1. INTRODUCTION

1.1 Broad Overview of the Study

The overall water quality of a receiving tidal waterbody such as the lower Hackensack River is directly related to the nature and the magnitude of pollutants discharged into its headwaters and tributary streams. These pollutants are introduced either through **point** sources or **non-point** sources. Of the **point** sources, discharges from industrial and municipal treatment facilities, thermal power plants and Combined Sewer Overflows (CSOs) are the most significant. Land surface runoff, landfill leachate, tidal marshes, groundwater and benthic exchange of pollutants constitute the major **non-point** sources and sinks of the system. This report describes an in-depth assessment of the relative impacts of Bergen County Utility Authority's discharge **and** all other point and non-point sources on the Dissolved Oxygen Regime of the lower Hackensack River.

Sewage Treatment Plants play a major role in the degradation of a stream's water quality. They may cause the frequent violation of stream water quality standards thus impairing the designated uses of the receiving water. However, it is imperative to realize that they remain as **one** of the contributing sources of pollutants to the aquatic system. Therefore, a judicious approach to assess such STP impacts requires the consideration and assessment of impacts from all the other pollutant contributing sources.

The improvement and control of water quality in the lower Hackensack can be achieved by intelligent regulation of pollutant discharges that most influence its water quality. While technically it may be possible to approach "pristine effluents" from STP's in the lower Hackensack River, this may neither be necessary nor economically feasible. The important engineering decisions in water quality control relate to the determination of the major sources and to a level of their control that is consistent with the multiple uses of the aquatic system under investigation. This implies the ability to forecast or predict the response of the lower Hackensack River water quality to future investments in higher levels of treatment and in other remedial controls on pollutant inputs.

The Hackensack River and its tributaries drain a 197-square mile area of Rockland County, New York, and Bergen and Hudson Counties, New Jersey (Figure 1.1). The Upper Hackensack River connects three major "run of the river" reservoirs which serve as important sources of potable water for several northern New Jersey communities. A dam at the most downstream reservoir, the Oradell, separates the Upper Hackensack River from the area of focus for the present study - the tidally influenced Lower Hackensack River or "Hackensack River Estuary". From its head of tide at the Oradell Dam, the lower Hackensack River extends southward nearly 22 miles to its seaward boundary at Newark Bay, forming a narrow inland extension to the New York Harbor complex. The Lower Hackensack River drains an 84-square mile area dominated by the Hackensack Meadowlands, a vast tidal wetlands occupying approximately 20,000 acres. The balance of the Lower Hackensack River basin has been altered from its original state by extensive urbanization, industrialization, and by dredge, fill and diking operations.

Water quality of the lower Hackensack River has also been influenced by urbanization and industrialization within the watershed and by tidal exchange with adjacent, coastal waterways (Mattson and Vallario, 1976). Due to its limited fresh water inflow and indirect communication with the open sea, the lower Hackensack River has a limited flushing ability. As a result, it is inherently susceptible to pollution introduced by numerous sources, including sewage treatment plants, thermal power plants, industrial discharges, combined and storm sewer outfalls, landfill leachate, tidal marsh inputs, benthal release, upstream "let-down", atmospheric deposition, and tidal exchange with Newark Bay. The collective inputs from all of these sources have adversely affected the water quality of this important estuarine ecosystem.

Since the northeast regional 208 studies were undertaken in the early 1970's, various pollution abatement strategies have been contemplated for the lower Hackensack River. In particular, improvements or diversions have been mandated recently for the largest point source discharge to the system, the Bergen County Utility Authority's (BCUA's) sewage treatment plant (STP) at Little Ferry. The BCUA's STP discharges secondary effluent into the tidal Hackensack River at the present average rate of about 65 million gallons per day (MGD). In January of 1985, the New Jersey Department of Environmental Protection (NJDEP) issued a modified permit for treated sewage effluent discharge into the River from BCUA's treatment facility. The NJPDES Permit No. NJ0020028 set two targets to be met by the discharge from the STP at Little Ferry. The first of these targets, which is considered to be an interim effluent limitation, required the upgrading of the plant to meet secondary effluent limitations by March 31, 1985. The second target, which is the ultimate objective of the NJPDES Permit issued, requires either (a) upgrading of the plant to Level 3 treatment, with very stringent water quality standards imposed on the plant effluent, or (b) conveying BCUA's discharge out of the Hackensack River Basin into the tidal Hudson River. The Permit specifies an ultimate date for the completion of the required plant modifications or discharge diversion by April 30, 1988.

