970 and 1991 in most segments of the three systems. The summer of 1989 and the spring of 1990 were particularly bad DO periods with many segments not exhibiting any observations of DO greater than 5 ppm. Neither temperature effects nor light-dark cycle effects can provide adequate explanation for these numerous excursions of DO levels below 5 ppm. These cycles in the dissolved oxygen conditions in the Inland Bays are characteristic of a eutrophic estuarine system.

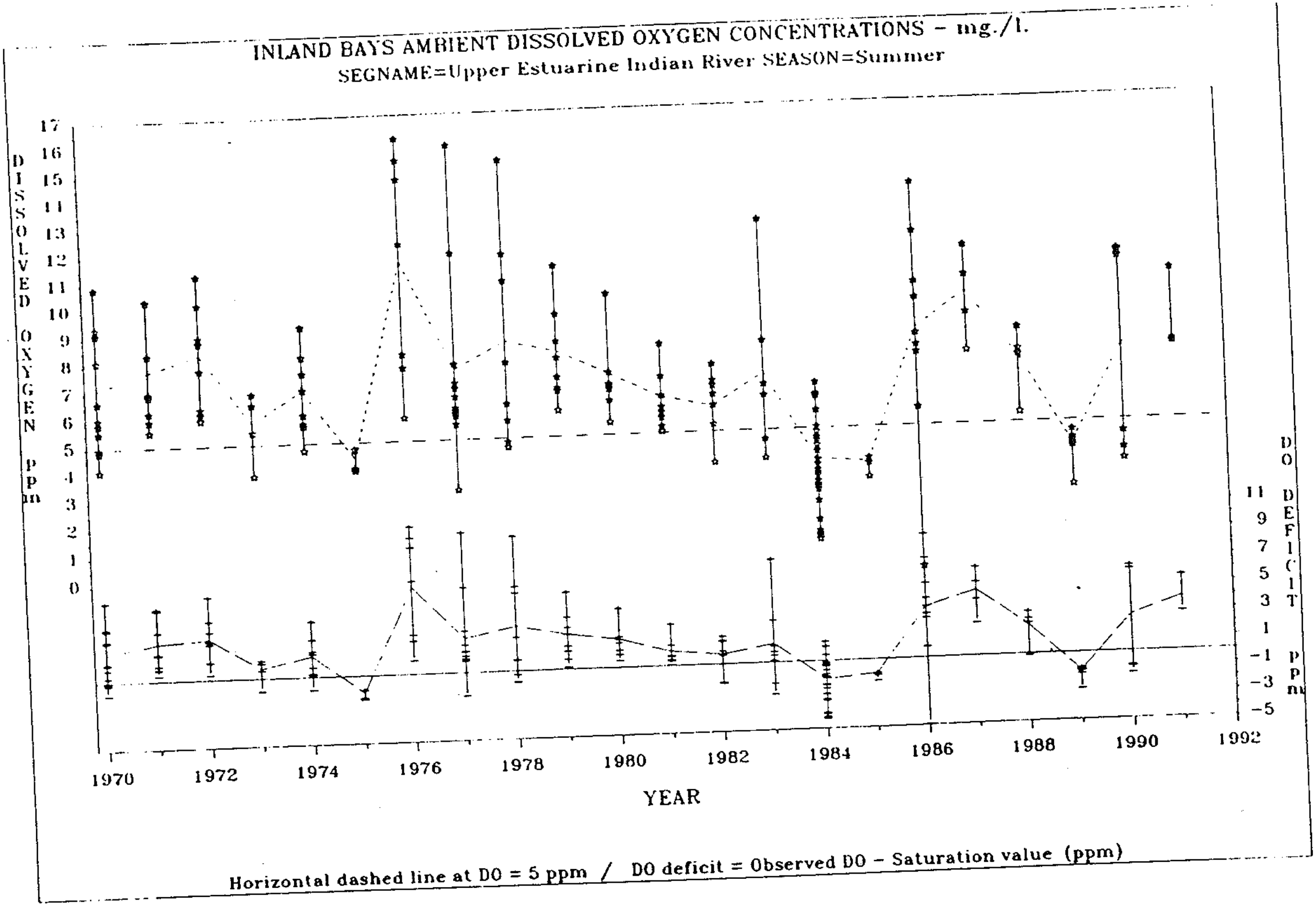

Fig. 2.12 Typical dissolved oxygen graph.

2.7 NUTRIENTS

2.7.1 Ambient Estuarine Nitrogen Concentrations

Annual and seasonal plots for total nitrogen (TN) observations collected between 1970 and 1991 are included in Appendix 2.6. Total Kjeldahl (TKN) and ammonia nitrogen plots are included in Appendix 2.7. Total Kjeldahl and Nitrite+Nitrate nitrogen (NO23) plots are included in Appendix 2.8. Typical examples of these are shown in Figures 2.13, 2.14, and 2.15.

Immediately obvious for all the TN, TKN and ammonia graphs is the apparent decrease in concentrations in almost all segments between the early to the mid-1970's. A controversy has arisen surrounding this apparent decrease in nitrogen, specifically regarding the ammonia concentrations that appear to be the major component of the apparent change. Some evidence suggests that laboratory or field techniques used at the time may have caused more variability in reported concentrations in earlier years. For instance, it appears that this same pattern of decreasing variability is observed in many other locations in the state, sampled by the same crews and analyzed by the same laboratory. These other locations, some fresh water, others not, are subject to varying point and nonpoint nitrogen loading conditions and yet all share a similar apparent reduction in ammonia variability over the early 1970's. Other evidence, however, would tend to make it difficult to dismiss the apparent nitrogen trends. For instance, the levels of ammonia reported for the lower Indian River segments show the familiar decrease, but in the uppermost areas of the estuary, the ammonia concentrations remain high, even after the time when the ammonia levels have declined in the higher salinity segments. The problem is complicated by the COE model results that indicate large increases in the tidal prism over that same time, and therefore, it is assumed, correspondingly large increases in tidally induced flushing. Increased tidal flushing over the period 1970 to 1975 would be expected to tend to reduce the concentrations of nitrogen in the system by dilution to the lower levels of the coastal ocean.

At this time, the question of the apparent decrease in ammonia concentrations through the early 1970's remains open, leaving open the question of the significance of any trends over the period of observed data. However, the more stabilized concentrations reported since 1980 can be used to elucidate the status of the Inland Bays with respect to nitrogen.

Since about 1980, the Rehoboth Bay segments have typically exhibited mean total nitrogen concentrations of around 1 ppm. There is no readily apparent seasonal trend for TN in these segments. Masseys Ditch TN levels fluctuate around a lower 0.5 ppm concentration while TN levels for the station located in the Little Assawoman South segment were typically reported in the 1-2 ppm range. Total nitrogen concentrations in the Millsboro Pond fresh water discharge (IRF) are typically in the 1-4 ppm range with means of around 3 ppm. The TN concentrations in the upper Indian river segment remain at these high levels, 2-3 ppm, even though they are considerably diluted by ocean water as evidenced by the relatively high salinities in this segment as discussed in Section 5.2. These sustained high nitrogen concentrations in the IRU segment might be attributed to the presence of high nitrogen concentration waste discharged by commercial food processors to surface and shallow ground waters directly adjacent to the

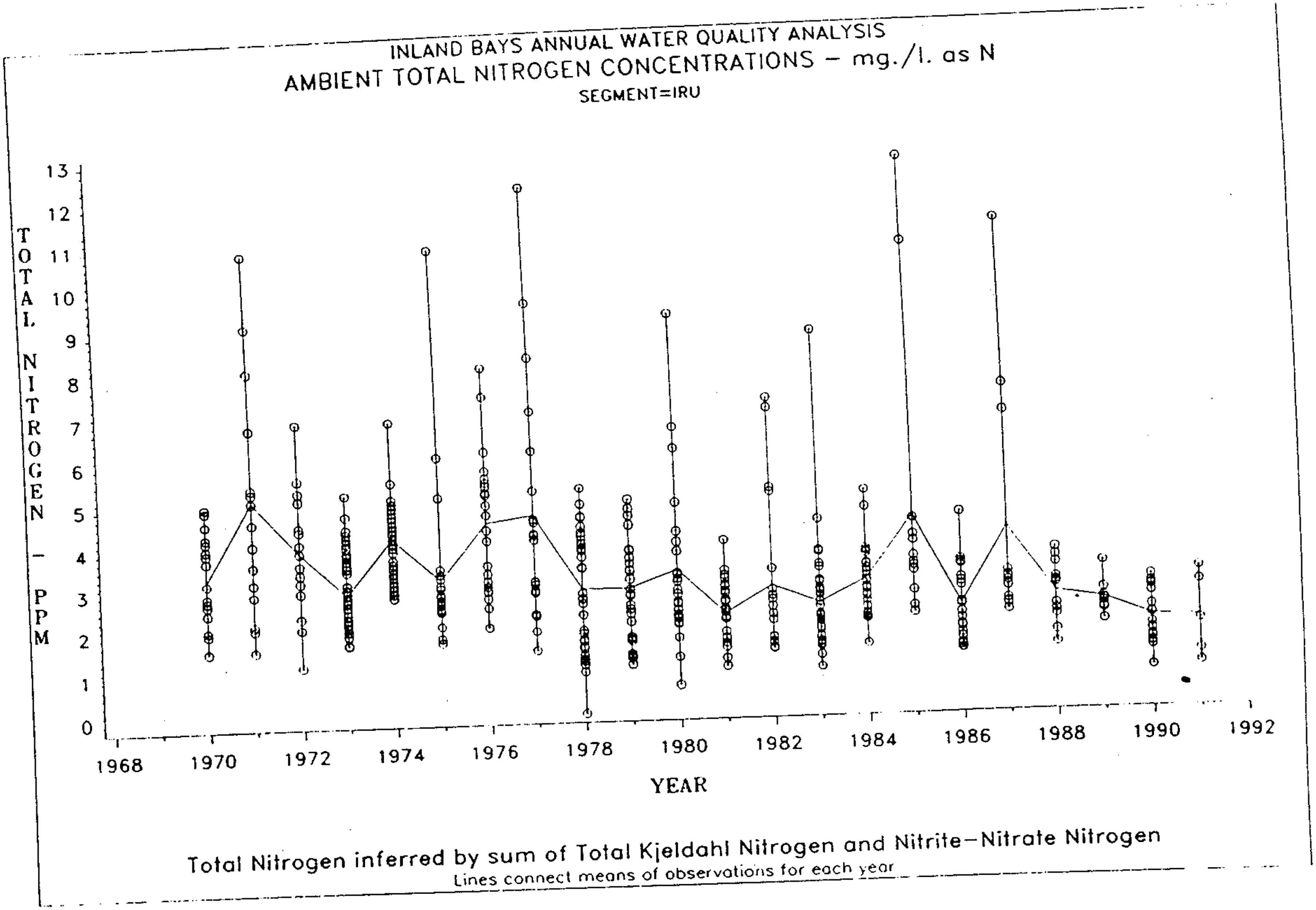

Fig. 2.13 Typical total nitrogen graph.

