Delaware Estuary Salinity Intrusion Study

US Army Corps of Engineers
Philadelphia District

Water Resources Investigation

December 1982

DELAWARE ESTUARY
SALINITY INTRUSION STUDY

WATER RESOURCES
INVESTIGATION

DEPARTMENT OF THE ARMY
Philadelphia District, Corps of Engineers
December 1982

DELAWARE ESTUARY

SALINITY INTRUSION STUDY

WATER RESOURCES INVESTIGATION

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF TABLES

TABLE OF CONTENTS (CONT'D)

LIST OF FIGURES

DELAWARE ESTUARY
SALINITY INTRUSION STUDY

THE STUDY AND REPORT

BACKGROUND

Salinity in the Delaware estuary has been a topic of discussion among industrial and municipal system water users, as well as conservationists, for many years. During the drought of the 1960's, particularly in 1965 and 1966, the discussions took on a very serious tone as the increasing salinity forced industries to close and municipalities to prepare emergency plans for rationing and obtaining alternate sources. As the drought ended, the Delaware River Basin Commission (DRBC) urged studies to define the relationship between river flow and salinity.

In the 1970's, DRBC engaged the services of Drs. M.L. Thatcher and D.R.F. Harleman to develop a numerical model for predicting salinity intrusion in the estuary for unsteady flow conditions.

A report entitled, "<u>A Comprehensive Study of the Tocks Island Lake Project and Alternatives</u>" was completed by the Corps in June 1975. The purpose of that report was to provide background to the Delaware River Basin States so that they could recommend to Congress whether the Tocks Island Lake Project should proceed to construction, be modified, be deferred, or be deauthorized. That project has not proceeded to construction. The report identified the most significant water supply need in the Delaware River Basin as maintenance of the river flow necessary to prevent serious salinity intrusion in the estuary.

During the mid-1970's, the DRBC held several meetings with water users and members of the Water Resources Association of the Delaware River Basin. These meetings led to a questionnaire from the Basin Commission to the industrial users dealing with water withdrawal, use, costs, etc. Also, during this period, the DRBC enlisted the services of various Federal agencies to address salinity-related matters. The Congressional Resolution for this study (included in Appendix 4) represented a part of this effort.

In October 1976, the DRBC stated the need for a salinity study in a letter to the Division Engineer for the North Atlantic Division (also included in Appendix 4). The letter emphasized that salinity intrusion was the Commissioners' highest priority issue and pointed out that the Basin States had committed funds to support a salinity study as proposed by the DRBC.

In the following months, the DRBC provided funds for the purpose of improving the Thatcher-Harleman numerical model. This effort produced a model with an improved ability to treat both point and non-point sources of flow and salinity, a new plotting routine, and several other improvements. (Appendix 1 presents a detailed discussion of this model).

The Corps study was initiated in December 1977. (A sample copy of the initiation letter is shown in Appendix 4).

In a letter dated 27 January 1978 (included in Appendix 4), the DRBC further refined its position regarding salinity intrusion. The letter stated that DRBC had two primary objectives: a) to establish the relationship between freshwater flows and the concentration of sea salts in the estuary; and b) to determine the benefits of controlling salinity or the costs entailed in permitting salinity intrusion. DRBC indicated that the first objective could be met by their numerical modeling efforts, in concert with studies underway by the Corps as part of a program to provide technical assistance to individual States (Section 22, P.L. 93-251), and DRBC's Level B Study.

However, DRBC felt that an answer to the economic objective was vitally needed and hoped that efforts by the Corps' Delaware Estuary Salinity Intrusion Study could be directed toward this end. Efforts made during the early part of Stage 2 were able to satisfy this request.

PURPOSE AND AUTHORITY

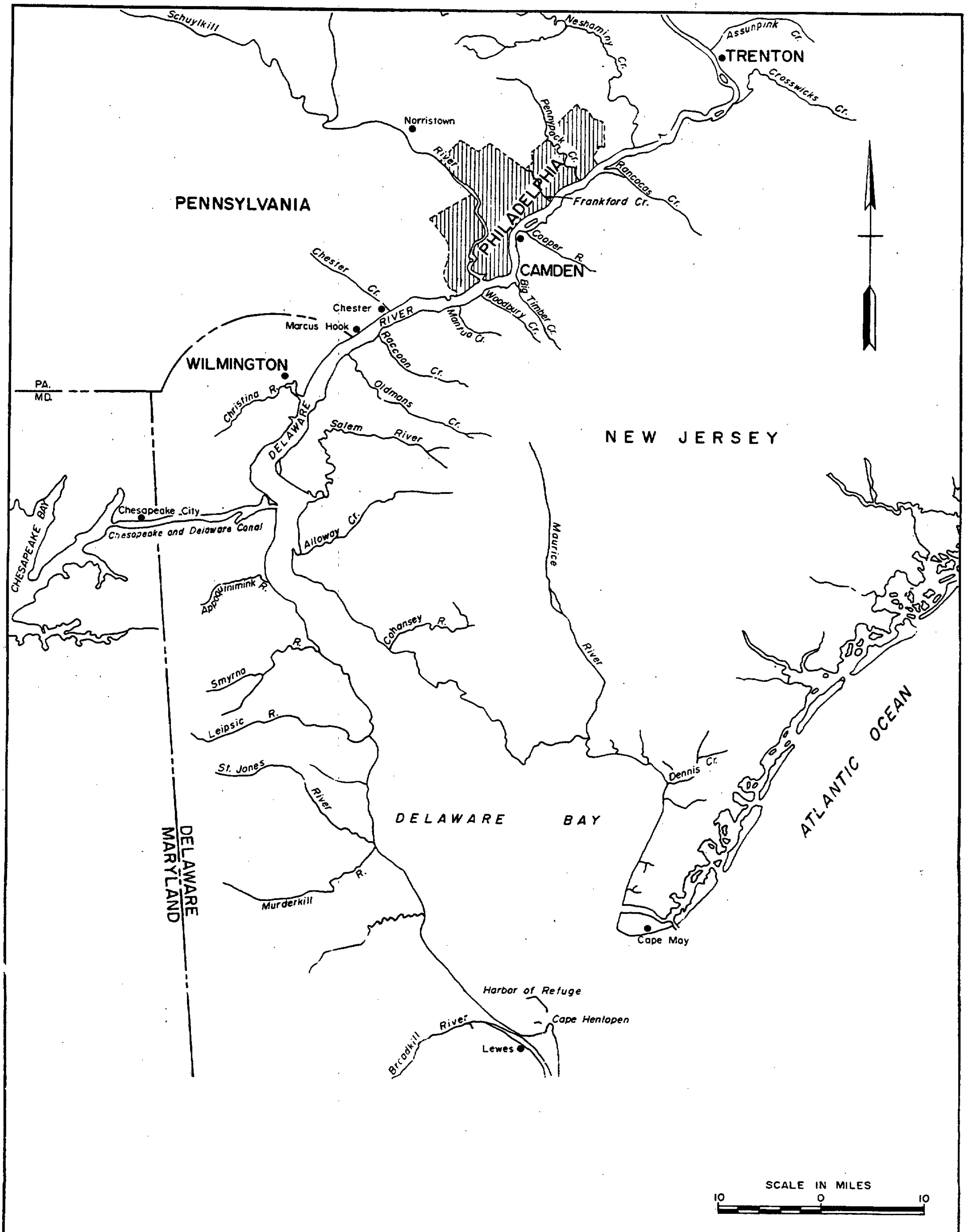
The Delaware Estuary Salinity Intrusion Study was authorized in a resolution adopted by the House Committee on Public Works and Transportation on 23 September 1976. A copy of the resolution is included in Appendix 4. The resolution directs the study to determine the probability for advance or retreat of salinity in the Delaware estuary and the quantity of freshwater inflow needed to protect the various water users in the estuary.

STUDY AREA

The study area (Figure 1) encompasses the Delaware River estuary, which extends from the mouth of the Delaware Bay at Cape Henlopen, Delaware, upstream past Philadelphia to Trenton, New Jersey. The Delaware estuary is bordered by Pennsylvania and Delaware on the western shore and by New Jersey on the eastern shore.

STREAM LOCATION AND IDENTIFICATION SYSTEM

This report adopted the DRBC stream location and identification system, which is based on distance from the Capes (Figure 2). This system considers

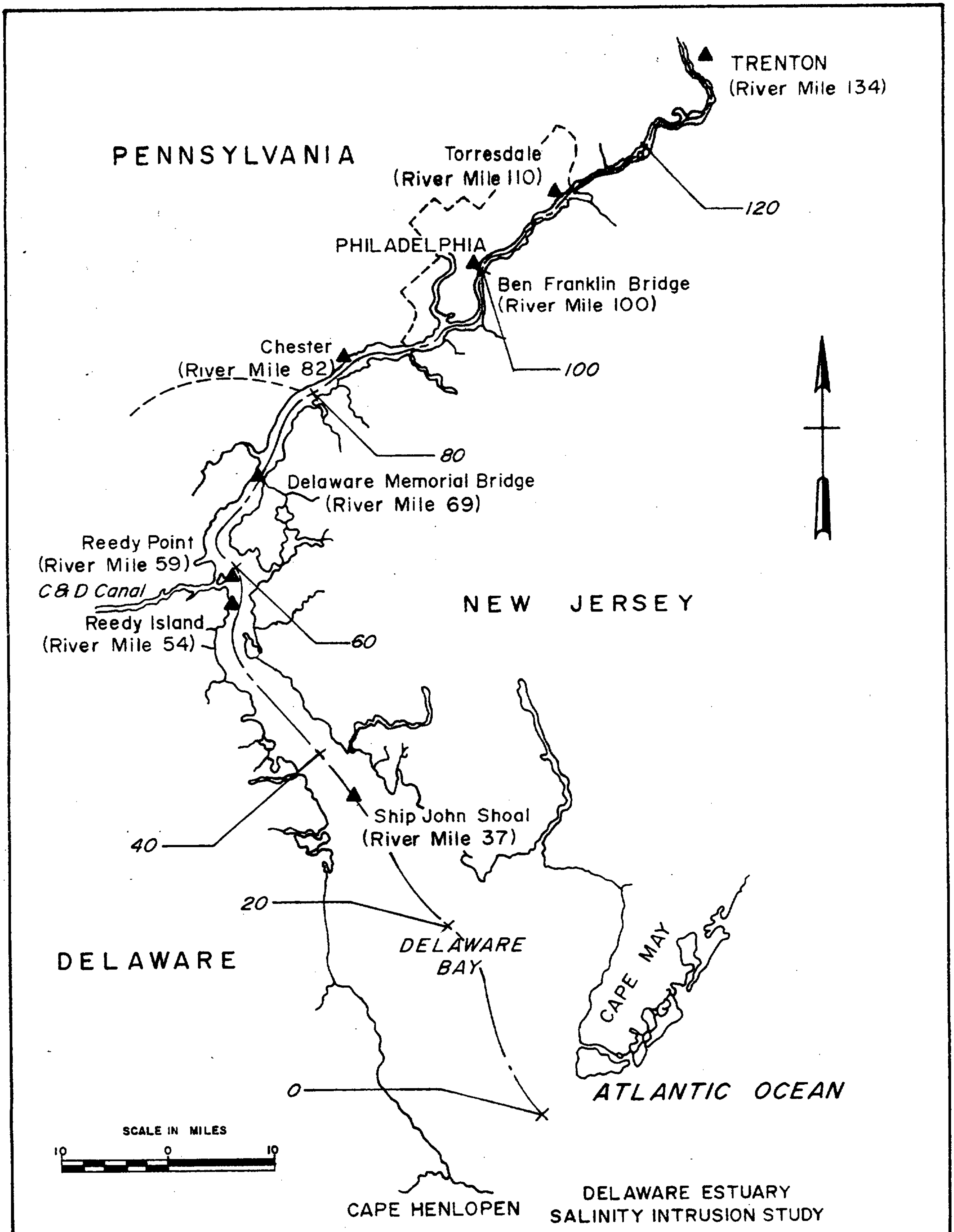


DELAWARE ESTUARY
SALINITY INTRUSION STUDY

STUDY AREA

PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 1



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
RIVER MILEAGE SYSTEM
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2

the mouth of Delaware Bay to be mile zero, and locations are identified by their distances in statute miles measured upstream along the centerline of the navigation channel.

GOALS AND OBJECTIVES

In responding to the Congressional Resolution directing the salinity study, the specific goals of the study are to determine:

A. the probability for advance or retreat of salinity in the Delaware estuary.

B. the quantity of freshwater inflow needed to protect the various water users along the estuary.

In satisfying these goals the following specific objectives were identified.

GOAL "A" (PROBABILITY)

a. determine economic impacts to direct industrial and municipal system water users of the Delaware estuary.

b. determine the impact of the Chesapeake and Delaware Canal in terms of flow and salinity.

c. determine salinity impacts on estuarine fish and wildlife resources.

d. develop probabilities of various salinity levels in the estuary.

GOAL "B" (QUANTITY OF FLOW)

e. determine the quantity of flow necessary to protect water users of the estuary.

f. development of a basin plan under drought and normal hydrologic conditions.

STUDY PARTICIPANTS AND COORDINATION

The Corps of Engineers, Philadelphia District, was responsible for conducting and coordinating the study. During the study, the Corps worked closely with representatives of the DRBC and the U.S. Fish and Wildlife Service. A more detailed discussion is presented in Appendix 4.

REPORT FORMAT

The results of the study are presented in five parts: the main report and four appendices. The main report is a non-technical document, which presents an overview of the study and its findings. Appendix 1 documents the hydraulic and economic studies in greater detail. Appendix 2 discusses the derivation of the the salinity-cost relationships for withdrawal users. Appendix 3 contains the environmental studies, and Appendix 4 contains pertinent correspondence relating to the study.

PRIOR AND CURRENT STUDIES

DELAWARE ESTUARY STUDIES

• DELAWARE ESTUARY COMPREHENSIVE STUDY. In July 1966, the Department of Interior's Federal Water Pollution Control Administration (forerunner of the EPA) published the Delaware Estuary Comprehensive Study. The study provided a comprehensive analysis of the pollution problems in the Delaware estuary, including identification, sources, possible solutions, and cost estimates for abatement measures. The study covered economics, water quality, water uses, goals, programs, and costs to improve quality, institutional arrangements, and delineation of further possible areas of study to effectively analyze the problem.

• STRANDBERG STUDY. The DRBC has sponsored many studies of the estuary. Of special note is <u>Control of Salinity Intrusion in the Delaware Estuary</u>, by William Strandberg, published in January 1975. Its purpose was to evaluate and comment on DRBC policies and salinity control measures. The report covered the following topics: the drought of the 1960's, Supreme Court's actions, conclusions drawn from model analyses, effects of flow regulation, and a survey of the policy and plans of major withdrawal users. The report recommended that additional studies in flow controls, flow-salinity relationship, well-monitoring, well-yield, and economic effects of salinity intrusion on all principal water users be conducted.

• THATCHER AND HARLEMAN STUDY. During the seventies the Delaware River Basin Commission contracted with Drs. M.L. Thatcher and D.R.F. Harleman to perform numerical model analyses on the flow-salinity relationship. This analysis was further modified and improved in a study titled, "<u>Development and Application of a Deterministic Time - Varying Salinity Intrusion Model for the Delaware Estuary</u>" by M. Llewellyn Thatcher and Donald R. F. Harleman (May 1978). The report treated many topics, including: discussion of the original salinity intrusion model developed in 1972, and its application to the Delaware estuary; model additions and modifications, calibration, and simulation studies performed with the modified model.

The modified model, identified as MIT-TSIM by its developers, is able to account for the salinity effects of many variables, including freshwater inputs from the Delaware River at Trenton, NJ, and estuary tributaries, water withdrawals and depletive use (including diversions), the impact of sea level rise, and reservoir regulation. The model can predict the incremental effect of changes in one or more of the variables on salinity at any location along the axis of the estuary from Trenton to the sea. This model served as the principal tool for the Commission's efforts to learn the relationship between flow and salinity.

CHESAPEAKE AND DELAWARE CANAL STUDIES

• 1938, CORPS OF ENGINEERS STUDY. In 1938, Philadelphia District, Corps of Engineers, conducted a study of flow in the then recently enlarged 27 foot deep, 250 foot wide canal. Tides and currents were measured over a period of 10 tidal cycles. Analysis of these data indicated that during the period of observation there was a net non-tidal eastward flow of approximately 1,000 cubic feet per second (cfs).

• WATERWAYS EXPERIMENT STATION STUDY. The Waterways Experiment Station Corps of Engineers, prepared a report entitled, "Enlargement of the Chesapeake and Delaware Canal" by M.B. Boyd et al., in October 1973. The study conducted physical and mathematical model tests to determine the effects of enlarging the canal on tides, currents, salinities, and net transport of water through the canal. The study concluded that the net water transported through the canal was greater than previously anticipated and recommended that after completion of the canal enlargement, measurements of tides, current, and salinity be made in the field for comparison with model predictions.

• PRITCHARD AND GARDNER STUDY. Pritchard and Gardner investigated the effect of canal enlargement on the transport of water within the canal and the salinity distribution in the canal and adjacent areas of the Chesapeake Bay and Delaware River. The study was entitled, "Hydrology of the Chesapeake and Delaware Canal", Technical Report No. 85, Chesapeake Bay Institute, John Hopkins University, February 1974. This study produced the first set of intensive prototype salinity data over the length of the canal. In July 1974, these investigations developed a one-dimensional non-linear numerical model that calculated instantaneous net transport in the canal from tide data. This is further documented in a report entitled, "Verification and Use of a Numerical Model of the Chesapeake and Delaware Canal", Technical Report 87, Chesapeake Bay Institute. Statistical analysis of the long term current and tidal data observed in the canal between 1969 and 1972 indicated a net non-tidal flow from the Chesapeake to the Delaware approximately 59 percent of the time.

• RIVES AND PRITCHARD STUDY. A study by Rives and Pritchard entitled, "Adaption of J.R. Hunter's One-Dimensional Model to the Chesapeake and Delaware Canal System", Special Report 66, 1978, extended the canal modeling work of Pritchard and Gardner. J.R. Hunter's Special Report 47, Chesapeake Bay Institute, John Hopkins University, 1975, presented a one-dimensional kinematic and dynamic mathematical model. This model was also adapted to the Chesapeake and Delaware Canal. It was calibrated and verified using current velocity measurements taken during April and May 1975, and a tracer dye study conducted during 1-8 May 1975. Using J.R. Hunter's model, flows were calculated using a time series of observed water-surface gradients between Town Point, MD,and Reedy Point, DE, at the western and eastern ends of the canal, respectively. For this period, the computed non-tidal flow in the canal was westerly. Since previous investigations indicated an easterly flow, this observation was of great importance as it illustrated that for significant time periods, the net flow could show an opposite directional movement.

• NAJARIAN, THATCHER, AND HARLEMAN STUDY. Thatcher and Harleman expanded their previously discussed study dealing with the impacts of the Chesapeake and Delaware Canal. Subsequently, they teamed with Dr. Tavit O. Najarian in a report entitled, "Effects of the Chesapeake and Delaware Canal on Salinity in the Delaware Estuary", November 1978. This report concluded that non-tidal flow through the canal could have a marked effect on salinity in the Delaware estuary, especially in its middle reaches. The researchers recommended long-term observations both in the canal and the Delaware estuary to assess accurately the "real-time" effects of the canal on the estuary.

DELAWARE RIVER BASIN STUDIES

• HISTORICAL FLOW SIMULATION. Under authorization of Section 22, P.L. 93-251, and Section 214, P.L. 89-298 (which provide funds to the Corps of Engineers for technical assistance to individual States), and upon the request of the Pennsylvania Department of Environmental Resources and the New York Department of Environmental Conservation, the Philadelphia District, Corps of Engineers, in coordination with DRBC, developed a historical daily flow simulation model of the Delaware River Basin from the headwaters to the Delaware Memorial Bridge for a base period of 50 years (1928-1977). The work was conducted in two phases. Phase one involved the development of the average daily flows in the basin for two conditions: (1) natural flows without the effect of existing impoundments and (2) flows with operation of the New York reservoirs (Pepacton, Cannonsville, and Neversink). The daily flow values were analyzed using the United States Geological Survey probability model, which yields the frequency of flow as an output. In Phase two, the daily flow simulation model was used to determine the capabilities of various combinations of existing and proposed reservoirs to meet a sustained flow level at specified downstream locations.

• LEVEL B STUDY. A basinwide comprehensive study of the water and land resources needs of the Delaware River Basin was conducted by the DRBC. The study, a Level B type as defined by the Water Resources Council (WRC), was performed under the authority of Section 209, P.L. 92-500, and Section 105 (a)(7), P.L. 89-80, as amended.

The major purpose of the Level B Study was to provide a basis for the reformulation and updating of the DRBC's Comprehensive Plan. The study was completed in May 1981. It considered various components including water supply, water quality, flow maintenance, flood loss reduction, fish and wildlife, water-based recreation, energy, and navigation needs. It represented a cooperative effort with financing and technical inputs contributed by various Federal and State agencies. Alternative plans to resolve the various concerns were identified. A "Preferred Plan" that balanced the objectives of environmental quality and national economic development was recommended. This plan represented the preferred mix of policies, programs, and projects. Also, an Environmental Impact Statement was prepared for the plan. Concerning sustainable flows in the Delaware River, the Preferred Plan recommended flows of not less than 3,072 cfs and 1,750 cfs be maintained at Trenton, New Jersey, and Montague, New Jersey, respectively, during normal hydrologic conditions. The report has been accepted as completed by the Commissioners of DRBC and by WRC. (A letter from WRC is shown in Appendix 4).

RESOURCES AND ECONOMY OF THE STUDY AREA

NATURAL RESOURCES

CLIMATOLOGY

The study area lies within one broad climatic zone, which is considered subtropical, with hot summers, mild winters, and regular rainfall. Summer weather patterns are influenced by maritime tropical air masses, (in which high pressure systems dominate and remain stable for several days at a time). Weather systems in the winter are generally more intense because of rapidly moving fronts and continental polar air masses. Airmasses change frequently in the spring and fall. Mean annual temperatures in the estuary are 55-58 degrees F.

Precipitation, about 44 inches annually, is well distributed throughout the year, with generally more than three inches reported every month. The driest month is October with rainfall varying between 2.5 and 3.0 inches. However, temporary droughts, or periods of subnormal runoff, are not uncommon in the study area.

TOPOGRAPHY AND GEOLOGY

Lands bordering the estuary from Trenton to the mouth are generally flat. Along the lower part of the estuary, the elevation ranges from 5 to 10 feet, about 20 feet at Wilmington, 20 to 30 feet at Philadelphia, and 40 to 50 feet near Trenton, NJ. Slopes near the lower estuary are generally less than 10 percent, while in the upper area, the slopes vary considerably with many steeper grades. The tributaries feeding the estuary below Trenton generally have a flat gradient with few rapids.

Geologically, the Delaware estuary is situated near the border between two subdivisions, the Appalachian Piedmont province and the Atlantic Coastal Plain province. The Piedmont Plateau lies along the eastern edge of the Appalachian Mountains and runs from New Jersey to Alabama. The rocks of the Piedmont are old, hard, and crystalline. They extend downward and toward the Atlantic, forming a platform that supports the Coastal Plain. The rocks of the Coastal Plain are much younger, largely unconsolidated sediments forming a thick wedge. The Coastal Plain layers are composed mainly of clays, sands, and intermediate materials, which slope to the southeast. The sandy layers are valued as aquifers, which are able to supply great quantities of water over extended periods.

Aquifers are porous geologic formations storing or transmitting groundwater in appreciable quantities. Significant aquifers underlying the study area include the Raritan, Cape May, and Pennsauken in Pennsylvania, the Raritan-Magothy, Englishtown, Mount Laurel-Wenonah, and Kirkwood-Cohansey Formation in New Jerse , and the Potomac, Magothy, Monmouth, Rancocas, Frederica, and Cheswold in Delaware.

The Potomac-Raritan-Magothy aquifer is the principal source of public water supplies for southern New Jersey. Aquifer beds of the Potomac-Raritan-Magothy outcrop along the Delaware River and extend northward into Raritan Bay and southward to New Castle County, Delaware. Infiltration from the Delaware River, particularly when salinity levels are high, is a major concern.

PHYSICAL CHARACTERISTICS

The Delaware estuary extends from Trenton, New Jersey, to the mouth of Delaware Bay, a distance of about 134 statute miles. The estuary includes a navigation channel serving the ports of Wilmington, Philadelphia, Camden, and Trenton. It receives freshwater inflow from two major sources (the

Delaware and Schuylkill Rivers) plus numerous small tributaries. It is connected to Chesapeake Bay by the Chesapeake and Delaware Canal.

As is typical of Atlantic Coastal Plain estuaries, tides in the Delaware River estuary are semidurnal. The mean tidal range is from 4.1 feet(ft) at the Bay mouth to 6.8 ft at Trenton, although tidal amplitudes to 13 ft have been reported during periods of extreme flood and ebb conditions. Variation in tidal amplitude occurs in the estuary due to the opposing effects of convergence of the sides of the estuary, (which tends to increase the amplitude) and friction (which tends to decrease it). Variations in water level are also highly dependent on wind speed and direction.

Current speed and direction throughout the Delaware estuary is dominated by tide generating forces, and vary with tidal stage. Non-tidal features such as freshwater runoff, meteorological conditions, and salinity gradients also have an effect on local salinity concentration. Currents are generally directed along the longitudinal axis of the estuary.

The Delaware estuary can be further categorized in salinity gradient ranges as follows:

a. The Delaware River above River Mile (RM) 50 is generally well mixed although a slight difference in salinity sometimes occurs between different depths.

b. The Delaware Bay below RM 30 possesses characteristics of either a well mixed or a partially stratified estuary. In winter and spring, there is a tendency toward stratification, especially in the middle bay. This tendency is not apparent in summer and early autumn.

c. A transition zone between RM 30 and 50 exhibits properties of either partially stratified or a well mixed estuary depending on location, season, and freshwater inflow.

MEASUREMENT AND VARIATION OF SALINITY

One unit of measurement of salinity is milligrams per liter (mg/l), which represents the total weight of dissolved solids in a sample of one liter of water. For mixtures of seawater and freshwater, salinity, which corresponds roughly to total dissolved solids (TDS), can also be expressed as equivalent chlorides. One mg/l of chloride is equivalent to approximately 1.8 mg/l of salinity. TDS is a water quality parameter that is not easily measured in the field. However, Keighton established a relationship between chloride and TDS concentration based on the analysis of data collected in the Delaware estuary. The chlorinity or salinity concentration in coastal waters is routinely measured, as these parameters can easily be monitored through the electrical conductivity of the water samples. In sea-water, the ratio of sodium to chloride is 0.556 to 1.00. In the Delaware estuary, this ratio can be applied with reasonable accuracy even when the total chlorides in the mixture of river and ocean water range as low as 200 mg/l. For example, a chloride concentration of 200 mg/l is equivalent to a sodium concentration of 111 mg/l.

Salinity along the length of the estuary ranges from freshwater less than 100 mg/l in the upper reaches of the tidal river to about 30,000 mg/l at the mouth of the bay.

SURFACE WATER

The surface water resources of the study area include the Delaware estuary and many tributaries. As discussed earlier, the Delaware estuary is connected to the Chesapeake Bay by the Chesapeake and Delaware Canal, which generally results in net interbasin transfer of fresher upper Chesapeake waters into the more saline middle Delaware estuary.

The freshwater inflow to the Delaware estuary is primarily from the drainage area above Trenton. The long-term average annual flow at Trenton was approximately 11,750 cfs for the 68 year period of record from February 1913 to September 1980. The average flows of major gaged tributaries are presented in Table 1.

TABLE 1

MAJOR GAGED TRIBUTARIES

Stream and Station Location	Gaged Drainage Area (square miles)	Period of Record	Average Annual Flow (cfs)
Assunpink Creek (Trenton, NJ)	89.4	1923-80	129
Crosswicks Creek (Extonville, NJ)	83.6	1940-51 1952-80	136
Neshaminy Creek (Langhorne, PA)	210.0	1934-79	291
North Branch Rancocas Creek (Pemberton, NJ)	111.0	1921-80	173
Pennypack Creek (Philadelphia, PA)	49.8	1965-70 1974-79	86
Schuylkill River (Philadelphia, PA)	1,893.0	1931-80	2,962
Chester Creek (Chester, PA)	61.1	1931-79	86
Brandywine Creek (Wilmington, DE)	314.0	1964-79	484
Christina River (Coochs Bridge, DE)	20.5	1943-79	29
White Clay Creek (Newark, DE)	89.1	1931-36 1943-57 1959-79	115
Red Clay Creek (Wooddale, DE)	47.0	1943-79	66

DROUGHT HISTORY

The Delaware River Basin has experienced eight extended periods of drought since 1905. The most severe drought occurred from 1961 to 1966. The list of extended droughts is presented below:

PERIODS OF DROUGHT

Year	Months	Length of Drought
1908	Jun-Dec	7 months
1909	Jul-Dec	6 months
1914	Feb-Dec	11 months
1930-31	Jan 30-Dec 31	24 months
1941-42	Jan 41-Feb 42	14 months
1957	May-Dec	8 months
1961-66	Jun 61-May 66	60 months
1980-1982	June 80-April 82	22 months

Awareness of the impacts of salinity in the Delaware estuary significantly increased during the unprecedented drought of 1961-1966. Low rainfall and aquifer depletion led to record low natural surface flows (defined as total discharge minus reservoir releases) in 1964 and 1965. It is estimated that this drought had a recurrence interval of several hundred years in the upper Basin and about 100 years at the mouth of the Schuylkill River.

Prior to the 1960's the most severe drought was that of 1930-32. The minimum mean monthly runoff at Trenton during the 1930's drought occurred in September 1932 when the flow was 1,762 cfs. This low figure is considered to have been a natural flow since the upstream reservoir system had not yet been constructed at that time. By comparison, the lowest natural average monthly flow during the 1960's drought was 1,106 cfs (September 1964).

The intrusion of record high levels of salinity into the upper reaches of the Delaware estuary during the 1960's drought threatened the municipal withdrawal systems and adversely affected the operations of direct industrial withdrawal users. Production cutbacks and the necessity of switchovers to alternate water sources were reported by the latter.

The Delaware River Basin Commission, established in 1961 just prior to the 1960's drought period, quickly became involved in water management problems. In 1967, the DRBC adopted water quality standards to maintain reasonable levels of salinity throughout the tidal portion of the Delaware River and to protect both withdrawal and instream users. The salinity standards, measured in chlorides, were as follows:

River-Mile(s)	Chloride Standard
133.4 - 108.4	Maximum 15-day average: 50 mg/l
108.4 - 95.4	Maximum instantaneous: 200 mg/l
95.4 - 78.8	Maximum instantaneous: 250 mg/l at river-mile 92.5 (mouth of the Schuylkill River)

For the first time since the record drought of the 1960's, the DRBC declared a water-supply emergency in January 1981. A discussion of measures taken during this drought is presented on page 68.

A comparison of the salt-line (as measured by the 250 mg/l isochlor) for the 1960's and 1980's drought is shown below.

ESTIMATED MAXIMUM LOCATION (IN RIVER MILES*) OF THE 250 mg/l CHLORIDE LINE IN THE DELAWARE RIVER ESTUARY

Month	1964	1965	1980	1981
February	--	--	--	97.5
August	96	95	88	87
September	96	98	93	89
October	100	94	96	91
November	101	-	90	85

* for comparison, the mouth of the Schuylkill River is at river mile 92.5

CURRENT WATER USE

Two categories of surface water withdrawals were identified within the study area: municipal system and direct industrial. A map showing the specific intake locations is included in Appendix 2. The municipal systems withdraw from the estuary or groundwater sources to provide water supply for domestic, industrial, commercial, and institutional use. Direct industrial users withdraw from the estuary or groundwater sources. Based on interviews with the municipal supply systems conducted during both the DRBC Inventory of Water Uses (1978), and the followup survey undertaken during this investigation the following estimates were developed (in millions gallons daily (mgd).

• SURFACE WATER. The following withdrawals (1978 water use) were made by the two categories of users.

(1) Municipal System	mgd	Intake Location (RM)
Philadelphia (Torresdale)	250	110
Bristol	5	119
Lower Bucks	9	122
TOTAL	264	

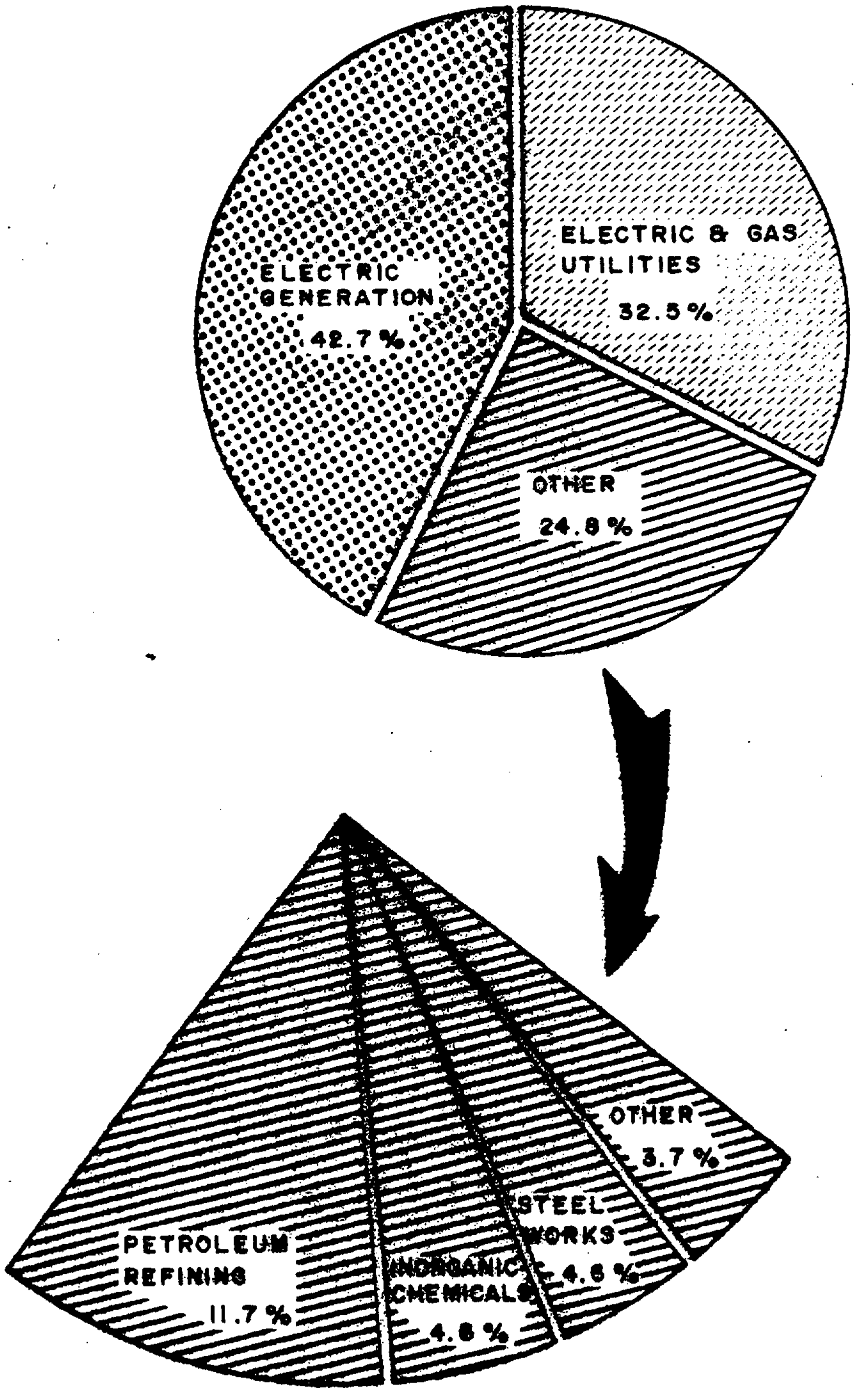
(2) Direct Industrial Users

The 1978 surveys identified fifty-six industrial plants that withdraw directly from the estuary. Water is used for various purposes as indicated in Table 2 and Figure 3.

TABLE 2

DIRECT INDUSTRIAL WITHDRAWAL
BY TYPE OF WATER USE

Type of Water Use	mgd
Once-Through Cooling	4857
Recirculating Cooling	22
Boiler Feed	16
Process	221
Sanitary and Other	11
TOTAL	5127



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
DISTRIBUTION OF TOTAL INDUSTRIAL WATER USE IN STUDY AREA
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 3

• GROUNDWATER. Groundwater withdrawals are relatively small as compared to the surface water withdrawals. Practically all groundwater is obtained from the Potomac-Raritan- Magothy aquifer system.

ESTUARY ECOSYSTEM

TIDAL MARSHES

The lower 50 to 60 miles of the estuary are fringed by sandy banks and tidal salt marshes. Collectively, these areas form the estuary wetlands. While all components of the wetlands are important to estuarine ecology, it is the vegetated marshes that are the most significant. These areas, with their wide expanses of vegetated flat land and numerous tidal creeks, are the basis of estuarine productivity cycles. Numerous mammals, fish, and birds utilize the creeks and grass zones for food and shelter. Some species utilize the marshes only at certain times, such as during spawning or migration periods. Other species are permanent marsh inhabitants.

The productivity of marshes results from the constant exchange of water between the vegetated flats and the tidal creeks. As tidal waters flow over the grasslands, dead grasses are picked up and washed into the creeks. There, they become available to a wide range of organisms that directly utilize this dead material, known as detritus. Some of the detritus is eaten by various benthic (bottom-dwelling) species and planktonic invertebrates. Much of it is colonized by microscopic bacteria that chemically break down the plants into basic chemical components. These chemicals are released into the water where they serve as nutrients for the growth of phytoplankton (small microscopic plants), or where they can be washed back over the marsh grasses, which also need the dissolved nutrients for their growth. The phytoplankton, in turn, serve as food for microscopic animals (zooplankton), which ultimately become food for a variety of fish and shellfish species, many of which man himself eventually utilizes. The productivity of the entire estuary is, thus, heavily dependent on the constant exchanges that occur between the vegetated marsh lands and the tidal creeks.

FISH AND WILDLIFE

The abundance and distribution of aquatic organisms in the Delaware estuary are influenced by natural and man induced water quality conditions. Industrialization and urbanization along the river between Philadelphia, PA, and Wilmington, DE, have, over time, caused severe alteration of the aquatic ecosystem. Above and below this zone, the estuary approaches more natural conditions and maintains a greater diversity and abundance of aquatic life. The more saline Delaware Bay supports a large breeding and nursery area, as well as a viable commercial fishery.

PLANKTON

Phytoplankton populations in the Delaware estuary exhibit seasonal patterns, marked by spring and fall blooms, somewhat lower population levels in summer, and minimal populations during the winter. Photosynthetic activity by phytoplankton occurs only within about three meters of the surface. However, since there is substantial mixing of waters within the river, phytoplankton are well distributed throughout the various depths of the estuary.

Zooplankton are more abundant in the brackish waters of the tidal Delaware River than in either the more saline seaward reaches of the Delaware Bay or in the freshwater, landward reach. Zooplankton densities vary seasonally, with the peak population generally occurring during the warmer months.

BENTHOS

A wide assortment of benthos exists in the Delaware estuary, especially in the seaward reaches of the bay. Included among these organisms are some economically important mollusks (oysters and hard clams) and crustaceans (blue crabs). Oysters are the most economically significant component of the Delaware River and Bay benthic community. They are located in the Delaware Bay and in the river as far north as Artificial Island (RM 55). The major beds are located south of the Cohansey River (RM 38). Oyster spawning occurs from early June through early August, with setting of the young beginning in late June and extending into early September. Though the largest oyster beds are artificially maintained in the bay, there are smaller oyster beds in many tidal streams.

Blue crabs, the second most economically important species, reproduce from May to October. Commercial crabbing activities are centered near Artificial Island, but range as far south as the Leipsic River (RM 35) and as far north as Pea Patch Island (RM 61).

Surf clams, American lobster, sea scallops, and hard clams are also harvested in the lower estuary, but are much less economically important than oysters and blue crabs.

FINFISH

Over 250 species of fish have been identified in the Delaware estuary; many of these species are known to spawn within its waters. The most important nursery grounds are located in the lower estuary. Many of the species that spawn and spend their early life in these nursery areas are directly or indirectly valuable to commercial fisheries.

The degraded nature of the Delaware River near Philadelphia severely limits the abundance and diversity of the resident fisheries. The most common indigenous fishes are killifish, catfish, carp, white perch, yellow perch, and eels.

Six species of anadromous fish; the American shad, striped bass, white perch, hickory shad, blueback herring, and alewife, and one catadromous species, the American eel, are common in the Delaware estuary. The populations of these species, especially the American shad and striped bass, have declined in the estuary during the last several decades. In large part, this is believed to be a result of reduced water quality. More recently, there has been some improvement, possibly as a result of better wastewater treatement.

HUMAN USE

Commercial fishing in the bay is a large industry accounting annually for over 4 million pounds valued in excess of 2 million dollars. Generally, oysters account for 70% of the total harvest value, with blue crabs second at 20%, and sea trout (weakfish) third at 4%. Other commercial species include Atlantic menhaden, American shad, striped bass, eels, and white perch.

Recreational fishing in the bay accounts for over one-million man-days annually. Principal sport species are weakfish, summer flounder, bluefish, black sea bass, white perch, and striped bass. Upriver fishing in the Delaware River in the Philadelphia vicinity accounts for over 100,000 man-days of fishing annually, with alewife, blueback herring, shad, bullhead, sucker, sunfishes, carp, and eel the main catches.

WILDLIFE

The wetland habitat contained in the study area supports a wide variety of aquatic and terrestrial organisms. Tidal marsh provides food and cover for many wildlife species, including wading birds, shorebirds, raptorial species, migratory waterfowl, and rodents.

Many species of mammals and birds provide an important recreation attraction to hunters, photographers, and other wildlife enthusiasts. Species of recreational value include migratory waterfowl, song birds, deer, rabbit, muskrat, raccoon, and oppossum.

HUMAN RESOURCES

PRINCIPAL COMMUNITIES AND INDUSTRIES

The most heavily populated reach of the Delaware estuary is the area bordering the estuary from Trenton, New Jersey, to Wilmington, Delaware. The principal municipalities along the main reach of the estuary are: Trenton, NJ, Philadelphia, PA, Camden, NJ, Chester, PA, and Wilmington, DE, (See Figure 4).

An extensive complex of industrial plants also lines both sides of the Delaware estuary. Industries produce goods such as chemicals and allied products, petroleum, primary metals, paper and allied products, processed foods, and electric power. The most heavily industrialized area is located in the Camden-Philadelphia-Chester reach of the estuary.

POPULATION

There are 13 counties in the study area, as shown on Figure 5, with a total estimated 1980 population of 5,182,600. Table 3 shows a breakdown of population by counties. County totals range from a concentration of 1,876,500 in Philadelphia County, to 62,900 in Salem County.

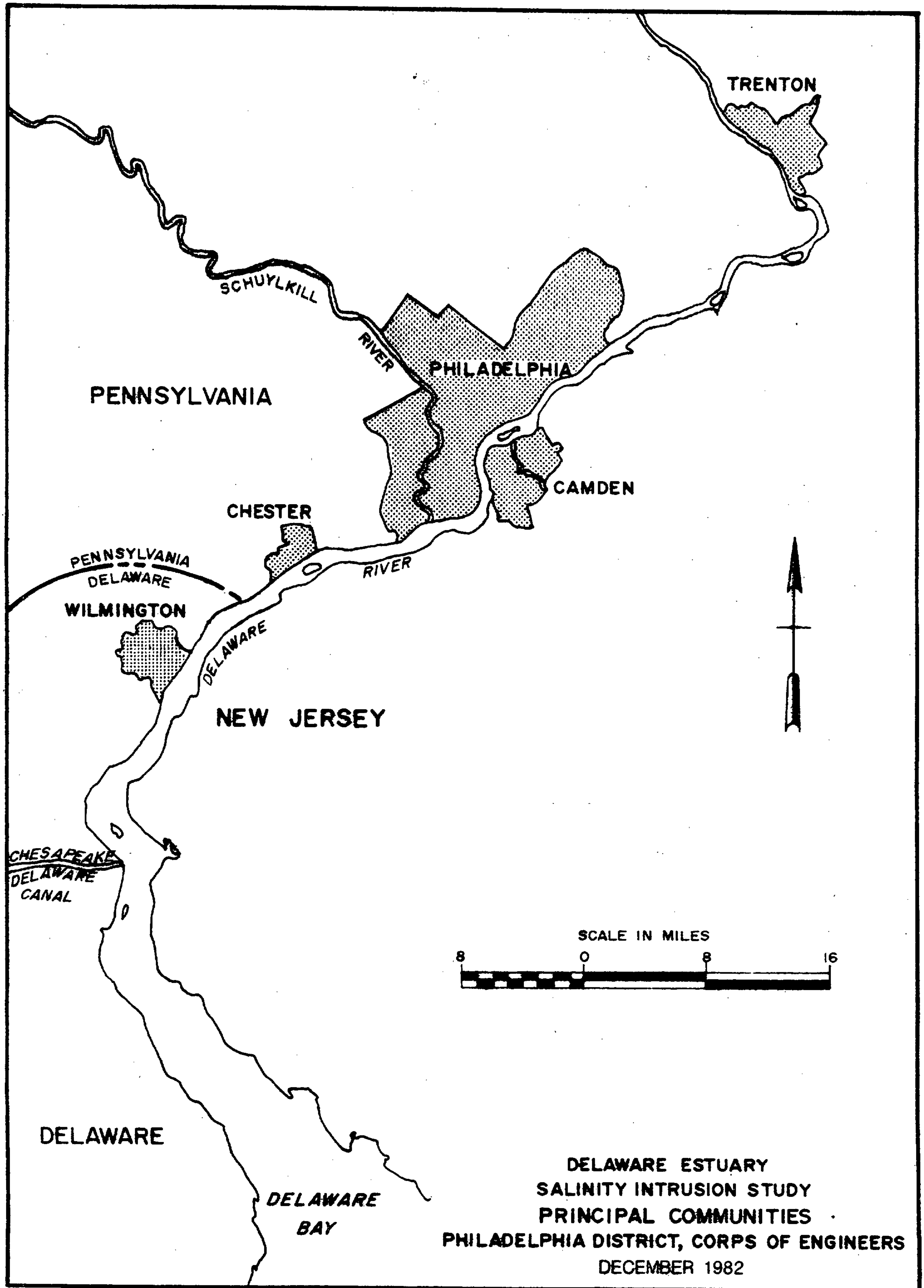
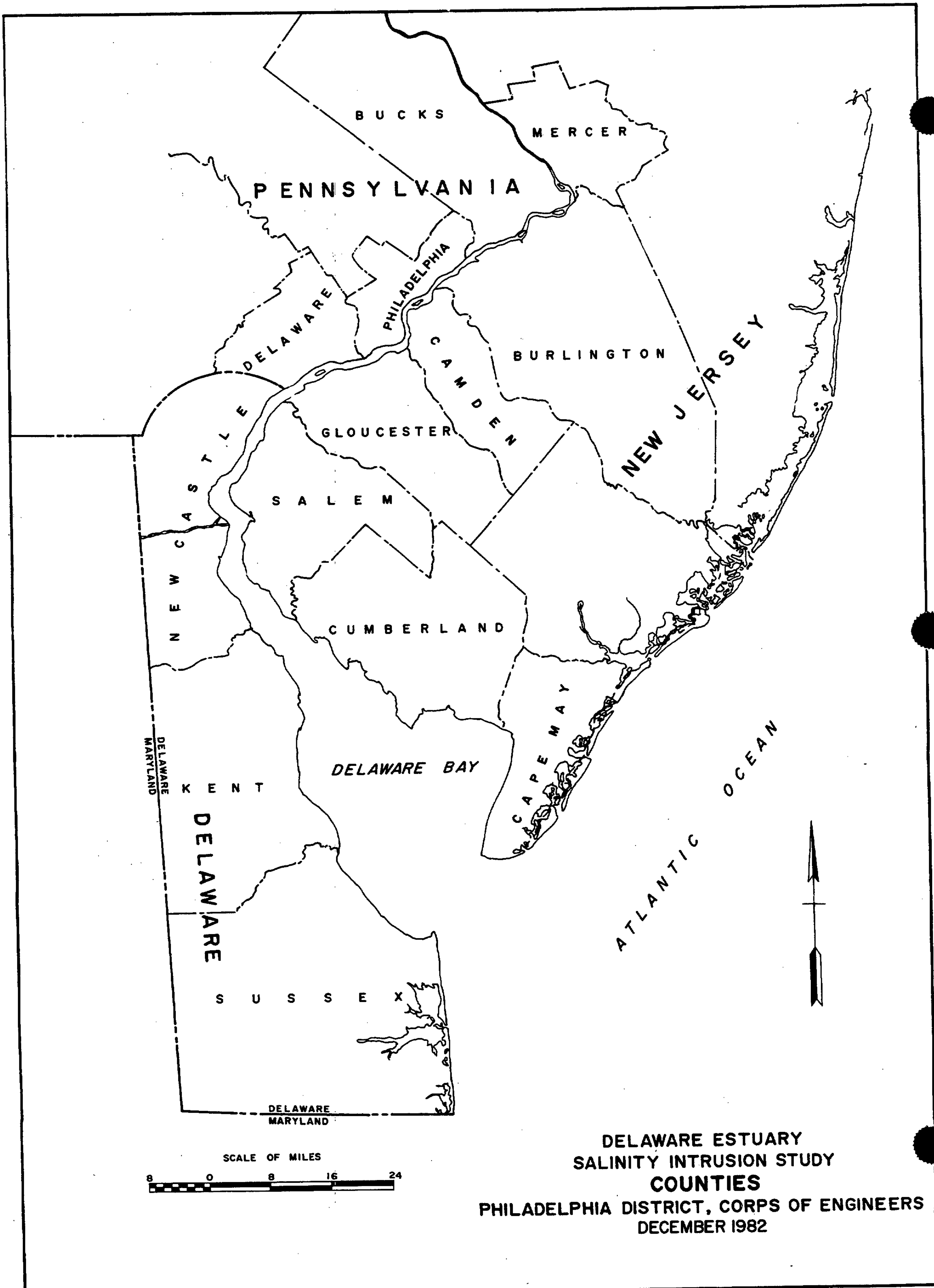

TRENTON
SCHUYLKILL
RIVER
PHILADELPHIA
PENNSYLVANIA
CAMDEN
CHESTER
PENNSYLVANIA
DELAWARE
RIVER
WILMINGTON
DELAWARE
NEW JERSEY
CHESAPEAKE
DELAWARE
CANAL
SCALE IN MILES
8
0
8
16
DELAWARE
DELAWARE
BAY
DELAWARE ESTUARY
SALINITY INTRUSION STUDY
PRINCIPAL COMMUNITIES
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 4



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
COUNTIES
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

The 1980 population estimates developed by the States of Pennsylvania, New Jersey, and Delaware were compared with population data recently assembled by the U.S. Bureau of Census. The census data showed reasonable agreement with these estimates of population in the study area.

TABLE 3

POPULATION OF STUDY AREA
BY COUNTIES (1980 FIGURES)

COUNTY		POPULATION
NEW JERSEY 1/		
	BURLINGTON	376,700
	CAMDEN	483,200
	CAPE MAY	85,900
	CUMBERLAND	135,100
	GLOUCESTER	201,300
	MERCER	323,500
	SALEM	62,900
PENNSYLVANIA 2/		
	BUCKS	453,000
	DELAWARE	586,100
	PHILADELPHIA	1,876,500
DELAWARE 3/		
	KENT	98,700
	NEW CASTLE	405,800
	SUSSEX	93,900
	STUDY AREA TOTAL	5,182,600

SOURCES:

1/ New Jersey revised total and interim age and sex population projected, April 1979.
2/ Pennsylvania projection series summary report, June 1978.
3/ Delaware Population, February 1980.

EMPLOYMENT

The classes of industry that employ the majority of persons in the study area are manufacturing and wholesale and retail trade. Another important field of employment is service. The total labor force is 2,284,500 persons, ranging from 804,300 persons in Philadelphia County to 29,250 persons in Salem County. Estimates of labor force in the study area by county are shown below:

COUNTY	LABOR FORCE
PENNSYLVANIA 1/	
BUCKS	214,400
PHILADELPHIA	804,300
DELAWARE	257,100
DELAWARE 2/	
NEW CASTLE	186,900
KENT AND SUSSEX	90,000
NEW JERSEY	
MERCER 3/	171,513
BURLINGTON 4/	157,058 ✓
CAMDEN 4/	212,793
GLOUCESTER 4/	47,875
SALEM 5/	29,250
CUMBERLAND 6/	66,306
CAPE MAY 7/	47,000
STUDY AREA TOTAL	2,284,495

SOURCES:

1/ Philadelphia Labor Area Annual Planning Report, May 1981
2/ State of Delaware Annual Planning Report, June 1980
3/ Trenton Labor Area Planning Report, May 1980
4/ Camden Labor Area Annual Planning Report, May 1980
5/ Salem Labor Area Annual Planning Report, May 1980
6/ Vineland - Millville - Bridgeton Labor Area Annual Planning Report, May 1980
7/ Ocean City - Wildwood - Cape May Labor Area Annual Planning Report, May 1980

INTRODUCTION

Due to the informational nature of this study, the normal tasks of the planning process (problem identification, plan formulation, impact assessment, and evaluation) do not apply directly. The ensuing discussion emphasizes the first two of these tasks.

PROBLEM IDENTIFICATION

CHARACTERISTICS OF SALINITY INTRUSION

The distribution of salinity in the estuary is for the most part a result of the interaction of freshwater flow and saltwater inflow. Freshwater flows from the headwaters of the Delaware River, from tributaries, as direct runoff from the land, and from groundwater seepage. Freshwater discharge varies with the season. It is generally greatest in March and April, owing to spring thaws, and least from June to October, when growing plants rapidly remove soil moisture and evapotranspiration is at its peak. Normally, during the summer and early fall, a greater proportion of the rainfall soaks into the ground and lesser proportion runs off directly to the streams. Freshwater inflow from the Schuylkill River and from other smaller tributaries, also affects salinity concentrations, but except for short time periods, the discharge at Trenton is a reasonable indicator of the total freshwater flow. The influence of variations in freshwater flow on the level of salinity in the lower estuary occurs over an extended period. The time required for flow changes at Trenton to influence lower estuary salinity normally takes only a few days, but the effects on salinity may persist for many months. Salinity, whether caused by sea-water intrusion or by the discharge of wastewaters containing dissolved solids, is a major concern in the Delaware estuary. The estuary serves as a source of water supply for municipalities and industries, and as a habitat for many fish and wildlife species. Chlorides have a special importance in the Delaware estuary as an indicator of sea water mixing with freshwater. DRBC hydrologists have generally defined the "salt line" in the estuary (indicating significant sea salt concentrations) as the location where the concentration of chlorides is 250 milligrams per liter (mg/l). This "salt line" fluctuates considerably during the year. In a normal year, it moves from a point (in spring) five miles below Wilmington, Delaware, to a point near Marcus Hook, Pennsylvania (in late summer or fall). This fluctuation varies from season to season in accordance with the variations in river flow.

Changes in sea level affect the salinity levels in the estuary. Sea level varies seasonally, primarily as a result of freshwater runoff and weather patterns. Sea levels are lower in December, January, and February, and are highest in August, September, and October.

There has been a long-term rising trend in the level of the ocean relative to the shore (marine transgression) along the northeast coast of the United States. While there have been variations in the rate of change, the mean annual rise in sea level since 1921 has been at an average rate of 3.7 millimeters per year (mm/yr). The DRBC used the Thatcher-Harleman (MIT-TSIM) Model to analyze the effect of rising sea level on salinity. The increment of increased chlorides attributed to the 35-year rise in sea level between years 1965-2000 (assuming a 3.7 mm/yr increase) shows an increase from 0.01 ppt to 0.39 ppt from Torresdale to Reedy Point, Delaware (RM 59). A reduced increment is projected from 0.39 ppt at Reedy Point to 0.05 ppt in the lower Delaware Bay (RM 10). When compared to the natural variations in salinity at any location in the lower Delaware estuary, the increases in salinity attributable to the projected rise in sea level do not appear to be very large. However, DRBC estimates that a flow augmentation of 150 cfs at Trenton would be required to offset the salinity-increasing effects of the projected 35-year rise in sea level from 1965 to the year 2000.

Salinity also varies with tidal cycle. During the tidal cycle, salinity is at a maximum at approximately the time of high water slack, and at a minimum at approximately the time of low water slack. Tidal amplitude and duration are influenced by lunar cycles, wind and atmospheric pressure. In addition, meteorological tides accompany hurricanes and other coastal storms and severely alter tide levels.

The summation of these factors results in net residual nontidal currents. However, relationships between the driving mechanisms and the presumed or observed flow patterns in an estuary are not completely understood.

A residual current in an estuary is defined as the net movement of water averaged over a period of time much longer than a tidal period. These currents are partially responsible for the exchange of water between estuary and ocean. Concurrent with the exchange of water is the exchange of physical and other properties, including salinity, pollutants, biological organisms, and sediments. The seaward surface residual flow in the bay is generally deflected toward the Delaware shore. Bottom landward residual flow follows the deep channels of the bay and then spreads laterally onto the adjacent shallower areas on both sides. The estuarine type circulation with landward bottom residual currents and surface offshore residual currents, extends at least 40 kilometers onto the adjacent ocean shelf. Disruption of residual currents could affect the upstream transport mechanism utilized by eggs and larvae of many aquatic organisms.

Salinity varies not only as one progressess downestuary but also at times, horizontally and vertically. Various factors, such as tidal currents, influence variations in localized salinity.

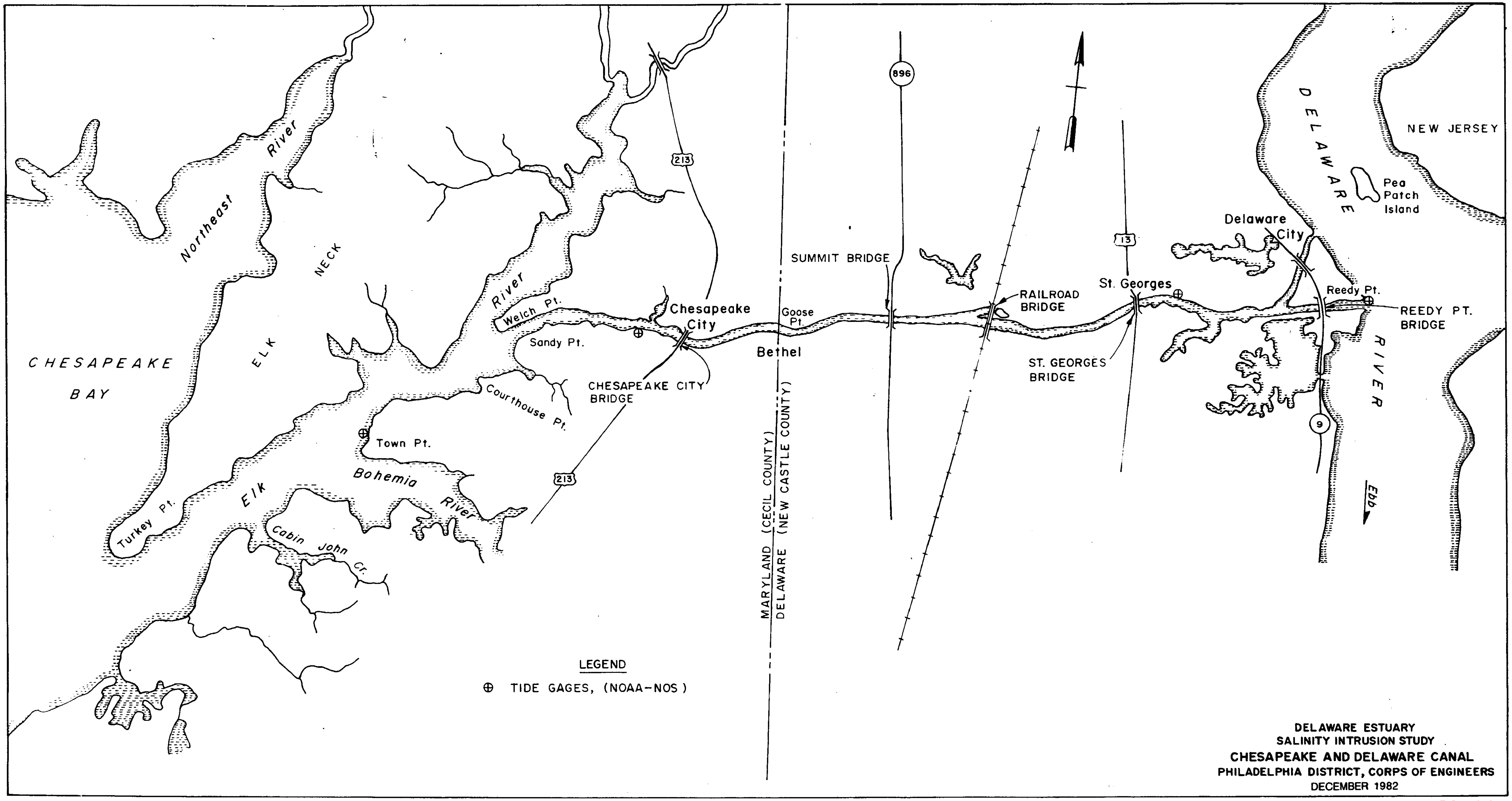
Longitudinal salinity sections taken of the bay indicate that there is stratification in winter and spring, while summer and fall conditions are more nearly vertically homogenous. Salinity data collected from cruises by the University of Delaware and the New Jersey Oyster Research Laboratory show that there is at least a slight vertical gradient in the bay throughout the year. With partial stratification, surface salinity will decrease with increased river flow, while bottom salinity will not decrease as rapidly, and under some circumstances, may actually increase.

IMPACT OF THE CHESAPEAKE AND DELAWARE CANAL ON SALINITY DISTRIBUTION IN THE DELAWARE ESTUARY

The Chesapeake and Delaware (C&D) Canal has a marked effect on salinity in the Delaware estuary. This sea level canal, constructed to provide a protected inland waterway between Baltimore, MD, and Philadelphia, PA, (see Figure 6), was enlarged between 1964 to 1975 to its current depth of 35 feet and width of 450 feet to accomodate larger vessels. The canal is over 17 miles long, extending from Reedy Point to Welch Point.

The flow in the canal is governed by water surface gradients caused by the water elevations at both ends of the canal. At the eastern end, the mean tide range is 5.5 ft, and at the western end, 2.2 ft. As a result of the physical differences of the Chesapeake and Delaware Bays, tides at the opposite ends of the canal are approximately 10 hours out of phase.

As discussed earlier, the average flow in the canal can vary significantly in quantity and direction. Most of the previous studies were centered on



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
CHESAPEAKE AND DELAWARE CANAL
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 6

attempting to understand the dynamics of the C & D Canal itself. However, those studies were not able to determine the impact of canal flows on the salinity distribution in the Delaware estuary over a relatively long period.

SENSITIVITY OF SALINITY CONCENTRATIONS TO WATER USERS

• HEALTH EFFECTS. Two criteria, total dissolved solids and chlorides, are commonly used to set standards of potability. For example, the recommended maximum levels of these constituents in drinking water are 500 mg/l total dissolved solids and 250 mg/l chlorides. The drinking-water criterion of 250 mg/l, chloride is based more on palatability than on health protection. This level is considered the extreme limit for all domestic uses (drinking, cooking, washing, etc.). However, for health and taste reasons, more stringent standards are prescribed. For example, persons suffering from cardiac, renal, and circulatory diseases should not consume water with high sodium concentrations. For persons on sodium restricted diets, the American Heart Association recommends an upper limit of 20 mg/l of sodium in drinking water. The State of New Jerse has adopted a sodium standard of 50 mg/l for drinking water.

• SALINITY-RELATED COSTS. Although the problems associated with use of water from an estuary with fluctuating levels of salinity have been well known, the costs associated with salinity have not been determined. For example, industrial water users bear costs of cleaning and replacing corroded parts, utilizing alternate water sources, and treatment of saline water. The municipal systems that withdraw estuary water, (Philadelphia, Bristol, and Lower Bucks County), need large quantities of water and face very costly alternate sources. They also bear costs of cleaning and replacing corroded parts. Domestic users face costs from corrosion of household facilities and treatment of saline water. This study undertook efforts to quantify the extent of salinity related costs to withdrawal users.

- IN-STREAM USERS. The ability of an organism to exist within a given environment depends on the needs of the organism and the characteristics of the environment. Such factors as the availability of food, space and breeding sites, disease and predator cycles, temperature, sunlight, and salinity combine to determine what species will be supported and to what degree. A species cannot maintain an existence under extreme physical or chemical conditions, but rather reside within an intermediate "range of tolerance", which varies for each organism and its stage of development. Within this range is a zone called the "optimum range" bracketed by upper and lower "zones of stress". Different environmental factors often do not operate independently, and a reduction in the total range of tolerance can be caused when an organism is stressed by any one factor.

In response to salinity variations, species may increase or decline in population, become extinct in an area, or migrate to suitable habitat in other parts of the estuary. A specific change in estuarine salinity will cause a gradual rather than instantaneous effect on species productivity. Estuarine aquatic species will adjust to such variation by changes in their growth, mortality, and reproduction rates, which combine to give overall biological productivity.

The timing of the flow into estuarine waters within a given year is important because of its effect on the productivity, stability, and general health of the estuarine ecosystem. Most species are tuned to the normal natural variation for critical life functions, breeding, feeding, and migration. The period between May and August is especially important because, during this time, the estuary provides important spawning and nursery needs for a majority of coastal and estuarine species. This period overlaps two different hydrologic periods of high spring flow and low summer flow.

The problems of salinity variation become critical when the aquatic population is subjected to natural conditions that put them under stress, such as that which occurs during natural drought conditions. During these conditions the addition of further stress could cause large changes in aquatic productivity.

Residual currents in the lower estuary are influenced by several factors including salinity. Disruption of residual currents could affect the upstream transport mechanisms utilized by eggs and larvae of many aquatic organisms.

SUMMARY OF PROBLEMS

The specific problems that have been identified and addressed in this study were discussed previously as study objectives and are reiterated below along with specific study accomplishments. These accomplishments are further described under Plan Formulation.

PROBABILITY GOAL

a. Economic Analysis. As indicated in the Plan of Study, work under this objective included both a preliminary analysis (or phase 1), which was used to provide input to DRBC, and a second phase used to determine average annual costs incurred over a long period.

b. Impact of the Chesapeake and Delaware Canal. These efforts included both the review of available modeling efforts and determination of the range of impacts as identified in the Plan of Study. In addition, a dynamic interactive modification to the MIT-TSIM Model was developed as part of this objective.

c. Impacts of Salinity Variation on Estuarine Fish and Wildlife Resources. As part of this objective, the relative impacts of variation of salinity were studied.

d. Development of Probabilities of Salinity in the Estuary. The specific accomplishments under this objective included using the MIT-TSIM Model as modified by "b" above to run the past 50 years of historical flow records. The results of these model runs were used to determine salinity probabilities as required by the Congressional resolution, and to serve as input to the second phase of the economic analysis (see "a" above).

QUANTITY OF FLOW GOAL

e. Determine the quantity of freshwater flow necessary to protect water users of the estuary.

f. Develop a basin plan for drought and normal hydrologic conditions.

The results of the first phase of the economic analysis described in "a", along with extensive other pertinent information, were used by DRBC to determine flow objectives (e,f) for the Delaware River Basin as part of their Level B Study. The results of the balance of the study ("a" thru "d") were reviewed by DRBC to determine whether further changes in the flow objectives were warranted.

ECONOMIC ANALYSIS

Since an answer to the economic objective was vitally needed by DRBC as part of the data they considered in determining a flow objective for the basin, the economic studies were conducted in two phases. Phase one entailed the development of salinity-cost relationships for municipal and industrial water users and application of these relationships to determine estimated salinity-related costs during both drought and normal hydrologic conditions. Phase two involved the computerization of these relationships and application over a long period of time.

PHASE 1 ECONOMIC STUDIES

The investigation of economic effects encompassed a variety of water users of the Delaware estuary and its tidal tributaries. Explicit salinity-cost relationships were developed for fifty-six industrial plants and three municipal water supply systems. Drinking water health-related costs were not included. Costs to groundwater users (whose supplies are taken from aquifers that are recharged in part by the Delaware estuary) were not quantified. While some wells have in the past been shut down, the causes for these closures are multi-faceted, and involve many water quality parameters in addition to salinity. By comparison to those identified costs the groundwater related costs were estimated to be minimal in view of the small groundwater withdrawals relative to surface water withdrawals. This assessment could change with increased groundwater use or increased salinity contamination of the aquifers involved. Further, only a portion of this impact would be attributable to salinity. Coordination was effected to quantify this impact; however, the available data are not adequate to allow quantitative evaluation of salinity-related costs to groundwater users near the estuary. Similarly, data are not available to assign costs of salinity-changes to the fisheries of the Delaware estuary. Consequently, further efforts in this regard were discontinued.

Relationships between salinity, defined as total dissolved solids, and unit costs for each of the following types of withdrawal use in dollars per million gallons were developed.

CATEGORY	TYPE OF USE
Direct Industrial Withdrawal	once-through cooling recirculating cooling process boiler feed sanitary and other intake
Municipal Systems	municipal facilities domestic industrial and commerical institutional

All costs are estimated on a per unit of water use basis over the range of salinities experienced. Three cost categories were defined and estimated:

"Investments Costs" - depending on <u>expected</u> salinity

"Contingency Costs" - applied above a <u>switchover criterion</u> salinity

"Daily-Salinity Costs" - predicated on <u>experienced</u> salinity

"Investment costs" involve investment decisions undertaken to reduce salinity effects and vary according to the location of the user. "Contingency costs" are the costs for alternate sources of water above a switchover criterion salinity. Cost of corrosion, including repair, downtime, early replacement and certain chemical treatment costs, were considered to be "daily-salinity" costs. These costs vary depending on the experienced level of salinity.

Refer to Appendix 2 for a detailed discussion of the development of the three cost categories and the salinity-cost relationships for each type of water use.

• USE OF TRANSIENT SALINITY INTRUSION MODEL (MIT-TSIM). In order to determine salinity-related costs for the drought and normal hydrologic conditions, DRBC's Transient Salinity Intrusion Model (MIT-TSIM) was used to simulate salinity concentrations in the Delaware estuary. Further detail in the development of the original model and its subsequent modifications are documented in Appendix 1.

The model simulated salinities for water years 1965 and 1970, which represent drought and normal hydrologic conditions, respectively. The simulated salinities were then applied to the relationships developed as part of this study (as presented in Appendix 2) to estimate salinity-related costs. The costs ignored the effects of daily variations in the Chesapeake and Delaware Canal on salinity.

• COORDINATION. An Executive Summary was prepared and distributed to all interested parties to document the results of the Phase 1 Economic Study. The data developed as part of this study, including both model runs and economic data, were used by DRBC in developing flow objectives. In developing these flow objectives DRBC established one of the cornerstones of their basin plan as presented in the Level B Study and also satisfied the quantity goal (goal B) of this study. Further detail regarding DRBC's effort is discussed under the quantity of flow objective portion of this report.

PHASE 2 ECONOMIC STUDIES

In this phase of the economic studies, a computer model (ECOSALT) was developed based on the salinity-cost relationships and equations for withdrawal users developed in Phase 1. The economic model calculates average annual costs to withdrawal users, based on spatial and temporal variation of salinity concentration in the Delaware estuary, and was used in the long-term simulations to determine salinity cost estimates.

IMPACT OF THE CHESAPEAKE AND DELAWARE CANAL

BACKGROUND

This study anticipated use of the Transient Salinity Intrusion Model to conduct the long-term analysis. However, the model as programmed did not account specifically for local wind effects, nor, as anticipated in the Plan of Study, the impact of the Chesapeake and Delaware Canal. Due to the extensive effort conducted in analysis of Chesapeake and Delaware Canal effects, this area is treated as a separate objective.

WIND EFFECTS

An analysis was undertaken to determine whether the effects of local wind (within the boundaries of the Delaware estuary) should be reflected in the MIT-TSIM Model before making long-term simulations. The analysis considered chloride distributions at six stations and revealed that local winds do not have a significant role in long-term salinity predictions. Based on these results, the local wind effects on salt intrusion were not incorporated in the model. The effects of ocean winds were taken into account by the use of observed tides at the mouth of Delaware Bay as inputs to the salinity model.

As described in the Plan of Study, the range of impacts of the C&D Canal was intended to be defined as part of the study. To determine the range of these impacts, various sensitivity analyses were undertaken. One phase of these analyses was used to determine the impact of flows in the C&D Canal over a relatively long period. A second phase considered various hypothetical hydrologic conditions to determine relative impacts. After reviewing the results of these analyses, it was realized that the canal could be dynamically incorporated in the MIT-TSIM; thus a Branched MIT-TSIM was developed. Finally, the pre- and post-enlargement conditions of the C&D Canal were analyzed using the Branched MIT-TSIM Model. Additional detail is provided in Appendix 1 of this report.

SYNOPTIC (4 MONTH) ANALYSIS

Previous investigations were based on extremely short time periods (such as several days). To test the impact of using a substantially longer period, a search was made for the longest available period of synoptic (same-time) tidal data in the Chesapeake Bay, Chesapeake and Delaware Canal, and Delaware estuary. From available data, a four month period (July-October 1979) was selected. The flows in the canal are governed by the tidal elevation gradient. Since extremely small differences in relative elevation at the ends of the canal could cause significant variations in flow, it was necessary that all the C&D tide gages be referenced to a common datum and that each gage datum be as accurate as technically possible. For this reason, a first order leveling survey was conducted during the summer and fall of 1979 along the C&D Canal between Reedy Point and Town Point. The tidal data for the selected period were adjusted to the new datum. Using Hunter's model, tide elevations were computed within close tolerances to the observed values. Consequently, real-time flows (generated by Hunter's model) were incorporated into the MIT-TSIM Model.

Quantities and direction of flow were calculated at Reedy Point, DE, representing net non-tidal flow in and out of the Delaware estuary through the C&D Canal. Flows as high as 81,700 cfs eastward and 50,800 cfs westward, averaged over a tidal cycle, were computed during the selected period. The four month average (July-October 1979) was 6,960 cfs eastward. As a result of this analysis, effects of the canal were found to occur in calculated Delaware estuary salinities between RM 47 (12 miles downstream of the confluence of the canal) and 80 (21 miles upstream).

HYDROLOGIC CONDITION ANALYSIS

The objective of this analysis was to determine the impact of the C&D Canal on the salt intrusion in the Delaware estuary under various hydrologic conditions.

Under this portion of the study, the influence of canal flows was derived assuming July-October 1979 conditions (in the canal) to coincide with freshwater inflows (to the Delaware) of 1965, 1970, and 1975. These water years are characterized as drought, medium, and high freshwater years, respectively, for the Delaware River Basin.

The sensitivity runs confirmed that canal flows have appreciable impact on salinity concentrations in the Delaware estuary. These impacts could be either positive or negative (indicating higher or lower salinity, respectively) depending on the location of interest and flows in the canal. Simulations using medium and high estuary flow conditions resulted in the most negative impact. However, for drought conditions canal flows had a positive effect; the impact of the canal was felt from Ship John Shoal (RM 37) to Torresdale (RM 110).

MIT-TSIM MODIFICATION TO INCLUDE THE CHESAPEAKE AND DELAWARE CANAL

As a result of the above effort, the study realized that modifications to the MIT-TSIM Model could be made to reflect the dynamic interaction of the canal with the estuary, and therefore, represent more realistic conditions. The original version of the MIT-TSIM Model was extended to incorporate the canal as a branch. This eliminated the need to use a separate model to compute C&D flows and the need for Reedy Point tidal data. With this modification, flows and salt transport in the C&D Canal are computed dynamically rather than serving as input conditions. The numerical solution technique of the MIT-TSIM Model, however, remained unchanged. With these alterations, a Branched MIT-TSIM Model was developed. The resulting model has two tidal boundaries, one at the entrance to Delaware Bay (Lewes, DE) and another at the head of, Chesapeake Bay (Town Point, MD). A third boundary (for river-flow inputs) exists at the head of tide in the Delaware estuary at Trenton, NJ.

PRE- AND POST-ENLARGEMENT CONDITIONS

The Branched MIT-TSIM Model was hydrodynamically recalibrated using the tidal data for the selected period (July-October 1979). Upon completion, it was used to conduct a sensitivity analysis for the pre-and post enlargement conditions of the C&D Canal under various boundary specifications. Table 4 summarizes the results of the analysis.

TABLE 4

SUMMARY OF MAXIMUM CHANGES IN CHLORIDE CONCENTRATIONS IN THE DELAWARE ESTUARY FOR SIMULATED PRE- AND POST- ENLARGEMENT CONDITIONS OF THE C&D CANAL

Station	DRBC River Mile	Maximum change in chloride concentrations as a percentage of the maximum pre-enlargement concentration, mg/l			
		1979	1965	1970	1975
Ship John Shoal	37	-9	-17	-14	-9
Reedy Island Jetty	54	16	-20	-13	15
Delaware Memorial Bridge	69	41	-14	40	33
Chester	82	47	-25	25	34
Ben Franklin Bridge	100	3	-18	3	2
Torresdale	110	1	-12	-1	-1

Note: All simulations based on July-October 1979 tidal elevations specified at Lewes, Delaware, and Town Point, Maryland. Tributary inflows are those for the year specified.

IMPACTS OF SALINITY VARIATION ON ESTUARINE FISH AND WILDLIFE RESOURCES

Salinity exerts strong effects on the Delaware estuarine ecosystem, influencing the distribution of marsh plants, benthic invertebrates, fishes, and certain wildlife. Relatively few aquatic species tolerate the entire salinity gradient from freshwater to saltwater; most occupy portions of the gradient. Salinity intrusion affects the estuary ecosystem by controlling biological productivity for many species considered important to man. This results from salinity-based variations of growth, mortality, and reproduction rates. The period between May and August is especially important because, during this time, the estuary provides important spawning and nursery habitat needs to many species.

The estuary is highly variable in terms of salinity and its inhabitants have de facto developed the ability to tolerate normal variations. The problem occurs when the aquatic population is subjected to natural conditions that put them under stress. At such times, they are less able to handle additional stress. One such situation occurs during droughts when insufficient freshwater is available for all demands.

Flows during the spring period ending in mid-June are typically the highest of the year. The result is a lowering of salinity in the estuary, which generally favors aquatic reproduction. The summer and fall flows, in comparison, are the lowest of the year and a relatively small amount of freshwater inflow can noticeably affect salinity levels. In addition to the natural variation in freshwater flow, man's needs also vary, peaking in the summer during periods of low freshwater flow. By analyzing the seasonal flow cycle and the various needs of the biologic community, it is possible to determine the qualitative effect of salinity change.

Increased salinity intrusion in spring would not affect marsh plant composition but would tend to inhibit seed germination and plant growth, reducing primary productivity. It would allow benthic invertebrates associated with higher salinities to advance up the bay. This would increase benthic diversity while reducing habitat for brackish and freshwater species. Oyster-drill predation could extend into seed oyster beds formerly protected by intermediate and low salinities. MSX disease may also be extended. Oyster losses could increase, damaging the oyster industry. Such damage would vary with the degree of increased salinity intrusion.

Significantly increasing spring salinities would shift the primary spawning and nursery grounds of estuarine fishes up the estuary. Larger number of eggs and larvae of weakfish could be brought closer to the intakes of the Salem Nuclear Generating Station, possibly increasing entrainment and impingement losses. More eggs and larvae of striped bass would be brought closer to the Philadelphia pollution zone, possibly increasing mortality. Increasing spring salinities would reduce the extent of the low salinity zone, limiting valuable spawning and nursery habitats for low-salinity-dependent fishes. Increasing salinity would not affect the composition of waterfowl food plants, but would tend to reduce productivity, forcing waterfowl to forage over larger areas.

During normal and wet hydrologic years, sufficient water is available to supply present and projected summer needs. But during dry years, available flow is not sufficient to satisfy all needs.

Reducing summer salinity levels would limit the seasonal shift of fishes up the estuary, which coincides with naturally declining river flow, thereby maintaining a buffer between the nursery areas and the Philadelphia pollution zone. It would also minimize the normal summer shrinkage of the low salinity zone. Decreasing summer salinities would restrict the advance of salt-tolerant benthos up the estuary and benefit brackish and freshwater types. Reducing salinity intrusion in summer would prevent conversion of brackish marsh to saltmarsh, thereby, benefiting waterfowl. Muskrat production, which is limited by high salinity, would also benefit from protection of brackish marshes. Wading birds and shorebirds would not be affected by increasing or decreasing salinity.

During moderately dry periods (between drought and normal conditions) the effect of competing water demands and rising sea level will cause a net increase in salinity. Increased salinity levels will cause a reduction in the productivity of many species that utilize the estuary, including commercially and recreationally important species, relative to normal conditions. The effect, while not catastrophic and probably not discernable within the naturally fluctuating populations of the species in question, will cause a net reduction in the overall productivity over an extended period.

While salinity does have a variety of impacts on the estuarine ecosystem, the impacts of salinity change as described in the above paragraphs, can be both positive and negative. (These impacts are treated in further detail in Appendix 3). The overall net impact cannot be quantified without reference to the degree of salinity change, nor without indicating relative preferences within species and even cycles within individual species. This report merely attempts to identify potential qualitative impacts of salinity on the ecosystem.