The discharge effluent limitations imposed by NJDEP on BCUA's STP are directed primarily towards improving the dissolved oxygen (DO) regime of the lower Hackensack River in the vicinity of Little Ferry. In a report prepared by NJDEP on the Use Attainability Analysis of the New York Harbor Complex, dated June 1985, the State regulatory agency rationalized their imposed effluent limitations and their contemplated improvement in the lower Hackensack River:

> "It is apparent that it is economically feasible to upgrade BCUA to Level 3, to achieve a minimum DO Level of 4.0 mg/l at any time in the Hackensack segment, which is currently experiencing the

largest DO deficit. Additionally, the Jersey City West flow will be diverted to the Jersey City East facility, thus removing a large BOD load from the Hackensack River.

With the implementation of these point source pollution control schemes, a minimum DO level of 4.0 mg/l at any time can be expected in the tidal Hackensack and the portion of the river, now classified as SE3 (min. DO = 3.0 mg/l), will be qualified for upgrading to SE2 classification (min. DO = 4.0 mg/l)."

The stringent plant effluent water quality standards imposed by the NJDEP are based largely upon results of field and modeling studies of the lower Hackensack River conducted in the 208 study (Teledyne, 1973). The validity of this study, however, and the technical basis for the imposed wasteload allocation, has been challenged by BCUA. As noted above, the Hackensack River is inherently susceptible to pollutant accumulation, and the degradation of its water quality is influenced by the **collective** pollutant loadings contributed by all point, nonpoint, and external sources. Thus, an accurate assessment of **all** pollutant sources must be performed to determine the relative impact of any one source. In the 208 studies however, non-point and transient loadings to the estuary were **assumed** rather than measured. As a result, potentially dominant contributions to the pollutant loadings due to both land surface runoff and leachate discharge from landfill sites were not assessed accurately in the 208 study. Thus, the efficacy of standards imposed on only one point source to achieve an SE3 classification is uncertain, since the relative impacts of other sources is undetermined.

The modeling methodology employed in the 208 study would not provide a defensible tool for isolating the effect of a single point discharge in question. The modeling tool utilized in the Teledyne study belongs to a class of steady-state, segmented (box) models whose applicability in systems such as the lower Hackensack River is severely limited by model assumptions. Models of this type are only applicable if the prototype estuary exhibits limited temporal and spatial variability. In the highly dynamic lower Hackensack River where temporal variations in DO concentrations ranging from 2 mg/l to 8.2 mg/l were observed in the Teledyne study, it is inappropriate to use a steady-state modeling methodology to establish effluent DO standards.

Due to these limitations and other inadequacies in the Teledyne study, BCUA determined that a more rigorous cost-benefit analysis of the proposed abatement strategies was required to justify an estimated expenditure of **69.3 million dollars** to meet the ultimate effluent discharge standard imposed by NJDEP. For these reasons, BCUA requested that a team of investigators from Clinton Bogert Associates (CBA), Najarian Associates, L.P. (NA), and General Testing Corporation (GTC) conduct a comprehensive field measurement and modeling program for the lower Hackensack River. Accordingly, this program was implemented by the scientific staff of CBA, NA and GTC during the period April 1988 through January 1990.