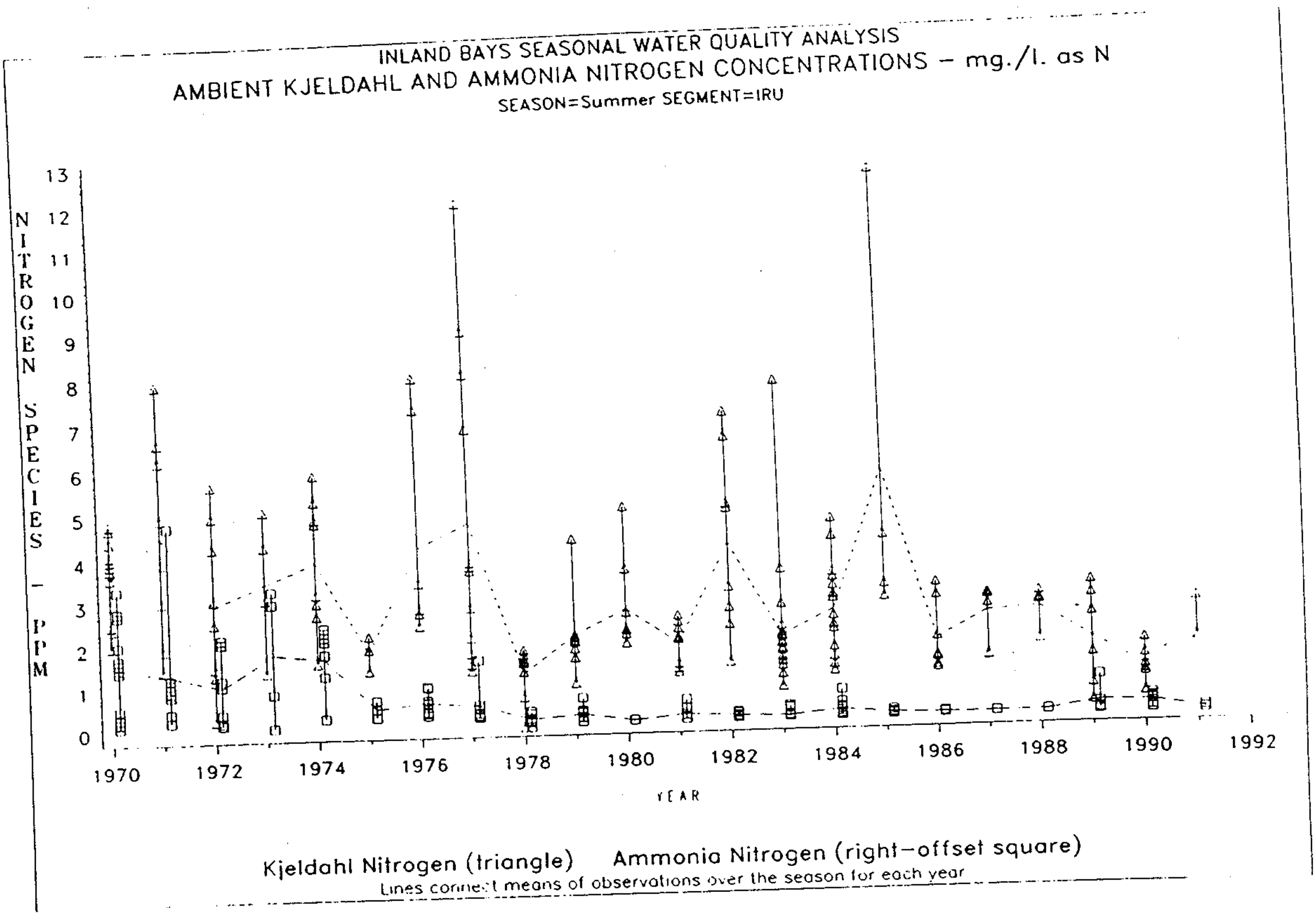

Fig. 2.14 Typical Kjeldahl and ammonia nitrogen graph.

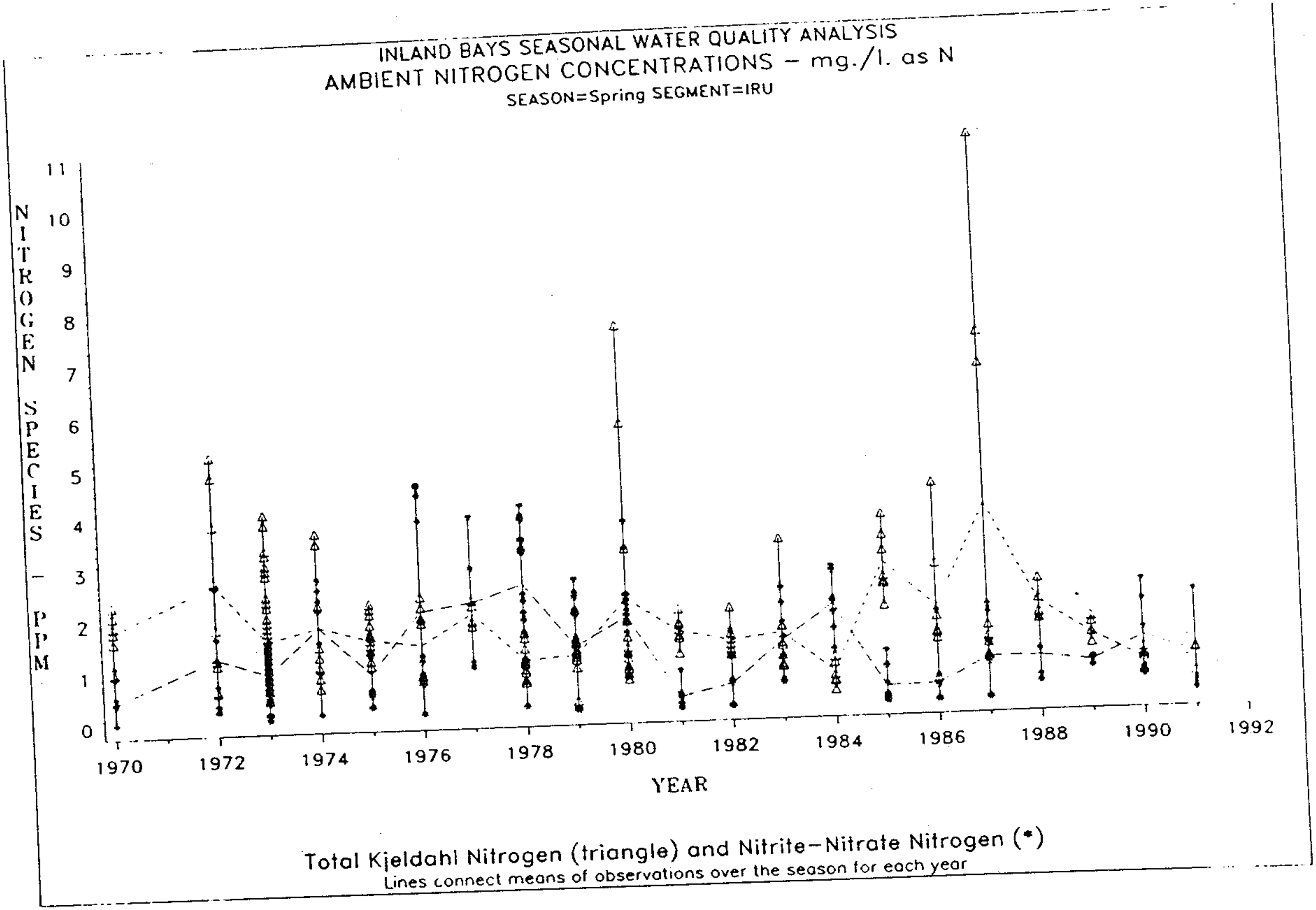

Fig. 2.15 Typical Kjeldahl and nitrite+nitrate nitrogen graph.

segment. The TN levels in the lower Indian River segment, like those of the Rehoboth segments, are typically 1 ppm.

Spring and summer TN concentrations and patterns are similar to those described above with the possible exception of elevated summer concentrations in the northern and central Rehoboth Bay segments to approximately a 1-2 ppm range. Note however that the summer data for these segments is sparse. The Rehoboth sewage treatment plant discharges to these segments and the Lewes-Rehoboth Canal connects to RBN. Both are possible sources of elevated nitrogen loading in the summer.

Throughout the 1980's to the present, the concentrations of nitrate and ammonia in the higher salinity waters of the Inland Bays, both annually and seasonally, were relatively low, with the majority of the total nitrogen made up of organic forms. In contrast, most of the nitrogen in inflowing fresh water at Millsboro is in the form of nitrite-nitrate at concentrations of between 1 and 4 ppm while ambient concentrations in IRU are often in excess of 1 ppm, especially during the spring. Ammonia concentrations are usually about 0.1 - 0.2 ppm and seldom reach 0.5 ppm. in any segment at any time of the year.

The significance of the nitrogen conditions and their potential relationship to eutrophication within the Bays will be considered in Section 2.10. Their relation to Delaware Inland Bays nutrient standards are discussed in Sec. 3 of this report.

2.7.2 Ambient Estuarine Phosphorous Concentrations

At least three different forms of phosphorous analytical techniques have been used over the years in the Inland Bays. Prior to 1978, most observations were in the form of total ortho-phosphorous reported as phosphate ion. Since then the most common measurement has been total phosphorous (TP) reported as elemental phosphorous. Another less common measure used since about 1980 is "phosphate" reported as elemental phosphorous. None of these forms are comparable for the purposes of trend analysis. Therefore no statement can be made regarding phosphorous trends between 1970 and the present in the Inland Bays but the more recent TP data can be used to establish the current status of phosphorous concentrations. Plots showing these three most commonly reported forms of phosphorous are included in Appendix 2.9.

The annual plots of total phosphorous concentrations within the Inland Bays show remarkably little variation among the segments. The Rehoboth Bay segments (RBN, RBM, RBS), Masseys Ditch (MD), the southern segment of Little Assawoman Bay (LAS), and the middle and lower segments of Indian River (IRM, IRL) all exhibit total phosphorous concentrations between 0.1 and 0.2 ppm. The concentrations in the freshwater discharge from Millsboro Pond (IRF) are below 0.1 ppm. The total phosphorous concentrations in the upper Indian River segment (IRU) during the summer often exceed 0.2 ppm, occasionally reaching as high as 0.5 - 1 ppm.

The significance of the phosphorous conditions and their potential relationships to eutrophication within the Bays will be considered in Section 2.10.

2.7.3 Nutrient Loadings

Nutrient loadings to the tidal waters of the Inland Bays have been estimated by Ritter (1986) using indirect techniques. Ritter's estimates include contributions from point sources, groundwater discharge, runoff, direct rainfall, wetlands, boating activities and septic tanks. Annual loading rates from each of these sources are given in Tables 13 - 31 of that report. Based upon the data shown in those tables, the upper Indian River segment is shown to receive very high nutrient loads from nonpoint sources in Iron Branch and above the Millsboro Pond outlet, and from point and nonpoint sources in the Swan Creek basin. The overall results of Ritter's work, summarized as relative nutrient contributions among the major sources, are shown here as Figure 2.16.

Seventy-five percent of the fresh water in Indian River is derived from groundwater discharge into the streams that drain the watershed (Johnston, 1976). Ritter (1986) has found no correlation between streamwater discharge rate and the corresponding nitrogen content, suggesting that groundwater, as opposed to stormwater, dominates as a source of nitrogen to the streams. High concentrations of nitrogen (principally as nitrate) in groundwater are widespread in the drainage basin and are principally caused by decades of intensive agricultural practices (Robertson, 1977). Because of the widespread contamination of the shallow aquifer beneath the watershed, because that aquifer supplies most of the water discharging from the streams of the watershed, and because groundwater in the shallow aquifer moves slowly (tens to hundreds of feet per year), it is likely that high nitrate loads may be observed for decades, even with best management practices.