DEVELOPMENT OF PROBABILITIES

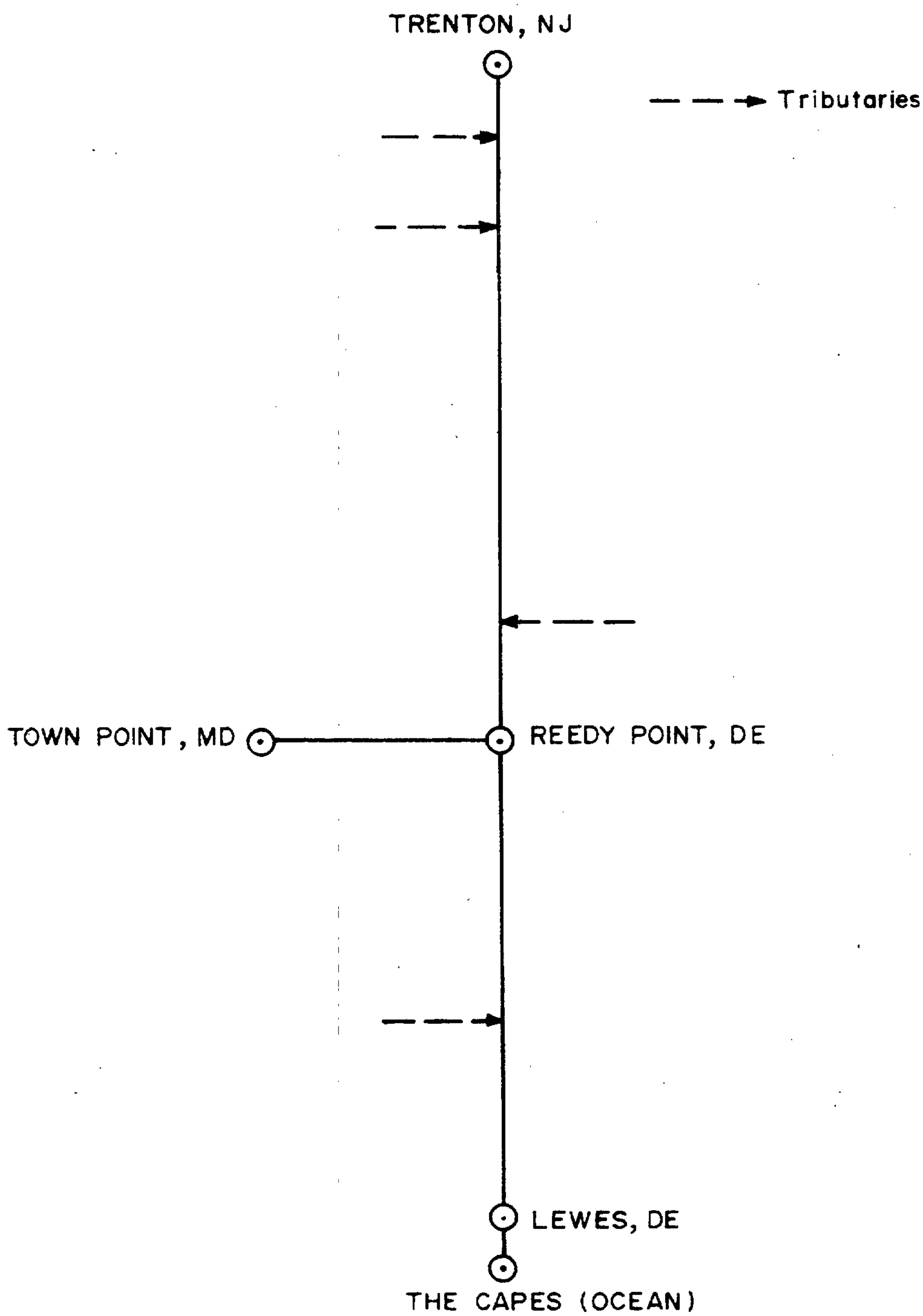
LONG-TERM (50-YEAR) ANALYSIS

A long-term simulation was conducted to determine probabilities of incurring various salinity levels. These probabilities, in turn, were coupled with the results of the economic analysis to determine economic impacts of salinity on withdrawal users of water from the estuary.

Freshwater inflows developed by the Section 22 study for the period of 1927-1977 served as input to the Branched Salinity Model. That input was used to generate time and space varying salinity concentrations in the Delaware estuary. The output of the Branched Model was used as input to the Economic (ECOSALT) Model to compute average annual costs to direct water users.

Figure 7 shows the Branched Model schematization of the Delaware estuary and Chesapeake and Delaware Canal system. The network consists of the main stem of the Delaware estuary from its ocean boundary at the Capes to the head of tide at Trenton, NJ and one branch. The branch represents the C&D Canal, which extends from Reedy Point on the Delaware River, DE, to Town Point on the Elk River, MD. The system described considers three boundaries situated at Lewes, DE; Trenton, NJ; and Town Point, MD. The confluence of the C&D Canal and the Delaware estuary at Reedy Point constitutes an internal point where no hydraulic or salinity specifications are necessary. The Branched Model internally computes these variables for this location. The modeled system also requires (as input) daily flow discharges from 24 tributaries along the Delaware estuary.

During the period covered by the simulation runs, the Chesapeake and Delaware Canal underwent three stages of enlargement from its original dimensions of 12 feet deep and 90 feet wide to its post 1975 geometry, 35 feet deep and 450 feet wide. The changes in canal geometry are not accounted for in the model; therefore the post-1975 geometry was assumed to be invarient for the entire 50-year simulation of salinity distribution in the Delaware estuary.



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
MODEL CONCEPTUALIZATION OF THE
DELAWARE ESTUARY/ C & D CANAL
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 7

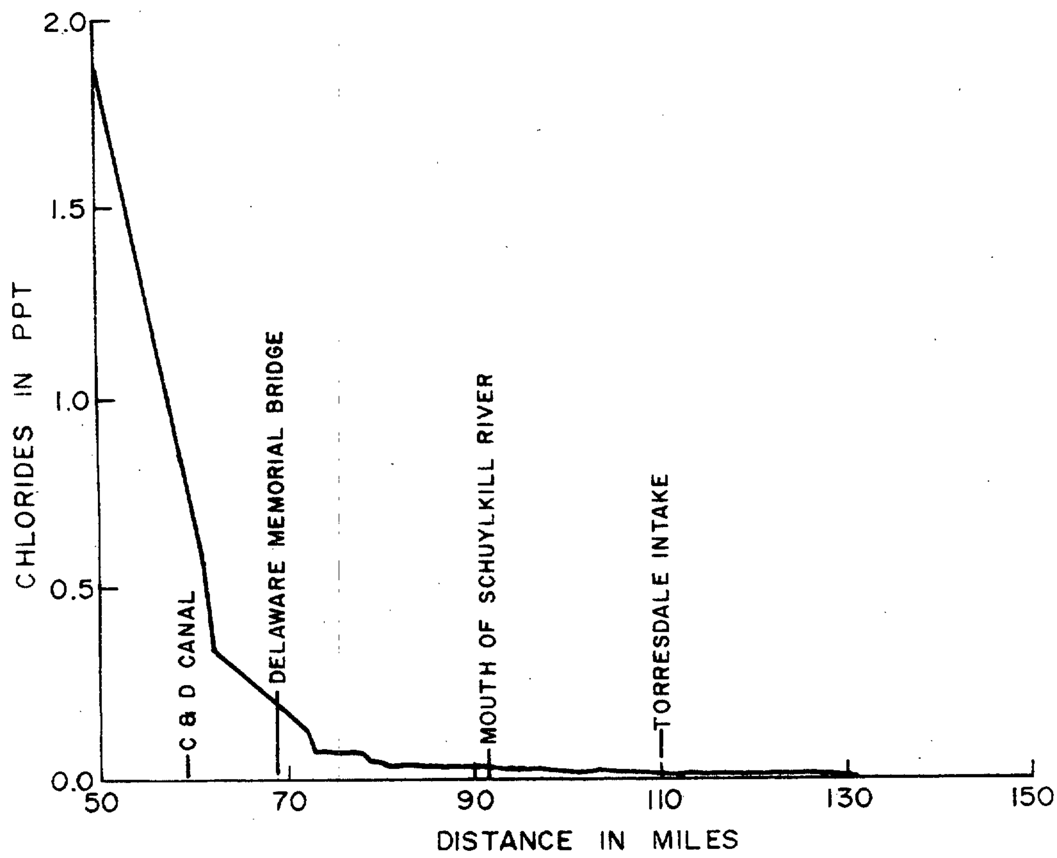
SYNTHESIS AND VERIFICATION OF MODEL

In order to conduct a 50 year simulation, a very large amount of data was acquired and organized. In addition to the freshwater inputs discussed above, 50-years of tidal elevations at Lewes, DE, (the seaward boundary of the estuary), and synoptic tidal elevation data at Town Point, MD, (the westward boundary of the Canal) were required. Methods used to fill in data gaps in tidal information available through the National Ocean Survey at these open boundaries of the system are presented in Appendix 1. That appendix also discusses further details of boundary salinity concentration and calibration of the model. A satisfactory calibration was obtained for the Branched MIT-TSIM Model. The verification of the calibrated model was determined through comparison of model output and field observation. A sensitivity analysis was performed to test the influence of chlorinity specification at Town Point, MD.

RESULTS OF LONG-TERM SALINITY SIMULATION

The Branched Model was exercised to simulate chloride distribution for the Delaware estuary over the 50-year period from water year 1928 through 1977. Refer to Figure 8 for a plot of 50-year average chloride distribution.

The analysis of the chlorinity variations, as computed by the model, showed the following. Almost invariably, the chlorinities at stations in the landward half of the estuary showed a strong correlation with the amount of freshwater inflows into the estuary. It was observed that the C&D Canal influence on chloride concentrations extended from Chester (RM 82) to Ship John Shoal (RM 37). Landward of that reach, the chlorinity concentrations were influenced more by the magnitude and the variation of flows from the Delaware River and other tributaries of the upper estuary. In



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
50 - YEAR AVERAGE CHLORIDES VS DISTANCE FROM OCEAN
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

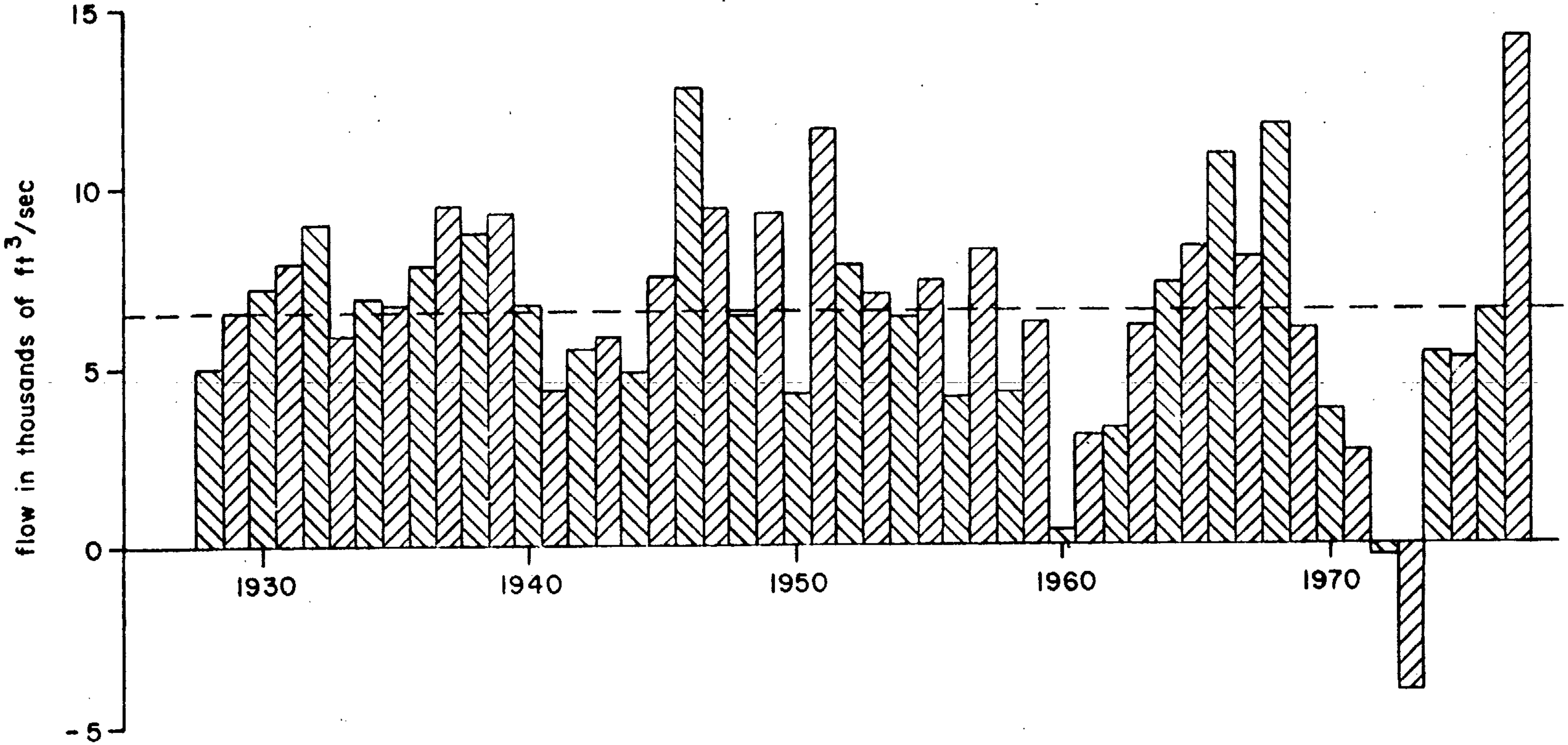
FIGURE 8

the seaward portion of the estuary, the chlorinity concentrations were influenced more by the variation of salinities, tides and sea level at the ocean boundary. The effect of the canal flows on the concentrations in the middle reaches of the Delaware estuary depended on: (a) the direction of average net flow through the canal; (b) the magnitude of the average net flow; and (c) the specified salinity concentrations at Town Point, MD, associated with eastward canal flows.

Figure 9 shows the yearly average net flows in the C&D Canal with positive direction corresponding to eastward flow. It can be seen that there is an appreciable year to year variation in the net annual flows through the canal over the simulated 50-year period. The net eastward annual flows vary from a maximum of 14,190 cfs to a minimum of 300 cfs. Only during two years of the simulation period are the net flows in the canal westward. The 50-year average of the net computed annual flows in the canal is 6,560 cfs eastward, based on post-enlargement dimensions.

PROBABILITY STUDIES

While the probability studies, as presented in the Plan of Study, originally envisioned calculation of salinity frequencies as a separate step, the long-term (50-year) simulations actually computed the necessary frequencies as part of an internal process. Therefore, the separate development of salinity frequencies was not required. However, as an illustration of salinity frequency, peak instantaneous chloride levels at RM 92.5 (mouth of Schuylkill River) were extracted from the model for each of the 50-years, and standard statistical procedures were applied to develop a probability curve (Figure 10). The curve shows the probability (percent chance of occurrence in any year) that a given peak salinity concentration could be expected to occur or be exceeded.



LEGEND

— — — 50-Year average flow : 6,560 ft^3/sec

Positive value indicates Eastward flow

DELAWARE ESTUARY
SALINITY INTRUSION STUDY
ANNUALLY AVERAGED COMPUTED NET
FLOWS IN THE C&D CANAL
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 9

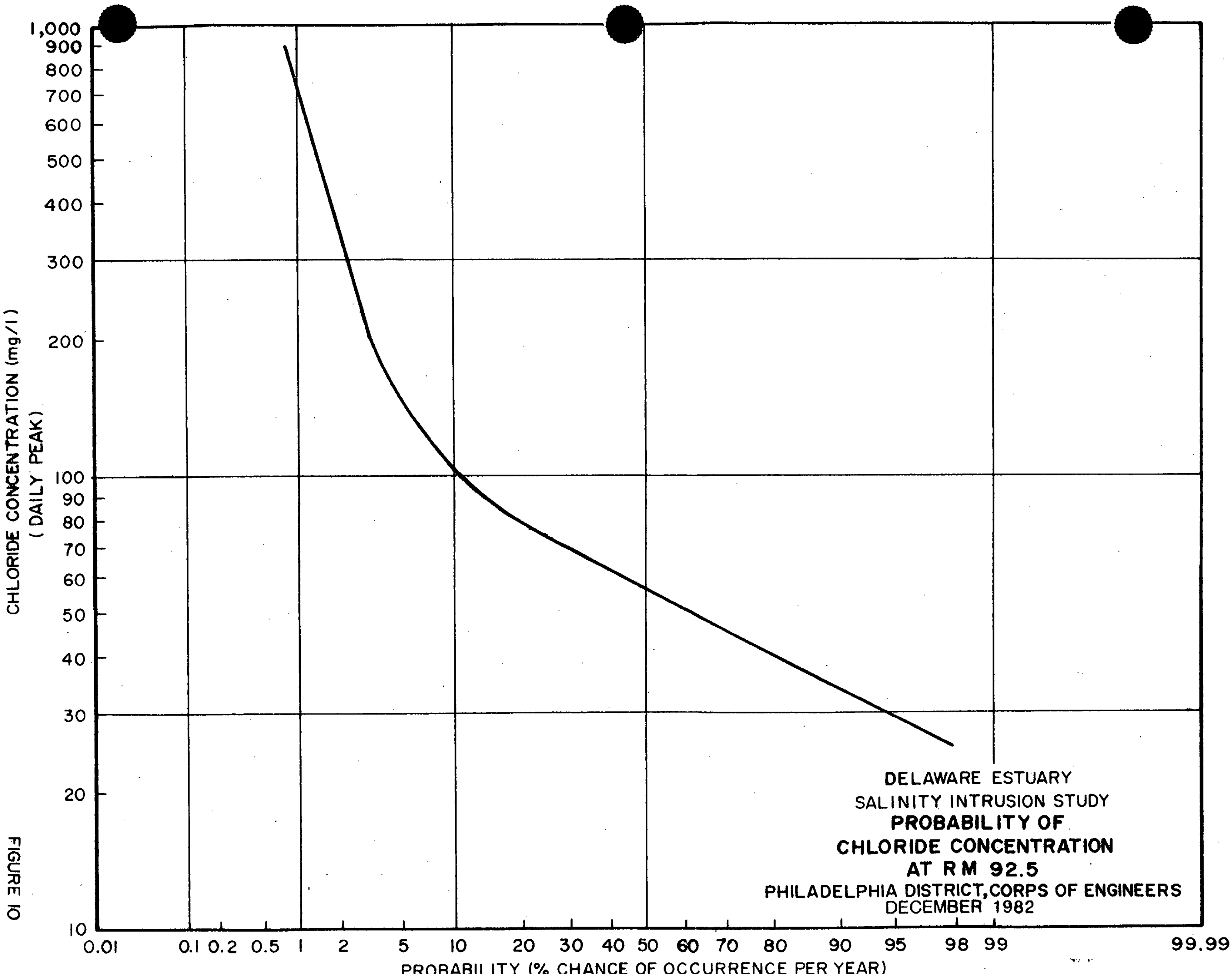

CHLORIDE CONCENTRATION (mg/l)
(DAILY PEAK)
1,000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0.01
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.99
PROBABILITY (% CHANCE OF OCCURRENCE PER YEAR)
DELAWARE ESTUARY
SALINITY INTRUSION STUDY
PROBABILITY OF
CHLORIDE CONCENTRATION
AT RM 92.5
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 10

AVERAGE ANNUAL COSTS

Table 5 presents a summary of salinity related average annual costs to withdrawal users of estuarine water with current water usage (based on a 50-year period of analysis). A detailed, year-by-year tabulation of costs by type of water use is given in Appendix 1.

TABLE 5

WITHDRAWAL USERS
AVERAGE ANNUAL SALINITY-RELATED COSTS
WITH CURRENT WATER USAGE (1978 price level)

TYPE OF WATER USE	WATER USE (MGD)	% OF TOTAL ESTUARY WITHDRAWAL	AVG. ANNUAL COSTS ($Mil.)	% OF TOTAL AVG. ANNUAL COSTS
Municipal Systems:				
Domestic	144	2.7	$10.918	55.1
Industrial/Commercial	91	1.7	1.361	6.9
Institutional	29	0.5	0.612	3.1
Municipal Facilities	(1)	(1)	0.614	3.1
Total Municipal	264	4.9	13.505	68.2
Direct Industrial Withdrawal:				
Once-Through Cooling	4857	90.1	0.120	0.6
Recirculating Cooling	22	0.4	0.672	3.4
Boiler Feed	16	0.3	0.455	2.3
Process	221	4.1	2.670	13.5
Sanitary and Other	11	0.2	0.316	1.6
Intake	(2)	(2)	2.069	10.4
Total Direct Ind. Withdrawal	5127	95.1	6.302	31.8

(1) All water supplied to municipal users is drawn through Municipal System Facilities (Torresdale, Lower Bucks, or Bristol).

(2) All direct industrial water use handled through private industrial intakes.

Of major significance, municipal system use represented a very sizeable percentage of total average annual costs, 68.2%, although utilizing only a small percentage of total surface water use, 4.9%. More specifically, domestic users of municipal water account for 55.1% of the total average annual costs incurred by surface water withdrawal users of estuarine water, while using only 2.7% of total withdrawals. One major reason for the large relative magnitude of domestic costs, in comparison to other uses, is attributable to costs incurred from soaps, cleaners, and softeners. These types of costs are not applicable to most other user categories. Also, domestic systems tend to use relatively small amounts of water in relation to that used by other municipal system users and the direct industrial withdrawal users. Usage by the latter, particularly, is on a much larger scale, (in million gallons per day) terms with equipment that tends to be less significantly impacted by the effects of salinity per equal increment of water use. Moreover, the exceedingly large number of domestic households (approximately 525,000) in comparison to the vastly smaller number of users in the other withdrawal categories (for instance, there are but three municipal suppliers and only 56 direct industrial withdrawers) also helps to explain the heavy percentage of total salinity costs that are incurred by the domestic category.

Direct industrial withdrawals represent 31.8% of the total average annual costs while accounting for an extremely large percentage of total water use, 95.1%. Of particular note, once-through cooling accounts for 90.1% of total estuarine water use, but merely 0.6% of total average annual salinity-related costs incurred. The major reason for the relatively low level of costs is the very corrosion resistant construction materials used in the once-through equipment. Once-through cooling involves running vast quantities of water continuously through a system designed to be very insensitive to the impact of fluctuating levels of salinity. However, such design requires extra capital costs.

Assuming current (1978) levels of water use, future salinity-related costs were estimated to the year 2030. Procedures that were utilized in the development of those costs are documented in Appendix 1.

DETERMINATION OF QUANTITY OF FLOW

BACKGROUND

In the Level B Study, DRBC determined the corresponding quantity of freshwater flow required for each of several possible salinity standards. Separate flow objectives were determined for both normal and low flow (drought) conditions. In determining the specific flow objectives, DRBC also satisfied the quantity goal of this study.

T e present salinity standards and anticipated modifications being considered by DRBC involve the following critical reaches or stations of the Delaware estuary.

1. River Mile 24.2 to 48.5 - This reach represents the location of natural seed oyster beds. Oysters are the most economically significant fishery in the estuary. While there is not an absolute correlation between oyster harvests and salinity, oyster experts believe that a more seaward location of the 15 ppt salinity concentration during the period between May through July provides for improved oyster survival on the natural seed-oyster beds by reduction in predation by the oyster drill, which can account for up to one third of summer oyster mortalities in the Delaware estuary.

2. River Mile 92.5 - This is the location for one of the present DRBC standards for chlorides (maximum instantaneous concentration of 250 mg/l) which, in turn, is the basis for the current flow objective of 3000 cfs at Trenton NJ (based on 1970 basin conditions and sea level).

3. River Mile 98.0 - The Level B Study selected this station to represent a reference point of the connection between the river and Potomac-Raritan-Magothy aquifer system. This aquifer system represents a major source of

ground water supply and, therefore, a major consideration for protection. The Level B Study recommended this station as the location for a proposed new standard, which, if met, would also assure reasonable salinity levels at other critcal points along the estuary.

4. <u>River Mile 110.4</u> - This is the location of the water supply intake for the City of Philadelphia at Torresdale. It is also the location of a present DRBC standard (maximum 15 day average chloride concentration of 50 mg/l).

DEVELOPMENT OF REVISED STANDARDS

As part of the Level B Study, the above standards and critical reaches or stations were reviewed to determine whether revisions were warranted. The study also considered various plans to achieve these standards and the corresponding flow objectives at Trenton in an attempt to determine the most reasonable combination of upstream plans and downstream salinity levels.

Numerous simulations using the MIT-TSIM Model were made to test the estuarine impacts of the various plans considered. DRBC also tested potential changes in basin conditions and various chloride averaging periods (ranging from instantaneous to 120 days).

As a result of these simulations, the Level B Study concluded that the design condition upon which the quantity objectives were to be determined should be the drought of record (the 1960s drought) recurring simultaneously with depletive water demands projected to the year 2000. The simulations for the Level B Study did not include data gathered during the recent drought (which ended in April 1982); this drought was much less severe than the 1960's drought. The model results reflected anticipated future growth in depletive water use and increased salinity projected to occur if the past trend of sea-level rise were assumed to continue through the year 2000. The model outputs were adjusted to take into account planned conservation measures during a drought to reduce depletive use 15 percent below the levels initially projected. Additional adjustments were made to account for anticipated diversions at Point Pleasant and increased bypassing of water around the Trenton gage by Yardley, Morrisville, and Trenton. The modeled Trenton flows for selected alternative plans developed in the Level B Study, are compared with the adjusted flows in Table 6.

TABLE 6

REQUIRED ADJUSTED FLOWS AT TRENTON, NJ
FOR VARIOUS MODELED FLOWS

Modeled Flow (cfs)	2,690	2,940	3,400
Adjusted Flow (cfs)	2,340	2,605	3,072

Typical examples of the type of summary data provided by the Level B Study is shown in Table 7.

TABLE 7

NEW YORK CITY AND NEW JERSEY EXPORTS VS. FLOW CAPABILITY AT MONTAGUE AND TRENTON IN YEAR 2000 DURING RECURRENCE OF THE 1964-1965 DROUGHT CONDITIONS

Alternative	Hydrologic Condition	Exports, mgd NYC	Exports, mgd NJ	Montague Flow (cfs)	Trenton Flow Capability (cfs)	Chloride Objective at RM 98 (mg/l) (30-day avg.)	Trenton Flow Needed for Salinity Control (cfs)
a	Normal	800	100	1,750			
	Drought Warning	600	75	1,650			
	Drought	480	60	1,600	2,315	121	3,072
b	Normal	800	100	1,750			
	Drought warning	600	75	1,650			
	Drought	480	60	1,600	2,315	180	2,605
c	Normal	800	100	1,750			
	Drought warning	600	75	1,650			
	Drought	480	60	1,600	2,315	220	2,340

Table 7 allows comparison of flows that would be needed in the Delaware River at Trenton in the year 2000, assuming a recurrence of the drought of the sixties to meet alternative chloride objectives of 121 mg/l, 180 mg/l, or 220 mg/l (maximum 30-day average) at river-mile 98. The comparison is based on an assumed set of variable diversions of water out of the Delaware Basin and the resulting sustainable average "summer" flow in the Delaware River at Trenton with a sequence of "normal", "drought-warning", and "drought" hydrologic conditions (as defined by the quantity of water in storage in New York City's upper-basin reservoirs). The "summer" flow capability at Trenton is the sustainable average flow for the four-month period from 1 June through 30 September, assuming no new storage reservoirs after the completion date of the Level B Study (1981). The salinity-control criterion would be applied at RM 98 to protect the quality of water in the Potomac-Raritan-Magothy aquifer system in the Camden, NJ, area.

In addition to the three alternatives shown in Table 7, many other combinations of water exports, Montague flows, Trenton flows, and chloride objectives were considered in the Level B Study. The Study Group recommended alternative "a", shown in Table 7, as the preferred plan.

Since completion of the Level B Study, representatives of the parties* to the U.S. Supreme Court's 1954 decree, which allocated water supplies among the exporters and in-basin users, have made tentative recommendations for chloride objectives and corresponding salinity-control flows. These recommendations call for a compromise between alternatives "a" and "b" of Table 7. The ultimate objective for chlorides at RM 98 would be a maximum

*The parties to the decree are the States of Delaware, New Jersey, New York, and Pennsylvania, and the City of New York.

30-day average concentration of 150 mg/l, requiring a level of stream flow regulation represented by a four-month average "summer" flow of about 2,880 cfs in the Delaware River at Trenton under projected year-2000 conditions. These chloride and flow objectives could be achieved only after modification of Prompton and Francis E. Walter Reservoirs to provide long-term active storage capacity, as well as construction of the proposed Merrill Creek Reservoir. For the interim period, the Supreme Court decree parties have suggested a temporary chloride objective of 180 mg/l (maximum 30-day concentration), which would require a lesser level of flow regulation represented by an average "summer" flow of 2,605 cfs.

The DRBC is currently (1982) awaiting the final recommendations of the decree parties, after which proposals to incorporate salinity-control and flow objectives in the DRBC's Comprehensive Plan will be subjected to public review and hearing, and if acceptable to the Commission, these objectives (or some modification of them) could become amendments to the Comprehensive Plan. It is anticipated that this process will be completed in 1983.

ESTUARINE ECOSYSTEM CONSIDERATION

Previous sections of the report have indicated the importance of the period between May and August to the estuarine ecosystem. Furthermore, variations in salinity from year to year can cause problems to the ecosystem, particularly during extended dry periods when the available flow is not sufficient to meet all estuarine needs.

Current Delaware River reservoir operations attempt to store water during high winter and spring runoff periods for subsequent release during low flow periods. Approximately nine percent of the Basin drainage area is controlled by major water supply reservoirs. Normal operating procedures vary with each reservoir, but when necessary, filling tends to reduce streamflows prior to spring. Consequently, the estimated amount of late spring freshwater flow reduction that is anticipated by year 2000 (even under worst case conditions) would change the flow at Trenton by only a few percent. This is well within the level of natural variation and should not cause a noticeable change in estuary aquatic productivity.

Estuary management by DRBC is designed to repel salinity intrusion at an upper estuary station during periods when undesirably high concentrations would otherwise occur. When flow is regulated during the low-flow months (June through November), there would be a tendency to lower salinities over the oyster beds (RM 24.2 to 48.5) and elsewhere in the lower estuary. The beneficial effect of the resulting improved oyster predator control would be partially offset by the decreased levels of freshwater flow during the preceding months as compared to unregulated flows. While not as measurable, similar results would generally occur for other aquatic species.

A quantitative evaluation of the net effects on the aquatic population that could result from various flow objectives and flow levels considered by DRBC cannot be made. Estuarine productivity involves many factors, of which salinity is only one. Each specific flow objective does relate to relative levels of estuary salinity, either lower or higher, depending on the season; these levels can be qualitatively addressed. Selection of a plan with a Trenton flow objective in the range from 2,605 cfs to 3,072 cfs would reduce the summer freshwater flow objective at Trenton as compared to the flow required to meet the existing standard for salinity control. However, the future conservation management plan, particularly that proposed for drought and drought-warning conditions, would partially compensate for the reduced level of flow at Trenton. The effect of regulating the estuary under one of the cited Level-B plans would tend to produce for an overall shift of the aquatic ecology toward more salinity tolerant (marine) species in the estuary. Such a shift would affect many of the species on which man has placed a high value, including commercial species.

Computer simulations performed by DRBC indicated that a recurrence of the 1960's drought of record with year 2000 projected level of unrestricted human water consumption and a rising sea level of 3.7 millimeters per year would cause an average salinity increase of less than 0.20 ppt during a 120-day (summer) period at RM 49 (upper limit of the oyster beds) over that occurring in 1965. This change is equivalent to about a three percent increase in salinity over that observed. For comparison, the difference between salinity values between drought and normal years is about 4.5 ppt.

With the river unable to provide sufficient water for unrestricted human use under drought conditions, the amount of water allowed for human use during this period must be controlled. The Delaware River Basin Commission is expected to require that water consumers restrict their withdrawals during future drought periods in order to limit salinity intrusion. Such restrictions were put into effect during the recent drought of the early 1980's.

An unanswered question concerns the potential indirect effect of freshwater flow regulation on salinity-related residual currents in the lower estuary. It has been reported that these currents aid in the transport of fish eggs, larvae and for some species in juvenile forms, up the estuary to optimal nursery areas. If these residual currents were disrupted, many valuable recreational and commercial species, (including blue crab, weakfish, striped bass, Atlantic menhaden, bay anchovy (forage), and spot (forage)) could be adversely affected. Residual currents are known to be influenced by freshwater flow, salinity gradients, the Coriolis force, wind, geometry of the estuary and possibly other presently unknown factors. The relative contribution of each of these factors to the total residual current is unknown at this time. However, among the known factors affecting residual currents, only the freshwater flow into the estuary and, indirectly, the salinity gradients are subject to change by streamflow regulation; the Coriolis force, wind, and estuarine geometry would be unaffected. We can deduce that as long as the level of freshwater flow is not reduced below that observed in the 1960's drought and that is the goal of DRBC, then this transport mechanism will not be seriously jeopardized.

In summary, while the fish and wildlife objectives have not been specifically defined, the potential salinity and flow objectives associated with the alternative Level-B plans reasonably considered the effects of salinity on the ecological system in determining the overall needs of the estuary.

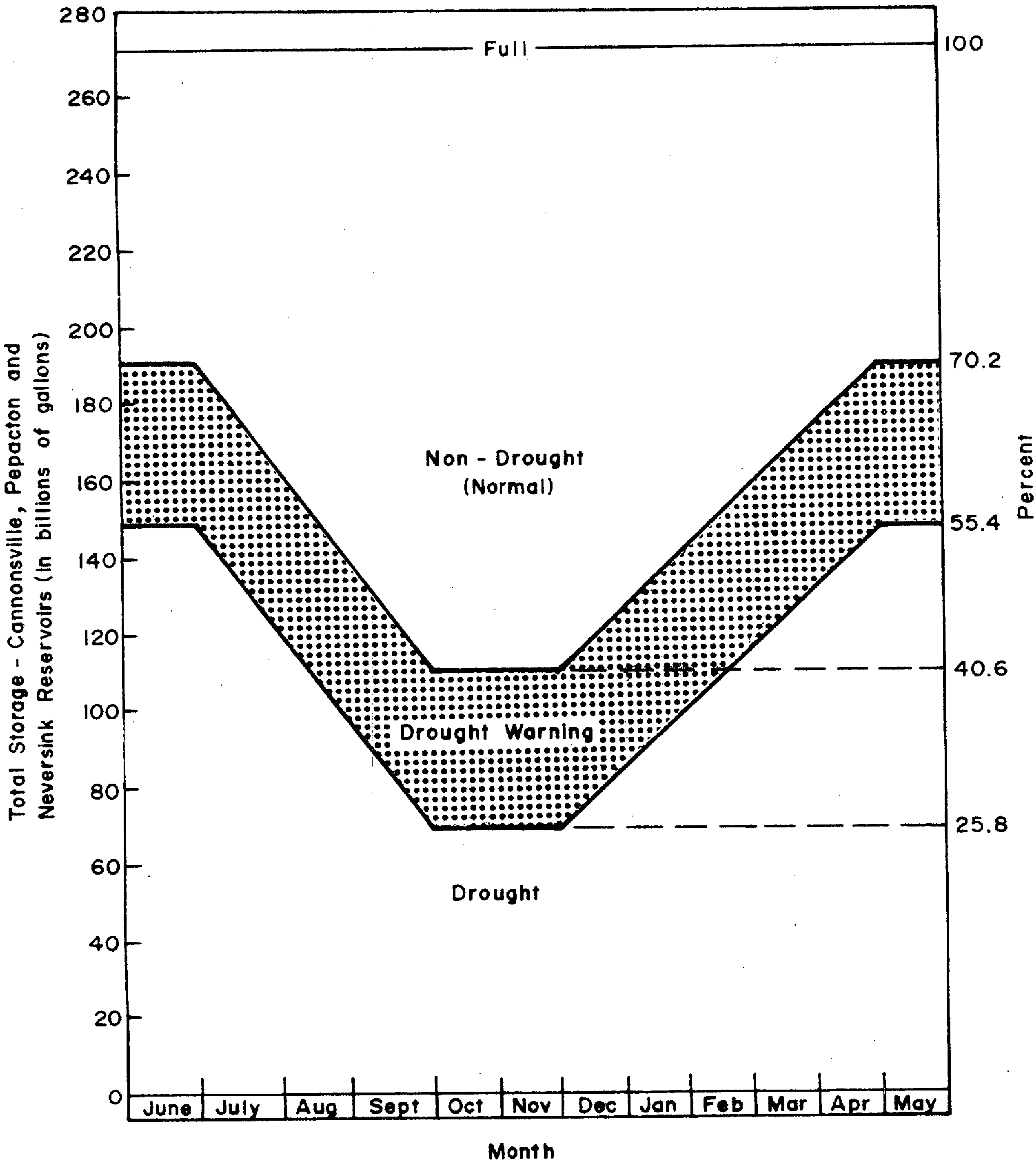
DEVELOPMENT OF THE BASIN PLAN

DROUGHT AND NORMAL CONDITIONS

The parties to the 1954 Supreme Court decree have tentatively proposed that for purposes of operations for salinity control and water conservation the hydrologic conditions of the basin be defined by the "rule curve" shown in Figure 11. The rule curve defines non-drought (normal), drought-warning, and drought conditions in terms of the total water storage at any given time of the year in New York City's Delaware River Basin reservoirs (Pepacton, Cannonsville, and Neversink), which account for about 90 percent of the Basin's entire active long-term storage capacity for water. Flow objectives at Montague and Trenton would vary seasonally and with storage and the location of the 250-mg/l chloride concentration in the Delaware estuary.

RECENT DROUGHT

For the first time since the drought of the 1960's, the Delaware River Basin Commission declared a water-supply emergency on 15 January 1981. This



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
PROPOSED "RULE CURVE" FOR
DROUGHT EMERGENCY OPERATIONS
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 11

declaration ordered a mandatory ban on nonessential uses of water throughout the region. This action proved to be necessary as the amount of rainfall experienced in the Delaware River Basin dropped sharply in July-September 1980. As a consequence, surface and groundwater supplies were depleted, particularly in the northern part of the Delaware Basin. The water storage in the three New York City water supply reservoirs in the upper Basin fell to 41 percent of their total combined capacity by early October, causing DRBC to declare a drought warning (October 17, 1980). In late November and early December, the capacity of the NYC reservoirs decreased further to about 30 percent, ultimately causing DRBC to declare a drought emergency.

Following the emergency declaration, the Delaware River Basin remained in a drought (fluctuating from relatively severe to relatively mild) for many months. Water supply storage in the three New York City reservoirs increased substantially during the first three months of 1982, eventually reaching normal storage levels. Consequently, the drought emergency status was lifted by DRBC on 27 April 1982.

SUMMARY AND CONCLUSIONS

The Corps' analysis served to meet the probability goal (goal (A)) of the study. Salinity-cost relationships were developed for all direct water users of the Delaware estuary. The previously developed model of the Delaware estuary (MIT-TSIM) was modified as part of this study to reflect more accurately the interaction of the Delaware estuary and the Chesapeake and Delaware Canal. This model, identified as Branched MIT-TSIM, was used to simulate long-term salinity concentrations incorporating the post-enlargement condition of the Chesapeake and Delaware Canal. The long-term salinity concentrations provided the continuous data needed to determine the probabilities of salinity levels in the estuary and served as input for the economic (ECOSALT) model. That model was developed as part of this study and was used to determine average annual salinity-related costs to estuarine water users.

The development of average annual costs to direct withdrawal users of water from the Delaware estuary constitutes a step in the formulation of judicious water resource management policies for the estuary. The economic model can analyze the potential of various plans for salinity-related costs to estuarine water users. Thus, the economic impacts of existing and future diversions, consumptive uses, and flow regulation on these users can be evaluated. Using the simulated long-term salinity concentrations, probabilities of various salinity levels were determined.

The range of possible impacts of salinity variation on the fish and wildlife resources was also presented.

The quantity goal (goal (B)) was met by the DRBC's Level B Study in conjunction with input provided by this study. The Level B Study completed in May 1981, identified various alternative flow objectives for the Delaware River at Trenton for protection of water users along the Delaware estuary. These objectives were based on controlling the invasion of salinity as measured by the maximum 30-day average chloride concentration at River Mile 98. Since completion of the Level B Study, the parties to the 1954 decree of the U.S. Supreme Court have made tentative recommendations for salinity and flow objectives that are within the range of those considered by the Level B report. These recommendations have been presented to the public for review and comment, after which the decree parties expect to make final recommendations to the DRBC. From these recommendations, the DRBC staff will prepare formal preliminary proposals to amend the Comprehensive Plan to include new objectives for salinity and corresponding salinity-control flows. These staff proposals will then be subjected to public hearing and review. After this review, staff analysis of public viewpoints may lead to modifications of the preliminary proposals for Comprehensive Plan amendments. The final staff proposals would then be submitted to the five Commission members for decision by majority vote. The Commissioners themselves may further modify the staff proposals before deciding what salinity and flow objectives to adopt.

RECOMMENDATION

No recommendations are made for Federal projects. However, the technical data developed as part of this study served as a valuable aid and guide to Delaware River Basin Commission's efforts in establishing revised salinity-control objectives to protect the water users of the Delaware estuary. The salinity objectives are designed to protect municipal and industrial water supplies, including the Potomac-Raritan-Magothy aquifer system in the Camden, NJ, area, and estuarine fisheries.

This report will be distributed to agencies that have an interest in the development and management of water resources in the Delaware Basin.

It is recommended that this report be approved as the final report.

Roger L. Baldwin

ROGER L. BALDWIN
Lieutenant Colonel, Corps of Engineers
Commanding

DELAWARE ESTUARY SALINITY INTRUSION STUDY

TECHNICAL STUDIES

US Army Corps of Engineers
Philadelphia District

APPENDIX 1

DELAWARE ESTUARY
SALINITY INTRUSION STUDY

APPENDIX 1
TECHNICAL STUDIES

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF TABLES

TABLE OF CONTENTS (CONT'D)

LIST OF FIGURES

APPENDIX I

TECHNICAL STUDIES

INTRODUCTION

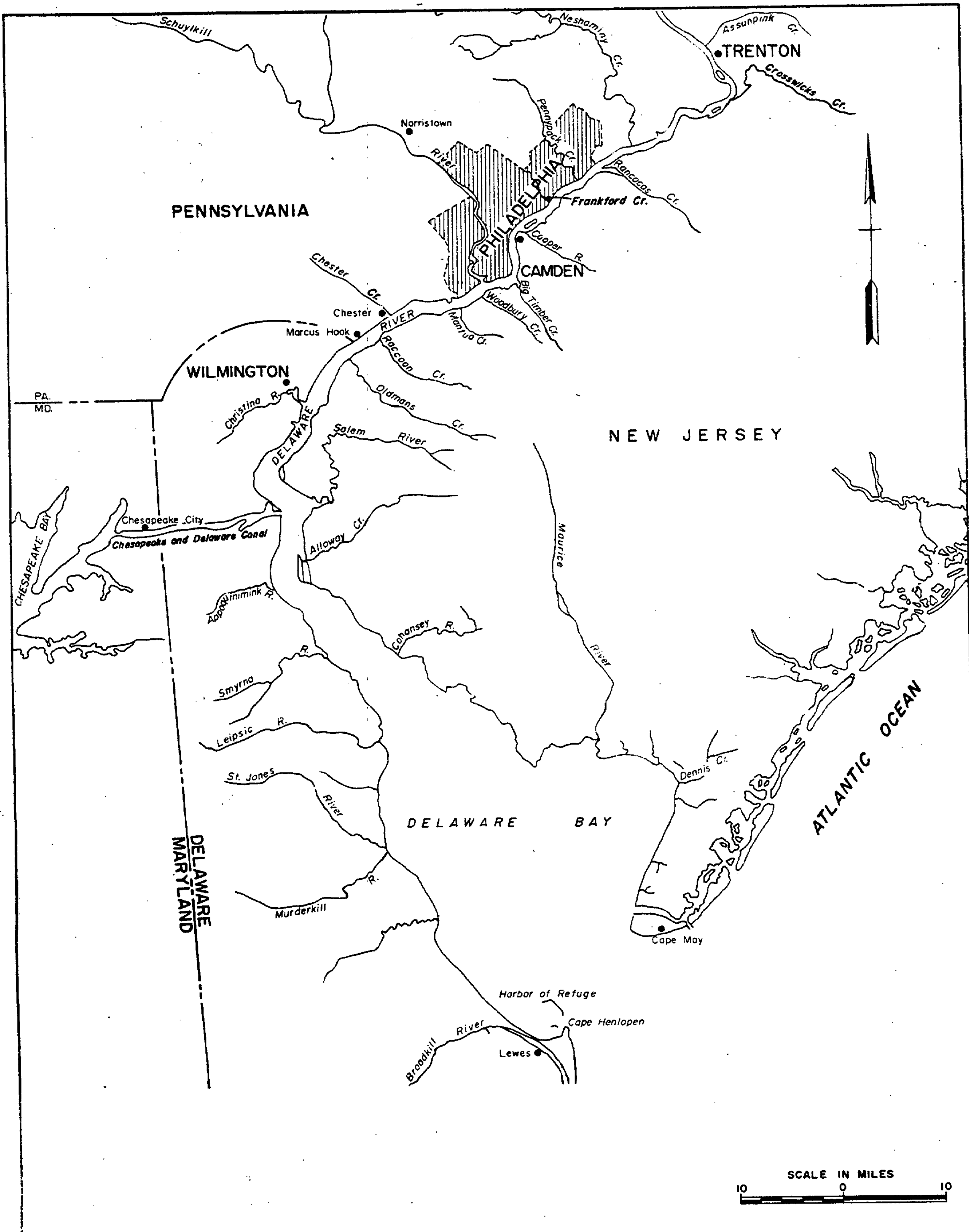
This appendix dicusses the technical studies that were undertaken to determine salinity-related costs to direct water users of the Delaware estuary. Results of previous and current investigations are presented. Also, descriptions of the methodologies, assumptions, and procedures used in conducting prior and current investigations are presented. Individual reports that are the basis for this appendix are on file in the Philadelphia District office.

PRIOR STUDIES

TRANSIENT SALINITY INTRUSION MODEL (MIT-TSI)

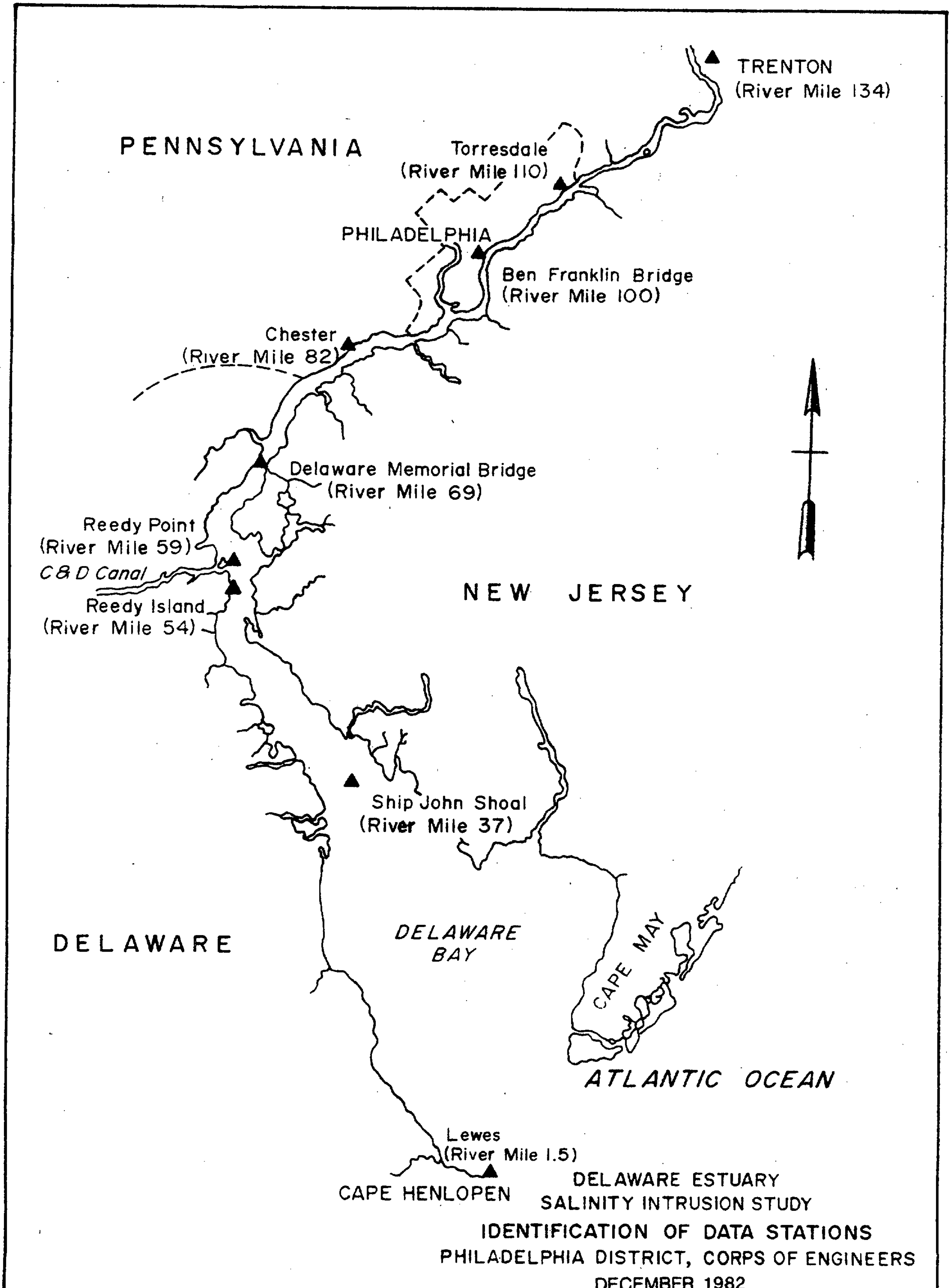
• BACKGROUND AND DESCRIPTION OF MODEL. As the 1960's drought ended, the Delaware River Basin Commission (DRBC) urged studies to define the relationship between the river flow and salinity in the Delaware estuary. In 1972, Drs. M.L. Thatcher and D.R.F. Harleman, then of Massachusetts Institute of Technology (MIT), with the support of the Office of Sea Grant of the National Oceanic and Atmosphere Administration, developed a Transient Salinity Intrusion Mathematical Model for the Delaware estuary. This model and its subsequent modifications became the basis for numerous analyses of salinity intrusion in the Delaware estuary as discussed below.

The Delaware estuary, shown in Figures 1-1 and 1-2, is defined as the body of water bounded by the Atlantic Ocean (a line between Cape Henlopen in Delaware and Cape May in New Jersey) and the rapids at Trenton, NJ. The primary inflow tributaries are shown in Figure 1-1; data stations are shown in Figure 1-2. There is a sea-level connection to upper Chesapeake Bay through the Chesapeake and Delaware (C&D) Canal.



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
DELAWARE ESTUARY AND
PRINCIPAL TRIBUTARIES
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE I-1



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
IDENTIFICATION OF DATA STATIONS
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 1-2

The general characteristics of the tidal river are that it is well-mixed (i.e. there is little difference between the salinities at the bottom and those at the surface), with flow being primarily tidal. Delaware Bay, which forms the seaward 48-mile reach of the estuary below Liston Point, is moderately stratified vertically during periods of high freshwater runoff, but becomes vertically well mixed during periods of low runoff. The mean tidal range of 4.1 feet at the ocean boundary increases in the upstream direction to approximately 6.8 feet at Trenton NJ.

The original Transient Salinity Intrusion Model, identified as MIT-TSI by its developers, is a one-dimensional, deterministic (i.e. it performs a numerical solution to physical equations governing the motion of water and the transport of chlorides within the Delaware estuary), longitudinal variable-area model of unsteady tidal hydrodynamics and salinity. This model numerically solves the continuity and longitudinal momentum equations and is linked to the salt balance equation through a relationship between salinity and density.

The original model was calibrated using data from the Corps of Engineers' Waterways Experiment Station salinity flume and verified with field data from the Delaware, Hudson, and Potomac estuaries. The model has the capability to predict the seasonal variation of salinity distribution as a function of longitudinal distance in the Delaware River under transient conditions of freshwater inflow and ocean tidal elevations.

• MEASUREMENT OF SALINITY. One unit of measurement of salinity is milligrams per liter (mg/l), which represents the total weight of dissolved solids in one liter of water sample. Salinity can also be measured in parts per thousand (ppt) and parts per million (ppm). The ppt units can be converted to ppm units, which are equivalent to concentrations in mg/l for most engineering purposes.

Salinity, which corresponds roughly to Total Dissolved Solids (TDS), can be expressed as Chlorides (Cl). Delaware estuary relationships between Chlorides and Total Dissolved Solids developed by Keighton were used in this study and are expressed as follows:

Cl Range (mg/l)	TDS (mg/l)
0-20	8.25 Cl
20-120	2.41 Cl + 118
120-2,000	1.90 Cl + 180
2,000-19,000	1.80 Cl + 380

Discussions pertaining to "salinity" in the following paragraphs correspond to salinity measured by TDS.

MODIFIED SALINITY INTRUSION MODEL (MIT-TSIM)

• NEED FOR MODEL. In 1977, DRBC indicated the need for a tool to account for the long-term effects of reservoir operations and of consumptive freshwater withdrawals on the salinity distribution in the Delaware estuary. Earlier investigators had attempted to determine the relationship between freshwater inflows and chlorinity through use of empirical relationships to define salinity as a function of the observed flow at Trenton. Although such empirical models are usually able to describe the observed conditions with fair accuracy, they cannot predict the long-term effects of year-round changes in flows or other salinity-controlling factors resulting from reservoir operations, increased diversions or depletive uses of water from the Delaware River Basin, or long-term change in sea level.

• MODIFICATION. As a result of the stated need, DRBC contracted with Drs. Thatcher and Harleman to improve the original model developed in 1972. The MIT-TSI Model in its original form was a useful and tested tool for predicting salinity intrusion. Nevertheless, the original model required modification, to calculate for a period of one or more water years, time-varying salinity distribution caused by natural and man-made conditions. For this long-term application, the following modifications were made:

a. In order to handle large volumes of input data and provide for more precise accounting of ocean and tributary boundary conditions, special purpose data handling computer programs were written.

b. Whereas the original model assumed that tributary inflows were of zero salinity, the modified model provided for specification of inflow salinity and tributary inflow. These modifications more accurately defined mass balance and permitted studies of consumptive withdrawal (freshwater) and incorporation of the Chesapeake and Delaware Canal as an inflow tributary with seasonal variation.

c. Whereas the original model assumed a tidal period of constant duration, a more precise specification of varying tidal period was developed. This specification enabled the user to specify an observed high and low tide time series as the hydraulic ocean boundary condition.

d. The location of as many as five user specified isochlors was provided for in the calculation.

e. The density in the momentum equation was more precisely defined as a function of both salinity (chlorinity) and temperature, (one average temperature being estimated for the entire estuary). In this manner, the model accounted for the seasonal variations of temperature.

The modified model was referred to as MIT-TSIM.

• CALIBRATION AND VERFICATION. The modified model was run for a low flow water year (1 October 1964 - 30 September 1965) or a total of 704 tidal cycles. The calculations proceeded at a time step of approximately three minutes over the entire year, or a total of about 176,000 time steps. The model was calibrated over a quarter-year period and verified over a three-quarter year period. The model results were compared with chlorides determined from specific conductance values observed at United States Geological Survey (USGS) quality observation stations.

• CONCLUSIONS. The final calibration and verification was successful, even though ignoring the Chesapeake and Delaware Canal for water-year 1965. One cannot conclude, however, that the canal's effect would be negligible, particularly since the cross-section of the canal was enlarged after 1965. Consequently, the MIT-TSIM Model cannot be used to predict the effects of the C&D Canal. Also, local wind effects were not accounted for in the model runs. Although wind effects are generally short-term, they occasionally persist for several days. Despite these limitations, the modified model is a valuable tool for simulation studies designed to compare the estuarine response to different projected conditions of upstream flow regulation.

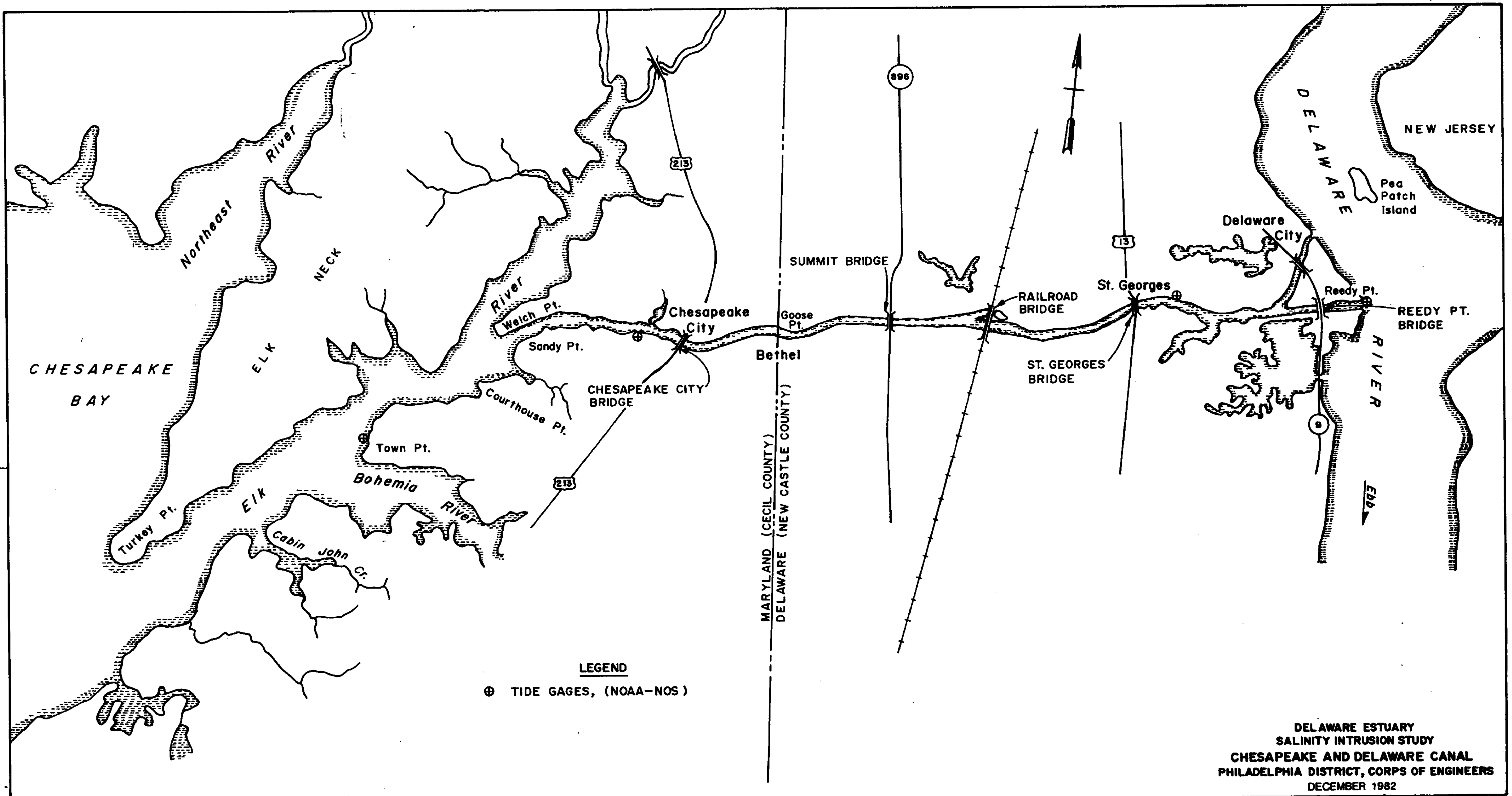
CHESAPEAKE AND DELAWARE CANAL EFFECTS ON SALINITY OF DELAWARE ESTUARY

Since the modified Transient Salinity Intrusion Model (MIT-TSIM) did not predict the effects of the C&D Canal on salinity and tidal conditions in the Delaware estuary, the DRBC contracted once again with Drs. Thatcher and Harleman along with Dr. T.O. Najarian to incorporate the C&D Canal as a tidal branch of the Delaware system into the modified MIT-TSIM Model, or into any other model.

• BACKGROUND. The C&D Canal is a man-made waterway connecting Chesapeake Bay with Delaware Bay. The canal extends over a distance of 17.5 miles from Reedy Point, DE, on the Delaware estuary to Welch Point, MD, on the Elk River, a tributary of Chesapeake Bay. Figure 1-3 shows the sea-level canal, which was originally designed to accomodate ship traffic of moderate size. A significant enlargement of the canal was constructed between 1963-1975 to accomodate larger ship traffic. The enlargement consisted of deepening the canal from 27 to 35 feet (below mean low water) and widening the bottom width from 250 to 450 feet. The channel cross section is trapezoidal with side slopes of 2:1 (horizontal:vertical).

• HYDRODYNAMICS. The flow in the canal is controlled by the Delaware estuary tide height at its eastern boundary, with a mean tide range of 5.5 feet, and by the Chesapeake Bay tide height at its western boundary, with a mean tidal range of 2.2 feet. The Delaware system is funnel shaped, narrowing from a wide mouth to a relatively narrow section at the junction with the canal at Reedy Point, about 50 nautical miles from the bay entrance. The Chesapeake system is much larger, approximately 150 nautical miles from the entrance Capes to the mouth of the Elk River, with an irregular width and relatively shallower depths.

As a result of the physical differences, tides at both ends of the canal are approximately 10 hours out of phase. A high water entering Delaware Bay at the juncture with the ocean requires about 4 to 5 hours to reach Reedy Point. The same ocean high water entering Chesapeake Bay requires about 14 to 15 hours to reach Courthouse Point near the western end of the canal. The direction of flow through the canal changes in accordance with tidal amplitude and phase and water densities (i.e., salinities) at the two ends of the canal.



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
CHESAPEAKE AND DELAWARE CANAL
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

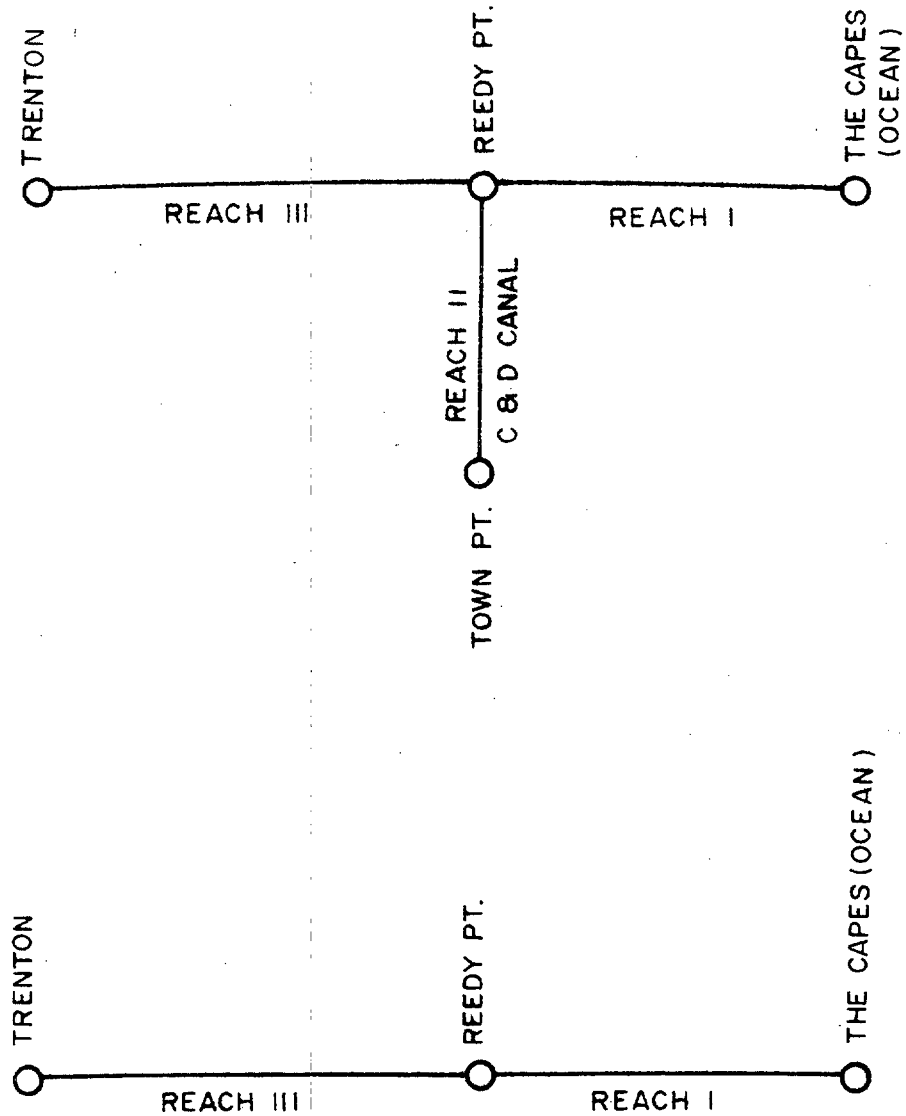
FIGURE I-3

Salinities in the Elk River can vary from zero (freshwater) to 9.0 ppt during the year, with an average of about 1.3 ppt. Average salinities in the Delaware River channel in the vicinity of the eastern end of the canal vary between 1.0 ppt and 8.0 ppt during high and low flow periods, with an average of about 5.0 ppt.

To assess the impact of the flows in the C&D Canal on the salinity distribution in the Delaware estuary, the investigators tried two approaches. First, the Delaware estuary and the C&D Canal were analyzed as reaches of a network system, and second, the C&D was treated as a tributary that delivers or withdraws net non-tidal flow into or out of the Delaware estuary. To conduct this investigation two separate mathematical models, the MIT-Dynamic Network Model (MIT-DNM) and the MIT-TSIM were used.

• APPLICATION OF MIT-DYNAMIC NETWORK MODEL. The MIT Dynamic Network Model was used to determine the salinity distribution in the Delaware estuary when its hydrodynamics are coupled to the tidal flows in the C&D Canal. This one-dimensional model was developed in 1972 by Daily and Harleman and is designed to predict temperature, biochemical oxygen demand, and dissolved oxygen, in addition to salinity.

The model was applied utilizing a network consisting of three reaches. The first reach is from the canal confluence with the Delaware (at Reedy Point) to the ocean, the second reach is the C&D Canal itself, and the third is the Delaware estuary from Trenton downstream to the canal (see Figure 1-4). Two approaches were taken to compare the ensuing salinity distributions in the Delaware estuary. First, the network was investigated as a three reach system in which the C&D Canal was assumed as a separate reach, and second,



DELAWARE ESTUARY

SALINITY INTRUSION STUDY

TWO AND THREE-REACH DYNAMIC NETWORK MODEL CONCEPTUALIZATION

PHILADELPHIA DISTRICT, CORPS OF ENGINEERS

DECEMBER 1982

FIGURE I-4

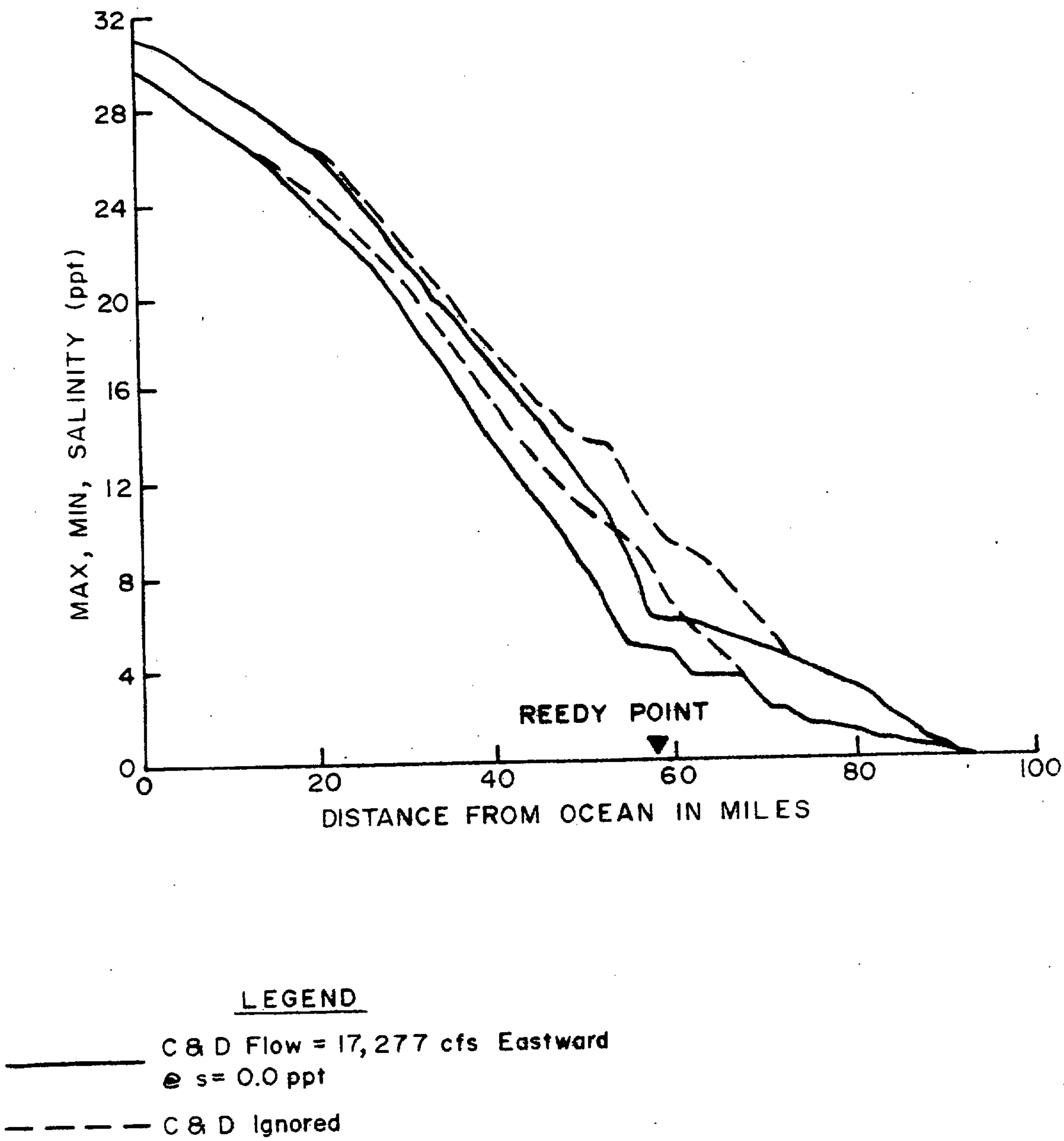
the network was investigated as a two-reach system with the C&D Canal being ignored. Simulation runs were conducted for the period of available boundary data in the C&D Canal. The most complete set of data was gathered by the Chesapeake Bay Institute during April and May 1975. The data consisted of two-dimensional current measurements at two stations within the canal for a period of one month, and measurements of specific conductance at various stations during the daylight hours from 5-8 May in 1975. The period 1-8 May was selected for model simulations.

• SIMULATION RESULTS. Utilizing the model, and allowing a variable C&D Canal net flow governed by the tidal elevations at either end of the canal, runs with and without the C&D Canal for the 1-8 May 1975 period indicated a salinity increase of almost 2.0 ppt for a station 5.8 miles downstream of the canal when the C&D was considered. The hydrodynamics of the Delaware system was not appreciably affected by the canal. Little difference in tidal discharges in the Delaware estuary was computed with and without the influence of the canal.

• APPLICATION OF MIT-TSIM MODEL. The application of the 1978 MIT-TSIM Model requires that the C&D Canal be treated as a tributary with either a net inflow with a prescribed salinity for each tidal period or as a net outflow for each tidal period. This investigation attempted to sensitize the potential variation of salinity distribution in the Delaware estuary when canal flows were ignored as opposed to being approximated by a net-flow assumption, particularly during extreme flow and salt-boundary conditions.

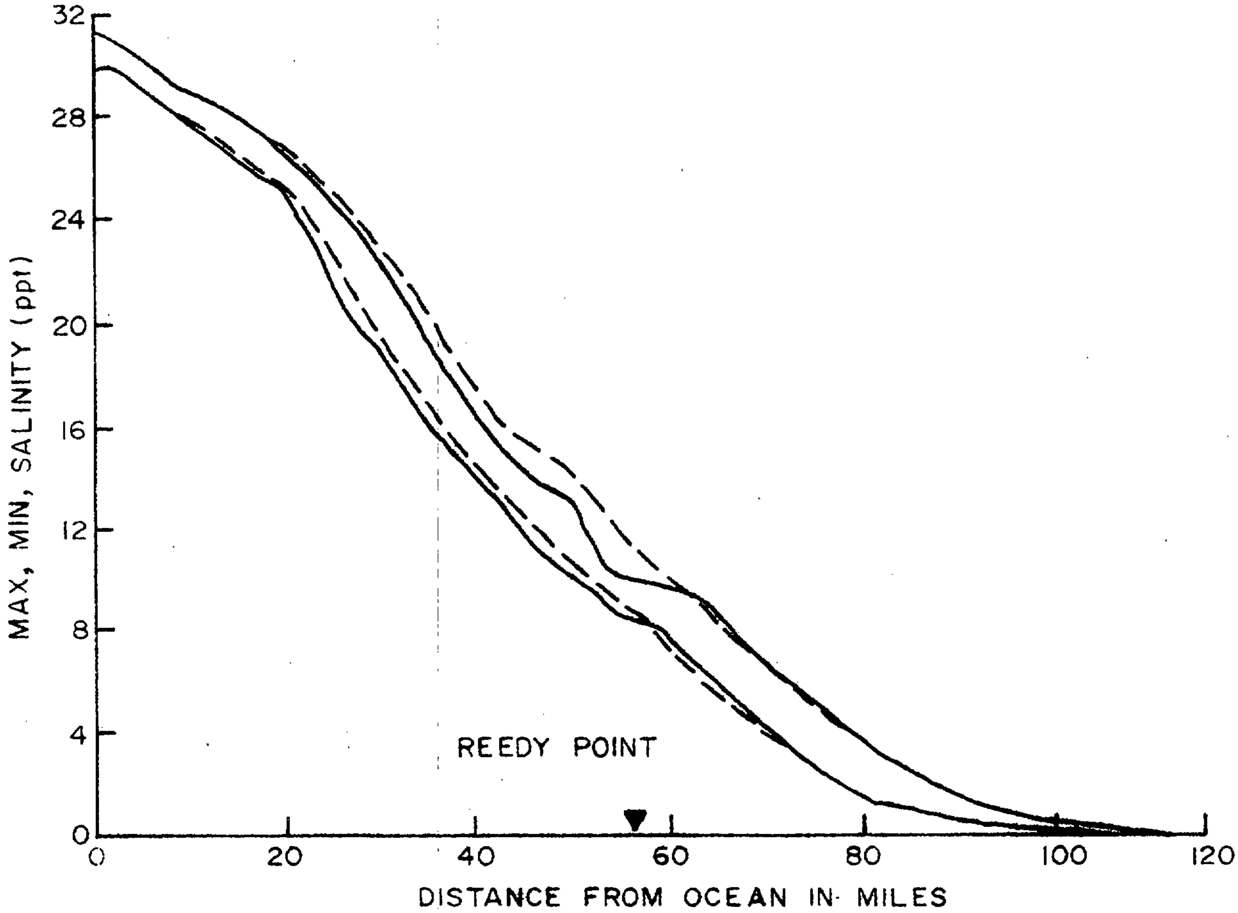
To generate a set of extreme flow conditions in the canal, non-tidal flows computed by the Chesapeake Bay Institute were used. The range of non-tidal flows was taken as the mean observed flow plus or minus one standard deviation (14,827 cfs). Thus, the net non-tidal flows considered were (2,450 + 14,827) cfs eastward and (2,450 - 14,827) cfs westward. Positive flows indicate eastward non-tidal discharge (from the Chesapeake Bay to the Delaware estuary). Salinity concentrations of the flows must be specified when they are eastward. Two extreme conditions were assumed: (1) zero salinity in the eastward flow, s = 0 ppt; and (2) high salinity in the eastward flow, s = 10.0 ppt. No salinity specification is required when the flow in the canal is westward, since, in those cases, it is assumed that the canal acts as an outlet that removes water of the same salt concentration as in the Delaware estuary at its confluence with the canal.

• SIMULATION RESULTS. The effect of the C&D Canal on the Delaware salinity at the end of five days in the vicinity of Reedy Point for various conditions is shown in Figures 1-5, 1-6, and 1-7. These curves show the trend for reduced salinity in the estuary when the canal flows are eastward (Figures 1-5 and 1-6). Figure 1-7 shows the trend for increased salinity when the canal flows are westward. The curves of Figure 1-5 show that the maximum and minimum salinities in the estuary in the vicinity of Reedy Point are reduced by about 4 ppt (30 percent reduction of maximum salinities and 40 percent reduction of minimum salinities) with easterly canal flows of zero salinity (freshwater) compared to the "no canal flow" simulation. Figure 1-6 shows that increasing the C&D Canal salinity specification to an extreme of 10 ppt results in much smaller reductions of Delaware estuary salinities compared to those exhibited in Figure 1-5. Figure 1-7 reveals that, for the condition tested, the westward canal flow increased the Delaware estuary salinity by about 3 ppt in the vicinity of Reedy Point (38 percent increase in the minimum salinity and 30 percent increase in the maximum salinity) compared to the "no canal flow" simulation.



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
SALINITY PROFILES WITH / WITHOUT CANAL FLOWS
(ZERO SALINITY IN ELK RIVER)
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 1-5



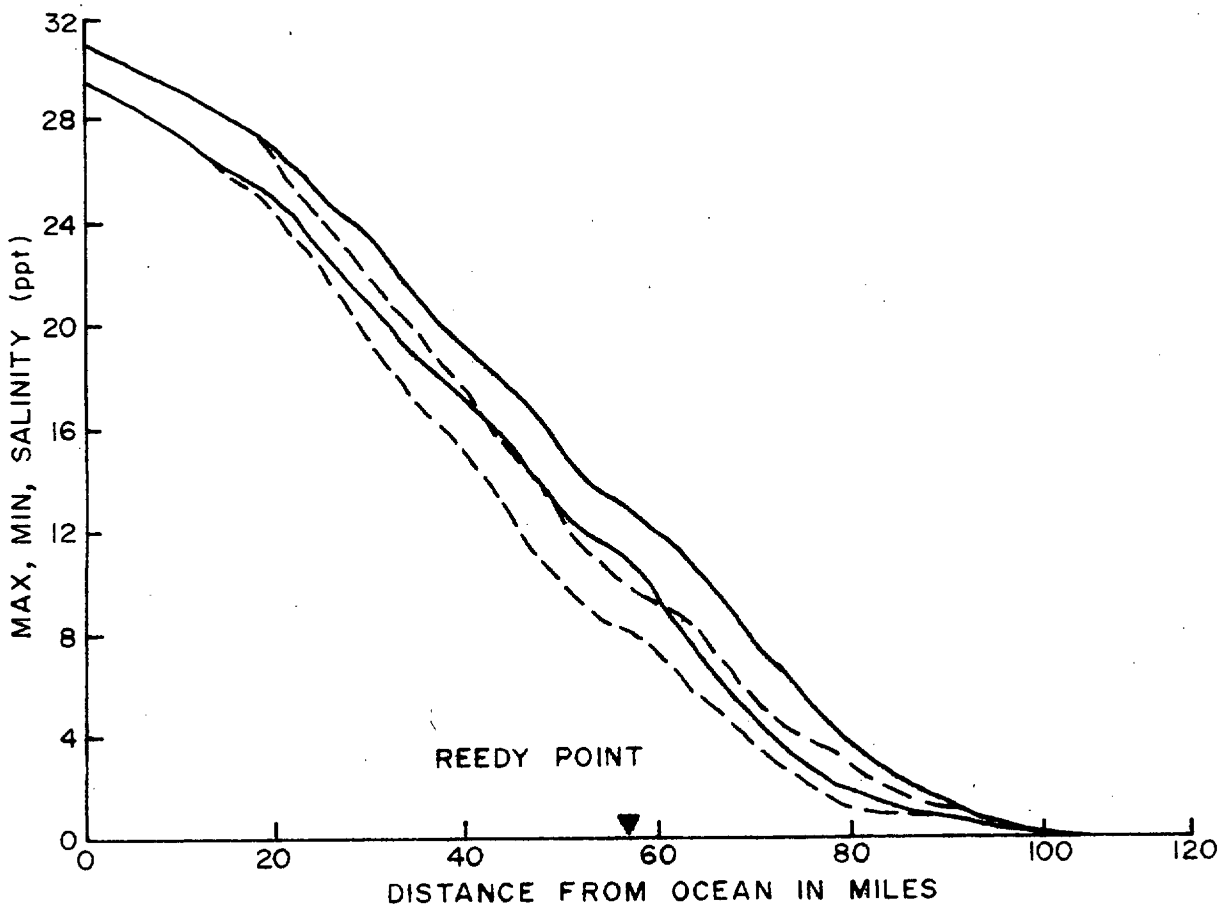
LEGEND

——— C & D Flow = 17, 277 cfs Eastward @ s = 10.0 ppt

– – – C & D Ignored

DELAWARE ESTUARY
SALINITY INTRUSION STUDY
SALINITY PROFILES WITH/WITHOUT CANAL FLOWS
(HIGH SALINITY IN ELK RIVER)
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE I-6



LEGEND

——— C & D Flow = 12,377 cfs Westward

– – – – C & D Ignored

DELAWARE ESTUARY
SALINITY INTRUSION STUDY

SALINITY PROFILES WITH/WITHOUT CANAL FLOWS (WESTWARD CANAL FLOW)

PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE I-7

• CONCLUSIONS. The exercise of the two types of models revealed interesting features of the system under consideration. The MIT-DNM Model showed that the canal has little effect on the tidal hydraulics of the Delaware estuary. Salt-concentration simulations, however, indicated a marked effect of the canal on the estuary, at least in the vicinity of Reedy Point. Due to the lack of real-time data, it was not possible to run the model for extended periods to fully demonstrate the effect of the canal along the entire longitudinal axis of the Delaware estuary.