1.2 Objectives of the Study

The principal goal of this study is to assess the impacts of BCUA's STP discharges on the temporal and spatial distributions of DO (and other water quality constituents) in the lower Hackensack River under specified discharge alternatives from BCUA's treatment plant. The major alternatives of interest include: (a) discharge under current level of treatment (b) under the permit-specified post-1988 effluent conditions, and (c) intra-basin transfer of BCUA's discharge to the Hudson River.

A complementary objective of this study is to assess quantitatively the relative impacts of **all** significant pollutant loads which discharge into the tidal Hackensack River. This assessment includes point, non-point, and external pollutant sources associated with the following: stormwater runoff, industrial and domestic sewage, leachate discharge from landfill sites, benthal release, nutrient fluxes from tidal marshes, upstream loading, atmospheric deposition, and pollutant influx from

Newark Bay. Here, both the transient nature of these discharges and their long-term inputs to the estuary are assessed.

1.3 Study Methodology

The overall methodology adopted for the study is presented in the flowchart shown in Figure 1.2. The ultimate goal of the study is to develop an environmentally sound and financially viable long-term water quality plan for the lower Hackensack River Watershed. Towards this objective, the study was divided into three major components:

- Generation of a comprehensive hydraulic and water quality database within the lower Hackensack River and its tributaries and to quantify all point and non-point sources

- Selection and Adaptation of relevant Mathematical Models to the lower Hackensack River and its watershed

- Development of a management tool for policy-making in the lower Hackensack River.

The details of the overall study plan are presented below in the following sections of the report.

1.3.1 Field Monitoring Program

An extensive field monitoring program was first implemented to provide an up-to-date hydrologic, hydraulic, and water quality data base for the Hackensack estuary/watershed ecosystem. The real-time data gathered in the field were used to quantify all point/non-point pollutant sources, and to adapt a set of state-of-the-art transient hydrodynamic and water quality models to this ecosystem. To this end, a transient, one-dimensional hydrodynamic and water quality model was adapted to the lower Hackensack River, while a real-time rainfall-runoff model was adapted to the watershed system. The runoff model was employed to generate both the short-term and long-term pollutant loads into the River from the watershed, while the receiving water model was utilized to analyze the impacts of the various pollutant loadings on the DO regime of the lower Hackensack River.

To facilitate water quantity/quality calibration of the watershed model, **three** separate intensive storm surveys were conducted at nine major Combined Sewer Overflows (CSO's) and at five selected storm sewer outfalls. For the estuary model, **four** independent sets of hydraulic and water quality data were collected at nine instream stations and the boundaries of the tributary streams to the Hackensack River. Two of these sets were gathered concurrently with the intensive storm sampling of the CSO's and storm sewer outfalls during two separate storm events. The remaining two sets of data consisted of continuous baseline surveys conducted during two separate 10-day periods when no major storm events occurred. One of these latter sets was collected during spring high-flow conditions; the other during summer low-flow conditions. Details concerning the sampled constituents and sampling design are discussed latter in this report.

Sediment oxygen demand (SOD), a potentially important sink term in the estuary water quality model, was monitored at five instream water quality monitoring stations over a one year period. Core incubation methods were employed to determine SOD, sediment water quality, and the rate of release of oxygen-consuming organics.

In addition to the data collected for model calibration/verification purposes, supplementary data was gathered to quantify nutrient fluxes from the extensive salt marshes, mudflats and landfills within the basin. Towards this objective, additional sampling was conducted over two seasons (Summer and Fall) at three major tributaries to the Hackensack estuary. Water quality samples were collected at fifteen instream sites and at three mudflat/marsh areas. These water quality measurements, combined with observed flows serve to quantify nutrient fluxes for these tributaries. Extrapolation of results from these experiments provided nutrient flux estimates for other tidal marsh areas in the estuary. The details of the marsh study are contained in Part II of this report.

The supplementary field studies also included de-nitrification experiments at two selected sites; measurements of flow, temperature and water quality from the Public Service Electirc & Gas Co. (PSE&G) thermal power plant at Ridgefield and all major municipal STP's within the watershed.