Andres (1992) has estimated nitrate fluxes to the Inland Bays through direct discharge of groundwater around the shorelines and upwards through the bottom. His estimates (250 tons/year for Indian River Bay and 46 tons/year for Rehoboth Bay) add about 20 percent to the nitrogen budget in Figure 2.16. Because of the different methods used by Ritter and Andres, it is not possible to define the percentage of total nitrogen that comes from direct groundwater discharge. Further, preliminary data (Seitsinger, 1993) seem to indicate that some or all of the nitrate that moves up through the bottom sediments of the bays is converted, by biogeochemical reactions, to nitrogen gas, before or at the time it enters the waters of the bays. Thus, we cannot state whether or how much nitrate enters the bays by direct groundwater discharge.

An attempt was made during the course of the characterization study to verify Ritter's lumped loading estimates for each major tributary. Included in the data base were 1,222 observations of water quality collected at non-tidal, fresh water stations within the Inland Bays basins. From these stations, the ones located nearest tidal waters within each major sub-basin were selected to attempt to characterize concentrations of inflowing waters. These concentrations were multiplied by the three-day mean daily discharge estimates for each basin to compute mean daily loading rates. The results for the phosphorous loads discharged from Millsboro Pond for each season are shown in Figures 2.17 through 2.20.

Nutrient Sources	Indian River Bay		Rehoboth Bay		Little Assawoman Bay	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Boating	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
Forest	11.0%	19.2%	7.4%	9.4%	6.7%	19.5%
Rainfall	6.2%	8.6%	8.8%	6.9%	12.8%	11.5%
Septic Tanks	16.0%	9.3%	11.2%	3.8%	14.6%	5.6%
Urban	9.8%	8.6%	11.7%	5.9%	11.2%	10.8%
Point Sources	12.5%	15.0%	27.3%	56.9%	0%	0%
Agriculture	44.6%	39.4%	33.0%	17.0%	54.7%	52.6%

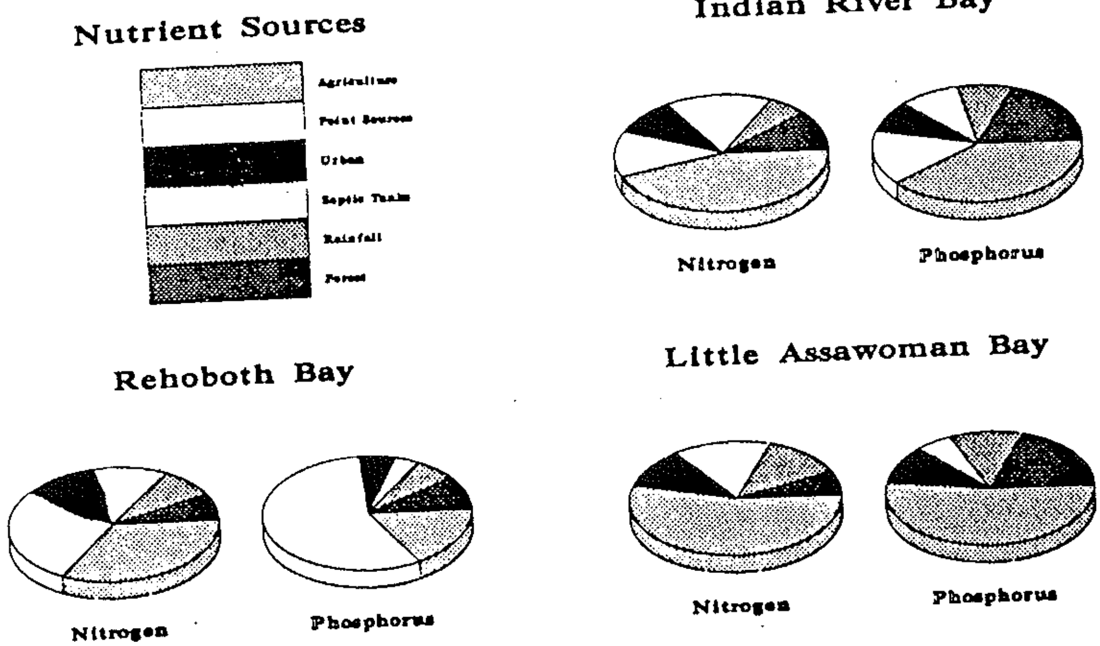

Fig. 2.16 Source of nutrient loadings as estimated by Ritter (DNREC 1991).

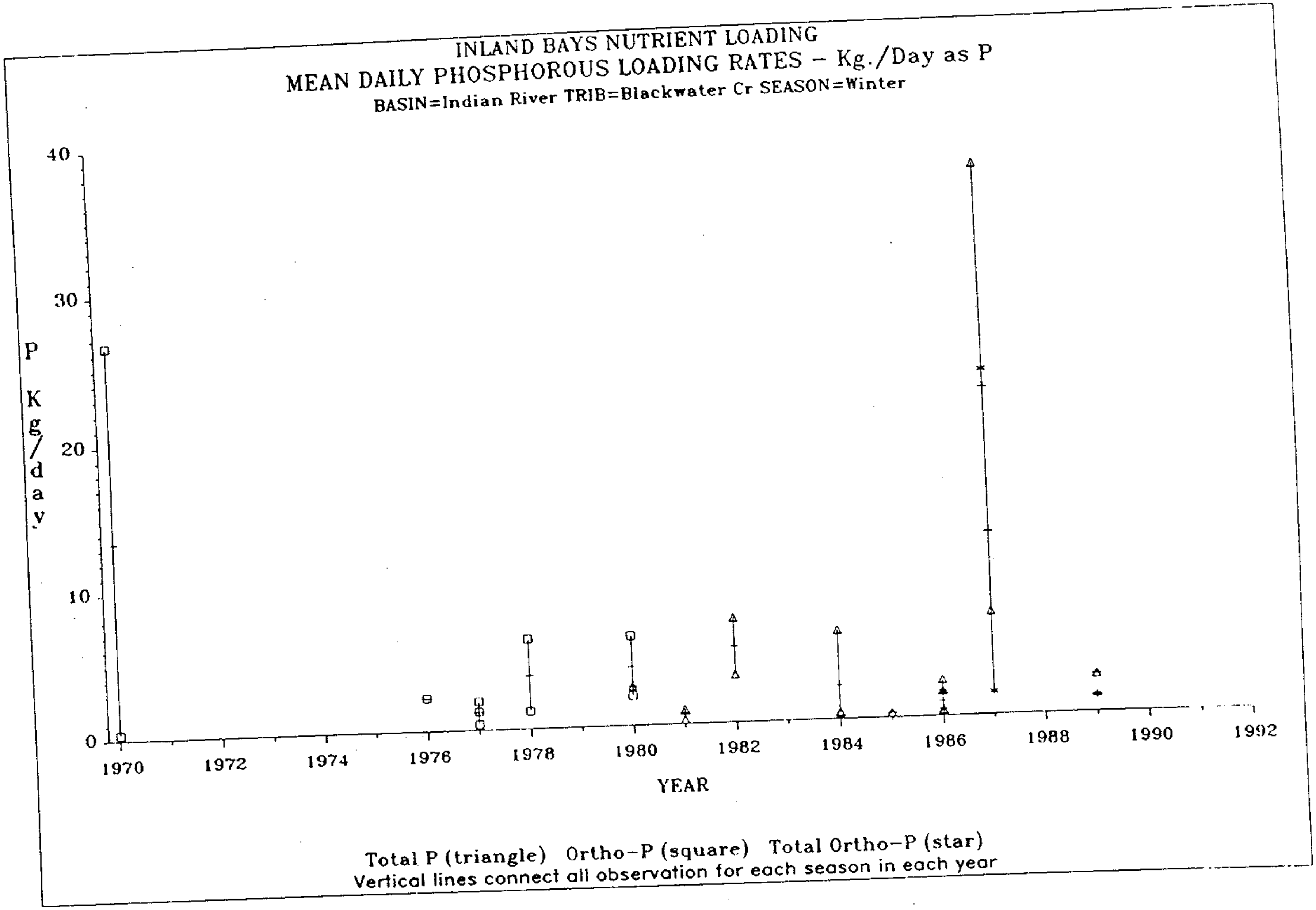

Fig. 2.17 Winter phosphorous loadi[illegible]ates - Millsboro Pond outlet.

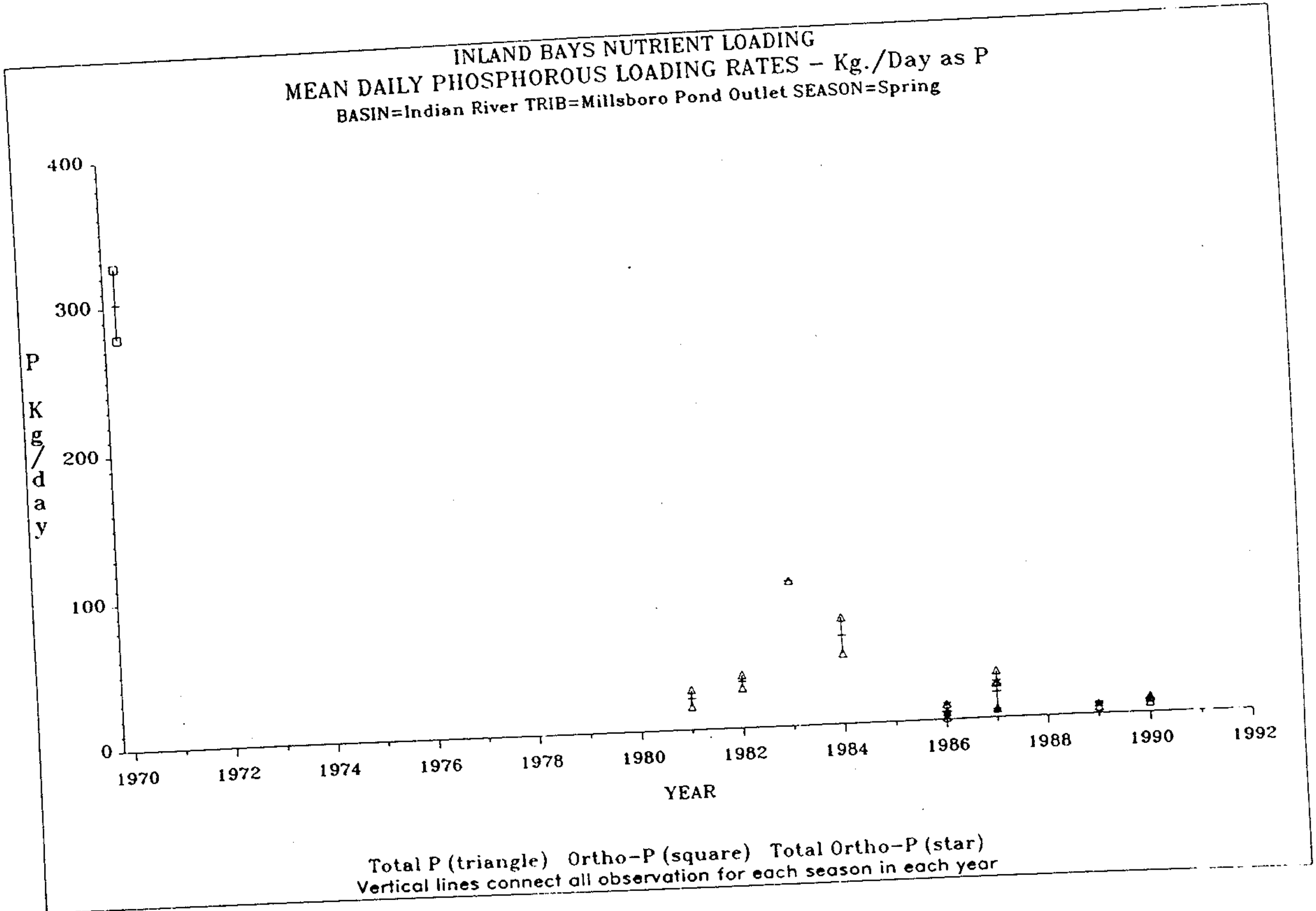

Fig. 2.18 Spring phosphorous loading rates - Millsboro Pond outlet.