The sensitivity analyses conducted with the MIT-TSIM Model, with different tidally averaged flow and salinity conditions specified for the canal, revealed that the largest salinity variation occurred when the flow in the canal is persistently westward when averaged over a period of 10 or more tidal cylces. An increase of 1.8 ppt in salinity, averaged over a tidal cycle, was obtained at a station 6.8 miles upstream of Reedy Point, under this flow condition in the canal.

CURRENT STUDIES

One of the objectives of this study was to determine salinity-related costs to users of water taken directly from the Delaware estuary. In order to meet this objective the following information is needed:

a. Long-term freshwater inflows into the Delaware estuary.

b. Salinity concentrations throughout the estuary over a relatively long-term period.

c. Chesapeake and Delaware Canal impacts on Delaware estuary salinity distribution.

d. Salinity-cost relationships for direct water users.

FRESHWATER INFLOWS

Salinity movements in the estuary are dependent on the prior variation of daily flows and boundary conditions during an antecedent period of many months. It is necessary to know freshwater inflows for an extended period of time to predict the salinity levels at given locations in the estuary. A flow-simulation model was previously developed under authorization provided by Section 22 of Public Law 93-25. The Section 22 study determined freshwater flows in the Delaware River Basin for a 50 year period reflecting regulation of the Upper Delaware River Basin by the New York City Reservoirs operating under a 1954 Supreme Court Decree. Only the New York City Reservoirs were included in this analysis, since these are water supply reservoirs that affect the daily flows in the upper Delaware River Basin. The effects of other reservoirs (such as the existing flood control reservoirs in the lower Basin) on the daily flows are not significant and were not included in the Section 22 simulations.

SALINITY CONCENTRATIONS

To determine the salinity concentrations, it was originally envisioned that the MIT-TSIM Model could be employed to simulate salinity data for the 50-year period using the daily flow data developed as part of the Section 22 study. This would provide the base period of salinity data needed for calculation of average annual salinity costs to direct users of water from the estuary. However, as mentioned previously, this model did not account for the wind effects (except as reflected by ocean tides observed at the mouth of Delaware Bay) and long-term effects of the Chesapeake and Delaware Canal on the salinity distribution in the Delaware estuary. To address these problems, this study performed the following additional analyses and refinements.

WIND EFFECTS

The wind analysis entailed a quantitative evaluation of the effects of local wind on the salinity concentration in the Delaware estuary and a determination of whether such effects should be included in the long-term (50-year) simulations. The MIT-TSIM Model (as developed for the DRBC by Thatcher and Harlemen in 1978) was used to determine potential impacts of wind. The wind stress calculation in the model was corrected and validated. Next, a four-month run was made using July-October 1979 conditions and the daily wind direction and velocity as recorded at Philadelphia. Comparisons were made with and without the wind effects on chloride concentrations at six stations in the Delaware estuary. The results of the analysis indicated that local wind effects play an insignificant role in long-term salinity predictions in the Delaware estuary, with a maximum chlorinity difference of only two percent. The largest response occurs when a significant wind stress component is aligned along the axis of the Delaware Bay. However, the overall wind response of the Delaware estuary was primarily due to tidal elevation changes at the ocean boundary, which reflect the effect of wind stress on the waters over the continental shelf. The model utilized observed tidal elevations at the ocean boundary (Lewes, DE), which included the effects of these ocean winds. Based on these findings, the local wind effects on salt intrusion were not incorporated in the long-term simulations.

CHESAPEAKE AND DELAWARE CANAL EFFECTS INVESTIGATION

An investigation was initiated during this study to determine the impact of flows in the Chesapeake and Delaware Canal on the salt intrusion in the Delaware estuary over a relatively long period of time, in order to establish whether it was necessary to incorporate the canal's effects in future runs of the Transient Salinity Intrusion Model (MIT-TSIM). Prior studies had revealed that the C&D Canal flows do indeed influence the concentration and distribution of salinities in the Delaware over a short period of time. In order to determine these impacts the following simulation was made.

• FOUR MONTH SIMULATION OF CANAL FLOWS. The longest available period of synoptic (same-time) tidal data in the Chesapeake and Delaware Canal and Delaware estuary covers the four-month period from July through October 1979, and these data were used to test the impact of the canal. The MIT-TSIM Model was run for the July-October 1979 period to establish a base condition (without the canal).

The next stage of the analysis was to include the July-October 1979 real-time C&D flows (and salinities) in the MIT-TSIM Model and compare the results with the previous run that ignored the canal flows. As indicated previously, the application of the MIT-TSIM Model to the Delaware estuary requires that the C&D Canal be treated as a tributary with either a net inflow at a prescribed salinity for each tidal period or as a net outflow for each tidal period. Thus, salt concentrations are only specified when flows in the canal are eastward. No salinity specification is needed when the flow in the canal is westward, since in this situation the canal acts as an outlet that removes water of the same salt concentration as that existing in the Delware estuary.

To simulate the real-time flows in the C&D Canal for the specified period, J. R. Hunter's one dimensional hydraulic model, adapted to the C&D Canal system by Rives and Pritchard, was used. It is a dynamic and numerical mathematical model that can determine flow flux in the canal. By specifying the tidal elevations in the canal, the model can calculate the quantity and direction of flow.

Since the flows in the canal are dependent on the tidal elevation gradient between the canal boundaries, it is necessary that the tide data at the gages be as accurate as technically possible. Due to the high sensitivity of canal flows to minor changes in elevation, it became apparent that the accuracy of the originally developed gage datums would have to be checked and possibly refined. A first-order leveling survey was performed during the summer and fall of 1979 along the C&D Canal between Reedy Point, DE, and Town Point, MD, to insure the required accuracy. The survey used the Chespeake City tide gage as the base and tied all other bench marks and gages into the net. The other gages involved were those at Town Point, St. Georges, and Reedy Point. All tidal data used in the simulations involving the C&D were adjusted to the new datum.

Tide elevations calculated with Hunter's model were close to observed values in the C&D Canal at Cheseapeake City and St. Georges. The verified model generated continuous flows at Reedy Point, representing volume fluxes into and out of the Delaware estuary through the C&D Canal. The real-time flows were incorporated as a tributary input to the calibrated and verified MIT-TSIM Model. The continuous flows were time-averaged over each tidal cycle to obtain a table of inflows and outflows at Reedy Point. For the period of July-October 1979, flows as high as 81,700 cfs eastward and 50,800 cfs westward, averaged over a tidal cycle, were computed. The long-term four month average was computed to be 6,960 cfs eastward.

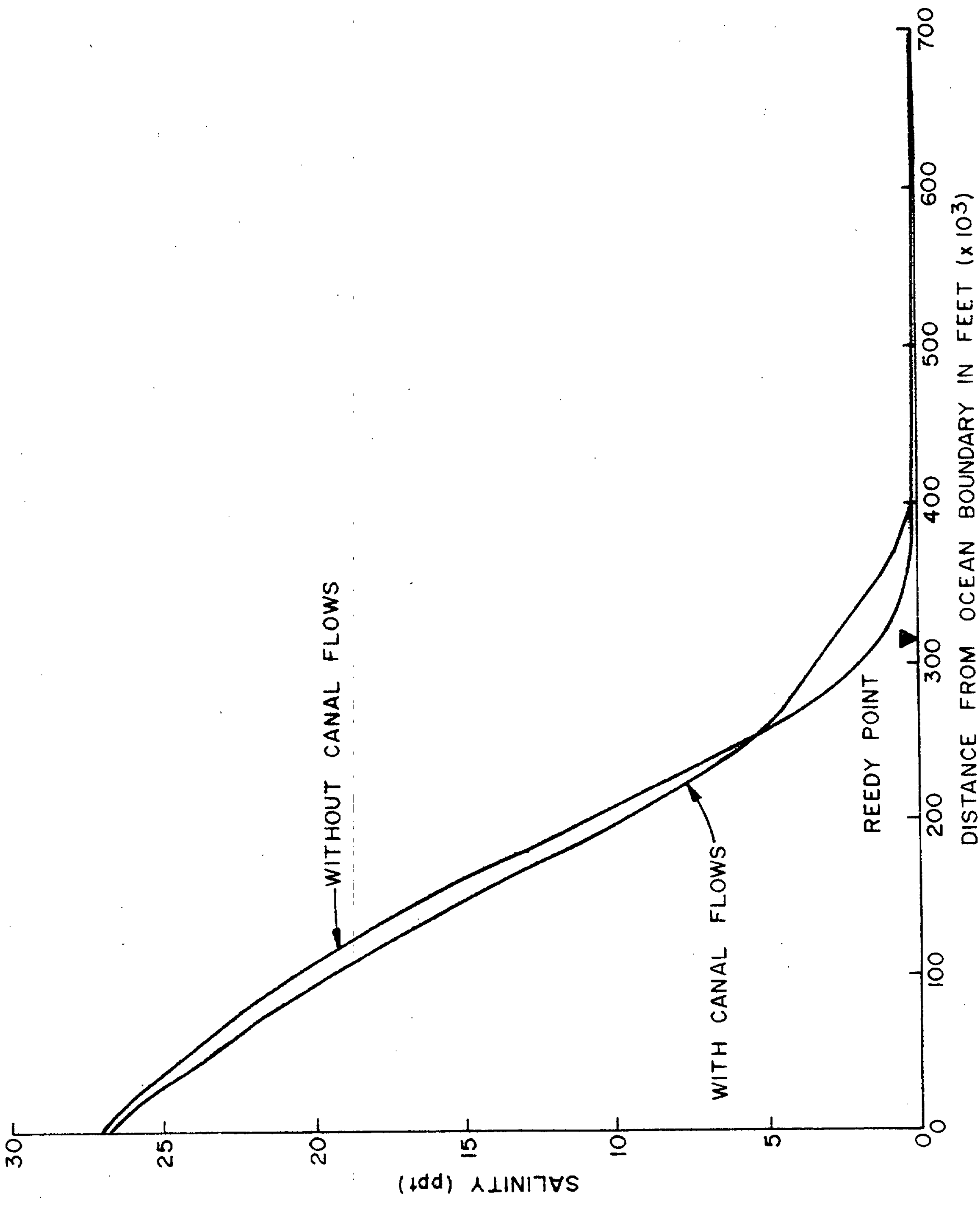
• SALINITY CONCENTRATIONS. In addition to the input of flow through the C&D Canal, a salinity concentration for the western boundary had to be specified when the flow was eastward. The available salinity record for the Elk River at Town Point was neither synoptic nor continuous for the four-month period of interest. From study of available data, it was determined that a realistic range of salinities at Town Point could be from 0.1 ppt to 8.0

ppt. A constant value of 8.0 ppt of salinity was assigned with eastward net flows for the sensitivity analysis. The relatively high value of salinity was used to demonstrate the maximum potential salinity impact on the Delaware estuary. Estuary inflows, tidal elevations, temperatures, and densities, all of which were required for input to the MIT-TSIM, were obtained from various sources for the selected period.

• RESULTS. The profiles shown in Figure 1-8 illustrate the cumulative effect of the specified C&D inflows at the end of the period of simulation (October 31, 1979). In the vicinity of the confluence with the canal (River Mile 58.9) and upstream to about River Mile 80 an increase in total dissolved solids concentration resulted. Downstream, about 250,000 feet from the ocean boundary, (River Mile 47), the concentration has been reduced by the addition of C&D waters. Concentrations within about 0.1 mile upstream of the canal increased by a maximum of 55 percent. Downstream of the canal, the concentration decreased by as much as 3.5 percent.

SENSITIVITY OF SALT INTRUSION IN THE DELAWARE ESTUARY TO DIFFERENT HYDROLOGIC CONDITIONS UNDER THE INFLUENCE OF C&D CANAL FLOWS

In addition to the analysis of the base period of July-October 1979, a sensitivity analysis was conducted to determine the canal's impact on the salt intrusion in the Delaware estuary under various hydrologic conditions in the Delaware River Basin. Three periods were selected for analysis: July-October 1965, 1970, and 1975, representing low, medium, and high freshwater flow conditions, respectively, in the Delaware River. In these three comparative analyses, it was assumed that simulated canal flows and salinities of July-October 1979 prevailed. This approach was adopted due to the lack of hydrologic and salinity data in the C&D Canal for these three



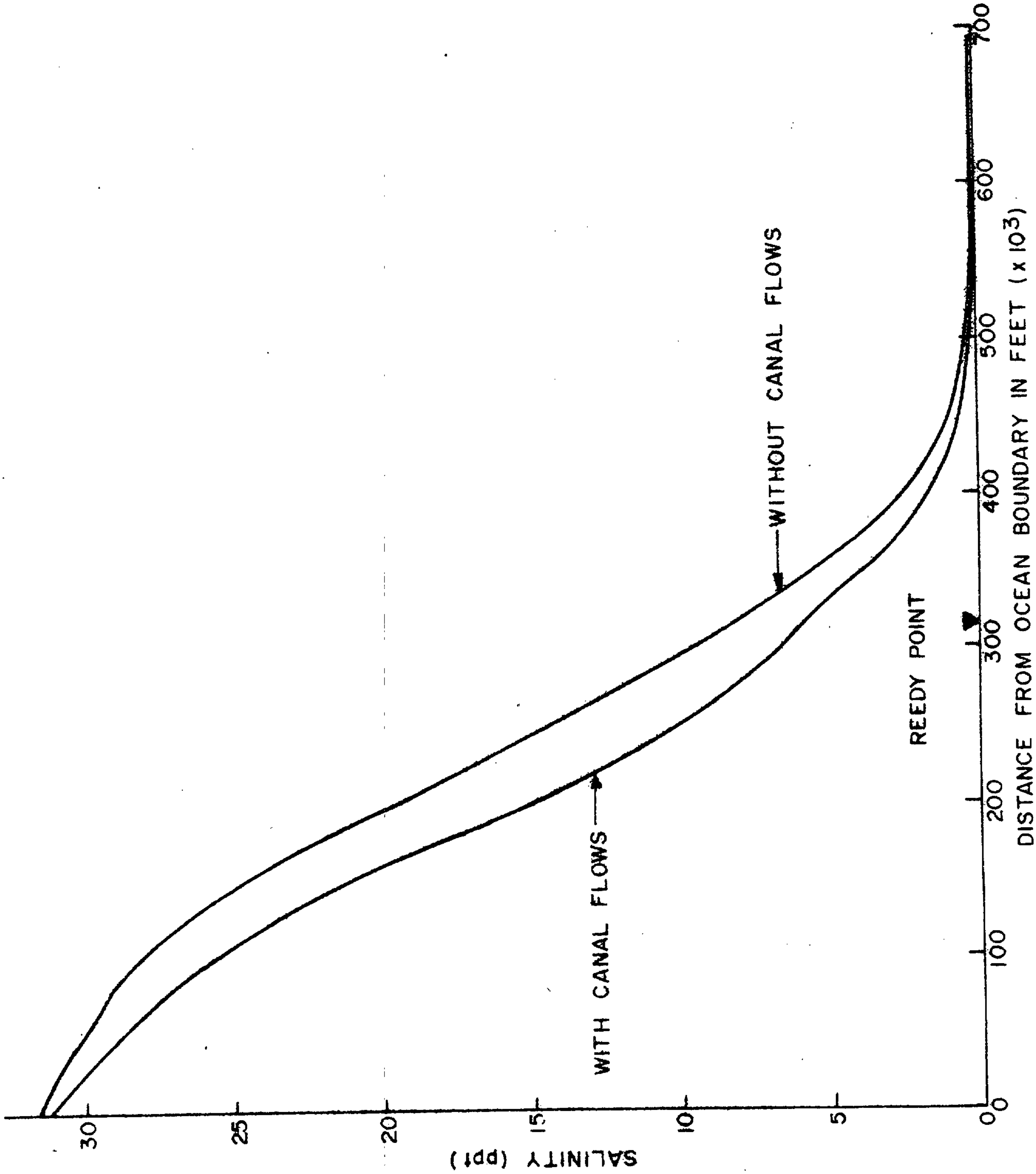
DELAWARE ESTUARY
SALINITY INTRUSION STUDY
SALINITY PROFILES WITH/WITHOUT CANAL FLOWS
JULY - OCTOBER 1979
(CONSTANT HIGH SALINITY IN ELK RIVER
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE I-8

years. The sensitivity analysis focused on the response of the Delaware estuary salinity distributions to net eastward canal flows.

• ANALYSIS UNDER DROUGHT CONDITION: JULY-OCTOBER 1965. Water-year 1965 was the most severe drought of record for the Delaware River Basin. Under these low freshwater inflow conditions, the salinity front in the Delaware estuary was near its most inland observed position. During the summer months in 1965, maximum daily salinities of about 14 ppt were observed at Reedy Island Jetty, which is five miles downstream of the confluence of the C&D Canal with the Delaware. As stated previously, the estimated long-term (four-month) average canal flow was eastward at 6,960 cfs. The easterly flows were assigned a salinity of 8.0 ppt. Under these conditions canal flows had a <u>salinity decreasing</u> impact on the salt intrusion on the Delaware, as they reduced chloride concentrations throughout the entire length of the estuary. Figure 1-9 shows profiles of the final tidal-day average TDS concentrations along the entire length of the Delaware estuary with and without the canal effects. It can be seen that the effects of four months of 8.0 ppt canal flows on the TDS concentrations in the Delaware are felt essentially from the ocean boundary to a point about 95 statute miles (500,000 feet) inland in the estuary. The maximum percentage decrease in concentration (29 percent) occurred at distance of 241,000 feet from the Capes (River Mile 45.6).

• ANALYSIS UNDER MEDIUM FLOW CONDITION: JULY-OCTOBER 1970. Simulations described in the previous section were repeated using the freshwater inflow and tidal boundary conditions that prevailed during July-October 1970. (Again, C&D Canal conditions were assumed to be as determined for July-October 1979). Hydrologically, water year 1970 is considered a medium freshwater year in the Delaware River Basin. Daily maximum salinity



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
SALINITY PROFILES WITH / WITHOUT CANAL FLOWS
JULY – OCTOBER 1965
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

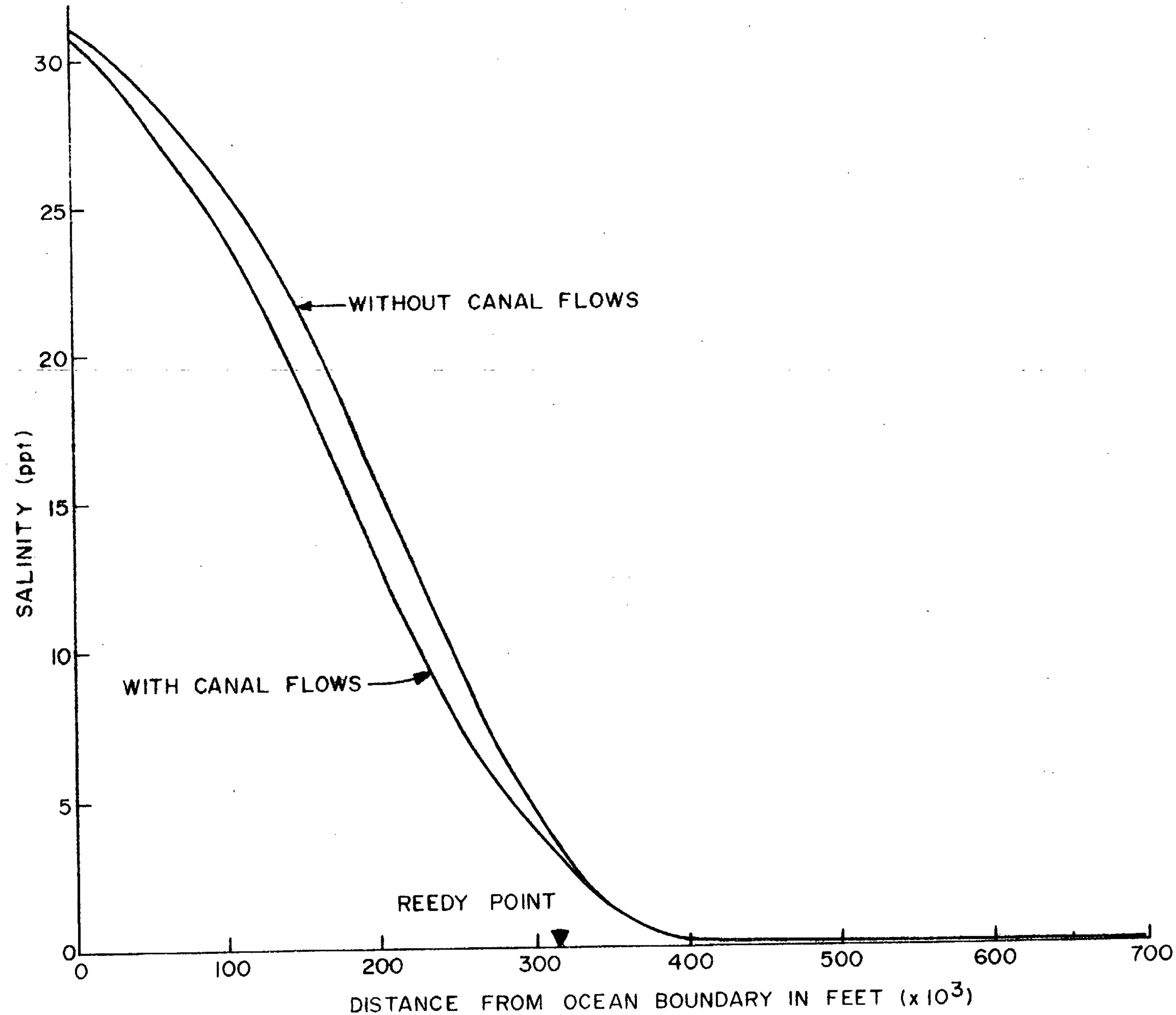
FIGURE I-9

concentration at Reedy Island Jetty varied from 5.5 ppt to 11.2 ppt during this period. With 8.0 ppt salinities assigned to eastward canal flows, it was anticipated that canal flows would have both salinity increasing and salinity decreasing effects on the Delaware, depending on the time and the location of the station being investigated.

Figure 1-10 shows the profiles of the final tidal-day average TDS concentrations along the entire length of the Delaware estuary. The figure indicates that the canal flows reduce the TDS concentrations in the Delaware reaches downstream of Reedy Island Jetty. Above Reedy Point, there appears to be no discernible impact. A maximum percentage reduction in concentration of 15 percent occurred at a location 180,000 feet above the Capes (River Mile 34.1).

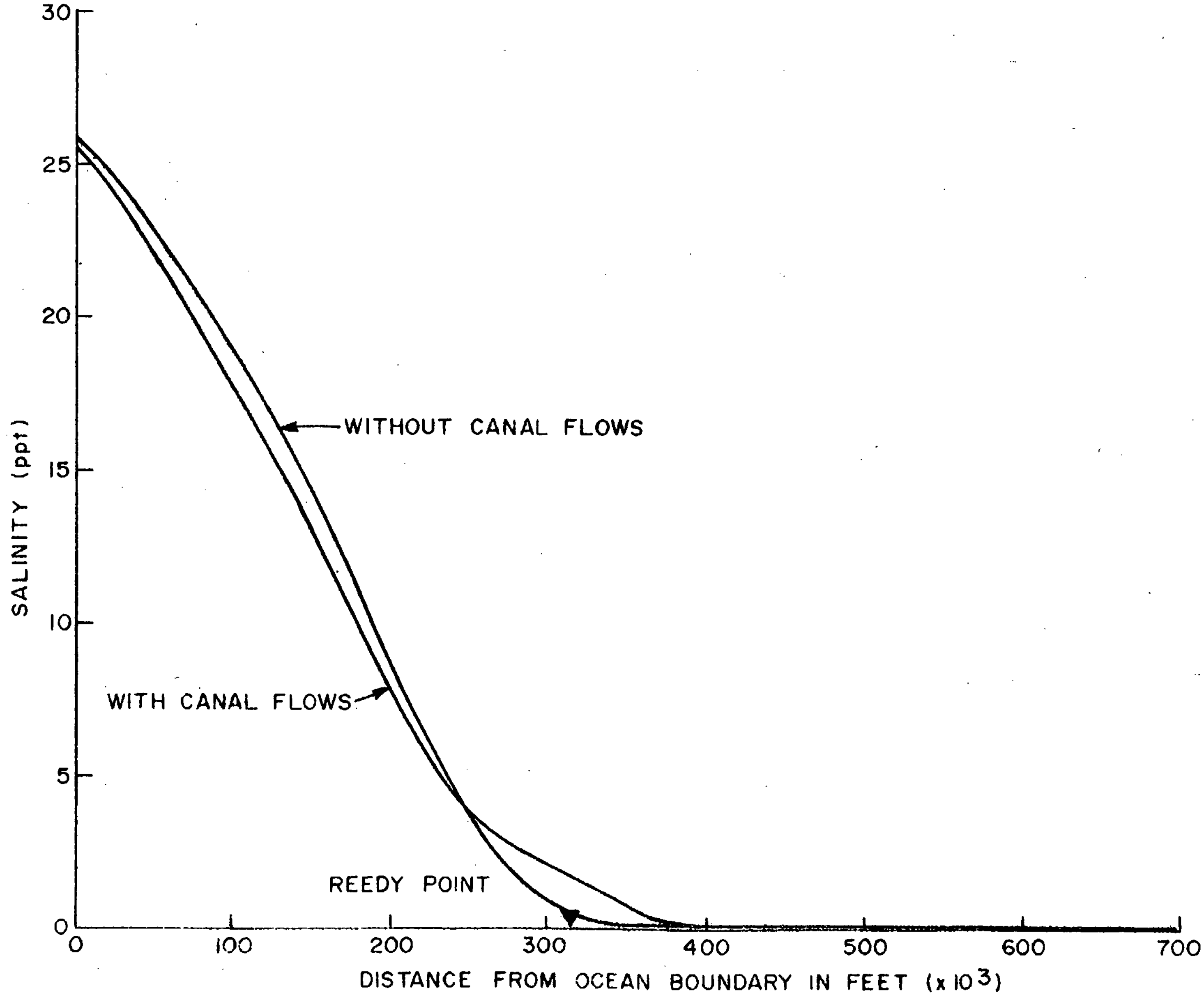
- ANALYSIS UNDER HIGH FLOW CONDITION: JULY-OCTOBER 1975. Water year 1975 was one of the wettest years in the period of record for the Delware River Basin. During this year, the salinity profile had receded to a point near its most seaward observed position, except for rare storm conditions. In fact, average salinities at Ship John Shoal, which is in the upper part of the bay, were less than 11.0 ppt for the selected period of study, July-October 1975. Further upstream at Reedy Island Jetty, maximum daily salinities of less than 7.0 ppt were observed for the same period. Thus, it was anticipated that canal flows of the summer of 1979 with dominantly eastward direction and 8.0 ppt salinities would reduce salt concentrations the most in the middle reaches of the Delaware estuary.

Figure 1-11 shows that although canal flows help to reduce TDS concentrations in the lower reaches of the estuary, the concentrations are increased above



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
SALINITY PROFILES WITH / WITHOUT CANAL FLOWS
JULY – OCTOBER 1970
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE I-10



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
SALINITY PROFILES WITH/WITHOUT CANAL FLOWS
JULY - OCTOBER 1975
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 1-11

River Mile 47.2, 249,000 feet from the ocean boundary. This impact diminishes to zero at a point about 390,000 feet from the ocean (River Mile 73.9). The maximum increase in salinity (from .6 to 1.9 ppt), occurs at River Mile 58.7.

• CONCLUSIONS. The comparative analysis under different hydrologic conditions showed that C&D Canal flows influence the salinity distribution in the Delaware estuary. The analysis also revealed that such effects could be neglible, positive, or negative depending upon the location of interest, the prevailing hydrologic conditions, and flows in the canal. However, limitations of the approach adopted in the analyses should be fully realized. The simulations performed for July-October 1965, 1970, and 1975 do not represent actual prototype conditions, but rather conditions assumed for sensitivity analyses. The results of the sensitivity analyses indicated that the C&D Canal should be included in the calculations for the long-term analysis of salinity intrusion in the Delaware estuary for purposes of economic analysis of salinity effects on water users. Also, the analyses revealed that certain assumptions needed further refinement in performing future simulations.

MIT-TSIM ADAPTATION TO INCLUDE THE CHESAPEAKE AND DELAWARE CANAL

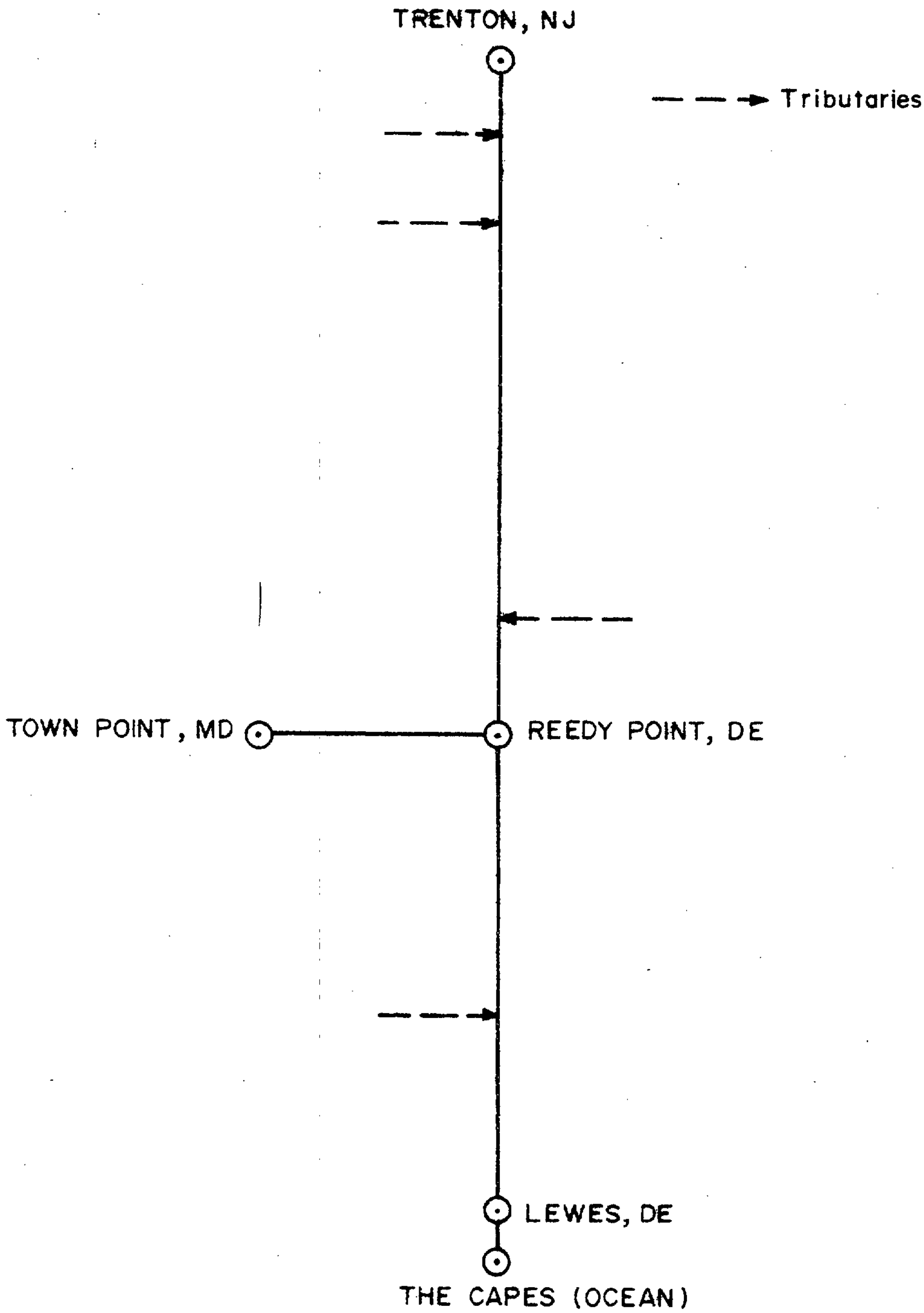
As a result of the above findings, this study adapted the single-stem MIT-TSIM Model to incorporate the C&D Canal as a dynamically-coupled single tidal branch. Previously, the C&D Canal flows were represented by tidally-averaged net flows to and from the Delaware estuary. In the present analysis the representation of the C&D Canal has been freed from the net-flow assumption and the dynamic interaction of the canal with the Delaware estuary is modelled.

• BOUNDARY CONDITIONS. The boundary for the model was modified to include a tidal boundary for the C&D Canal at the western end at Town Point, Maryland, on the Elk River. The boundaries for the Delaware estuary remained unchanged. The model retained the flow boundary at the head of tide in the Delaware estuary at Trenton, New Jersey, and the tidal boundary at the entrance to Delaware Bay at Lewes, Delaware. Figure 1-12 shows the model schematization of the system made up of the Delaware estuary and the C&D Canal. The confluence at Reedy Point, Delaware, constitutes an internal point where no hydraulic or salinity specifications are necessary.

• HYDRAULIC EQUATIONS. For the hydrodynamic computations, at the junction of the branch and the main stem, two conditions provide the basis for coupling the single-stem model and the branch. These are: (a) the conservation of mass; and (b) the identity of the kinematic surface elevation. The original explicit finite-difference equations of MIT-TSI were effectively coupled using these two conditions.

• SALINITY EQUATIONS. The salinity equations for the coupled system are formulated based on the conservation of salt within the junction control volume.

With these alterations, the flows and the salt transport in the C&D Canal are computed dynamically rather than serving as input conditons. The numerical solution technique of the model remained unaltered. The only change in the model structure consisted of adding a set of internal boundary equations at the junction node representing the canal confluence with the Delaware estuary and, of course, changing the boundary input from Reedy Point to Town Point. With these alterations the Branched MIT-TSIM was developed.



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
MODEL CONCEPTUALIZATION OF THE DELAWARE ESTUARY/ C & D CANAL
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE I-12

• CALIBRATION OF BRANCHED MIT-TSIM MODEL. The Branched MIT-TSIM Model was hydrodynamically recalibrated using the tidal data for the four-month period July-October 1979. The relative mean elevations between Town Point and Reedy Point were adjusted to reproduce the same net flows in the canal as were generated using Hunter's model.

The Branched MIT-TSIM Model results agreed quite well with the results of Pritchard and Gardner, who stated, "the net non-tidal flow for any given net head difference between the two ends of the canal for post-enlargement conditions will be about 2.48 times the corresponding flow for pre-enlargement conditions. A relatively simple theoretical approach suggests that this ratio might be as high as 2.7." The present study with the Branched Model yielded a ratio of 2.85 for post- and pre-enlargement flows in the canal.

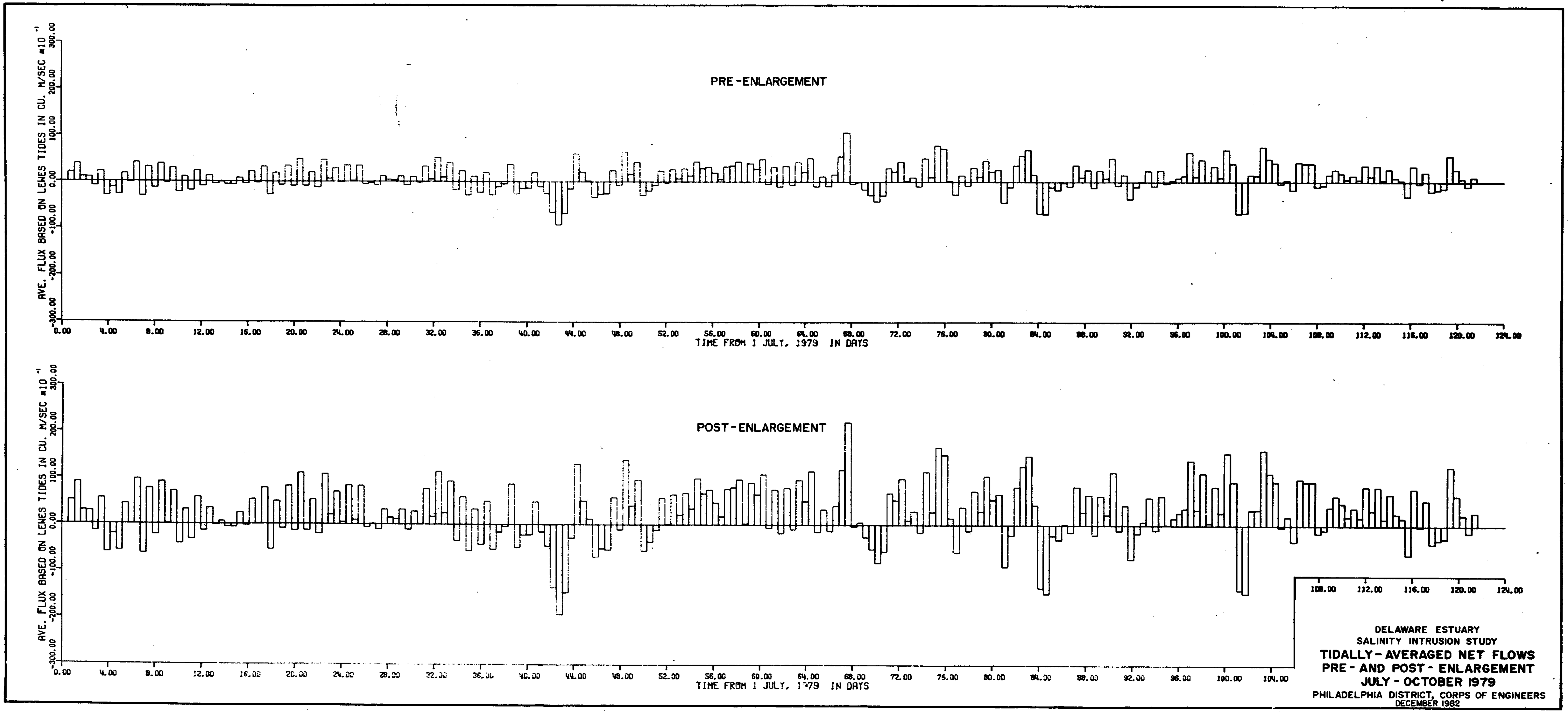
The predicted chloride distributions using the single-stem and branched MIT-TSIM Models for July-October 1979 conditions were compared. The only noticeable differences were in the vicinity of the C&D Canal confluence, as expected, and an overall difference corresponding to the small difference in mean net flow between the two cases.

EXERCISE OF BRANCHED MIT-TSIM MODEL WITH PRE- AND POST-ENLARGEMENT GEOMETRY OF THE C&D CANAL UNDER 1965, 1970, 1975, AND 1979 FLOW CONDITIONS

• CANAL GEOMETRY. In general, the pre- and post-enlargement geometry can be described by the change from a trapezoidal channel 27 feet deep and 250 feet wide with side slopes of 2:1 (horizontal:vertical), to a channel 35 feet deep and 450 feet wide with the same side slopes. The pre- and post-enlargement geometries were schematized from NOS charts and Corps of Engineers drawings.

Sensitivity analyses were made by using the calibrated Branched MIT-TSIM Model with a chloride concentration of 4.43 ppt (salinity of 8.0 ppt) at Town Point. Tidal hydraulics corresponding to the July-October 1979 period served as inputs to the Branched Model. Freshwater inflows to the Delaware estuary corresponding to the conditions of July-October 1965, '70, '75, and '79 were used. Comparative analyses were made between pre- and post-C&D Canal conditions under these four sets of boundary specifications.

• COMPARATIVE ANALYSES. Eight model calculations were made as determined by the four time periods and the two geometries. Figure 1-13 shows the tidally averaged (net) flows in the canal for the two geometries considered in the present study. The July-October average net flow was 3,214 cfs eastward for the pre-enlargement condition and 9,146 cfs eastward for the post-enlargement condition. The latter value obtained in the pre- and post-enlargement analyses was further refined for the long-term (50-year) analysis. Upon further calibration the post-enlargement average net flow was 7,027 cfs eastward. This is less than one percent larger than flows obtained using Hunter's model. This increase in flow affected the calibrated chloride distribution in the Delaware estuary by increasing and, in some cases, decreasing the chloride concentration by the amounts summarized in Table 1-1.



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
TIDALLY-AVERAGED NET FLOWS
PRE- AND POST- ENLARGEMENT
JULY - OCTOBER 1979
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE I-13

TABLE 1-1

SUMMARY OF MAXIMUM CHANGES IN CHLORIDE CONCENTRATIONS FOR SIMULATED PRE- AND POST-ENLARGEMENT CONDITIONS OF THE C&D CANAL

Station	DRBC River Mile	Maximum change in chloride concentrations as a percentage of the maximum pre-enlargement concentation, mg/l			
		1979	1965	1970	1975
Ship John Shoal	37	-9	-17	-14	-9
Reedy Island Jetty	54	16	-20	-13	15
Delaware Memorial Bridge	69	41	-14	40	33
Chester	82	47	-25	25	34
Ben Franklin Bridge	100	3	-18	3	2
Torresdale	110	1	-12	-1	-1

Note: All simulations based on July-October 1979 tidal elevations specified at Lewes, Delaware, and at Town Point, Maryland. Tributary inflows are those for the year specified.

• CONCLUSIONS. By releasing the single-stem constraint on the MIT-TSIM Model, a more accurate representation of the C&D Canal and Delaware estuary system has been formulated. Using this improved engineering tool, a comparative analysis was made of the impact of the enlargement of the canal. This impact was evaluated for a time period when the flow in the canal was predominantly easterly. The increase in net flow due to canal enlargement does have an impact on the Delaware estuary chlorides under the conditions of simulation. The Branched Model developed and applied in these analyses is an improved tool with respect to simulations of salinity in the Delaware estuary, as it permits a better representation of the C&D Canal as part of the system.

SALINITY-RELATED COSTS TO WITHDRAWAL USERS

Salinity-cost relationships were determined for all direct users of water from the Delaware estuary. Relationships between salinity, defined as total dissolved solids, and unit costs for withdrawal water use (e.g., dollars per million gallons) were estimated (refer to Appendix 2 for the derivation of these relationships). Salinity-cost relationships were estimated for municipal system use (domestic, industrial, commercial, and institutional), and direct industrial withdrawal use (once-through cooling, process, recirculating cooling, boiler feed, sanitary, and intake systems). Costs associated with salinity effects on groundwater users (whose supplies are taken from aquifers that are recharged in part by the Delaware estuary), health (as related to sodium and other contaminants in drinking water), and estuary fisheries were not generated, as there is insufficient data to determine those salinity-related impacts. However, general impacts of variations of salinity concentration on the estuary fisheries are presented in Appendix 3.

COMPUTERIZATION OF ECONOMIC MODEL

A computer model, ECOSALT, was developed based on the salinity-cost relationships and equations for withdrawal users described in Appendix 2. Complete documentation is contained in a three-volume report. Volume I is a summary report which discusses the development of the equations used in the program and the results of the calibration, testing, and use of the model. Volume II, a user's manual, serves as a reference guide for the use of the program. Descriptions of the input requirements, sample reports, and sample data decks are provided therein. Volume III, a programmer's manual, covers the detailed program documentation (including flow charts, program unit descriptions, and cross-reference tables).

The economic model calculates average annual costs to water users based on spatial and temporal variation of TDS concentration in the Delaware estuary. The model can evaluate various water management strategies for the Delaware estuary with respect to salinity-related costs.

LONG-TERM (50 YEAR) ANALYSIS

• INTRODUCTION. All of the above preparatory analyses concentrated on developing the necessary tools to be used in simulating long-term salinity variation in the Delaware estuary so that salinity-related costs could be determined. This section discusses the linkage of those tools and the conclusions reached. Three simulation models were used to conduct the long-term analyses: the Daily Flow Model (Section 22 study), Branched Transient Salinity Intrusion Model (MIT-TSIM) and the Economic (ECOSALT) Model. The Daily Flow Model provided the daily flows as input to the Branched Salinity Model. The Branched Model was used to generate spatially-varying salinity concentrations in the Delaware estuary, which in turn served as an input to the economic model. Average annual costs to all direct users of water from the Delaware estuary were computed by the economic model.

• SYSTEM BOUNDARIES - MODEL INPUT PARAMETERS. The Branched MIT-TSIM Model requires synoptic descriptions of hydraulic and water-quality parameters at the boundaries of the system being modelled. The numerical computations of the flows and the salinity (chlorinity) concentrations are performed at 6 to 10 minute intervals. Thus, it is essential to provide input data for the external boundaries of the system at frequencies that are compatible with the computational frequencies of the model.

The system includes two "open boundaries", one at Lewes, DE, and the other at Town Point, MD. At these boundaries, the time-varying water surface elevations are specified as observed or predicted tides. At the head of tide near Trenton, NJ, the daily-varying freshwater inflows into the estuary from the non-tidal reach of the Delaware River are specified, as are the daily-varying inflows into the estuary through its tributaries below Trenton. Water temperature observations at Lewes, DE, and Philadelphia, PA, are used to estimate the average daily temperature of estuarine water. These data serve as inputs to the Branched MIT-TSIM Model for the computation of the hydrodynamics of the system.

For computation of the salinity (chlorinity) concentrations in the system, the monthly varying "ocean" or "open" boundary concentrations are specified. Both at Lewes, DE, and at Town Point, MD, the maximum salinity associated with the flooding flows are specified during each tidal cycle. The model internally computes the salinity (chlorinity) concentrations at these boundaries during the ebbing flows (seaward at Lewes, and southward in the Elk River at Town Point). At Trenton, NJ, and at all the other tributaries, time-varying concentrations of non-ocean chlorides associated with daily flows into the estuary are specified. These data are sufficient for the computation of the transient salt intrusion in the Delaware estuary. In the following paragraphs a description of the procedures used in (a) compilation of the needed data; (b) filling of gaps; and (c) verification of such data for consistency and accuracy is presented.

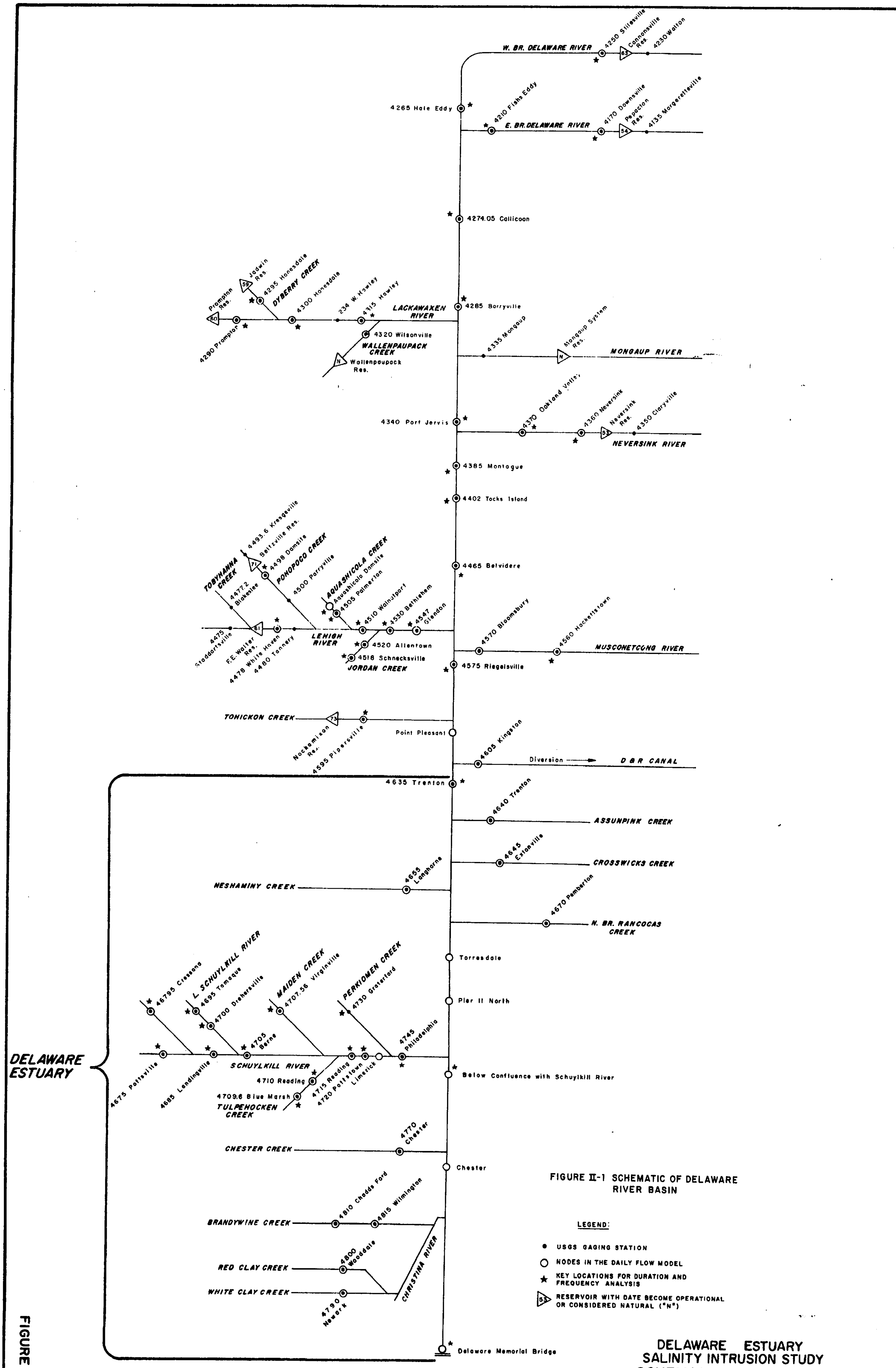
SYNTHESIS AND VERIFICATION OF INPUT DATA FOR 50-YEAR SALINITY SIMULATIONS

• INTRODUCTION. The total simulation period must include an antecedent period long enough to insure that the salinity outputs for the time of interest fully reflect the lagged influence of the changes many months or possibly even years earlier. To address this concern, the study used daily flows developed for the continuous 50-year period. This was also compatible with output from the Section 22 study.

• HYDROGRAPHIC DATA:

(1) Freshwater Inflows Data Development. Daily freshwater inflows are required as input to the Branched MIT-TSIM Model at Trenton, NJ, and tributaries of the Delaware estuary. Under the Section 22 study, mean daily flows were determined or estimated for the Delaware River Basin from its headwaters to the Delaware Memorial Bridge at Wilmington, DE, under "naturalized" (no regulation) flow conditions for a 50-year base period. These "natural flows" were then modified by assuming the existence of the New York City reservoirs operating under the 1954 decree of the U.S. Supreme Court for the entire 50-year period. These modified flows served as an input to the Branched MIT-TSIM Model.

Daily flows were simulated for key locations (model nodes) for the 50-year period from October 1927 to September 1977. Model nodes were located at existing USGS gages, points of proposed or existing diversion, places of proposed or existing impoundments, and other points of interest. (Refer to Figure 1-14 for a schematic diagram). When records for a station were not available for the entire 50-year period, the daily flows for that station were generated through correlation and extension procedures. Available



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
SCHEMATIC DIAGRAM OF DELAWARE RIVER BASIN
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE I-14

records were correlated with those for long-term recording stations using linear regression equations. (Some headwater stations required generation of flows even though records were available because the recorded flows included regulation).

(2) Description of Tributary Inflows. Ten gaging stations provided freshwater inflows for tributaries shown in Table 1-2. The inflows for the ungaged tributaries were estimated by prorating ungaged to gaged drainage area. A total of twenty-four freshwater inflow points, including the Delaware River at Trenton, NJ, were modelled. These are listed in Table 1-3. The tributary inflows of the lower estuary (below the Delaware Memorial Bridge) are derived based on the flows of White Clay Creek.

TABLE 1-2

SOURCES OF INFLOW DATA

No.	Station	Name
1	1-4800	Red Clay Creek at Wooddale, NJ
2	1-4790	White Clay Creek near Newark, DE
3	1-4815	Brandywine Creek at Wilmington, DE
4	1-4770	Chester Creek near Chester, PA
5	1-4715	Schuylkill River at Philadelphia, PA
6	1-4670	N.B. Rancocas Creek at Pemberton, NJ
7	1-4650	Neshaminy Creek near Langhorne, PA
8	1-4645	Crosswicks Creek at Extonville, NJ
9	1-4640	Assunpink Creek at Trenton, NJ
10	1-4635	Delaware River at Trenton, NJ

TABLE 1-3

RELATIONSHIP OF TRIBUTARY INFLOWS TO "GAGED" INFLOWS

Tributary	Gaging Station used as Source of Inflow(s) (from table 1-2)	Drainage-Area Ratio
Broadkill River, DE	2	1.773
Dennis Creek, NJ	2	1.437
Maurice River, NJ	2	4.198
Murderkill River, DE	2	1.953
St. Jones River, DE	2	1.280
Leipsic River, DE	2	1.874
Cohansey River, NJ	2	2.997
Alloway Creek, NJ	2	0.823
Salem River, NJ	2	1.285
C&D Canal, DE	1	3.528
Christina River, DE	1, 2, 3	1.313
Oldmans Creek, PA	4	1.124
Raccoon Creek, NJ	4	1.100
Chester Creek, PA	4	3.863
Mantua Creek, NJ	4	1.280
Schuylkill River, PA	5	1.008
Big Timber Creek, NJ	5	0.042
Cooper River, NJ	6	0.696
Frankford Creek, PA	6	0.524
Rancocas Creek, NJ	6	4.071
Neshaminy Creek, PA	7	1.752
Crosswicks Creek, NJ	8	2.014
Assunpink Creek, NJ	9	1.072
Delaware River, Trenton, NJ	10	1.000

(3) Tidal Data At Lewes, DE, and at Town Point, MD.

(a) Data Available. The National Ocean Survey (NOS) (or its predecessor, the Coast and Geodetic Survey) is the source of both observed and predicted tide data at the two open boundaries of the system. Data covering the period between 1927 and 1977 were required for the 50 year computer runs of the Branched MIT-TSIM Model. Although some tide elevation data existed for Town Point, MD, the record covered only a short period. Consequently, Baltimore, MD, tide data were used as a basis for simulating Town Point tide elevations. Data were available from the NOS for the period October 1927 through August 1967 for Baltimore, and for the period 1921-1973 for Lewes, DE. Unfortunately, there was a total of approximately 19 years of data gaps for the Lewes station.

(b) Gap-Filling Using The NOS Prediction Program. The NOS prediction program was used to fill data gaps. A validation of the tidal prediction program was made by comparing generated values with those published in the Tide Tables by the National Oceanic and Atmospheric Administration (NOAA). The generated values agreed very well with the published values.

(c) Sea Level Rise During Water Years (1928-1977). Hull and Tortoriello have shown that the historical trend of a rising sea level could significantly affect the salinity in the Delaware estuary. Consequently, it was important that tidal elevation data be consistent in terms of their relationship to sea level. Observed data from the NOS are given with respect to a specific tidal datum; usually the mean low water (MLW) of a particular tidal epoch (19-year period).

The previously mentioned data from the NOS were furnished with an accompanying list of corrections that related the data to the local mean low water of the 1960-1979 tidal epoch. The National Geodetic Vertical Datum (NGVD) can be used to relate non-stationary datums. The set of relationships between NGVD and the MLW of Lewes, DE, Baltimore, MD, and Town Point, MD, is given in Table 1-4.

Hicks has analyzed observed tidal data at Lewes, DE, (1921-1975, but with missing data). He calculated a rising trend of 3.7 millimeters/year. This trend, which is equivalent to 0.012 ft/year, has been used for adjusting predicted data that were required to fill gaps.

TABLE 1-4

DATUM RELATIONSHIPS FOR LEWES, DE,
BALTIMORE, MD, AND TOWN POINT, MD

	Lewes, Delaware	Baltimore, Maryland	Town Point, Maryland
1941-1959 Tidal Epoch			
MLW above Staff datum	2.49	3.96	2.67
NGVD above MLW	1.74	0.19	0.62
1960-1978 Tidal Epoch			
MLW above Staff datum	2.67	4.12	2.85*
NGVD above MLW	1.56	0.04	0.44*

*Based on the same sea-level rise between epochs (0.18 ft.) as that at Lewes, DE

(d) Synthesis of Tidal Data. The synthesis of the final tidal data used by the Branched MIT-TSIM Model required an orderly merging of data from (a) hourly observed values, (b) high and low observed tides, and (c) high and low predicted tides. Finally, the Baltimore, MD, tidal data were corrected to represent Town Point, MD, by using the correction factors given in the NOS Tide Tables.

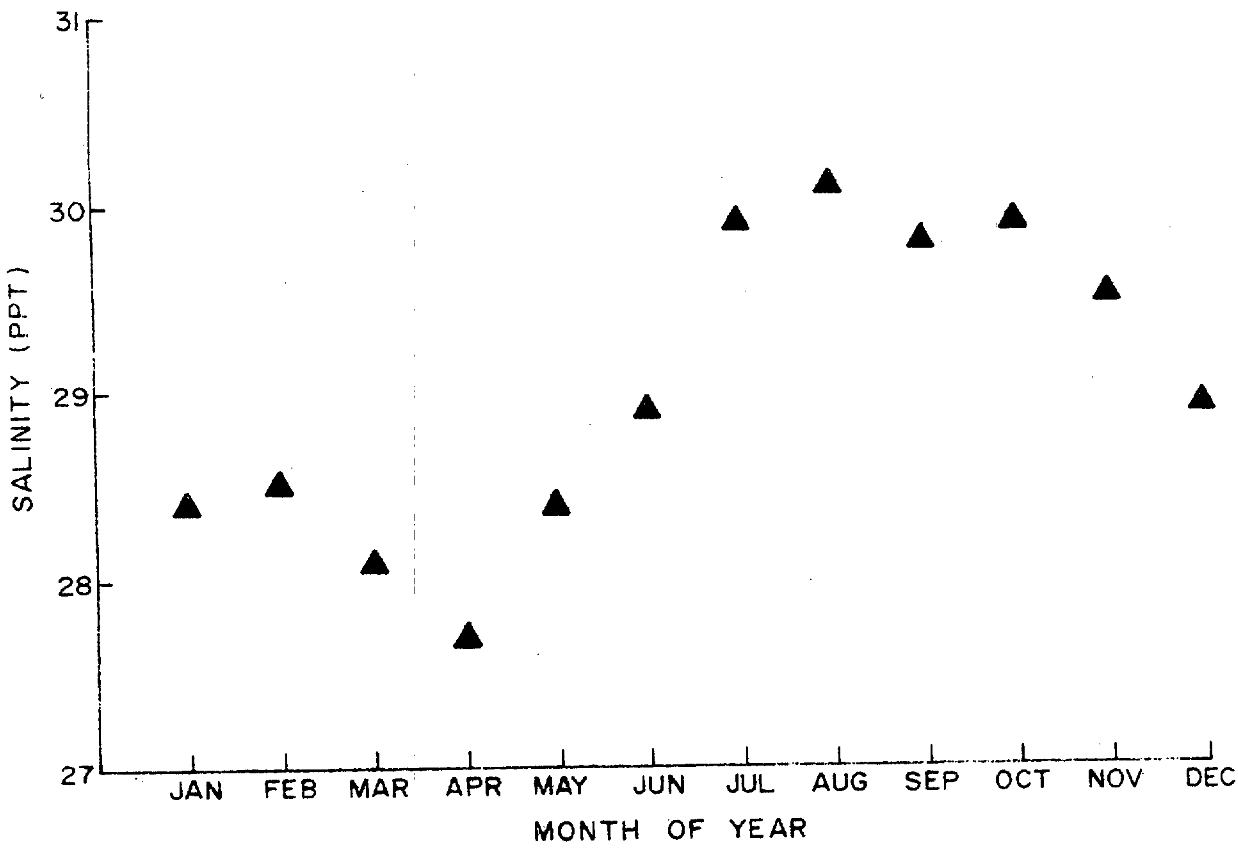
A program was written to process the hourly data in order to extract the series of high and low tides from these data. Another program was written to develop data for Town Point based on correlations with Baltimore data.

• SALINITY (CHLORINITY) DATA:

(1) Freshwater Inflow Background Chlorinities. Chloride data were not always available at all the tributary gaging stations. Even if such data were available, the chloride contribution by such tributaries to the estuary would be underestimated if based solely on the gaging-station data, as most of the gaging stations are upstream of urbanized areas near the Delaware estuary. Such data would not reflect the contribution of background chlorinity (i.e., non-ocean salt) to the estuary that results from storm runoff or point discharges from municipal and industrial plants downstream of the gaging stations.

In an effort to account for these additional sources of chloride, DRBC made a study to correlate the long term net chloride flux between pairs of quality monitoring stations in the tidal Delaware River and the upstream inflow at Trenton, NJ. The technique used is called the Zonal Net Flux method. It has the advantage of accounting for significant non-point and point sources of chloride contributions to the estuary that could not be accounted for by using data collected at tributary gaging stations. The Branched MIT-TSIM Model uses this technique.

(2) Description of Chlorinity at Lewes, DE. Salinity and surface water temperature at the ocean entrance to Delaware Bay has been recorded by the NOS for many years. A distinct seasonal variation in mean monthly salinity is shown in Figure 1-15 and Table 1-5. This variation, though small,



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
SEASONAL SALINITIES AT LEWES, DE.
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE I-15

nonetheless is significant and can be explained in terms of the annual variation of freshwater runoff from all rivers discharging to the Mid-Atlantic Continental Shelf. As a specification on the landward (flooding) flow, the chlorinity variation at Lewes, DE, was taken from the NOS, NOAA surface water and density values presented in Publication No. 31-1, dated March 1973.

TABLE 1-5

MEAN MONTHLY SALINITY AND CHLORINITY VARIATION
AT LEWES, DELAWARE*

MONTH	SALINITY ppt	CHLORINITY ppt
January	28.4	15.7
February	28.5	15.8
March	28.1	15.6
April	27.7	15.3
May	28.4	15.7
June	28.9	16.0
July	29.9	16.6
August	30.1	16.7
September	29.8	16.5
October	29.9	16.5
November	29.5	16.3
December	28.9	16.0

* Computed from yearly averages extending from 1919 through 1971 (Data source: NOAA, Surface Water Temperture and Density, Publication No. 31-1, March 1973)

(3) <u>Description of Salinity Variation at Town Point, MD</u>. It was necessary to formulate a realistic salinity boundary condition at Town Point, MD, as it represented the western extremity of the C&D Canal. Sparse but reliable salinity data were available for two stations in the Elk River

near the western end of the canal covering the period 1969-1974. A methodology was adopted to construct a year-long salinity description at Town Point that has a biweekly resolution. A realistic year-long salinity description at this boundary was developed through a statistical analysis of the Elk River data. Care was taken to assure that the described salinities at Town Point reflected characteristics that are more representative of the waters of the upper Chesapeake Bay than of the waters of the Delaware estuary, since analysis of the Elk River salinity data indicated that unusually high salt concentrations occur at certain times in the river, due to salt transport through the Canal from the Delaware estuary. The formulated year-long salinity variations at Town Point were used repetitively during each of the 50 years of the salinity simulations for the Delaware estuary.

Cross-sectionally averaged salinities were determined from the six years of data. Sets of bi-weekly average salinity data for the six years were grouped within corresponding 15-day intervals, and statistical analyses were performed to derive mean salinities and standard deviations.

To investigate the sensitivity of salinity variations in the Delaware estuary to different specifications of salinity at Town Point, MD, two sets of year-long biweekly varying data sets were developed. These data sets, listed in Table 1-6, reflected salinity variations at Town Point that were one standard deviation above and below the mean. Sensitivity analysis demonstrated that only small salinity differences in the Delaware estuary resulted from Town Point salinities that fell within one standard deviation above or below the mean seasonally varying observed salinities. Therefore, the mean salinity variations were used in the simulation runs of the Branched MIT-TSIM Model.

TABLE 1-6

STATISTICAL ANALYSIS OF BIWEEKLY SALINITY VARIATION
AT TOWN POINT, MD

JULIAN DAY **	Mean concentration, ppt Salinity	Mean concentration, ppt Chlorides	$\overline{S}$ - σ* ppt	(Chl - σ) ppt	$\overline{S}$ - σ* ppt	(Chl - σ) ppt
8	0.226	(0.125)	0.226	(0.125)	0.226	(0.125)
24	0.115	(0.064)	0.096	(0.053)	0.135	(0.075)
40	0.445	(0.246)	0.218	(0.121)	0.673	(0.372)
56	0.572	(0.317)	0.000	(0.000)	1.417	(0.784)
72	0.455	(0.086)	0.119	(0.066)	0.192	(0.106)
88	0.312	(0.173)	0.048	(0.027)	0.577	(0.319)
104	0.933	(0.516)	0.578	(0.320)	1.287	(0.712)
120	0.359	(0.199)	0.330	(0.183)	0.388	(0.215)
136	0.213	(0.118)	0.141	(0.078)	0.284	(0.157)
152	0.357	(0.198)	0.231	(0.128)	0.482	(0.267)
168	0.341	(0.189)	0.008	(0.004)	0.674	(0.373)
184	0.551	(0.307)	0.282	(0.156)	0.826	(0.457)
200	0.391	(0.216)	0.000	(0.000)	0.808	(0.447)
216	0.970	(0.537)	0.013	(0.007)	1.928	(1.067)
232	0.770	(0.426)	0.600	(0.332)	0.939	(0.520)
218	0.775	(0.429)	0.671	(0.371)	0.879	(0.486)
264	1.765	(0.977)	0.868	(0.480)	2.663	(1.474)
280	2.114	(1.170)	0.550	(0.304)	3.679	(2.036)
296	2.283	(1.263)	2.123	(1.175)	2.442	(1.351)
312	3.619	(3.126)	4.473	(2.475)	6.826	(3.778)
328	1.963	(0.388)	0.750	(0.415)	1.376	(0.761)
344	0.862	(0.477)	0.264	(0.146)	1.461	(0.809)
360	0.863	(0.480)	0.588	(0.325)	1.148	(0.635)

* σ Is the standard deviation for each interval of 15 days.

** Julian Day 1 is January 1st.

BRANCHED MIT-TSIM CALIBRATION AND SENSITIVITY ANALYSIS

• SELECTION OF A PERIOD FOR CALIBRATION. The calibration of the Branched MIT-TSIM Model for salt intrusion studies in the Delaware estuary requires accurate and synoptic observed hydrographic and salinity data. These data consist of:

a. C&D Canal geometry.

b. time-varying freshwater inflows into the system from the Delaware River at Trenton, NJ, and from the seaward tributaries of the estuary.

c. time-varying salinity (chloride) concentrations associated with the freshwater inflows.

d. time-varying water surface elevations at Lewes, DE, and Town Point, MD.

e. time-varying salinities at Lewes and at Town Point.

f. time-varying water surface elevations and salinities at several stations within the domain of interest.

g. time-varying temperature at Philadelphia and Lewes.

An extensive review of the field data revealed a very limited number of periods for which available synoptic data satisfied all of the above requirements. Two factors further complicated the selection of a period for model calibration. First, the economic analysis (cost impacts for 50-year period) would be based on the present, enlarged geometry of the C&D Canal. Second, an accurate description of the canal geometry was not available for the period between the years 1963 and 1975, as the canal was undergoing enlargement during these years.

During July-October 1979, the National Ocean Survey gathered continuous water surface elevation data at Town Point. These tidal data were used in the previous investigations of canal flow influences on salt intrusion in the Delaware estuary. However, those investigations were based on an assumption of constant salinity concentrations (8.0 ppt) with easterly canal flows.

This assumption was adopted in the absence of salinity observations in the C&D Canal or at its western boundary for 1979. It was felt that an alternate period should be selected, for which at least monthly observations of salinity at Town Point were available. Thus, the period July-October 1979 was eliminated from consideration for calibration purposes.

Although water-years 1964 and 1970 were within the period when the canal was being enlarged, they were the only two remaining options. The period of water-year 1964 presented two major problems. First, since the canal enlargement had been initiated only shortly before, the 1964 canal geometry would reflect the pre-enlargement condition more than the post-enlargement condition. The second problem dealt with the availability of monthly salinity data at Town Point, MD, in the Elk River. The Chesapeake Bay Institute (CBI) did not begin compiling monthly (or more frequent) depth-varying salinity concentrations at Town Point until 1969. Review of the CBI data bank indicated that such data were gathered through the years 1969-1974 in a relatively consistent manner. Water-year 1970 remained the most reasonable choice for calibration.

Water-year 1970 provided a few attractive features that are useful for the calibration of a model targeted for 50-year simulation of hydraulic and salinity behavior in the Delaware estuary. First, 1970 was a medium freshwater inflow year for the Delaware Basin. Second, by 1970, the canal enlargement was almost completed, with the exception of a reach of less than a mile near the eastern end of the canal. This reach retained approximate pre-enlargement canal dimensions until the spring of 1975. However, the flow through the canal in 1970 was believed to be almost as great as it would have been if the enlargement had been completed before that year. Third, there were 11 vertical salinity profile observations reported by CBI at Town Point, MD, between October 1969 and September 1970. These factors encouraged the choice of this period for calibrating the Branched Model. However, there were two major obstacles to be overcome if an accurate year-long calibration of the model was to be achieved. First, there were no observed tidal elevations at Town Point for water-year 1970. Second, no details were available as to the exact dimensions of the unenlarged reach that constricted flows into and out of the canal through its eastern entrance at Reedy Point, DE.

To overcome these two obstacles, the following approach was taken. Town Point, tidal elevation data were generated using the NOS prediction program. These data were developed by applying the proper phase and amplitude factors to the predicted tides at Baltimore, MD. Regarding the unenlarged reach, it was assumed that the canal had its complete post-enlargement dimensions during the period of calibration.

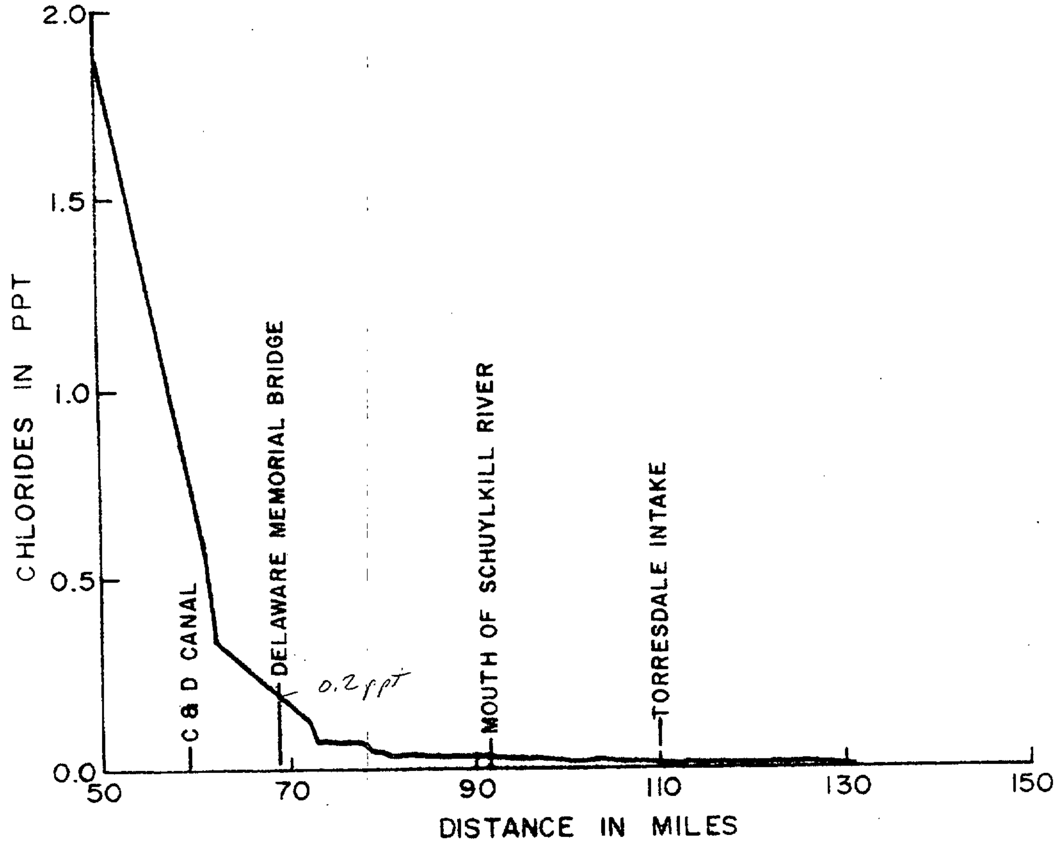
• RESULT OF BRANCHED (MIT-TSIM) MODEL CALIBRATION. Data for the first three months of water-year 1970 were prepared for input to the Branched MIT-TSIM Model. The intent here was to calibrate the model initially using input data corresponding to 1 October-31 December 1969. A satisfactory calibration was obtained at all stations using the 1970 water-year data. The parameters of the calibration--Manning's friction coefficient, n; stratification-related dispersion coefficient, K; and the Taylor dispersion multiplier, m --were all identical to the values obtained during the previous calibration of the same model in the same system using July-October 1979 data. The model calibration therefore represented a verification of the previous efforts.

• SIMULATION OF 50-YEAR CHLORINITIES IN THE DELAWARE ESTUARY. The calibrated and verified Branched MIT-TSIM Model was employed for the 50-year period using the input data previously described. The following is a brief description of the analysis performed and conclusions reached.

Chloride data for the end of September 1927 were not available to allow determination of actual initial conditions. Consequently, initial conditions were assumed to be the same as those used for water-year 1970, medium flow year. Experience with previous Delaware estuary simulations has shown that within about a year, all lagged salinity effects of the initial condition are eliminated, and that most of the effects of the initial condition are gone after several months of calculation. Previous studies had shown also that computed and observed hydraulic conditions converge within a few days when the computations start with still water. Consequently, a correct set of hydraulic conditions in terms of discharge and initial water surface elevations was used to begin the 50-year simulation. Therefore, the initial hydraulic conditions for 1 October 1927, were established by executing the model for the final five days of September 1927, starting with a slack-water condition.

• 50-YEAR AVERAGE CHLORIDE DISTRIBUTION. The 50-year average chloride distribution from River Mile 50 to River Mile 131 are presented in Figure 1-16. These values are plotted using the computed station means of the entire 50-year period of record.

• DISCUSSION OF RESULTS. The computed tidal elevations, one-dimensional velocities, and chloride concentrations in the entire system remained stable throughout the 50 years of simulation. The analysis of the chlorinity

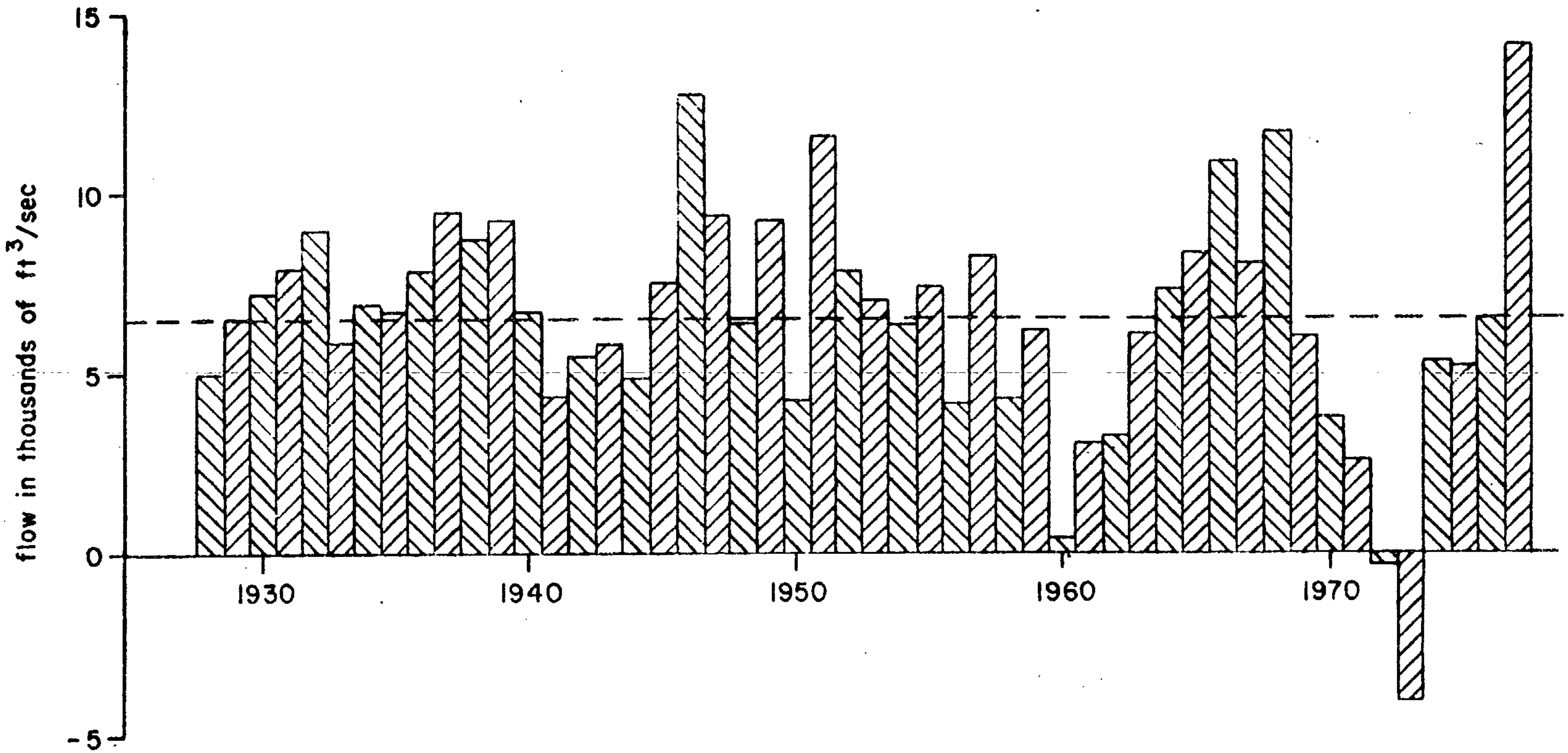


DELAWARE ESTUARY
SALINITY INTRUSION STUDY
50-YEAR AVERAGE CHLORIDES VS DISTANCE FROM OCEAN
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

variations at 34 estuary stations computed by the model showed that the C&D Canal influence on the chloride concentrations in the Delaware estuary was, for all practical purposes, limited to a 45-mile reach that extends from Chester, PA (River Mile 82), to Ship John Shoal, NJ (River Mile 37). Above this reach, the chloride concentrations were influenced more by the magnitude and the variation of flows from the Delaware River and its tributaries. In the seaward portion of the estuary, the chloride concentrations were influenced more by the variations of salinities at the ocean boundary.

Figure 1-17 shows the computed yearly average net flows in the C&D Canal for the 50-year simulation (positive direction corresponds to eastward flows). These flows do not reflect the actual conditions that prevailed in the canal during the years 1927-1977. Whereas the canal geometry underwent three alterations during that period, the analysis assumed post-1975 canal geometry for the entire period. Also, this figure shows an appreciable yearly variation in the net annual flows through the canal over the simulated 50-year period. These flows vary from a maximum of 14,190 cfs eastward to a minimum of 300 cfs eastward, with only two years (1972 and 1973) indicating net westward flow. The 50-year average of the simulated net annual flows in the canal is 6,560 cfs eastward.