1.3.2 Modeling Methodology

Using the database described above, a set of relatively sophisticated existing mathematical models were adapted to the lower Hackensack River and its watershed. For the watershed area, the transient-state hydrologic and water quality model, "SWMM-4" (Huber and Dickerson, 1988), was selected. In contrast to the Teledyne study, the transient quantity and quality of runoff from the Hackensack River drainage basin was computed through a rigorous procedure of adaptation, calibration, and verification of the SWMM-4 model. The SWMM-4 model assesses non-point constituent loadings delivered to the River via CSO outfalls, storm sewers, and direct runoff over the banks of the River. For given antecedent conditions, soil types, land use, and topography, this mathematical model converts precipitation on individual subcatchments into runoff quantity and quality.

With the recent addition of a subsurface runoff algorithm, SWMM-4 is further capable of assessing discharges from subsurface zones. The model carefully "bookkeeps" the volume of water that is lost due to evaporation, depression storage, and other abstractions, and the volume that is transported to subsurface zones through infiltration and percolation. The model equations for mass and momentum conservation describe the runoff for both overland flow and within sewer networks. Along with the volume of runoff, the model accounts for the amount of deposition and decay of various pollutants and their eventual wash-off during storm events. The simulated wash-off processes are related to the intensity and duration of storm events along with the percent imperviousness of the drainage basin. SWMM-4 is particularly well-suited to urbanized drainage basins with large impervious or nearly impervious areas, deeming it an appropriate tool for runoff analysis in the lower Hackensack River Watershed.

The SWMM-4 model is a general program structure which must be adapted to fit a given basin before it can be used in a meaningful fashion. The first stage in the adaptation process is geometrical schematization. The Lower Hackensack River drainage basin is conceptually reduced to a simplified geometry of idealized subcatchment and CSO areas, stream channels, and pipes. The simulated runoff generated in these areas is routed downstream via a network arrangement of these idealized components. A complete description of this procedure is given in Chapter 4.

Following the schematization procedure, a model input database of watershed characteristics is assembled. Next, the field data collected is utilized for the purpose of model calibration and verification. After a successful calibration and verification, the model is considered adapted to the watershed, and can be exercised in a predictive mode for the different alternatives of interest.

The output of transient flows and constituent loadings produced by the SWMM-4 model serve as input to the model for the receiving waters of the lower Hackensack River - The MIT-Dynamic Network Model (DNM) (Harleman et al, 1977). DNM is a transient-state, one-dimensional, hydrodynamic and water quality model developed under the sponsorship of the U.S. Environmental Protection Agency (USEPA, 1977). The hydrodynamic component of the DNM model computes the temporal and spatial variations of elevations and velocities in a riverine or estuarine network. It is based on the numerical solution of the transient, one-dimensional continuity and momentum equations. The output of hydraulic computations are directly fed to the ecological/water quality component of the model. In this component, a set of coupled and uncoupled mass conservation equations are solved numerically to generate the temporal and spatial distribution of variables of concern in receiving waters. The solution is elaborated within the time period of the tidal cycle, thereby freeing the dispersion relationship from the spatial fixity of time-averaging over a tidal cycle. This permits the model to be a predictive engineering tool for conditions other than those of calibration.

Similar to the watershed model, DNM must be adapted to a specific ecosystem through schematization, calibration, and verification procedures. To this end, the morphology of the Lower River is conceptualized as a simplified network of river segments or "reaches". For each reach, a database of geometric and topographic information is assembled from existing Hackensack River bathymetric data. After adopting site-specific geometrical and hydraulic data into the model, a hydraulic calibration is performed. The model is exercised repeatedly on the subject estuary for various bottom friction coefficient values, until the simulated water surface elevations and velocities match those observed in the field experiments. The calibration is considered successful if the model reproduces accurately the observed elevations, without excessive "tuning" or adjusting of frictional coefficients. With the frictional coefficients fixed at the calibration values, the model is then exercised on a second, independent set of hydraulic data. Agreement between simulated and observed elevations constitutes a successful model verification.