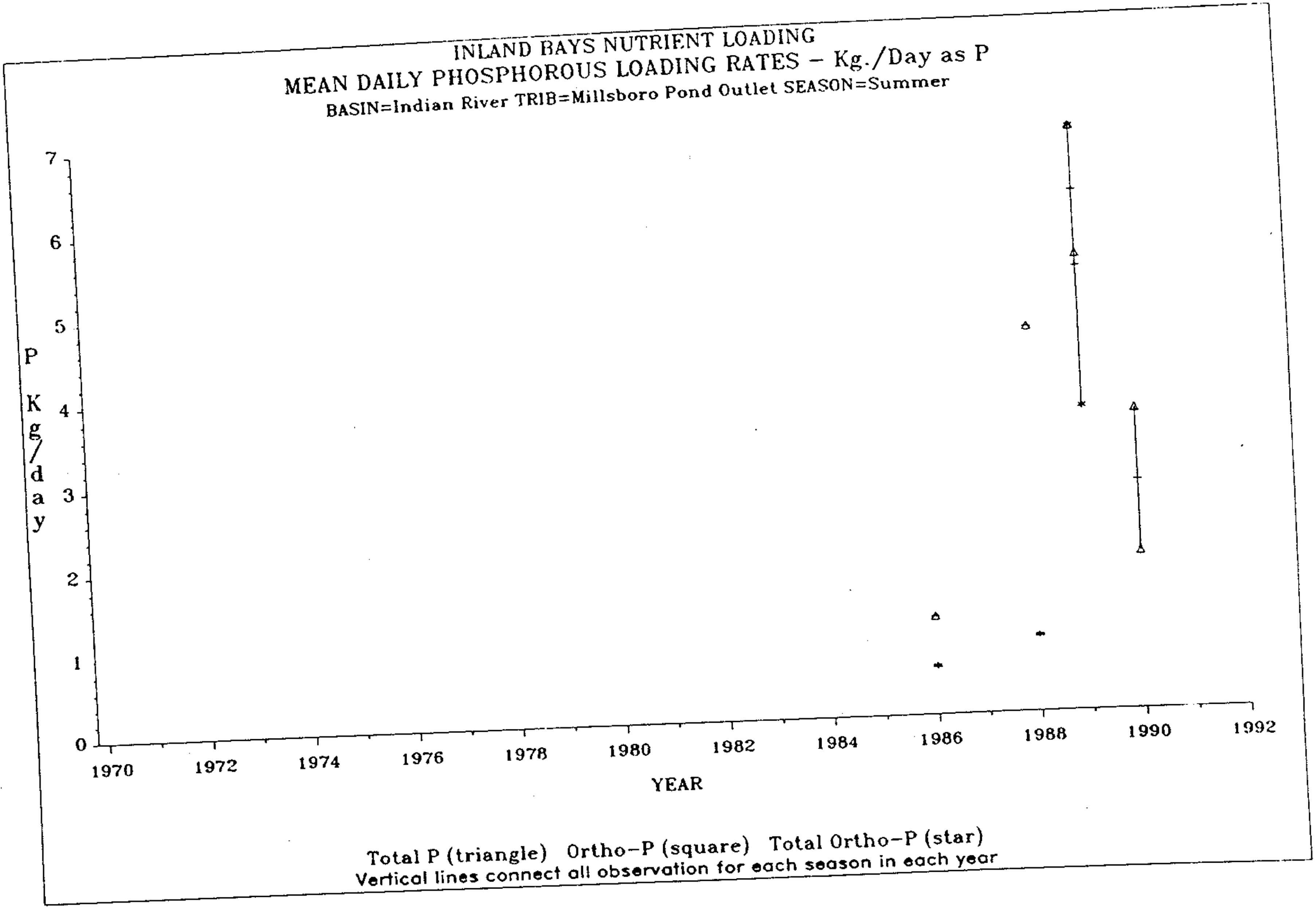

Fig. 2.19 Summer phosphorous loading rates - Millsboro Pond outlet.

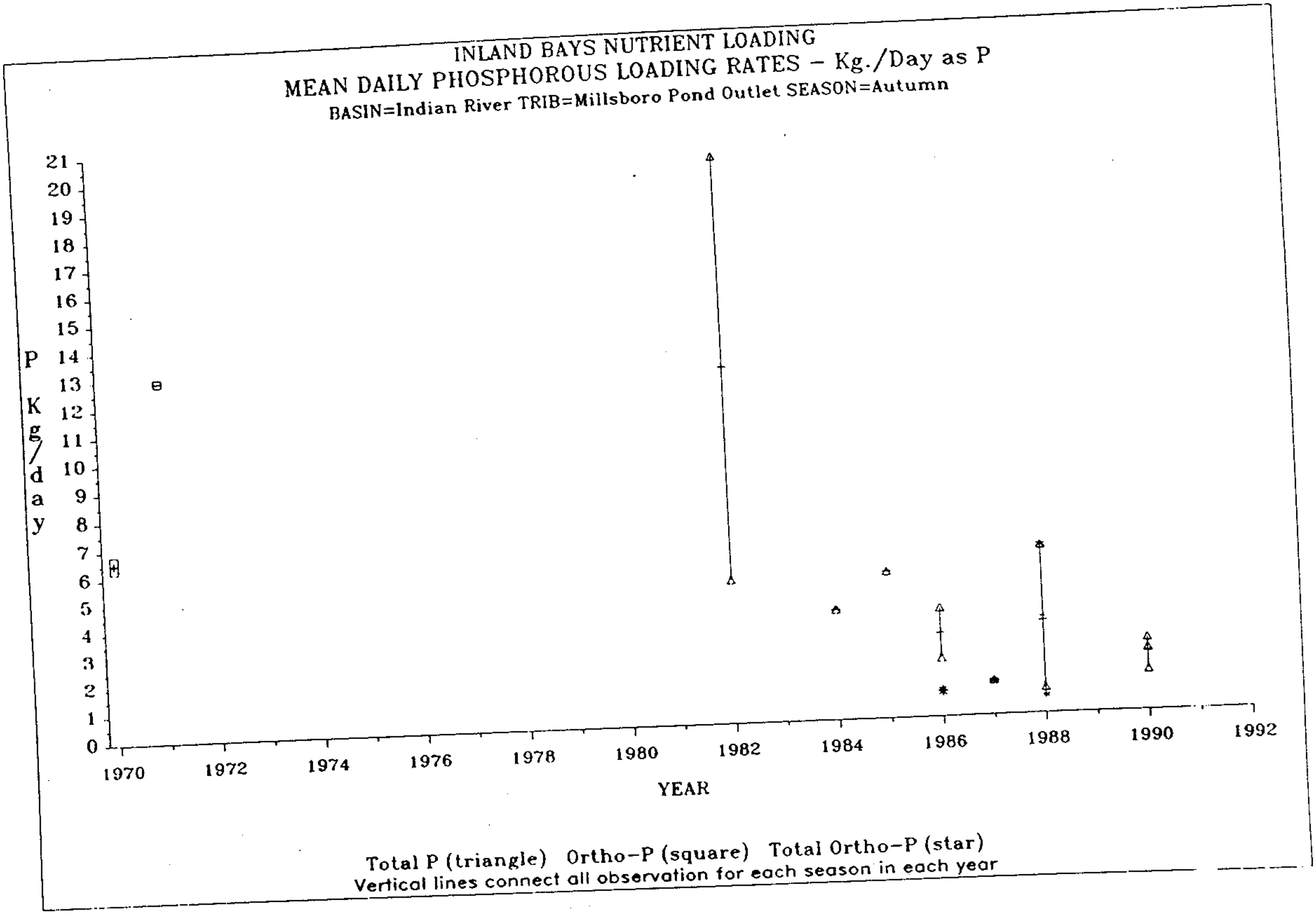

Fig. 2.20 Autumn phosphorous loading rates - Millsboro Pond outlet.

These graphs show that the data are far too sparse to provide any but the most rudimentary basis for verifying Ritter's loading estimates. For example, Ritter (Table 18) estimated that for a range of dry to wet years, the phosphorous loading rate at the Millsboro Pond outlet was between approximately 4 to 12 Kg/day. Observations of the computed values shown in Figures 2.17 through 2.20 reveal reasonable agreement with Ritter's estimates. However, these figures show the high degree of variability in the computational results. They are typical of the graphs that were produced for other parameters. Similar attempts for the other sub-basins generally yielded even more sparsely distributed results.

Many attempts were made to use the data to develop both parametric and non-parametric statistical models relating watershed discharge concentrations and discharge flow rates. However, no statistically significant relationships were found. In most cases, the available degrees of freedom (i.e., the number of observations) were considered to be too low to support the development of significant models. Therefore, we have no basis to decide if the loadings are driven by a variability of constituent concentration over a range of flows or if flow rate is the dominant driver of the loading rate. It is concluded that it is not possible to improve upon Ritter's loading estimates by using the existing available observed data either in graphically-based or statistically-based analyses. However, the existing data may be sufficient to calibrate computer-based, hydrologic/water quality, watershed-scale models of the basins. These models could be used to infer seasonal and annual loads as well as to provide a computational basis for evaluating watershed management decisions. The use of such models was beyond the scope of this characterization study. Therefore, at this time, Ritter's work represents the best available source of comprehensive, basin-wide loading estimations for the Inland Bays.

2.7.4 Salinity-Nutrient Property Relationships

Seasonal plots of nutrients versus observed salinity for data collected in Indian River Bay between 1970 and 1991 are included in Appendix 2.10. Salinity-property plots are shown for spring and summer for Nitrite+Nitrate nitrogen, Total Kjeldahl, Total Nitrogen, Total Phosphorous, and Total Ortho-phosphorous.