Figure 1-18 shows the variation of chlorinity at the Ben Franklin Bridge (River Mile 100), and at the Delaware Memorial Bridge (River Mile 69) during water-year 1973. Also shown in the figure is the freshwater inflow to the Delaware estuary at Trenton, NJ. This year was chosen to illustrate the canal flow influence on the chlorinity concentrations during a period with net westward flow. The chlorinity in the upper Delaware estuary is strongly influenced by the freshwater inflow at Trenton, NJ, as the chloride concentrations at both stations are dramatically reduced by increasing freshwater



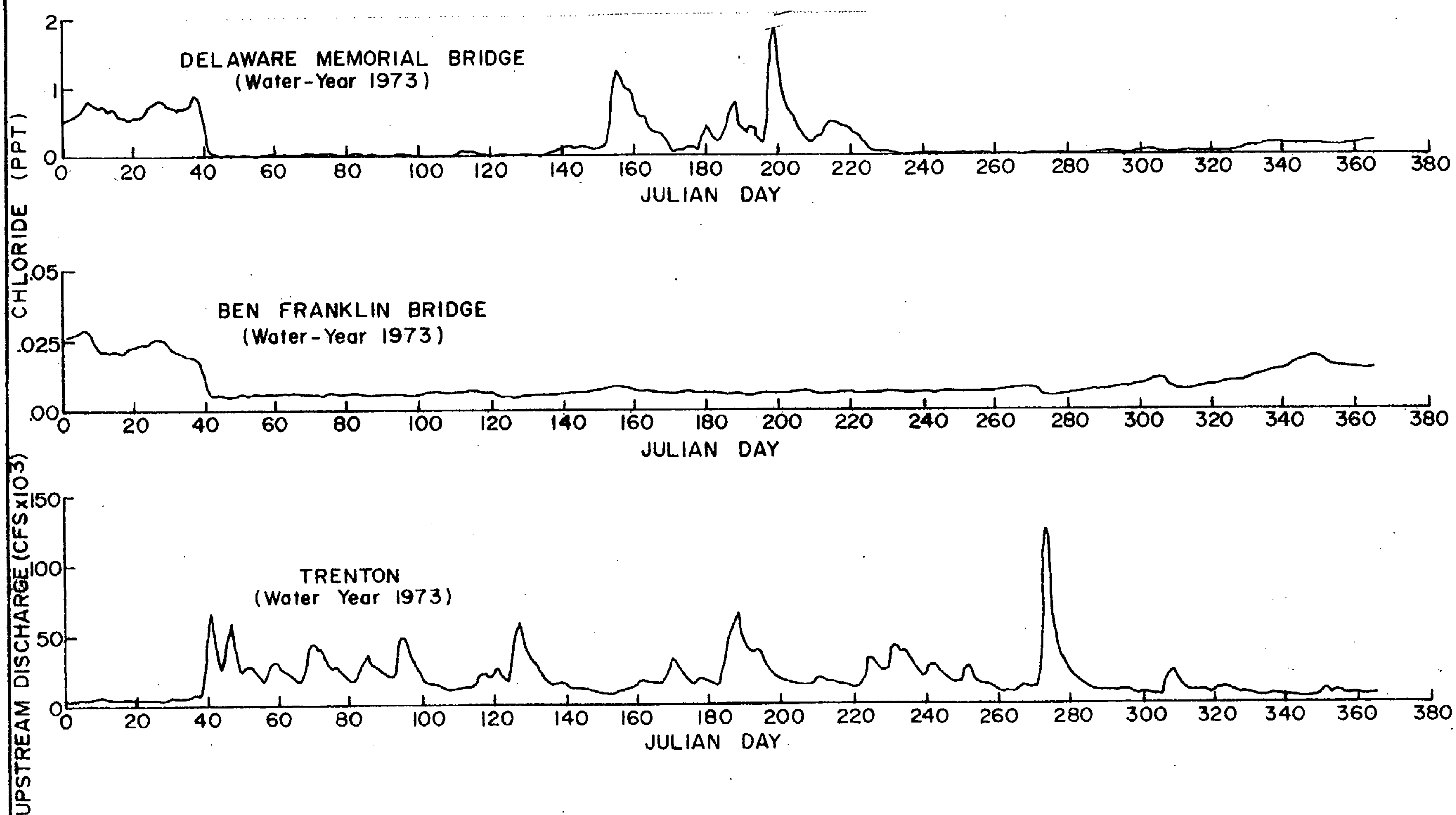
LEGEND

— — — 50-Year average flow : 6,560 ft^3/sec

Positive value indicates Eastward flow

DELAWARE ESTUARY
SALINITY INTRUSION STUDY
ANNUALLY AVERAGED COMPUTED NET FLOWS IN THE C&D CANAL
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 1-17



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
VARIATION OF DAILY MEDIAN
CHLORIDES AND HYDROGRAPH
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 1-18

inflows. However, from day 190 to day 220, the chloride concentrations at the Delaware Memorial Bridge dramatically increased despite moderately high freshwater inflows at Trenton. This chlorinity increase at Delaware Memorial Bridge is attributed to the large net westward flows in the canal, which enhanced the propagation of the salinity front farther upstream in the Delaware estuary. The impact of such westward flows in the canal is not felt at the Ben Franklin Bridge, because relatively high freshwater inflows to the estuary hold the salinity front seaward of this bridge.

APPLICATION OF THE ECONOMIC MODEL FOR THE ASSESSMENT OF AVERAGE ANNUAL SALINITY-RELATED COSTS

The Economic Model (ECOSALT) was utilized to translate the chloride values from the Branched MIT-TSIM Model into costs to estuarine water users. Three fundamental inputs were furnished to the economic model. These are:

a. The delineation of each user's location in terms of the nearest river mile (as measured from the ocean boundary).

b. The "expected TDS" for each river mile, defined by the 50-year "experienced TDS" mean.

c. The frequency distribution of chloride concentration at each of the 34 points of interest (i.e, nearest river miles to locations of users), for each of the 50 years.

Costs were then developed by a straightforward application of the economic model.

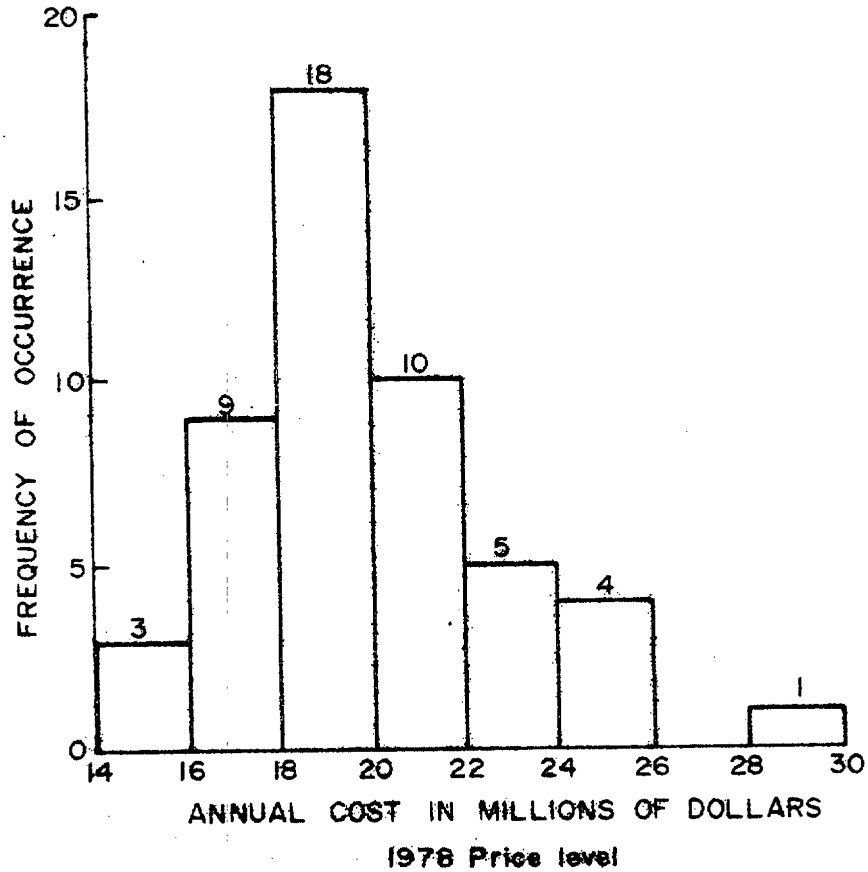
• AVERAGE ANNUAL SALINITY-RELATED COSTS--SUMMARY OF FINDINGS. A detailed, year-by-year tabulation of annual costs (1978 price level) by type of water use is given in Table 1-7. Total average annual salinity-related costs is equivalent to $19.807 million. For graphical visualization of the frequency of occurrence of levels of annual costs over the 50 years (water years 1928-1977), a histogram of annual costs is depicted in Figure 1-19.

Table 1-7

AVERAGE ANNUAL SALINITY-RELATED COSTS BY TYPE OF WATER USE (1978 PRICE LEVEL)

SALINITY COSTS BY WATER YEAR
(MILLIONS OF DOLLARS)

	MUNICIPAL SYSTEMS					DIRECT INDUSTRIAL WITHDRAWAL							
WATER YEAR	MUNIC.	DOMS.	INDUS/ COMM	INSTIT	TOTAL MUNIC.	ONCE-THR COOL	RECIRC COOL	BOILER FEED	PROCESS& CON.COOL	SANITARY & OTHER	INTAKE	TOTAL INDUS	GRAND TOTAL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1928	0.420	8.683	0.921	0.417	10.441	0.071	0.487	0.341	1.914	0.207	1.530	4.551	14.992
1929	0.683	11.706	1.515	0.681	14.584	0.125	0.735	0.488	2.753	0.326	2.131	6.559	21.143
1930	0.659	11.430	1.462	0.657	14.208	0.102	0.712	0.480	2.653	0.326	1.908	6.181	20.390
1931	0.830	13.417	1.855	0.830	16.932	0.163	0.802	0.532	3.507	0.424	2.570	7.998	24.929
1932	0.858	13.746	1.919	0.858	17.381	0.142	0.798	0.532	3.411	0.420	2.370	7.673	25.054
1933	0.587	10.599	1.297	0.584	13.068	0.085	0.663	0.449	2.383	0.288	1.674	5.541	18.609
1934	0.586	10.590	1.295	0.584	13.056	0.105	0.679	0.461	2.439	0.293	1.912	5.889	18.945
1935	0.514	9.756	1.132	0.511	11.913	0.086	0.592	0.410	2.193	0.257	1.702	5.240	17.154
1936	0.653	11.380	1.451	0.652	14.136	0.086	0.674	0.456	2.550	0.308	1.723	5.797	19.933
1937	0.587	10.608	1.300	0.585	13.080	0.100	0.672	0.453	2.483	0.297	1.907	5.913	18.993
1938	0.496	9.544	1.091	0.493	11.624	0.085	0.583	0.405	2.156	0.256	1.703	5.188	16.812
1939	0.609	10.854	1.349	0.607	13.418	0.079	0.645	0.437	2.433	0.288	1.651	5.533	18.951
1940	0.662	11.480	1.469	0.660	14.271	0.139	0.733	0.486	2.797	0.321	2.272	6.748	21.019
1941	0.627	11.067	1.389	0.625	13.708	0.136	0.719	0.483	2.654	0.317	2.202	6.510	20.219
1942	0.685	11.741	1.523	0.684	14.633	0.198	0.745	0.503	3.436	0.397	2.814	8.095	22.728
1943	0.569	10.396	1.259	0.567	12.791	0.089	0.613	0.420	2.299	0.277	1.746	5.445	18.235
1944	0.694	11.847	1.542	0.692	14.775	0.159	0.747	0.497	2.906	0.342	2.451	7.103	21.878
1945	0.542	10.078	1.196	0.539	12.355	0.131	0.638	0.436	2.503	0.290	2.152	6.150	18.505
1946	0.503	9.631	1.108	0.500	11.742	0.065	0.576	0.400	2.131	0.252	1.475	4.900	16.641
1947	0.545	10.118	1.203	0.543	12.409	0.106	0.638	0.434	2.360	0.276	1.907	5.721	18.130
1948	0.550	10.180	1.213	0.547	12.490	0.112	0.633	0.431	2.337	0.274	1.958	5.744	18.234
1949	0.667	11.523	1.481	0.665	14.335	0.110	0.702	0.468	2.720	0.315	2.011	6.326	20.661
1950	0.623	11.023	1.381	0.621	13.649	0.136	0.693	0.467	2.644	0.316	2.228	6.485	20.134
1951	0.575	10.469	1.272	0.573	12.889	0.077	0.637	0.432	2.377	0.278	1.645	5.445	18.335
1952	0.468	9.235	1.029	0.465	11.196	0.065	0.534	0.372	2.034	0.234	1.436	4.674	15.870
1953	0.606	10.819	1.342	0.604	13.371	0.083	0.644	0.430	2.467	0.276	1.705	5.605	18.976
1954	0.729	12.248	1.624	0.728	15.329	0.137	0.744	0.496	2.934	0.355	2.270	6.935	22.265
1955	0.653	11.367	1.450	0.651	14.122	0.121	0.713	0.479	2.685	0.322	2.076	6.395	20.517
1956	0.501	9.619	1.103	0.498	11.721	0.138	0.620	0.421	2.380	0.258	2.246	6.062	17.783
1957	0.746	12.436	1.662	0.745	15.588	0.127	0.748	0.498	2.986	0.350	2.211	6.919	22.507
1958	0.684	11.727	1.521	0.683	14.615	0.119	0.725	0.482	2.820	0.338	2.068	6.552	21.167
1959	0.564	10.334	1.245	0.561	12.705	0.121	0.668	0.454	2.420	0.289	2.053	6.004	18.709
1960	0.483	9.413	1.063	0.480	11.440	0.122	0.577	0.400	2.126	0.249	2.011	5.485	16.924
1961	0.530	9.937	1.167	0.527	12.160	0.135	0.645	0.439	2.351	0.271	2.176	6.017	18.177
1962	0.732	12.280	1.629	0.731	15.372	0.163	0.761	0.502	2.994	0.352	2.463	7.235	22.607
1963	0.737	12.340	1.641	0.736	15.454	0.178	0.768	0.511	3.141	0.361	2.616	7.575	23.029
1964	0.802	13.105	1.792	0.802	16.502	0.157	0.822	0.547	4.286	0.554	2.614	8.979	25.481
1965	0.975	15.087	2.190	0.976	19.228	0.199	0.864	0.568	4.945	0.645	2.977	10.198	29.426
1966	0.879	13.979	1.967	0.879	17.704	0.142	0.809	0.538	3.658	0.449	2.424	8.021	25.726
1967	0.551	10.183	1.215	0.548	12.497	0.132	0.697	0.483	3.011	0.350	2.298	6.972	19.469
1968	0.576	10.485	1.273	0.574	12.908	0.092	0.658	0.447	2.395	0.289	1.798	5.679	18.586
1969	0.590	10.638	1.305	0.588	13.121	0.152	0.698	0.470	2.645	0.303	2.388	6.656	19.777
1970	0.607	10.828	1.343	0.604	13.382	0.206	0.729	0.509	3.784	0.452	2.912	8.591	21.974
1971	0.541	10.065	1.194	0.538	12.338	0.127	0.621	0.424	2.318	0.270	2.107	5.867	18.204
1972	0.482	9.396	1.061	0.479	11.417	0.102	0.542	0.377	2.076	0.235	1.816	5.148	16.565
1973	0.477	9.330	1.050	0.474	11.331	0.170	0.585	0.394	2.281	0.238	2.438	6.106	17.437
1974	0.507	9.677	1.117	0.504	11.805	0.095	0.592	0.407	2.192	0.253	1.799	5.338	17.143
1975	0.431	8.802	0.946	0.428	10.608	0.081	0.486	0.343	1.898	0.212	1.607	4.627	15.235
1976	0.473	9.291	1.039	0.470	11.273	0.082	0.544	0.381	2.053	0.238	1.637	4.935	16.208
1977	0.657	11.415	1.458	0.655	14.186	0.077	0.702	0.470	2.573	0.311	1.659	5.792	19.977
AVG	0.614	10.918	1.361	0.612	13.505	0.120	0.672	0.455	2.670	0.316	2.069	6.302	19.807
MIN	0.420	8.683	0.921	0.417	10.441	0.065	0.486	0.341	1.898	0.207	1.436	4.439	14.874
MAX	0.975	15.087	2.190	0.976	19.228	0.199	0.864	0.568	4.945	0.645	2.977	10.198	29.426



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
HISTOGRAM OF ANNUAL SALINITY-RELATED COSTS
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 1-19

SIGNIFICANCE OF SALINITY-RELATED COSTS TO WITHDRAWAL USERS

• MUNICIPAL SYSTEM USERS:

(1) Summation. Total salinity-related average annual costs for municipal system users represent a very sizeable portion of the total for all estuary withdrawal users, 68.2 percent (%), although utilizing only a small portion of the total water use, 4.9%.

(2) Domestic. As shown in Table 1-8, average annual costs to domestic users of municipal water account for 55.1% of the total average annual costs incurred by withdrawal users of estuarine water, while using only 2.7% of total withdrawals. More specifically, as delineated in Table 1-8, domestic users account for 80.8% of average annual salinity-related costs incurred strictly by municipal system users (and utilize 54.6% of total municipal water use). The large relative magnitude of domestic costs, in comparison with other uses, is attributable to costs incurred for soaps, cleansers, and softeners. These types of costs are not applicable to most other user categories. Also, domestic systems tend to use relatively small amounts of water in relationship to that used by other municipal users and direct industrial withdrawal users. Usage by the latter, particularly, is on a much larger scale (in millions of gallons per day (mgd) terms) with equipment that tends to be less significantly impacted than domestic facilities by the effects of salinity per equal increment of water use. Moreover, the exceedingly large number of domestic households (approximately 525,000), in comparison with the vastly smaller number of users in the other withdrawal categories (for instance, there are but three municipal suppliers and only 56 direct industrial withdrawers) also helps to explain the heavy percentage of total salinity costs that are incurred by the domestic category.

TABLE 1-8

SIGNIFICANCE OF MUNICIPAL SYSTEM USERS
(1978 Pice Level)

Category	Water Use (MGD) (a)	% of total Municipal System Water Use (a)/264.0	Avg. Ann. Costs (b) ($ Mil)	% of total Municipal System Costs (b)/$13.505	% of Total Estuary Water (a)/5391.318[3]	% of Total Avg. Ann. Costs (b)/$19.807[4]
	MUNICIPAL SYSTEM USE ONLY				COMPARISON WITH TOTAL ESTUARY WITHDRAWAL	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Domestic	144.109	54.6	$10.918	80.8	2.7	55.1
Industrial/ Commercial[1]	91.115	34.5	1.361	10.1	1.7	6.9
Institutional	28.776	10.9	0.612	4.5	0.5	3.1
Municipal Facilities[2]	2	2	0.614	4.5	2	3.1
Total*	264.0	100.0	13.505	100.0	4.9	68.2

1)Includes water drawn through Municipal Systems by Industries
2)All water supplied to municipal users is drawn through Municipal Systems Facilities (Torresdale, Lower Bucks, Bristol)
3)Current total estuary withdrawal use (mgd)
4)Avg. Ann. Costs (50-year period of analysis) for total estuary withdrawal use (See column 14 of Table 1-7).
* May not total exactly due to rounding.

(3) Three Municipal Suppliers (Torresdale, Bristol, and Lower Bucks). All water supplied through the municipal distribution systems to domestic, industrial/commercial, and institutional users is handled by the municipal suppliers, but costs to the three municipal suppliers represents only 4.5% of the total costs for municipal system use (see Table 1-8). The municipal use of 264.0 mgd, in turn, represents only 4.9% of the total daily estuary withdrawal. Costs to the three municipal suppliers are 3.1% of the total average annual salinity-related costs of $19.807 million.

(4) Industrial/Commercial and Institutional. These categories utilize 45.4% of the water and account for 14.6% of the annual salinity-related costs for municipal system use. On a broader scale, these categories represent 2.2% of water use and 10.0% of average annual costs for total estuary withdrawal.

• DIRECT INDUSTRIAL WITHDRAWAL USERS. Based on the characteristics of the types of uses undertaken by direct industrial withdrawers, the Delaware estuary can be delineated into three areas:

- Area 1 -- RM 50 (most seaward user) to RM 75 (halfway between Wilmington and Marcus Hook)
- Area 2 -- RM 75 to RM 110 (location of Torresdale intake)
- Area 3 -- RM 110 to RM 134 (Trenton, NJ)

The following breakouts of water use by area in the estuary can be made:

Area	% of Once-through Cooling	% of Recirculating Cooling	% of Boiler Feed	% of Process	% of Sanitary and Other	% of Direct Industrial Water Use	No. of Industrie
1	54	0	0	0	0	51	9
2	27	99	84	59	85	29	39
3	19	1	16	41	15	20	8
Total	100	100	100	100	100	100	56

The direct industrial users in Area 1 withdraw estuarine water exclusively for once-through cooling purposes. The incremental costs of increases in levels of salinity for once-through cooling tend to be relatively minimal. Investment decisions lead to the purchase of equipment capable of handling wide fluctuations in salinity.

Area 2 is the most critical zone of withdrawal use regarding costs experienced from variations in the level of salinity. More sensitive applications of direct industrial withdrawal are undertaken than the once-through cooling use in Area 1 (i.e., recirculating cooling, boiler feed, process, and sanitary and other).

Area 3 is located sufficiently far upriver in the estuary that fluctuations in salinity levels, due to the overriding influence of freshwater inflows, are less than those experienced in Area 2. Thus, salinity-related costs for the sensitive applications of direct industrial withdrawal use are not as great for equivalent increments of water use.

(1) Once-Through Cooling. In contrast with the great magnitude of estuarine water withdrawn for this purpose (4,857 mgd out of total direct industrial withdrawal use of 5,127 mgd, or 94.7%), the salinity related costs are extremely minimal. For example, average annual costs were only $0.120 million (or 1.9%) of the $6.302 million determined for direct industrial withdrawal use. Of further note, once-through cooling consists of 90.1% (4,857 mgd/5,391 mgd) of the total estuarine use, but merely 0.61% ($0.120 million/$19.807 million) of total average annual salinity-related costs incurred. The major reason for the relatively low level of costs is the very corrosion resistant (and expensive) construction materials used in the

once-through equipment. Once-through cooling involves running vast quantities of water continuously through a system, with the equipment designed to be very insensitive to the impact of fluctuating levels of salinity.

(2) Recirculating Cooling, Boiler Feed, Process, and Sanitary and Other. These four sensitive applications of direct industrial withdrawal use incur much more significant levels of salinity costs than once-through cooling, even though the sensitive applications use much less water. Table 1-9 displays the significance of each category of sensitive application.

A point of major interest is the large portion of average annual salinity-related costs for process (42.4%), considering this category's small portion of total direct industrial water use (only 4.3%). Considering the percentage of direct withdrawal use handled by the four sensitive applications (i.e., 5.3%), the percentage of the total average annual salinity-related costs for direct industrial withdrawal of 65.3% for the four uses is very significant. However, the four categories made much smaller contributions to the total of all average annual salinity-related costs (20.8%) despite the four categories percentage of total estuary withdrawal use versus the percentage for direct industrial withdrawal use only diminishing very slightly from 5.3% to 5.0%. This result accents the very heavy relative weighting of salinity costs incurred by municipal systems (especially domestic users).

(3) Intake Systems. All direct industrial water use is handled through intake systems. Average annual salinity-related costs to intakes is 32.8% of total direct industrial withdrawal costs related to salinity (see Table 1-10). Also, although industrial intake systems are used for 95.1 % of total estuary withdrawal use, costs to these intakes comprise only 10.4% of total average annual salinity-related costs.

TABLE 1-9

SIGNIFICANCE OF SENSITIVE APPLICATIONS OF DIRECT INDUSTRIAL WITHDRAWAL USE
(1978 Price Level)

Category	Water Use (MGD) (a)	% of Direct Industrial Withdrawal Use (a)/5127.318[1]	Avg. Ann. Costs (b) ($ Mil)	% of Direct Industrial Withdrawal Costs (b)/$6.302[2]	% of Total Estuary Withdrawal Water Use (a)/5391.318[4]	% of Total Avg.Ann.Costs (b)/$19.807[5]
	DIRECT INDUSTRIAL WITHDRAWAL ONLY				TOTAL ESTUARY WITHDRAWAL	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Recirculating Cooling	22.331	0.4	$0.672	10.7	0.4	3.4
Boiler Feed	15.738	0.3	0.455	7.2	0.3	2.3
Process	220.982	4.3	2.670	42.4	4.1	13.5
Sanitary and Other	11.414	0.2	0.316	5.0	0.2	1.6
Total*	270.465	5.3	4.113	65.3[3]	5.0	20.8

1) Total direct industrial withdrawal use (mgd)
2) Total average annual costs for direct industrial withdrawal use including once-through cooling ($0.120) and Intake Systems ($2.069--see Table 1-10, Column 4).
3) Remainder of direct industrial withdrawal costs consist of once-through cooling (1.9%) and intake systems (32.8%--see Table 1-10, Column 5).
4) Current total estuary withdrawal use (mgd)
5) Total average annual costs (50-year period of analysis) for all estuary withdrawal use (see Table 1-7, Column 14)
* May not total exactly due to rounding.

TABLE 1-10

SIGNIFICANCE OF INTAKE SYSTEMS (DIRECT INDUSTRIAL WITHDRAWAL)
(1978 Price Level)

	DIRECT INDUSTRIAL WITHDRAWAL ONLY				TOTAL ESTUARY WITHDRAWAL	
Category (1)	Direct Water Use (MGD) (a) (2)	% of Direct Industrial Withdrawal Use (a)/5127.318[1] (3)	Avg. Ann. Costs (b) ($ Mil) (4)	% of Direct Industrial Withdrawal Costs (b)/$6.302[2] (5)	% of Total Estuary Withdrawal Water Use (a)/5391.318[3] (6)	% of Total Avg Ann Costs (b)/$19.807[4] (7)
Industrial Intake Systems	5127.318	100.0	$2.069	32.8	95.1	10.4

1)Total direct industrial withdrawal use (mgd)
2)Total average annual costs for direct industrial withdrawal use (see Table 1-7, Column 13).
3)Current total estuary withdrawal use (mgd)
4)Total average annual costs (50-year period of analysis) for all estuary withdrawal use (see Table 1-7, Column 14).

• <u>COMPARISON BETWEEN COSTS DURING A DROUGHT AND AVERAGE ANNUAL SALINITY-RELATED COSTS</u>. Table 1-11 displays a comparison of maximum annual salinity-related costs for the drought water year (WY) 1965 with average annual costs for the 50-year period of analysis. Key points revealed by the comparison are discussed below:

a. For WY 1965, total salinity-related costs incurred were 48.6% higher than the 50-year average annual value. Municipal system use accounted for 59.5% of the difference, and direct industrial withdrawal use accounted for the remaining 40.5%.

b. All water-use categories realized increases in costs (with percentage changes ranging from 24.8% to 104.1%).

c. For total municipal system use, the percentage increase was 42.4%. Of the subcategories, domestic water use showed, by a large margin, the greatest increase in dollar cost ($4.169 million), but the lowest relative increase (38.2%).

d. The percentage increase for direct industrial water use was 61.8%. As shown in Table 1-11, though, this was an average percentage that was a result of the offsetting effects of, a) three lower percentage increases ((intake systems (43.9%), recirculating cooling (28.6%), and boiler feed (24.8%)), and b) two higher percentage increases (process (85.2%) and sanitary and other (104.1%)). Process had the most notable increase in dollar costs ($2.275 million). The sanitary and other subcategory, because of its small amount of water use relative to other direct industrial withdrawal categories, increased in costs by only $0.329 million despite incurring the largest percentage increase.

TABLE 1-11

COMPARISON OF MAXIMUM ANNUAL SALINITY-RELATED COSTS (WATER YEAR 1965)
WITH AVERAGE ANNUAL COSTS FOR 50-YEAR PERIOD (WY 1928-WY 1977)
(Costs in Million of Dollars)
(1978 Price Level)

	ANNUAL SALINITY-RELATED COSTS				CATEGORY COSTS AS PERCENTAGE OF TOTAL COSTS		
Water Use Category	50-Year Average (a) (Y)	Water Year (b) (Z)	Difference Water Year 1965 minus 50-Year Average $	%	50-Year Average % (a)/$19,807	Water Year 1965 % (b)/$29.426	Difference Water Year 1965% minus 50-Year average %
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Municipal Systems:							
Domestic	$10.918	$15.087	$4.169	38.2	55.1	51.3	-3.8
Municipal Suppliers	0.614	0.975	0.361	58.8	3.1	3.3	+0.2
Industrial/ Commercial	1.361	2.190	0.829	60.9	6.9	7.4	+0.5
Institutional	0.612	0.976	0.364	59.5	3.1	3.3	+0.2
TOTAL MUNICIPAL*	13.505	19.228	5.723	42.4	68.2	65.3	-2.9
Direct Industrial Withdrawal:							
Once-Through Cooling	0.120	0.199	0.079	65.8	0.6	0.7	+0.1
Recirculating Cooling	0.672	0.864	0.192	28.6	3.4	2.9	-0.5
Boiler Feed	0.455	0.568	0.113	24.8	2.3	1.9	-0.4
Process	2.670	4.945	2.275	85.2	13.5	16.8	+3.3

TABLE 1-11 (Con't)

COMPARISON OF MAXIMUM ANNUAL SALINITY-RELATED COSTS (WATER YEAR 1965)
WITH AVERAGE ANNUAL COSTS FOR 50-YEAR PERIOD (WY 1928-1977)
(Costs in Million of Dollars)
(1978 Price Level)

Water Use Category	ANNUAL SALINITY-RELATED COSTS				CATEGORY COSTS AS PERCENTAGE OF TOTAL COSTS		
	50-Year Average (a) (Y)	Water Year (b) (Z)	Difference Water Year 1965 minus 50-Year Average $	%	50-Year Average % (a)/$19,807	Water Year 1965 % (b)/$29.426	Difference Water Year 1965 minus 50-Year average %
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sanitary and Other	0.316	0.645	0.329	104.1	1.6	2.2	+0.6
Intake	2.069	2.977	0.908	43.9	10.4	10.1	-0.3
TOTAL - * DIRECT INDUSTRIAL WITHDRAWAL	6.302	10.198	3.896	61.8	31.8	34.7	+2.9
TOTAL - All * ESTUARY WITHDRAWAL	19.807	29.426	9.619	48.6	100%	100%	-

(Y) See Table 1-7, Column 1-14.
(Z) See Table 1-7, Column 1-14.
* May not total exactly due to rounding

e. Comparing average annual salinity-related costs to the salinity-related costs solely for the maximum annual cost water year (1965) (see Table 1-11), it was determined that the relative percentage of costs to municipal system users to the costs for direct industrial withdrawal users did not significantly differ. Municipal system users costs showed a slight decrease of 2.9%, dropping from 68.2% of average annual salinity-related costs to 65.3% of salinity-related costs for water year 1965. Of course, concurrently, direct industrial users incurred an offsetting 2.9% increase (from 31.8% to 34.7%) in their share of total costs.

• <u>ANALYSIS OF THE PERCENTAGE CHANGE IN THE RELATIVE MAGNITUDE OF COSTS</u>:

(1) <u>Municipal System Users</u>. As shown in Table 1-11, domestic use manifests a loss of 3.8% of total salinity-related costs in comparing its percentage share of average annual costs to the costs for water year 1965 (dropping from 55.1% to 51.3%). The other three municipal water use categories all displayed slight increases (0.5% or less).

(2) <u>Direct Industrial Withdrawal Users</u>. The six subcategories displayed mixed results in direction of change when comparing water year 1965 costs with the 50-year average annual costs. Process had the most significant increase (3.3%), while once-through cooling and sanitary and other showed small rises (0.1% and 0.6%, respectively). On the other side of the ledger, small decreases in the percentage share of costs were determined for the recirculating cooling (0.5%), boiler feed (0.4%), and intake system (0.3%) categories.

• <u>COMPARISON OF COSTS FOR HIGH-SALINITY WATER YEARS</u>:

(1) <u>Municipal System User and Direct Industrial Withdrawal User Categories</u>. An analysis (see Table 1-12) determined that the relationship between municipal system user costs and direct industrial withdrawal user costs did not fluctuate to a significant extent for water years with the highest salinity costs. Appropriate water years were selected from the summation data in Table 1-7, and included the following drought years: 1962-66, 1931-32, and 1942.

(2) <u>Domestic and Process Use</u>. An additional analysis, using the same eight highest salinity cost water years as above, was conducted for two sub-categories, domestic and process use. These two uses displayed in Table 1-11, the greatest fluctuation in percentage of total annualized salinity-related costs for the 50-year period of analysis in relation to percentage of total costs solely for water year 1965. Table 1-13 shows that, on the whole, domestic user costs tended to increase slightly compared to the 50-year average, as a percentage of total costs, for the eight highest salinity cost water years.

TABLE 1-12

COMPARISON OF MUNICIPAL SYSTEM AND DIRECT INDUSTRIAL WITHDRAWAL COSTS FOR EIGHT HIGHEST SALINITY COST WATER YEARS
(1978 Price Level)

	ANNUAL COSTS, MILLIONS OF DOLLARS			ANNUAL COSTS PER CATEGORY AS PERCENTA[GE] OF TOTAL ANNUAL COSTS	
Water Years	Municipal System Users (a)	Direct Industrial Withdrawal Users (b)	All Users (c)	Municipal System Users (a)/(c)	Direct Industrial Withdrawal users (b)/(c)
(1)	(2)	(3)	(4)	(5)	(6)
1965	$19.228	$10.198	$29.426	65.3	34.7
1966	17.704	8.021	25.726	68.8	31.2
1964	16.502	8.979	25.481	64.8	35.2
1932	17.381	7.673	25.054	69.4	30.6
1931	16.932	7.998	24.929	67.9	32.1
1963	15.454	7.575	23.029	67.1	32.9
1942	14.633	8.095	22.728	64.4	35.6
1962	15.372	7.235	22.607	68.0	32.0

(1)High total-cost years for all users during 50-year period 1928-1977 listed in descending order of total annual salinity-related costs incurred by all users.

(a) See Table 1-7, Column 6.
(b) See Table 1-7, Column 13.
(c) See Table 1-7, Column 14.

TABLE 1-13

COMPARISON OF DOMESTIC AND PROCESS USER SALINITY-RELATED COSTS
FOR EIGHT HIGHEST SALINITY COST WATER YEARS
(1978 Price Level)

	ANNUAL COSTS, MILLIONS OF DOLLARS			ANNUAL COSTS PER CATEGORY AS A PERCENTAC OF TOTAL ANNUAL COSTS	
Water Years	Domestic Users (a)	Industrial Process Users (b)	All Users (c)	Domestic Users (a)/(c)	Industrial Process Users (b)/(c)
(1)	(2)	(3)	(4)	(5)	(6)
1965	$15.087	$4.945	$29.426	51.3	16.8
1966	13.979	3.658	25.726	54.3	14.2
1964	13.105	4.268	25.481	51.4	16.8
1932	13.746	3.411	25.054	54.9	13.6
1931	13.417	3.507	24.929	53.8	14.1
1963	12.340	3.141	23.029	53.6	13.6
1942	11.741	3.436	22.728	51.7	15.1
1962	12.280	2.994	22.607	54.3	13.2

(a) See Table 1-7, Column 3.
(b) See Table 1-7, Column 10.
(c) See Table 1-7, Column 14.

FUTURE SALINITY-RELATED COSTS

Future salinity-related costs were projected to the year 2030 using available future water use projections.

• WATER USE PROJECTIONS. Water use by various categories were projected to year 2030. Year 1978 served as a base from which projections were made. Indices for water uses in the various categories (1978 index equals 100) were then projected for each of the decennial years from 1990 to 2030. The indices for water use projections are listed in Table 1-14. The water use indices for the residential, industrial and commercial (combined), and institutional categories were estimated using projections developed for the Camden Metropolitan Urban Study, a study completed by the Philadelphia District, Corps of Engineers, in April 1980. The Camden Metropolitan Urban Study projections to the year 2030 depicted an increase in water use for the above four categories. The once-through cooling index shown for 1990 is based on the Pennsylvania Department of Environmental Resources (Pa DER) projection of a decline in electric generating station once-through water use from 1978 to 1990 as utilities change over from once-through to recirculating cooling systems. This downward trend has been extrapolated for the decennial years after 1990. The recirculating cooling index listed for 1990 is also based on Pa DER's projections, with the indices for decennial years after 1990 being a continuation of the trend of a ten percent increase each decade.

A number of projection sources were analyzed during the selection of the water use indicies listed in Table 1-14. The DRBC's Level B Study projections were not considered directly applicable to this study since these projections dealt predominantly with depletive usage (whereas much of the water withdrawn by users analyzed in the current study is eventually returned to the system). Projections made by the States of Pennsylvania and New

TABLE 1-14

WATER USE PROJECTION INDICES
DECENNIAL YEARS, 1990-2030 (1978=100)

CATEGORY	1990	2000	2010	2020	2030
Residential	116	133	145	155	163
Industrial and Commercial	108	115	120	125	129
Institutional	109	118	125	131	136
Industrial	103	104	103	103	102
Once-Through Cooling	57	50	45	40	35
Recirculating Cooling	135	145	155	165	175

Jersey agreed fairly well with that of the Camden Metropolitan Urban Study. The Pa DER projections were developed for 1990 and 2000, while New Jersey Department of Environmental Protection projections extended through year 2020. Relevant projects for New Castle County, Delaware, developed by the Wilmington Metropolitan Area Planning Coordinating Council also agreed well with those used in this analysis. Refer to Table 1-15 for projected water uses.

• SALINITY-RELATED COSTS. Salinity-cost relationships as described in Appendix 2, were estimated for each type of water use (and related facilities). It was assumed that, over time, the characteristics of the types of water use and facilities would not change significantly. So, modification of the salinity-cost curves on a decennial basis was not made. The average annual salinity-related costs developed in Appendix 1 (summarized in Table 1-7) in conjunction with the indices of water use projections (Table 1-14) were used as a basis to approximate the potential magnitude of salinity-related costs for each 10-year period from 1978-2030 (Table 1-16). As shown in Tables 1-15 and 1-16 municipal system water use and costs display a fairly significant rise over the period of analysis (predominantly due to a large increase for the domestic category). Conversely, direct industrial withdrawal water use (Table 1-15) shows a decrease of approximately 56% from 1978 to 2000 (mostly due to a drastic projected drop in once-through cooling useage). Related direct industrial withdrawal costs though would only slightly diminish, since once-through cooling systems incur only very low levels of costs in relation to the magnitude of water used. Thus, overall total water use is expected to diminish significantly, while salinity-related costs are projected to rise 35% from 1978 to 2030.

TABLE 1-15

PROJECTED WATER USES (in million gallons/day)
1978 to Year 2030

CATEGORY	1978	1990	2000	2010	2020	2030
Municipal System Use:						
Domestic	144.1	167.2	191.7	208.9	223.4	234.9
Industrial/Commercial	91.1	98.4	104.8	109.3	113.9	117.5
Institutional	28.8	31.4	34.0	36.0	37.7	39.2
Municipal Facilities [(a)]	264.0	297.0	330.5	354.2	375.0	391.6
Direct Industrial Withdrawal Use:						
Once-Through Cooling	4857.0	2768.5	2428.5	2185.7	1942.8	1700.0
Recirculating Cooling	22.3	30.1	32.3	34.6	36.8	39.0
Boiler Feed	15.7	16.2	16.3	16.2	16.2	16.0
Process	221.0	227.6	229.8	227.6	227.6	225.4
Sanitary and Other	11.4	11.7	11.9	11.7	11.7	11.6
Intake [(b)]	5127.3	3054.1	2718.8	2475.8	2235.1	1992.0
TOTAL	5391.3	3351.1	3049.3	2830.0	2610.1	2383.6

(a) All water supplied to municipal system users is drawn through municipal facilities.

(b) All water withdrawn for direct industrial use is drawn through intake systems.

TABLE 1-16

SALINITY-RELATED COSTS
FOR PROJECTED USES (1978 to Year 2030)
1978 Price Level (in millions of dollars)

CATEGORY	1978 1/	1990	2000	2010	2020	2030
Municipal System Use:						
Domestic	$10.918	$12.665	$14.521	$15.831	$16.923	$17.796
Industrial/Commercial	1.361	1.470	1.565	1.633	1.701	1.756
Institutional	0.612	0.667	0.722	0.765	0.802	0.832
Municipal Facilities	0.614	0.691	0.769	0.824	0.872	0.911
Direct Industrial Withdrawal Use:						
Once-Through Cooling	0.120	0.068	0.060	0.054	0.048	0.042
Recirculating Cooling	0.672	0.907	0.974	1.042	1.109	1.176
Boiler Feed	0.455	0.469	0.473	0.469	0.469	0.464
Process	2.670	2.750	2.777	2.750	2.750	2.723
Sanitary and Other	0.316	0.325	0.329	0.325	0.325	0.322
Intake	2.069	1.232	1.097	0.999	0.902	0.804
TOTAL	19.807	21.244	23.287	24.692	25.901	26.826

1/ Average annual cost for period of water years 1928-1977 (see Table 1-7).

DELAWARE ESTUARY SALINITY INTRUSION STUDY

ECONOMIC INVESTIGATION

DEVELOPMENT OF SALINITY-COST RELATIONSHIPS

APPENDIX 2

US Army Corps of Engineers
Philadelphia District

DELAWARE ESTUARY
SALINITY INTRUSION STUDY

APPENDIX 2
ECONOMIC INVESTIGATION
DEVELOPMENT OF SALINITY-COST RELATIONSHIPS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

APPENDIX 2
ECONOMIC INVESTIGATION
DEVELOPMENT OF SALINITY-COST RELATIONSHIPS

INTRODUCTION

This appendix presents the development of salinity-cost relationships for withdrawal users of estuarine water. Uses include municipal (domestic, industrial, commercial, and institutional users), and direct industrial withdrawal (once-through cooling, process, recirculating cooling, boiler feed, sanitary, and intake systems).

OVERVIEW

The economic investigation is concerned with the economic cost of salinity in the Delaware estuary. Salinity, defined as total dissolved solids (TDS), is naturally present in low concentrations in the freshwater inflows to the estuary. In the lower part of the estuary, however, TDS concentrations are increased substantially by the intrusion of salt water from the ocean. The extent of this intrusion is a function of the time-varying tides and freshwater inflows.

This investigation is concerned strictly with the economic costs of salinity, not with what determines the levels or patterns of salinity or how they might be controlled.

COSTS

Costs of salinity to withdrawal users include costs to 1) direct industrial withdrawers, and 2) direct municipal water supply withdrawers and their industrial, domestic, commercial, and institutional customers (indirect users). Major cost categories are 1) costs of investment in more corrosion-resistant facilities and in treatment facilities to avoid or reduce the effects of salinity, 2) costs of alternate water supply sources for periods of very high estuarine salinity, 3) costs of treatment chemicals, and 4) costs of repair and early replacement due to the corrosive effects of salinity.

DIRECT WITHDRAWAL USERS

Fifty-six industrial plants and three municipal water supply systems have been identified as direct withdrawers of water from the Delaware estuary (1978 Survey). Table 2-1 presents total direct withdrawal by 3-digit Standard Industrial Classification (SIC) Codes for industrial uses. Withdrawal by the municipal water supply systems is also listed. Figure 2-1 shows the locations of industrial water users (by SIC Code) and municipal water supply systems.

FRAMEWORK AND PROCEDURES FOR ESTIMATING SALINITY-COST RELATIONSHIPS FOR WITHDRAWAL USERS

OVERVIEW

This section outlines the framework and procedures used in the development and estimation of salinity-cost relationships. The framework encompasses the identification and classification of different kinds of relationships and, conceptually, how to integrate these relationships. The procedures discuss the use of different information sources, salinity-cost relationship modelling for different types of use, and the selection of appropriate interest rates and cost indices.

TABLE 2-1

INTAKE WITHDRAWALS

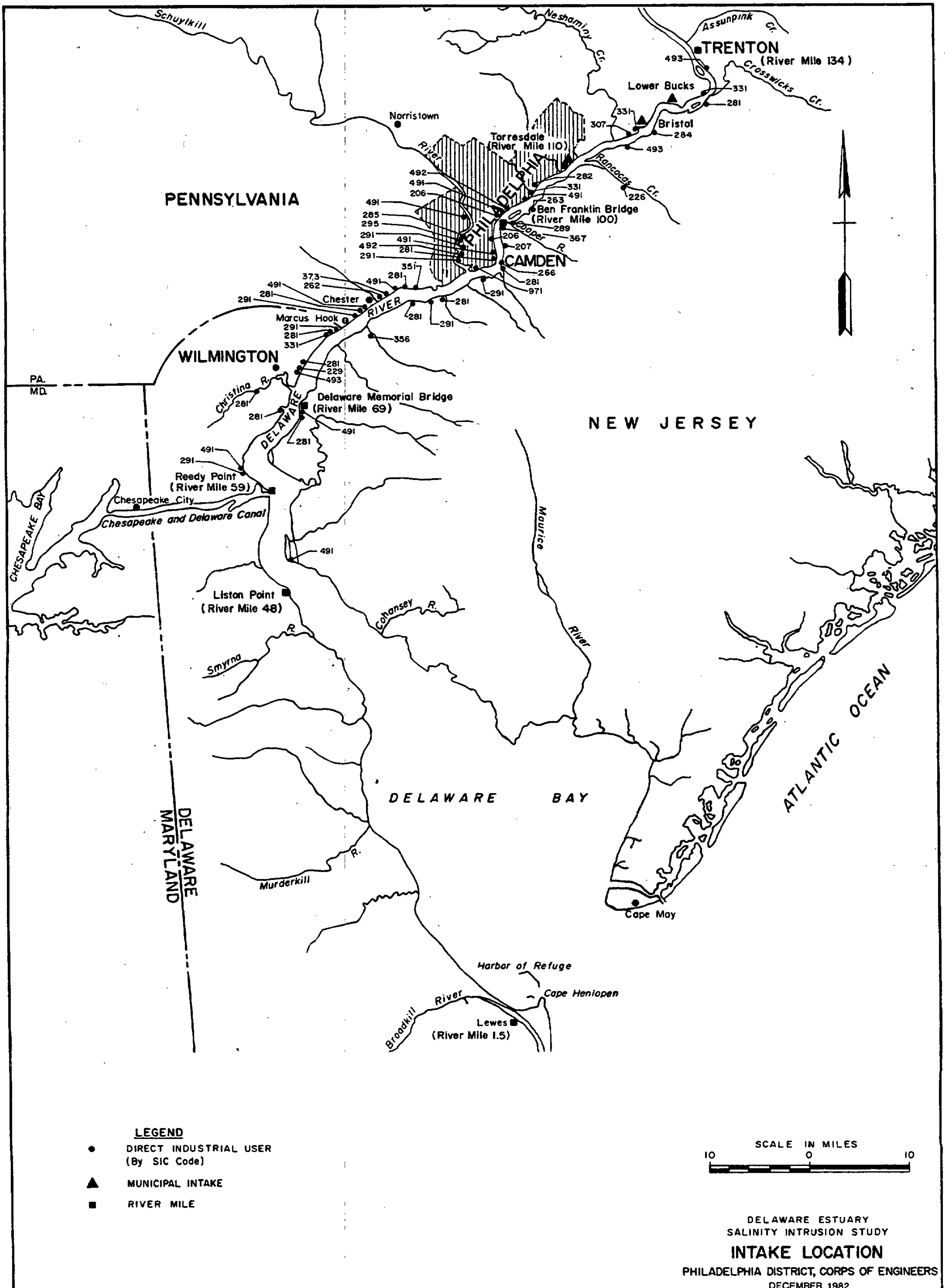
A. TOTAL DIRECT INDUSTRIAL WITHDRAWAL USE (1978 Survey)

Rank	SIC	Industry	Inventory Water Use (mgd)	Percent of total (%)
1	491	Electric Generation	2,185.9	42.63
2	493	Utilities	1,664.7	33.47
3	291	Petroleum Refining	600.6	11.71
4	281	Inorganic Chemicals	245.6	4.79
5	331	Steel Works	234.2	4.57
6	206	Sugar and Confectionary Products	35.9	0.70
7	351	Non-Electrical Machinery	31.3	0.61
8	971	Naval Shipyard	28.9	0.56
9	492	Gas Production and Distribution	24.3	0.47
10	307	Plastics	22.0	0.43
11	262	Paper Mills	19.9	0.39
12	282	Plastic Materials and Synthetics	11.2	0.22
13	289	Chemical Products	7.2	0.14
14	285	Paints and Allied Products	3.7	0.07
15	207	Fats and Oils	3.3	0.06
16	373	Ship Building	2.6	0.05
17	367	Electric Machinery	2.1	0.04
18	356	General Industrial Machinery	1.4	0.03
19	263	Paperboard Mills	1.2	0.02
20	266	Building Paper Mills	0.6	0.01
21	295	Paving and Roofing Material	0.3	0.01
22	284	Toilet Preparations	0.3	0.01
23	229	Textile Products	0.1	0.01
		TOTAL	5,127.3	100%

NOTE: Numbers may not add due to rounding.

B. MUNICIPAL SYSTEM WITHDRAWAL USE (1978 Survey)

Rank	Municipal System	Water Use (mgd)	Percent of Total (%)
1	Torresdale	250	94.70%
2	Lower Bucks County	9	3.41%
3	Bristol	5	1.89%
	TOTAL	264	100%



TRENTON
(River Mile 134)
Lower Bucks
Bristol
Torresdale
(River Mile 110)
PHILADELPHIA
Ben Franklin Bridge
(River Mile 100)
CAMDEN
Norristown
PENNSYLVANIA
Chester
Marcus Hook
WILMINGTON
Delaware Memorial Bridge
(River Mile 69)
Reedy Point
(River Mile 59)
Chesapeake City
Chesapeake and Delaware Canal
Liston Point
(River Mile 48)
NEW JERSEY
DELAWARE BAY
ATLANTIC OCEAN
Cape May
Harbor of Refuge
Cape Henlopen
Lewes
(River Mile 1.5)
Schuylkill
Neshaminy Cr.
Assunpink Cr.
Crosswicks Cr.
Rancocas Cr.
Cooper R.
Christina R.
Smyrna R.
Murderkill R.
Broadkill River
Cohansey R.
Maurice River
DELAWARE RIVER
CHESAPEAKE BAY
PA.
MD.
DELAWARE
MARYLAND
LEGEND
DIRECT INDUSTRIAL USER (By SIC Code)
MUNICIPAL INTAKE
RIVER MILE
SCALE IN MILES
10 0 10
DELAWARE ESTUARY
SALINITY INTRUSION STUDY
INTAKE LOCATION
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-1

FRAMEWORK FOR ESTIMATING SALINITY-COST RELATIONSHIPS

Three types of salinity related costs were identified. Costs of the first type, termed "investment" costs, depend on expected levels and patterns of salinity, but not on actual or experienced day-to-day variations in salinity. Costs of the second type, termed "contingency" costs, depend on experienced salinity being above a certain critical level, but not on the day-to-day variations in the experienced levels of salinity once the critical level has been reached. Costs of the third type, termed "daily-salinity" costs, depend on the day-to-day variations in salinity, (i.e., the actual experienced levels of salinity). The terms "investment", "contingency", and "daily-salinity" are always placed in quotation marks in this report when used to refer to salinity costs. The reason is to avoid confusion with accounting phraseology for the terms investment and daily (or operating) costs. "Investment" costs include operation, maintenance, repair, and replacement costs that are associated with investment for salinity avoidance or to improve salinity tolerance, but that are not related to experienced salinity levels. Conversely, "daily-salinity" costs include the shortening of investment life as well as facilities, maintenance and repair costs from corrosion, and treatment chemical and other operating costs. "Daily-salinity" costs depend on day-to-day (i.e., experienced) levels of salinity, and are not "investment" type costs, despite the fact that shortening of investment life is involved.

These distinctions are important because the costs involved depend on different measures of salinity, and this factor is essential in the development of the salinity-cost relationship estimates.

The three types of salinity-related costs and the framework for their analysis are fully discussed in the following paragraphs.

"INVESTMENT" COSTS

In order to avoid or reduce the cost effects of salinity, withdrawal users formulate and implement various investment decisions taking into account expectations concerning levels and patterns of salinity. These include investments in:

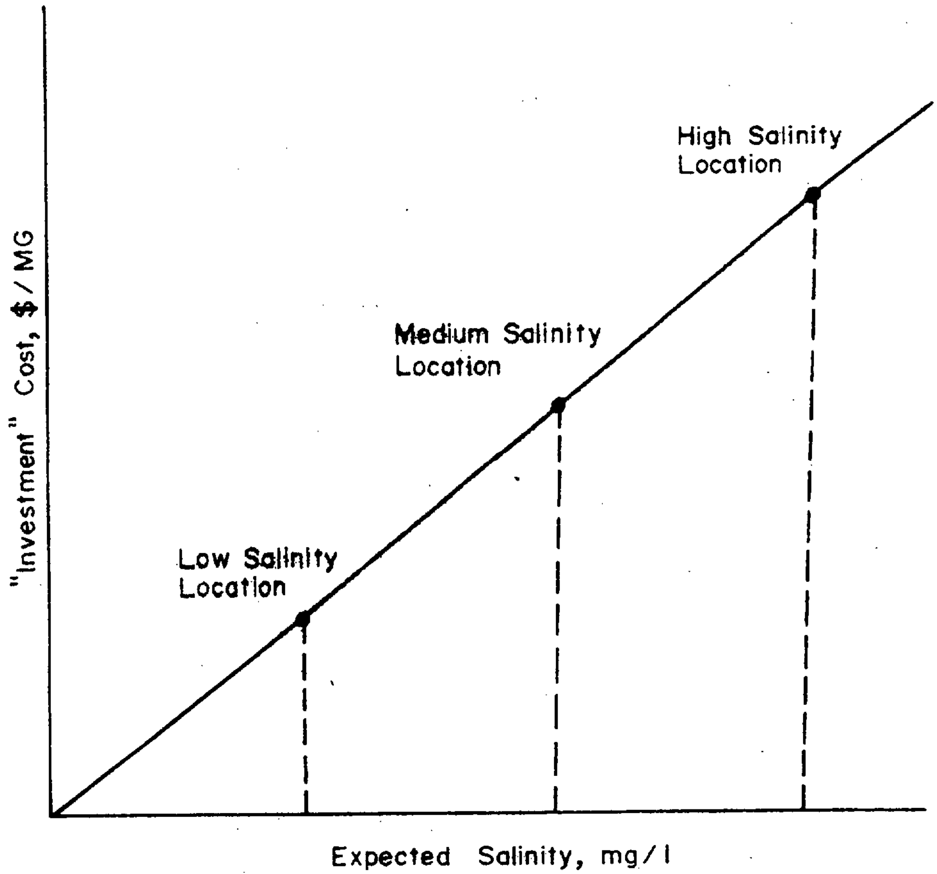
a. More salinity resistant materials.
b. Treatment facilities.
c. First cost of standby alternative water supply systems for periods of unusually high salinities.
d. Types and capacities of operating equipment and processes.

The expected patterns as well as levels of salinity may be important in an investment decision. Investment in treatment facilities would depend on some design maximum expected salinity. Investment decisions concerning construction of standby alternative facilities would clearly depend on the anticipated range and variance of salinity. Investment in salinity resistant materials, however, is predicated mainly on expected average levels of salinity.

"Investment" costs will tend to be greater in a location with relatively high salinity levels than in locations with either medium or relatively low levels of salinity. The form of the relationship is shown in Figure 2-2.

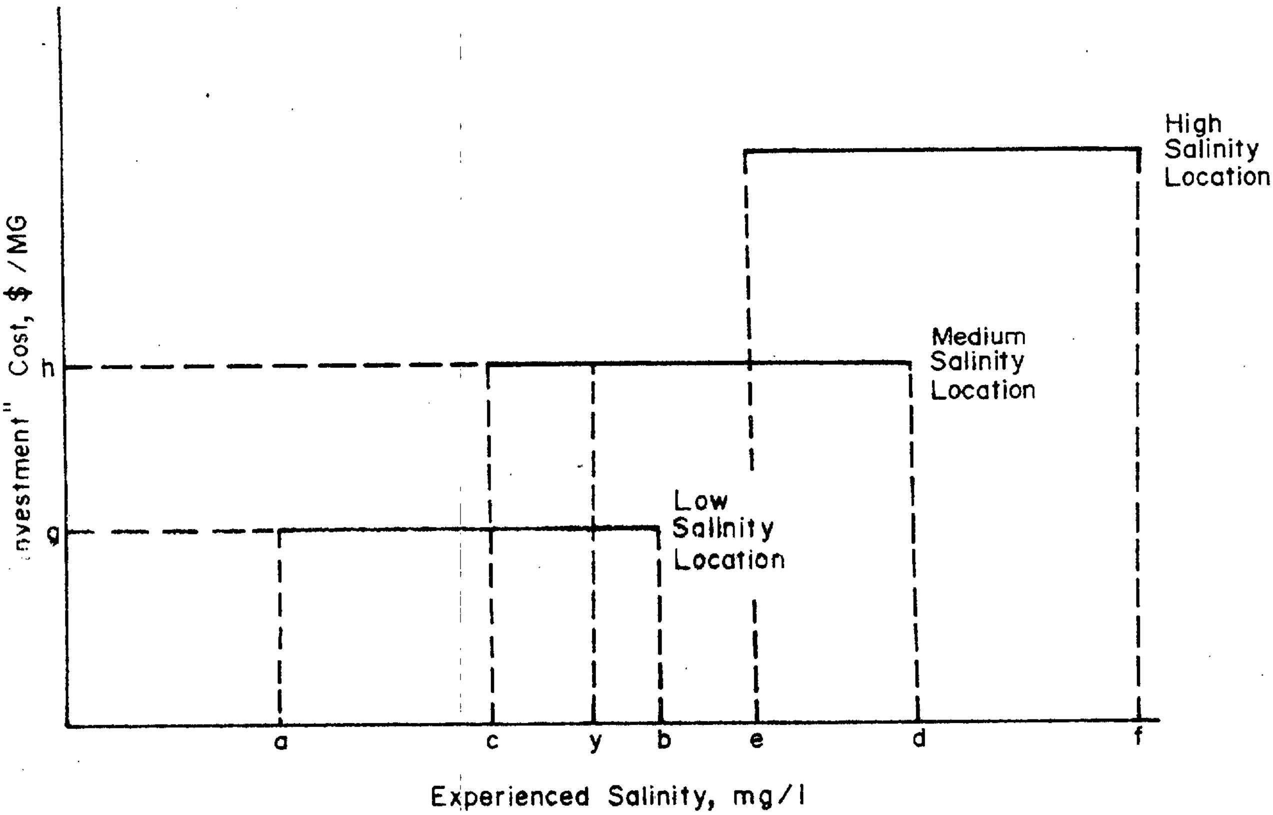
Figure 2-3 depicts the "investment" costs-experienced salinity relationship. In a low salinity area of the Delaware estuary, experienced salinity is envisioned to vary over a range from a to b. "Investment" costs, in dollars per million gallons of water use ($/MG)*, do not vary with

* The procedures for estimating and expressing investment cost in $/MG of water use are discussed in subsequent sections.



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
"INVESTMENT" COST — EXPECTED
SALINITY RELATIONSHIPS
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-2



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
"INVESTMENT" COST-EXPERIENCED
SALINITY RELATIONSHIPS

PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-3

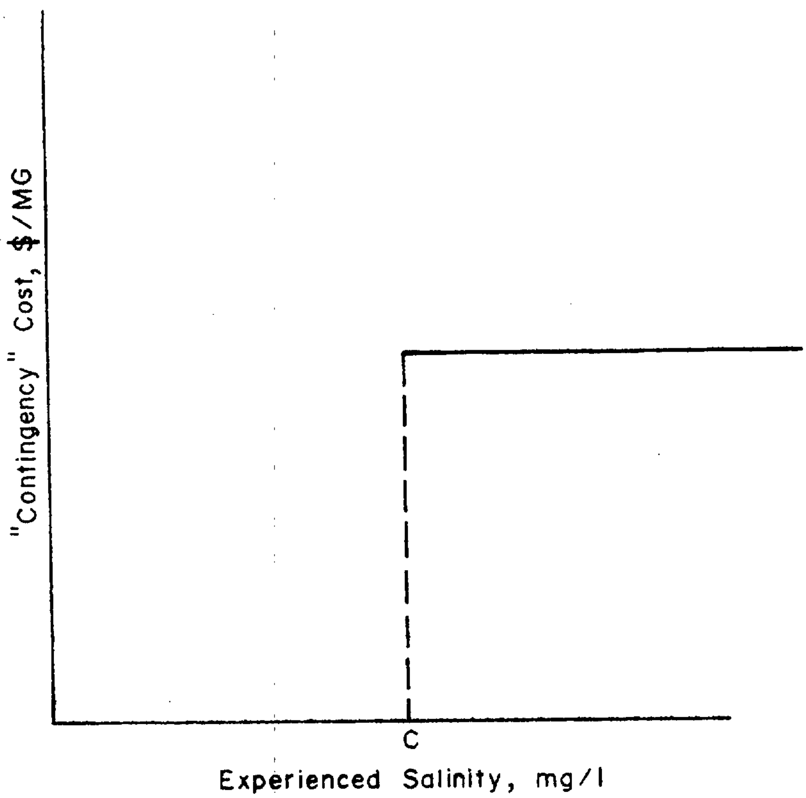
experienced salinity over this range, but are fixed at level g. This level, however, is applicable only to this particular location (i.e., having this level and range of expected salinity). At a medium salinity location in the estuary, "investment" cost in $/MG will be at a higher level, h, but still fixed at h with respect to variation in experienced salinity over the range of variation from c to d. Figure 2-3 also shows that for any particular level of experienced salinity, for example, y, there can be different investment costs (in the case shown, g for the low salinity location, and h for the medium salinity location), depending on the withdrawal location in the estuary.

"CONTINGENCY" COSTS

The major "contingency" cost entails a potential switch to an alternate source of water above a defined critical experienced estuarine salinity level. A second possible "contingency" cost involves the shutting down of a product line above a critical experienced salinity level.

The form of the relationship involving a switch at a critical experienced salinity level is shown in Figure 2-4. The "contingency" cost per MG is zero below the critical experienced salinity level, or switchover point, because the alternate source is not used, and is relatively fixed above the critical salinity level with respect to experienced salinity for the alternate source.

In addition to switching based on experienced salinity levels, users will switch to an alternate source for supplying certain uses when expected salinities rise above certain criterion levels. For example, fewer users employ estuarine water for sensitive uses such as boiler feed and process



C = Critical experienced salinity level or switch-over point above which a switch is made to an alternate water supply source

DELAWARE ESTUARY
SALINITY INTRUSION STUDY

"CONTINGENCY" COST—EXPERIENCED SALINITY RELATIONSHIPS

PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-4

water in higher salinity estuary locations. This suggests that if expected estuarine salinities (which are usually some measure of past experienced salinities) rise, users will be increasingly apt to switch to alternate sources, depending on the sensitivities to salinity for the various uses. The costs of switching to an alternate source based on expected salinity are here also classified as "contingency" costs. These "contingency" costs must be carefully delineated as separate from the "investment" costs incurred for the cost of initial construction of the standby alternate water supply systems (as discussed on p. 2-5, 2-6).

"DAILY-SALINITY" COSTS

Cost of water use varies with experienced day-to-day levels of salinity and includes the following categories:

a. Reduction in life of facilities because of corrosion; that is, early replacement or reduced-life-span costs.

b. Facilities maintenance and repair costs due to the corrosive effects of salinity. This would include increased downtime as well as the direct costs of maintenance and repair.

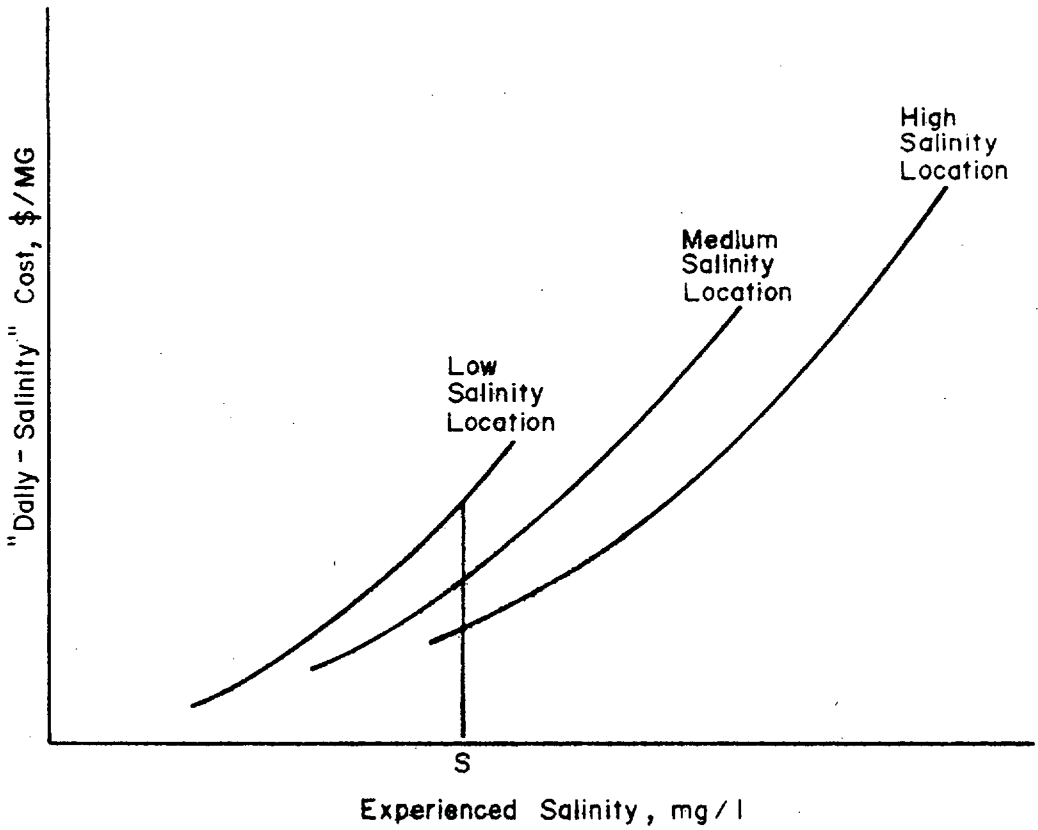
c. Treatment chemical and other operating costs that vary with salinity levels. These costs would include the use of soaps and cleansers due to hardness associated in water salinity, and the use of sodium chloride as the regenerant in water softeners.

These three cost categories are termed operation (item c), maintenance (item b), repair (item b), and replacement (item a), or, taken together as the total "daily-salinity" costs, OMR&R (operation, maintenance, repair, and replacement).

"Daily-salinity" costs will rise with increases in experienced, day-to-day salinities. The level of these costs, however, will be predicated on the level of investment undertaken to reduce or avoid these costs. This is shown in Figure 2-5. "Daily-salinity" costs per MG of the same type of water use, for a particular experienced salinity level, typically will be lower in the higher salinity locations where greater investment for the avoidance of salinity damage will have been made. Thus, in Figure 2-5, at a given salinity level S, the "daily-salinity" cost is higher in the low-salinity location than in the medium-salinity location or the high-salinity location.

INTERGRATING THE COST FUNCTIONS, AND TOTAL SALINITY COSTS

• INTERGRATING "DAILY-SALINITY" AND "CONTINGENCY" COSTS. "Daily-salinity" costs are variable costs that can be avoided by switching to an alternative source. They are variable, as opposed to fixed or sunk, which are terms that characterize "investment" costs. While the "daily-salinity" cost (which are due to experienced estuary salinity) can be avoided by switching to an alternate source, the variable cost of purchasing the alternate source and variable costs experienced from the salinity levels of this alternative source would be incurred. The economic switchover point for switching from one source of water to another will depend on the comparative variable costs of water from each source. Estuarine water will be used at salinity levels where its variable costs per MG of water use are lower than the costs related to use of the alternative source, and, conversely, alternate source water will be used where its costs per MG of water use are lower than the variable costs associated with use of the estuarine water.



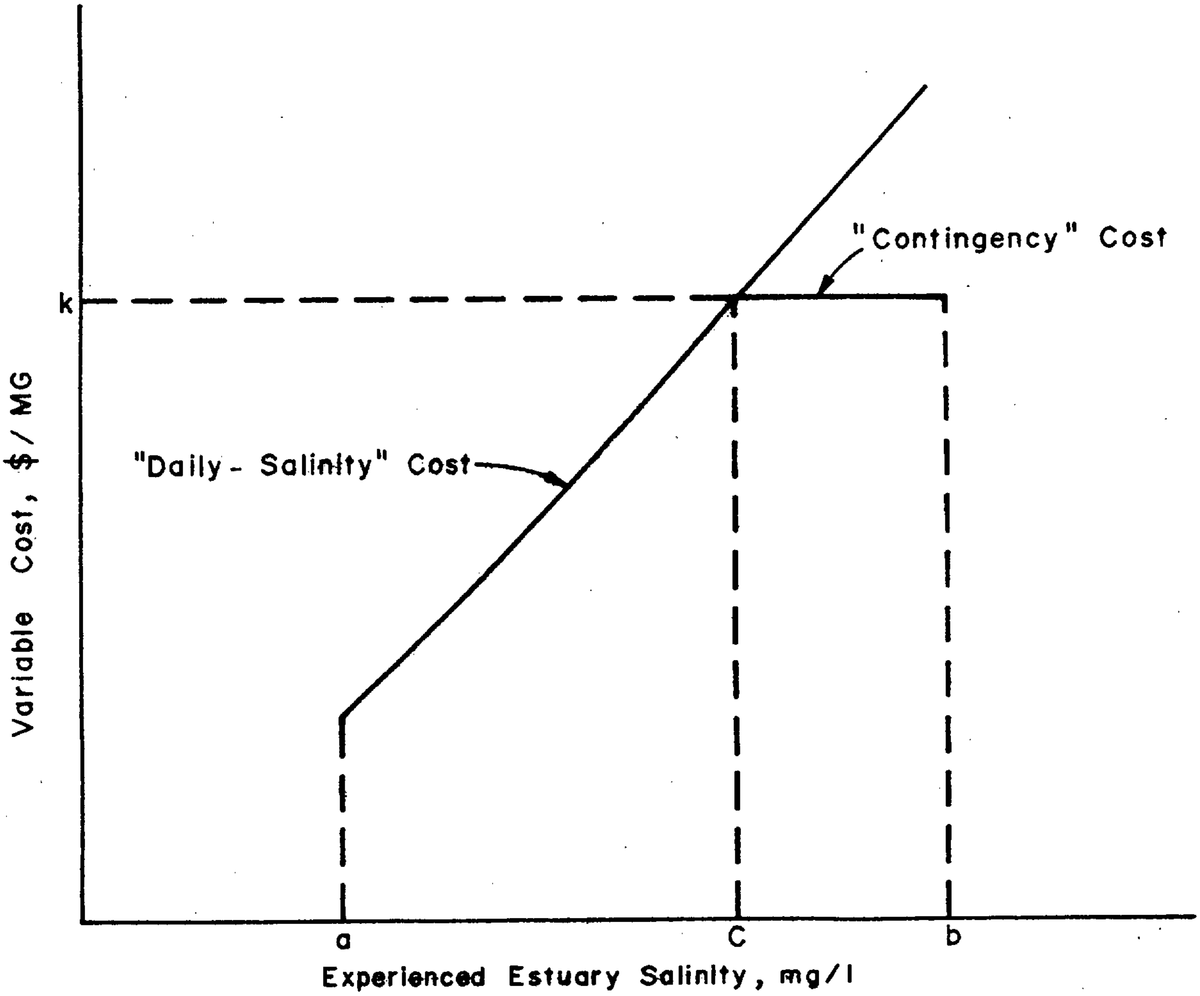
DELAWARE ESTUARY
SALINITY INTRUSION STUDY
"DAILY - SALINITY" COST — EXPERIENCED
SALINITY RELATIONSHIPS
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-5

The costs for the alternate water source will include the use charges for the water and the cost resulting from the level of salinity in this alternate water. Alternate source use charges and salinity costs will not depend on (i.e., will not be fixed with respect to) experienced estuarine salinity, since it is assumed that the alternate source is a true alternate, and not just an indirect source of estuarine water displaying the same salinity variation characteristics as the estuarine water.

Figure 2-6 depicts the integration of "daily-salinity" and "contingency" costs for a single estuarine location and for one particular alternate source of water. The "daily-salinity" costs are of a lower magnitude than the variable costs of alternate source water in the experienced salinity range from a to the switchover point C, and are, thus, borne in that range, while the "contingency" costs, k, are of lower magnitude than the "daily-salinity" costs in the experienced salinity range from C to b, and are, thus, borne in that range.

(1) <u>An Individual User Utilizing an Alternate Source for Certain Uses Only.</u> This category entails, for an individual user, an alternate source for one type of water use, for example, boiler feed, but not for another, such as once-through cooling. In the situation depicted in Figure 2-7, if B.F. represents the "daily-salinity" cost curve for boiler feed water, and alternate source water is available at unit cost k, rational decision-making will necessitate a switch to alternate source water at salinity level C, with "contingency" costs, at level k, borne at salinities above point C. If, on the other hand, C.W. is the "daily-salinity" cost curve for once-through cooling, then there will be no switch to alternate source water for this use over the depicted experienced salinity range ab, because k is always greater than the costs along the C.W. curve.

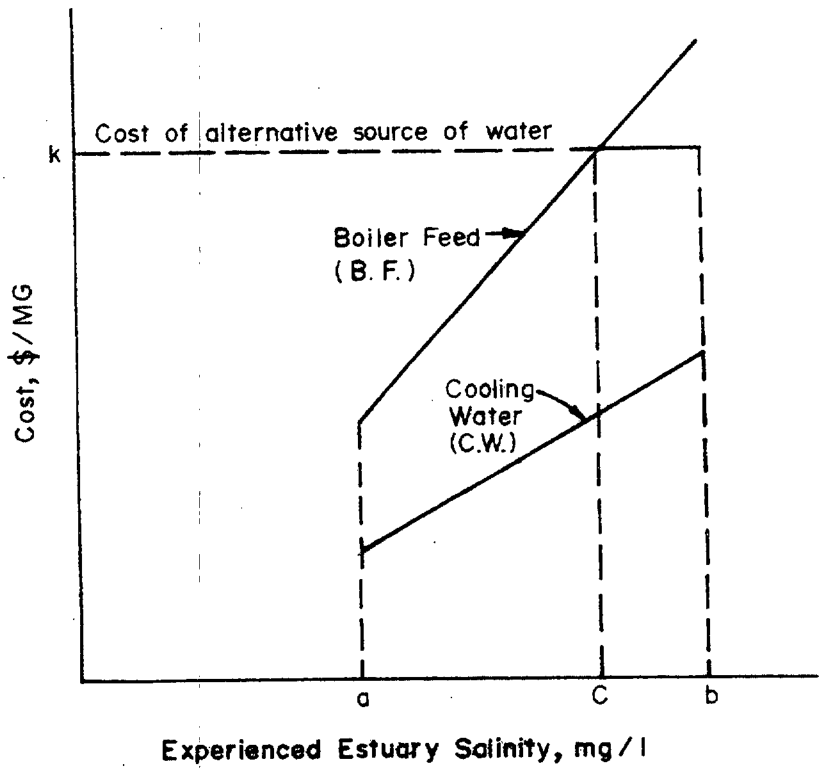


DELAWARE ESTUARY
SALINITY INTRUSION STUDY

INTEGRATION OF "DAILY - SALINITY" AND "CONTINGENCY" COSTS

PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-6



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
SWITCHOVER CRITERION FOR ALTERNATE SOURCE WATER (FOR AN INDIVIDUAL USER)
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-7

(2) "Contingency" and "Daily-Salinity" Costs as Related to Locations. It has been shown that "daily-salinity" costs will vary with the location of withdrawal in the estuary. The costs can be expressed as the function: C_{DS} ("daily-salinity" cost) = $f_R(s)$, where R = River mile of withdrawal intake and s is experienced salinity. "Contingency" costs will also vary, not according to experienced salinity, but rather according to use charges for alternate-source water in different locations (or pumping costs for a groundwater alternative), and the level of salinity of the alternate source. C_C, "contingency" cost, will be equivalent to the function K_R, where R = River Mile of the alternate source intake. The total salinity cost function would then be represented in two segments, each in \$/MG:

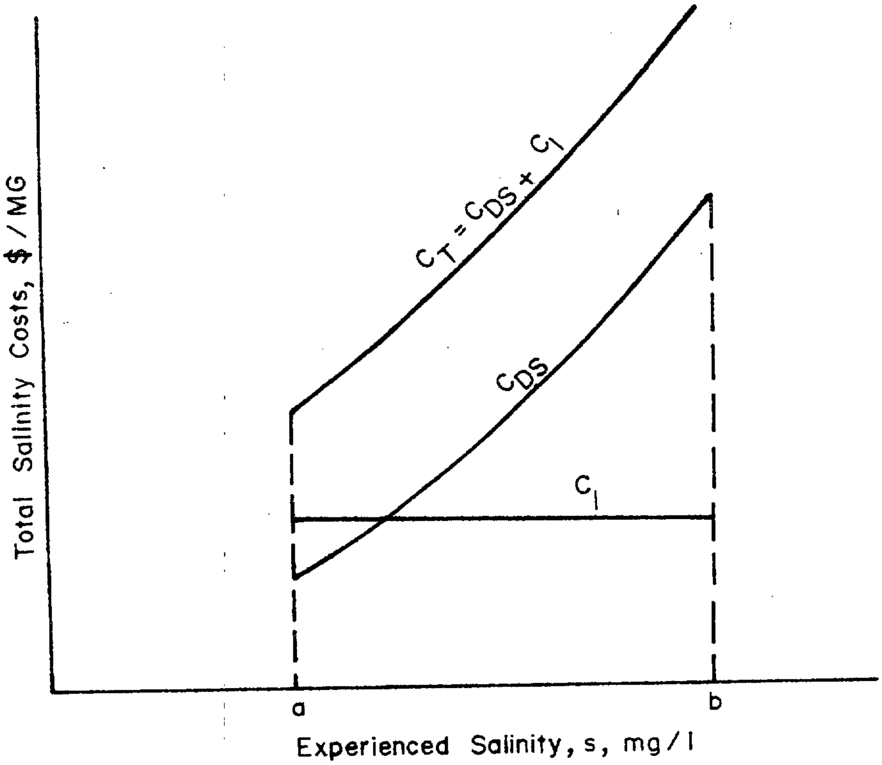
$$C_{TR1} = C_{DSR} = f_R(s);\ s < C, \text{ the switchover point}$$

$$C_{TR2} = C_{CR} = K_R;\ s \gtrsim C$$

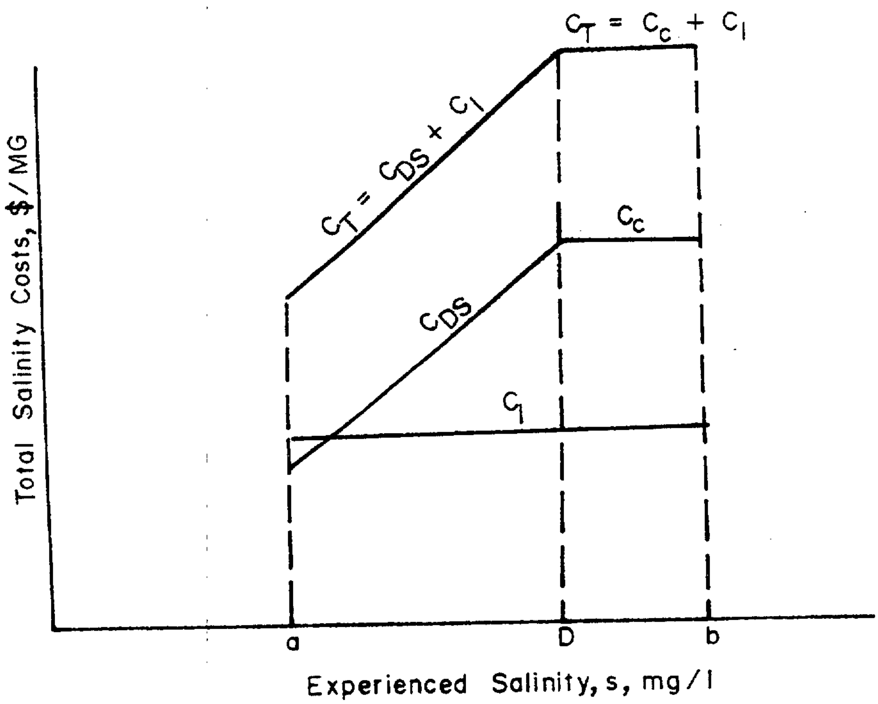
Where:

CTR_1, CTR_2 = The two segments of total salinity cost function; CTR_1 delineates the segment below the switchover salinity point, CTR_2 delineates the segment above the switchover salinity point.