The water quality component of the DNM model is adapted, calibrated, and verified in an analogous fashion. For the various water quality constituents of interest, reaction rate coefficients are assigned within ranges that are reported in the literature. The model is exercised repeatedly until simulated constituent concentrations match observed, real-time data.

2. DESCRIPTION OF THE STUDY AREA

2.1 Characteristics of the Lower Hackensack River and Watershed

2.1.1 Topography and Geomorphology

The Hackensack River Basin is approximately rectangular in shape, varying in width from about 4 to 7 miles (Figure 1.1). From the vicinity of Haverstraw, New York, the Basin extends 34 miles southward to its lower terminus at Newark Bay. Elevations of approximately 300 feet above mean sea level are found in the upper Basin, while sea level elevations persist in the lower Basin. These elevations correspond to a relatively moderate average slope of approximately 0.17% for the entire basin. The Hackensack River Basin is separated from the Passaic River Basin to the west by rolling hills ranging in elevation from 600 feet in the north to 100 feet in the south (U.S. Army Corps of Engineers, 1982). The drainage divide to the east, the Hudson River Palisades, ranges in elevation from 300 feet in the north to 100 feet in the south.

The Hackensack River Basin is confined to the Piedmont Plateau - the easternmost province of the Appalachians. The basin is underlain with Triassic strata of the Newark Group composed of sedimentary sandstone and shale (U.S. Army Corps of Engineers, 1982). The Hackensack River valley was glacially scoured by several overruns of glacial icesheets. An overlay of glacial till consisting of sand, gravel, and clay was left by the most recent overrun, the retreat of the Wisconsin Glaciation about 7,500 years ago. Layers of peat and organic soil presently cover some of these glacial deposits.

The entire Hackensack River flows 50 miles from its headwaters near Haverstraw, New York to its confluence with Newark Bay, New Jersey. The tidal Hackensack is the lower 21.7 mile segment downstream from the Oradell Dam. The average upper River slope is approximately 2.8 feet per mile over a 19-mile reach just above the

Through the combination of field and model studies described above, a defensible modeling tool is developed to assess the relative impacts of BCUA's STP on the water quality of the lower Hackensack River. In Chapters 2 and 3, a more detailed description of the study area and field experiments is presented. In Chapters 4 and 5, the adaptation, calibration, and verification procedures for the watershed and estuarine models are discussed in detail. Chapter 6 contains a description of the various alternatives analyzed in resolving the water quality issues of the lower Hackensack River, while the results for the entire study are summarized in Chapter 7.

The overall study of the lower Hackensack River is presented in two parts. Part I consists of the main report and result of the River Modeling and Runoff Modeling aspects of the study. Part II consists of the results of the Marsh Modeling effort. The data collected for the study during the April, July and August, 1988 intensive river and watershed surveys, and the data collected during 1988 and 1989 within the tidal marshes of the lower Hackensack River Basin are contained in separate reports prepared by GTC.

The flow data shown in Table 2.1 suggests that fresh water inflow represents a very small portion of the estuary's total water regime which is dominated below Oradell Dam by tidal flows.

The tidal Hackensack is a coastal plain estuary formed by rising sea levels, and attendant drowning of a glacial lake bed during the post-recession period of the Wisconsin Glaciation. The introduction of the tides into the system transformed the Glacial Lake Hackensack into a dynamic estuary over the course of time. Even today, the characteristics of these tides influence water quality, as noted below.

Tides within the estuary are predominantly semi-diurnal, with two high waters and two low waters per day. According to published National Oceanographic and Atmospheric Administration (NOAA) tide tabulations, the mean astronomical tidal range within the estuary varies from 5.0 feet near the mouth to 5.3 feet near the head. Moreover, the corresponding spring tidal ranges are 6.0 and 6.4 feet, respectively. Thus, tides within the system are nearly equal in amplitude or slightly amplified relative to tides at the open boundary. Also, the tidal bulge arrives a few miles below the head of the estuary at the city of Hackensack approximately 85 minutes after arrival at the mouth. Consequently, the tidal rise and fall is nearly uniform in amplitude and phase throughout the 22-mile estuary. Thus, the Hackensack responds to ocean sea level forcing approximately in a pumping mode. In actuality, due to the 85 minute lag noted above, the Hackensack tides are partially progressive, and not pure standing waves. In any case, it is clear that Hackensack tides are energetic and capable of vigorous mixing.