Figure 2.21 is a plot from Appendix 2.10 showing spring nitrite-nitrate nitrogen concentrations versus salinity for Indian River Bay. This figure shows that nitrite-nitrate concentrations are mostly greater than 0.5-1.0 mg/l N when salinities are less than 15 ppt and are generally within or below that range of nitrogen when salinities exceed 15 ppt. The data appear to support conditions indicative of an upstream source of nitrite-nitrate in the range of 1-4 mg/l that is diluted moving along the salinity gradient by mixing with ocean waters that appear to typically exhibit nitrite-nitrate concentrations at or below 0.3 mg/l. The slight upward "cupping" shape of the plot would tend to indicate that nitrite-nitrate possibly is being removed. This shape of the curve could, for instance, indicate nitrate uptake by phytoplankton and perhaps removal by zooplankton grazing and detrital settling. However, the corresponding total nitrogen data plotted in Figure 2.22 exhibits a fairly conservative (i.e., straight line) dilution effect, indicating that perhaps the nitrite-nitrate is converted to organic matter but remains in the water column. The

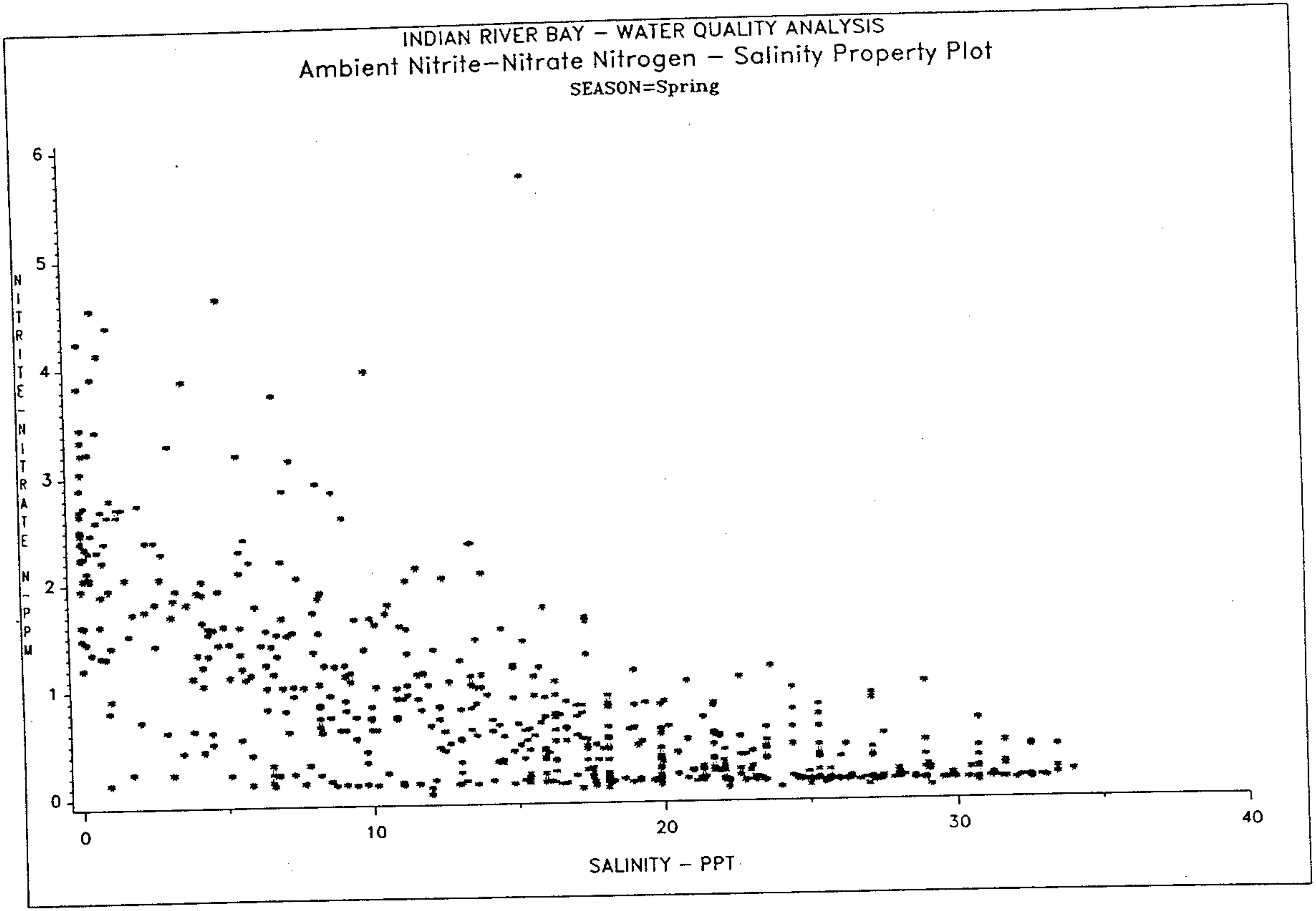

Fig. 2.21 Salinity/Nitrate Plot for Springtime, Indian River Bay.

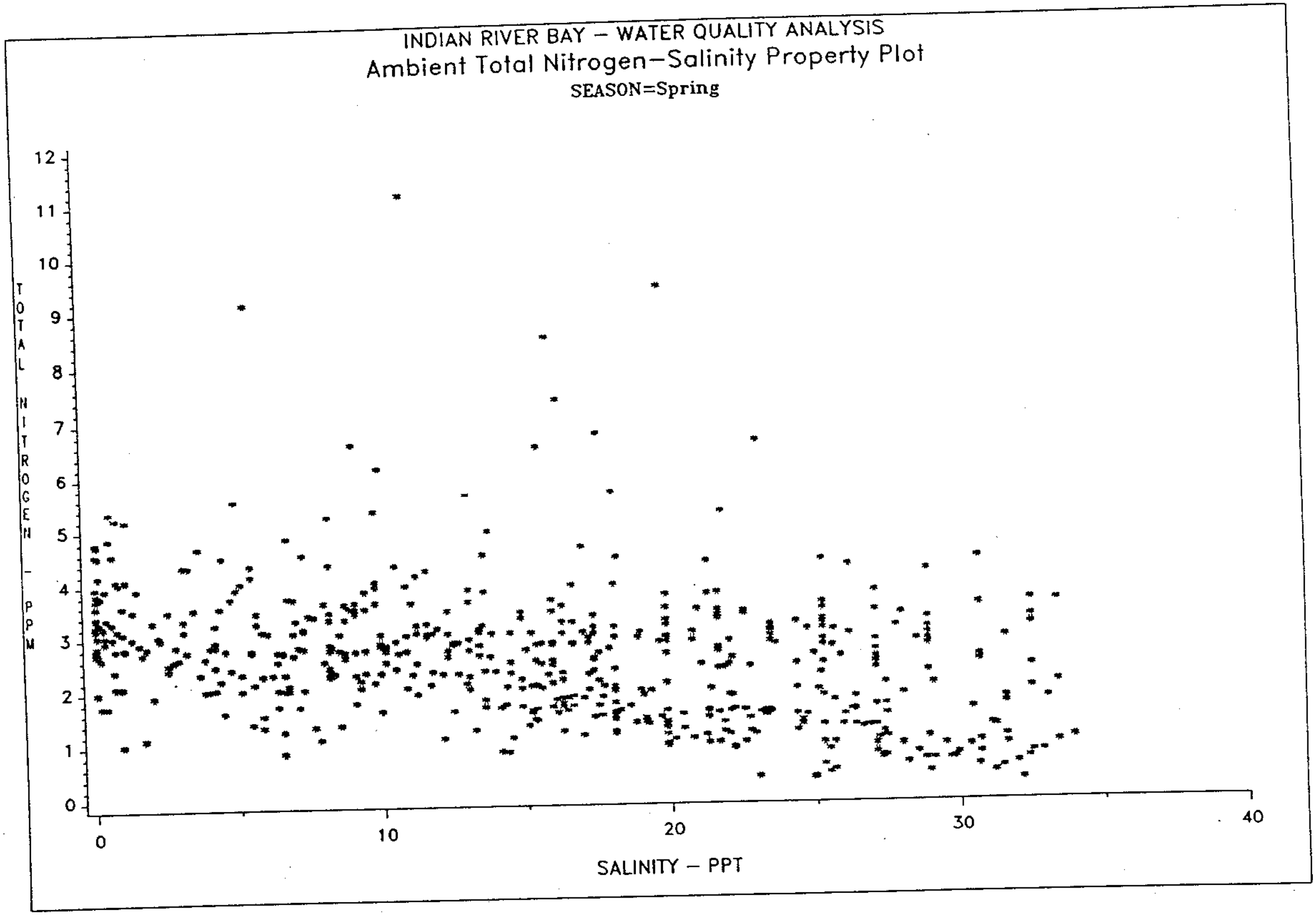

Fig. 2.22 Salinity/TN Plot for Springtime, Indian River Bay.

fairly diffuse but flat plot of spring Kjeldahl nitrogen (Figure 2.23) may indicate that two sources exists along the salinity gradient. One likely explanation may be the formation of organic nitrogen in the estuary from nitrate via plankton uptake, and the other could be the import of organic material from the ocean. These patterns are not observed in the summer plots.

Attempts to produce plots for Rehoboth and Little Assawoman were less enlightening as there typically was an inadequate range of salinity to support meaningful graphical results.

Salinity-nitrogen property plots delineating the periods 1970-1975 and 1986-1991 are also included in Appendix 2.10. We separated the time periods to determine whether measurable differences in nutrient concentrations were apparent in Indian River Bay. Total Kjeldahl nitrogen shows generally lower concentrations in the higher salinity areas in the recent data sets, but show no change in the fresh water concentrations from the earlier data sets. (See Section 2.7.1 for a discussion of the possible causes of this trend.)

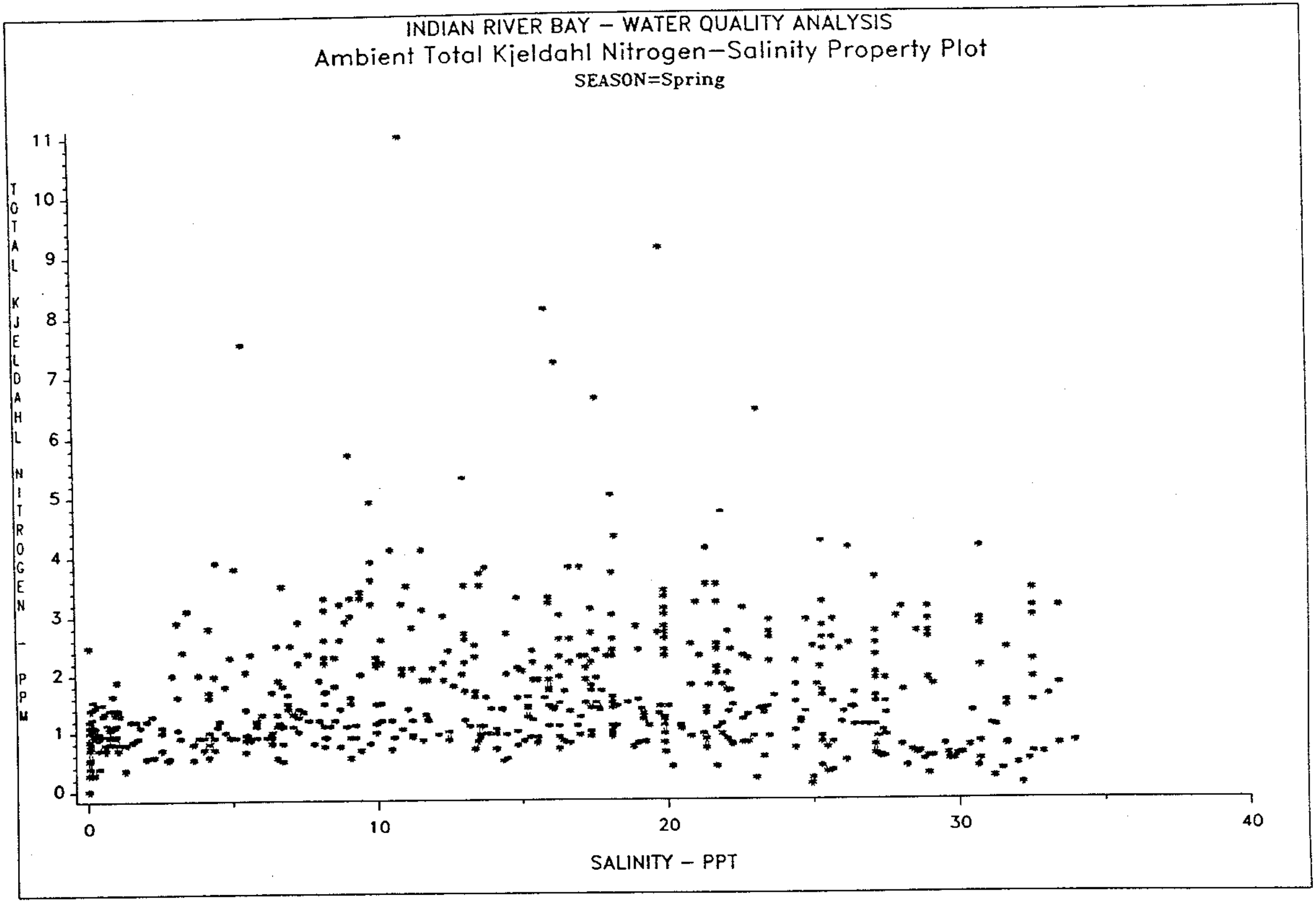

Fig. 2.23 Salinity/TKN Plot for Springtime, Indian River Bay.