- INTEGRATING "INVESTMENT" COSTS WITH "DAILY-SALINITY" AND "CONTINGENCY" COSTS TO ARRIVE AT TOTAL SALINITY COSTS. With costs expressed in \$ per million gallons, "investment" costs are added vertically to "daily-salinity" costs, or to "daily-salinity" and "contingency" costs over different segments, to arrive at the total salinity costs (as depicted in Figure 2-8). The simple case, for one withdrawal user, is shown in Subfigure 2-8a, where only "daily-salinity" and "investment" costs are involved. Subfigure 2-8b shows a case where "contingency" costs are also involved. For the former, $C_T = C_{DS} + C_I$ over the entire range of experienced salinity, ab. For the latter:



Subfigure 8a



Subfigure 8b

DELAWARE ESTUARY

SALINITY INTRUSION STUDY

ADDITION OF "INVESTMENT" COSTS TO "DAILY-SALINITY" COSTS AND TO "DAILY-SALINITY"-"CONTINGENCY" COSTS

PHILADELPHIA DISTRICT, CORPS OF ENGINEERS

DECEMBER 1982

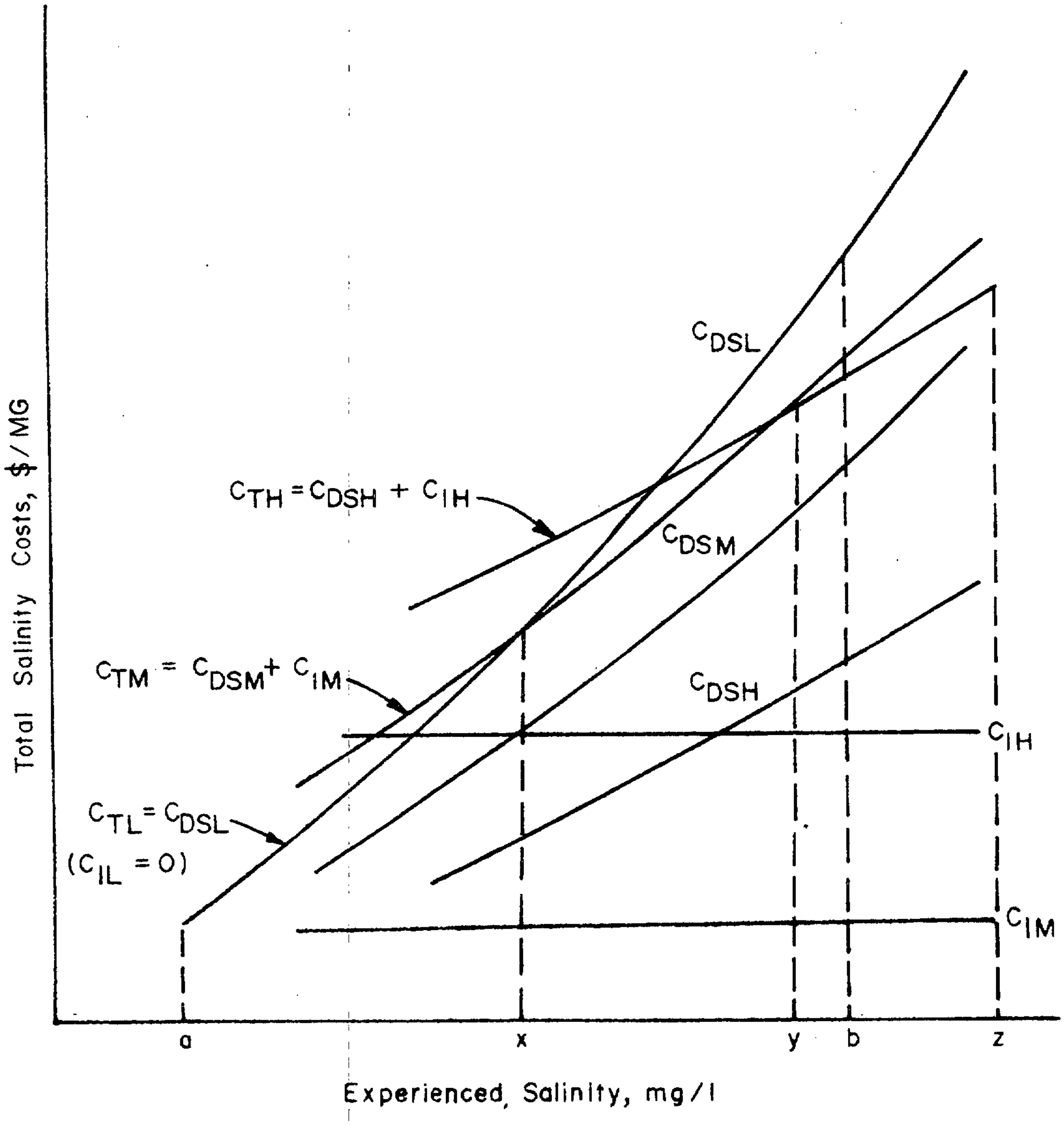
FIGURE 2-8

$$C_T = C_{DS} + C_I, \; s \leq D;$$

and $$C_T = C_C + C_I, \; s > D$$

where: C_T = Total salinity cost, \$/MG
C_{DS} = "Daily-salinity" cost, \$/MG
C_C = "Contingency" cost, \$/MG
C_I = "Investment" cost, \$/MG
D = Switchover point, mg/l
s = Experienced salinity, mg/l
a = Lower end of experienced salinity range, mg/l
b = Upper end of experienced salinity range, mg/l

Figure 2-9 shows the addition of "investment" costs (C_I) to "daily-salinity" costs (C_{DS}) for low (L), medium (M), and high (H) salinity estuary locations. For simplification, "contingency" costs are assumed to be zero. "Investment" costs are highest in the high salinity area because of the high expected salinities, and thus, relatedly, "daily-salinity" costs are lowest. Total salinity costs are lowest in the low salinity location when low salinities, those ranging from a to x in Figure 2-9 are experienced; lowest in the high salinity location when high salinities, those ranging from y to z in Figure 2-9, are experienced; and lowest for the medium salinity location when medium salinities, those ranging from x to y in Figure 2-9, are experienced. If, for example, in the low salinity location there are salinities (x to y) for which total salinity costs would have been lower if the investment for the medium salinity range had been made (C_{TH} rather C_{TL}), and salinities (y to b) for which total salinity costs would have been lower if the investment for the high salinity range had been made (C_{TM} rather than C_{TL}). If, however, experienced salinities for the low salinity location fall mainly in the a to x range, where C_{TL} is lower than C_{TM} and C_{TH}, the investment at the low salinity location (for the illustration the investment is assumed to be zero) is optimum. The opposite



DELAWARE ESTUARY
SALINITY INTRUSION STUDY

ADDITION OF "INVESTMENT" COSTS TO "DAILY-SALINITY" COSTS IN LOW, MEDIUM, AND HIGH SALINITY LOCATIONS ("CONTINGENCY" COSTS ARE ASSUMED TO BE ZERO)

PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-9

is true for the high salinity location. There, the high salinity location investment is optimum if the experienced salinities fall mainly in the range b to z. Conversely, for salinities less than z, the total salinity costs would have been lower if the investment for the medium salinity location had been made (C_{TM} rather than C_{TH}). (Note that the "investment" cost for a lower salinity location cannot be added to the "daily-salinity" cost for another location, because the investment level itself, not the location, determines the "daily-salinity" cost relationships that are applicable.)

PROCEDURES FOR ESTIMATING SALINITY-COST RELATIONSHIPS

OVERVIEW

An overview of the basic procedures used for estimating salinity-cost relationships is covered first in this section. Next, the procedure for estimating "investment" and "daily-salinity" costs, which involves investment, OMR&R (operation, maintenance, repair, and replacement), and the applicable interest rates are described. Equation summaries of the different types of salinity-cost relationships are given. Then, the effect which the level of the interest rate used will have on the cost estimates for the different salinity-cost relationships is presented. Finally, the use of constant value dollars and the relative unit costs of facilities involved is addressed.

THE BASIC PROCEDURE

The basic procedure for estimating salinity-withdrawal user cost relationships was to model the relationships for various types of water uses and systems, using information obtained from surveys, interviews, and the literature, and inputting economic inference, engineering knowledge, experience, and judgement.

Salinity-cost relationships for domestic water uses were based on models and coefficients developed by Tihansky (1974). Tihansky's results were verified with results obtained by Patterson and Banker (1968) and McDonald, Barney and Smith (1978) in similar studies. Salinity-cost relationships for municipal supply and waste treatment systems were modelled using interview information from system managers, model coefficient information provided by Tihansky (1974), and engineering inputs. Relationships for industrial uses were modelled using information from the Delaware River Basin Commission's 1976 Survey of Industrial Users and updates of that Survey conducted during this investigation (including person-to-person meetings with users). The specific details of these surveys are on file in the Philadelphia District Office.

The information from the surveys was utilized in conjunction with engineering inputs, Tihansky's model, and coefficient relationships for industrial facilities and equipment similar to certain household facilities and equipment to develop salinity-cost relationships for industrial uses.

The development of these models, the types of water use and facilities to which they apply, and the use of different sources of information are described below. In each case, the estimation was by type of facilities or use: for domestic uses these included, pipes, appliances, clothing, use of soaps and cleansers, softeners etc.; for municipal systems, production facilities, distribution systems, meters, etc.; and for direct industrial uses, once-through cooling, recirculating cooling, boiler feed, process (including contact cooling), sanitary, and intake systems.

Industrial uses and systems, except process, were found to be non-specific to individual SIC codes. It was ascertained that even with process uses, the salinity effects were mainly, if not exclusively, effects on equipment involved and not on the product. Because of this factor, a generalized salinity-cost relationship was determined to be appropriate for process use. In application, the by-use relationships were applied directly to estuarine water use by direct industrial withdrawal type.

The potential impact of high-salinity duration on salinity effects to withdrawal users was investigated. A major cost effect of salinity is corrosion. A question of importance is whether materials become either increasingly immune, or conversely, increasingly sensitive, to experienced salinity after extended periods of high salinity. Unfortunately, while salinity duration-cost relationships may exist, an in depth literature search and interviews conducted during the investigation were not able to elicit information to document or quantify such relationships or indicate their most likely direction if, in fact, they do exist. In the absence of any information on sensitivity or immunity effects, no salinity duration effects have been included in the salinity-cost relationships.

ECONOMIC PROCEDURES FOR ESTIMATING "INVESTMENT" AND "DAILY-SALINITY" COSTS INVOLVING INVESTMENT, OMR&R, AND THE INTEREST RATE

This section presents in generalized, but rigorous, mathematical form, the economic procedures that were used for estimating salinity-cost relationships for these two cost categories. In the analysis, the cost units used for expressing the salinity-cost relationship are dollars per million gallons of water use ($/MG). Note that "contingency" costs are not pertinent to this section's discussion.

• "INVESTMENT" COSTS. Salinity-related "investment" costs involve investment related to the expected level of salinity and directly associated OMR&R (operation, maintenance and repair, and replacement) costs. The directly associated OMR&R annual costs are those associated with or necessitated by the investment, but not related to the levels of experienced salinity. For example, Tihansky (1974) reports that softeners in domestic service need replacement approximately every 12 years, but that this service length does not vary with experienced levels of salinity.

Information was obtained either directly on salinity-related investment, or on total investment at different levels of expected salinity (in which case the salinity-related investment was calculated to be the total investment minus the investment at zero expected salinity). Salinity-related investment multiplied by the interest rate is equivalent to the annual interest cost portion of the "investment" cost. Directly associated OMR&R annual costs are a function of the level of investment. The addition of the interest cost portion and the OMR&R portion gives the total "investment" cost.

• "DAILY-SALINITY" COSTS. "Daily-Salinity" costs involve only the OMR&R costs that are associated with experienced levels of salinity predicated on predetermined levels of investment for withdrawal users. As with investment, information was obtained either directly, or by obtaining information on total costs and then subtracting the costs inherent at zero salinity.

The reduction-in-life-of-facilities cost is a replacement cost. This cost is calculated as the salinity-related investment multiplied by the amortization portion of the capital recovery factor.

The OM&R (operation, maintenance, and repair) portion of the OMR&R costs that are directly related to experienced salinities are a function of these salinities as well as the level of investment. Thus, the total "daily-salinity" cost is the sum of the reduction-in-life (or replacement) and the OM&R costs, (i.e., the total OMR&R costs).

• "INVESTMENT" AND "DAILY-SALINITY" COSTS IN EQUATION FORM AND THE USE OF THE INTEREST RATE. The interest rate, r, is equivalent to the interest portion of interest and amortization factors, which together comprise the capital recovery factor (CRF). The formula for the CRF is derived as follows:

$$\text{CRF} = r \text{ (the interest factor)} + \frac{r}{(1+r)^n-1} \text{ (the amortization factor)}$$

$$= \frac{(1+r)^n r}{(1+r)^n-1}$$

where: n = Length of Life

r = Annual Interest Rate

The interest factor is calculated by direct application of the interest rate only. Thus, interest costs (the interest cost portion of "investment" costs) depend only on this rate and the investment, I, not on length of life of facilities, (i.e., not on how frequently the investment must be replaced).

(1) <u>"Investment" Costs</u>. In equation form, the interest portion of the "investment" costs (on a \$/MG basis) is:

$$C_{I\ i}\ (\$/\text{MG}) = \frac{I(\$)r}{Q\ (\text{mgd})\, 365\ (\text{days})}$$

where: $C_{I\ i}$ = Interest portion of "investment" cost in \$/million gallons

I = Investment in \$'s (1978 price level)

r = Interest Factor

Q = Water use in millions of gallons per day (mgd)

The replacement cost portion of the OMR&R portion of "investment" costs (C_{IP}), in \$/MG, is:

$$C_{IP}(\$/MG) = \left(\frac{r}{(1+r)^{n}-1}\right)\left(\frac{I(\$)}{Q\ (mgd)\,365\ (days)}\right)$$

The OM&R portion of "investment" cost ($C_{I\ OM\&R}$) in \$/MG is:

$$C_{I\ OM\&R}\ (\$/MG) = \frac{I\ (\$)(f_{I})_{OM\&R}(I)}{Q\ (mgd)\,365}$$

(where $f_{I\ OM\&R}\ (I)$ is the relationship between annual OM&R costs and investment in dollars)

Total investment cost (C_I) is:

$$C_I = C_{I\ i} + C_{IP} + C_{I\ OM\&R}$$

(2) <u>"Daily-Salinity" Costs</u>. The reduced-life portion of the "daily-salinity" costs ($C_{DS\ p}$) in \$/MG is:

$$C_{DS\ p}\ (\$/MG) = a\left(\frac{I\ (\$)}{Q\ (mgd)\ \times\ 365\ (days)}\right)$$

where

$$a = \left(\frac{r}{(1+r)^{n}-1}\right)-\left(\frac{r}{(1+r)^{m}-1}\right)$$

where: n = length of life for experienced daily salinity level

m = length of life at zero salinity level

r = applicable interest rate

The n's are specific to each level of experienced daily salinity and both the m's and n's are specific for the associated level of expected-salinity investment, I. The best information for actual estimation of the relationship, however, is facility life for average levels of experienced salinity over long periods, and for the most part, for average levels of investment covering ranges of investment. For the different levels of investment with respect to salinity, the amortization portion only of the CRF (i.e., $\frac{r}{(1+r)^n-1}$) must be used.

However, if there are no differences in investment, or if an average level of investment covering all ranges is used because of lack of information, the CRF can be used because the interest portion is the same for all levels of salinity and is nullified in subtracting costs at zero salinity from costs at the levels of experienced salinity.

The OM&R portion of "daily-salinity" costs ($C_{DS\ OM\&R}$) is:

$$C_{DS\ OM\&R}\ (\$/MG) = \frac{I(\$)\ \ (f_{OM\&R}\ (s)(I))/day}{Q(mgd)}$$

(where $(f_{OM\&R}(s)(I))/(day)$ is the relationship between these OM&R costs, daily salinity levels, s, and the level of investment, I.

The total "daily-salinity" costs, are the sum of the life-reduction and OM&R portions:

$$C_{DS} = C_{DS\ P} + C_{DS\ OM\&R}$$

There will be specific values of C_I and C_{DS} for each withdrawal location:

$$C_I = C_{I\ i} + C_{I\ P} + C_{I\ OM\&R}$$

$$C_{DS} = C_{DS\ P} + C_{DS\ OM\&R}$$

With the addition of contingency costs (C_c), the total salinity cost (C_T) for each location is:

$$C_T = C_I + C_{DS} + C_c$$

• EFFECT OF THE LEVEL OF THE INTEREST RATE ON COST ESTIMATES. This section examines the effect that the level of the interest rate will have on the estimated salinity costs. This subject is discussed as a prelude to determinaton of the choice of interest rates for estimating costs and for subjecting the results to a sensitivity analysis.

Examination of the equations showed that interest costs will vary directly with the interest rate, whereas replacement or amortization costs will vary inversely with the interest rate. In addition, interest costs are independent of length of life, whereas amortization costs vary inversely with the length of life.

Thus, the interest cost portion of "investment" costs will vary directly with the interest rate used for assessing costs. For example, a 10% rate will give two times and a 15% rate three times the costs of a 5% rate.

On the other hand, the reduced-life portion of "daily-salinity" costs, which is an amortization cost, will vary inversely with the interest rate used. In addition, the magnitude of the cost differential will vary substantially with length of life.

An example of the effect of the interest rate and length of life on reduced-life costs is displayed in Table 2-2, which gives the amortization factor for the 5%, 10%, and 15% interest rates, and for lengths of life of various years ranging from 2 to 75. For a two year life, the amortization factor of 0.47 for a 15% interest rate is approximately 95% of the

TABLE 2-2

EFFECT OF THE INTEREST RATE ON AMORTIZATION FACTORS
(REDUCED-LIFE COST FACTORS)

Life, n (years)		Amortization Factor, $\frac{r}{(1+r)^n-1}$, and its Value as a Percent of its Value at r = 5%		
		5%	10%	15%
2	Amortization Factor	0.49	0.48	0.47
	Factor as % of Factor at r = 5%	100%	98%	95%
3	Amortization Factor	0.32	0.30	0.29
	Factor as % of Factor at r = 5%	100%	94%	91%
5	Amortization Factor	0.18	0.16	0.15
	Factor as % of Factor at r = 5%	100%	91%	83%
10	Amortization Factor	0.08	0.06	0.05
	Factor as % of Factor at r = 5%	100%	79%	63%
15	Amortization Factor	0.05	0.03	0.02
	Factor as % of Factor at r = 5%	100%	68%	40%
20	Amortization Factor	0.03	0.02	0.01
	Factor as % of Factor at r = 5%	100%	58%	33%
25	Amortization Factor	0.02	0.01	0.005
	Factor as % of Factor at r = 5%	100%	49%	25%
30	Amortization Factor	0.015	0.006	0.002
	Factor as % of Factor at r = 5%	100%	40%	15%
50	Amortization Factor	0.005	0.00086	0.00014
	Factor as % of Factor at r = 5%	100%	18%	3%
75	Amortization Factor	0.0013	0.000079	0.0000042
	Factor as % of Factor at r = 5%	100%	6%	0.3%

amortization factor for a 5% rate. It is lower because the undiscounted annual replacement factor of 0.5 (for a two year life) is discounted more with a 15% interest rate than with a 5% rate. The difference, however, is not very significant. On the other hand, for a 25 year life, the amortization factor of 0.005 for a 15% interest rate is considerably less than (only 22% of) the factor for a 5% rate. Thus, the higher interest rate has a much greater effect on the discounting of replacement costs, the further in the future they are incurred. Because of this, the higher the interest rate, the smaller will be the cost of any reduction in life due to salinity effects. Also, the longer the useful life of the facility, the greater will be the difference.

This "higher-the-interest-rate, smaller-the-costs" effect is very important because of the greater prevalence of reduced-life effects as opposed to interest-cost effects for withdrawal users. The following specifics can be outlined with respect to interest cost effects:

a. For the muncipal systems interviewed, it was reported that no salinity related investments were made. The same investment for treating, transporting, and delivering water and handling wastes would have been made if salinities had been equal to zero. This conforms with engineering-experience inputs for modelling. The system cost differences incorporated in the system models were size related, not salinity related.

b. For domestic systems, except for the level of investment in softeners based on expected hardness (which is TDS related) there does not appear to be special salinity resistant plumbing, appliances, clothing etc., available for purchase. In the models, except for softeners, no salinity related investments were assumed, based on engineering inputs.

c. For many industrial water-handling systems, the same investment is made that would be made if salinity were zero, and this applies even for withdrawal users located well down into the estuary. This is supported by both survey results and engineering experience.

On the other hand, with respect to reduced-life effects, there are substantial effects dependent on estuarine withdrawal locations. Given the comparative "universal" occurrence of reduced-life effects to withdrawal users, the higher the interest rate used for estimating costs, the lower the estimated total salinity costs for withdrawal users are.

- INTEREST RATES CHOSEN FOR ANALYSIS. Interest rates were selected based on the market rates of recent years. These are relatively high in relation to the long-term historical average. However, it must be emphasized that using these rates rather than lower long-term average rates gives a downward (i.e., conservative) rather than upward bias to present-worth cost estimates. Sensitivity tests have been performed to verify this conclusion.

In the preliminary analysis stage, two approaches were used in applying interest rates. One was based on monetary costs to individual users. For this, an interest rate of 15% per year was used for estimating costs to industrial users, 10% for domestic users, and 5% for municipal systems.

The 15% for industrial users was chosen to reflect approximately current corporate costs of money, shaded downward somewhat from the upper range of the most recent rates (which are extremely high based on historical precedence). Corporate costs fluctuate depending on the mix of debt and equity, how income taxes are treated, whether the nominal interest rate or the interest rate corrected for inflation is used, and whether long-term average or most recent interest rates are applied. For these reasons, sensitivity tests were performed using a 10% and a 20% rate.

For domestic water users, the 10% rate reflects the approximate rate for new home mortgages in recent years shaded downward from the alarmingly high recent rates which have been in the 15-18% range. Results were tested using a 5% rate (approximately the return to private individuals from savings accounts) and a 15% rate.

For publicly held municipal systems (the three municipal systems withdrawing estuarine water are publicly held), the 5% rate reflects the approximate current cost of money to public agencies, again shaded downward somewhat from recent rates. Here, rather than testing against a lower interest rate (which, as was indicated previously, has the effect of <u>increasing</u> the estimated costs of salinity), costs were tested with respect to the current 7 5/8% Federal discount rate and a 15% rate. Costs to the three municipal systems and institutional users are approximately 10% less at 7 5/8% than at 5%. Since these two categories of water use comprise only 6.2% of total average annual costs (see Table 1-8), the overall impact of using the 5% rate, instead of the 7 5/8% rate, is relatively very insignificant. The 15% would be the rate if the systems were corporately rather than publicly held, and would coincide with the 15% industrial user rate discussed above.

The second approach for applying interest rates was based on the use of a single rate, regardless of user, on the grounds that the social costs due to salinity effects are not dependent on who invests in the impacted facilities. A 10% across-the-board interest rate was used. This approach takes the viewpoint that the real costs to society of the costs from salinity should not be a function of who owns the facilities and what interest rates they individually face, but a function of a single social point of view and single interest rate.

The approximate effect of using an across-the-board 10% interest rate rather than individual rates for estimating costs is to increase the overall cost estimates on the order of 5%. Municipal system and institutional user costs are lower at the 10% rate than at a 5% individual rate. This is more than offset, however, by the effect on the direct industrial uses and the industrial and commercial uses of municipal water. Costs, in terms of present worth, are higher at the 10% rate than at the 15% individual rate for these users.

• CONSTANT VALUE DOLLARS AND RELATIVE UNIT COSTS. All dollar estimates are expressed at the 1978 price level, and in terms of relative unit costs of the facilities involved for the equations developed in this appendix. Where cost information for other years was initially utilized, costs were converted to the 1978 price level by the use of a cost index. A facilities-specific index, the Chemical Engineering Plant Cost Index (CEI), rather than a general price index, was used in order to adjust not only for changes in the value of the dollar against all goods and services, but to adjust also for changes in the relative unit costs of the facilities involved compared to average prices of all goods and services.

ESTIMATES OF SALINITY-COST RELATIONSHIPS

OVERVIEW

In this section, estimates of salinity-cost relationships are presented for (1) domestic water users (households); (2) municipal water supply and sewer systems; (3) direct industrial withdrawal users, and (4) industrial, commercial, and institutional users of municipal water. Information sources and model development are discussed for each category.

In order to be conservative, approaches that tend to underestimate salinity costs are used in estimating salinity-cost relationships. For example, for domestic uses, costs from salinity effects for some very minor water use categories, such as the washing of automobiles, are not quantified because of lack of information. For industrial, commercial and institutional users of municipal water the approach was also conservative. For example, no costs for use of soaps and cleansers were included, even though there is considerable commercial, industrial and institutional use of soaps and cleansers.

Full-scale calibration of the salinity-cost relationships has been conducted using wide ranges of both interest rates and levels of salinity in order to assure the validity of the cost curves developed.

SALINITY-COST RELATIONSHIPS FOR DOMESTIC WATER USERS

- USERS AFFECTED. Three municipal water supply systems supplying households withdraw water from the Delaware estuary, 1) the Torresdale service portion of the Philadelphia Water Department, 2) the Bristol Water Department, and 3) the Lower Bucks County Joint Municipal Authority. Based on interviews with representatives of the systems, DRBC records of withdrawals, and estimates of domestic water use in the literature (Tihansky 1974), it is estimated that approximately 500,000 households are served from Torresdale and another 25,000 from the other two systems, with an average use of about 100,000 gallons per year per household. No private domestic users who withdraw directly from the estuary were identified.

- APPROACH FOR ESTIMATING SALINITY-COST RELATIONSHIPS. Primary information for estimating relationships was taken from the literature. Several authors have evaluated the impact of TDS on costs to domestic users, but most present only a total cost graph with little explanation of the model, variables, and coefficients used, such as interest rates, life of equipment factors, etc., that would be necessary for application of their findings in developing relationships. Three sources, however, were found to have conducted significant research into the development of salinity-cost relationships: Tihansky (1974); Patterson and Banker (1968), and McDonald, Barney, and Smith (1978). Of the three, Tihansky's was the most comprehensive. His analysis were predicted on a compilation of 32 cited literature sources, including Patterson and Banker, and exhibited reasonability. Moreover, his equations and coefficients agreed well with those systems also specifically covered by McDonald, Barney, and Smith. Therefore, Tihansky's equations and coefficients were used as the model for estimating salinity-cost relationships.

Tihansky's equations and coefficients are shown in Table 2-4. The price (i.e. average investment) for each affected item was updated to the 1978 price level during the development of the salinity-cost relationships for use in this study. In addition to equations directly applicable to household costs, Tihansky developed equations applicable to water supply systems and sewage facilities systems on a household-allocated basis.

(1) <u>"Investment" Costs</u>. Tihansky showed investment varying with expected salinity levels (more precisely hardness, which directly varies with salinity) for only one investment item, water softeners. For other items, including plumbing, appliances, utensils and washable clothing, he presented only a single, average investment (price) per household. Since special salinity resistance plumbing, appliances, clothing, etc. are not readily available for purchase, no salinity-related investments were judged to be applicable.

TABLE 2-4

TIHANSKY'S DAMAGE EQUATIONS FOR

TYPICAL UNITED STATES HOUSEHOLDS

Affected item (1)	Price, in dollars (2)	Life span,[a] in years (3)	Annual OM&R,[a] in years (4)
Water Pipes	280.0	$12 + 30e^{-0.0018t}$	$0.0013t + 2.259$
Wastewater Pipes	504.0	$10 + 44e^{-0.0006t}$	$0.0008t + 1.820$
Water Heater	115.5	$5 + 11e^{-0.0014t}$	$0.0013t + 17.65$
Faucets	184.1	$11.5 - 0.0028t$	$0.0008t + 1.814$
Toilets	22.3	$2 + 11e^{-0.0015t}$	$0.0018t + 0.6789$
Garbage Grinder	8.4	$5 + 5e^{-0.0012t}$	$0.0001t + 0.1181$
Washing Machine	126.0	$5 + 6e^{-0.0008t}$	$0.0011t + 3.512$
Cooking Utensils	21.0	$10.18 - 0.0007t$	—
Washable Clothing	1168.6	$4.633 - 0.0001t$	—
Supply System[b]			
Production	134.4	$30.83 - 0.0033t$	$0.0003t + 5.065$
Distribution	504.0	$60 + 50e^{-0.0009t}$	$0.0013t + 3.543$
Storage tanks	67.2	$50.83 - 0.0033t$	$0.0007t + 0.3827$
Service lines	112.0	$46.67 - 0.0067t$	—
Water meter	44.8	$30.5 - 0.0020t$	$0.0003t + 0.6627$
Sewage Facilities[b]	100.8	$30.83 - 0.0033t$	$0.0003t + 3.799$
Bottled Water	—	$e^{-3.727}t^{0.8042}$	$0.0240t^{0.8042}$
Water Softener	$0.21h$	12.0	$0.1594hr,\ r = 0.0007h$
Soap and Cleansers			
TDS-related	—	—	$0.0029t + 12.61$
Hardness-related	—	—	$0.1578h(1 - r) + 11.65$

[a]The variable, t, stands for TDS, in milligrams per liter/(parts per million), and the variable, h, stands for hardness, expressed in milligrams per liter/(parts per million), as $CaCO_3$.

[b]This item pertains to the allocated cost of the public system.

(a) Interest Cost Portion of "Invesment" Costs. Tihansky determined that the per household investment in softeners (1978 price level) was $0.36h (h is hardness in mg/l). The relationship between h and TDS is: $h = 0.286TDS + 14$ (Note that with this equation, because of the constant value of 14, an adjustment must be made at very low TDS concentrations.) Using this h to TDS relationship, $I = \$0.36\,(0.286\,TDS + 14)$.

Thus, the interest cost portion of "investment" costs ($C_{I\ i}$) will vary according to expected levels of salinity, and is represented by the following equation:

$$C_{I\ i} = \frac{\$0.36\ (0.286TDS + 14)r}{Q\ (MG/yr)}$$

The applicable interest rate is represented by r. Tihansky gives Q (water use per household) as 0.1 MG/yr. Thus the cost per MG is:

$$C_{I\ i}\ (\$/MG) = \frac{\$0.36\ (0.286TDS + 14)r}{0.1}$$

(b) Directly Associated OMR&R Cost Portion of "Investment" Costs.

(i) Replacement Portion of Directly Associated OMR&R Costs. Tihansky reports that the 12-year average life span of softeners is unrelated to salinity levels. Replacement costs for softeners are therefore a directly-associated OMR&R "investment" cost, specifically, the replacement cost portion of these costs. The costs will depend on the level of investment in softeners, which, in turn, is predicated on expected salinity levels.

The replacement portion (C_{IP}) of directly-associated OMR&R "investment" costs per MG is:

$$C_{IP}(\$/MG) = \frac{3.629(r)\ (.286T + 14)}{(1 + r)^{12} - 1}$$

where: T = expected salinity

r = applicable interest rate

(ii) Operation, Maintenance, and Repair (OM&R) Portion of Directly Associated OMR&R Costs. Tihansky's OM&R costs for softeners are delineated as annual costs per household. The equation derived is OM&R = \$0.1594 hx, with x = 0.0007h. X has been substituted here for the r variable used by Tihansky (see Table 2-4) in order to avoid confusion with the r variable utilized in this appendix to represent the applicable interest rate. The x variable is the proportion of households with softeners, and \$0.1594h is the OM&R cost per softener. Because the OM&R cost per softener does not have a constant term, that is, does not have a term relating salinity to hardness, Tihansky concluded that there are no directly associated OM&R "investment" costs. Thus, the estimate of these costs is zero. There are OM&R costs for softeners not related to salinity, such as adjustment of timing mechanisms that go on and off each day regardless of the salinity level. However, these costs are estimated to be very insignificant compared to other costs, and are, thus, not calculated.

(c) Total "Investment" Costs. Total domestic "investment" costs are the sum of interest and the replacement portion of directly-associated OMR&R costs.

(2) "Contingency" Costs. None of the three water supply systems for domestic households currently use alternate sources of water during

periods of high experienced salinity.[1] For domestic users themselves, bottled water represents an alternate to drinking use. To switch during periods of high experienced salinity only, however, domestic users would need to have available information concerning day to day salinity levels. Because they do not, users are assumed to switch to bottled water based on some average or general idea of TDS, which can be taken to be expected TDS levels. This is approximated by Tihansky's equation for the cost of bottled water per MG:

$$C_c \ (\$/MG) = 4147 \ (T)^{.8042}$$

T = expected salinity

(3) "Daily-Salinity" Costs. Tihansky's equations for household items cover life-span effects and OM&R costs for various items of plumbing, appliances, cooking utensils, washable clothing, water softeners, soaps, and cleaners. Coverage is also given to allocated costs to households for effects on water supply systems and sewage facilities. Tihansky, however, does not address salinity effects on very minor categories of domestic water use, such as the washing of cars, either commercially or at home, and salinity effects on car cooling systems. Tihansky also does not place a cost on the

1/ While acknowledgement must be made that at some high level of salinity in the future these suppliers might give serious consideration to switching to an alternate source, estimates of such an uncertain event is beyond the scope of this investigation. The possibility also exists that, in the future, other water companies that do not currently take Delaware estuary water to supplement their supplies, might withdraw estuarine water for storage during times when estuary salinity concentrations are low. In such cases, the cost of the main supply would be a "contingency" cost with respect to Delaware River water use. For example, the Chester Water Authority has given consideration to this approach for meeting future needs. Again, however, no estimates can be made at this time of possible future "contingency" costs.

undesirable effects of hard water that households without softeners bear. Those without softeners are a sizable proportion of all households in typical ranges of hardness; for instance, 96 1/2% of households at an expected hardness of 50 mg/1, 93% at an expected hardness of 100 mg/1 (based on Tihansky's equations). The analysis determined that those with softeners pay a significant net amount (over savings in soap and cleaners) for softened water. Those without softeners presumably would be willing to pay something, though not as much as those with softeners. "Daily-Salinity" costs are calculated based on salinities experienced per tidal cycle and quantity of water use by each withdrawal user.

(a) Life-Span Reduction Portion of "Daily-Salinity" Costs. The first step in estimating the life-reduction (salinity-related replacement) portion of "daily-salinity" costs is to utilize Tihansky's equations in the estimation of the life span-salinity relationships for the various items of equipment.

Items include water pipes, wastewater pipes, water heaters, faucets, toilets, garbage grinders, washing machines, cooking utensils, and washable clothing. The equation for the life-span reduction portion of "daily-salinty" costs is as follows:

$$C_{DS\ P}\ (\$/MG) = \left[\left(\frac{r}{(1+r)^{n}-1}\right) - \left(\frac{r}{(1+r)^{m}-1}\right)\right] \frac{\$I(1978)/\text{household}}{0.1\ \text{mg/yr/household}}$$

where n = equipment life at experienced salinity level

m = equipment life if salinity level equals zero

\$I/household = average investment per household per item

0.1 MG/yr = average water use per household

(b) OM&R Portion of "Daily-Salinity" Costs.

(i) Relationship Where Investment Does Not Vary With Expected Salinity (Single Relationships for Each Item). As stated, the investment in all items except softeners is the same at all levels of expected salinity. Therefore, one salinity-cost relationship applies for the OM&R portion of "daily-salinity" costs. Tihansky expresses these costs on the basis of dollars per household per year as a function of s (experienced salinity). Below are the summation of cost relationships for the various items of equipment and for TDS-related use of soaps and cleansers (1978 price level):

$$C_{DS\ OM\&R}\ (\$/MG) = \$.174528(s)$$

(ii) Relationship Where Investment Does Vary with Expected Salinity (Multiple Relationships for the Items Involved). The salinity-cost relationships for softener OM&R costs and for soap and cleanser costs, both of which are related to the proportion of households having softeners, will depend on expected salinity (i.e., on hardness, which is related to salinity).

The relationships are as follows:

a) For softener OM&R,

$$C_{DSOM\&R}\ (\$/MG) = .00015771\ sT + .00772011T + .00772011s + .3779076$$

b) For hardness related costs--soaps and cleansers,

$$C_{DS\ OM\&R}\ (\$/MG) = -.000156128\ sT - .0076426\ T + .77221705s + 37.80086124$$

where s = experienced salinity

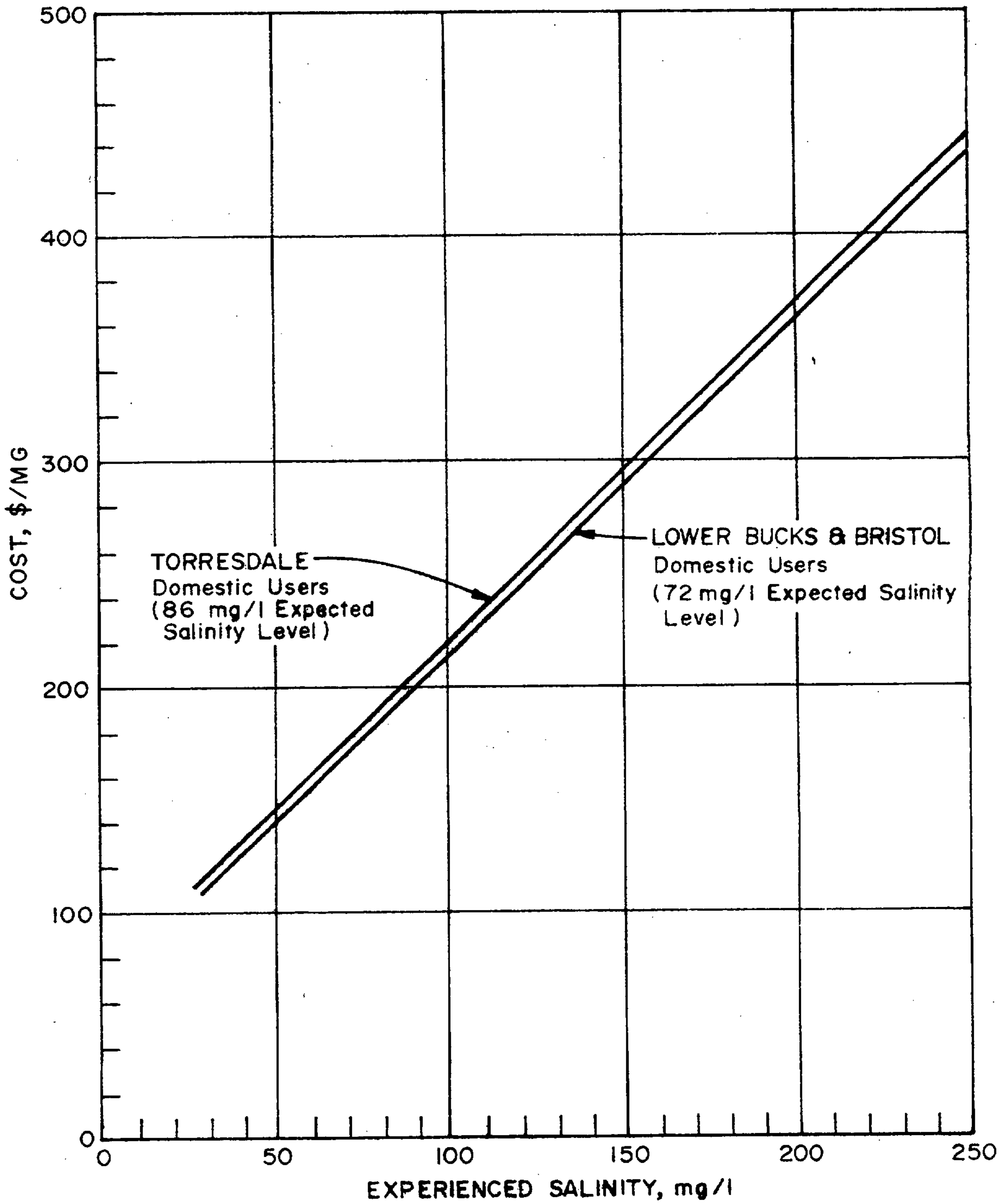
T = expected salinity

The hardness-related costs of soaps and cleansers are very high compared to other cost items. Yet, because of its lower cost coefficient with respect to salinity, 0.1578, compared to the cost coefficient for softener OM&R costs, 0.1594, the savings in soap and cleansers with softeners is less than the added softener OM&R costs. Thus, households with softeners pay a net OM&R cost plus the "investment" cost for avoiding the undesirable features of hard water. This underscores the point made earlier that households without softeners possibly bear a significant "undesirable-features-of-hardness" cost, varying with experienced daily salinities and associated hardness. A conservativeness is, thus, lent to the cost estimates by the exclusion of these additional "undesirable-features-of-hardness" costs.

(iii) Summation of Salinity-Cost Equations. The final equation for the OM&R portion of "daily-salinity" costs is:

$$C_{DS\ OM\&R}\ (\$/MG) = .000001583sT + .0000775T + .954465s + 38.179$$

(4) Total Salinity Costs, Domestic Users. The costs are the summation of "investment" costs (interest costs and directly associated OMR&R costs), "contingency" costs, and "daily-salinity" costs (life-span reduction costs and OM&R costs). Figure 2-10 presents a graphical representation of the domestic cost curves at a 10% interest rate. Expected TDS (mg/l) levels at the three municipal systems' intake locations are integral variables for the determination of the cost configurations of the domestice users. The mean experienced salinity values over the study's 50-year period of analysis serve as a reasonable proxy for expected TDS values. For Torresdale, the 50-year mean is 86 mg/l, and for Bristol and Lower Bucks, 72 mg/l.



1978 Price level
10% Interest rate

DELAWARE ESTUARY
SALINITY INTRUSION STUDY
DOMESTIC USERS
TOTAL SALINITY-COST RELATIONSHIP
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-10

SALINITY COSTS TO MUNICIPAL WATER SUPPLY AND SEWAGE FACILITIES SYSTEMS

• MUNICIPAL SYSTEMS AFFECTED:

(1) Overview. The following three municipal water supply systems withdraw water directly from the Delaware estuary:

Municipal System	Location, River Mile
Torresdale (Philadelphia Water Department)	110
Bristol Water Department	119
Lower Bucks County Joint Muncipal Authority	122

Wastewater from each of these system's service areas is routed to municipal sewage facilities.

(2) Interview Information and Model Development. Representatives of the three water supply systems were contacted to obtain information on water use, salinity effects, and cost factors. None reported being aware of any problems specifically due to salinity; all said they had noticed no increased corrosion rates or other cost phenomena due to salinity. They suggested that their intake locations were too far upstream to be significantly impacted by salinity at the levels experienced in the past. Torresdale representatives were able to provide some scaling inputs for salinity-cost modelling. However, total information available on operating expenses from the three municipal systems was too incomplete to allow for the proper development of cost relationships. Thus, salinity-cost relationship models were prepared based predominantly on Tihansky's equations concerning salinity-cost relationships for water supply systems and for

sewage facilities on an annual cost per household basis. These costs are per 0.1 MG (the average annual water use per household annually) and can be applied to all water handled by municipal as well as domestic systems.

(3) Salinity-Cost Relationships.

(a) "Investment" Costs. For the various elements of supply systems and sewerage facilties, Tihansky determined an average level of investment, which was derived from the analysis of numerous systems with salinity values ranging from a few mg/l TDS to approximately 3000 mg/l TDS. No quantitive information was available, however, on salinity-related "investment" cost relationships. The three systems investigated did not report any salinity-related investment. Thus, estimates of "investment" costs are not considered applicable for estimation in this investigation. However, this does not mean that a significant increase in average salinity in the upper estuary in the future would not lead to additional investments related to salinity.

(b) "Contingency" Costs. Presently, no "contingency" costs related to salinity are borne by the three municipal supply systems. While it is conceivable that in the future the systems could go to alternate sources during periods of high salinity, the low probability of such a necessity places the estimation of possible future salinity-related "contingency" cost relationships beyond the scope of the current investigation.

(c) "Daily-Salinity" Costs. Tihansky's equations were deemed appropriate for estimating "daily-salinity" cost relationships for the Delaware estuary municipal systems.

(i) Life-Span Reduction Portion of "Daily-Salinity" Costs. As with household items, the first step in estimating the life-span-reduction portion (salinity-related replacement portion) of "daily-salinity" costs was to use Tihansky's equations to estimate the life span-salinity relationships.

Based on interview information on size and engineering inputs, the investment per 0.1 MG/yr (household equivalent) was then estimated for the various facilities for the three municipal systems. Estimates were directly made for production facilities and ratioed to obtain investment estimates for the other facility items based on Tihansky's ratios of item costs and scaling factors.

For each element of the three systems, life span reduction costs were calculated as follows:

$$C_{DS}\ P\ (\$/MG) = \left[\left(\frac{r}{(1+r)^{n}-1}\right)-\left(\frac{r}{(1+r)^{m}-1}\right)\right] \frac{\$I(1978)}{.1MG/yr}$$

where the $\frac{\$I}{0.1\ MG/yr}$ = investment in water supply systems and sewer facilities (calculated separately for each item for each of the municipal systems)

n = life span at level of experienced salinity(s), in years

m = life span if s = 0, in years

Investment items included sewer facilities and the following supply system facilities: production, distribution storage tanks, service lines, and water meters.

(ii) OM&R Portion of "Daily-Salinity" Costs. The OM&R portion of "daily-salinity" cost relationships was calculated using Tihansky's equations. Costs for the municipal system facilities were calcuated as a function of s, the experienced salinity. The equation in final form is:

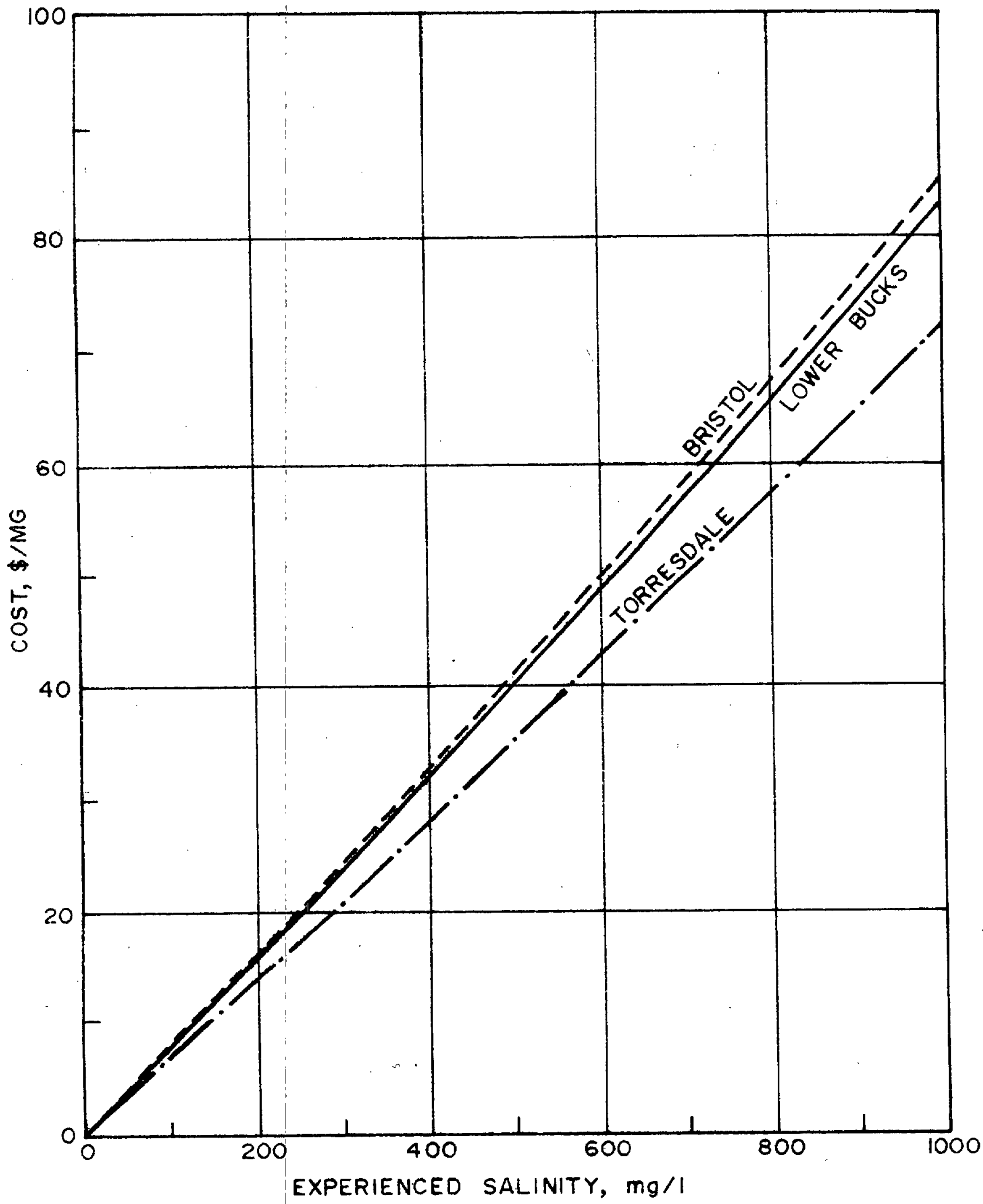
C_{DS} OM&R ($/MG) = .05(s)

The .05 is the sum of the slope coefficients developed by Tihansky (updated to the 1978 price level) divided by 0.1 MG/year of water use.

(4) Total Salinity Costs, Municipal Systems. For municipal water supply and sewage facilities systems, since there are no "investment" or "contingency" costs, total salinity costs are equivalent to the summation of "daily-salinity" costs (life span reduction and OM&R). Figure 2-11A depicts, for a 5% interest rate, the cost curves for the Torresdale, Burlington, and Lower Bucks municipal systems. The cost curves differ somewhat as a result of variations in the investment characteristics of sewer and supply system facilities for each of the three municipal systems. These investment items were discussed in the above section concerning the life-span reduction of "daily-salinity" costs. Figure 2-11B presents a closeup view of the cost curves for levels of salinity ranging from 0 mg/l to 200 mg/l.

SALINITY-COST RELATIONSHIPS FOR DIRECT INDUSTRIAL WITHDRAWAL USERS

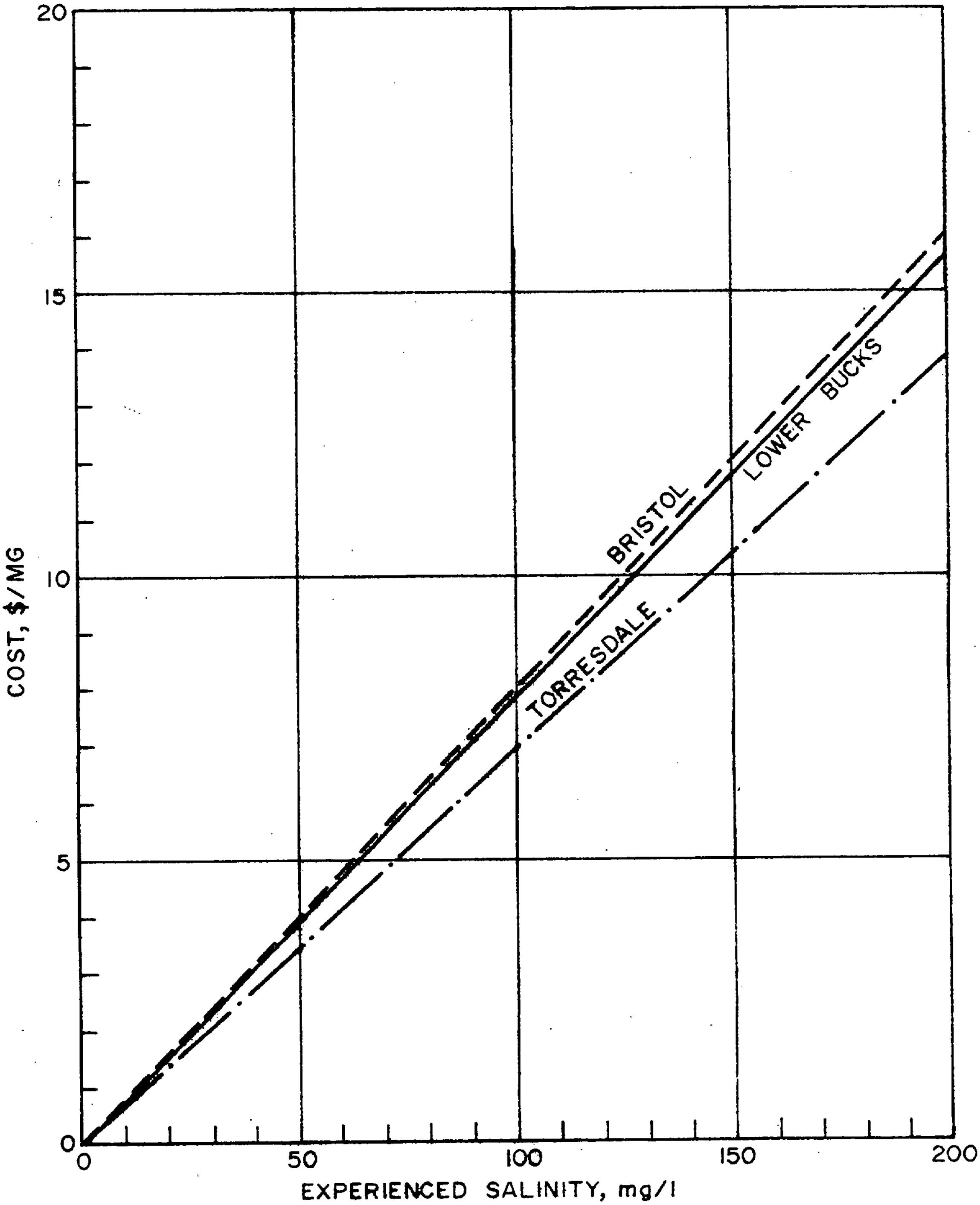
● INDUSTRIES AFFECTED BY ESTUARINE TDS CONCENTRATIONS. Industries affected by Delaware estuary TDS concentrations include those directly withdrawing estuarine water (see Figure 2-1 and Table 2-1), and those using water supplied from the three municipal systems. The Delaware River Basin Commission Inventory of Withdrawal Users (1978) provided information on users, their withdrawal location, and total estuarine water use. The DRBC 1976 Salinity Cost Survey of Industrial Users and an update of that survey conducted during this investigation elicited information on water use by type and salinity effects. Census information was obtained, by SIC code, for industries served by the three municipal water supply systems.



1978 Price Level
5% Interest Rate

DELAWARE ESTUARY
SALINITY INTRUSION STUDY
MUNICIPAL SYSTEMS - TOTAL SALINITY-COST RELATIONSHIP
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-11A



1978 Price level

5% Interest rate

DELAWARE ESTUARY

SALINITY INTRUSION STUDY

INDEPTH VIEW (0-200 mg/l)

MUNICIPAL SYSTEMS - TOTAL

SALINITY-COST RELATIONSHIP

PHILADELPHIA DISTRICT, CORPS OF ENGINEERS

DECEMBER 1982

FIGURE 2-11B

The approach used in estimating direct industrial water use salinity-cost relationships was to use the survey information on salinity costs, economic inference, engineering inputs, and information from Tihansky (1974) concerning effects on household items similar to those found in industry. Direct industrial uses consist of 1) once-through cooling, 2) recirculating cooling, 3) boiler feed, 4) process, including contact cooling, 5) sanitary and "other", treated as a single category, and 6) the intake systems thru which water is drawn for the above uses.

• ONCE-THROUGH COOLING SALINITY-COST RELATIONSHIPS. Once-through cooling water is used in very great quantities. For example, electric-generating stations, at times, utilize 1000 MG for once-through cooling in just a few days of operation. Thus, all costs are expressed on a $ per 1000 MG basis, rather than on the $/MG basis used for most other type uses.

(1) <u>"Investment" Costs</u>. The once-through cooling model determined no difference in investment in facilities for once-through cooling between different estuary locations (i.e., between different expected salinity levels). The same material of construction (90/10 copper-nickel) is used in heat exchangers at all locations. Investment in pumps and piping are minor compared to investment in heat exchangers, and are included in the intake system category for this investigation. (Carbon steel is the usual material of construction for piping). Since no salinity-related treatment of once-through cooling water is undertaken in the Delaware estuary, there is no salinity related investment in treatment facilities. Because of no differences in investment, there are no salinity-related "investment" costs for once-through cooling.

(2) <u>"Contingency" Costs</u>. No users in the Delaware estuary use salinity-related alternate source water for once-through cooling or

otherwise bear salinity related "contingency" costs for once-through cooling uses. The major reason is that the quantities of water involved are too great for users to feasibly consider alternative sources for once-through application. A few small-quantity users do occasionally switch to an alternative source, but such switches are attributed to high temperature rather than increases in salinity.

(3) "Daily-Salinity" Costs. At the present time, 90/10 copper-nickel heat exchangers are used exclusively by withdrawal users in the Delaware estuary. However, research determined that engineers do recommend the substitution of a more expensive material for heat exchangers, titanium, as expected salinity concentrations approach those of the sea.

This recommendation implies increasing corrosion rates for copper-nickel heat exchangers as salinity rise, warranting a switch to the higher cost titanium. The approach used to estimate "daily-salinity" costs for once-through cooling is based on the economic inference that, for the above recommendation to be correct, "daily-salinity" costs associated with 90/10 copper-nickel exchangers increase with rising levels of experienced salinity along a path (assumed to be linear), to meet at ocean salinities the added "investment" costs of titanium exchangers.

Once-through cooling systems are delineated into two subcategories, 1) <40 mgd, and 2) ≥ 40 mgd systems.

The equation developed is:

$$C_{DS}\ (\$/1000\ \text{MG}) = \frac{I\ r\ 1000}{365}\left(\frac{(1+r)^{35}}{(1+r)^{35}-1}\right)$$

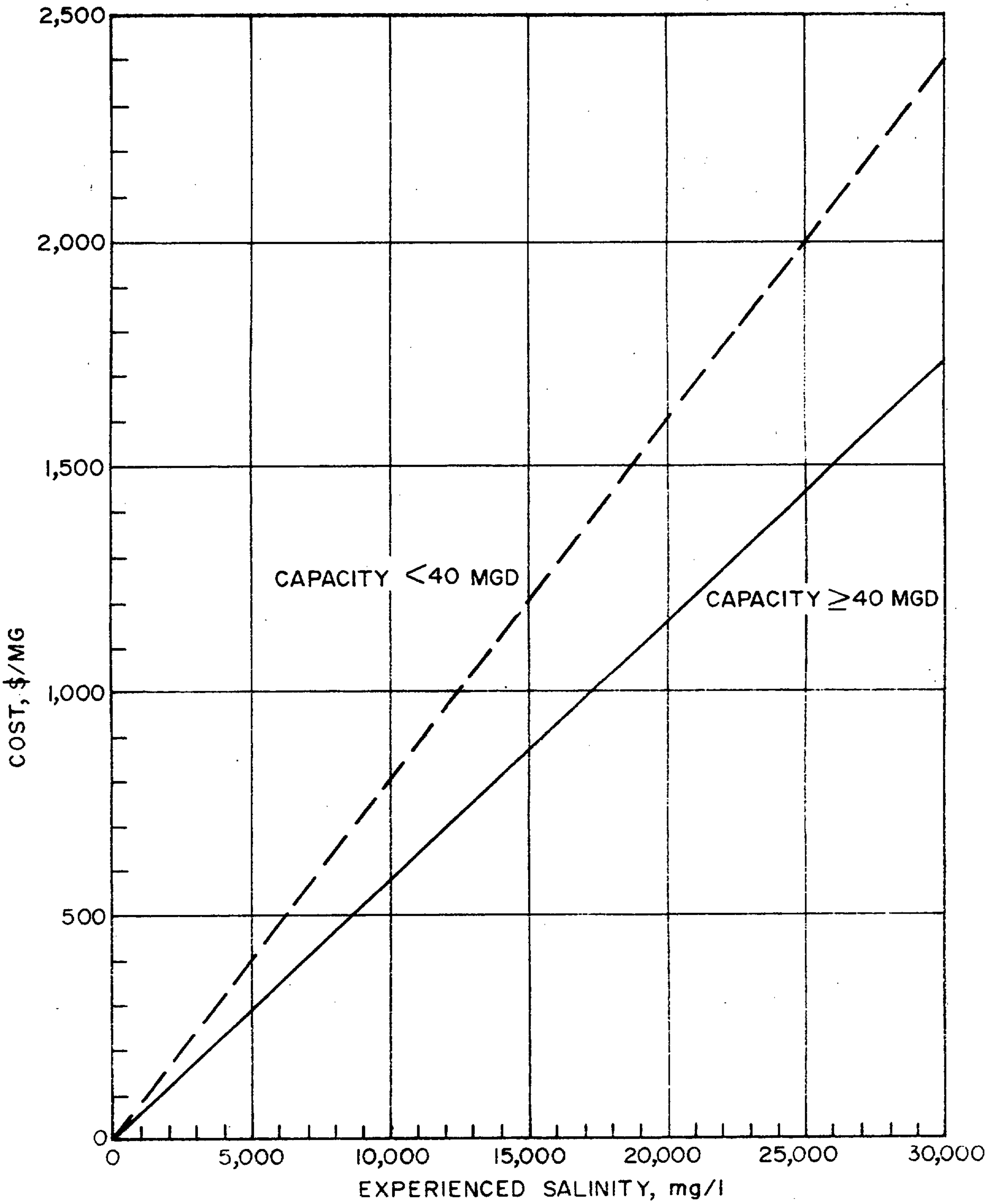
where: I = average level of investment (<40 mgd or ≥ 40 mgd system categories), r = applicable interest rate.

(4) Total Salinity Costs. Because there are no salinity-related "investment" or "contingency" costs for once-through cooling, total salinity costs are equivalent to total "daily-salinity" costs. Figure 2-12 presents cost curves, at 15% interest, for the $<$ 40 mgd and $\geq$ 40 mgd systems.

• BOILER FEED SALINITY-COST RELATIONSHIPS. Information for modelling boiler feed salinity-cost relationships was developed through sample interviews. The information and the modelled relationships derived are presented below.

(1) Modelled Salinity-Cost Relationships.

(a) "Daily-Salinity" Costs. Interviewing ascertained that average boiler feed users switch to municipal water when the experienced estuarine salinity reaches the 200 mg/l level. This switchover point of 200 mg/l was based on the following considerations. Engineers and boiler manufacturers recommend holding the TDS level in a boiler constant, and, as TDS levels in the raw makeup water increase, they recommend increasing the blowdown rate in order to hold the TDS level constant. Although, this practice avoids increased costs of corrosion, scaling, or other ill effects in the boiler itself, it does increase other costs. These costs include (1) increased costs of boiler treatment chemicals to replace those lost in the blowdown (i.e., to treat the greater quantities of makeup and feedwater needed to replace increased quantities of water blown down), (2) increased costs of softening for the greater quantities of makeup and feedwater, and (3) increased cost of heating additional quantities of boiler feedwater to boiler temperatures (i.e., the increased costs due to increased quantities of heat wasted through blowdown).



1978 Price level
15% Interest rate

DELAWARE ESTUARY
SALINITY INTRUSION STUDY

ONCE - THROUGH COOLING - TOTAL SALINITY-COST RELATIONSHIP

PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-12

The operating criterion of maintaining boiler TDS concentrations constant is economic if, above that TDS concentration, the marginal rate of damage (in dollar cost terms) to the boiler of added concentrations exceeds the sum of the marginal costs of the additional boiler chemical, softening, and heating requirements with increased blowdown. Below that TDS concentration the opposite is true, with the corollary that the marginal cost of damage to the boiler exceeds any marginal savings from decreasing the recommended levels of use of boiler treatment chemicals or softening. These operating criteria are utilized as the cost basis for salinity-cost modelling.

Using the recommended levels and costs of boiler treatment chemicals and the costs of softening, including the chemicals used, at different raw makeup salinity levels, salinity-cost relationships were estimated. Estimating heat loss was very difficult because of opportunities for savings through preheaters or for offsetting the losses through condensate return. Costs were estimated based on costs of fuel per British Thermal Unit (BTU) and saturated steam table information on BTU content in the blowdown water (not steam) at typical operating temperatures. The average use charge for municipal water is approximately \$60/MG (1978 price level). Thus, if the municipal water were of zero salinity (and zero hardness), its variable cost would be \$60/MG (1978). Theoretically, the variable cost for estuarine water should just equal the variable cost for municipal water at the chosen switchover point. The variable cost for estuarine water is comprised of pumping costs and "daily-salinity" costs.

Pumping costs are judged to be neglible. "Daily-Salinity" costs would include boiler life-span reduction, OM&R costs, and costs of water treatment. Predicated on rational decision-making as the criterion, these "daily-salinity" costs must equal at least \$60/MG (1978) at the switchover point. In fact, the 200 mg/l switchover point is merely a lower limit because the municipal water is not salinity free. The costs incurred would add to the total variable costs of the municipal water. The average variable cost of softener regenerant chemicals for alternate source water treated at 200 mg/l TDS is approximately \$30/MG (1978).

Based on engineering analysis, \$17.51/MG (1978) is the estimated cost of boiler feedwater treatment chemicals for the alternate source. These costs were estimated using increasing blowdown with rising levels of estuarine water salinity to maintain a constant TDS concentration in the boiler. Thus, boiler corrosion costs would be a factor related to feedwater salinity levels. Also, loss of heat in the blowdown would be a factor. For model purposes, it was assumed that some of this heat would be saved through preheaters. Conservatively, the above \$17.51/MG is rounded upwards to \$20/MG(1978) in order to account for this factor.

Adding the \$30 for softening and the \$20 for treatment chemicals and heat losses to the \$60 use cost gives a total variable cost of \$110/MG for the alternate source at 200 mg/l.

This is applied as a reasonable proxy for the "daily-salinity" cost of estuarine water at the switchover point. A linear relationship was assumed for the range 0 to 200 mg/l, with a zero "daily-salinity" cost at zero salinity for estuarine water. The coefficient of the relationship is, thus, 110/200 = 0.55, and the equation for "daily-salinity" costs is:

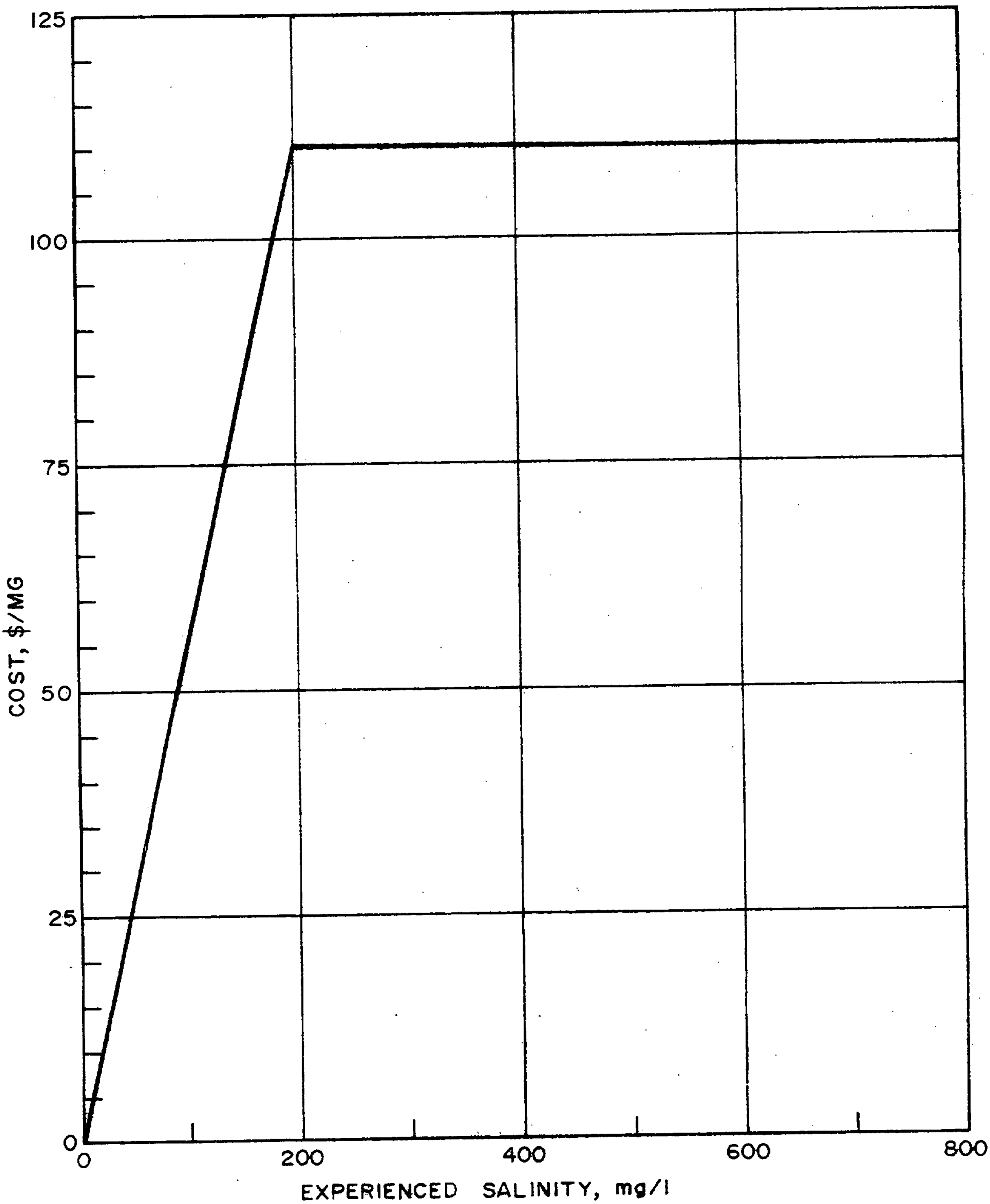
$C_{DS}(\$/MG) = \$0.55s,\ s \leq 200$, where s is experienced daily salinity, mg/l.

(b) "Contingency" Costs. "Contingency" costs resulting from the switchover to an alternate source are applicable for all experienced salinities above 200 mg/l:

C_c (\$/MG) = \$110/MG, s $\geqslant$ 200 mg/l.

(c) "Investment" Costs. Salinity related investment involves only softeners. Other investment requirements for additional makeup capacity for high blowdown rates and the boiler feedwater treatment chemical system associated with higher salinities are minor. Demineralizers are a substitute for softeners for higher pressure boilers. There are no boiler feed users using estuarine water without softeners, and there is no variation in these costs with respect to expected salinities. Thus, in effect, there are no salinity-related "investment" costs incurred for boiler feed systems. (This differs from the case of households, where different proportions of households invest in softeners at different expected salinities).

(2) Total Salinity Costs. Total salinity costs are equivalent to "daily-salinity" costs experienced with estuarine salinity at or below 200 mg/l TDS, and "contingency" costs incurred above 200 mg/l TDS estuarine water. Because there would be costs from salinity resulting from the use of alternate source water, the "daily-salinity" costs of estuarine water use, which depend directly on the level of the "contingency" costs, tend to be conservatively estimated. Also, because "investment" costs in alternate-supply facilities were judged to be minor compared to "daily-salinity" costs, these "investment" costs were not included in total salinity costs. Figure 2-13 presents the salinity-cost relationship for boiler feed systems.



1978 Price level
15% Interest rate

DELAWARE ESTUARY
SALINITY INTRUSION STUDY
BOILER FEED & RECIRCULATING COOLING
SALINITY-COST RELATIONSHIP
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-13

• RECIRCULATING COOLING SYSTEM SALINITY-COST RELATIONSHIPS. Engineering experience indicates that there are significant costs due to makeup water salinity in recirculating cooling systems. As salinity increases, blowdown increases, and treatment chemical cost increases. Since users report utilizing a very similar switchover criterion for recirculating cooling systems as that determined for boiler feed systems, the same equations are considered reasonable for the "daily-salinity" cost and "contingency" cost relationships:

$$C_{DS}\ (\$/MG) = \$(0.55)/MG, \quad s \leq 200\ mg/l$$

$$C_C\ (\$/MG) = \$110/MG, \quad s > 200\ mg/l$$

Thus, the same cost curve is also applicable (see Figure 2-13). It is assumed, similar to boiler feed, that there is no variation in investment with respect to expected salinities, and, thus, salinity-related "investment" costs are effectively zero.

• PROCESS WATER SALINITY-COST RELATIONSHIPS. The Tihansky cost equations for household items that come in contact with water, excluding washable clothing, are deemed appropriate for estimating salinity related costs for industrial process equipment. These items include water pipes, wastewater pipes, water heaters, faucets, toilets, garbage grinders, washing machines, toilets, and cooking utensils. These items are similar, in terms of materials subject to impact, to the kinds of items with which process water comes in contact.

(1) <u>"Daily-Salinity" Costs</u>.

(a) <u>Salinity-Related Replacement Costs</u>. It was determined that direct use of Tihansky's equations required a significant time requirement in order to complete the necessary calculations. Therefore, a best-fit formula was developed to facilitate the salinity-cost calculations. First, costs were developed at various interest rates (2.5%-25%) over a range of "experienced" salinities from 0 mg/l to 750 mg/l. These costs were then statistically analyzed against salinity using both linear regression and second-order polynomial fit curves. The second-order polynominal expressions yielded excellent fits with R^2 values exceeding .99, and provided salinity-cost relationships with the following general equation format:

$$C_{DS\ P}\ (\$/MG) = X_1\ (s) + X_2(s^2) + X_3$$

For use in the higher salinity ranges (experienced salinity above 750 mg/l), this relationship was extrapolated linearly through the 500 mg/l point.

Thus, if $s > 750$ mg/l: $C_{DSP} = s/500$ (i.e., a relative percentage of costs at 500 mg/l based on the level of salinity).

(b) Salinity-Related OM&R Costs. For salinity-related OM&R costs, the equation is:

$$C_{DS\ OM\&R}\ (\$/MG) = \$.1244\ s/MG$$

The 0.1244 is the sum of slope coefficients developed by Tihansky (updated to the current price level) divided by 0.1 MG/year use; s equals to the level of experienced salinity.

(2) "Contingency" and "Investment" Costs. A few users have reported using alternate sources for process water when experienced salinity reached exceptionally high levels in relation to the average at their estuarine locations. However, alternate source use was very infrequent and the magnitude of water use was ascertained to be insignificant in relative proportion to total process water use. Thus, the development of "contingency" costs was not considered necessary. Also, "investment" costs were determined to be not applicable.

(3) Total Salinity Costs. In conclusion, total process water salinity costs are equivalent to the total "daily-salinity" costs for replacement and OM&R. Figure 2-14 depicts the cost curve at the 15% interest rate.

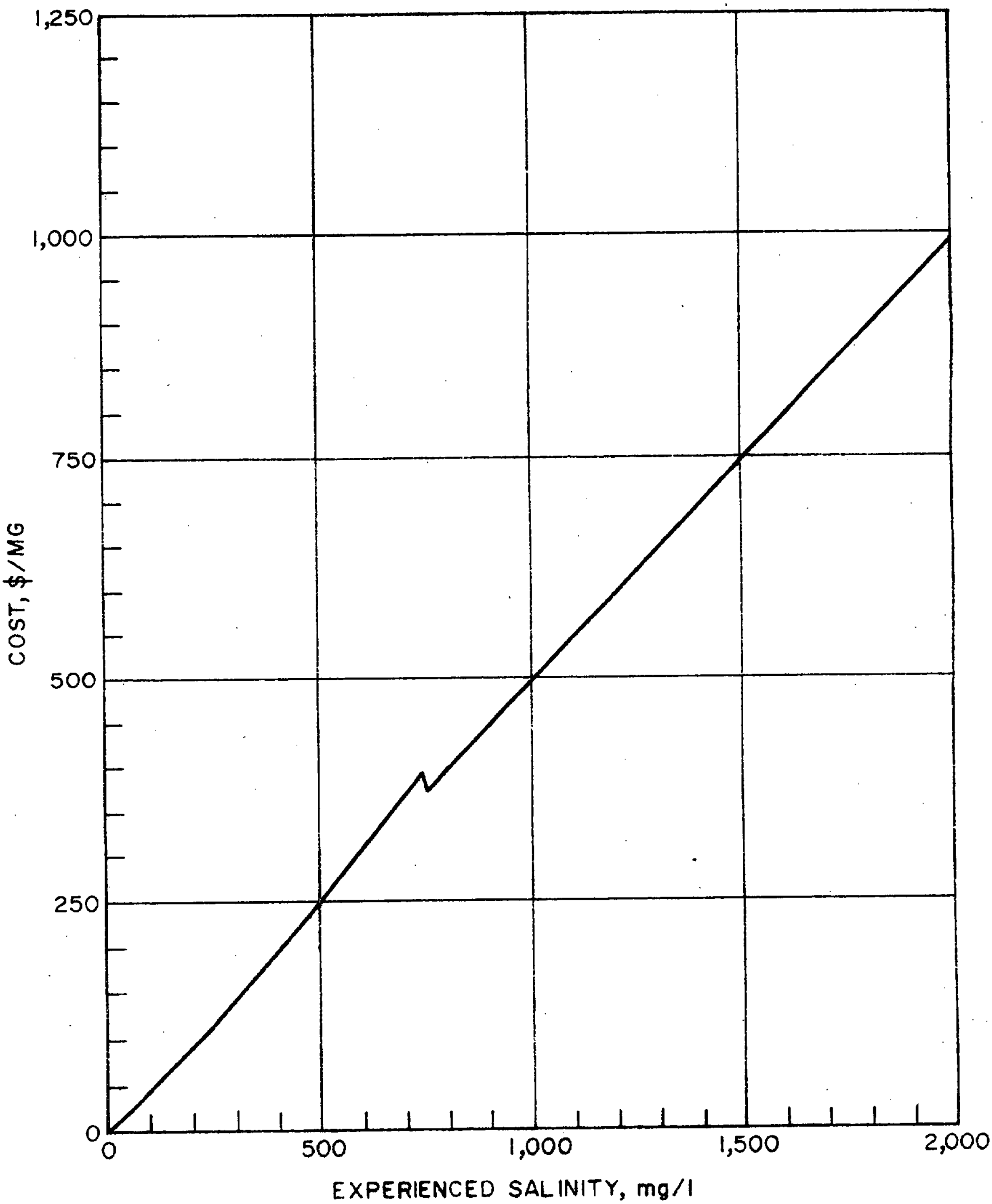
• SANITARY AND OTHER SALINITY-COST RELATIONSHIPS. For sanitary (and other) salinity-cost relationships, the relationships developed for process water are deemed reasonable. This is based on the close relationship of sanitary uses in industry to domestic sanitary uses(from which the process water relationships were derived). Figure 2-14 presents the cost curve at the 15% interest rate.

• INTAKE SYSTEMS SALINITY-COST RELATIONSHIPS. As with cooling systems, all costs for intake systems are expressed on a $ per 1,000 MG basis because of the vast volumes of water involved. Equipment subject to salinity impacts includes items such as screens, pumps, and piping. Wooden or concrete bulkheads and platforms are excluded, since these facilities are not subject to significant salinity effects.

Intake systems are modelled in 2 sizes, (a) less than 10 mgd, and (b) greater than 10 mgd; and in two different materials of construction, carbon steel for freshwater estuary locations and stainless steel for brackish water estuary locations. Investment in the intake facilities impacted by salinity is shown below. (Note that the investment, or capital cost, is expressed in $/mgd, whereas "investment" costs, which include the interest and directly associated OMR&R costs for that investment, are expressed in $/MG.)

Investment in Salinity-Impactible Intake Equipment

Modelled for Systems of mgd Size	Capital Cost $(1978)/mgd		
	Fresh Water (I_F)	Brackish Water (I_B)	Added Investment Brackish Water ($I_B - I_F$)
<10	10,465	20,800	10,335
≥ 10	7,050	12,510	5,460



1978 Price level
15% Interest rate

DELAWARE ESTUARY
SALINITY INTRUSION STUDY
PROCESS, SANITARY & OTHER
TOTAL SALINITY—COST RELATIONSHIP
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-14

(1) "Investment" Costs. The salinity-related capital cost is zero in freshwater locations because facilities of this type would be installed even in zero salinity water. Salinity-related investment in brackish-water locations is the added investment over that undertaken in freshwater locations. The "investment" costs are the combination of interest costs and the directly associated OMR&R costs (replacement and OM&R).

(a) Interest Cost Portion of "Investment" Costs. The interest cost portion of "investment" costs is

$$\text{(Brackish) } C_{Ii} \text{ (\$/1,000 MG)} = \frac{(I_B - I_F)r1000}{365}$$

$$\text{(Freshwater) } C_{Ii} = 0$$

(b) Directly Associated OMR&R Portion of "Investment" Cost. For the life of the facilities and replacement costs, a model was adopted using relevant equations developed by Tihansky and engineering inputs. The following equations were derived:

$$\text{Freshwater: } n = 3 + 5e^{-0.0012t}$$

$$\text{Brackish-Water: } n = 7.5 + 12.5e^{-0.0012t}$$

where n = facility life in years

t = salinity in mg/l

Because the brackish-water facilities in the model are stainless steel, whereas the freshwater facilities are carbon steel, the brackish-water facilities will have a longer life. The brackish-water facilities life was modelled at 2.5 times the life of the freshwater facilities. This relationship remains constant at all salinity levels.

The brackish-water facilities will also have a higher capital cost. The directly associated replacement cost, which is the added replacement costs of the brackish-water facilities at zero salinity, could therefore be either positive or negative. (The directly associated replacement costs are analyzed at zero salinity, because any reduction in life resulting from salinity levels above zero is evaluated as a "daily-salinity" cost).

If the replacement costs are negative, this means that the longer life of the brackish-water investment more than offsets the higher capital cost in determining replacement costs. The equations for replacement costs are:

$$\underset{\text{(Brackish)}}{C_{IP}(\$/1000MG)} = \frac{rI_B 1000}{((1+r)^m-1)365} - \frac{rI_F 1000}{((1+r)^n-1)365}$$

$$\underset{\text{(fresh)}}{C_{IP}\ (\$/1000MG)} = \$0$$

where:

r = interest rate

m = life at zero salinity (brackish-water)

n = life at zero salinity (fresh-water)

I_B = Investment (Brackish-Water)

I_F = Investment (Fresh-Water)

(c) OM&R Costs. Equations were developed for OM&R costs, with coefficients based on engineering inputs. The equations were:

Freshwater: \$ (OM&R)/0.1MG = 0.0000617s + 0.168

Brackish-Water: \$ (OM&R)/0.1MG = 0.0000247s + 0.067

The difference in the constant terms of these equations (0.168 for freshwater and 0.067 for brackish-water) is the directly associated OM&R cost of the brackish-water investment. The cost in \$/1000 MG is:

$$\underset{\text{(Brackish)}}{C_I\ OM\&R\ (\$/1000MG)} = \$(0.067 - 0.168)\ 10{,}000 = \$-1{,}010$$

$$\underset{\text{(Freshwater)}}{C_I\ OM\&R\ (\$/1000MG)} = 0$$

The OM&R cost is negative because there is a savings in OM&R with the brackish water investment. The savings is applicable to all size investments.

(d) Total "Investment" Costs. "Investment" costs for intake systems are the sum of interest costs and directly associated OMR&R costs (replacement and OM&R).

(2) "Contingency" Costs.

There are no "contingency" costs for intake systems.

(3) "Daily-Salinity" Costs.

Equations modelled on Tihansky's equations for "investment" costs and engineering inputs were adopted for modelling "daily-salinity" costs.