Estimates for the tidal prism (intertidal volume) are generally large relative to the fresh water inflow to the estuary. For example, Mattson et al. (1976) calculate a total volume influx on two successive flooding tides on 7/7/75 of 13,800 mgd. This daily prism is large relative to **their** estimated total daily-averaged fresh water inflow of

340 mgd (including contributions from runoff, STP discharge, and upstream discharge).

Due to its large tidal prism relative to the fresh water inflow, and relatively shallow depth, the estuary is generally **well-mixed vertically and laterally**. However, the estuary has a significant longitudinal salinity gradient over its 22-mile extent from its head to its mouth. Longitudinal variations in salinity as large as 17 ppt have been observed in this system. Thus, the Tidal River may be classified as a sectionally homogeneous estuary (Pritchard, 1955).

Approximately 40% of the incoming tidal flow is diverted to the expansive tidal flats along Sawmill Creek (Mattson et al., 1976). Consequently, tidal exchange processes are less effective in the upstream reaches of the estuary where considerable quantities of wasteloads are introduced.

2.1.3 Land Use and Soil Characteristics

The drainage basin of the Lower Hackensack River is characterized by densely urbanized areas along the northern and eastern sections and by low-lying meadowlands along the western and southern sections of the basin. The areal distribution of various land uses within this lower basin were compiled and summarized in Figure 2.1. This figure is based on existing land use maps prepared by the Bergen and Hudson County Planning Boards and the Hackensack Meadowlands Development Commission (HMDC) supplemented with information from current aerial photography.

An inspection of Figure 2.1 reveals that medium density residential land use predominates the lower Hackensack River Basin. Approximately 28.9 square miles, or 34.4%, of the total watershed area of 84 sq. miles is comprised of medium and low density residential development in Bergen County. For the most part, medium density residential development is located outside of the HMDC jurisdiction. High density residential land use occupies approximately 1.1 square miles, or 1.3%, of the watershed and is located in the eastern portions of the basin in Hudson County. Industrial development, comprising 20.2 square miles, or 24.0%, of the watershed is concentrated mainly at the northern, southern, and peripheral regions of the Meadowlands. Open space comprises approximately 30.4 square miles, or 36.2%, of the watershed is situated mainly within the Hackensack Meadowlands District. Commercial land use, comprising 3.4 square miles acres, or 4.1%, of the watershed, is distributed mainly outside of Meadowland regions.

Specific land use distributions such as those described above influence both the quantity and quality of runoff from a particular drainage basin. From a hydrologic standpoint, for example, the conversion of open space to impervious cover would reduce infiltration and increases both the rate and total volume of precipitation converted to overland runoff. Land use also affects pollutant accumulation and washoff rates from the watershed. For instance, agricultural areas may generate relatively high loadings of pesticides and nutrients. Urbanized areas generate a variety of substances including nutrients, oil, grease, and heavy metals. These factors were incorporated into the adapted watershed model for the lower Hackensack River Basin.

The lower basin contains numerous soil series. This variety in soil types is due to natural variation and to the artificial addition of fill material in wetland areas. For the purposes of this study, the specific characteristics of each soil type are unimportant. Factors of concern are the hydrologic characteristics of the different soil groups, including the rate of infiltration and percolation, the potential for erosion and evapotranspiration. On the basis of these characteristics, soil types can be partitioned into a limited number of groups. The Soil Conservation Service (SCS) divides soils into four hydrologic soil groups A, B, C and D. These groups are classified in order of increasing runoff potential with soil type A having the lowest runoff potential. The breakdown of the different soil groups are presented in Table 2.2, while Figure 2.2 shows the areal distribution of these different soil groups.