2.8 CHLOROPHYLL AND TURBIDITY

Chlorophyll *a* observations generally are available from DNREC since about 1989. Historic chlorophyll data stored on the STORET system were removed prior to the initiation of this study. Other investigators have collected chlorophyll data in Indian River, most notably the Academy of Natural Sciences for a year in 1985-86, and Brooks, et al. (1974). Lacoutre and Sellner (1988) analyzed these data and found a significant decrease in chlorophyll in upper and middle Indian River Bay between 1974 and 1985. This timing corresponds grossly to the decrease in nitrogen (Section 2.7.1) and the increase in flushing (Section 2.1) in these same areas.

The available DNREC data, collected over 3 years, was used to establish the status of the system. The forthcoming publication of recently collected data by Ullman et al. will significantly increase the data base for determination of status. The DNREC chlorophyll *a* data collected in 1989 through 1991 has been plotted and included in Appendix 2.11. Note that both uncorrected and corrected data, each denoted by a separate plotting character, are plotted for these annual series. Chlorophyll *a* concentrations in the Rehoboth Bay segments ranged as high as 40 ppb with most concentrations below 20 ppb. Masseys Ditch concentrations were 10 ppb or less while those in the Inlet were observed as high as 18 ppb. Most chlorophyll *a* concentrations observed in the three Little Assawoman segments were between 20 and 40 ppb with one observation in excess of 200 ppb in LAN. The Indian River upper and middle segments (IRU and IRM) typically ranged as high as 200 ppb while those in IRL were generally less than 15 ppb. Spring, summer, and autumn plots are included for the IRU segment. About half of the summer chlorophyll *a* concentrations in IRU exceeded 80 ppb

Seasonal and annual plots of Turbidity (FTU), suspended solids (SS or non-filterable residue), and organic nitrogen are included as Appendix 2.12. To optimize the plotting area, the values of turbidity have been divided by 2 and the values of non-filterable residue have been divided by 10 prior to plotting. An estimate of organic nitrogen was calculated by subtracting ammonia values from total Kjeldahl nitrogen values.

Typical concentrations of suspended solids in the Rehoboth, Masseys Ditch and Little Assawoman segments range from 10 to 70 ppm. The turbidity values for these segments are on the order of 5 - 10 FTUs and the organic nitrogen concentrations are approximately 1 ppm or less. The concentrations of suspended solids in the Millsboro Pond discharge (IRF) were seldom observed above 50 ppm, turbidity values for IRU are on the order of 5 - 10 FTUs, the organic nitrogen concentrations are approximately 1 ppm or less. However, the IRU and IRM segments exhibit considerably higher suspended solids concentrations, ranging from 10 to over 100 ppm. Similarly, turbidity observations in these segments are in the 5 - 20 FTU range while organic nitrogen concentrations range from 1 to 10 ppm with typical concentrations between 2 and 3 ppm. The observations of these parameters in the lower Indian River are closer to those of the Little Assawoman and Rehoboth segments.

The plankton form part of the materials suspended in the waters of the Bays. Non-living organic matter and inorganic minerals comprise the bulk of suspended matter. Portions of this material serve as a substrate for chemical and biologically mediated chemical reactions, as food for filter feeding organisms, and as contributors to the turbidity of the water column. The concentration of suspended matter varies from 3 ppm - >200 ppm on time scales of hours-years. Highest concentrations are usually observed during extreme events like very high freshwater discharges or high wind events. Gibbs (1988) found changes in suspended matter from 30 ppm to 85 ppm at one station during one afternoon and attributed the change to an increase in wind speed. Gibbs found that organic matter comprised about 30% of the material in suspension in Indian River Bay though, in summer, it could reach 50% of the total. There do not appear to be seasonal trends in the concentration of material in suspension. Rather, wind and freshwater discharge events seem to control suspended matter concentrations. There is a seasonal pattern in turbidity of the waters of the Inland Bays. Both anecdotal and technical observations verify clear waters in the winter and turbid waters in the summer (see, for example Timmons and Price, 1993) even though there are no parallel trends in suspended sediment concentration. This is probably due to the fact that water transparency is related to the size, composition, and concentration of suspended matter, not to concentration alone. The seasonal pattern of turbidity, as illustrated by Secchi disk measurements for southern Rehoboth Bay, is depicted in Figure 2.24. We have also plotted total suspended sediment and chlorophyll concentrations on the illustration. It is apparent that total suspended solids may be high or low when the water is clear, but the water is always turbid when chlorophyll is high during the summer. This pattern was also noted by Lacoutre and Sellner (1988). Associated with the chlorophyll, which may be concentrated in large plankton, are the picoplankton, the smallest individuals, with the largest surface area available for light absorption. The mean size of the phytoplankton of the Bays is about 10 µm, while the picoplankton are about 1µm. Spheres 1µm in diameter have 100 times the surface area of the same mass of 10µm particles. However, as calculated by Geider (personal communication), the quantity of chlorophyll observed in the Inland Bays is usually insufficient to account for more than 20% of the observed turbidity, even in summer. The calculation assumes that scattering within a cell suspension is offset by the "packaging effect" which can cause absorption of a cell suspension to be less than that of dissolved pigments.

In summary, we can say that the maximum annual turbidity of all three systems correlates with the summer chlorophyll maximum, that all three systems are characterized by the presence of large numbers of cyanobacteria (an order of magnitude larger in number than any other class of plankton) during the summer, and that the total concentration of material in suspension is variable and shows no correlation with seasonal turbidity. We suggest that, if management of turbidity is important to achieve ecological or recreational objectives, then further investigation of the causes of Inland Bays turbidity is warranted. Important local high turbidity may be induced by the turbulence caused by boat traffic, especially in high use and otherwise protected areas (Wright and Wagner, 1991).

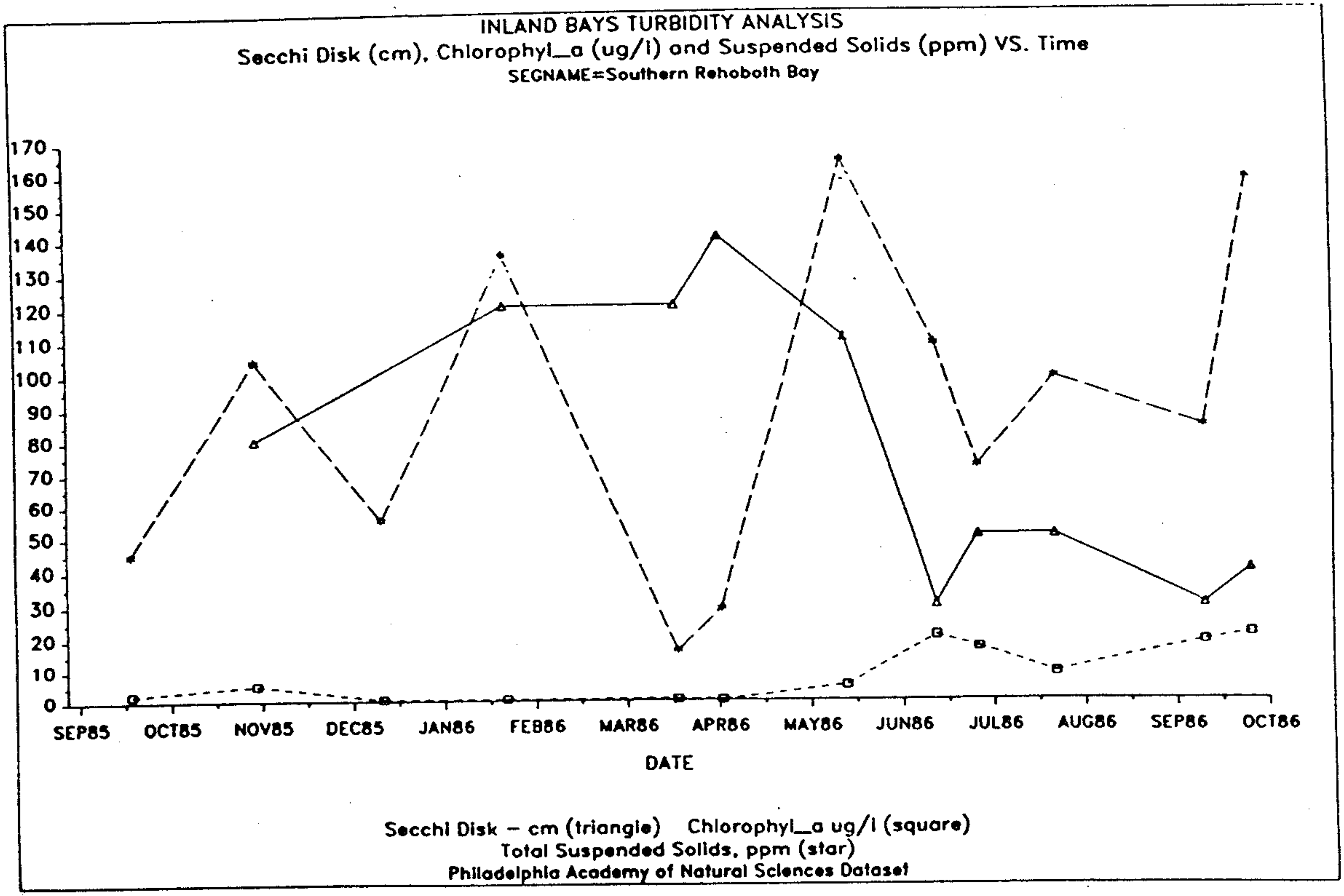

Fig. 2.24 Seasonal Turbidity in Southern Rehoboth Bay

2.9 TOXIC SUBSTANCES

As indicated in Sec. 2.2.4, there are insufficient data to characterize the importance of toxics in the Inland Bays. Some feeling for agricultural and industrial toxic inputs are summarized. Agricultural activities can contribute toxic substances to the bays. In Table 2.2, we have modified NOAA (1992) data for pesticides that are applied to cropland around the Inland Bays. Each year, a total of 130,000 pounds of various pesticides are applied to the watersheds. Although we don't know the specific trends for the Inland Bays, in the five years between 1982-87, pesticide use declined by 14% nationwide due principally to land set-asides and the introduction of new low application rate formulations (NOAA, 1992). We don't know the concentration of pesticides in the bay waters, sediments, or biota. We do know that the Inland Bays have a moderate Pesticide Hazard Ranking as do Chincoteague and Barnegat Bays.