(a) Reduced life span portion of "Daily-Salinity" Costs. The reduced life span costs were calculated as follows:

$$C_{DS\ P}\ (\$/1000MG)\ (\text{Brackish-water}) = \left[\left(\frac{r}{(1+r)^{nb}-1}\right)-\left(\frac{r}{(1+r)^{mb}-1}\right)\right]\frac{1000\ I_B}{365}$$

$$C_{DS\ P}\ (\$/1000MG)\ (\text{Freshwater}) = \left[\left(\frac{r}{(1+r)^{nf}-1}\right)-\left(\frac{r}{(1+r)^{mf}-1}\right)\right]\frac{1000\ I_F}{365}$$

$$nb = 7.5 + 12.5e^{-0.0012t}$$
(Brackish-water)

$$nf = 3 + 5e^{-0.0012t}$$
(Freshwater)

where:

r = interest rate

t = experienced salinity

nb = life (brackish) at given salinity

mb = life (brackish) at zero salinity

nf = life (freshwater) at given salinity

mf = life (freshwater) at zero salinity

I_F = Investment (freshwater)

I_B = Investment (brackish)

(b) OM&R Portion of "Daily-Salinity" Costs. As previously indicated, Tihansky's work and engineering inputs were used for OM&R costs. The relevant portions of these equations for experienced salinity related OM&R costs (expressed per 0.1MG per year) were:

Freshwater: OM&R = 0.0000617t

Brackish-Water: OM&R = 0.0000247t

Costs per 1,000 MG would be 10,000 times these costs, or

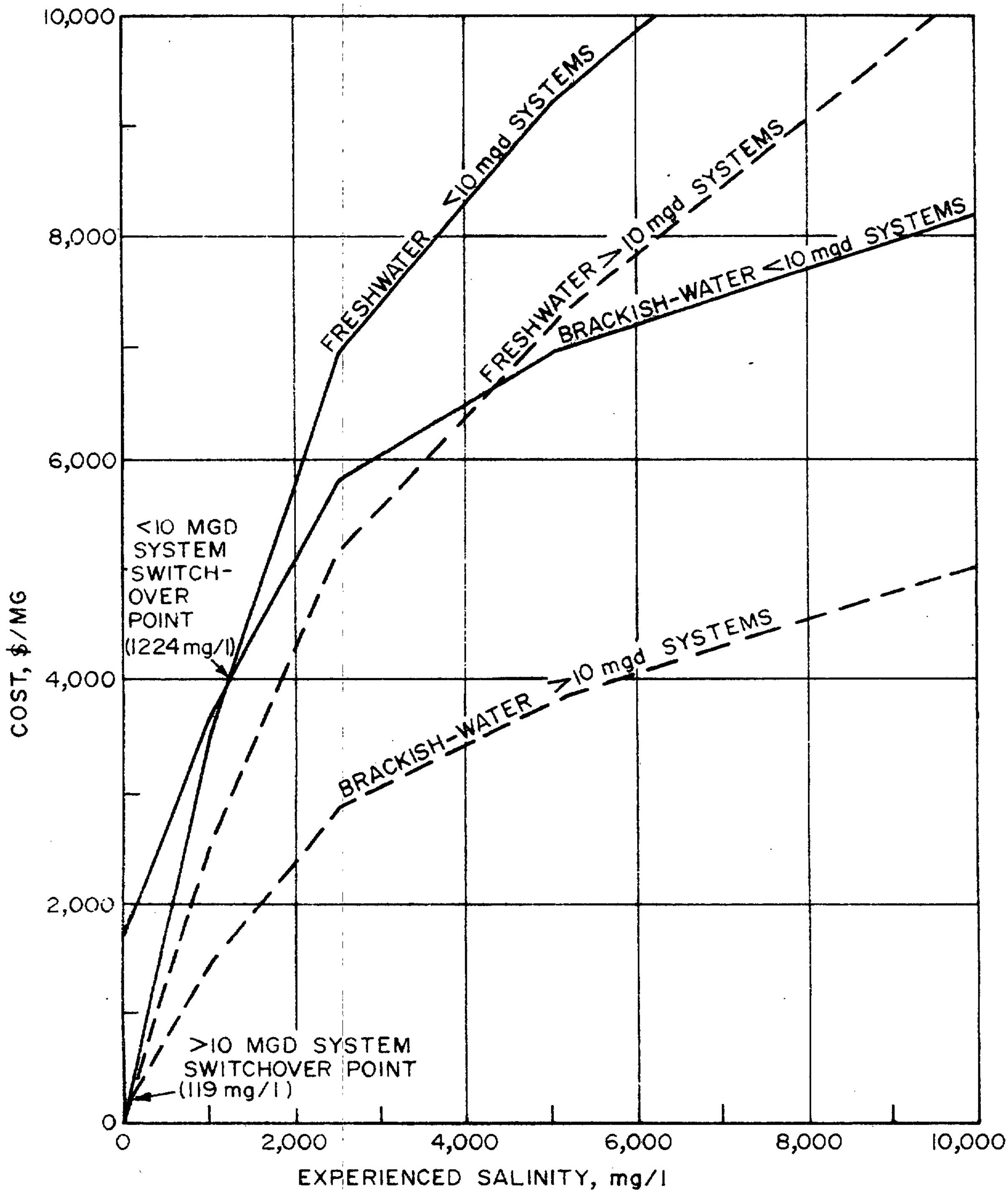
Freshwater: $C_{DS\ OM\&R}$($/1,000 MG) = 0.617t

Brackish-Water: $C_{DS\ OM\&R}$ ($/1,000 MG) = 0.247t

(c) Total "Daily-Salinity" Costs. "Daily-Salinity" costs are the sum of reduced life span and OM&R costs.

(4) Total Salinity Costs. Total salinity costs for intake systems are equivalent to the sum of "investment" and "daily-salinity" costs. Figure 2-15 presents the cost curves, for interest at 15%, for the four categories of intake systems, 1) freshwater $<$10 mgd, 2) freshwater $\geq$10 mgd, 3) brackish-water $<$ 10 mgd, and 4) brackish-water $\geq$10 mgd.

(5) Salinities At Which Investments Apply For Intake Systems. Applying the theory that capital investment decisions are made on the basis of rational decision-making, users will switch to the higher capital cost investment system (brackish-water), when, based on average experienced TDS levels over the 50-year period of analysis (i.e. expected salinity) for



1978 Price level
15% Interest rate

DELAWARE ESTUARY
SALINITY INTRUSION STUDY
INTAKE SYSTEMS - TOTAL
SALINITY-COST RELATIONSHIP
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-15

their locations, the added total "daily-salinity" costs of the freshwater facilities over the brackish exceed the added "investment" costs of the brackish-water facilities over the freshwater. The switchover points, at a 15% interest rate (as shown in Figure 2-15), are 1224 mg/l for $<$10 mgd systems and 119 mg/l for $\geq$10 mgd systems.

SALINITY-COST RELATIONSHIPS FOR INDUSTRIAL, COMMERCIAL, AND INSTITUTIONAL USERS OF MUNICIPAL WATER SUPPLIES

Municipal water is supplied to industrial, commercial, and institutional customers. For each category of use, salinity costs are incurred in the same manner, mainly through corrosion, as incurred by household items. However, the costs are distributed differently among the items applicable for these user categories. For example, salinity costs for industrial users of municipal water are of a similar nature to those borne by direct withdrawal users, but are distributed somewhat differently among uses (i.e., there is minimal once-through cooling, while sanitary takes on a much more significant percentage of total water use). Each industrial, commercial and institutional customer of the municipal systems has items comparable to those used by households, such as water pipes, wastewater pipes, and faucets. Most have toilets. Many have water heaters, at least for hand washing. Also among the customers are commercial laundries, the food and beverage industry, hotels, motels, restaurants, and institutions, such as hospitals, with substantial hot water demands. Many of these, too, have washing machines, dishwashers, garbage grinders, and cooking utensils.

Most bathing, clothes washing, and food washing and preparation is done in the household. Because of the relatively heavy costs ascertained by Tihansky in the use of soaps and cleansers, softeners, and clothes washing categories, inclusion of these categories for non-household users of municipal water supplies could lead to cost overestimates. For this reason, it was estimated that the same salinity-cost relationships that were developed for process and sanitary use, which did not include the above cost items, were reasonable for industrial, commercial, and institutional users of municipal water supplies. Deletion of the above cost items lends a conservativeness to costs because, in fact, there is considerable clothes, linen, dish, personal, and other washing conducted outside the household. Figure 2-16 presents the cost curves: 1), for industrial and commercial users at 15%, and 2) for institutional users at 5%.

SUMMARY OF SALINITY-COST RELATIONSHIP EQUATIONS

Below, presented in summary form, is a reiteration of the equations for salinity-cost relationships outlined in this appendix:

- DOMESTIC USERS:

(1) "Investment" Costs.

(a) Interest Cost Portion.

$$C_{I\ i}\ (\$/MG) = \frac{\$0.36\ (0.286\ TDS + 14)r}{0.1}$$

(b) Replacement portion directly associated OMR&R costs.

$$C_{IP}\ (\$/MG) = \frac{3.629\ (r)\ (.286\ TDS + 14)}{(1+r)^{12} - 1}$$

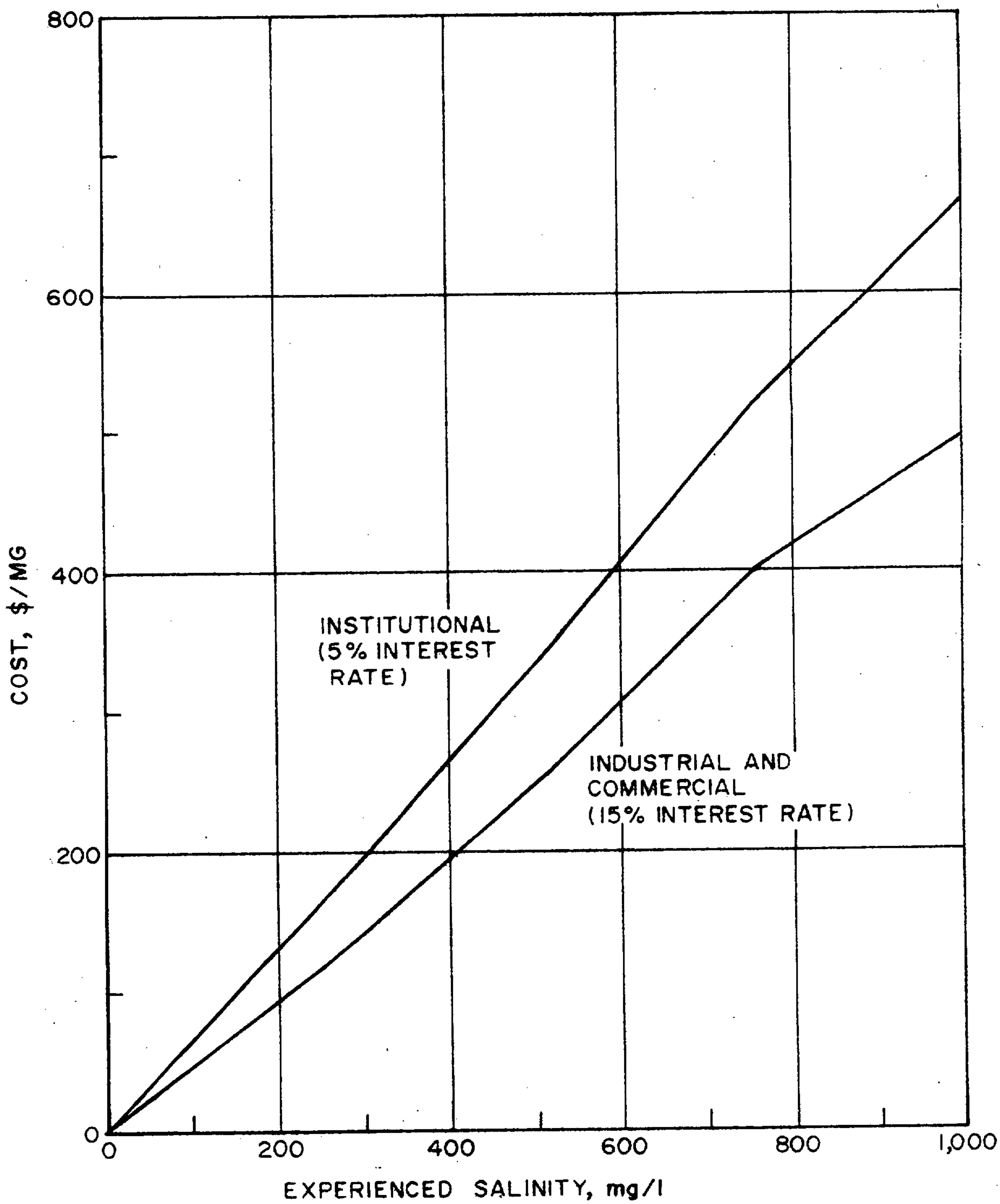
(2) "Contingency" Costs.

$$C_c\ (\$/MG) = .4147\ (T)^{.8042}$$

(3) "Daily-Salinity" Costs.

(a) Life-span reduction portion.

$$C_{DS\ P}\ (\$/MG) = \left[\left(\frac{r}{(1+r)^n - 1}\right) - \left(\frac{r}{(1+r)^m - 1}\right)\right] \frac{\$(1978)/\text{household}}{0.1\ \text{MG/yr/household}}$$



1978 Price level

DELAWARE ESTUARY
SALINITY INTRUSION STUDY
CONNECTED INDUSTRIAL, COMMERCIAL & INSTITUTIONAL USERS OF MUNICIPAL WATER SUPPLY SYSTEMS
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 2-16

(b) OM&R Portion.

$$C_{DS}\ \mathrm{OM\&R}(\$/MG) = .000001583\ sT + .0000775\ T + .954465\ s + 38.179$$

- MUNICIPAL SYSTEMS:

(1) "Daily-Salinity" Costs.

(a) Life-span reduction portion.

$$C_{DS}\ P\ (\$/MG) = \left[\left(\frac{r}{(1+r^{n})-1}\right)-\left(\frac{r}{(1+r)^{m}-1}\right)\right] \frac{\$I(1978)}{0.1MG/yr.}$$

(b) OM&R portion.

$$C_{DS}\ \mathrm{OM\&R}\ (\$/MG) = .05(s)$$

- DIRECT INDUSTRIAL WITHDRAWAL SYSTEMS:

(1) Once-through cooling.

(a) "Daily-Salinity" Costs.

$$C_{DS}(\$/MG) = \left(\frac{I\ r\ 1000}{365}\right)\left(\frac{(1+r)^{35}}{(1+r)^{35}-1}\right)$$

(2) Boiler Feed and Recirculating Cooling.

(a) "Daily-Salinity" Costs.

$$C_{DS}(\$/MG) = \$0.55s, \text{ (where } s \leq 200 \text{ mg/l)}$$

(b) "Contingency" Costs.

$$C_{c}(\$/MG) = \$110/MG \text{ (where } s > 200 \text{ mg/l)}$$

(3) Process Water and Sanitary.

"Daily-Salinity" Costs.

(a) Salinity-Related Replacement Costs.

$$C_{DS}\ P\ (\$/MG) = X_1(s) + X_2\ (s^2) + X_3$$

Best fit second-order polynomial expression of Tihansky's equations.

(b) Salinity-related OM&R costs.

$$C_{DS\ OM\&R}\ (\$/MG) = 0.1244\ s$$

- INTAKE SYSTEMS:

(1) "Investment" Costs.

(a) Interest cost portion.

$$\underset{\text{(Brackish)}}{C_{Ii}}\ (\$/1000\ MG) = \frac{(I_B - I_F)r1000}{365}$$

$$\underset{\text{(Freshwater)}}{C_{Ii}}\ (\$/1000\ MG) = 0$$

(b) Directly associated OMR&R portion.

(i) Replacement costs.

$$C_{IP}(\$/1000\ MG) = \frac{rI_B1000}{((1+r)^{m}-1)365} - \frac{(rI_F1000)}{((1+r)^{n}-1)365}$$

$$\underset{\text{(Freshwater)}}{C_{IP}}\ (\$/1000\ MG) = 0$$

(ii) OM&R Costs.

$$\underset{\text{(Brackish)}}{C_{I\ OM\&R}}\ (\$/1000\ MG) = \$(0.067 - 0.168)\ 10{,}000 = \$-1{,}010$$

$$\underset{\text{(Freshwater)}}{C_{I\ OM\&R}}\ (\$/1000\ MG) = \$0$$

(2) "Daily-Salinity" Costs.

(a) Reduced-life-span portion.

$$\underset{\text{(Freshwater)}}{C_{DS\ P}}\ (\$/1000\ MG) = \left[\left(\frac{r}{(1+r)^{nf}-1}\right) - \left(\frac{r}{(1+r)^{mf}-1}\right)\right] \frac{1000\ I_F}{365}$$

$$\underset{\text{(Brackish)}}{C_{DS\ P}}(\$/1000\ MG) = \left[\left(\frac{r}{(1+r)^{nb}-1}\right) - \left(\frac{r}{(1+r)^{mb}-1}\right)\right] \frac{1000\ I_B}{365}$$

$$\underset{\text{(freshwater)}}{nf} = 3 + 5e^{-.0012t}$$

$$nb = 7.5 + 12.5e^{-.0012t}$$

(b) OM&R Portion.

$$\underset{\text{(Freshwater)}}{C_{DS\ OM\&R}}\ (\$/1000\ MG) = 0.617t$$

$$\underset{\text{(Brackish)}}{C_{DS\ OM\&R}}\ (\$/1000\ MG) = 0.247t$$

- INDUSTRIAL, COMMERCIAL, AND INSTITUTIONAL USE OF MUNICIPAL WATER SUPPLIES:

  (1) "Daily-Salinity" Costs.

  (a) Salinity-Related Replacement Costs.

  (b) Salinity-Related OM&R Costs.

  The same equations are applicable as utilized for process and sanitary system uses.

DELAWARE ESTUARY
SALINITY INTRUSION STUDY

ENVIRONMENTAL STUDIES

APPENDIX 3

US Army Corps
of Engineers
Philadelphia District

DELAWARE ESTUARY SALINITY
INTRUSION STUDY

APPENDIX 3

SALINITY IMPACTS ON ESTUARINE FISH AND
WILDLIFE RESOUCRES

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

This portion of the study is designed to indicate the sensitivity of the estuarine ecosystem to fluctuations in the salinity regime. Because of the enormous diversity of flora and fauna in the ecosystem and data constraints, it was necessary to concentrate study efforts on species of direct or indirect commercial or recreational importance.

Upon completion of early work stages, it became apparent that addressing the effects of salinity change on the biota in economic terms could not be accomplished. Estuarine organisms are regulated by a host of factors that act independently or synergistically to control the species. It is difficult to define how these factors will operate singularly or together on individual species, parts of the ecosystem, or the ecosystem as a whole from one year to the next, and it is even more difficult to translate the effect into economic terms. What can be determined about individual species is their preferred salinity range, where that range occurs in the ecosystem, and how its location, and thereby the species, may be impacted by changes in the salinity regime.

Technical input to this study has been directly provided by the U.S. Fish and Wildlife Service and the National Marine Fisheries Services. In addition many governmental agencies and educational institutions have contributed, either directly or in earlier efforts by the federal natural resources agencies.

THE CYCLE OF SALINITY CHANGE IN THE DELAWARE ESTUARY

The main sources of flow (freshwater inflow, ocean tidal flow, and inter-basin transfer via the Chesapeake and Delaware Canal) are the chief factors determining salinity concentrations in the Delaware estuary. Lower spring salinities correspond to peak freshwater runoff and lower salinity concentrations of ocean and C&D Canal flows, while higher summer and early autumn salinities result from opposite conditions. Fifty years of computer simulation revealed that the C&D Canal flows would normally influence the middle estuary salinities between RM 37 and 82. Above RM 82, the magnitude and variation of freshwater flow was the main influence on salinity concentrations. Below RM 37, estuary salinities were primarily influenced by variations in ocean salinity, tides, and sea level. Variation in mean seasonal salinity values due to differences in river flow and ocean salinity can be as great as 3 ppt.

Other variations in salinity occur as a result of tide level variation; peak salinities generally occur at or near high slack tide and minimums at or near low slack tide, with possible differences of over 4 ppt daily. Localized variations in salinity also occur horizontally and vertically; a maximum salinity difference of 10 ppt between surface and bottom can occur in the bay during spring.

ROLE OF SALINITY IN THE DELAWARE ESTUARY ECOSYSTEM

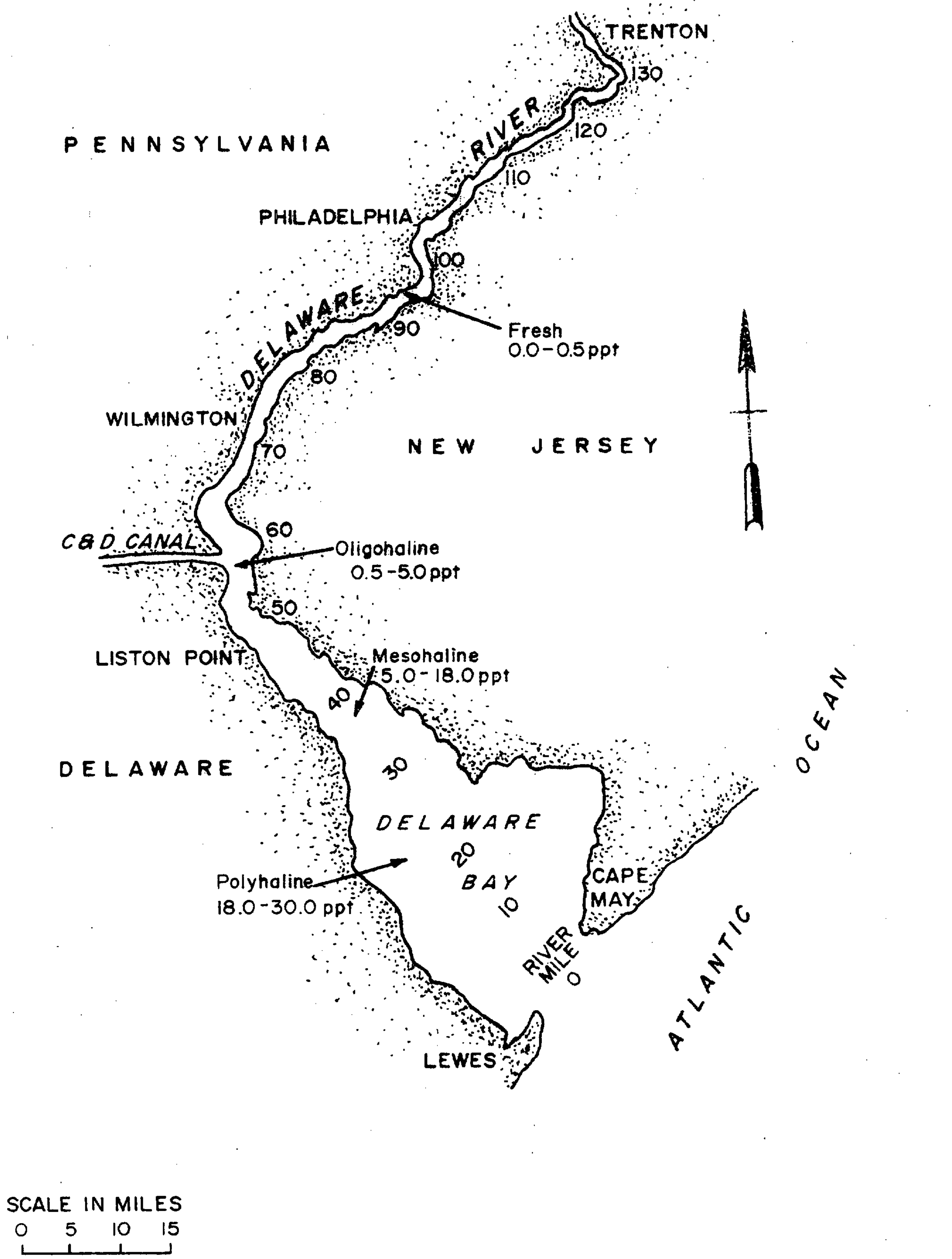
The ability of an organism to reside within a given environment depends on the needs of the organism and the characteristics of the environment. Most organisms cannot tolerate extreme physical or chemical conditions. They exist only within an intermediate range, which is referred to as the "range of tolerance." Every organism has a separate range of tolerance for different environmental factors. Any factor approaching or exceeding this range is said to be a "limiting factor". Each range of tolerance contains a narrow zone called the ("optimum range"), in which the organism functions at peak efficiency. Bracketing the optimum range between the upper and lower limits of tolerance lie the upper and lower "zones of stress". Within these zones the organism is placed under a special burden, and the closer to the limits of tolerance, the greater the stress on the organism (Darnell 1976).

Different environmental factors often do not operate independently of each other. When an organism is stressed by one factor, its limit of tolerance to other factors tend to be reduced. Limits of tolerance are broadly, not sharply, defined due to this interaction of factors. The range of tolerance, limits of tolerance, optimum ranges, and zones of stress usually differ among species. Some organisms have broad tolerance ranges while others have narrow ranges of tolerance (Darnell 1976).

Salinity is a major limiting factor influencing the distribution of marsh plants (Walton and Patrick 1973), benthic invertebrates (Ichthyological Associates 1980), and fishes (Abbe 1967; Ichthyological Associates 1980) in the Delaware estuary. It also influences the distribution of birds and mammals (Daiber 1977). Most aquatic organisms found above Wilmington, DE, are freshwater types tolerant of only small amounts of salt. Conversely, most organisms found in Delaware Bay are marine types requiring high salinity. In between the two zones, in the lower river and upper bay, are found brackish-water types exist which tolerate intermediate salinities. While many organisms are restricted to one of these zones, some function over a broad range of salinity and are inhabitants of two or three zones. Species that occur throughout a broad range of salinities are said to be "euryhaline". Those that have a narrow salinity range (e.g., marine and freshwater types) are "stenohaline". Many organisms that are dependent on estuarine nursery areas have varying salinity tolerance levels during different life stages of their development; many marine finfish are stenohaline as adults but are euryhaline during their egg, larval, and juvenile life stages.

The longitudinal gradient is greatest in the lower river and upper bay of the oligo-mesohaline zone (average salinity 0.5 - 18.0 ppt) (Daiber and Smith 1972); (Ichthyological Associates 1980), Refer to Figure 3-1. The dynamic nature of physio-chemical and hydrologic parameters in this 45-mile reach results in a variable and demanding environment. However, these factors also create an abundance of food resources attractive to species able to tolerate the salinity fluctuations. Tidal fluctuations enhance productivity by supplying food, nutrients, and oxygen. Additionally, vertical mixing recycles and traps nutrients, sediments, detritus, and planktonic organisms. The adjoining marshland also contributes to the food base (Ichthyological Associates 1980).

The highly productive brackish reach is important to shellfish and fishery resources. The area offers food, protection from stenohaline predators (which inhabit the area of the estuary with average salinity of 16.5 to 30 ppt), and high water temperatures during spring and summer, which favor increased growth rates (Ichthyological Associates 1980). Oysters thrive in it partly because of protection against predation by oyster drills, which are unable to withstand salinities less than 15 ppt. Blue crabs mate there and young crabs, after a period of early development in downbay areas, move into the region to mature. Atlantic menhaden, weakfish, striped bass, white perch, bluefish, summer flounder, American eel, white catfish, carp, Atlantic Silverside, bay anchovy, mummichog, and spot use these waters for



DELAWARE ESTUARY
SALINITY INTRUSION STUDY

ZONES OF SALINITY IN THE DELAWARE ESTUARY

PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 3-1

early growth. Euryhaline organisms occupying this reach have a distinct advantage over stenohaline types. Not only can they tolerate wide salinity variation, but they use this ability to maintain their populations. In summary, the salinity characteristics of this reach favor abundant food supply protection from predation, and growth early in the life cycle for species. These functions are important in maintaining populations of valuable commercial and recreational species.

TIDAL MARSHES

Approximately 165,000 acres of tidal marshes border the tidal Delaware River and Bay. Most of these wetlands occur in Delaware and the lower New Jersey counties of Salem, Cumberland, and Cape May. Relatively little wetlands remain in Pennsylvania or in the upper New Jersey counties of Gloucester Camden and Burlington (Daiber *et al*. 1976; Ferrigno *et al*. 1973).

Research has raised the possibility that salinity may be a major factor influencing distribution of many wetland plants (Ferren and Schuyler 1980). Throughout the upper part of the estuary, extending from Trenton, NJ, to Wilmington, DE, tidal marshes are of the freshwater type. Common plant species include *Scirpus americanus*, *S. olneyi*, *Polygonum punctatum*, *Eleocharis* spp., *Saggitaria* spp., *Zizania aquatica*, *Peltandra virginica*, *Nuphar advena*, *Pontederia* spp. and *Lythrum* spp. (Walton and Patrick 1973). These species also occur in inland freshwater tidal marshes along the bay (Daiber *et al*. 1976; Walton and Patrick 1973). In general, these species are not able to tolerate salinities in excess of 5 ppt.

Proceeding southward down the estuary from Wilmington, the marshes gradually change to saltmarsh type. Common species in this area of the estuary are *Phragmites communis* (dominant in mid-estuary), *Spartina alterniflora*,

S. patens, Distichlis spicata, Iva frutescens, and Baccharis halimifolia (Walton and Patrick 1973). These species are euryhaline and, except for P. communis, are tolerant of salinities up to and exceeding seawater concentrations.

Symptoms of salinity stress on species of marsh plants include the yellowing or blanching of leaf margins. Toxic concentrations cause twisting and finally necrosis (i.e., death of living tissue). Toxicity symptoms generally first appear on the older leaves and progress to the younger foliage (Haller et al. 1974).

The majority of saltmarsh flora show maximum seed germination under freshwater conditions. Germination time is often correlated to a period of minimum soil salinity. High salinity inhibits the germination process (Chapman 1966). Seeds and young seedlings are usually more sensitive to salt concentrations than are established plants (Woodhouse 1979).

Major saltmarsh species (i.e., Spartina alterniflora) show better growth under less saline conditions. The great majority produce the best growth under slightly brackish or freshwater conditions. High salinities, although not survival threatening, tend to cause a stunting of plant growth (Chapman 1960; Adams 1963; Gosselink 1970; Phleger 1971; Palmisano 1972; and Haller et al. 1974).

BENHTIC INVERTEBRATES

At least 180 species of benthic invertebrates inhabit Delaware Bay (Leathem et al. 1976). A total of 109 and 125 species were collected in baywide sampling in 1972 and 1973, respectively. The most widely distributed species were Tellina agilis, Heteromastus filiformis, Glycera dibranchiata, Nephtys picta, Mulina lateralis, Protohaustorius wigleyi, Gemma gemma, and Nucla proxima (Watling et al. 1976).

Similar to other estuaries throughout the world, Delaware Bay exhibits a greater diversity of benthic species as salinity increases (Carriker 1967). A marked decline in species occurs in the reach adjacent to Woodland Beach, Delaware. This is the area of transition between mesohaline and oligohaline waters (Watling et al. 1976).

A total of 57 benthic-invertebrate taxa were collected in the upper bay and lower river during 1974-1976 (a period of relatively high river flows). Scolecolepides viridis, Polydora sp., Paranais littoralis, Balanus improvisus, and Cynathura polita were dominant, comprising 78 to 80 percent of annual mean density of total benthic invertebrates. These taxa are physiologically tolerant of the wide range of salinity in this part of the estuary (Ichthyological Associates 1980).

A total of 70 benthic-invertebrate taxa were collected in the Delaware River between Beverly and Burlington, New Jersey, during 1970-1973. Limmondrilus spp., Procladius culiciforms, Corbicula manilensis, and Peloscolex ferox dominated the catch (Crumb 1977). These species do not appear in catches taken in the lower river and bay (Ichthyological Associates 1980, Watling et al. 1976) because of their intolerance to salinity.

The following is a summarized account of the effect of salinity on the most commercially important invertebrates in the Delaware estuary.

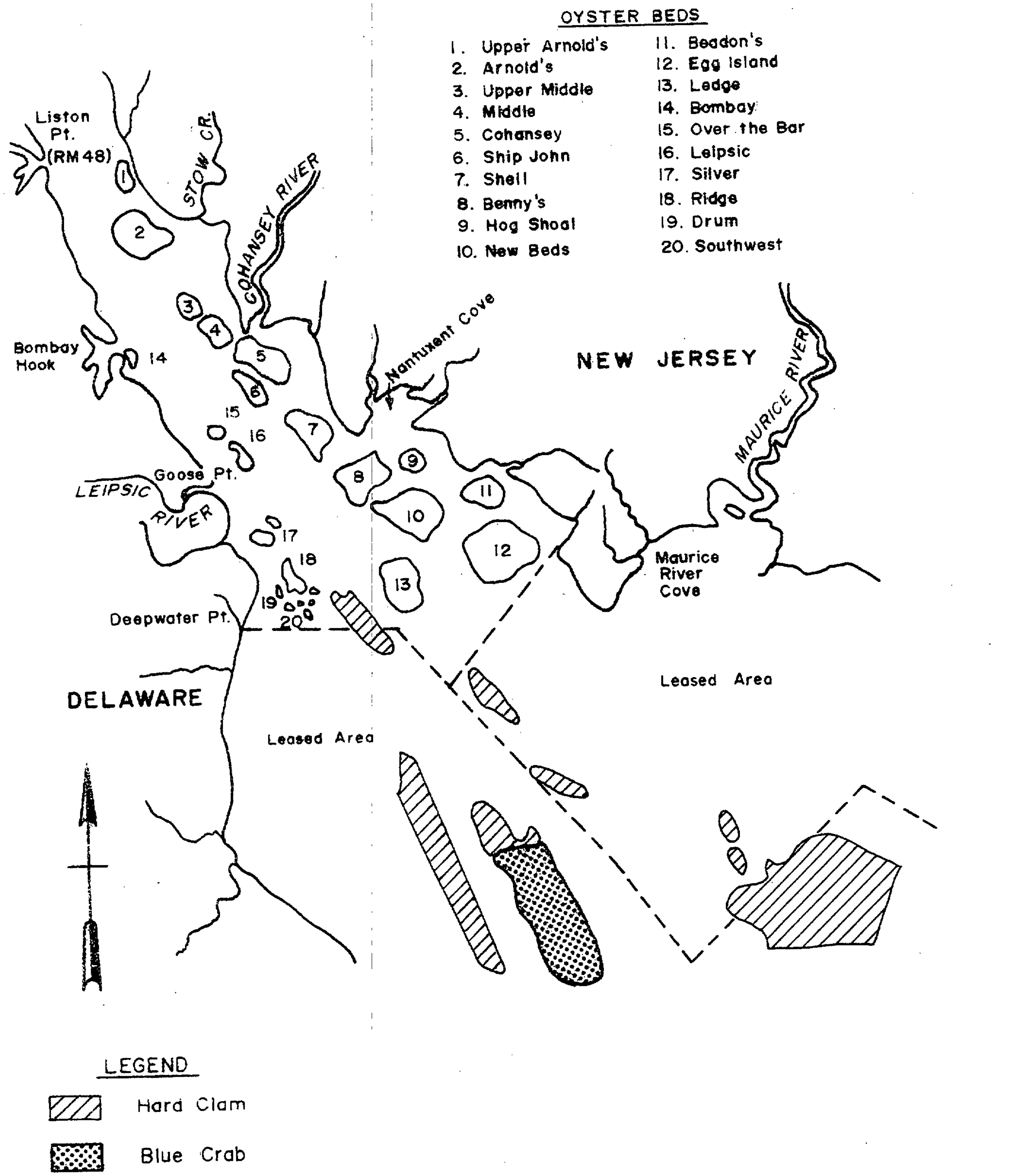
- Crassostrea virginica - American oyster. The American oyster is an euryhaline species found in the region extending from the Gulf of Saint

Lawrence to the Gulf of Mexico. The species is also located in the West Indies. In the Delaware Bay, natural seed oyster beds extend from the vicinity of Egg Island Point (RM 22) to Liston Point (RM 48). Leased beds occur south of Egg Island Point to the mouth of Delaware Bay. Refer to Figure 3-2.

The American oyster in the Delaware Bay is an essential resource for the watermen of New Jersey and Delaware. Oyster harvests and productivity have varied considerably since the late 1800's. Oyster harvests were highest from the 1800's to about the mid 1930's and were the lowest from the late 1950's to the late 1960's. The decline was due to a combination of factors including over-harvesting, disease, predation, fouling organisms, and water quality (U.S. Fish and Wildlife Service 1979(b)). Some population recovery and stabilzation have occurred since the late 1960's.

Oyster spawning begins in the Delaware Bay after water temparature exceeds about 25^{o}C, generally during June and July. Within one or two days, microscopic larvae develop with a pair of transparent shells joined along a straight hinge line. Between these shells is an extended swimming organ, the velum, composed of a tuft of whip-like cilia, which enable larvae to move vertically within the water mass.

For two weeks oyster larvae are transported back and forth by tidal currents, gradually being carried seaward by the near surface non-tidal drift. During their second week, oyster larvae generally remain on or close to the estuary bottom where they are influenced by the upstream movement of flood tide. Nelson (1921) postulated that the larvae in the Delaware Bay were more active during increasing salinity periods; therefore, they would



DELAWARE ESTUARY
SALINITY INTRUSION STUDY
OYSTER, CLAM, AND CRAB BEDS
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
DECEMBER 1982

FIGURE 3-2

tend to rise actively during flood currents and be carried passively up the estuary. Haskin (1964) indicated that salinity variations can be playing a dominant role in larval activity in nature even in the absence of halocline or saltwedge. Later Hidu and Haskin (1978) further investigated oyster larvae swim speeds in relation to differing salinities and suggested a toxic component to the salinity response. As they approach setting size, larvae work back upstream towards the beds from which they originally came using the differential vertical movement in the tidal cycle.

Oyster larvae, which generally set the first few weeks of July, require a clear hard substrate for attachment. The successful set of oyster spat is dependent on a number of factors: the availability of cultch material to set upon, the amount of fouling organisms on the cultch, and the success of the spawn earlier in the month. The shells of living oysters are frequently covered (fouled) with encrusting Bryozoa. Experiments demonstrate that Membranipora, an encrusting bryozoa, and other fouling organisms cause oyster settlement differences that are related to salinity gradients (Haskin and Tweed 1976). Those shells in higher salinity areas have more dense and diverse fouling communities and the setting surface for oyster spat is reduced accordingly.

Ready-to-set oyster larvae (which are of a size barely visible to the unaided eye), have developed an active foot with which they seek a clear area on any solid object. Finding this, the shell is cemented fast and within six hours the foot, velum, and eyespots are absorbed (Nelson 1960). Within a week after setting, spat suffer a mortality of about 40% due largely to mud-crab predation. After the first week, mortality rates decline in the more saline seed beds due to alternate food sources for the crabs and greater growth of the oyster's protective shell. Mortality rates in the less saline beds further up the estuary remains high.

The oyster drill *Urosalpinx cinerea* is an important oyster predator on the Atlantic Coast. In some years, oyster drills, account for up to 33% of the summer oyster mortalities in Delaware Bay. A single drill, depending on its size, can kill anywhere from 30-200 oysters per season. Early studies conducted by the Oyster Research Laboratory in New Jersey indicated that the drill is limited to its invasion of upper Delaware Bay by salinities at the time of its reproduction in late spring and early summer. Egg laying by drills begin at water temperatures of 15°C (about May 1), reaches its peak at 20°C (about June 1), and gradually declines into the summer and fall. Short exposure to salinities below 15 ppt will control predation at these times, and, thus prevent successful oyster drill reproduction. Lowered salinities during periods of high summertime water temperatures can also kill adult drills (Haskin and Tweed 1976).

Another cause of significant oyster mortality was discovered in the spring of 1958 and given the name *Minchinia nelsoni*, and is commonly known as "MSX" (multinucleate - sphere X) (Haskin, Stauber, and Mackin 1966). The micro-organism, a protozoan, invades oysters through the epthelial tissues of gill, palp, water tubes, and occasionally the digestive tract.

The activity of MSX has fluctuated, with the highest oyster mortalities experienced in the late 1950's, 1964-1967, and again in 1972. Historical data of Delaware oyster beds show that MSX has been consistently highest in the lower bay and lowest in the beds in lower salinity areas. (Miller 1980). Laboratory experiments have shown that there is considerable remission when transferred to low-salinity areas. Salinity has not explained all the increased MSX disease activity since first recorded in the Delaware Bay in 1957; normal levels of salinity have also, at times, coincided with the outbreak of disease.

• Callinectes sapidus - Blue crab. A second major commercially developed shellfish is the blue crab (Callinectes sapidus). Commercial crabbing began in the 1870's and records have been maintained by individual States since 1880. Since 1929, the catch for the East Coast of the U.S. has steadily increased, reaching an annual average of 119 million pounds (8.5 million dollars value) during 1969-1970. Most of the crabs came from Chesapeake Bay (Van Engle et al. 1973). During the period 1971-1977, the average annual catch in the Delaware Bay was 4.0 million pounds with an average annual value of 1.0 million dollars (U.S. Fish and Wildlife Service 1980 (a)).

Blue crabs are caught throughout the year by use of many techniques. However, commercial crabbers concentrate primarily on two types in Delaware Bay; baited pots and winter dredging. Baited pots are used from May to December and constitute the most important harvesting method in Delaware. During the winter, fisherman harvest most crabs with a basket-like dredging device that is towed on the bottom of the lower bay.

The blue crab has recreational as well as commercial value. Sport fishermen gather crabs with handlines, dipnets, trotlines, or pots (Van Engle et al. 1973).

Although the life cycle of the blue crab has been studied in greatest detail in Chesapeake Bay, it is believed to have a similar cycle in the Delaware Bay (Epifanio and Garvine 1979). Mating occurs from March to October in the upper parts of the bay. Shortly afterward, females move to higher salinity waters in the lower bay, some migrating into the ocean. Egg laying may occur in August, but is most often delayed until the following May or June (Van Engle 1958).

A spawning female may produce from 700,000 to over 2 million eggs, which are attached to form a sponge or eggmass underneath her abdominal flap. It has been estimated that for every million eggs spawned, one adult is eventually produced (Van Engle 1958). The eggs develop and hatch in about two weeks. The larval (zoeal) stage develops through seven molts, which take from 31 to 49 days, and takes place more abundantly in higher salinity water, concentrated near the surface. After the seventh zoeal molt, free swimming megalops develop. After six to nine days, swimming ceases and the animals settle to the bottom fully capable of walking (Daiber _et al_. 1976; Tyrawski 1979). The last molt of megalops transforms the larvae into a small adult-like crab, slightly more than one inch in length.

Juveniles generally remain with the adult males in lower salinity areas during the summer but migrate down bay to higher salinity water during the fall and winter (Miller _et al_. 1975). Juveniles mature in approximately 12-14 months (Daiber _et al_. 1976) and live an average of three years. Optimum salinity for hatching of eggs is 23 to 30 ppt. Salinities below 9 ppt and above 33 ppt prevent hatching. Optimum salinity for early zoeal development is 21 to 28 ppt. Salinities below 18 ppt or above 29 ppt. decrease larval activity (Sandoz and Roger 1944). Late stage larvae die if exposed to 32 ppt (Costlow and Bookhout 1959). Megalops tolerate salinities of 10 to 40 ppt, but are intolerant of 5 ppt. Duration of the megalops life stage increases in the salinity range from 20 to 40 ppt (Costlow 1967).

Juvenile crabs die if exposed to very low salinities (1 ppt). The mortality at this salinity level has a high correlation with the molting phase control the osmotic process upon which molting depends (Holland _et al_. 1971). This control is lacking in the larvae and is reported to be differently developed in adult males and females; males are more efficient osmoregulators than females (Tan and Van Engle 1966).

FISHES

The Delaware estuary is inhabited by at least 228 species of resident and migratory fishes (Table 3-1). It is primarily important as a spawning, nursery ground, and summer and winter feeding ground. Early life stages of 112 species have been detected in tidal waters and non-tidal waters near the tidal limit in the State of Delaware (Wang and Kernehan 1979). Eggs and/or larvae of 44 taxa were collected near Artificial Island (Ichthyological Associates 1980).

At least 30 species of fish are commercially taken in the estuary. During the period 1960-1975, 58 million pounds of fish valued then at 3.2 million dollars were harvested. The most commercially valuable species during that period were *Brevoortia tyrannus*, *Morone saxatilis*, *Cynoscion regalis*, *Anguilla rostrata*, *Alosa sapidissima*, and *Morone americana*.

Recreational fishing is an important industry in the bay. Martin (1973) reported that 330,935 man-days of recreational fishing activity took place on boats on the Delaware side in 1973. Smith (1975) estimated that sportfishing contributes 4.5 million dollars to the west bay economy. Miller (1977) estimated 225,129 man-days of shore fishing from the Delaware side in 1976. An estimated 300,000 to 650,000 man-days of sportfishing effort have been expended annually on the New Jersey side (U.S. Fish and Wildlife Service 1975). Weakfish, summer flounder, black sea bass, black drum, and bluefish are the most sought after species (Martin 1973).

The following is a summarized account of the effect of salinity on the most important commercial and recreational fishes and four important forage fishes in the Delaware estuary.

Table 3-1 List of fishes collected from the Delaware Estuary: Trenton to the Sea. Type of species: m = marine; b = brackish (Salinity 1-10 ppt); f = fresh. Primary activity: m = migrant; sp = spawning; sf = summer feeding; wf = winter feeding; n = nursery; r = resident; st = stray (Thomas 1971; Maurer and Wang 1973; Miller et al. 1975; Wang and Kernehan 1980).

Species	Type of Species	Primary Activity
Petromyzon marinus	m, b, f	m
Carcharias taurus	m, b	sf
Alopias vulpinus	m	sf
Odontaspis taurus	m	m
Carcharhinus milberti	m	sf
C. obscurus	m	st
Mustelus canis	m	sf
Prionace glauca	m	sf
Scoliodon terra and nova	m	st
Sphyrna tiburo	m	sf
S. zygaena	m	
Torpedo nobiliana	m	st
Scyliorhhinus retifer	m	m
Squalus acanthias	m	wf
Squatina dumerili	m	sf
Raja eglanteria	m	n, sf
R. erinacea	m	wf
R. garmani	m	st
R. laevis	m	
R. ocellata	m	wf
R. radiata	m	
Dasyatis centroura	m	sf
D. sabina	m	
D. sayi	m	n, sf
Gymnura altavela	m	
G. micrura	m	
Urolophus jamaicensis	m	st
Myliobatis freminvillei	m	sf
Rhinoptera bonasus	m	st
Hydrolagus colliei	m	st
Acipenser oxyrhyncus	m, b, f	n
A. brevirostrum	m, b, f	m
Megalops atlantica	m	st
Anguilla rostrata	m, b, f	m, sf, n, r
Conger oceanicus	m	n
Alosa aestivalis	m, b, f	sp, n
A. mediocris	m, b, f	sp, n, sf
A. pseudoharengus	m, b, f	sp, n
A. sapidissima	m, b, f	sp, n, sf
Brevoortia tyrannus	m, b, f	sp, n, sf
Clupea harengus	m, b	sp, n
Dorosoma cepedianum	f, b	r, sp

Table 3-1(continued).

Species	Type of Species	Primary Activity
Etrumeus teres	m, b?	
Opisthonema oglinum	m	
Anchoa hepsetus	m, b	sp, n
A. mitchilli	m, b, f	sp, n, sf
Engraulis eurystole	m, b	
Umbra pygmaea	f	st
Esox americanus	f, b	r, sp
E. niger	f, b	r, sp
Synodus foetens	m	
Carassius auratus	f, b	r, sp, n
Cyprinus carpio	f, b	r, sp, n
Exoglossum maxillingua	f, b	r, sp
Hybognathus nuchalis	f, b	r, sp, n
Notemigonus crysoleucas	f, b	r, sp, n
Notropis analostanus	f	r, sp
N. cornutus	f	r, sp
N. bifrenatus	m, b	n, wf
N. hudsonius	f, b	r, sp
N. prounce	f	r, sp
Rhinichthys atratulus	f,	r, sp
R. cataracte	f	r, sp
Semotilus corporalis	f	r, sp
Carpoides cyprinus	f	r, sp
Catostomus commersoni	f	r, sp
Erimyzon oblongus	f	r, sp
Hypentelium nigricans	f	r, sp
Ictalurus catus	f, b	r, sp, n
I. natalis	f	r, sp
I. nebulosus	f, b	r, sp, n
I. punctatus	f, b	r, sp
Noturus gyrinus	f	r, sp
N. flavus	f	r, sp
N. insignis	f	r, sp
Opsanus tau	m, b	sp, n
Lophius americanus	m, b?	st
Enchelyopus cimbrius	m	n, sp
Gadus morhua	m	n, sp, wf
Melanogrammus aeglefinus	m	n, sp, wf
Merluccius bilinearis	m, b	n, sp
Pollachius virens	m	n, sp
Urophyscis chuss	m, b	n, sp
U. regius	m, b	n, sf
U. tenus	m, b	
Cypselurus heterurus	m	
Hyporhamphus unifasciatus	m, b	n
Ablennes hians	m	n, sp
Hemiramphidae		
Strongylura marina	m, b, f	n, sf
S. raphidoma	m	
Cyprinodon variegatus	m, b, f	r, sp, n

Table 3-1 (continued).

Species	Type of Species	Primary Activity
Fundulus diaphanus	f, b, m	r, sp
F. heteroclitus	b, f, m	r, sp
F. luciae		r, sp, n
F. majalis	m, b	r, sp, n
Lucania parva	m, b	r, sp, n
Gambusia affinis	m, b, f	r, sp
Rissola marginata	m, b	n
Membras martinica	m, b, f	sp, n, sf
Menidia beryllina	b, f, m	r, sp, n
M. menidia	m, b, f	r, sp, n
Polymixis lowei	m	st
Apeltes quadracus	m, b, f	n, wf
Gasterosteus aculeatus	m, b, f	n, wf
Hippocampus erectus	m, b	n
H. hudsonius	m, b	
H. obtusus	m	st
Syngnathus fuscus	m, b, f	sp, n, sf
S. pelagicus	m	
Centropomus undecimalis	m	
Fistularia tabacaria	m, b?	sf
Macrorhamphosus scolapax	m	sf
Centropristes striatus	m, b?	n, sf
Epinephelus niveatus	m	st
Caranx crysos	m	n
C. hippos	m, b, f	n, sf
Decapterus macarellus	m	st
C. punctatus	m	st
Selar crumenopthalmus	m	
Selene vomer	m, b	n
Seriola dumerili	m	st
S. zonata	m	n
Trachinotus carolinus	m	n, sf
T. falcatus	m	n
Trachurus lathami	m	
Vomer setapinnis	m	
Coryphaena hippurus	m	
Orthopristis chrysoptera	m	sp, n
Lagodon rhomboides	m, b	n
Stenotomus chrysops	m, b?	sp, n
Chaetodipterus faber	m	st
Lutjanus griseus	m, b, f	n
Rhomboplites aurorubens	m, b, f	st
Bairdiella chrysura	m, b, f	sp, n, sf
Cynoscion regalis	m, b, f	sp, n, sf
Leiostomus xanthurus	m, b, f	n, sf
Menticirrhus saxatilis	m, b	sp, n
Micropogon undulatus	m, b, f	sp, n, wf
Pogonias cromis	m, b, f	sp, n, sf
Sciaenops ocellata	m, b, f	n

Table 3-1 (continued).

Species	Type of Species	Primary Activity
Palinurichthys perciformis	m	
Peprilus alepidotus	m	
Poronatus triacanthus	m, b	sf
Psenes maculatus	m	
Mugil cephalus	m, b, f	sp, n, sf
M. curema	m, b, f	sp, n
Pholis gunnellus	m	
Sphyraena borealis	m	n
Ulvoria subbifurcata	m	
Astros y - graecum		
A. guttatus	m, b	n
Chasmodes bosquianus	m	n
Anarhichus lupus	m	st
Macrozoarces americanus	m	
Gobionellus boleosoma	m	sp, n
G. oceanicus	m	
G. bosci	m, b, f	sp, n, sf
G. ginsburgi	m, b?	sp, n
Microgobius thalassinus		
Peristedion miniatum	m	sf
Prionotus carolinus	m	sp, n
P. evolans	m, b	sp, n, sf
Hemitripterus americanus	m	
Myoxocephalus aenaeus		
M. octodecem spinosus	m	
Liparis liparis	m	st
Dactylop teridae	m	
Dactylopterus volitans	m	st
Citharichthys spilopterus	m	
Paralichthys oblongus	m, b	
Ammodytes americanus	m, b?	sp, n
Symphurus plagiusa		
Echeneis naucrates	m	st
Remora osteochir	m	st
R. remora	m	st
Citharichthys spilopterus	m	
Etropus grossotus		
E. microstomus	m, b	n, sf
Paralichthys dentatus	m, b	sp, n, sf
P. oblongus	m, b	sp, n
Scophthalmus aquosus	m, b	sp, n, sf
Glyptocephalus cynoglossus	m	
Limanda ferruginea	m, b	sp, n
Pseudopleuronectes americanus	m, b, f	sp, n, sf
Trinectes maculatus	m, b, f	sp, n, sf
Chaetodon ocellatus	m	n
Holacanthus bermudensis	m	
H. ciliaris	m	
Tautoga onitis	m	sp, n
T. adsperus	m	sp, n

Table3-1(continued).

Species	Type of Species	Primary Activity
Scarus guacamaia	m	
Trichiurus lepturus	m	
Acanthocybium solanderi	m	
Scomber japonicus	m	
Scomberomorus cavalla	m	
Thunnus alalunga	m	
T. thynnus	m	
Authynnus alletteratus		
Sarda sarda	m	
Scomber scombrus	m, b	
Makaira albida	m	st
M. nigricans	m	st
Xiphias gladius	m	st
Aluterus schoepfi	m, b?	st
Balistes capriscus	m	
Monacanthus hispidus	m	
Lagocephalus laevitagus	m	
Sphaeroides maculatus	m, b	st
Morone americana	b, f, m	n, sp
M. saxatilis	b, f, m	n, sp
Pristigenys alta	m, b	n
Enneacanthus chaetodon	f	st
Lepomis auritus	f	r, sp
L. gibbosus	f, b	r, sp
L. macrochirus	f, b	r, sp, n
Micropterus salmoides	f, b	r, sp, n
Pomoxis annularis	f, b	r, sp, n
P. nigromaculatus	f, b	r, sp
Etheostoma fusiforme	f, b	
E. olmstedi	f, b	
Perca flavescens	f, b	r, sp, n
Percina peltata	f	r, sp
Stizostedion vitreum	f	r
Pomatomus saltatrix	m, b, f	n, sf
Chilomycterus schoepfi	m	
Ostracion diaphanum	m, b	
Mola	m	sp

• Brevoortia tyrannus - Atlantic menhaden. The Atlantic menhaden has been commercially important since colonial times. In fact, during much of this century it supported the largest commercial fishery, tonnage-wise, along the Atlantic Coast. Since the mid-1960's, though, it has been of relatively little economic value to the Delaware Bay fishing industry. Ecologically, it remains an important link in the food chain as a plankton feeder and a prey species for many commercially and recreationally important fishes such as bluefish, weakfish, and striped bass.

The Atlantic menhaden spawns in waters off the Atlantic Coast. Hatching occurs at sea and in areas close to shore from late spring through early winter (Durand and Nadeau 1972). After hatching, larvae migrate or are transported into estuaries to oligohaline and freshwater nursery grounds. The Delaware River from Wilmington to Artificial Island and the Chesapeake and Delaware Canal are important nursery grounds (Wang and Kernehan 1979). Tidal creeks of the lower Delaware River are also important (Smith 1971). Young fish emigrate to higher salinity and deeper waters as water temperatures decline in fall; most migrate south and spend winters in offshore waters (Wang and Kernehan 1979).

Lewis (1966) studied menhaden larvae at different salinities in a laboratory setting and found that one-third of those held between 15 ppt-40 ppt developed spinal abnormalities. He suggested that larvae have a better chance to survive in the estuary if temperatures remain above 4°C and salinity ranges from 10-20 ppt. Lewis also suggested that salinity and food supply affected upstream distribution of the larvae more than temperature. Lewis and Hettler (1968) found that temperature, not salinity, had the greatest effect on survival of young menhaden.

• Morone saxatilis - Striped bass. The striped bass is an anadromous species; it spawns in the lower reaches of large rivers. Its most important spawning grounds are the Roanoke River, certain tributaries of Chesapeake Bay, the Chesapeake and Delaware Canal, and the Delaware and Hudson estuaries. Stocks have been reduced in the Delaware estuary since 1940 (Tyrawski 1979) for reasons probably related to lack of suitable spawning habitat (Ichthyological Associates 1980).

Along the mid and north Atlantic Coast it is an important (greater than $20 million annually) sport and commercial species (Dovel 1977). The estimated commercial gill net landing in 1980 for the State of Delaware ranked striped bass fifth in pounds landed and third in doller value (Seagraves 1981). The Delaware sport catch is of minor importance, comprising less than two percent of the State's total landings.

Adults spend most of the year in the lower bay or offshore, entering the upper bay and lower river for spawning in April and May. Some eggs have been taken near Artificial Island, the product of local spawning and/or transport from the Chesapeake and Delaware Canal, or both. The young utilize this area as a nursery ground during summer and fall (Ichthyological Associates 1980), eventually moving to the lower bay in winter.

Albrecht (1964) demonstrated that low salinities (0.9 ppt) enhance egg survival, salinities around 4.6-4.7 ppt are not detrimental, and higher salinties decrease egg survival. Tagatz (1961) showed that adult and juveniles are able to tolerate abrupt changes between salt water (34 ppt) and freshwater at most temperatures.

Turner and Chadwick (1972) found highly significant correlations between striped bass abundance, salinity, and water diverted from the Sacramento-San Joaquin delta area, the first two of which were related to the amount of river flow. Annual striped bass distribution was also related to river flow and salinity, with bass being found further upstream in years of low runoff and high salinity.

Time of spawning and distribution of young bass are also function of flow, with spawning taking place later and the young being found further downstream during high flows. Water temperature appears to be the critical factor for egg survival (Bason 1971).

Chittenden (1971) concluded that gross pollution of the tidal freshwater area of the Delaware River has destroyed its potential as a spawning and nursey area. This damage may not be permanent, as efforts are underway to clean up the river (U.S. Environmental Protection Agency 1979; 1980).

- Cynoscian regalis - Weakfish. The weakfish (locally called seatrout) is the most economically important finfish in the Delaware Bay in recent years, during 1930-1949 it was the second most abundant food fish in commercial landings from New York to Virginia (Perlmutter 1959). In 1955 it ranked first in commercial food fish landings in the State of Delaware and second in sport catch within the Bay (Daiber 1957). Since 1969 the weakfish has been the most important species in the annual multi-million dollar Delaware estuary marine sport fishery. A recent increase in abundance and specimen size is probably the major reason for the reported tripling in sport fishing effort in the Delaware Bay during the 1970's (Lesser and Ritchie 1979).

Adults spawn in the lower bay from about May through September (Smith 1971). Eggs have been collected as far up-bay as Mad Horse Creek (RM 45) (Wang and Kernehan 1979). After hatching the larvae sink to the bottom of the water column to be carried upstream by subsurface flow (Thomas 1971). Free swimming larvae and young move up the estuary as far as Wilmington, Delaware, with low dissolved oxygen concentrations in the area perhaps serving as a limiting factor (Wang and Kernehan 1979). Young weakfish also utilize the tidal creeks of the upper part of the estuary as nursery grounds (Smith 1971; Thomas 1971), moving to the lower estuary in the fall and eventually wintering in nearshore areas along the coast (Ichthyological Associates 1980).

Optimum hatching of eggs occurs between salinties of 12-32.5 ppt (Maurer and Wang 1973). Sudden changes in salinity of 5-6 ppt increase mortality of eggs. Normal movement of eggs by tidal currents from one salinity zone to another may cause egg mortality. Also, freshwater inflow from tributaries during periods of heavy watershed runoff may sufficiently lower salinities to cause egg mortality (Harmic 1958).

- Anguilia rostrata - American eel. The American eel is a catadromous species; it lives in freshwater systems, but spawns at sea. Young, transparent "glass eels" are carried by ocean currents and eventually swim to the mouths of coastal estuaries where they develop further into elvers and eventually adults. Each year glass eels first appear in the Delaware estuary during December and continue to enter the estuary throughout the month of May. Most young move up the estuary to low salinity and freshwater areas, especially tidal tributaries (Wang and Kernehan 1979).

Smith (1971) collected eels in four low salinity (1-10.5 ppt) tidal tributaries of the Delaware Bay. DeSylva et al. (1962) collected eels in many different areas of the bay. Jeffries (1960) suggested that low salinity values or temperature gradients attract young eels from the sea into estuaries.

• Alosa sapidissima - American shad. The Delaware was once considered the best shad-producing river along the Atlantic Coast. The catch peaked in 1896 when 19,203,000 pounds were taken by shore-seines and drift nets. From the beginning of the 20th Century, the catch of shad declined drastically to the point where it was of only minor economic importance. In recent years, however, the shad fishery has begun to recover due to increased efforts toward improved water quality conditions. The American shad in 1980 ranked third in pounds landed and second in value of the in-shore gill net fishery in the State of Delaware (Seagraves 1981). It is an anadromous species, spawning upstream in the non-tidal portion of the Delaware River. Spawning adults normally pass through the estuary in early spring before the dissolved oxygen "barrier" establishes itself in the Philadelphia area. The seaward migration of the juveniles usually begins in September and peaks in October (Tyrawski 1979). Most adults die after spawning but some survive and return to the sea (Gunter et al. 1974).

Chittenden (1973) found no mortality in young shad subjected to salinity increases, including abrupt changes from 5 ppt to 30 ppt. Complete mortality occurred with abrupt salinity decreases from 30 ppt to 0 ppt, but no mortality was noticed with only gradual decreases in salinity.

- Morone americana - White perch. The semi-anadromous white perch migrates from mesohaline waters (5-18 ppt) of the Delaware Bay in spring, moving upriver to spawn in low salinity or freshwater. Spawning is most common above Newbold Island, but also occurs from Lambertville to Artificial Island. After spawning, adults begin to move in prolonged stages back down river. They prefer low salinity or freshwater in the Delaware River and tributaries. Adults and young continue to move downriver in late summer and fall, ultimately wintering in the deep, warm waters of Delaware Bay (Ichthyological Associates 1980).

Eggs were collected in the Artificial Island area at salinities ranging from 0.0-0.5 ppt. Larvae were taken at 0.0-0.6 ppt (Ichthyological Associates 1980). Mansueti (1964) found that larvae will survive salinities up to 8 ppt. The species has been caught at salinities up to 30 ppt. (DeSylva et al. 1962).

Adults and young are abundant south of Artificial Island when heavy runoff causes salinity in the river to be low (less than 5 ppt). As salt water intrudes upstream, they move upriver and into local creeks (Ichthyological Associates 1980).

The effect of salinity on four important forage fishes is summarized as follows:

- Menidia menidia - Atlantic silverside. The Atlantic silverside is a euryhaline species that inhabits shallow marine, estuarine, and tidal freshwaters of the Atlantic Coast. Although, it has been collected over a wide range of salinities in the Delaware estuary, it is most adundant at salinities greater than 15 ppt (Ichthyological Associates 1980). DeSylva et al. (1962) described the Atlantic silverside as the most widespread and with the exception of the bay anchovy, the most abundant fish in the mesohaline (5-30 ppt) portions of the bay. The species is a major source of forage food for commercially important piscivorous fish (Ichthyological Associates 1980).

Silverside eggs are usually found in salinities above 10 ppt (Daiber *et al*. 1976) from April through August. Optimum salinity is reported to be 30 ppt (Middaugh and Lempesis 1976). However, eggs have been spawned in salinities as low as 2 ppt (Wang and Kerhehan 1979). Reduced salinity (10 ppt) delays and lowers hatching success, with larvae survival better at 30 ppt than at 20 ppt (Middaugh and Lempesis 1976). Adults have been collected in salinities ranging from 2 to 35 ppt (DeSylva *et al* 1962).

- *Anchoa mitchilli* - *Bay anchovy*. The bay anchovy is an euryhaline species that is abundant and ubiquitous in the Delaware estuary. Spawning occurs in the mid to lower portions of the estuary at salinities of 5.0 ppt and greater. Larvae are transported into low salinity nursery grounds (3-7 ppt), mature, and remain there until declining water temperature initiates a downstream movement to deepwater areas in the lower bay (Ichthyological Associates 1980). The bay anchovy is considered a very important forage fish within Delaware Bay because most of the larger predatory fish are known to feed heavily upon it (DeSylva *et al*. 1962). Wang and Kernehan (1979) report that peak spawning activity likely occurs at 10-20 ppt and that little successful spawning occurs at salinities less than 5 ppt. Normally, low numbers of eggs are taken in the Artificial Island area where salinities are generally less than 10 ppt. However, during 1974, when salinity often exceeded 10 ppt, large numbers of eggs were taken, suggesting that an upward shift in the estuary had occurred (Kernehan *et al*. 1975). Larvae and young do occur over a much more extensive range of salinity (0.0-31.0 ppt.) than eggs although they are much more abundant at lower salinities (0-5 ppt) (Wang and Kernehan 1979). Adults occur in salinities of 0-31 ppt (DeSylava _et al_. 1962).

- _Fundulus heteroclitus_ - _Mummichog_. The mummichog is a resident euryhaline species that is common in shallow inshore waters, tidal creeks and marshes in the Delaware estuary. It occurs in salinities ranging from freshwater to sea water, but is most abundant in mesohaline waters (5.0-20.0 ppt). Spawning occurs primarily in mesohaline water during April through August with peaks in activity coinciding with lunar spring tides. Larvae and young prefer shallow waters for nursery grounds (Wang and Kernehan 1979). The mummichog is an important food item for game fish and blue crab (Ichthyological Associates 1980).

Eggs are extremely tolerant to a wide variation in salinity. Both extremes, freshwater and salinities far in excess of salt water, do not affect survival (Yamamoto 1941). Joseph and Saksena (1966) found that larvae also have an extremely wide salinity tolerance (0.39-100 ppt). DeSylva (1962) collected adults in the Delaware estuary at salinities from 0 to 35 ppt.

- _Leiostomus xanthurus_ - _Spot_. The spot is a small sciaenid (drum family) fish common in inshore and estuarine waters of the Atlantic and Gulf Coasts. It is one of the most abundant species in the Delaware estuary. Older young adults prefer higher salinity waters but small young prefer low salinity water as nursery grounds (Wang and Kernehan 1979). Spot spawn off the coast in winter and early spring (Dawson 1958). Larvae and the young migrate inshore to estuarine nursery areas followed by the adults. Young spot reach the Delaware estuary during April (Wang and Kernehan 1979) and move upstream as far as Wilmington (Preddice 1974). Tidal creeks are also used as nursery areas (Smith 1971). Spot move out of the estuary in the fall (Wang and Kernehan 1979). Large predatory fish such as striped bass feed on spot (McClane and deSylva 1972).

Since spot spawn in marine waters, eggs are salt tolerant. Wang and Kernehan (1979) report that young spot are inhabitants of both deeper channel waters and inshore waters of the lower Delaware River, which could indicate that they utilize both deep and shallow waters to reach low salinity nursery grounds. It is probable that only those young of the year that have developed locomotion capabilities utilize the shallows during their migration. Juveniles have been taken in salinities ranging from freshwater (0 ppt) (Nelson 1967) to full-strength sea water (34.2 ppt) (Springer and Woodburn 1960). Adults have been captured in salinities of 0-60 ppt (Dawson 1958).

WILDLIFE

The Delaware estuary is inhabited by many different species of birds, mammals, amphibians, and reptiles. An estimated 300,000 ducks and geese, comprising 30 species, winter in the estuary, mostly in tidal wetlands, providing an estimated 320,000 man-days of hunting annually. The estuary also supports a valuable fur industry, with muskrat and racoon being the most important species. An estimated 118,000 man-days of trapping occur annually, (U.S. Fish and Wildlife Service, 1979(a)).

Salinity influences wildlife composition in the estuary. Distinctive plant-animal relationships exist in the tidal marshes. The absence of certain plants due to an inability to tolerate the salinity regime may result in the absence of certain wildlife species or a reduction in population levels of those species (Daiber 1977).

Muskrats inhabit all wetland types within the estuary, including saltwater, brackish, and freshwater marshes. Population densities vary greatly, depending on such habitat factors as diversity and abundance of food plants, availability of animal foods throughout the winter, maintenance of optimum water depth, and availability of denning sites if suitable vegetation is lacking for construction of muskrat houses.

Muskrats can survive in salinities upward of 30 ppt. However, muskrat food and populations decrease as salinity increases (Harris 1937; Dozier 1947 et al. 1948; Daiber 1977). Muskrats prefer the less saline types of vegetation such as Scirpus olneyi, S. robustus, S. americanus, and Typha spp. Less favored foods are Spartina alterniflora, S. patens, Distichlis spicata, and Juncus romerianus (Daiber 1977). Dozier (1947) reported slight differences in the weights of muskrats based on salinity difference in habitat. Heavier specimens were associated with lower salinities. He also indicated that muskrats tend to be more abundant where tidal influence is reduced.

Waterfowl use the estuary as a staging ground during migration and also as a wintering area. Most use is concentrated in and around the bay and lower river where much of the tidal marsh is located. Freshwater and brackish plant foods are favored, although certain waterfowl do consume saltmarsh plants or animal foods associated with salt marshes.

Stewart (1962) considers "brackish estuarine bays" to be the most important habitat for waterfowl. "Fresh estuarine bays", "brackish estuarine marshes", and "estuarine river marshes" also attract large numbers of waterfowl.

"Salt estuarine bay marshes", characterized by high salinity and narrow tidal fluctuation, are used extensively by black ducks, but other species are scarce. Daiber (1977), commenting on Stewart's results, noted that a relationship exists between the horizontal distribution of salinity and vegetation types and food habits. He presumed that this is a reflection of increased diversity and availability associated with less saline areas.

The Delaware estuary is used by numerous species of herons, ibises, and egrets, all three commonly known as large wading birds. The birds range throughout the estuary in saltwater, brackish, and freshwater areas. Their food habits include a great variety of animal foods and only incidental use of plant materials. Fish, eels, frogs, toads, salamanders, lizards, snakes, crayfish, and many kinds of insects are eaten. Some of the large herons prey on mice, birds and young rats (Bent 1963). In general, large wading birds are mobile, opportunistic feeders, adept at capturing prey under diverse conditions.

Two important heron rookeries (or nesting sites) occur in the estuary. Both are located in the oligohaline zone. Data collected in 1977 show that Pea Patch Island provided nesting for nine species of wading birds, totaling over 6,000 pairs. The J. Gordon Armstrong site near Delware City, Delaware, supports over 100 pairs of great blue herons.

Salinity changes may effect the distribution of food such as crustaceans and fish for wading birds. However, it is unlikely that these changes would have a significant effect on wading bird populations. The birds are mobile enough to take advantage of feeding opportunities elsewhere. It appears that human interference or lack of nesting habitat may be factors limiting to wading birds, not the variety or lack of food, which occurs throughout the estuary in all salinities.

Small wading birds, also known as shorebirds, also are inhabitants throughout the estuary. They are most common along sandy beaches, mudflats and the shallows of ponds, streams, and tidal guts. Except for the spotted sandpiper, willet, black-necked stilt, killdeer, and possibly the piping plover, all the shorebirds breed north of the estuary, many on Canada's arctic tundra.

Shorebirds, in migration, frequent most of the habitat types found in the Delaware estuary, feeding on a variety of small marine and freshwater animals. Included in their diet are insects, worms, mollusks, crustaceans, fish, and small amounts of plant material. The most productive feeding areas are large tidal mudflats. Thus, shorebird concentrations are greatest in the lower estuary where large expanses of tidal mudflats are more common. Since shorebirds, like large wading birds, are mobile, opportunistic feeders, it is unlikely that shorebird populations would be significantly affected by salinity changes.

POTENTIAL EFFECTS OF ALTERING THE SALINITY REGIME ON THE DELAWARE ECOSYSTEM

In the following section qualitative "best estimates" of the ecological effects of salinity change to the lower river and Delaware Bay are presented to assist in decisions affecting the public resources of the Delaware estuary.

TIDAL MARSHES

Salinity changes during spring would probably not change the composition of the tidal marshes. Salinity during this time of year is normally depressed and even substantial increases in salinity would not approach levels experienced naturally during the low flow period in summer. Measures to reduce high summer salinity levels may slightly benefit brackish marshes, by preventing the expansion of salt marshes into new areas.

Although a compositional change in marsh flora is not anticipated as a result of increasing spring salinities, seed germination and plant growth may be inhibited, causing a lowering of primary productivity. The magnitude of the reduction would reflect the degree of salinity change. A significant inhibition would be detrimental throughout the estuarine system, since marshes are a major source of detrital nutrients, fundamental components of the estuarine food chain.

BENTHIC INVERTEBRATES

Above normal levels of spring salinity would permit down-bay benthic invertebrates to invade the lower river and upper bay area. The invasion of salt-tolerant benthic forms farther up the estuary than normally occurs during this time period would increase benthic diversity, while reducing the amount of habitat available to brackish and freshwater types. Reducing salinity in the summer and early fall would repel or restrict the advance of the salt-tolerant forms and benefit brackish and freshwater types.

Predacious oyster drills are among the marine species that would benefit from higher spring salinity levels. These organisms would invade formerly protected areas of the natural seed oyster beds, reducing seed stocks. Although the upper beds in New Jersey would not be exposed to the drills, these beds are less desirable as sources of seed because of reduced MSX resistance and increased hauling distance for replanting at the leased grounds. Drills are already a serious problem on the Delaware seed beds.

During a spring of naturally occurring low flow, further salinity increases would aggravate the drill problem and cause additional economic hardship on the oyster industry.

The degree of hardship depends on the amount of salinity increases on the seed bed areas primarily during the months of May and June. Short exposures to salinities less than 15 ppt would control the upstream advance of oyster drill reproduction. The adverse effect of increased spring salinities could be mitigated or eliminated by refraining from storing water in April and May (Delaware River Basin Commission 1981). Augmented flows during low flow conditions would tend to compensate for increasing depletive use and rising sea level, thereby maintaining a relatively "normal" position of the 15 ppt isohaline and would tend to reduce the drill population (Haskin and Tweed 1976).

During a spring of higher freshwater discharge, increasing salinity would benefit blue crabs (Pearson 1948). During spring periods of normal or lower discharge, there could be a shift up the estuary with increased salinities, while in summer, decreasing salinity would limit the shrinkage of nursery habitat for the blue crab by maintaining preferred salinities downstream of the severe water quality conditions near Philadelphia.

FINFISH

During the traditionally high flow months of April and May influencing salinity could also alter some factors that determine residual bottom currents which are believed to carry eggs and larvae into or up the bay and lower river. Disruption of this process could interfere with early development, adversely impacting many estuarine dependent species, including important commercial and recreational types. The degree of disruption would be dependent on the amount of spring flow reduction. During periods of high to normal spring flows the impact would be minimal. During periods of low spring flow any further reduction in freshwater flows would cause additional stress to an already stressed estuary. If reduction of spring flows were to be significant, a disruption of residual drift could be harmful to populations of Atlantic menhaden, weakfish, summer flounder, bay anchovy, and spot (U.S. Fish and Wildlife Service 1980 (b)). The degree of spring flow reduction that would be required to disrupt residual drift in the Delaware estuary is not known. Some spawning of these species continue during late spring and summer when flow regulation would be likely to increase flows and thereby aid in the drifting process.

Increased spring salinity could shift spawning and nursery areas up the estuary. The severity of impacts will depend on how far the salinity is brought upstream and for what duration. An upstream shift could relocate the main concentration of weakfish young closer to the intake of the Salem Nuclear Generating Station, possibly increasing entrainment and impingement losses. More eggs and larvae of striped bass would be brought closer to the Philadelphia pollution zone, possibly increasing mortality. Finfish nursery habitat could also be shifted up the estuary, closer to the Philadelphia pollution zone, thereby reducing this important habitat type.

Reduced salinity in summer would limit the upstream shift of some fishes that occurs with declining river flow. By maintaining the important nursery habitat as far downstream from the Philadelphia-Camden pollution zone as possible, populations of weakfish, striped bass, and other low salinity dependent fishes would benefit.

WILDLIFE

Increasing salinity in spring is not expected to change composition of waterfowl food plants. However, lowered plant productivity as a result of increased salinity may force waterfowl to forage over larger areas to obtain needed food supplies. Reduced salinity in summer would prevent encroachment of saltwater marsh plants into brackish plant communities. This would benefit most waterfowl species since brackish marshes harbor a more diverse food supply.

Neither would increased spring salinity affect the distribution of muskrat food plants. Again, however, lowered plant productivity may affect the amount of food available. Reduced summer salinity would prevent brackish marsh from converting to saltmarsh, benefiting muskrats.

Due to their inability to take advantage of food opportunities presented along the entire salinity gradient, large wading birds and shorebirds are not likely to be affected by increases in salinity at any particular location.

RESIDUAL CURRENTS

A considerable amount of concern has been recently expressed over potential disruption of the upstream transport mechanisms utilized by eggs and larvae of many aquatic estuarine organisms. Residual upstream bottom currents result from several physical forces; those that are known include wind, the Coriolis force, freshwater flow, and salinity density differential between fresh and saltwater. The relative contributions of these forces to the net residual currents is unknown at this time. These residual currents are postulated to transport or aid in the transport of oyster larvae, oyster-drill larvae, blue crab larvae, and various finfish eggs and larvae. They are thought to position these organisms both spatially and temporarily in the nursery habitats required for these species. Some species, such as oyster larvae, have the ability to migrate vertically upward during flood tides in order to utilize the up-estuary tidal currents for migration, then settle to the bottom during ebb tides to maintain these positions (Wood and Hargis 1971). It is presently unknown how much residual bottom currents contribute to the net upstream movement of this method of migration.

A reasonable hypothesis can be developed that the disruption of the residual current transport mechanism could alter both mortality rates and growth of passive migrants. The result could be a net decrease in overall fishery production at a level sufficient to cause a sizable reduction in commerical and sport fisheries. At present, the factors that drive residual currents are not completely understood. In order to assess the impacts of varying residual currents on those passively migrating organisms, it would be necessary to quantify the relative influence of each of the contributing factors that combine to produce velocity and timing of these residual currents.

BIBLIOGRAPHY

Abbe, G. R. 1967. An evaluation of the distribution of fish populations of the Delaware River estuary. M. S. thesis, University of Delaware, Newark.

Adams, D. A. 1963. Factors influencing vascular plant zonation in North Carolina salt marshes. Ecology 44(3):445-456.

Albrecht, A. B. 1964. Some observations on factors associated with survival of striped bass eggs and larvae. California Fish and Game 50(2):100-113.

Bason, W. H. 1971. Ecological study of the Delaware River in the vicinity of Artificial Island; Ecology and early life history of striped bass, *Morone saxatilis*, in the Delaware Estuary. Ichthyological Associates, Bull. No. 4. 122 p.

Bent, A. C. 1963. Life histories of North American marsh birds. Dover Publications, Inc., New York. 392 pp.

Carriker, M. R. 1967. Ecology of estuarine invertebrates: a perspective, *in* G. H. Lauff, ed. Estuaries. A.A.A.S. Publ. 83, Washington, D.C.

Chapman, C. R. 1966. The Texas Basins Project, *in* R. F. Smith, A. H. Swartz, and W. H. Marsman, eds. A symposium on estuarine fisheries. Amer. Fish. Soc. Spec. Publ. 3 (Suppl. to Trans. Amer. Soc. 95(4)).

-----. 1977. Freshwater discharge, *in* J. Clark, ed. Coastal ecosystem management. Conservation Foundation.

Chapman, V. J. 1960. Salt marshes and salt deserts of the world. Leonard Hill (Books) Ltd., London. 392 pp.

Chittenden, M. E., Jr. 1971. Status of the striped bass, *Morone saxatilis*, in the Delaware River. Ches. Sci. 12(3):131-136.

-----. 1973. Salinity tolerance of young American shad, *Alosa sapidissima*, in the Delaware River. Fishery Bull. 74(3):207-210.

Clark, J. ed. 1977 Coastal Ecosystem Management. Conservation Foundation. 928 p.

Costlow, J. D., Jr. 1967. The effect of salinity and temperature on survival and metamorphosis of megalopa of the blue crab *Callinectes sapidus*. Helgolander wiss. Mieresunters. 15:84-97.

-----. and C. G. Bookhout. 1959. The larval development of *Callinectes sapidus* Rathbun reared in the laboratory. Bio. Bull 116:373-396.

Daiber, F. C. 1957. Sea trout research. Estuarine Bull. 2(5):1-6.

-----. 1977. Salt-marsh animals: distributions related to tidal flooding, salinity and vegetation, in V. J. Chapman, ed. Wet coastal ecosystems. 428 pp.

-----., and R. Smith. 1972. An analysis of fish populations in the Delaware Bay area. Ann. Dingel-Johnson Rept., 1971-1972, Project F-13-R-14. 94 pp.

-----, et al. 1976. An atlas of Delaware's wetlands and estuarine resources. Technical Rept. No. 2, Delaware Coastal Management Program. College of Marine Studies, University of Delaware. Prepared for Delaware State Planning Office. 528 pp.

Darnell, R. M. 1976. Impacts of construction activities in wetlands of the United States. Environmental Research Laboratory, Office of Research and Development, Corvallis, Oregon. EPA-600/3-76-045. 392 pp.

Dawson, C. E. 1958. A study of the biology and life history of the spot, Leiostomus xanthrus Lasepede with special reference to South Carolina. Contrib. Bears Bluff Laboratory, Wadmalow Island 28-48.

Delaware River Basin Commission, 1981. The Delaware River Basin Comprehensive (Level B) study - the final report and environmental impact statement. 140 pp.

deSylva, D. P., F. A. Kalber, Jr., and C. N. Shuster. 1962. Fishes and ecological conditions in the shore zone of the Delaware River estuary, with notes on other species collected in deeper water. University of Delaware Marine Laboratory Information Ser. Publ. No. 5. 164 pp.

Dovel, W. L. 1977. Fishes: Freshwater and Anadromous species. Pages 84-85 in L. H. Wienstein, ed. An atlas of the biological resources of the Hudson Estuary. Boyce Thompson Institute for Plant Research.