Major trace metal sources by industrial activities around the Inland Bays are probably limited to the Delmarva Power and Light Power Plant on middle Indian River. O'Shea (1980) has measured the distribution of lead, zinc, and cadmium in marsh deposits near the coal fired power plant and contrasted them with marsh sediments from a control site. Although the Pb and Zn concentrations increase dramatically from older to younger marsh sediments, they do not exceed either the naturally enriched background concentrations found in the control site or in the nearby Nanticoke watershed.

Most inorganic and organic pollutants are sequestered in fine sediments and, if these are problems in the Inland Bays, they should be manifest in fine sediments, described in detail in Sec. 3.3.

Table 2.2 : Herbicide, Insecticide, and Fungicide Application to Delaware Inland Bays Watersheds
NOAA (1992)

Ranking	Pesticide Top Ten Hazard Ranking[1]	Pounds per year	Ranking	Top Ten Applications[2]	Pounds per year
1	Endosulfan	tr*	1	Alachlor	41,667
2	Phorate	434	2	Atrizine	21,831
3	Permethrin	1,464	3	Metalachlor	20,063
4	Fenvalerate	148	4	Linuron	11,507
5	Chlorpyrifos	1,029	5	Carbofuran	7,165
6	Parathion	tr*	6	Cyanazine	6,356
7	Profenofos	0	7	Terbufos	3,382
8	Terbufos	3,382	8	Butylate	3,034
9	Trifluralin	1,655	9	Trifluralin	1,655
10	Carbofuran	7,165	10	Permethathin	1,464

* tr = trace (less than 100 pounds/year)

1 The hazard ranking incorporates data on fish toxicity, bioconcentration factor (for fish), and soil half-life.

2 Application is computed from a list of 35 pesticides used on more than 1% of the crop acreage in Delaware, reported in the 1987 Census of Agriculture and verified through the cooperative extension agent. The application rates and crop types were then applied to the Inland Bays drainage area.

2.10 EUTROPHICATION

"...Eutrophic conditions typify the region;...High nutrient concentrations support high phytoplankton biomass;...Bloom forming blue-green algae were common in the (upper) Indian River stations..." (Sellner, 1988). Fish kills, described as massive (Tyler, 1989), occurred in the May-June periods of 1987 and 1988 in Indian River. The kills occurred during red tides, but neither a specific organism (toxic algae) or condition (low oxygen) could be shown to be the cause.

Nutrient concentrations have declined substantially during the last twenty years in some regions of the Inland Bays. Middle Indian River Bay is an example of the change in nitrogen since 1970 (Figure 2.25). The sum of the two curves (Kjeldahl and Ammonia) is a reasonable approximation of total nitrogen because nitrate is almost always less than 0.1 ppm. While Kjeldahl N still exceeds 1 ppm, ammonia N has declined from 2 to 0.2 ppm from 1970 to 1990. In Section 2.7.1 we discussed potential explanations for the decrease in ammonia including analytical problems, source reductions, and process changes. We cannot distinguish among these possibilities. Kjeldahl nitrogen has remained relatively high in upper Indian River, yet there appears to be a decrease by a factor of two in Kjeldahl nitrogen in mid Indian River Bay. This decrease in nitrogen is coincident in magnitude and direction with a doubling of the tidal prism during the same time period and strongly suggests that dilution of the mesohaline and polyhaline waters of the Inland Bays with ocean water is a major cause of nutrient concentration reduction. Lacoutre and Sellner (1988) observed a statistical decrease in chlorophyll concentrations in these same areas at the same time, while not detecting measurable chlorophyll changes in upper Indian River. Beasley (1987) noted a decrease in nutrient favoring diatoms in the top of her core from central Rehoboth Bay. We conclude that improved water quality (N and chlorophyll) for the polyhaline and mesohaline areas of the Inland Bays has resulted from the increased flushing of these areas.

The balance between nutrient concentrations and estuarine resources has been developed in the Chesapeake and is generally applicable to the Inland Bays (Table 2.3-A). The attainment of certain water quality criteria do not necessarily ensure that environmental or resource objectives will be achieved. Inferior water quality will not support certain resources, but other environmental factors may prevent resource recovery even if water quality is improved. With the afore-mentioned caveats in mind, we have computed the status of nitrogen and phosphorus concentrations for the Bays and have applied the Chesapeake water quality measures (Table 2.3-B). In general, we find that Rehoboth quality is healthy to fair, Assawoman and Indian River quality ranges from degraded to healthy. Further, the upstream two-thirds of Indian River Bay seems to be most degraded, especially because observed nutrient concentrations are exceptionally high for relatively saline portions of estuaries. NOAA (1993) is developing an eutrophication scheme for U.S. coastal waters using N, P, chlorophyll and turbidity, among other parameters. Though NOAA attaches no ecological significance to the rankings, one can see from Table 2.4 that most parameters in the Inland Bays rank as moderate, high or eutrophic and follow a geographic pattern similar to that of the Chesapeake.

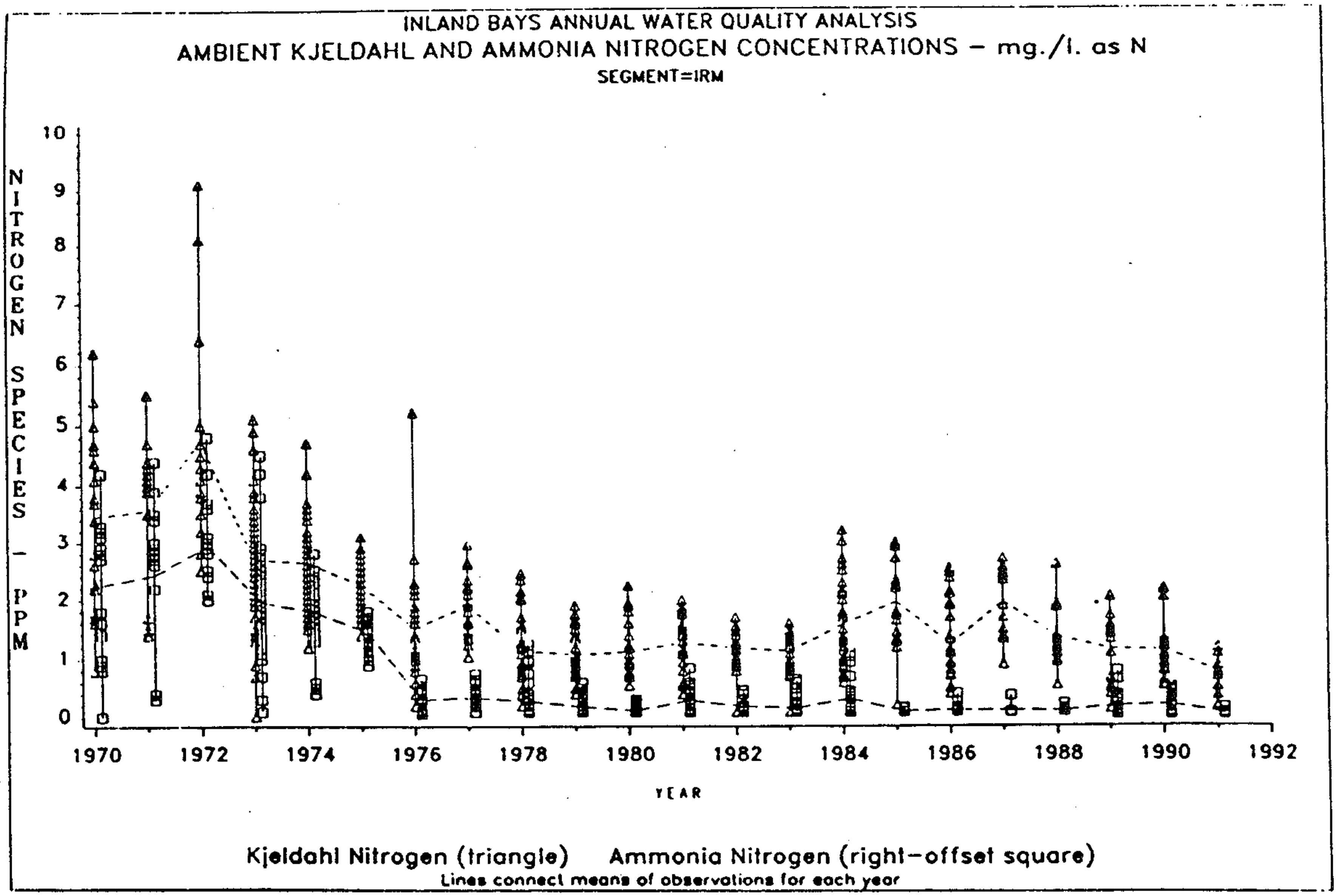

Fig. 2.25 Middle Indian River Bay Nitrogen Concentration

TABLE 2.3-A

Inland Bays Environmental Quality Classification[a] Scheme

Class	Quality	Objectives	TN[b]	TP[b]
A	Healthy	Supports maximum diversity of benthic resources, SAV, and fisheries	<0.6	<0.08
B	Fair	Moderate resource diversity, reduced SAV, chlorophyll occasionally high	0.6-1.0	0.08-0.14
C	Poor	Significant reduction in resource diversity, loss of SAV, occasional algae blooms	1.1-1.8	0.15-0.20
D	Degraded	Limited pollution tolerant resources, massive, persistent blooms	>1.8	>0.20

[a] Based on Chesapeake classification scheme, USEPA, 1983
[b] TN and TP are total nitrogen and total phosphorus per liter

TABLE 2.3-B

Segment	TN[1]	TP[1]	Class[2]	N/P[3]
Rehoboth				
North	0.8	0.08	B	22
Middle	0.9	0.09	B	22
South	0.8	0.07	B-A	25
Masseys	0.7	0.08	B	19
Inlet	0.7	0.07	B-A	22
Assawoman				
North	1.6	0.11	C-B	32
Middle	1.9	0.09	D-B	46
South	1.1	0.06	C-A	40
Indian River				
Fresh	2.8	0.02	D-A	308
Upper	1.8	0.02	C-A	198
Middle	1.6	0.09	C-B	39
Lower	0.6	0.06	B-A	22

[1] Annual mean total nitrogen and phosphorus (mg/L^{-1}) for 1990.
[2] Class from Table 1-A, multiple measures may be used where N and P classes differ.
[3] N/P ratios (atomic) calculated from TN and TP values.

TABLE 2.4

NOAA Estuarine Eutrophication Survey (Draft) 1993

Chlorophyll *a*	**Turbidity**
E > 60 µg/l	H secchi disk < 1m
H > 20 but ≤ 60 µg/l	M secchi disk ≥ 1 but ≤ 3m
M > 5 but ≤ 20 µg/l	L secchi disk > 3m
L > 0 but ≤ 5 µg/l	N/A Not available
TN	**TP**
H ≥ 1 mg/l	H ≥ 0.1 mg/l
M ≥ 0.1 but < 1 mg/l	M ≥ 0.01 but < 0.1 mg/l
L ≥ 0 but < 0.1 mg/l	L ≥ 0 but < 0.01 mg/l

	Chl	**Turbidity**	**TN**	**TP**
Rehoboth				
North	M	M	M	M
Middle	M	M	M	M
South	M	M	M	M
Masseys	M	NA	M	M
Inlet	NA	NA	M	M
Assawoman				
North	H	H	H	H
Middle	M	H	H	M
South	M	H	H	M
Indian River				
Fresh	NA	NA	H	M
Upper	E	E	H	M
Middle	E	E	H	M
Lower	M	M	M	M

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To assist managers to control or restore water quality in the Inland Bays, we have examined nitrogen and phosphorus concentrations to determine which might be the limiting nutrient, that is, the one by which phytoplankton growth is constrained. There are three methods for estimating whether nitrogen or phosphorus is limiting, the use of half-saturation constants, N/P ratios, and nutrient additions. Half-saturation constants were estimated for the Inland Bays by Lacoutre and Sellner (1986). They found that every measurement (136) that they made indicted that phosphorus was limiting. They and we used N/P ratios to estimate the limiting nutrient for the Inland Bays. Lacoutre and Sellner found that phosphorus was limiting almost all of the time during 1985-86. In Table 2.3-B, we have estimated the N/P ratio for all samples (103) in the database for 1990. For the mean values for all Inland Bays segments, the ratios exceed 20, an indication of phosphorus limitation. Recently, Ullman and Geider (personnel communication) have conducted nutrient enrichment experiments on phytoplankton populations in Rehoboth and Indian River Bays. They found that phosphorus was limiting in Indian River at the Delmarva Power Station, that nitrogen and phosphorus were co-limiting in eastern Indian River Bay and that although nitrogen and phosphorus were co-limiting in Rehoboth Bay, nitrogen was more limiting.

The sources of nutrients to the Inland Bays have been estimated by Ritter (1986) (Table 2.5). For Indian River and Assawoman Bays, the principal source of both nitrogen and phosphorus is agriculture through the application of inorganic fertilizers and manures. These practices, applied to the sandy, permeable soils of the watershed, have resulted in widespread contamination of the unconfined aquifer by nitrates. For Rehoboth, agriculture is the principal source for nitrogen but point sources are the major source of phosphorus, almost all of which originates from the Rehoboth Wastewater Treatment Plant.

The nitrates are transported to the Bays by way of groundwater discharge directly to the Bays, baseflow discharge to streams and direct runoff. Over 20% of the nitrates appear to be transported through direct groundwater discharge, though there is a question of whether the nitrates are converted to nitrogen gas as they pass through the bottom sediments of the Bays. Phosphorus, also applied as a fertilizer and manure, is fairly insoluble in fresh water and generally attaches to particles. The phosphorus concentration in both fresh waters and estuaries seems to be fairly constant and controlled by a buffering mechanism, that is, the dissolved phosphorus is maintained at concentrations around 0.04 ppm by solution from particles or adsorption onto particles (Aston, 1980). Adsorption onto particles is at a maximum in the pH range of 3-7, so that phosphate removal is maximized in fresh and brackish waters. The general behavioral differences in the transport mechanism for nitrogen (primarily dissolved and non-point source) and for phosphorus (generally particulate or point source) lead to potential strategies for control. <u>Inland Bays managers should examine strategies that keep soils and sediments on the land and remove as much phosphorus as possible from point sources, thus reducing, in the short term, the phosphorus input to the Bays. For nitrogen, an aggressive plan to control manure and fertilizer application is needed</u>. A note of caution is warranted; the Chesapeake Program adopted a strategy to reduce nitrogen and phosphorus loads by 40% in a decade. While they are on schedule for phosphorus control, nitrogen loads have increased slightly, in spite of significant efforts at reduction. Recently, Houlahan et al., (1992) estimated the impact of Maryland's

TABLE 2.5

Annual Nitrogen and Phosphorus Loadings to the Inland Bays During a Normal Rainfall Year

Nutrient Sources	Indian River Bay Nitrogen	Indian River Bay Phosphorus	Rehoboth Bay Nitrogen	Rehoboth Bay Phosphorus	Little Assawoman Bay Nitrogen	Little Assawoman Bay Phosphorus
Boating	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
Forest	11.0%	19.2%	7.4%	9.4%	6.7%	19.5%
Rainfall	6.2%	8.6%	8.8%	6.9%	12.8%	11.5%
Septic Tanks	16.0%	9.3%	11.2%	3.8%	14.6%	5.6%
Urban	9.8%	8.6%	11.7%	5.9%	11.2%	10.8%
Point Sources	12.5%	15.0%	27.3%	56.9%	0%	0%
Agriculture	44.6%	39.4%	33.0%	17.0%	54.7%	52.6%
Total Mass[1] Metric tons	843	38	457	36	125	8
Direct Groundwater Discharge[2]	250	NA	46	NA	NA	NA

[1] Data from Ritter (1986)
[2] Data from Andres (NA - not available)

Critical Area Act on nutrient delivery to a tributary of the Chesapeake. The authors found that present nonpoint nutrient and sediment loadings could be reduced by 20-30%, through implementation of the Act, while preserving agricultural lands and allowing limited residential and urban development. Perhaps, there has been insufficient time for the benefits of the Act to be reflected in Bay-Wide loadings.

2.11 CONCLUSIONS

The combination of the dredging of the Indian River channel and the increased tidal flushing resulting from inlet scouring has probably greatly increased the longitudinal extent of salinity intrusion in that estuary. It is likely that some unknown extent of the upper Indian River system that used to be tidal and predominately limnetic during the spring, say 30 years ago, is now predominately oligohaline during the spring.

The Inland Bays are, overall, eutrophic. For example, the characterization efforts in the Chesapeake Bay yielded a classification system for Bay waters based upon total nitrogen and total phosphorous concentrations. The Inland Bays combination of ambient total nitrogen concentrations generally in excess 1 ppm and total phosphorous concentrations generally in the range of 0.1 and 0.2 ppm would rank the Inland Bays among the most enriched of the 32 sub-estuarine systems in the Chesapeake Bay rankings. Based upon that ranking system, the middle and upper segments of the Indian River estuary are more enriched than any segment of the Chesapeake Bay listed in that analysis.

The total nitrogen concentrations in most segments of the Inland Bays are in excess of the concentrations that were found by Chesapeake characterization investigators to correlate with low survival potential for submerged aquatic vegetation.

Significant increases in tidal flushing rates over the past 20 years may have mediated the progression of advancing eutrophic conditions, especially in the lower, higher salinity reaches of the system.

Although the narrow, tidal reach of the Indian River above the confluence with Pepper Creek may be much less eutrophic than it was 20 to 30 years ago, we have no direct, uncontested, scientific evidence to support that supposition. We do have anecdotal evidence that the area is visibly less turbid and "green" now than it was then. We do know that some upstream point sources of nitrogen in the Georgetown area have been eliminated. We also know that there has been no significant reduction in nitrogen discharged in wastewater in the upper Indian River since Jensen's 1976 inventory, although the major source, one industrial discharger, now spray irrigates along lower Swan Creek and no longer discharges directly to surface waters. It is not clear the degree to which that discharge removes nitrogen nor how much of the nitrogen reaches tidal water through shallow alluvial aquifer transport. However, we suspect that agricultural and urban nonpoint loadings have maintained both the mass of nutrients entering the tidal waters from surface and ground water and the concentration of nutrients in stream baseflows.

It is clear that the IRU and IRM segments appear to be the most eutrophic reaches in the Inland Bays. We suspect that a significant reduction in nutrient inputs to these reaches will be required to effect a source-derived change in trophic status of the downstream segments.

DELAWARE'S INLAND BAYS

SECTION 3

HABITAT MODIFICATION AND LOSS STATUS AND TRENDS

SECTION 3
DELAWARE'S INLAND BAYS
HABITAT MODIFICATION AND LOSS:
STATUS AND TRENDS

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SECTION 3

DELAWARE'S INLAND BAYS HABITAT MODIFICATION AND LOSS: STATUS AND TRENDS

3.0 INTRODUCTION

Delaware's Inland Bays and adjacent areas within their drainage basins consist of a variety of natural environments and habitats. The waters of the bays and their tributary streams, the tidal and freshwater wetlands surrounding the bays, the littoral zones (shorelines), and the subtidal environments support a variety of flora and fauna, including phytoplankton, zooplankton, macroflora, benthos, shellfish, finfish, waterfowl, and other wildlife. The natural environments of the Inland Bays vicinity are also important with regard to the recreational amenities offered to residents and visitors.

Natural evolutionary changes in Delaware's Inland Bays environments and habitats have occurred in response to sea-level rise, storm events, shoreline erosion, sedimentation, inlet dynamics, and other natural processes. Human alterations, such as dredging, filling, placement of artificial shoreline structures, channelization/ditching, and inlet stabilization have also contributed to habitat loss and modification. The resultant changes include wetlands loss and degradation; coastal erosion; intertidal and subtidal habitat loss; and changes in salinity within their bays and their tributary streams due primarily to natural changes and artificial stabilization of Indian River Inlet. The effects of temperature changes and the addition of heated water discharge from the Indian River power generating station have been described in Section 2 (Water Quality).

3.0.1. Delaware's Inland Bays Habitats: Database Analysis

The objective of the Inland Bays characterization study is to compile existing available scientific data about the Inland Bays Habitats to provide a scientific description of the bays; to help define natural processes and human-induced causes of alterations; and to identify, where possible, trends and rates of environmental change. It must be recognized that there is a complex interrelationship among habitat, water quality, and living resources. Emphasis in this section is on characterizing the physical aspects of the habitats and associated environments. The waters of the bays and associated tidal streams are described in the "Water Quality" chapter of this report. The flora and fauna inhabiting these environments are described in detail in the "Living Resources" chapter of this report (Chapter 4).

Data sources on Delaware's Inland Bays were identified in the "1990 Annotated Bibliography for Delaware's Inland Bays" (Maurmeyer and Carey, 1990), and in "A Preliminary Research Master Plan for Delaware's Inland Bays" (Maurmeyer and Carey, 1986). These annotated bibliographies present a reference collection of a total of over 350 scientific and technical reports, as well as other relevant non-technical publications, on Delaware's Inland Bays. Key references from the both of the annotated bibliographies were identified and compiled into a Habitat Loss/Modification database, from which the information presented in this section was obtained. Nearly seventy published references were included in this database, covering general aspects of habitat characterization; wetlands; shorelines; sediments (subtidal habitats); and historical modifications (including stabilization of Indian River Inlet). Supplemental reference materials (including aerial photographs, U.S.G.S. topographic quadrangles, N.O.A.A. charts, bathymetric surveys, and wetlands maps) were also examined to provide quantitative and qualitative information for those areas where data gaps existed. Additional supplemental information was provided through discussions with investigators conducting ongoing research projects. Recent publications (1991 and 1992) and draft reports were included to provide current information. Anecdotal information, when available, was included to provide public perceptions of historic conditions of Inland Bays habitats and environments. The integration of all of these sources of information provides a characterization of the present status of Delaware's Inland Bays habitats, and an indication of the historic trends in habitat modification and loss. Chapter 5 presents a synthesis integrating changes in water quality, habitat, and living resources.

3.0.2. Organization of the Habitat Loss/Modification Characterization

The Habitat Loss/Modification section presents a characterization of the status and trends of the following Inland Bays environments and habitats:

- Tidal (coastal) Wetlands
- Freshwater (non-tidal) Wetlands
- Littoral (shoreline) Environments
- Subtidal Habitats (Bottom Sediments)
- Indian River Inlet

For each habitat/environment, a summary of relevant background information and previous studies is presented from which the characterization is drawn. The most recent available data are utilized to characterize the current status of each habitat. This chapter focuses primarily on the physical characteristics of the habitats; a detailed characterization (status and trends) of the living resources within these habitats is presented in the following chapter.