Dozier, H. L. 1947. Salinity as a factor in Atlantic Coast tide water muskrat production. Trans. N. Am. Wildl. Conf. 12:398-420.

-----, H. L., M. H. Markley, and L. M. Llewellyn. 1948. Muskrat investigations on the Blackwater National Wildlife Refuge, Maryland, 1941-1945. J. Wildl. Manage. 12(2):177-190.

Durand, J. B., and R. J. Nadeau. 1972. Water resources development in the Mullica River Basin. Water Resources Research Institute, Rutgers University. 138 pp.

Epifanio, C. E. , and R. W. Garvine. 1979. Dispersal and recruitment of blue crab larvae. University of Delaware - Sea Grant Program Proposal R/M-4. Pages 401-417.

Ferren, W. R., and Schuyler, A. E., 1980. Intertidal vascular plants of river systems near Philadelphia. Procd. Acad. Nat. Sci. Philadelphia 132:86-120.

Ferrigno, F., L. Widjeskog , and S. Toth. 1973. Wetland ecology, marsh destruction. Job Progress Rept., Project No. W-53-R-1, Job No. IG. New Jersey Division of Fish, Game and Shellfisheries. 20 pp.

Ford, S. E. 1972. Recent trends in the epizootiology of Minchinia nelsoni in Delaware Bay (abstract). Proc. National Shellfishery Assoc. 63:2-3.

Gosselink, J. G. 1970. Growth of Spartina patens and S. alterniflora as influenced by salinity and source of nitrogen. Coastal Studies Bull. No. 5:97-100.

-----, B. S. Ballard, and A. Venkataramiah. 1974. Salinity problem of organisms in coastal areas subject to the effect of engineering works. U. S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. Contract Rept. H-73-3.

Haller, W. T., D. L. Sutton, and W. C. Barlowe. 1974. Effects of salinity on growth of several aquatic macrophytes. Ecology 55:891-894.

Harmic, J. L. 1958. Some aspects of the development and the ecology of the pelagic phase of the gray squeteague, Cynoscion regalis (Bloch and Schneider) in the Delaware estuary. Ph.D. thesis, University of Delaware, Newark. 164 pp.

Harris, E. S. 1937. Muskrat culture and its economic significance in New Jersey. Proc. New Jersey Mosquito Exterm. Assoc., 24:20-25.

Haskin, H. H. 1964. The distribution of oyster larvae. Symp. on Exp. Ecol. Occasional Publ. No. 2, Narragansett Marine Laboratory, University of Rhode Island. p. 76-80.

-----, and S. Tweed. 1976. Oyster setting and early spat survival at critical salinity levels on natural seed oyster beds of Delaware Bay. Water Research Institute, Rutgers University. 66 pp.

-----, L. A. Stauber , and J.A. Mackin. 1966. Minchinia nelsoni. n. sp. (Haplosporida, Haplosporidiidae): Causative agent of the Delaware Bay oyster epizootic. Sci. 153 p. 1414-1416.

Hidu, H. , and Haskin, H. 1978. Swimming speeds of oyster Crassostrea virginica in different salinities and temperature. Estuaries Vol. 1, No. 4, p. 252-255.

Holland, J. S., D. V. Aldrich, and K. Strawn. 1971. Effects of temperature and salinity on growth, food conversion, survival and temperature resistance of juvenile blue crabs, Callinectes sapidus Rathbun. Sea Grant Publ. TAMU-SG-71-222. Texas A & M University. 165 pp.

Ichthyological Associates, Inc. 1980. An ecological study of the Delaware River near Artificial Island, 1968-1976: a summary. For Public Service Electric and Gas Company. 303 pp.

Jefferies, H. P. 1960. Winter occurrences of Anguilla rostrata elvers in New England and Middle Atlantic estuaries. Limnology and Oceanography 5: 338-440.

Joseph, E. B., and V. P. Saksena. 1966. Determination of salinity tolerances in mummichog (Fundulus heteroclitus) larvae obtained from hormone-induced spawning. Chesapeake Sci. 7(4):193-197.

Kernehan, R. J., B. E. Beitz, and S. L. Tyler. 1975. Ichthyoplankton, in Ecological studies in the vicinity of the Summit Power Station, January through December 1974. Ichthyological Associates, Inc. Vol. 3. 618 pp.

Leathem, W., C. Wethe, and L. Watling. 1976. Seasonal changes of benthic assemblages in the Lightering area, in L. Watling and D. Maurer, Eds. Ecological studies on benthic and planktonic assemblages in lower Delaware Bay. College of Marine Studies, University of Delaware, Newark. CMS-RANN-3-76. 634 pp.

Lewis, R. M. 1966. Effects of salinity and temperature on survival and development of larval Atlantic menhaden, Brevoortia tyrannus. Trans. Amer. Fish. Soc. 95:423-426.

-----, and W. F. Hettler, Jr. 1968. Effects of temperature and salinity on the survival of young Atlantic menhaden, Brevoortia tyrannus. Trans. of the Amer. Fish. Soc. 94(4):344-349.

Lesser, C. A. and T. P. Ritchie. 1979. Coastal Fisheries Assistance, Delaware Coastal Zone Management Program. 87 pp.

Mansueti, J. R. 1964. Eggs, larvae and young of the white perch, Roccus americanus, with comments on its ecology in the estuary. Ches. Sci. 5(1-2):3-45.

Maurer, D., and H. Wang. 1973. Environmental vulnerability of the Delaware Bay area to supertanker accommodation. Rept. submitted to CEQ, Vol. II, Biology. 352 pp.

-----. 1973. Environmental vulnerability of the Delaware Bay area to supertanker accommodation. Rept. submitted to CEQ, Vol. IV: Biology Appendix. College of Marine Studies and College of Engineering, University of Delaware.

Martin, C. 1973. Sport fishing survey of the Delaware estuary. Delaware Department of Natural Resources and Environmental Control, Division of Fish and Wildlife. Project F-24-R. 15 pp.

McClane, A. J. and D. P. deSylva. 1972. Life history of the spot Leisotomus xanthurus, in A. J. McClane, ed. McClane's standards fishing encyclopedia and international angling guide. Holt, Rinehart and Winston, New York.

Middaugh, D. P., and D. W. Lempesis. 1976. Laboratory spawning and rearing of marine fish. The silverside Menidia menidis menidia. Marine Biol. (Berlin) 35(4):295-300.

Miller, J. P., et al. 1975. Ann. Prog. Rept. Delaware River Anadromous Fish Project. U. S. Fish and Wildlife Service.

Miller, R. W. 1977. Marine recreational fishing in Delaware. Delaware Division of Fish and Wildlife. Project No. F-29-R. 28 pp.

-----. 1980. Memorandum from the Department of Natural Resources and Environmental Control, Division of Fish and Wildlife -- Future water withdrawals from the Delaware River. May 13, 1980.

Nelson, T.C. 1921. The report of the Department of Biology. In N.J. Agr. Exp. Sta. 34th Ann. Rept., p. 288-292.

-----. 1960. Oyster seed production on Cape May's tidal flats. Estuarine Bulletin Vol. 5, No. 1, p. 3-6.

Nelson, W. R. 1967. Studies on the croaker, Micropogon undulatus, and the spot, Leiostomus xanthurus Lacepede, in Mobile, Alabama. M. S. thesis, University of Alabama. 85 pp.

Palmisano, W. W. 1972. The effect of salinity on the germination and growth of plants important to wildlife in the Gulf Coast marshes. Proc. Annual Conf. SE Assoc. Game and Fish Comm. 25:215-223.

Pearson, J. 1948. Fluctuations in the abundance of the blue crab in Chesapeake Bay. Research rept. 14. U. S. Fish and Wildlife Service. 26 pp.

Perlmutter, A. 1959. Changes in the populations of fishes and in their fisheries in the middle Atlantic and Chesapeake regions. 1930 to 1955. Trans. N.Y. Acad. Sci., Ser. 2, 21(6):484-496.

Phleger, F. 1971. Effects of salinity on growth of salt marsh grass. Ecology 52:908-911.

Preddice, T. L. 1974. Fishes taken by trawl and seine, in an ecological study of the Delaware River in the vicinity of the Edge Moor Power Station. Progress Report for the period October through December 1973. Ichthyological Associates, Inc. 109 pp.

Sandoz, M. D., and R. Rogers. 1944. The effect of environmental factors on hatching, moulting, and survival of zoea larvae of the blue crab, Callinectes sapidus Rathbun. Ecology 25:216-228.

Seagraves, R. J. 1981. Delaware Annual Report of Catch and Effort Statistics. Unpubl.

Smith, B. A. 1971. An ecological study of the Delaware River in the vicinity of Artificial Island: the fishes of four low-salinity tidal tributaries of the Delaware River estuary. Ichthyological Associates, Bull. No. 5. 291 pp.

Smith, R. 1975. Sportfishing in western Delaware Bay: Assessment of critical areas. College of Marine Studies, University of Delaware. 22 pp.

Springer, V. G., and K. D. Woodburn. 1960. An ecological study of the fishes of the Tampa Bay area. Florida Board Conserv. Marine Research Lab., Prof. Paper Ser. 1 V + 140 pp.

Stewart, R. E. 1962. Waterfowl populations in the upper Chesapeake region. U. S. Fish and Wildlife Service Spec. Rept. Wildl., 65. 208 pp.

Sykes, J. E. and B. A. Lehman. 1957. Past and present Delaware River shad fishery and considerations for its future. U. S. Fish and Wildlife Serv. Res. Rep. 46. 25 pp.

Tagatz, M. E. 1961. Reduced oxygen tolerance and toxicity of petroleum products to juvenile American shad. Chesapeake Sci. 2(1-2):65-71.

-----, and D. L. Dudley. 1961. Seasonal occurrence of marine fishes in four shore habitats near Beaufort, North Carolina, 1957-1960. U. S. Fish and Wildlife Service Spec. Sci. Rept. - Fish No. 390. 19 pp.

Tan, E. C. and W. A. Van Engle. 1966. Osmoregulation in the adult blue crab, Callinectes sapidus Rathbun. Chesapeake Sci. 7(1):30-35.

Thomas, D. L. 1971. The early life history and ecology of six species of drum (Sciaenidae) in the lower Delaware River, a brackish tidal estuary. Ichthyological Associates Bull. 3. 247 pp.

Turner, J. L., and H. K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, Morone saxatilis, in relation to river flow in the Sacramento-San Joaquin estuary. Trans. Am. Fish. Soc. 101(3).:442-452.

Tyrawski, J. M. 1979. Shallows of the Delaware River - Trenton, New Jersey to Reedy Point, Delaware. Prep. for Philadelphia District, U. S. Army Corps of Engineers. 519 p.

U. S. Environmental Protection Agency. 1979. EPA Alert - Middle Atlantic Environment 6(5), July-August.

-----. 1980. EPA Alert - Middle Atlantic Environment 7(4), April-May.

U. S. Fish and Wildlife Service. 1975. Preliminary report on fish and wildlife aspects related to the Delaware Bay Shore Study, Salem, Cumberland and Cape May Counties, New Jersey. Rept. to the Philadelphia District, Army Corps of Engineers

-----. 1979(a)Preliminary report: fish and wildlife inventory of the lower Delaware River and Bay region. Prepared for the Philadelphia District, Army Corps of Engineers. 67 pp.

-----. 1979(b) Planning Aid Report--the effect of salinity change on the American oyster in Delaware Bay. 26 pp.

-----. 1980(a). Planning aid report -- the effect of salinity change on the blue crabs in Delaware Bay.

-----. 1980(b). Planning Aid Report -- the effect of salinity change on selected finfish in Delaware Bay. 31. pp.

-----. 1980(c). Planning Aid Report--the relative impacts of the Chesapeake and Delaware Canal on the ecology of the Delaware estuary. 21 pp.

-----. 1980(d). Planning Aid Report--the relative impacts on selected forage fish in Delaware Bay from salinity intrusion. 29 pp.

-----. 1981(a) Planning Aid Report--the effect of salinity change on vascular aquatic plants in the Delaware estuary. 18 pp.

-----. 1981(b). Planning Aid Report--the effect of salinity change on wildlife in the Delaware estuary. 12 pp.

Van Engle, W. A. 1958. The blue crab and its fishery in Chesapeake Bay, Part I - reproduction, early development, growth and migration. Comm. Fish. Rev. 29(6):6-17.

-----, D. G. Cargo, and F. J. Wojak. 1973. The edible blue crab...abundant crustacean. Marine Resources of the Atlantic Coast. Leaflet No. 15., Atlantic States Fisheries Commission. 8 pp.

Walton, T. E. III, and R. Patrick (eds.). 1973. The Delaware Estuary System, environmental impacts and socio-economic effects; the Delaware River estuarine survey. A report of the Nat. Sci. Found. RANN Program, Acad. Sci. Philadelphia, University of Delaware, Rutgers University. 174 pp.

Wang, J. C. S., and R. Kernehan. 1979. Fishes of the Delaware estuaries, a guide to the early life histories. Ecological Analysts, Inc., Townson, Maryland. 410 pp.

Watling, L., D. Maurer, and C. Wethe. 1976. Delaware Bay benthic invertebrate assemblages, in L. Watling and D. Maurer, eds. Ecological studies on benthic and planktonic assemblages in lower Delaware Bay. College of Marine Studies, University of Delaware, Newark. CMS-RANN-3-76. 634 pp.

Wood, L., and W.J. Hargis. 1971. Transport of Bivalve Larvae in a Tidal Estuary. In Fourth European Biology Symposium, Cambridge Univ. Press, Cambridge, pp. 29-44.

Woodhouse, W. W. Jr. 1979. Building salt marshes along the coasts of the continential United States. Special Rept. No. 4, Prep. at Coastal Engineering Research Center, Fort Belvoir, Virginia. 96 pp.

Yamamoto, T. 1941. The osmotic properties of the egg of the freshwater fish Oryzias latipes. J. Fac. Sic. Univ. Tokyo Sec. Iv. Zool. 5(3):461-472.

DELAWARE ESTUARY SALINITY INTRUSION STUDY

PERTINENT CORRESPONDENCE

APPENDIX 4

US Army Corps of Engineers
Philadelphia District

DELAWARE ESTUARY
SALINITY INTUSION STUDY

APPENDIX 4
PERTINENT CORRESPONDENCE

TABLE OF CONTENTS

INTRODUCTION

This appendix includes correspondence pertinent to the Delaware Estuary Salinity Intrusion Study. During the Plan of Study coordination was initiated with regional, Federal, State and County agencies. Throughout Stage 2, coordination continued with extensive liaison being maintained with the study sponsor, the Delaware River Basin Commission (DRBC), and U.S. Department of Interior, Fish and Wildlife Service. Pertinent correspondence is included in this appendix. An Executive Summary was prepared in 1980 and distributed to all water users and interested parties. The Executive Summary documented the results of the Phase 1 Economic Study (see page 40) and indicated estimates of salinity-related costs (i.e. replacement of corroded parts and equipment, use of alternative water sources, and treatment of saline water). Agencies which provided input during the course of the study are:

a. U.S. Geological Survey - data on stream flow and water quality.

b. National Oceanic and Atmospheric Administration - tide data, temperature, and density.

c. U.S. Fish and Wildlife Service - inventory of fish and wildlife resources, salinity impacts on estuarine fish and wildlife.

d. National Fisheries Service - literature search and input to Fish and Wildlife Service work.

e. U.S. Bureau of Census - population data.

f. Delaware River Basin Commission - inventory of estuarine water uses, water quality, population data, water management plans (flows), MIT-TSIM Model, and advice concerning development of MIT-TSIM Branched Model.

g. Delaware Valley Regional Planning Commission - regional and local population and economic projections and inventory data.

h. Delaware Department of Natural Resources and Environmental Control, Division of Fish and Wildlife - input to Fish and Wildlife work.

i. Pennsylvania Department of Environmental Resources - State Water Plan.

j. Pennsylvania Fish Commission - input to Fish and Wildlife work.

k. New Jersey Department of Environmental Protection - State Water Plan; Division of Fish Game and Shellfisheries - input to Fish and Wildlife Service work.

l. New Castle County Planning Commisssion - water use, population data.

m. Chesapeake Bay Institute - salinity and tide data.

n. Water Resources Association of the Delaware River Basin - provided assistance in surveys of industrial water use and distributed the Executive Summary to water users.

In lieu of holding a final public meeting, an Information Bulletin was used as a vehicle to coordinate the conclusions of the study with interested agencies and parties. A copy of this bulletin is included in this appendix.

During the final coordination efforts with U.S. Department of Interior, Fish and Wildlife Service, this office received comments on the draft final report in a letter dated 19 August 1982, (included in this appendix). These comments were considered in the preparation of the final report. However, several of the comments are clarified in the following paragraphs.

Concerning the "quantity of flow" (goal b), it is the opinion of the Service that the value of the study is minimized by deference to concurrent work done by DRBC. The approach used in this study, as documented in the Reconnaissance Report dated December 1978, intended incorporation of ongoing DRBC efforts, particularly the Level B Study which responded to the quantity of flow goal. This approach was adopted in an attempt to avoid duplication of effort. The Service was involved with the Plan of Study (during which the decision for this approach was reached), the ensuing Stage 2 activities, (during which time the approach and tasks outlined in the Plan of Study were carried out) and the Level B Study (during which the activities concerning quantity of flow were carried out).

During the Level B Study, opportunity to provide inputs to the quantity-of-flow objective was afforded to all agencies, and these inputs have been considered by DRBC in addressing this objective. It is the view of the Corps of Engineers that it would be duplicative to repeat DRBC's efforts, and, furthermore, such duplication would not improve the outcome. It is emphasized that the results of the Level B Study have been accepted by the Commission (which includes the Governors of the affected States and the Secretary of the Interior), and by the Water Resources Council.

The Service is also concerned that the Corps is unwilling to recommend measures to minimize adverse impacts, particularly regarding spring flow requirements as affected by storage runoff in existing or proposed reservoirs. In the Service's view, these requirements are necessary to protect estuarine fauna from manipulation of freshwater flows and to maintain estuarine productivity. While the resolution of these concerns is beyond the scope of this study, these issues were considered by the DRBC Level B Study and the overlapping negotiations among the parties to the 1954 Supreme Court decree that allocates the waters of the Delaware River among the Basin States. Further consideration can be given as part of the site-specific project studies and public hearings that will be required under the Delaware River Basin Compact before construction of any new impoundment. The Corps is willing to participate in these continuing efforts. However, the Corps recognizes that multipurpose reservoir operation is an extremely complex issue involving many factors, not just estuarine ecology.

It is emphasized that normal reservoir operation prefer filling available long-term storage capacity prior to spring and in most years the reservoir would be filled before April. It is the opinion of this office that the establishment of a set of defined individual operating criteria for each reservoir is the best vehicle for maximization of project benefits and minimization of adverse effects.

Extensive coordination was maintained with the Delaware River Basin Commission throughout the conduct of the Study. DRBC provided review and technical assistance in the development of data and analysis. Pertinent correspondence is included in this appendix.

FRANK THOMPSON, JR.
4TH DISTRICT, NEW JERSEY

COMMITTEES:
EDUCATION AND LABOR
CHAIRMAN, SUBCOMMITTEE ON LABOR-MANAGEMENT RELATIONS
HOUSE ADMINISTRATION
CHAIRMAN, SUBCOMMITTEE ON ACCOUNTS
MEMBER, DEMOCRATIC STEERING AND POLICY COMMITTEE
MEMBER, BOARD OF TRUSTEES, JOHN F. KENNEDY CENTER FOR THE PERFORMING ARTS

3

Congress of the United States
House of Representatives
Washington, D.C. 20515

WASHINGTON OFFICE:
2109 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, D.C. 20515

WILLIAM T. DEITZ
ADMINISTRATIVE ASSISTANT

ROBERT A. REVELES
EXECUTIVE SECRETARY

DISTRICT OFFICES:
10 RUTGERS PLACE
TRENTON, NEW JERSEY 08618
201 ROUTE NO. 516
OLD BRIDGE, NEW JERSEY 08857

July 27, 1976

Honorable Robert E. Jones, Chairman
Committee on Public Works and Transportation
2165 Rayburn Office Building
Washington, D.C. 20515

Dear Mr. Chairman:

The Delaware River Basin Commission has proposed a study of salinity intrusion in the Delaware River estuary to resolve certain questions left unresolved by the 1975 study by URS/Madigan-Praeger of the Tocks Island Lake project. The DRBC member representing the State of New Jersey has assigned the highest priority to this study, and the Basin States have committed some of the funds needed for the study. An additional amount of $100,000 is needed to carry out the study as proposed, including funds for hydraulic modeling of sea-water intrusion to be carried out by the Corps of Engineers using the existing physical model of the estuary located at the Waterways Experiment Station (WES) at Vicksburg, Mississippi. The Corps has estimated that the proposed WES modeling would cost from $60,000 to $70,000.

It has been suggested that Congress make a specific authorization of $100,000 to the Corps of Engineers for the purpose of carrying out the WES-modeling studies, with a pass-through of the excess over that needed by the Corps to the Delaware River Basin Commission for use in supplementing the State funds as needed to complete other phases of the salinity-intrusion study. These other phases include mathematical modeling and analysis of the impacts of various potential levels of salinity on municipal and industrial water users along the estuary. Assuming the timely availability of funds, it is anticipated that the salinity-intrusion studies can be completed within fiscal year 1977.

Our purpose in addressing you is to express our interest in this proposed study which is of such vital interest to the States of New Jersey, Delaware, and Pennsylvania, and to request your support to an authorization of $100,000 for the purposes outlined above. It occurs to us that such an authorization might be conveniently coupled with the proposed Corps' study of a "no dam" flood protection program for the Delaware River, as discussed in the letter of November 14, 1975, addressed to you from several Members of Congress. In any event, both of these studies are needed to evaluate various proposed alternatives to the Tocks Island Lake project.

We are,

Most respectfully,

Frank Thompson

Rep. Frank Thompson, Jr.

Edwin B. Forsythe

Rep. Edwin B. Forsythe

William J. Green

Rep. William Green

James J. Florio

Rep. James J. Florio

Joshua Eilberg

Rep. Joshua Eilberg

Robert N.C. Nix

Rep. Robert N.C. Nix

Rep. Edward G. Biester, Jr.

Robert W. Edgar

Rep. Robert W. Edgar

cc: Mr. James F. Wright
Lt. Gen. William Gribble

COMMITTEE ON PUBLIC WORKS AND TRANSPORTATION
U.S. HOUSE OF REPRESENTATIVES
WASHINGTON, D.C.

RESOLUTION

Resolved by the Committee on Public Works and Transportation of the House of Representatives, United States., that the Board of Engineers for Rivers and Harbors is hereby requested to review the report on the Delaware River Basin, New York, New Jersey, Pennsylvania, and Delaware, published in House Document 522, 87th Congress, 2nd Session, and other pertinent reports, with a particular view to determining the probability for advance or retreat of salinity in the Delaware Estuary and the quantity of fresh-water inflow needed to protect the various water users along the Estuary.

Adopted: September 23, 1976

ATTEST: Robert E. Jones
Chairman

U.S. GOVERNMENT PRINTING OFFICE 51-481-b

Requested by: Hon. Frank Thompson, Jr., Hon. Edwin B. Forsythe, Hon. William Green, Hon. James J. Florio, Hon. Joshua Eilberg, Hon. Robert Nix, Hon. Edward G. Biester, Jr. Hon. Robert W. Edgar

DELAWARE RIVER BASIN COMMISSION
P. O. BOX 7360
WEST TRENTON, NEW JERSEY 08628
(609) 883-9500

JAMES F. WRIGHT
EXECUTIVE DIRECTOR

HEADQUARTERS LOCATION
25 STATE POLICE DRIVE
WEST TRENTON, N. J.

October 12, 1976

Dear General Kelly:

As you know, the study of the Tocks Island Lake project directed by the Congress in August 1974 and completed in July 1975 left unresolved the question of the need for fresh-water flow into the Delaware estuary for control of sea-water intrusion. Conducted by URS/Madigan-Praeger, the salinity study was found by the Delaware River Basin Commission staff to be invalid in certain respects and incomplete in others. This staff view was generally concurred in by a panel of estuarine experts called together by the DRBC to review the salinity intrusion aspects of the URS report. At a meeting in Newark, New Jersey, on July 17, 1975, these internationally recognized experts recommended additional study of the salinity-flow relationships, using both mathematical and hydraulic modeling techniques, as well as observations of the prototype estuary itself.

As a result of the experts' recommendation, the DRBC directed its staff to prepare a plan of study designed to resolve the unanswered questions relating to the salinity intrusion problem, and also directed the staff to seek funds to support such a study. Accordingly, in September 1975 the staff prepared a plan of study, a copy of which is enclosed.

Since September 1975 we have contacted various agencies and the Congress seeking financial assistance for the proposed salinity study. As you know, in late January 1976 we conferred with you on the possibility of Corps of Engineers' funding of the salinity study under some existing authorization. It was your opinion that a specific authorization by Congress would be needed before you could request an appropriation of funds for the salinity study.

Through the efforts of several Congressmen from the Delaware Basin area, the Committee on Public Works and Transportation of the House of Representatives adopted a resolution on September 23, 1976, requesting that the Board of Engineers for Rivers and Harbors review the report on the Delaware River Basin (House Document 522, 87th Congress, 2nd Session) to determine the probability of salinity in the Delaware estuary and the quantity of fresh-water inflow needed to protect the various water users along the estuary. It is our understanding that this resolution constitutes the specific authorization that you had earlier indicated would be needed before the Corps could request funds for the salinity study.

During our discussion of this matter in your office on October 5, 1976, you expressed the view that although the Congressional resolution of September 23 meets the need for a specific authorization for the salinity study, a Corps request for an appropriation for this purpose would depend upon priorities for allocation of the limited total budget assigned to the North Atlantic Division. In setting your priorities, it may be useful to know that our Commissioners, in establishing our program for the near future, have assigned the highest priority to the resolution of the salinity intrusion issue. They recognize that such resolution is necessary not only to determine the ultimate disposition of the Tocks Island Lake project (construction or deauthorization), but also to determine the construction timing and operation of all proposed storage reservoirs in the Delaware River Basin, including the several major multipurpose impoundments authorized for construction by the Corps of Engineers.

Regarding the Tocks Island project and its relation to the salinity study, Governor Byrne of New Jersey has emphasized the importance of the salinity study with respect to the deauthorization of this Corps project. In his letter of July 25, 1976, to Senator Mike Gravel, Chairman of the Subcommittee on Water Resources of the Senate Committee on Public Works, Governor Byrne urged the Subcommittee to defer action on deauthorization and noted that the DRBC has begun to evaluate the suggestion that a reduced standard for minimum water flow in the Delaware River at Trenton may not risk undue intrusion of sea salts to downstream municipal and industrial water supplies. Governor Shapp of Pennsylvania, in his statement presented to the Subcommittee on July 23, 1976, also opposed deauthorization, and stressed the need for maintenance of river flows to help control salinity in the estuary. Governor Tribbitt of Delaware, in a statement presented to the Subcommittee, also noted the salinity question and other unresolved issues in arguing that deauthorization of the Tocks Island project now would be premature.

New Jersey has recently initiated a major study and preparation of a state water supply master plan, and this study will consider the viability of proposed diversions of water from the Delaware River to meet the needs of northeastern New Jersey. The results of the proposed salinity study will be a necessary input to the evaluation of any such diversion.

Current water quality planning efforts by the Delaware Valley Regional Planning Commission and other agencies under Public Law 92-500 and other legislation are dependent to a significant degree on knowledge of the flow that will be available in the Delaware River at Trenton for assimilation of treated wastes discharged into the upper estuary. The dependable river flow that necessarily will be used as a basis for design of wastewater treatment facilities will be determined by the need for sustained minimum regulated flows for control of sea-water intrusion. Rational planning for pollution abatement in the estuary cannot proceed very far without determination of the fresh-water flows that are to be provided for salinity control. This fact alone supports a high priority for the salinity study.

I cannot emphasize too strongly the importance of the salinity-control issue in relation to all of the active long-term storage capacity called for in the Comprehensive Plan, not just that portion of the total authorized capacity that would be provided by the Tocks Island Project. The widely held but invalid impression, created by the 1975 URS/Madigan-Praeger report, that low-flow augmentation is not needed for salinity control, was a key factor in the success of the Tocks Island project opponents in halting that project. If this impression prevails, it will promote similar opposition to other Comprehensive Plan water-storage projects that are designed in part to contribute to salinity control. Until the incomplete URS salinity study is supplemented by an authoritative comprehensive study to resolve the issue, it will be difficult to proceed with construction of any of the authorized storage projects, including those proposed by the Corps of Engineers.

Another factor in the question of Corps priorities is the relationship between the salinity intrusion study and the current comprehensive water resources study of Burlington, Camden, and Gloucester Counties of New Jersey by the Philadelphia District of the Corps of Engineers under its Urban Studies Program. The water supply aspects of this tri-county study are closely related to the recharge of aquifers along the Delaware estuary by the tidal waters of the Delaware River and its sea-level tributaries. No firm conclusions regarding water supply for this region can be made in the absence of more precise information than is now available on the salinity-flow relationship. The salinity study is designed to provide such information.

Regarding financing of the proposed salinity study, you should be aware that we have received commitments from the Basin States to provide $60,000 directly to the DRBC for support of the study. In addition, New York State has requested transfer of "Section 214" funds from several Corps of Engineers districts to the Philadelphia District for use in conducting salinity modeling tests planned as part of the study, to be carried out with the hydraulic model of the Delaware estuary at the Corps' Waterways Experiment Station at Vicksburg, Mississippi.

We have also asked the Environmental Protection Agency to consider the possibility of EPA funding of part of the proposed salinity study. Although we have received no written response, informal discussions with EPA officials have indicated that although they recognize the need for, and importance of, the salinity study, that agency has no funds available to allocate to that purpose.

We have also contacted the U.S. Water Resources Council for possible funding of the salinity study by a grant under that agency's special studies program. To date, we have received no response except a WRC request for additional information concerning the proposed study, which we have supplied. In the meantime, because of the current Corps authorization, I have advised the Water Resources Council that the request is to be held in abeyance at this time.

In requesting a review of House Document 522, the House Committee on Public Works has recognized the important significance of the salinity issue as it relates to the federally authorized projects for multipurpose development of the water-resources of the Delaware River Basin. I believe the salinity issue merits a very high priority with respect to implementation of authorized storage impoundments in the Basin, particularly the multipurpose reservoirs proposed for construction by the Corps of Engineers.

This Commission will be glad to cooperate with the Corps in this matter. It is our suggestion that funds be appropriated to the Corps adequate for the entire salinity study, with the Corps funding the hydraulic modeling work at the Waterways Experiment Station in Vicksburg, and with a pass-through to the Commission of the remaining funds appropriated, to be used by the Commission in carrying out the mathematical modeling and other aspects of the study as outlined in the Plan of Study.

The Waterways Experiment Station has recently informed us that the basic cost for preparing the hydraulic model and operating it for calibration, verification, and three test runs will be $66,000, including a 10 percent contingency item. The three test runs would include simulation of the 1965 hydrographic data with (1) net flow eastward through the enlarged Chesapeake and Delaware Canal; (2) net flow westward through the C & D Canal; and (3) one additional set of data consistent with projected streamflow modifications resulting from post-1965 storage impoundments, increased consumptive use and diversions of water, and releases from storage. The three runs for which the WES estimate is now $66,000 are fewer than we had earlier had in mind when we discussed the study with WES and received an estimate of $60,000. The estimated cost has changed but little, but the scope of work has been significantly reduced within the estimate. However, it appears that the $260,000 reported to Congress by the Corps will be adequate to cover the cost of additional model runs deemed necessary to answer all pertinent questions, with enough remaining for the other parts of the study to be carried out by the DRBC.

Our staff members who will be particularly concerned with the salinity study are Mr. Herbert A. Howlett and Dr. C.H.J. Hull. We will welcome the opportunity for further consultation after you have reviewed this matter. I would hope that we might complete our joint planning and make adequate funding arrangements for the salinity study this fall so that we may be ready to initiate the study early in calendar year 1977.

Sincerely,

James F. Wright

James F. Wright

Brigadier General James L. Kelly, Division Engineer
U.S. Army Corps of Engineers - North Atlantic Division
90 Church Street
New York, New York 10007

September 15, 1975

Delaware River Basin Commission

Outline of Plan of Study
of
Salinity Intrusion in the Delaware Estuary

A. Need for study

B. Impact of salinity intrusion

1. Surface water users
   a. Municipal water supply users (by location)
      1) Domestic use
         a) Water quality criteria
      2) Industrial (supplied by public systems)
         a) Water quality criteria
      3) Commercial (supplied by public systems)
         a) Water quality criteria

   b. Self-supplied industries
      1) Location of industries
      2) Water quality criteria (for each industry)
         a) Process water (chlorides, TDS, etc.)
         b) Cooling water

2. Ground water users
   a. Municipal water supply users
      1) Domestic
      2) Industrial
      3) Commercial

   b. Self-supplied industries
      1) Location of industries (River mile)
      2) Water quality criteria (chlorides, TDS, etc.)
         a) Process water
         b) Cooling water
         c) Drinking water

3. Health and medical aspects of increased salinity

4. Economic effects of increased salinity

5. Ecological effects

C. Review of earlier studies

1. Terrenzio (1953)
2. Waterways Experiment Station (1952, etc.)
3. Pritchard, D. W. (1959)
4. Sheppard T. Powell and Legette and Brashears (1954)
5. Keighton (1965, etc.)
6. Paulson, R. W. (1969) (1970)
7. Thatcher and Harleman (1972)
8. United Engineers and Constructors (1974)
9. Strandberg (1975)
10. Madigan-Praeger, Inc. (1975)
11. Newark Salinity Seminar (1975)
12. Others

D. Water quality data

1. Types of data available (by location)
   a. Total dissolved solids
   b. Specific conductance
   c. Major sea-water ions
      1) Chlorides
      2) Sodium
      3) Sulphates
      4) Magnesium
      5) Calcium
      6) Potassium
   d. Relation between conductance and major ions.
   e. Other significant contaminants (e.g., silica)

E. Hydrologic data

1. Observed flows at various locations

2. Natural runoff (USGS studies for DRBC)

3. Synthetic flows at Trenton (Madigan-Praeger)

4. Synthetic flows for tributaries (???)

F. Land-based sources of dissolved salts

1. Delaware River at Trenton (flow and quality)

2. Tributaries (Locate by river mile and characterize by hydrological and water-quality data)

3. Point sources (location, volume, and quality)
   a. Municipal wastewater outfalls
   b. Municipal stormwater outfalls
   c. Industrial wastewater outfalls

4. Non-point sources
   a. Road salts
      1) Pennsylvania (below Morrisville)
      2) New Jersey (below Trenton)
      3) Delaware
   b. Other non-point sources

G. Relationship between fresh-water inflow and sea-water intrusion

1. Proposed studies
   a. Prototype study--analysis of relationship between observed flows and salinity distribution
      1) Drought of 1960's
      2) Other years
      3) Typical chloride profiles
   b. Deterministic model study (Thatcher model)
      1) Calibration and verification (Using data from drought period)
      2) Determination of future salinity distribution
         a) For typical droughts of past adjusted for flow regulation (releases from storage and depletive use)
         b) Probability of exceeding various salinity levels at given locations throughout estuary (derived by combining synthetic fresh-water inflows for all tributaries with Thatcher deterministic model)

c. Hydraulic model study (Waterways Experiment Station, Vicksburg, Miss.)
   1) Calibration and verification (using data from drought of 1960s)
   2) Determination of future salinity distribution
      a) For typical dry years of record, adjusted for existing and proposed flow regulation (storage, releases, diversions, and consumptive use)

H. Benefits from salinity control

1. Estimated monetary value of salinity reductions for various degrees of flow regulation
   a. Municipal water supplies
      1) Surface supplies
      2) Ground-water supplies
   b. Industrial water supplies
      1) Surface supplies
      2) Ground-water supplies
   c. Fisheries (including shellfish)

Narrative summary

It is proposed to conduct or sponsor a comprehensive study of salinity intrusion in the Delaware estuary to determine the fresh-water inflow needed to protect the various water users along the estuary from Trenton to the oyster beds near the head of Delaware Bay. The year-round distribution of salinity in the estuary for various levels of depletive water use and streamflow regulation in the Delaware River Basin will be determined using synthetic hydrology coupled with a deterministic mathematical model. Synthetic fresh-water inflows for the Delaware River at Trenton and for various other significant tributaries will be developed for use in the analysis of the probability of exceeding various salinity (or chlorinity) concentrations at given locations at different seasons of the year. The synthetic fresh-water flows will be adjusted as appropriate to take into account the existing and projected levels of flow regulation by impoundments and by depletive use (in-basin consumptive use and out-of-basin diversions).

At attempt will be made to show the effects of non-sea salts as well as sea salts on the total salinity and chlorinity in the upper estuary. This will be done by using model inputs of salts to represent the waste discharges of major industries and municipalities.

The study would include a survey of all existing municipal and industrial water users along the estuary from Trenton to the Bay to determine their quality needs with respect to salinity (total dissolved solids), chlorinity, and other sea-water ions. An attempt will be made to assign costs to these water users as a function of sea-water intrusion (or as a function of the frequency and duration of salinity concentrations).

Damages attributable to decreased flows (caused by storage or depletive use) will be assessed. Benefits (reduction in damages) that would be expected for various levels of low-flow augmentation will also be estimated. To the extent possible, damages of salinity intrusion and benefits of salinity control will be estimated as average annual values.

The effect of the enlargement of the Chesapeake and Delaware Canal on salinity distribution in the Delaware estuary will be evaluated, both for (1) normal runoff conditions in the Susquehanna-Chesapeake Bay drainage area when salinity in the upper Chesapeake Bay is low; and (2) for drought conditions in the Susquehanna-Chesapeake Bay drainage area when salinity in the upper Chesapeake Bay is relatively high.

It is anticipated that the synthetic flows for the Delaware River at Trenton developed by Madigan-Praeger (1975) for the review of the Tocks Island Lake project will be available and useful for the proposed new study of salinity intrusion. Synthetic flows for tributaries seaward of Trenton will have to be generated. It is expected that minor tributaries can be grouped for various reaches of the estuary to simplify modeling the system without significant loss of accuracy.

A comprehensive bibliography on salinity intrusion will be prepared. This bibliography will include all known studies of salinity in the Delaware estuary, as well as more general references. A preliminary bibliography is attached to this Plan of Study (appendix A).

Cost of study

The cost of the proposed study is estimated to be $181,800. This estimate is based on an assumption that the study will be carried out primarily by the DRBC staff, assisted as appropriate by consultants.

Duration of study

It is estimated that the study will require 14.5 man-months of staff time. With two staff members assigned full time to the study, it could be completed in about seven months. Parts of the overall study could be selected for priority treatment, and thus these parts could be completed in advance of the full study and report. However, the assembling of the basic data would be a necessary prerequisite of the study. For example, the data on flows, point sources, and nonpoint sources are needed as input data to study the relationship between flow and salinity for all three proposed methods of analysis (prototype, mathematical deterministic model, and hydraulic model).

Extra-staff assistance

It is anticipated that outside assistance from consultants, agencies, and water users will be necessary to assemble the necessary data, supervise and review the study, and to carry out parts of the study. For example, data on water-quality criteria for various water users can be supplied best and most reliably only by these water users. Also, consultants will be useful, if not essential, in setting up and running the Thatcher deterministic model (if that model is used). The assistance of the Corps of Engineers will be necessary if the Vicksburg hydraulic model is used. Consultants will also be needed to review and interpret the results of the various studies of the relationship between flow inputs and salinity distribution, as well as to set up and run computer programs for the generation of synthetic flows (for the tributaries seaward of Trenton).

Advisory committees.--It will probably be useful to establish one or more advisory committees to guide, assist, and review the study. Such an advisory committee could include representatives of water users (municipal and industrial--including fisheries) affected by salinity intrusion.

Appendix B

Estimated Costs of Salinity Intrusion Study

Part	Description	Time man-months	Cost DRBC staff*	Cost Consultant
A	Need for study (Introduction)	0.25	$ 600	--
B	Impacts	1.0	2,600	--
1	Surface users			
2	Ground water			
3	Health and medical			
4	Economic			
5	Ecological			
C	Review of earlier studies	1.0	2,600	--
D	Water-quality data	1.0	2,600	--
E	Hydrologic data	1.0	2,600	--
1	Observed flows			
2	Natural runoff			
3	Synthetic flows, Trenton			
4	Synthetic flows, Tribs.			
F	Land-based sources of dissolved salts	4.0	10,500	--
1	Delaware River at Trenton			
2	Tributaries			
3	Point sources			
4	Non-point sources			
G	Relationship between flow and salinity	3.0	7,900	$35,000
1	Prototype studies			
2	Deterministic model studies			
3	Hydraulic model studies			
H	Benefits from salinity control	--	--	--
1	Municipal			
	Industrial			
	Fisheries			

* Estimated cost assumes average DRBC staff direct-salary cost of $15.00 per hour, and does not include overhead, fringe benefits, etc. Estimates are based on 22 working days per month.

Part	Description	Time man-months	Cost DRBC staff*	Cost Consultant
I	Preparation of report	3.0	$ 7,900	$ 2,000
	Draft report			
	Review of draft			
	Final report			
	Reproduction of report	0.3	800	--
	Draft (50 copies)			
	Final (100 copies)			
	Sub totals	14.55	$38,100	$37,000
	DRBC overhead (15% of salaries)		5,700	--
	Total staff salaries and consultants' fees		43,800	37,000

Additional DRBC Costs

Item		Amount
Meetings of Advisory Committee (s)		0
Travel, staff		2,000
Travel expenses, consultants		3,000
Computer runs		30,000
	Subtotal	$ 35,000
Total DRBC costs		$115,800

USGS

Item		Amount
Natural flow studies		$ 5,000
Water quality data (computer printouts)		1,000
	Subtotal	$ 6,000

Corps of Engineers

Item		Amount
Vicksburg model and studies		60,000
	Subtotal	$ 60,000
Grand total		$181,800

DEPARTMENT OF THE ARMY
PHILADELPHIA DISTRICT. CORPS OF ENGINEERS
CUSTOM HOUSE—2 D & CHESTNUT STREETS
PHILADELPHIA, PENNSYLVANIA 19106

IN REPLY REFER TO
NAPEN-R

30 DEC 1977

Dear Sir:

I am pleased to inform you that we have initiated the Delaware Estuary Salinity Intrusion Study. This Congressionally authorized study is to analyze the movement of salinity concentrations in the estuary and identify the amount of fresh-water flow in the Delaware River needed to protect water users of the estuary. This study was authorized by the House Committee on Public Works and Transportation on 23 September 1976. Efforts in the following year will concentrate on establishing a systematic program for conducting the study.

We expect that our study will include investigations of the following: quality needs of water users; increased costs or inherent damages if water of higher salinity must be used; relationship between stream regulation in the upper basin and advance or retreat of salinity concentrations in the esutary; quantity of upstream storage necessary for low-flow augmentation; and the impact on estuarine fish and wildlife of changes in salinity. The study will assess the problems and identify alternatives to diminish the detrimental effects of varying salinity.

We welcome any contribution you can make to this study. We would like your views regarding the significance of the salinity problem, the possible environmental, social or economic impacts and any other areas you feel are pertinent. We look forward to your assistance.

Any questions or correspondence in regard to the study may be directed to Mr. John F. Murphy, Chief, Planning Branch, by mail at the above address, or by phone at (Area Code 215) 597-4837. As the study progresses, we will inform you of major developments.

Sincerely yours,

Joel T. Callahan

JOEL T. CALLAHAN
Lieutenant Colonel, Corps of Engineers
Acting District Engineer

DELAWARE ESTUARY SALINITY INTRUSION STUDY
List of Notified Parties

Federal Representatives

Delaware

Honorable Joseph R. Biden, Jr.
United States Senate
Washington, D.C. 20510

Honorable William V. Roth, Jr.
United States Senate
Washington, D.C. 20510

Honorable Thomas B. Evans, Jr.
House of Representatives
Washington, D.C. 20515

New Jersey

Honorable Clifford P. Case
United States Senate
Washington, D.C. 20510

Honorable Harrison A. Williams, Jr.
United States Senate
Washington, D.C. 20510

Honorable James J. Florio
House of Representatives
Washington, D.C. 20515

Honorable William J. Hughes
House of Representatives
Washington, D.C. 20515

Honorable Frank Thompson, Jr.
House of Representatives
Washington, D.C. 20515

Honorable Edwin B. Forsythe
House of Representatives
Washington, D.C. 20515

Pennsylvania

Honorable Richard S. Schweiker
United States Senate
Washington, D.C. 20510

Honorable Henry J. Heinz, III
United States Senate
Washington, D.C. 20510

Honorable Michael O. Myers
House of Representatives
Washington, D.C. 20515

Honorable Robert N. Nix
House of Representatives
Washington, D.C. 20515

Honorable Raymond F. Lederer
House of Representatives
Washington, D.C. 20515

Honorable Joshua Eilberg
House of Representatives
Washington, D.C. 20515

Honorable Robert W. Edgar
House of Representatives
Washington, D.C. 20515

Honorable Peter H. Kostmayer
House of Representatives
Washington, D.C. 20515

Federal Agencies

Director, Northeast Region
Regional Technical Service Center
Soil Conservation Service
U.S. Department of Agriculture
1974 Sproul Road
Broomall, PA 19008

Water Resources Coordinator
Office of the Secretary, OPDC
Department of Commerce
Washington, D.C. 20230

Regional Representative of
the Secretary of Commerce, Region II
Federal Building, Room 1311
26 Federal Plaza
New York, NY 10007

Director
National Marine Fisheries Service
National Oceanic and Atmospheric
Administration
Washington, D.C. 20235

The Director
National Ocean Survey
National Oceanic & Atmospheric
Administration
U.S. Department of Commerce
Rockville, MD 20852

Regional Director, Region 5
U.S. Fish & Wildlife Service
Department of the Interior
One Gateway Center, Suite 700
Newton Corner, Mass 02158

District Chief, WRD, USGS
420 Federal Building
P. O. Box 1238
Trenton, NJ 08607

Regional Hydrologist
Geological Survey
National Center - Mail Stop 433
12291 Sunrise Valley Drive
Reston, Virginia 22092

The Administrator
U.S. Environmental Protection Agency
Waterside Mall
4th & M Streets, S.W.
Washington, D.C. 20460

Regional Administrator
Region III, EPA
6th & Walnut Streets
Phila., PA 19106

Regional Representative of
the Secretary of Commerce, Region III
William J. Green Federal Building
600 Arch Street, Room 10424
Philadelphia, PA 19106

Regional Director, Northeast Region
National Marine Fisheries Service
U.S. Department of Commerce
Federal Building, 14 Elm Street
Gloucester, Mass. 01930

Interagency Coordinator
Office of Coastal Zone Management
Department of Commerce, NOAA
3300 Whitehaven Street, N.W.
Page Building #2, Room 327
Washington, D.C. 20235

District Chief, WRD
USGS
208 Carroll Bldg., 8600 LaSalle Rd.
Towson, MD 21204

District Chief, WRD
USGS
P. O. Box 1107
Harrisburg, PA 17108

Commandant
U.S. Coast Guard
400 7th Street, SW
Washington, D.C. 20590

Cammander
3rd District
Governors Island
NY, NY 10004

Regional Administrator
Region II EPA
26 Federal Plaza, Room 1009
New York, NY 10007

Chairman
Council on Environmental Quality
722 Jackson Place, N.W.
Washington, D.C. 20006

Regional Agencies

Mr. Gerald M. Hansler, Executive Director
Delaware River Basin Commission
P. O. Box 7360
West Trenton, NJ

Executive Director
DVRPC
3rd Floor Penn Towers
1819 J.F. Kennedy Blvd.
Phila., PA

Director WILMAPCO
Metropolitan Clearinghouse
2062 New Castle County
New Castle, DE 19720

State Agencies

Dr. Maurice K. Goddard, Secretary
Dept. of Environmental Resources
P. O. Box 1467
Harrisburg, PA 17120

Mr. Rocco D. Ricci, Commissioner
Dept. of Environmental Protection
P. O. Box 1889
Harrisburg, PA 17120

Mr. Austin P. Olney, Secretary
Dept. of Natural Resources & Environmental Control
Edward Tatnall Building
Dover, DE 19901

Dr. Theodore L. Hullar, Commissioner
Dept. of Environmental Conservation
50 Wolf Road
Albany, NY 12233

Clearinghouses

State Clearinghouse - Delaware
Delaware State Planning Office
530 E. DuPont Highway
Dover, DE 19901

State Clearinghouse - Pennsylvania
Pennsylvania State Planning Board
503 Finance Building
State Capitol
Harrisburg, PA

State Clearinghouse - New Jersey
Division of State & Regional Planning
Department of Community Affairs
P. O. Box 2768
Trenton, N.J.

County Agencies

Director
Bucks County Planning Commission
Administration Building, 6th Floor
Doylestown, PA 18901

Executive Director
Delaware County Planning Commission
Fronefield Building
214 North Avenue
Media, PA 19063

Chairman
Burlington County Planning Board
Burlington County Office Building
49 Rancocas Road
Mount Holly, NJ 08060

Chairman
Camden County Planning Board
Court House Annex
Pennsauken, NJ 08110

Chairman
Gloucester County Planning Board
Courthouse
Woodbury, NJ 08096

Director
Kent County Planning Commission
16 the Green
Dover, DE 19901

Chairman
Salem County Planning Board
Court House
Salem, NJ 08079

Director of Planning
New Castle County
Engineering Building
P. O. Box 165
Wilmington, DE 19899

Municipal Agencies

Chairman
Camden Planning Board
Municipal Building
6th & Market Streets
Camden, NJ 08101

Executive Director
Philadelphia Planning Commission
City Hall Annex 13th Floor
Philadelphia, PA 19102

Civic Associations

Gretchen Leahy
Pollution Control Group, Lower Bucks Co.
728 N. Pennsylvania Ave.
Morrisville, PA 19067

Mr. Langdon Warner
Environmental Defense Fund
1525 18th St. NW
Washington, D.C. 20036

DELAWARE RIVER BASIN COMMISSION
P. O. BOX 7360
WEST TRENTON, NEW JERSEY 08628
(609) 883-9500

GERALD M. HANSLER
EXECUTIVE DIRECTOR

HEADQUARTERS LOCATION
25 STATE POLICE DRIVE
WEST TRENTON, N. J.

January 27, 1978

Jerry

Dear Colonel Dutchyshyn:

Re: Salinity Intrusion Studies

In accordance with our agreement on January 17, 1978, members of our staffs have met and discussed (1) the purpose and objective of various elements of salinity intrusion studies; (2) the status of work completed or under way by the DRBC; (3) the elements that should receive priority attention with the available funds; and (4) a desirable timetable for completion of all elements.

The Commission's objectives in endorsing this series of salinity studies were to establish, through the most modern techniques available, (1) the relationship between quantities and duration of freshwater flows and the location and concentration of sea salts; and (2) the benefits which would accrue from controlling salinity intrusion or, conversely, the cost entailed in allowing sea salts to overrun existing installations, potential industrial sites, and groundwater recharge areas. With such facts in hand, the Commission will be able to evaluate the pros and cons of alternative water management programs, and adopt the best policy for meeting the overall needs of the Basin community.

The Commission has embarked upon and is nearing completion of mathematical modeling studies which will make it possible to readily answer flow-salinity questions. Based upon the anticipated success of this effort, we now believe that it will not be necessary to expend public funds for this phase of the work at the WES in Vicksburg, Mississippi. However, there is still some uncertainty concerning the effects of the recent enlargement of the Chesapeake and Delaware Canal on salinity levels in the Delaware estuary, and our currently funded study may not be able to resolve this question completely. This is a matter which may need your attention next fiscal year.

We anticipate that the daily flows being generated by the Corps for the State of Pennsylvania under "Section 22" will be useful, in conjunction with the mathematical model of salinity intrusion, in determining the recurrence interval of various salinity levels at critical locations along the estuary.

In the summer of 1976, the Commission staff, in co-operation with the WRA/DRB, initiated and completed a letter-questionnaire survey of the damage along the estuary resulting from historic intrusions of sea salts. While this effort provided some insight into the severity of the problem, it did not answer the benefit-cost questions. I view the economic evaluation of salinity intrusion and control as the highest priority work among those elements remaining to be done.

Our Level B Study is scheduled for completion by April 30, 1979. The amount of freshwater inflow to the estuary will be one of the fundamental planning considerations around which water management programs must turn. Therefore, every effort must be made to direct available funds toward answering this question. We will have developed answers to the flow-salinity questions, but we desperately need defensible answers to the economic questions. The funds appropriated to you appear to be the only ones now available that could be devoted in a crash effort that would bring timely answers.

I have reviewed the file on our efforts which resulted in funds being earmarked for your office to undertake a special salinity study. The letter dated July 27, 1976 to Congressman Robert E. Jones, Chairman of the Committee on Public Works and Transportation, initiated by Congressman Frank Thompson, Jr., and also signed by seven other Lower Basin Congressmen, states the importance and urgency of the task at hand, and suggests "a pass through /of funds/...to the Delaware River Basin Commission for use in supplementing the State funds as needed to complete other phases of the salinity intrusion study." These other phases include "...analysis of the impact of various potential levels of salinity on municipal and industrial water users along the estuary." The Congressmen noted that "assuming the timely availability of funds,... the salinity intrusion studies can be completed within fiscal year 1977."

As the DRBC was instrumental in obtaining Congressional endorsement of the $50,000 appropriation for the salinity study, I am confident that their use of H.D. 522, 87th, 22nd as the basic authorization did not foresee as broad-scope an effort as your staff seems to be contemplating. Indeed, with the numerous other studies currently under way by your office, other Federal and state offices and our own, I believe we should concentrate on those voids that need to be filled. The economic appraisal of salinity advance and retreat is just such a void.

I strongly recommend that the major portion of the current year's appropriation be directed to this matter so that a product will be available for use in the final report of the Level B Study.

Sincerely,

Jerry

Gerald M. Hansler

Colonel Harry V. Dutchyshyn
Corps of Engineers
2nd and Chestnut Streets
Philadelphia, Pennsylvania 19106

HAH - 1/31/78

Sea Salt Study

Estimated Cost

	Fiscal Year 1978 DRBC	Fiscal Year 1978 Corps	Fiscal Year 1979 DRBC	Fiscal Year 1979 Corps
1. Mathematical Modeling	$150,000	$10,000	-	
2. C & D Canal	8,000		$23,000	$ 50,000
3. Probability studies	-	-	8,000	40,000
4. Economic analysis	-	30,000	-	20,000
5. Hydraulic model	-	-	-	90,000
6. Reports	-	10,000	8,000	28,000
Totals	$158,000	$50,000	$39,000	$228,000

PLAN OF STUDY--FISCAL YEARS 1978-1979
SALINITY INTRUSION IN THE DELAWARE ESTUARY

1. Mathematical modeling - Complete June 30, 1978

The development of a mathematical model of salinity in the Delaware estuary is nearing completion. The model being used is a refined version of the Thatcher-Harleman (1972) model originally developed at the Massachusetts Institute of Technology (MIT).

The model will be used to generate salinity distribution throughout the estuary (here considered to include the entire tidal Delaware River from Trenton to Liston Point, as well as Delaware Bay from Liston Point to the Capes), for various scenarios of fresh-water discharge into the estuary. Initially, the model will be calibrated and verified using the observed fresh-water flows for the severe drought period from October 1, 1964, through September 30, 1965 (water-year 1965). Then the flows will be adjusted to simulate any combination of reservoir storage capacity added since 1965, or anticipated to be added in the future. Flow adjustments will be made also to reflect decreasing "excess releases" from New York City's upper-Basin reservoirs, in accordance with the Montague formula specified in the U. S. Supreme Court decree of 1954. The flows into the estuary will be modified also to show the effect of increasing consumptive use of water within the Delaware River Basin, and increasing diversions of water out of the basin. Finally, to the extent that the change in the flows through the Chesapeake and Delaware Canal as a result of its recent enlargement can be determined, these altered flows will be simulated in the model to show the effect, if any, on the distribution of salinity in the Delaware estuary.

In addition to water-year 1965, water years 1970 and 1975 will also be simulated to show the extent and duration of salinity intrusion in a medium-flow and a high-flow year, respectively. The results of the three base-period simulations should shed light on the range of annual average salinity conditions in the Delaware estuary. Additional simulations, reflecting the flow changes resulting from changes in storage capacity consumptive use, interbasin transfers, and enlargement of the C & D Canal, will provide a basis for an approximating economic analysis of the resulting changes in salinity.

2. Chesapeake and Delaware Canal - Start August 1, 1978 - Complete February 28, 1979

Although several studies of limited scope have been conducted to determine the exchange of water between the Chesapeake Bay and the Delaware estuary through the Chesapeake and Delaware (C & D) Canal, there remain considerable uncertainties regarding the quantity and quality of water flowing through the canal. These uncertainties need to be resolved before the effects of the canal and its recent enlargement on the salinity in the Delaware estuary can be determined with confidence. Such determination is a prerequisite to the determination of the relationship between controlled flows in the Delaware River at the mouth of the Schuylkill River and salinity distribution in the estuary.

It is anticipated that some field work will be required to determine accurately the characteristics of the flow through the C & D Canal. Such field work probably will require measurements of salinity at two or more locations along the length of the canal, in addition to flow measurements and tide observations in the canal, during a period of several weeks.

3. Probability studies - Start October 1, 1978 - Complete February 28, 1979

In order to refine the economic evaluation of projected or proposed flow changes, it will be necessary to simulate a series of 12-month periods--enough such periods to construct a frequency curve showing the probabilities of various levels of annual average salinity levels at specific locations along the estuary. These frequency curves will be developed for sets of two scenarios. The first scenario of each set will show the probabilities for a base-flow condition, such as natural flows. The second scenario will show the probabilities for a modified-flow condition, for example, to show the potential effect of an increased diversion to northeastern New Jersey. The change in probability of salinity intrusion must then be transformed into a change in cost of using water from the increased-salinity reaches of the estuary.

4. Economic analyses - Start May 1, 1978 - Complete December 31, 1978

Derivation of the costs of using the brackish waters of the estuary will require the use of salinity-damage functions for typical water-users along the estuary. Such damage functions are related to the cost of treating water of various salinity levels, or to the cost of switching to alternative supplies when the salinity of the water in the estuary at a given intake reaches intolerable levels for any purpose. Information needed for development of these costs include the levels of various salts that can be tolerated for given water uses. For example, the Scott Paper Company plant at Chester, Pennsylvania, can use the river water when the chloride concentration is as high as 75 mg/l, but for higher concentrations, the plant must curtail normal production or switch to the more costly municipal water supply of the Chester Water Authority, which imports water from the Susquehanna River Basin.

Many industries do not have an alternative source of water to select when salinity levels in the estuary reach intolerable levels. These industries, therefore, must curtail operations or incur added expense for treating the high-salinity water taken from the estuary. For example, some industries demineralize the river water for use as boiler-feed water. The cost of demineralization is approximately directly proportional to the concentration of dissolved solids in the raw water. Many of these same industries, as well as others, use water from the tidal river for cooling purposes. Much of the cooling water is treated for control of fouling organisms or corrosion. The costs of these treatments generally increase with salinity of the intake cooling water.

Salinity-cost functions must be developed not only for industries that are self-supplied with estuary water, but also for industries, households, and other water users that obtain their water from municipal water systems that use the estuary as a source of raw water. This applies not only to those municipal systems that currently (in 1978) use estuary water, but also those that can be expected to use this water in the future. For example, the City of Chester expects--within the foreseeable future--to meet its growing demands for water by taking water from the Delaware River to supplement its diversion from the Susquehanna River Basin. The cost of this dual-source water system, when implemented, will be proportional to the frequency and duration of intolerable levels of salinity in the Delaware estuary.

The economic analysis of water supplies as related to salinity necessarily must consider not only those systems that take water directly from the estuary via a pipe in the tidal waterway, but also those systems that take the river water indirectly via aquifers and wells that are recharged in part by the tidal river. Therefore, it will be necessary to identify all such ground-water users along both sides of the estuary from Trenton to Delaware Bay, and to develop collective or individual salinity-cost functions for these water users.

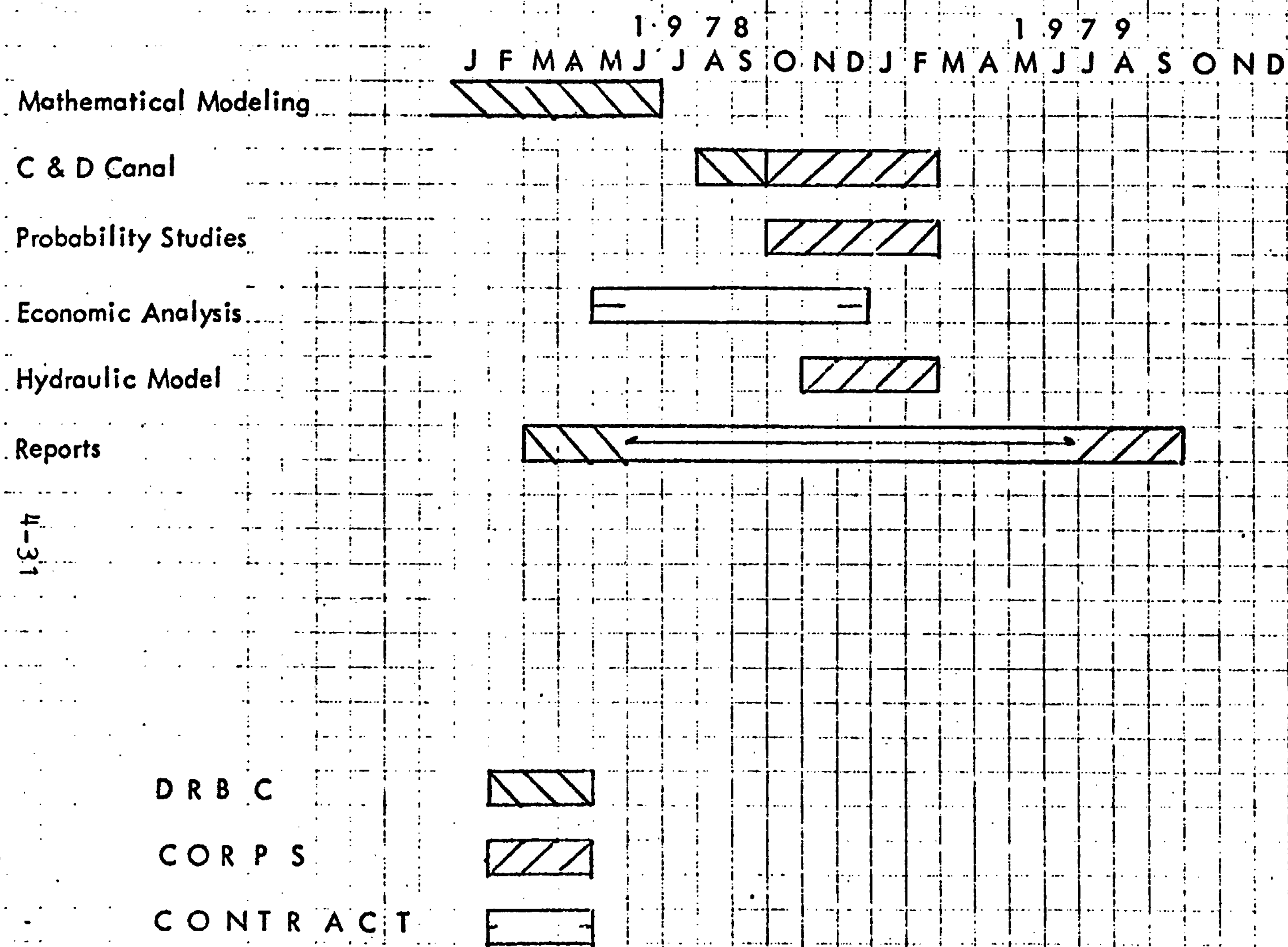
The salinity cost or damages functions will be used in conjunction with the probability analyses of various salinity levels to develop average annual costs of using or avoiding the salt-laden waters of the Delaware estuary. These average annual costs can, in turn, be used by decision makers to judge the economic justification of such measures as stream impoundments and flow regulation for salinity control, transbasin diversions, and increased consumptive use.

5. <u>Hydraulic modeling</u> - Start November 1, 1978 - Complete February 28, 1979

The Waterways Experiment Station (WES) of the Corps of Engineers at Vicksburg, Mississippi has constructed a hydraulic model of the Delaware estuary, and has used this model to study various aspects of the salinity-intrusion problem in the estuary. The hydraulic model is to be used to check key results of the mathematical modeling.

6. <u>Reports</u> - Start March 1, 1978 - Complete September 30, 1979

CHJH--DRBC--January 31, 1978



1978
1979
J F M A M J J A S O N D J F M A M J J A S O N D
Mathematical Modeling
C & D Canal
Probability Studies
Economic Analysis
Hydraulic Model
Reports
D R B C
C O R P S
C O N T R A C T

DRBC 1 31 78

DELAWARE RIVER BASIN COMMISSION
P. O. BOX 7360
WEST TRENTON, NEW JERSEY 08628
(609) 883-9500

GERALD M. HANSLER
EXECUTIVE DIRECTOR

HEADQUARTERS LOCATION
25 STATE POLICE DRIVE
WEST TRENTON, N. J.

August 27, 1980

Dear Colonel Ton:

This is in response to your letter of August 12, 1980, in which you requested confirmation of the understanding of the goals and roles of the Corps of Engineers and the Delaware River Basin Commission in the Delaware River Salinity Intrusion Study.

The Delaware River Salinity Intrusion Study has been an outstanding example of interagency cooperation from the very beginning. The forthcoming policy decisions of the Delaware River Basin Commission on salinity flow objectives will be based upon (1) technical analysis aided by use of the Thatcher-Harleman Transient Salinity Intrusion model, (2) your first-cut economic impact studies, and (3) environmental assessments of alternative water management options conducted on an element of the Water Resources Council sponsored Level B Study. These policy decisions will be amended into the Commission's Comprehensive Plan, and will also be reflected in agreements among the parties to the 1954 Supreme Court Decree in New Jersey vs. New York (347 U.S. 995 (1954).

The Commission has been informed that your analysis of the C&D Canal has not been completed and that some uncertainty regarding the quantity of fresh water required to control salinity will remain until your effort is concluded in FY 1982. However, overriding considerations dictate commitments during this calendar year. The range of conclusions which may result from your study has been weighed, and we believe that construction schedules for upstream storage projects to repel salinity can be altered, if necessary, when the C&D technical findings are in hand.

I appreciate the timely assistance you have provided during the course of this cooperative venture, and assure you of our continued support in the future.

Sincerely,

Jerry Hansler

Gerald M. Hansler

Colonel James G. Ton, District Engineer
U. S. Corps of Engineers
Custom House
Second and Chestnut Streets
Philadelphia, Pennsylvania 19106

UNITED STATES WATER RESOURCES COUNCIL

SUITE 800 • 2120 L STREET, NW WASHINGTON, DC 20037

October 20, 1981

Mr. Gerald M. Hansler
Executive Director
Delaware River Basin Commission
P.O. Box 7360
West Trenton, NJ 08628

Dear Mr. Hansler:

We are pleased to receive the final report of the Delaware River Basin Level B Study. The report reflects the excellent work done by the Commission and its staff during this study of the basin's water resource planning needs. As you know, the Council has on several occasions singled out the results of this effort as examples of what can be accomplished through a well managed Level B study.

The plan presented in the final report is more than adequate in meeting our guidelines for Level B studies and fully satisfies the conditions in our Memorandum of Agreement.

Since the Council's future is still uncertain we regret that we do not anticipate being able to present the report to the Council of Members in the near future. I would, however, encourage you to make the final report widely available to the appropriate Federal representatives.

Sincerely,

Gerald D. Seinwill

Gerald D. Seinwill
Acting Director

Enclosure

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Suite 322
315 South Allen Street
State College, PA 16801

February 16, 1982

Lt. Colonel Roger L. Baldwin
District Engineer, Philadelphia District
U.S. Army Corps of Engineers
Custom House, 2nd & Chestnut Sts.
Philadelphia, PA 19106

Dear Colonel Baldwin:

This responds to Mr. Sheridan's letter dated December 31, 1981, requesting Fish and Wildlife Service (Service) review and comment on the draft Technical Appendix on Fish and Wildlife and Insert into Main Report prepared by the Philadelphia District, Corps of Engineers, for the Delaware Estuary Salinity Intrusion Study. The following comments were prepared in accordance with provisions of the Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 et seq.), but do not constitute the report of the Secretary of the Interior within the meaning of Section 2(b) of the Act.

The Service concurs with most of the appendix and insert to the main report. Much of the wording is taken directly from our final planning aid report, dated July 1981, which summarized the Service's contributions to the study. Areas of disagreement are primarily technical in nature and were communicated by telephone to members of your planning and environmental staff. Unfortunately, the value of this study is minimized because the appendix and insert stop short of recommending ways to protect the Delaware estuarine ecosystem against natural or man-induced changes in the salinity regime. We repeat the most important conclusion and only recommendation contained in our final planning aid report:

1. Increasing salinity within the Delaware estuary during spring would decrease estuarine productivity, the magnitude of decline dependent on the degree of change.

2. Interruption and temporary storage of freshwater outflow should be avoided or minimized during spring (April 1 to July 1) to protect and maintain the health of the Delaware estuarine ecosystem.

Our conclusion and recommendation are not new. During planning discussions for the proposed Tocks Island Dam, we expressed concern about the effect of an altered salinity regime on the American oyster. Eventually, this problem was solved when the Corps agreed to modify the project rule curve and operations to preclude storage beginning April 1. Although the Tocks Island project would have been a major threat to the natural salinity regime, the combination of several smaller reservoirs could have the same undesirable effect.

The Service is pleased to have participated in this study. We ask that the Corps consider and respond to these comments.

Sincerely,

Charles J. Kulp

Charles J. Kulp
Field Supervisor

DEPARTMENT OF THE ARMY
Philadelphia District, Corps of Engineers
Custom House - 2d & Chestnut Streets
Philadelphia, Pennsylvania 19106

NAPEN-E

3 MAR 1982

Mr. Charles J. Kulp
Field Supervisor
U. S. Fish & Wildlife Service
315 S. Allen Street, Suite 322
State College, PA 16801

Dear Mr. Kulp:

Thank you for your Fish and Wildlife Coordination Act letter of 16 February 1982 which contains the Service's comments on the Delaware River Estuary Salinity Intrusion Study. We have considered your comments and believe it important to clarify certain matters essential to this study.

The purposes of the Corps' Salinity Study did not include "recommending ways to protect the Delaware estuarine ecosystem against natural or man-induced changes in the salinity regime", or making any specific recommendations. Rather the Corps' objective was to identify the effects resulting from salinity variation and where possible, the resulting costs. Management of the water resources in the Delaware River Basin is the direct responsibility of the Delaware River Basin Commission (DRBC) and the Commission was sponsor for this study as well as primary recipient of its results. DRBC would then utilize this study of which the ecosystem analysis is a part in management of the overall basin needs. Since this Corps' study was in effect a portion of a larger undertaking, we avoided a needless duplication of effort by adopting the findings and results of the Level B study prepared by DRBC. The Level B stream flows and related impoundment scenarios represent the best available data and management rationale for the Delaware River. The Corps recognizes the results of Level B were obtained after a long thorough formal process of planning, coordination and environmental impact review by all interested parties.

In consideration of this background to Level B and its further development by the Salinity Study, we disagree with the Service's comment that the value of the Salinity Study is minimized, due to a lack of Corps' recommendations. DRBC's Level B Report utilized information gathered by the Salinity Study in developing their preferred plan and concurred that "the adverse effects of storage of portions of available storage could be mitigated or eliminated by refraining from storing water in April and May". (Level B, page 34). This office will also include the Service in providing input for developing reservoir operating criteria for new projects.

We satisfied the stated objectives of the Salinity Study in developing a state of the art computer tool and, with your input and advice, resource impact information for use by the DRBC in future flow management decisions. The Corps is confident that the Commission will continue to include all factors, especially fish and wildlife resources, in reaching these decisions. Your own comment on the positive effect of Fish & Wildlife concerns in modifying the Tocks Island Lake regulation curve demonstrates the past basis or working toward mutually accepptable water management decisions.

Sincerely,

NICHOLAS J. BARBIERI
Acting Chief, Planning/Engineering Division

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Suite 322
315 South Allen Street
State College, PA 16801

March 15, 1982

Mr. Nicholas J. Barbieri
Acting Chief, Planning, Engineering Div.
U.S. Army Corps of Engineers
Philadelphia District
Custom House, 2nd & Chestnut Streets
Philadelphia, PA 19106

Dear Mr. Barbieri:

Thank you for your letter of March 3, 1982, addressing our February 16, 1982, comments on the draft Technical Appendix on Fish and Wildlife and Insert into Main Report prepared by the Philadelphia District for the Delaware Estuary Salinity Intrusion Study. While we appreciate your effort to "clarify certain matters essential to the study", we do not believe the Service has labored under a misconception of study objectives, their degree of achievement or the intended study use. Quite the opposite, we believe the Corps has departed from the original study objectives.

In our planning aid report to the Corps, dated July 1981, the Service quoted from Lieutenant Colonel Callahan's letter of December 30, 1977, to the Service which initiated the study. Two excerpts from the letter appear below:

> This Congressionally authorized study is to analyze the movement of salinity in the estuary and identify the amount of fresh-water flow in the Delaware River needed to protect water users of the estuary.
>
> The study will assess the problems and identify alternatives to diminish the detrimental effects of varying salinity.

These statements indicate that the Corps' study objectives were two-fold: to analyze the movement of salinity and to identify alternatives for reducing the detrimental effects of varying salinity on estuary users. Unfortunately, the second objective was not carried out, an apparent deference to water resource management responsibilities of the Delaware River Basin Commission. We do not doubt or dispute the overall river management role enjoyed by the Commission, however, it puzzles us to see this responsibility suddenly emphasized when it existed at the start of the study and, in fact, existed when the Corps agreed to modify the flow regulation curve for the proposed Tocks Island Dam. It also puzzles us that the Commission, which is the primary recipient of the study, completed the Level B study before the salinity study was finished. We still believe it is appropriate for the Corps to assess its findings and recommend to the Commission methods of protecting the estuary and its users. We are particularly interested in a recommendation about manipulation of spring flows. As noted in your letter, the Commission is already aware that adverse effects of storage on estuarine biota could be mitigated or eliminated by refraining from storing water in April and May. This awareness is reinforced by the results of the salinity study, and in our opinion, these results justify establishment of no storage during spring as standard operating procedure. This does not mean special circumstances cannot be considered, such as long term drought, chemical spills, etc. Extraordinary events could justify some variance to the procedure. The important thing is to establish a protective procedure first and then consider variations to it.

We regret that you disagree with our assessment of the value of the salinity study. However, unless the Corps interprets its findings and provides at least conceptual guidance, our assessment will not change.

Sincerely,

Charles J. Kulp
Field Supervisor

DELAWARE RIVER BASIN COMMISSION
P.O. BOX 7360
WEST TRENTON, NEW JERSEY 08628

(609) 883-9500

GERALD M. HANSLER
EXECUTIVE DIRECTOR

HEADQUARTERS LOCATION
25 STATE POLICE DRIVE
WEST TRENTON, N.J.

April 2, 1982

Dear Colonel Baldwin:

This is to supplement my letter dated August 27, 1980, regarding the Delaware Estuary Salinity Intrusion Study.

As you are aware, we have recently (May 1981) developed a "Level B" water resources plan for the Delaware River Basin. As part of that plan, a series of flow objectives, defined in terms of fresh water inflows needed to protect water users of the estuary, was determined. The specific goal, under the preferred plan, for the Delaware River flow objective was recommended to be 3,072 cfs at Trenton, New Jersey, during the low-flow season of a drought year. This represents the estimated level of flow regulation required to control invasion of sea salts so that the maximum 30-day average chloride concentration at River Mile 98 (5.5. miles upstream of the Schuylkill River) would not exceed 121 mg/l in the year 2000. Under another "mixed objective plan," the Trenton flow objective would be 2,605 cfs, which would control invasion of sea salts so that the maximum average chloride concentration at River Mile 98 would not exceed 180 mg/l in year 2000. It is anticipated that both of these salinity control flows and quality objectives will be subjected to public hearing later this year. Subsequent to that hearing, the Commission will select that level of flow and salinity control that will be included in the Comprehensive Plan, and be the driving force of the Basinwide water management plan, pursuant to the Compact.

Several early products of the Delaware Estuary Salinity Intrusion Study provided valuable input to our work. These products included both the Executive Summary, which contained preliminary estimates of potential salinity-related damages and preliminary simulations with the MIT-TSIM salinity-intrusion model. We are also aware of concerns raised by the U. S. Fish and Wildlife Service regarding protection of the estuarine ecology. These concerns were considered during the development of the Level B water resources plan discussed above. We will continue to consider these concerns in the further planning, development, and operation of specific projects.

The information developed as part of your study since the flow objective was determined has also been considered to see if changes are appropriate. In particular, we note that although the values in the Executive Summary have been revised to reflect more accurate data developed during the course of the study, these changes merely support our previous decisions. Also, the added detail that was not (until now) available due to the completion of Branched MIT-TSIM Model has and will continue to provide invaluable supporting data.

In summary, the Delaware Estuary Salinity Intrusion Study has been an outstanding example of coordination between our respective agencies, and I trust that similar cooperation will carry into future efforts.

Sincerely,

Jerry Hansler

Gerald M. Hansler

Lt. Colonel Roger L. Baldwin, District Engineer
U. S. Army Corps of Engineers
Second and Chestnut Streets
Philadelphia, Pennsylvania 19106

NAPEN-E

05 AUG 1982

Mr. Charles J. Kulp
Field Supervisor
U. S. Fish & Wildlife Service
315 South Allen Street, Suite 322
State College, PA 16801

Dear Mr. Kulp:

Under separate cover you were previously furnished a draft copy of the Delaware Estuary Salinity Intrusion Study for your review. As further discussed in our office on 20 July 1982 and by telephone, in order to complete our study, we request a letter from the Service indicating technical and other comments on the study document.

I request that your letter be returned to us not later than 16 August 1982. If you have questions on the document, please contact Dr. John Burnes at FTS: 597-4833 or 3931.

Sincerely,

NICHOLAS J. BARBIERI, P.E.
Chief, Planning/Engineering Division

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Suite 322
315 South Allen Street
State College, PA 16801

August 19, 1982

Lt. Colonel Roger L. Baldwin
District Engineer, Philadelphia District
U.S. Army Corps of Engineers
Custom House, 2nd and Chestnut Streets
Philadelphia, PA 19106

Dear Colonel Baldwin:

This responds to Mr. Nicholas J. Barbieri's letter, dated August 5, 1982, requesting the Fish and Wildlife Service's comments on the Delaware Estuary Salinity Intrusion Study (DRAFT), dated April 1982.

These comments provide technical assistance only and do not represent the review comments of the Department of the Interior on any forthcoming environmental statement.

The Service played an active role in the Delaware Estuary Salinity Intrusion Study; contributing eight planning aid reports that addressed the sensitivity of the estuarine ecosystem to altering the natural cycle of salinity change. The Service also reviewed an earlier draft of excerpts from the draft, submitting comments in letters dated Febuary 16, 1982, and March 15, 1982. These comments were followed by various communications between our offices, during which we were informed of a major change in the original intent of the study. We refer to Goal "B" or the "quantity flow" goal which was dropped in 1978 in deference to certain concurrent work activities undertaken by the Delaware River Basin Commission (DRBC). This refinement in study objectives greatly reduced the scope of the study and, in our opinion, minimizes the study's value. As far as we are concerned, the value of this study in assessing the impact of salinity intrusion on fish and wildlife has been lost if the Corps is unwilling to recommend measures which would minimize adverse impacts identified in the assessment.

There are certain deficiencies in the text which should be corrected in the final report. These and other comments follow the format of the document.

<u>Page 18</u>
The Table indicating "Periods of Drought" should be amended to indicate an official end to the 1980 drought in April 1982.

<u>Page 19</u>
According to the DRBC, the 250 mg/l chloride line advanced to RM 97.5 on February 2, 1981.

Page 23
To illustrate the importance of the first statement under "Fish and Wildlife," we suggest adding the following:

> For example, "after the New York City diversions commenced in 1953, the (oyster) drill line moved from just below Ben Davis Point almost to Ship John bed. Approximately 1,000 acres of Delaware State (oyster) seed beds and about 1,000 acres of the Shell Rock and Ben Davis beds in New Jersey were depleted by the loss of Delaware River flow." (From: URS/Madigan-Praeger, Inc. 1975. A Comprehensive Study of the Tocks Island Lake Project and Alternatives.)

Page 31
The second paragraph mentions that flow changes at Trenton influence lower estuary salinity after only a few days and that the "effects" may persist for many months. The term "effects" is unclear and should be explained.

Page 38
The Service strongly concurs with the statement that timing of flow into estuarine waters is important in its effect on productivity, stability and general health of the estuarine ecosystem. This importance was emphasized by the Corps and the Delaware River Basin Commission when both agencies agreed to modify the flow regulation curve of the proposed Tocks Island Reservoir, precluding storage after April 1.

Page 50
The last sentence in paragraph 1, ending "...overall availability over an extended period" makes no sense. Should "productivity" be substituted for "availability"?

Page 63
According to the DRBC, modification of Francis Walter and Prompton Reservoirs and construction of the Merrill Creek Reservoir will mean 20 percent of the basin's land runoff area will be controlled, more than double the current amount. We are not aware of any lower estuary spring flow requirements for the existing reservoirs or for the proposed reservoirs. Furthermore, there appear to be no limits on the timing of storage. With the amount of drainage to be placed under control at 20 percent and the absence of storage constraints, it is only a matter of time before the need arises to store significant amounts of spring flows, depleting supplies to the estuary. The resulting change in estuarine aquatic productivity may or may not be noticeable depending on how much fresh water is withheld and when. Certainly the possibility for a noticeable change increases as water supply demands increase and as new reservoirs are constructed to satisfy that demand. In our opinion, it is naive not to expect estuarine fauna to suffer from the increasing manipulation of their freshwater supply.

Page 65
We do not agree that the Level B cited plans reasonably considered the effects of salinity on the ecological system in determining the overall needs of the estuary. Examination of the Level B report and EIS shows that estuarine ecologic needs were considered in part and dismissed. Most consideration was given to the oyster seed beds which were shown to be adversely affected by

reduction in spring flow. We are not aware of DRBC consideration of other estuarine fauna or of efforts to protect these resources from manipulation of freshwater flow.

Page 66
See comment under Page 18.

Page 3-7
The word "neurosis" should be "necrosis."

Page 3-15
The number "28" should be "228."

As these comments demonstrate, the Service continues to believe in the need to modify reservoir operations (i.e. no storage after April 1) in order to maintain estuarine productivity. If the Corps is unwilling to support this concept, we request the final report state the Service's views on this matter.

Sincerely,

Edward Perry

for Charles J. Kulp
Field Supervisor

DEPARTMENT OF THE ARMY
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
CUSTOM HOUSE—2 D & CHESTNUT STREETS
PHILADELPHIA, PENNSYLVANIA 19106

INFORMATION BULLETIN

14 OCT 1982

DELAWARE ESTUARY SALINITY INTRUSION STUDY

The Philadelphia District Corps of Engineers has completed a study on the Salinity Intrusion of the Delaware River Estuary. This study is in response to a resolution of the House of Representatives' Committee on Public Works, adopted 23 September 1976.

In responding to the Congressional Resolution directing the Delaware Estuary Salinity Intrusion Study, the specific goals of the study were to determine the probability for advance or retreat of salinity in the Delaware Estuary, and the quantity of fresh water inflow needed to protect the various water users along the estuary.

The Corps of Engineers concentrated on addressing the first of these goals. Salinity-cost relationships were developed for all direct water users of the Delaware Estuary. The previously developed mathematical model (the Transient Salinity Intrusion Model of the Delaware Estuary) by the Delaware River Basin Commission was modified as part of this study to reflect the interaction of the Delaware Estuary and the Chesapeake and Delaware Canal. By comparing the results of these two computer models, the influence of the Canal on chloride concentrations was found to extend from Chester, Pennsylvania to Ship John Shoal, a distance of 45 miles. The modified model was used to simulate long term salinity concentrations incorporating the post-enlargement condition of the Chesapeake and Delaware Canal. Flow in the Canal has varied both in volume and direction. However, the long-term (50-year) average was calculated to be 6,560 cubic feet per second eastward. Long term salinity concentrations were also determined as part of the study which provided continuous data needed to determine the probabilities of salinity levels in the estuary.

In addition, the data from the long term model runs served as input to an economic model. That model was also developed as part of this study and was used to determine average annual costs to estuarine withdrawal water users. These costs are indicators of the expenses incurred by the water users such as replacing corroded parts and equipment, utilizing alternative water sources and treatment of the saline water. The results of this portion of the study indicated that the average annual salinity related costs to municipal and direct industrial users are 19.8 million dollars per year.

A range of possible impacts of salinity variation on fish and wildlife resources was also addressed. Impacts were found to be both positive and negative depending on relative species' preferences and sometimes life cycles within individual species.

The second goal was addressed by the Delaware River Basin Commission which has the responsibility for the control and development of the water resources of the Delaware River Basin. The Commission consolidated the results of this salinity study and other efforts, and determined a range of flow objectives for the protection of water users along the Delaware Estuary as part of their Delaware River Basin Comprehensive (Level B) Study. That study has been accepted by the Water Resources Council. The flow objectives as determined by the Commission were incorporated into this study. Close coordination was maintained with the Commission during the two studies. It is anticipated that future adjustments of the flow objectives will be made by the Delaware River Basin Commission through its long-term basin planning program. Under this program, interstate water management recommendations will be made to reflect continuous planning efforts regarding any changing conditions throughout the Basin.

You will be notified when the report is available documenting the above studies. In the interim, further information regarding the study may be obtained from the Office of the District Engineer, U.S. Army Corps of Engineers, Philadelphia District, Custom House, 2nd and Chestnut Streets, Philadelphia, Pennsylvania 19106. Should you have any questions, please contact Mr. John Murphy, Chief, Planning Branch, at (Area Code 215) 597-4839.

Frank M. Vinci
for NICHOLAS J. BARBIERI, P.E.
Chief, Planning/Engineering Division

DELAWARE RIVER BASIN COMMISSION
P.O. BOX 7360
WEST TRENTON, NEW JERSEY 08628
(609) 883-9500

GERALD M. HANSLER
EXECUTIVE DIRECTOR

HEADQUARTERS LOCATION
25 STATE POLICE DRIVE
WEST TRENTON, N.J.

November 12, 1982

Dear Colonel Baldwin:

This supplements my earlier letters of August 27, 1980, and April 2, 1982, regarding the Delaware Estuary Salinity Intrusion Study being conducted by your office.

We have reviewed a recently revised draft of the final report of the Salinity Intrusion Study. We find that the Corps' Study, together with the Commission's own studies of salinity intrusion in the Delaware estuary, has met the information needs that prompted the Commission's petition to Congress to authorize the study. Due to effective coordination efforts by your staff, the DRBC staff has been kept informed of the Corps' findings throughout the Corps' Salinity Intrusion Study.

The Delaware Estuary Salinity Study has provided much useful information on the ecologic and economic impacts of salinity in the Delaware estuary. This information proved to be of value in formulating alternative plans, as presented in the Commission's Level B Report, for consideration by the Basin community. The Corps' modification of the DRBC's mathematical salinity model of the Delaware estuary to include the Chesapeake and Delaware Canal as a tidal branch and the results obtained with the branched model were more helpful in assessing the effects of the canal on Delaware estuary salinities. The economic model developed and used by the Corps provided evaluations of the salinity-related costs incurred by water users along the estuary. We anticipate that these models and the data presented in the study report will continue to be useful in the continuing planning programs of this Commission.

I congratulate you and your staff on bringing this difficult and complex technical study to a successful conclusion. This Commission has the remaining task of establishing salinity-control objectives for the Delaware estuary. Since my April 1982 letter, we have continued efforts to resolve the question of salinity standards and minimum flows needed in the Delaware River for salinity control.

We very much appreciate the opportunity to review the draft report of the Delaware Estuary Salinity Intrusion Study, and we look forward to receiving a copy of the published document.

Sincerely,

Jerry Hansler

Gerald M. Hansler

Lt. Colonel Roger L. Baldwin, District Engineer
U. S. Army Corps of Engineers
Second and Chestnut Streets
Philadelphia, Pennsylvania 19106

DELAWARE ESTUARY SALINITY INTRUSION STUDY

PERTINENT CORRESPONDENCE

US Army Corps of Engineers
Philadelphia District

APPENDIX 4

DELAWARE ESTUARY
SALINITY INTUSION STUDY

APPENDIX 4
PERTINENT CORRESPONDENCE

TABLE OF CONTENTS

INTRODUCTION

This appendix includes correspondence pertinent to the Delaware Estuary Salinity Intrusion Study. During the Plan of Study coordination was initiated with regional, Federal, State and County agencies. Throughout Stage 2, coordination continued with extensive liaison being maintained with the study sponsor, the Delaware River Basin Commission (DRBC), and U.S. Department of Interior, Fish and Wildlife Service. Pertinent correspondence is included in this appendix. An Executive Summary was prepared in 1980 and distributed to all water users and interested parties. The Executive Summary documented the results of the Phase 1 Economic Study (see page 40) and indicated estimates of salinity-related costs (i.e. replacement of corroded parts and equipment, use of alternative water sources, and treatment of saline water). Agencies which provided input during the course of the study are:

a. U.S. Geological Survey - data on stream flow and water quality.

b. National Oceanic and Atmospheric Administration - tide data, temperature, and density.

c. U.S. Fish and Wildlife Service - inventory of fish and wildlife resources, salinity impacts on estuarine fish and wildlife.

d. National Fisheries Service - literature search and input to Fish and Wildlife Service work.

e. U.S. Bureau of Census - population data.

f. Delaware River Basin Commission - inventory of estuarine water uses, water quality, population data, water management plans (flows), MIT-TSIM Model, and advice concerning development of MIT-TSIM Branched Model.

g. Delaware Valley Regional Planning Commission - regional and local population and economic projections and inventory data.

h. Delaware Department of Natural Resources and Environmental Control, Division of Fish and Wildlife - input to Fish and Wildlife work.

i. Pennsylvania Department of Environmental Resources - State Water Plan.

j. Pennsylvania Fish Commission - input to Fish and Wildlife work.

k. New Jersey Department of Environmental Protection - State Water Plan; Division of Fish Game and Shellfisheries - input to Fish and Wildlife Service work.

l. New Castle County Planning Commisssion - water use, population data.

m. Chesapeake Bay Institute - salinity and tide data.

n. Water Resources Association of the Delaware River Basin - provided assistance in surveys of industrial water use and distributed the Executive Summary to water users.

In lieu of holding a final public meeting, an Information Bulletin was used as a vehicle to coordinate the conclusions of the study with interested agencies and parties. A copy of this bulletin is included in this appendix.

During the final coordination efforts with U.S. Department of Interior, Fish and Wildlife Service, this office received comments on the draft final report in a letter dated 19 August 1982, (included in this appendix). These comments were considered in the preparation of the final report. However, several of the comments are clarified in the following paragraphs.

Concerning the "quantity of flow" (goal b), it is the opinion of the Service that the value of the study is minimized by deference to concurrent work done by DRBC. The approach used in this study, as documented in the Reconnaissance Report dated December 1978, intended incorporation of ongoing DRBC efforts, particularly the Level B Study which responded to the quantity of flow goal. This approach was adopted in an attempt to avoid duplication of effort. The Service was involved with the Plan of Study (during which the decision for this approach was reached), the ensuing Stage 2 activities, (during which time the approach and tasks outlined in the Plan of Study were carried out) and the Level B Study (during which the activities concerning quantity of flow were carried out).

During the Level B Study, opportunity to provide inputs to the quantity-of-flow objective was afforded to all agencies, and these inputs have been considered by DRBC in addressing this objective. It is the view of the Corps of Engineers that it would be duplicative to repeat DRBC's efforts, and, furthermore, such duplication would not improve the outcome. It is emphasized that the results of the Level B Study have been accepted by the Commission (which includes the Governors of the affected States and the Secretary of the Interior), and by the Water Resources Council.

The Service is also concerned that the Corps is unwilling to recommend measures to minimize adverse impacts, particularly regarding spring flow requirements as affected by storage runoff in existing or proposed reservoirs. In the Service's view, these requirements are necessary to protect estuarine fauna from manipulation of freshwater flows and to maintain estuarine productivity. While the resolution of these concerns is beyond the scope of this study, these issues were considered by the DRBC Level B Study and the overlapping negotiations among the parties to the 1954 Supreme Court decree that allocates the waters of the Delaware River among the Basin States. Further consideration can be given as part of the site-specific project studies and public hearings that will be required under the Delaware River Basin Compact before construction of any new impoundment. The Corps is willing to participate in these continuing efforts. However, the Corps recognizes that multipurpose reservoir operation is an extremely complex issue involving many factors, not just estuarine ecology.

It is emphasized that normal reservoir operation prefer filling available long-term storage capacity prior to spring and in most years the reservoir would be filled before April. It is the opinion of this office that the establishment of a set of defined individual operating criteria for each reservoir is the best vehicle for maximization of project benefits and minimization of adverse effects.

Extensive coordination was maintained with the Delaware River Basin Commission throughout the conduct of the Study. DRBC provided review and technical assistance in the development of data and analysis. Pertinent correspondence is included in this appendix.

FRANK THOMPSON, JR.
4TH DISTRICT, NEW JERSEY

COMMITTEES:
EDUCATION AND LABOR
CHAIRMAN, SUBCOMMITTEE ON LABOR-MANAGEMENT RELATIONS
HOUSE ADMINISTRATION
CHAIRMAN, SUBCOMMITTEE ON ACCOUNTS
MEMBER, DEMOCRATIC STEERING AND POLICY COMMITTEE
MEMBER, BOARD OF TRUSTEES, JOHN F. KENNEDY CENTER FOR THE PERFORMING ARTS

3

Congress of the United States
House of Representatives
Washington, D.C. 20515

WASHINGTON OFFICE:
2109 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, D.C. 20515

WILLIAM T. DEITZ
ADMINISTRATIVE ASSISTANT

ROBERT A. REVELES
EXECUTIVE SECRETARY

DISTRICT OFFICES:
10 RUTGERS PLACE
TRENTON, NEW JERSEY 08618

201 ROUTE NO. 516
OLD BRIDGE, NEW JERSEY 08857

July 27, 1976

Honorable Robert E. Jones, Chairman
Committee on Public Works and Transportation
2165 Rayburn Office Building
Washington, D.C. 20515

Dear Mr. Chairman:

The Delaware River Basin Commission has proposed a study of salinity intrusion in the Delaware River estuary to resolve certain questions left unresolved by the 1975 study by URS/Madigan-Praeger of the Tocks Island Lake project. The DRBC member representing the State of New Jersey has assigned the highest priority to this study, and the Basin States have committed some of the funds needed for the study. An additional amount of $100,000 is needed to carry out the study as proposed, including funds for hydraulic modeling of sea-water intrusion to be carried out by the Corps of Engineers using the existing physical model of the estuary located at the Waterways Experiment Station (WES) at Vicksburg, Mississippi. The Corps has estimated that the proposed WES modeling would cost from $60,000 to $70,000.

It has been suggested that Congress make a specific authorization of $100,000 to the Corps of Engineers for the purpose of carrying out the WES-modeling studies, with a pass-through of the excess over that needed by the Corps to the Delaware River Basin Commission for use in supplementing the State funds as needed to complete other phases of the salinity-intrusion study. These other phases include mathematical modeling and analysis of the impacts of various potential levels of salinity on municipal and industrial water users along the estuary. Assuming the timely availability of funds, it is anticipated that the salinity-intrusion studies can be completed within fiscal year 1977.

Our purpose in addressing you is to express our interest in this proposed study which is of such vital interest to the States of New Jersey, Delaware, and Pennsylvania, and to request your support to an authorization of $100,000 for the purposes outlined above. It occurs to us that such an authorization might be conveniently coupled with the proposed Corps' study of a "no dam" flood protection program for the Delaware River, as discussed in the letter of November 14, 1975, addressed to you from several Members of Congress. In any event, both of these studies are needed to evaluate various proposed alternatives to the Tocks Island Lake project.

We are,

Most respectfully,

Frank Thompson, Jr.

Rep. Frank Thompson, Jr.

Edwin B. Forsythe
Rep. Edwin B. Forsythe

William J. Green
Rep. William Green

James J. Florio
Rep. James J. Florio

Joshua Eilberg
Rep. Joshua Eilberg

Robert N.C. Nix
Rep. Robert N.C. Nix

Rep. Edward G. Biester, Jr.

Robert W. Edgar
Rep. Robert W. Edgar

cc: Mr. James F. Wright
Lt. Gen. William Gribble

COMMITTEE ON PUBLIC WORKS AND TRANSPORTATION
U.S. HOUSE OF REPRESENTATIVES
WASHINGTON, D.C.

RESOLUTION

Resolved by the Committee on Public Works and Transportation of the House of Representatives, United States., that the Board of Engineers for Rivers and Harbors is hereby requested to review the report on the Delaware River Basin, New York, New Jersey, Pennsylvania, and Delaware, published in House Document 522, 87th Congress, 2nd Session, and other pertinent reports, with a particular view to determining the probability for advance or retreat of salinity in the Delaware Estuary and the quantity of fresh-water inflow needed to protect the various water users along the Estuary.

Adopted: September 23, 1976

ATTEST: Robert E. Jones
Chairman

U.S. GOVERNMENT PRINTING OFFICE 51-481-b

Requested by: Hon. Frank Thompson, Jr., Hon. Edwin B. Forsythe, Hon. William Green, Hon. James J. Florio, Hon. Joshua Eilberg, Hon. Robert Nix, Hon. Edward G. Biester, Jr. Hon. Robert W. Edgar

DELAWARE RIVER BASIN COMMISSION
P. O. BOX 7360
WEST TRENTON, NEW JERSEY 08628
(609) 883-9500

JAMES F. WRIGHT
EXECUTIVE DIRECTOR

HEADQUARTERS LOCATION
25 STATE POLICE DRIVE
WEST TRENTON, N. J.

October 12, 1976

Dear General Kelly:

As you know, the study of the Tocks Island Lake project directed by the Congress in August 1974 and completed in July 1975 left unresolved the question of the need for fresh-water flow into the Delaware estuary for control of sea-water intrusion. Conducted by URS/Madigan-Praeger, the salinity study was found by the Delaware River Basin Commission staff to be invalid in certain respects and incomplete in others. This staff view was generally concurred in by a panel of estuarine experts called together by the DRBC to review the salinity intrusion aspects of the URS report. At a meeting in Newark, New Jersey, on July 17, 1975, these internationally recognized experts recommended additional study of the salinity-flow relationships, using both mathematical and hydraulic modeling techniques, as well as observations of the prototype estuary itself.

As a result of the experts' recommendation, the DRBC directed its staff to prepare a plan of study designed to resolve the unanswered questions relating to the salinity intrusion problem, and also directed the staff to seek funds to support such a study. Accordingly, in September 1975 the staff prepared a plan of study, a copy of which is enclosed.

Since September 1975 we have contacted various agencies and the Congress seeking financial assistance for the proposed salinity study. As you know, in late January 1976 we conferred with you on the possibility of Corps of Engineers' funding of the salinity study under some existing authorization. It was your opinion that a specific authorization by Congress would be needed before you could request an appropriation of funds for the salinity study.

Through the efforts of several Congressmen from the Delaware Basin area, the Committee on Public Works and Transportation of the House of Representatives adopted a resolution on September 23, 1976, requesting that the Board of Engineers for Rivers and Harbors review the report on the Delaware River Basin (House Document 522, 87th Congress, 2nd Session) to determine the probability of salinity in the Delaware estuary and the quantity of fresh-water inflow needed to protect the various water users along the estuary. It is our understanding that this resolution constitutes the specific authorization that you had earlier indicated would be needed before the Corps [illegible]

Hon. William Green, Hon. James J. Florio, Hon. Joshua Eilberg, Hon. Robert Nix, Hon. Edward G. Biester, Jr. Hon. Robert W. Edgar

During our discussion of this matter in your office on October 5, 1976, you expressed the view that although the Congressional resolution of September 23 meets the need for a specific authorization for the salinity study, a Corps request for an appropriation for this purpose would depend upon priorities for allocation of the limited total budget assigned to the North Atlantic Division. In setting your priorities, it may be useful to know that our Commissioners, in establishing our program for the near future, have assigned the highest priority to the resolution of the salinity intrusion issue. They recognize that such resolution is necessary not only to determine the ultimate disposition of the Tocks Island Lake project (construction or deauthorization), but also to determine the construction timing and operation of all proposed storage reservoirs in the Delaware River Basin, including the several major multipurpose impoundments authorized for construction by the Corps of Engineers.

Regarding the Tocks Island project and its relation to the salinity study, Governor Byrne of New Jersey has emphasized the importance of the salinity study with respect to the deauthorization of this Corps project. In his letter of July 25, 1976, to Senator Mike Gravel, Chairman of the Subcommittee on Water Resources of the Senate Committee on Public Works, Governor Byrne urged the Subcommittee to defer action on deauthorization and noted that the DRBC has begun to evaluate the suggestion that a reduced standard for minimum water flow in the Delaware River at Trenton may not risk undue intrusion of sea salts to downstream municipal and industrial water supplies. Governor Shapp of Pennsylvania, in his statement presented to the Subcommittee on July 23, 1976, also opposed deauthorization, and stressed the need for maintenance of river flows to help control salinity in the estuary. Governor Tribbitt of Delaware, in a statement presented to the Subcommittee, also noted the salinity question and other unresolved issues in arguing that deauthorization of the Tocks Island project now would be premature.

New Jersey has recently initiated a major study and preparation of a state water supply master plan, and this study will consider the viability of proposed diversions of water from the Delaware River to meet the needs of northeastern New Jersey. The results of the proposed salinity study will be a necessary input to the evaluation of any such diversion.

Current water quality planning efforts by the Delaware Valley Regional Planning Commission and other agencies under Public Law 92-500 and other legislation are dependent to a significant degree on knowledge of the flow that will be available in the Delaware River at Trenton for assimilation of treated wastes discharged into the upper estuary. The dependable river flow that necessarily will be used as a basis for design of wastewater treatment facilities will be determined by the need for sustained minimum regulated flows for control of sea-water intrusion. Rational planning for pollution abatement in the estuary cannot proceed very far without determination of the fresh-water flows that are to be provided for salinity control. This fact alone supports a high priority for the salinity study.

I cannot emphasize too strongly the importance of the salinity-control issue in relation to all of the active long-term storage capacity called for in the Comprehensive Plan, not just that portion of the total authorized capacity that would be provided by the Tocks Island Project. The widely held but invalid impression, created by the 1975 URS/Madigan-Praeger report, that low-flow augmentation is not needed for salinity control, was a key factor in the success of the Tocks Island project opponents in halting that project. If this impression prevails, it will promote similar opposition to other Comprehensive Plan water-storage projects that are designed in part to contribute to salinity control. Until the incomplete URS salinity study is supplemented by an authoritative comprehensive study to resolve the issue, it will be difficult to proceed with construction of any of the authorized storage projects, including those proposed by the Corps of Engineers.

Another factor in the question of Corps priorities is the relationship between the salinity intrusion study and the current comprehensive water resources study of Burlington, Camden, and Gloucester Counties of New Jersey by the Philadelphia District of the Corps of Engineers under its Urban Studies Program. The water supply aspects of this tri-county study are closely related to the recharge of aquifers along the Delaware estuary by the tidal waters of the Delaware River and its sea-level tributaries. No firm conclusions regarding water supply for this region can be made in the absence of more precise information than is now available on the salinity-flow relationship. The salinity study is designed to provide such information.

Regarding financing of the proposed salinity study, you should be aware that we have received commitments from the Basin States to provide \$60,000 directly to the DRBC for support of the study. In addition, New York State has requested transfer of "Section 214" funds from several Corps of Engineers districts to the Philadelphia District for use in conducting salinity modeling tests planned as part of the study, to be carried out with the hydraulic model of the Delaware estuary at the Corps' Waterways Experiment Station at Vicksburg, Mississippi.

We have also asked the Environmental Protection Agency to consider the possibility of EPA funding of part of the proposed salinity study. Although we have received no written response, informal discussions with EPA officials have indicated that although they recognize the need for, and importance of, the salinity study, that agency has no funds available to allocate to that purpose.

We have also contacted the U.S. Water Resources Council for possible funding of the salinity study by a grant under that agency's special studies program. To date, we have received no response except a WRC request for additional information concerning the proposed study, which we have supplied. In the meantime, because of the current Corps authorization, I have advised the Water Resources Council that the request is to be held in abeyance at this time.

In requesting a review of House Document 522, the House Committee on Public Works has recognized the important significance of the salinity issue as it relates to the federally authorized projects for multipurpose development of the water-resources of the Delaware River Basin. I believe the salinity issue merits a very high priority with respect to implementation of authorized storage impoundments in the Basin, particularly the multipurpose reservoirs proposed for construction by the Corps of Engineers.

This Commission will be glad to cooperate with the Corps in this matter. It is our suggestion that funds be appropriated to the Corps adequate for the entire salinity study, with the Corps funding the hydraulic modeling work at the Waterways Experiment Station in Vicksburg, and with a pass-through to the Commission of the remaining funds appropriated, to be used by the Commission in carrying out the mathematical modeling and other aspects of the study as outlined in the Plan of Study.

The Waterways Experiment Station has recently informed us that the basic cost for preparing the hydraulic model and operating it for calibration, verification, and three test runs will be $66,000, including a 10 percent contingency item. The three test runs would include simulation of the 1965 hydrographic data with (1) net flow eastward through the enlarged Chesapeake and Delaware Canal; (2) net flow westward through the C & D Canal; and (3) one additional set of data consistent with projected streamflow modifications resulting from post-1965 storage impoundments, increased consumptive use and diversions of water, and releases from storage. The three runs for which the WES estimate is now $66,000 are fewer than we had earlier had in mind when we discussed the study with WES and received an estimate of $60,000. The estimated cost has changed but little, but the scope of work has been significantly reduced within the estimate. However, it appears that the $260,000 reported to Congress by the Corps will be adequate to cover the cost of additional model runs deemed necessary to answer all pertinent questions, with enough remaining for the other parts of the study to be carried out by the DRBC.

Our staff members who will be particularly concerned with the salinity study are Mr. Herbert A. Howlett and Dr. C.H.J. Hull. We will welcome the opportunity for further consultation after you have reviewed this matter. I would hope that we might complete our joint planning and make adequate funding arrangements for the salinity study this fall so that we may be ready to initiate the study early in calendar year 1977.

Sincerely,

James F. Wright

James F. Wright

Brigadier General James L. Kelly, Division Engineer
U.S. Army Corps of Engineers - North Atlantic Division
90 Church Street
New York, New York 10007

September 15, 1975

Delaware River Basin Commission

Outline of Plan of Study
of
Salinity Intrusion in the Delaware Estuary

A. Need for study

B. Impact of salinity intrusion

1. Surface water users
    a. Municipal water supply users (by location)
        1) Domestic use
            a) Water quality criteria
        2) Industrial (supplied by public systems)
            a) Water quality criteria
        3) Commercial (supplied by public systems)
            a) Water quality criteria

    b. Self-supplied industries
        1) Location of industries
        2) Water quality criteria (for each industry)
            a) Process water (chlorides, TDS, etc.)
            b) Cooling water

2. Ground water users
    a. Municipal water supply users
        1) Domestic
        2) Industrial
        3) Commercial

    b. Self-supplied industries
        1) Location of industries (River mile)
        2) Water quality criteria (chlorides, TDS, etc.)
            a) Process water
            b) Cooling water
            c) Drinking water

3. Health and medical aspects of increased salinity

4. Economic effects of increased salinity

5. Ecological effects

C. Review of earlier studies

1. Terrenzio (1953)
2. Waterways Experiment Station (1952, etc.)
3. Pritchard, D. W. (1959)
4. Sheppard T. Powell and Legette and Brashears (1954)
5. Keighton (1965, etc.)
6. Paulson, R. W. (1969) (1970)
7. Thatcher and Harleman (1972)
8. United Engineers and Constructors (1974)
9. Strandberg (1975)
10. Madigan-Praeger, Inc. (1975)
11. Newark Salinity Seminar (1975)
12. Others

D. Water quality data

1. Types of data available (by location)
   a. Total dissolved solids
   b. Specific conductance
   c. Major sea-water ions
      1) Chlorides
      2) Sodium
      3) Sulphates
      4) Magnesium
      5) Calcium
      6) Potassium
   d. Relation between conductance and major ions.
   e. Other significant contaminants (e.g., silica)

E. Hydrologic data

1. Observed flows at various locations

2. Natural runoff (USGS studies for DRBC)

3. Synthetic flows at Trenton (Madigan-Praeger)

4. Synthetic flows for tributaries (???)

F. Land-based sources of dissolved salts

1. Delaware River at Trenton (flow and quality)

2. Tributaries (Locate by river mile and characterize by hydrological and water-quality data)

3. Point sources (location, volume, and quality)
    a. Municipal wastewater outfalls
    b. Municipal stormwater outfalls
    c. Industrial wastewater outfalls

4. Non-point sources
    a. Road salts
        1) Pennsylvania (below Morrisville)
        2) New Jersey (below Trenton)
        3) Delaware
    b. Other non-point sources

G. Relationship between fresh-water inflow and sea-water intrusion

1. Proposed studies
    a. Prototype study--analysis of relationship between observed flows and salinity distribution
        1) Drought of 1960's
        2) Other years
        3) Typical chloride profiles
    b. Deterministic model study (Thatcher model)
        1) Calibration and verification (Using data from drought period)
        2) Determination of future salinity distribution
            a) For typical droughts of past adjusted for flow regulation (releases from storage and depletive use)
            b) Probability of exceeding various salinity levels at given locations throughout estuary (derived by combining synthetic fresh-water inflows for all tributaries with Thatcher deterministic model)

c. Hydraulic model study (Waterways Experiment Station, Vicksburg, Miss.)
   1) Calibration and verification (using data from drought of 1960s)
   2) Determination of future salinity distribution
      a) For typical dry years of record, adjusted for existing and proposed flow regulation (storage, releases, diversions, and consumptive use)

H. Benefits from salinity control

1. Estimated monetary value of salinity reductions for various degrees of flow regulation
   a. Municipal water supplies
      1) Surface supplies
      2) Ground-water supplies
   b. Industrial water supplies
      1) Surface supplies
      2) Ground-water supplies
   c. Fisheries (including shellfish)

<u>Narrative summary</u>

It is proposed to conduct or sponsor a comprehensive study of salinity intrusion in the Delaware estuary to determine the fresh-water inflow needed to protect the various water users along the estuary from Trenton to the oyster beds near the head of Delaware Bay. The year-round distribution of salinity in the estuary for various levels of depletive water use and streamflow regulation in the Delaware River Basin will be determined using synthetic hydrology coupled with a deterministic mathematical model. Synthetic fresh-water inflows for the Delaware River at Trenton and for various other significant tributaries will be developed for use in the analysis of the probability of exceeding various salinity (or chlorinity) concentrations at given locations at different seasons of the year. The synthetic fresh-water flows will be adjusted as appropriate to take into account the existing and projected levels of flow regulation by impoundments and by depletive use (in-basin consumptive use and out-of-basin diversions).

At attempt will be made to show the effects of non-sea salts as well as sea salts on the total salinity and chlorinity in the upper estuary. This will be done by using model inputs of salts to represent the waste discharges of major industries and municipalities.

The study would include a survey of all existing municipal and industrial water users along the estuary from Trenton to the Bay to determine their quality needs with respect to salinity (total dissolved solids), chlorinity, and other sea-water ions. An attempt will be made to assign costs to these water users as a function of sea-water intrusion (or as a function of the frequency and duration of salinity concentrations).

Damages attributable to decreased flows (caused by storage or depletive use) will be assessed. Benefits (reduction in damages) that would be expected for various levels of low-flow augmentation will also be estimated. To the extent possible, damages of salinity intrusion and benefits of salinity control will be estimated as average annual values.

The effect of the enlargement of the Chesapeake and Delaware Canal on salinity distribution in the Delaware estuary will be evaluated, both for (1) normal runoff conditions in the Susquehanna-Chesapeake Bay drainage area when salinity in the upper Chesapeake Bay is low; and (2) for drought conditions in the Susquehanna-Chesapeake Bay drainage area when salinity in the upper Chesapeake Bay is relatively high.

It is anticipated that the synthetic flows for the Delaware River at Trenton developed by Madigan-Praeger (1975) for the review of the Tocks Island Lake project will be available and useful for the proposed new study of salinity intrusion. Synthetic flows for tributaries seaward of Trenton will have to be generated. It is expected that minor tributaries can be grouped for various reaches of the estuary to simplify modeling the system without significant loss of accuracy.

A comprehensive bibliography on salinity intrusion will be prepared. This bibliography will include all known studies of salinity in the Delaware estuary, as well as more general references. A preliminary bibliography is attached to this Plan of Study (appendix A).

Cost of study

The cost of the proposed study is estimated to be $181,800. This estimate is based on an assumption that the study will be carried out primarily by the DRBC staff, assisted as appropriate by consultants.

Duration of study

It is estimated that the study will require 14.5 man-months of staff time. With two staff members assigned full time to the study, it could be completed in about seven months. Parts of the overall study could be selected for priority treatment, and thus these parts could be completed in advance of the full study and report. However, the assembling of the basic data would be a necessary prerequisite of the study. For example, the data on flows, point sources, and nonpoint sources are needed as input data to study the relationship between flow and salinity for all three proposed methods of analysis (prototype, mathematical deterministic model, and hydraulic model).

Extra-staff assistance

It is anticipated that outside assistance from consultants, agencies, and water users will be necessary to assemble the necessary data, supervise and review the study, and to carry out parts of the study. For example, data on water-quality criteria for various water users can be supplied best and most reliably only by these water users. Also, consultants will be useful, if not essential, in setting up and running the Thatcher deterministic model (if that model is used). The assistance of the Corps of Engineers will be necessary if the Vicksburg hydraulic model is used. Consultants will also be needed to review and interpret the results of the various studies of the relationship between flow inputs and salinity distribution, as well as to set up and run computer programs for the generation of synthetic flows (for the tributaries seaward of Trenton).

Advisory committees.--It will probably be useful to establish one or more advisory committees to guide, assist, and review the study. Such an advisory committee could include representatives of water users (municipal and industrial--including fisheries) affected by salinity intrusion.

Appendix B

Estimated Costs of Salinity Intrusion Study

Part	Description	Time man-months	Cost: DRBC staff*	Cost: Consultant
A	Need for study (Introduction)	0.25	$ 600	--
B	Impacts	1.0	2,600	--
1	Surface users			
2	Ground water			
3	Health and medical			
4	Economic			
5	Ecological			
C	Review of earlier studies	1.0	2,600	--
D	Water-quality data	1.0	2,600	--
E	Hydrologic data	1.0	2,600	--
1	Observed flows			
2	Natural runoff			
3	Synthetic flows, Trenton			
4	Synthetic flows, Tribs.			
F	Land-based sources of dissolved salts	4.0	10,500	--
1	Delaware River at Trenton			
2	Tributaries			
3	Point sources			
4	Non-point sources			
G	Relationship between flow and salinity	3.0	7,900	$35,000
1	Prototype studies			
2	Deterministic model studies			
3	Hydraulic model studies			
H	Benefits from salinity control	--	--	--
1	Municipal			
	Industrial			
	Fisheries			

* Estimated cost assumes average DRBC staff direct-salary cost of $15.00 per hour, and does not include overhead, fringe benefits, etc. Estimates are based on 22 working days per month.

Part	Description	Time man-months	Cost: DRBC staff*	Cost: Consultant
1	Preparation of report	3.0	$ 7,900	$ 2,000
	Draft report			
	Review of draft			
	Final report			
	Reproduction of report	0.3	800	--
	Draft (50 copies)			
	Final (100 copies)			
	Sub totals	14.55	$38,100	$37,000
	DRBC overhead (15% of salaries)		5,700	--
	Total staff salaries and consultants' fees		43,800	37,000

Additional DRBC Costs

Item		Amount
Meetings of Advisory Committee (s)		0
Travel, staff		2,000
Travel expenses, consultants		3,000
Computer runs		30,000
	Subtotal	$ 35,000
Total DRBC costs		$115,800

USGS

Natural flow studies		$ 5,000
Water quality data (computer printouts)		1,000
	Subtotal	$ 6,000

Corps of Engineers

Vicksburg model and studies		60,000
	Subtotal	$ 60,000
Grand total		$181,800

DEPARTMENT OF THE ARMY
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
CUSTOM HOUSE—2D & CHESTNUT STREETS
PHILADELPHIA, PENNSYLVANIA 19106

IN REPLY REFER TO
NAPEN-R

30 DEC 1977

Dear Sir:

I am pleased to inform you that we have initiated the Delaware Estuary Salinity Intrusion Study. This Congressionally authorized study is to analyze the movement of salinity concentrations in the estuary and identify the amount of fresh-water flow in the Delaware River needed to protect water users of the estuary. This study was authorized by the House Committee on Public Works and Transportation on 23 September 1976. Efforts in the following year will concentrate on establishing a systematic program for conducting the study.

We expect that our study will include investigations of the following: quality needs of water users; increased costs or inherent damages if water of higher salinity must be used; relationship between stream regulation in the upper basin and advance or retreat of salinity concentrations in the esutary; quantity of upstream storage necessary for low-flow augmentation; and the impact on estuarine fish and wildlife of changes in salinity. The study will assess the problems and identify alternatives to diminish the detrimental effects of varying salinity.

We welcome any contribution you can make to this study. We would like your views regarding the significance of the salinity problem, the possible environmental, social or economic impacts and any other areas you feel are pertinent. We look forward to your assistance.

Any questions or correspondence in regard to the study may be directed to Mr. John F. Murphy, Chief, Planning Branch, by mail at the above address, or by phone at (Area Code 215) 597-4837. As the study progresses, we will inform you of major developments.

Sincerely yours,

Joel T. Callahan

JOEL T. CALLAHAN
Lieutenant Colonel, Corps of Engineers
Acting District Engineer

DELAWARE ESTUARY SALINITY INTRUSION STUDY
List of Notified Parties

Federal Representatives

Delaware

Honorable Joseph R. Biden, Jr.
United States Senate
Washington, D.C. 20510

Honorable Thomas B. Evans, Jr.
House of Representatives
Washington, D.C. 20515

Honorable William V. Roth, Jr.
United States Senate
Washington, D.C. 20510

New Jersey

Honorable Clifford P. Case
United States Senate
Washington, D.C. 20510

Honorable James J. Florio
House of Representatives
Washington, D.C. 20515

Honorable Frank Thompson, Jr.
House of Representatives
Washington, D.C. 20515

Honorable Harrison A. Williams, Jr.
United States Senate
Washington, D.C. 20510

Honorable William J. Hughes
House of Representatives
Washington, D.C. 20515

Honorable Edwin B. Forsythe
House of Representatives
Washington, D.C. 20515

Pennsylvania

Honorable Richard S. Schweiker
United States Senate
Washington, D.C. 20510

Honorable Michael O. Myers
House of Representatives
Washington, D.C. 20515

Honorable Raymond F. Lederer
House of Representatives
Washington, D.C. 20515

Honorable Robert W. Edgar
House of Representatives
Washington, D.C. 20515

Honorable Henry J. Heinz, III
United States Senate
Washington, D.C. 20510

Honorable Robert N. Nix
House of Representatives
Washington, D.C. 20515

Honorable Joshua Eilberg
House of Representatives
Washington, D.C. 20515

Honorable Peter H. Kostmayer
House of Representatives
Washington, D.C. 20515

Federal Agencies

Director, Northeast Region
Regional Technical Service Center
Soil Conservation Service
U.S. Department of Agriculture
1974 Sproul Road
Broomall, PA 19008

Water Resources Coordinator
Office of the Secretary, OPDC
Department of Commerce
Washington, D.C. 20230

Regional Representative of
 the Secretary of Commerce, Region II
Federal Building, Room 1311
26 Federal Plaza
New York, NY 10007

Director
National Marine Fisheries Service
National Oceanic and Atmospheric
 Administration
Washington, D.C. 20235

The Director
National Ocean Survey
National Oceanic & Atmospheric
 Administration
U.S. Department of Commerce
Rockville, MD 20852

Regional Director, Region 5
U.S. Fish & Wildlife Service
Department of the Interior
One Gateway Center, Suite 700
Newton Corner, Mass 02158

District Chief, WRD, USGS
420 Federal Building
P. O. Box 1238
Trenton, NJ 08607

Regional Hydrologist
Geological Survey
National Center - Mail Stop 433
12291 Sunrise Valley Drive
Reston, Virginia 22092

The Administrator
U.S. Environmental Protection Agency
Waterside Mall
4th & M Streets, S.W.
Washington, D.C. 20460

Regional Administrator
Region III, EPA
6th & Walnut Streets
Phila., PA 19106

Regional Representative of
 the Secretary of Commerce, Region III
William J. Green Federal Building
600 Arch Street, Room 10424
Philadelphia, PA 19106

Regional Director, Northeast Region
National Marine Fisheries Service
U.S. Department of Commerce
Federal Building, 14 Elm Street
Gloucester, Mass. 01930

Interagency Coordinator
Office of Coastal Zone Management
Department of Commerce, NOAA
3300 Whitehaven Street, N.W.
Page Building #2, Room 327
Washington, D.C. 20235

District Chief, WRD
USGS
208 Carroll Bldg., 8600 LaSalle Rd.
Towson, MD 21204

District Chief, WRD
USGS
P. O. Box 1107
Harrisburg, PA 17108

Commandant
U.S. Coast Guard
400 7th Street, SW
Washington, D.C. 20590

Commander
3rd District
Governors Island
NY, NY 10004

Regional Administrator
Region II EPA
26 Federal Plaza, Room 1009
New York, NY 10007

Chairman
Council on Environmental Quality
722 Jackson Place, N.W.
Washington, D.C. 20006

Regional Agencies

Mr. Gerald M. Hansler, Executive Director
Delaware River Basin Commission
P. O. Box 7360
West Trenton, NJ

Executive Director
DVRPC
3rd Floor Penn Towers
1819 J.F. Kennedy Blvd.
Phila., PA

Director WILMAPCO
Metropolitan Clearinghouse
2062 New Castle County
New Castle, DE 19720

State Agencies

Dr. Maurice K. Goddard, Secretary
Dept. of Environmental Resources
P. O. Box 1467
Harrisburg, PA 17120

Mr. Rocco D. Ricci, Commissioner
Dept. of Environmental Protection
P. O. Box 1889
Harrisburg, PA 17120

Mr. Austin P. Olney, Secretary
Dept. of Natural Resources & Environmental Control
Edward Tatnall Building
Dover, DE 19901

Dr. Theodore L. Hullar, Commissioner
Dept. of Environmental Conservation
50 Wolf Road
Albany, NY 12233

Clearinghouses

State Clearinghouse - Delaware
Delaware State Planning Office
530 E. DuPont Highway
Dover, DE 19901

State Clearinghouse - Pennsylvania
Pennsylvania State Planning Board
503 Finance Building
State Capitol
Harrisburg, PA

State Clearinghouse - New Jersey
Division of State & Regional Planning
Department of Community Affairs
P. O. Box 2768
Trenton, N.J.

County Agencies

Director
Bucks County Planning Commission
Administration Building, 6th Floor
Doylestown, PA 18901

Chairman
Burlington County Planning Board
Burlington County Office Building
49 Rancocas Road
Mount Holly, NJ 08060

Executive Director
Delaware County Planning Commission
Fronefield Building
214 North Avenue
Media, PA 19063

Chairman
Camden County Planning Board
Court House Annex
Pennsauken, NJ 08110

Chairman
Gloucester County Planning Board
Courthouse
Woodbury, NJ 08096

Chairman
Salem County Planning Board
Court House
Salem, NJ 08079

Director
Kent County Planning Commission
16 the Green
Dover, DE 19901

Director of Planning
New Castle County
Engineering Building
P. O. Box 165
Wilmington, DE 19899

Municipal Agencies

Chairman
Camden Planning Board
Municipal Building
6th & Market Streets
Camden, NJ 08101

Executive Director
Philadelphia Planning Commission
City Hall Annex 13th Floor
Philadelphia, PA 19102

Civic Associations

Gretchen Leahy
Pollution Control Group, Lower Bucks Co.
728 N. Pennsylvania Ave.
Morrisville, PA 19067

Mr. Langdon Warner
Environmental Defense Fund
1525 18th St. NW
Washington, D.C. 20036

DELAWARE RIVER BASIN COMMISSION
P. O. BOX 7360
WEST TRENTON, NEW JERSEY 08628
(609) 883-9500

HEADQUARTERS LOCATION
25 STATE POLICE DRIVE
WEST TRENTON, N. J.

GERALD M. HANSLER
EXECUTIVE DIRECTOR

January 27, 1978

Jerry
Dear Colonel Dutchyshyn:

Re: Salinity Intrusion Studies

In accordance with our agreement on January 17, 1978, members of our staffs have met and discussed (1) the purpose and objective of various elements of salinity intrusion studies; (2) the status of work completed or under way by the DRBC; (3) the elements that should receive priority attention with the available funds; and (4) a desirable timetable for completion of all elements.

The Commission's objectives in endorsing this series of salinity studies were to establish, through the most modern techniques available, (1) the relationship between quantities and duration of freshwater flows and the location and concentration of sea salts; and (2) the benefits which would accrue from controlling salinity intrusion or, conversely, the cost entailed in allowing sea salts to overrun existing installations, potential industrial sites, and groundwater recharge areas. With such facts in hand, the Commission will be able to evaluate the pros and cons of alternative water management programs, and adopt the best policy for meeting the overall needs of the Basin community.

The Commission has embarked upon and is nearing completion of mathematical modeling studies which will make it possible to readily answer flow-salinity questions. Based upon the anticipated success of this effort, we now believe that it will not be necessary to expend public funds for this phase of the work at the WES in Vicksburg, Mississippi. However, there is still some uncertainty concerning the effects of the recent enlargement of the Chesapeake and Delaware Canal on salinity levels in the Delaware estuary, and our currently funded study may not be able to resolve this question completely. This is a matter which may need your attention next fiscal year.

We anticipate that the daily flows being generated by the Corps for the Stde of Pennsylvania under "Section 22" will be useful, in conjunction with the mathematical model of salinity intrusion, in determining the recurrence interval of various salinity levels at critical locations along the estuary.

In the summer of 1976, the Commission staff, in cooperation with the WRA/DRB, initiated and completed a letter-questionnaire survey of the damage along the estuary resulting from historic intrusions of sea salts. While this effort provided some insight into the severity of the problem, it did not answer the benefit-cost questions. I view the economic evaluation of salinity intrusion and control as the highest priority work among those elements remaining to be done.

Our Level B Study is scheduled for completion by April 30, 1979. The amount of freshwater inflow to the estuary will be one of the fundamental planning considerations around which water management programs must turn. Therefore, every effort must be made to direct available funds toward answering this question. We will have developed answers to the flow-salinity questions, but we desperately need defensible answers to the economic questions. The funds appropriated to you appear to be the only ones now available that could be devoted in a crash effort that would bring timely answers.

I have reviewed the file on our efforts which resulted in funds being earmarked for your office to undertake a special salinity study. The letter dated July 27, 1976 to Congressman Robert E. Jones, Chairman of the Committee on Public Works and Transportation, initiated by Congressman Frank Thompson, Jr., and also signed by seven other Lower Basin Congressmen, states the importance and urgency of the task at hand, and suggests "a pass through /of funds/...to the Delaware River Basin Commission for use in supplementing the State funds as needed to complete other phases of the salinity intrusion study." These other phases include "...analysis of the impact of various potential levels of salinity on municipal and industrial water users along the estuary." The Congressmen noted that "assuming the timely availability of funds,... the salinity intrusion studies can be completed within fiscal year 1977."

As the DRBC was instrumental in obtaining Congressional endorsement of the $50,000 appropriation for the salinity study, I am confident that their use of H.D. 522, 87th, 22nd as the basic authorization did not foresee as broad-scope an effort as your staff seems to be contemplating. Indeed, with the numerous other studies currently under way by your office, other Federal and state offices and our own, I believe we should concentrate on those voids that need to be filled. The economic appraisal of salinity advance and retreat is just such a void.

I strongly recommend that the major portion of the current year's appropriation be directed to this matter so that a product will be available for use in the final report of the Level B Study.

Sincerely,

Jerry

Gerald M. Hansler

Colonel Harry V. Dutchyshyn
Corps of Engineers
2nd and Chestnut Streets
Philadelphia, Pennsylvania 19106

Sea Salt Study

Estimated Cost

	Fiscal Year 1978 DRBC	Fiscal Year 1978 Corps	Fiscal Year 1979 DRBC	Fiscal Year 1979 Corps
1. Mathematical Modeling	$150,000	$10,000	-	
2. C & D Canal	8,000		$23,000	$ 50,000
3. Probability studies	-	-	8,000	40,000
4. Economic analysis	-	30,000	-	20,000
5. Hydraulic model	-	-	-	90,000
6. Reports	-	10,000	8,000	28,000
Totals	$158,000	$50,000	$39,000	$228,000

PLAN OF STUDY--FISCAL YEARS 1978-1979
SALINITY INTRUSION IN THE DELAWARE ESTUARY

1. Mathematical modeling - Complete June 30, 1978

The development of a mathematical model of salinity in the Delaware estuary is nearing completion. The model being used is a refined version of the Thatcher-Harleman (1972) model originally developed at the Massachusetts Institute of Technology (MIT).

The model will be used to generate salinity distribution throughout the estuary (here considered to include the entire tidal Delaware River from Trenton to Liston Point, as well as Delaware Bay from Liston Point to the Capes), for various scenarios of fresh-water discharge into the estuary. Initially, the model will be calibrated and verified using the observed fresh-water flows for the severe drought period from October 1, 1964, through September 30, 1965 (water-year 1965). Then the flows will be adjusted to simulate any combination of reservoir storage capacity added since 1965, or anticipated to be added in the future. Flow adjustments will be made also to reflect decreasing "excess releases" from New York City's upper-Basin reservoirs, in accordance with the Montague formula specified in the U. S. Supreme Court decree of 1954. The flows into the estuary will be modified also to show the effect of increasing consumptive use of water within the Delaware River Basin, and increasing diversions of water out of the basin. Finally, to the extent that the change in the flows through the Chesapeake and Delaware Canal as a result of its recent enlargement can be determined, these altered flows will be simulated in the model to show the effect, if any, on the distribution of salinity in the Delaware estuary.

In addition to water-year 1965, water years 1970 and 1975 will also be simulated to show the extent and duration of salinity intrusion in a medium-flow and a high-flow year, respectively. The results of the three base-period simulations should shed light on the range of annual average salinity conditions in the Delaware estuary. Additional simulations, reflecting the flow changes resulting from changes in storage capacity consumptive use, interbasin transfers, and enlargement of the C & D Canal, will provide a basis for an approximating economic analysis of the resulting changes in salinity.

2. Chesapake and Delaware Canal - Start August 1, 1978 - Complete February 28, 1979

Although several studies of limited scope have been conducted to determine the exchange of water between the Chesapeake Bay and the Delaware estuary through the Chesapeake and Delaware (C & D) Canal, there remain considerable uncertainties regarding the quantity and quality of water flowing through the canal. These uncertainties need to be resolved before the effects of the canal and its recent enlargement on the salinity in the Delaware estuary can be determined with confidence. Such determination is a prerequisite to the determination of the relationship between controlled flows in the Delaware River at the mouth of the Schuylkill River and salinity distribution in the estuary.

It is anticipated that some field work will be required to determine accurately the characteristics of the flow through the C & D Canal. Such field work probably will require measurements of salinity at two or more locations along the length of the canal, in addition to flow measurements and tide observations in the canal, during a period of several weeks.

3. Probability studies - Start October 1, 1978 - Complete February 28, 1979

In order to refine the economic evaluation of projected or proposed flow changes, it will be necessary to simulate a series of 12-month periods--enough such periods to construct a frequency curve showing the probabilities of various levels of annual average salinity levels at specific locations along the estuary. These frequency curves will be developed for sets of two scenarios. The first scenario of each set will show the probabilities for a base-flow condition, such as natural flows. The second scenario will show the probabilities for a modified-flow condition, for example, to show the potential effect of an increased diversion to northeastern New Jersey. The change in probability of salinity intrusion must then be transformed into a change in cost of using water from the increased-salinity reaches of the estuary.

4. Economic analyses - Start May 1, 1978 - Complete December 31, 1978

Derivation of the costs of using the brackish waters of the estuary will require the use of salinity-damage functions for typical water-users along the estuary. Such damage functions are related to the cost of treating water of various salinity levels, or to the cost of switching to alternative supplies when the salinity of the water in the estuary at a given intake reaches intolerable levels for any purpose. Information needed for development of these costs include the levels of various salts that can be tolerated for given water uses. For example, the Scott Paper Company plant at Chester, Pennsylvania, can use the river water when the chloride concentration is as high as 75 mg/l, but for higher concentrations, the plant must curtail normal production or switch to the more costly municipal water supply of the Chester Water Authority, which imports water from the Susquehanna River Basin.

Many industries do not have an alternative source of water to select when salinity levels in the estuary reach intolerable levels. These industries, therefore, must curtail operations or incur added expense for treating the high-salinity water taken from the estuary. For example, some industries demineralize the river water for use as boiler-feed water. The cost of demineralization is approximately directly proportional to the concentration of dissolved solids in the raw water. Many of these same industries, as well as others, use water from the tidal river for cooling purposes. Much of the cooling water is treated for control of fouling organisms or corrosion. The costs of these treatments generally increase with salinity of the intake cooling water.

Salinity-cost functions must be developed not only for industries that are self-supplied with estuary water, but also for industries, households, and other water users that obtain their water from municipal water systems that use the estuary as a source of raw water. This applies not only to those municipal systems that currently (in 1978) use estuary water, but also those that can be expected to use this water in the future. For example, the City of Chester expects--within the foreseeable future--to meet its growing demands for water by taking water from the Delaware River to supplement its diversion from the Susquehanna River Basin. The cost of this dual-source water system, when implemented, will be proportional to the frequency and duration of intolerable levels of salinity in the Delaware estuary.

The economic analysis of water supplies as related to salinity necessarily must consider not only those systems that take water directly from the estuary via a pipe in the tidal waterway, but also those systems that take the river water indirectly via aquifers and wells that are recharged in part by the tidal river. Therefore, it will be necessary to identify all such ground-water users along both sides of the estuary from Trenton to Delaware Bay, and to develop collective or individual salinity-cost functions for these water users.

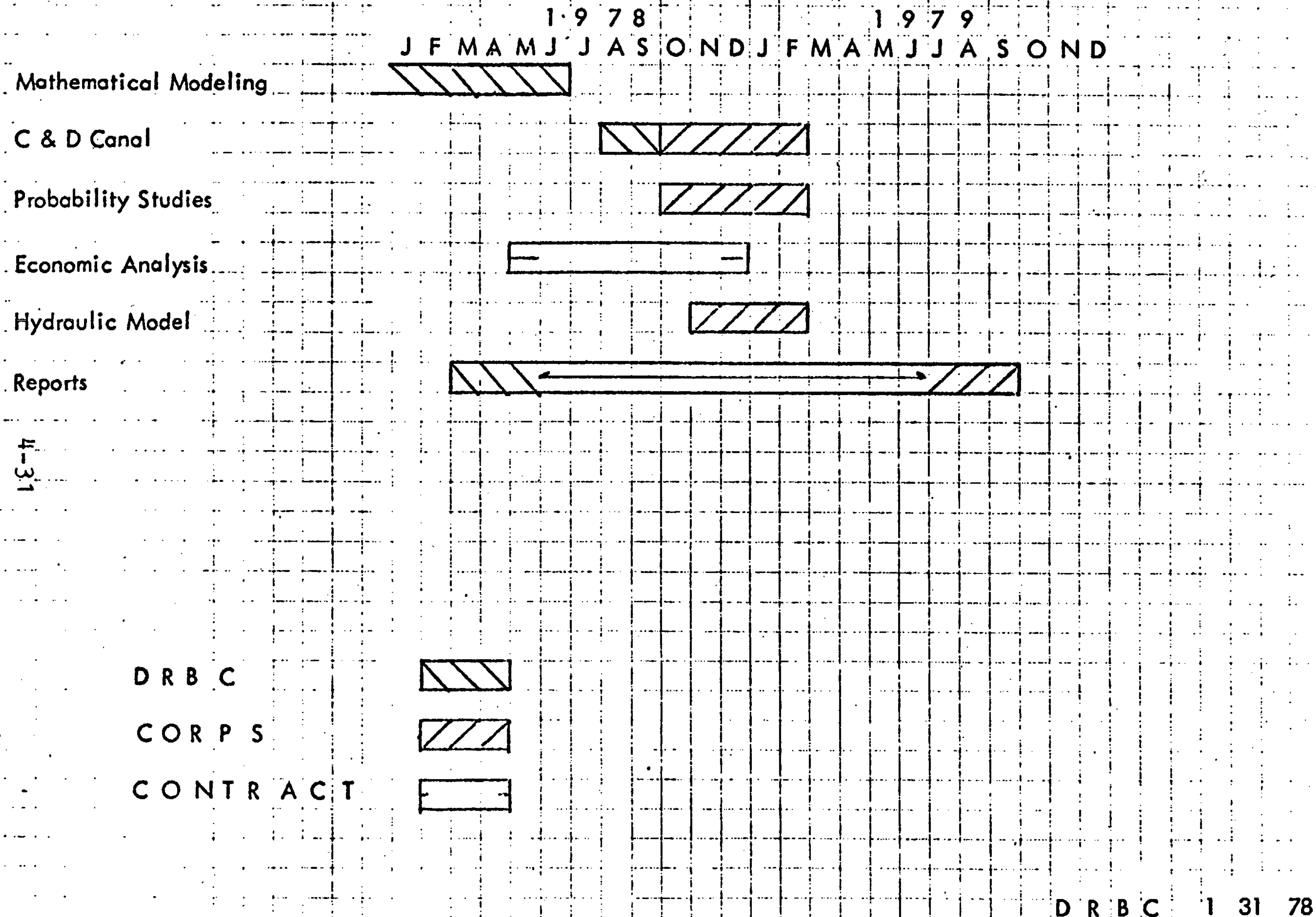
The salinity cost or damages functions will be used in conjunction with the probability analyses of various salinity levels to develop average annual costs of using or avoiding the salt-laden waters of the Delaware estuary. These average annual costs can, in turn, be used by decision makers to judge the economic justification of such measures as stream impoundments and flow regulation for salinity control, transbasin diversions, and increased consumptive use.

5. Hydraulic modeling - Start November 1, 1978 - Complete February 28, 1979

The Waterways Experiment Station (WES) of the Corps of Engineers at Vicksburg, Mississippi has constructed a hydraulic model of the Delaware estuary, and has used this model to study various aspects of the salinity-intrusion problem in the estuary. The hydraulic model is to be used to check key results of the mathematical modeling.

6. Reports - Start March 1, 1978 - Complete September 30, 1979

CHJH--DRBC--January 31, 1978


1978
1979
J F M A M J J A S O N D J F M A M J J A S O N D
Mathematical Modeling
C & D Canal
Probability Studies
Economic Analysis
Hydraulic Model
Reports
DRBC
CORPS
CONTRACT
DRBC 1 31 78

DELAWARE RIVER BASIN COMMISSION
P. O. BOX 7360
WEST TRENTON, NEW JERSEY 08628
(609) 883-9500

GERALD M. HANSLER
EXECUTIVE DIRECTOR

HEADQUARTERS LOCATION
25 STATE POLICE DRIVE
WEST TRENTON, N. J.

August 27, 1980

Dear Colonel Ton:

This is in response to your letter of August 12, 1980, in which you requested confirmation of the understanding of the goals and roles of the Corps of Engineers and the Delaware River Basin Commission in the Delaware River Salinity Intrusion Study.

The Delaware River Salinity Intrusion Study has been an outstanding example of interagency cooperation from the very beginning. The forthcoming policy decisions of the Delaware River Basin Commission on salinity flow objectives will be based upon (1) technical analysis aided by use of the Thatcher-Harleman Transient Salinity Intrusion model, (2) your first-cut economic impact studies, and (3) environmental assessments of alternative water management options conducted on an element of the Water Resources Council sponsored Level B Study. These policy decisions will be amended into the Commission's Comprehensive Plan, and will also be reflected in agreements among the parties to the 1954 Supreme Court Decree in New Jersey vs. New York (347 U.S. 995 (1954).

The Commission has been informed that your analysis of the C&D Canal has not been completed and that some uncertainty regarding the quantity of fresh water required to control salinity will remain until your effort is concluded in FY 1982. However, overriding considerations dictate commitments during this calendar year. The range of conclusions which may result from your study has been weighed, and we believe that construction schedules for upstream storage projects to repel salinity can be altered, if necessary, when the C&D technical findings are in hand.

I appreciate the timely assistance you have provided during the course of this cooperative venture, and assure you of our continued support in the future.

Sincerely,

Gerry Hansler

Gerald M. Hansler

Colonel James G. Ton, District Engineer
U. S. Corps of Engineers
Custom House
Second and Chestnut Streets
Philadelphia, Pennsylvania 19106

UNITED STATES WATER RESOURCES COUNCIL

SUITE 800 • 2120 L STREET, NW WASHINGTON, DC 20037

October 20, 1981

Mr. Gerald M. Hansler
Executive Director
Delaware River Basin Commission
P.O. Box 7360
West Trenton, NJ 08628

Dear Mr. Hansler:

We are pleased to receive the final report of the Delaware River Basin Level B Study. The report reflects the excellent work done by the Commission and its staff during this study of the basin's water resource planning needs. As you know, the Council has on several occasions singled out the results of this effort as examples of what can be accomplished through a well managed Level B study.

The plan presented in the final report is more than adequate in meeting our guidelines for Level B studies and fully satisfies the conditions in our Memorandum of Agreement.

Since the Council's future is still uncertain we regret that we do not anticipate being able to present the report to the Council of Members in the near future. I would, however, encourage you to make the final report widely available to the appropriate Federal representatives.

Sincerely,

Gerald D. Seinwill
Acting Director

Enclosure

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Suite 322
315 South Allen Street
State College, PA 16801

February 16, 1982

Lt. Colonel Roger L. Baldwin
District Engineer, Philadelphia District
U.S. Army Corps of Engineers
Custom House, 2nd & Chestnut Sts.
Philadelphia, PA 19106

Dear Colonel Baldwin:

This responds to Mr. Sheridan's letter dated December 31, 1981, requesting Fish and Wildlife Service (Service) review and comment on the draft Technical Appendix on Fish and Wildlife and Insert into Main Report prepared by the Philadelphia District, Corps of Engineers, for the Delaware Estuary Salinity Intrusion Study. The following comments were prepared in accordance with provisions of the Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 et seq.), but do not constitute the report of the Secretary of the Interior within the meaning of Section 2(b) of the Act.

The Service concurs with most of the appendix and insert to the main report. Much of the wording is taken directly from our final planning aid report, dated July 1981, which summarized the Service's contributions to the study. Areas of disagreement are primarily technical in nature and were communicated by telephone to members of your planning and environmental staff. Unfortunately, the value of this study is minimized because the appendix and insert stop short of recommending ways to protect the Delaware estuarine ecosystem against natural or man-induced changes in the salinity regime. We repeat the most important conclusion and only recommendation contained in our final planning aid report:

1. Increasing salinity within the Delaware estuary during spring would decrease estuarine productivity, the magnitude of decline dependent on the degree of change.

2. Interruption and temporary storage of freshwater outflow should be avoided or minimized during spring (April 1 to July 1) to protect and maintain the health of the Delaware estuarine ecosystem.

Our conclusion and recommendation are not new. During planning discussions for the proposed Tocks Island Dam, we expressed concern about the effect of an altered salinity regime on the American oyster. Eventually, this problem was solved when the Corps agreed to modify the project rule curve and operations to preclude storage beginning April 1. Although the Tocks Island project would have been a major threat to the natural salinity regime, the combination of several smaller reservoirs could have the same undesirable effect.

The Service is pleased to have participated in this study. We ask that the Corps consider and respond to these comments.

Sincerely,

Charles J. Kulp

Charles J. Kulp
Field Supervisor

DEPARTMENT OF THE ARMY
Philadelphia District, Corps of Engineers
Custom House - 2d & Chestnut Streets
Philadelphia, Pennsylvania 19106

NAPEN-E

3 MAR 1982

Mr. Charles J. Kulp
Field Supervisor
U. S. Fish & Wildlife Service
315 S. Allen Street, Suite 322
State College, PA 16801

Dear Mr. Kulp:

Thank you for your Fish and Wildlife Coordination Act letter of 16 February 1982 which contains the Service's comments on the Delaware River Estuary Salinity Intrusion Study. We have considered your comments and believe it important to clarify certain matters essential to this study.

The purposes of the Corps' Salinity Study did not include "recommending ways to protect the Delaware estuarine ecosystem against natural or man-induced changes in the salinity regime", or making any specific recommendations. Rather the Corps' objective was to identify the effects resulting from salinity variation and where possible, the resulting costs. Management of the water resources in the Delaware River Basin is the direct responsibility of the Delaware River Basin Commission (DRBC) and the Commission was sponsor for this study as well as primary recipient of its results. DRBC would then utilize this study of which the ecosystem analysis is a part in management of the overall basin needs. Since this Corps' study was in effect a portion of a larger undertaking, we avoided a needless duplication of effort by adopting the findings and results of the Level B study prepared by DRBC. The Level B stream flows and related impoundment scenarios represent the best available data and management rationale for the Delaware River. The Corps recognizes the results of Level B were obtained after a long thorough formal process of planning, coordination and environmental impact review by all interested parties.

In consideration of this background to Level B and its further development by the Salinity Study, we disagree with the Service's comment that the value of the Salinity Study is minimized, due to a lack of Corps' recommendations. DRBC's Level B Report utilized information gathered by the Salinity Study in developing their preferred plan and concurred that "the adverse effects of storage of portions of available storage could be mitigated or eliminated by refraining from storing water in April and May". (Level B, page 34). This office will also include the Service in providing input for developing reservoir operating criteria for new projects.

We satisfied the stated objectives of the Salinity Study in developing a state of the art computer tool and, with your input and advice, resource impact information for use by the DRBC in future flow management decisions. The Corps is confident that the Commission will continue to include all factors, especially fish and wildlife resources, in reaching these decisions. Your own comment on the positive effect of Fish & Wildlife concerns in modifying the Tocks Island Lake regulation curve demonstrates the past basis or working toward mutually accepptable water management decisions.

Sincerely,

NICHOLAS J. BARBIERI
Acting Chief, Planning/Engineering Division

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Suite 322
315 South Allen Street
State College, PA 16801

March 15, 1982

Mr. Nicholas J. Barbieri
Acting Chief, Planning, Engineering Div.
U.S. Army Corps of Engineers
Philadelphia District
Custom House, 2nd & Chestnut Streets
Philadelphia, PA 19106

Dear Mr. Barbieri:

Thank you for your letter of March 3, 1982, addressing our February 16, 1982, comments on the draft Technical Appendix on Fish and Wildlife and Insert into Main Report prepared by the Philadelphia District for the Delaware Estuary Salinity Intrusion Study. While we appreciate your effort to "clarify certain matters essential to the study", we do not believe the Service has labored under a misconception of study objectives, their degree of achievement or the intended study use. Quite the opposite, we believe the Corps has departed from the original study objectives.

In our planning aid report to the Corps, dated July 1981, the Service quoted from Lieutenant Colonel Callahan's letter of December 30, 1977, to the Service which initiated the study. Two excerpts from the letter appear below:

> This Congressionally authorized study is to analyze the movement of salinity in the estuary and identify the amount of fresh-water flow in the Delaware River needed to protect water users of the estuary.
>
> The study will assess the problems and identify alternatives to diminish the detrimental effects of varying salinity.

These statements indicate that the Corps' study objectives were two-fold: to analyze the movement of salinity and to identify alternatives for reducing the detrimental effects of varying salinity on estuary users. Unfortunately, the second objective was not carried out, an apparent deference to water resource management responsibilities of the Delaware River Basin Commission. We do not doubt or dispute the overall river management role enjoyed by the Commission, however, it puzzles us to see this responsibility suddenly emphasized when it existed at the start of the study and, in fact, existed when the Corps agreed to modify the flow regulation curve for the proposed Tocks Island Dam. It also puzzles us that the Commission, which is the primary recipient of the study, completed the Level B study before the salinity study was finished. We still believe it is appropriate for the Corps to assess its findings and recommend to the Commission methods of protecting the estuary and its users. We are particularly interested in a recommendation about manipulation of spring flows. As noted in your letter, the Commission is already aware that adverse effects of storage on estuarine biota could be mitigated or eliminated by refraining from storing water in April and May. This awareness is reinforced by the results of the salinity study, and in our opinion, these results justify establishment of no storage during spring as standard operating procedure. This does not mean special circumstances cannot be considered, such as long term drought, chemical spills, etc. Extraordinary events could justify some variance to the procedure. The important thing is to establish a protective procedure first and then consider variations to it.

We regret that you disagree with our assessment of the value of the salinity study. However, unless the Corps interprets its findings and provides at least conceptual guidance, our assessment will not change.

Sincerely,

Charles J. Kulp
Field Supervisor

DELAWARE RIVER BASIN COMMISSION
P.O. BOX 7360
WEST TRENTON, NEW JERSEY 08628

(609) 883-9500

GERALD M. HANSLER
EXECUTIVE DIRECTOR

HEADQUARTERS LOCATION
25 STATE POLICE DRIVE
WEST TRENTON, N.J.

April 2, 1982

Dear Colonel Baldwin:

This is to supplement my letter dated August 27, 1980, regarding the Delaware Estuary Salinity Intrusion Study.

As you are aware, we have recently (May 1981) developed a "Level B" water resources plan for the Delaware River Basin. As part of that plan, a series of flow objectives, defined in terms of fresh water inflows needed to protect water users of the estuary, was determined. The specific goal, under the preferred plan, for the Delaware River flow objective was recommended to be 3,072 cfs at Trenton, New Jersey, during the low-flow season of a drought year. This represents the estimated level of flow regulation required to control invasion of sea salts so that the maximum 30-day average chloride concentration at River Mile 98 (5.5. miles upstream of the Schuylkill River) would not exceed 121 mg/1 in the year 2000. Under another "mixed objective plan," the Trenton flow objective would be 2,605 cfs, which would control invasion of sea salts so that the maximum average chloride concentration at River Mile 98 would not exceed 180 mg/1 in year 2000. It is anticipated that both of these salinity control flows and quality objectives will be subjected to public hearing later this year. Subsequent to that hearing, the Commission will select that level of flow and salinity control that will be included in the Comprehensive Plan, and be the driving force of the Basinwide water management plan, pursuant to the Compact.

Several early products of the Delaware Estuary Salinity Intrusion Study provided valuable input to our work. These products included both the Executive Summary, which contained preliminary estimates of potential salinity-related damages and preliminary simulations with the MIT-TSIM salinity-intrusion model. We are also aware of concerns raised by the U. S. Fish and Wildlife Service regarding protection of the estuarine ecology. These concerns were considered during the development of the Level B water resources plan discussed above. We will continue to consider these concerns in the further planning, development, and operation of specific projects.

The information developed as part of your study since the flow objective was determined has also been considered to see if changes are appropriate. In particular, we note that although the values in the Executive Summary have been revised to reflect more accurate data developed during the course of the study, these changes merely support our previous decisions. Also, the added detail that was not (until now) available due to the completion of Branched MIT-TSIM Model has and will continue to provide invaluable supporting data.

In summary, the Delaware Estuary Salinity Intrusion Study has been an outstanding example of coordination between our respective agencies, and I trust that similar cooperation will carry into future efforts.

Sincerely,

Jerry Hansler

Gerald M. Hansler

Lt. Colonel Roger L. Baldwin, District Engineer
U. S. Army Corps of Engineers
Second and Chestnut Streets
Philadelphia, Pennsylvania 19106

NAPEN-E

05 AUG 1982

Mr. Charles J. Kulp
Field Supervisor
U. S. Fish & Wildlife Service
315 South Allen Street, Suite 322
State College, PA 16801

Dear Mr. Kulp:

Under separate cover you were previously furnished a draft copy of the Delaware Estuary Salinity Intrusion Study for your review. As further discussed in our office on 20 July 1982 and by telephone, in order to complete our study, we request a letter from the Service indicating technical and other comments on the study document.

I request that your letter be returned to us not later than 16 August 1982. If you have questions on the document, please contact Dr. John Burnes at FTS: 597-4833 or 3931.

Sincerely,

NICHOLAS J. BARBIERI, P.E.
Chief, Planning/Engineering Division

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Suite 322
315 South Allen Street
State College, PA 16801

August 19, 1982

Lt. Colonel Roger L. Baldwin
District Engineer, Philadelphia District
U.S. Army Corps of Engineers
Custom House, 2nd and Chestnut Streets
Philadelphia, PA 19106

Dear Colonel Baldwin:

This responds to Mr. Nicholas J. Barbieri's letter, dated August 5, 1982, requesting the Fish and Wildlife Service's comments on the Delaware Estuary Salinity Intrusion Study (DRAFT), dated April 1982.

These comments provide technical assistance only and do not represent the review comments of the Department of the Interior on any forthcoming environmental statement.

The Service played an active role in the Delaware Estuary Salinity Intrusion Study; contributing eight planning aid reports that addressed the sensitivity of the estuarine ecosystem to altering the natural cycle of salinity change. The Service also reviewed an earlier draft of excerpts from the draft, submitting comments in letters dated Febuary 16, 1982, and March 15, 1982. These comments were followed by various communications between our offices, during which we were informed of a major change in the original intent of the study. We refer to Goal "B" or the "quantity flow" goal which was dropped in 1978 in deference to certain concurrent work activities undertaken by the Delaware River Basin Commission (DRBC). This refinement in study objectives greatly reduced the scope of the study and, in our opinion, minimizes the study's value. As far as we are concerned, the value of this study in assessing the impact of salinity intrusion on fish and wildlife has been lost if the Corps is unwilling to recommend measures which would minimize adverse impacts identified in the assessment.

There are certain deficiencies in the text which should be corrected in the final report. These and other comments follow the format of the document.

<u>Page 18</u>
The Table indicating "Periods of Drought" should be amended to indicate an official end to the 1980 drought in April 1982.

<u>Page 19</u>
According to the DRBC, the 250 mg/l chloride line advanced to RM 97.5 on February 2, 1981.

Page 23
To illustrate the importance of the first statement under "Fish and Wildlife," we suggest adding the following:

> For example, "after the New York City diversions commenced in 1953, the (oyster) drill line moved from just below Ben Davis Point almost to Ship John bed. Approximately 1,000 acres of Delaware State (oyster) seed beds and about 1,000 acres of the Shell Rock and Ben Davis beds in New Jersey were depleted by the loss of Delaware River flow." (From: URS/Madigan-Praeger, Inc. 1975. A Comprehensive Study of the Tocks Island Lake Project and Alternatives.)

Page 31
The second paragraph mentions that flow changes at Trenton influence lower estuary salinity after only a few days and that the "effects" may persist for many months. The term "effects" is unclear and should be explained.

Page 38
The Service strongly concurs with the statement that timing of flow into estuarine waters is important in its effect on productivity, stability and general health of the estuarine ecosystem. This importance was emphasized by the Corps and the Delaware River Basin Commission when both agencies agreed to modify the flow regulation curve of the proposed Tocks Island Reservoir, precluding storage after April 1.

Page 50
The last sentence in paragraph 1, ending "...overall availability over an extended period" makes no sense. Should "productivity" be substituted for "availability"?

Page 63
According to the DRBC, modification of Francis Walter and Prompton Reservoirs and construction of the Merrill Creek Reservoir will mean 20 percent of the basin's land runoff area will be controlled, more than double the current amount. We are not aware of any lower estuary spring flow requirements for the existing reservoirs or for the proposed reservoirs. Furthermore, there appear to be no limits on the timing of storage. With the amount of drainage to be placed under control at 20 percent and the absence of storage constraints, it is only a matter of time before the need arises to store significant amounts of spring flows, depleting supplies to the estuary. The resulting change in estuarine aquatic productivity may or may not be noticeable depending on how much fresh water is withheld and when. Certainly the possibility for a noticeable change increases as water supply demands increase and as new reservoirs are constructed to satisfy that demand. In our opinion, it is naive not to expect estuarine fauna to suffer from the increasing manipulation of their freshwater supply.

Page 65
We do not agree that the Level B cited plans reasonably considered the effects of salinity on the ecological system in determining the overall needs of the estuary. Examination of the Level B report and EIS shows that estuarine ecologic needs were considered in part and dismissed. Most consideration was given to the oyster seed beds which were shown to be adversely affected by

reduction in spring flow. We are not aware of DRBC consideration of other estuarine fauna or of efforts to protect these resources from manipulation of freshwater flow.

Page 66
See comment under Page 18.

Page 3-7
The word "neurosis" should be "necrosis."

Page 3-15
The number "28" should be "228."

As these comments demonstrate, the Service continues to believe in the need to modify reservoir operations (i.e. no storage after April 1) in order to maintain estuarine productivity. If the Corps is unwilling to support this concept, we request the final report state the Service's views on this matter.

Sincerely,

Edward Perry

for Charles J. Kulp
Field Supervisor

DEPARTMENT OF THE ARMY
PHILADELPHIA DISTRICT, CORPS OF ENGINEERS
CUSTOM HOUSE—2 D & CHESTNUT STREETS
PHILADELPHIA, PENNSYLVANIA 19106

INFORMATION BULLETIN

14 OCT 1982

DELAWARE ESTUARY SALINITY INTRUSION STUDY

The Philadelphia District Corps of Engineers has completed a study on the Salinity Intrusion of the Delaware River Estuary. This study is in response to a resolution of the House of Representatives' Committee on Public Works, adopted 23 September 1976.

In responding to the Congressional Resolution directing the Delaware Estuary Salinity Intrusion Study, the specific goals of the study were to determine the probability for advance or retreat of salinity in the Delaware Estuary, and the quantity of fresh water inflow needed to protect the various water users along the estuary.

The Corps of Engineers concentrated on addressing the first of these goals. Salinity-cost relationships were developed for all direct water users of the Delaware Estuary. The previously developed mathematical model (the Transient Salinity Intrusion Model of the Delaware Estuary) by the Delaware River Basin Commission was modified as part of this study to reflect the interaction of the Delaware Estuary and the Chesapeake and Delaware Canal. By comparing the results of these two computer models, the influence of the Canal on chloride concentrations was found to extend from Chester, Pennsylvania to Ship John Shoal, a distance of 45 miles. The modified model was used to simulate long term salinity concentrations incorporating the post-enlargement condition of the Chesapeake and Delaware Canal. Flow in the Canal has varied both in volume and direction. However, the long-term (50-year) average was calculated to be 6,560 cubic feet per second eastward. Long term salinity concentrations were also determined as part of the study which provided continuous data needed to determine the probabilities of salinity levels in the estuary.

In addition, the data from the long term model runs served as input to an economic model. That model was also developed as part of this study and was used to determine average annual costs to estuarine withdrawal water users. These costs are indicators of the expenses incurred by the water users such as replacing corroded parts and equipment, utilizing alternative water sources and treatment of the saline water. The results of this portion of the study indicated that the average annual salinity related costs to municipal and direct industrial users are 19.8 million dollars per year.

A range of possible impacts of salinity variation on fish and wildlife resources was also addressed. Impacts were found to be both positive and negative depending on relative species' preferences and sometimes life cycles within individual species.

The second goal was addressed by the Delaware River Basin Commission which has the responsibility for the control and development of the water resources of the Delaware River Basin. The Commission consolidated the results of this salinity study and other efforts, and determined a range of flow objectives for the protection of water users along the Delaware Estuary as part of their Delaware River Basin Comprehensive (Level B) Study. That study has been accepted by the Water Resources Council. The flow objectives as determined by the Commission were incorporated into this study. Close coordination was maintained with the Commission during the two studies. It is anticipated that future adjustments of the flow objectives will be made by the Delaware River Basin Commission through its long-term basin planning program. Under this program, interstate water management recommendations will be made to reflect continuous planning efforts regarding any changing conditions throughout the Basin.

You will be notified when the report is available documenting the above studies. In the interim, further information regarding the study may be obtained from the Office of the District Engineer, U.S. Army Corps of Engineers, Philadelphia District, Custom House, 2nd and Chestnut Streets, Philadelphia, Pennsylvania 19106. Should you have any questions, please contact Mr. John Murphy, Chief, Planning Branch, at (Area Code 215) 597-4839.

for NICHOLAS J. BARBIERI, P.E.
Chief, Planning/Engineering Division

DELAWARE RIVER BASIN COMMISSION
P.O. BOX 7360
WEST TRENTON, NEW JERSEY 08628

(609) 883-9500

GERALD M. HANSLER
EXECUTIVE DIRECTOR

HEADQUARTERS LOCATION
25 STATE POLICE DRIVE
WEST TRENTON, N.J.

November 12, 1982

Dear Colonel Baldwin:

This supplements my earlier letters of August 27, 1980, and April 2, 1982, regarding the Delaware Estuary Salinity Intrusion Study being conducted by your office.

We have reviewed a recently revised draft of the final report of the Salinity Intrusion Study. We find that the Corps' Study, together with the Commission's own studies of salinity intrusion in the Delaware estuary, has met the information needs that prompted the Commission's petition to Congress to authorize the study. Due to effective coordination efforts by your staff, the DRBC staff has been kept informed of the Corps' findings throughout the Corps' Salinity Intrusion Study.

The Delaware Estuary Salinity Study has provided much useful information on the ecologic and economic impacts of salinity in the Delaware estuary. This information proved to be of value in formulating alternative plans, as presented in the Commission's Level B Report, for consideration by the Basin community. The Corps' modification of the DRBC's mathematical salinity model of the Delaware estuary to include the Chesapeake and Delaware Canal as a tidal branch and the results obtained with the branched model were more helpful in assessing the effects of the canal on Delaware estuary salinities. The economic model developed and used by the Corps provided evaluations of the salinity-related costs incurred by water users along the estuary. We anticipate that these models and the data presented in the study report will continue to be useful in the continuing planning programs of this Commission.

I congratulate you and your staff on bringing this difficult and complex technical study to a successful conclusion. This Commission has the remaining task of establishing salinity-control objectives for the Delaware estuary. Since my April 1982 letter, we have continued efforts to resolve the question of salinity standards and minimum flows needed in the Delaware River for salinity control.

We very much appreciate the opportunity to review the draft report of the Delaware Estuary Salinity Intrusion Study, and we look forward to receiving a copy of the published document.

Sincerely,

Jerry Hansler

Gerald M. Hansler

Lt. Colonel Roger L. Baldwin, District Engineer
U. S. Army Corps of Engineers
Second and Chestnut Streets
Philadelphia, Pennsylvania 19106