Table 2.2 - Distribution of Hydrologic Soil Groups in the Lower Hackensack River Watershed

Soil Type:*	A	B	C	D
Area (%):	0.1	15.8	37.2	42.0

* Open Water Occupies 4.9%

2.1.4 Water Quality

From the field data collected for this study during 1988, longitudinal profiles of the sample mean concentrations were constructed for several important water quality constituents. These longitudinal profiles are illustrated in Figures 2.3 and 2.4 for the April 12-22, 1988 survey and the August 23-30, 1988 surveys. Each plotted point represents an arithmetic mean of approximately 100 samples collected over the respective interval. Each error bar represents one sample standard deviation about the sample mean. Both surface and bottom water quality profiles are displayed.

From the longitudinal salinity profile, Figure 2.3, it is apparent that salinities vary over a broad range throughout the estuary. Longitudinal variations in the sample mean salinity ranging from approximately 2 ppt (at river mile 18) to 19 ppt (at river mile 1.4) were recorded for the August sampling period, while corresponding means ranging from approximately 2 ppt to 14 ppt were recorded during the April sampling period. In contrast to these large longitudinal and seasonal salinity variations, the data indicates only slight vertical variations in the mean salinity. Thus, it is likely that the estuary generally is **vertically well-mixed and unstratified.** Comparisons of

Tide data needed for the study was collected by the staff of Ocean Surveys, Inc. (OSI) of Old Saybrook, Connecticut while the flow and water quality data was collected and analyzed by General Testing Corporation located in Hackensack, New Jersey.

3.1 River Model Data

The adoption of the river model (MIT-DNM) to any estuarine/riverine system requires the following data:

- Detailed description of channel morphology, including storage and embayment areas.
- Hydrodynamic data (flow and tides) at all the boundaries and relevant instream locations.
- Corresponding water quality data at the same locations.

Detailed information on channel geometry (100-foot intervals) and basin topography (2 foot contours) were obtained from the U.S. Army Corps of Engineers (New York District) for the entire watershed and its tributaries. This data was supplemented by data collected during subsequent studies, including the plume study conducted for BCUA.

Hydraulic data (flow and tides) were collected at all the boundary and instream stations within the lower Hackensack River during the 1988 sampling period. Table 3.1 provides a description of the different sampling stations, while Figure 3.2 shows their locations within the river. Eight TDR-3A tide recorders were installed and maintained at stations H3, H5, H6, H7, H8, H9 and H10 for a period of six months (April through September of 1988) and at H1 from April to November 1988, respectively.

Table 3.1 - Hackensack River Hydraulic Gaging Stations

No.	Location	Approximate Distance Upstream of Newark Bay (miles)	Description
H1	Riverbank at Rte. 1 & 9 Bridge - Gypsum Street Pier	1.3	Temporary Tide Gage at Newark Bay Boundary
H3	Conrail Railroad Bridge	7.1	Temporary Tide Gage for Calibration/Verification
H5	Rte. 46 Bridge (Hess Oil Co. Pier)	13.7	Temporary Tide Gage for Calibration/Verification
H6	Old Bridge Road Bridge	18.0	Temporary Tide Gage for Calibraiton/Verification
H7 (USGS)	New Milford Dam	21.7	Permanent River Gage at Upstream Boundary
H8	Coles Brook at Main Street	--	Temporary River Stage Recorder at Tributary Boundary
H9	Overpeck Creek above NJ Turnpike Bridge	--	Temporary River Stage Recorder at Tributary Boundary
H9A	Overpeck Creek below NJ Turnpike Bridge	--	Temporary River Stage Recorder at Tributary Boundary
H10	Berrys Creek at Industrial Avenue Bridge	--	Temporary River Stage Recorder at Tributary Boundary

During these periods, tidal elevations were recorded continuously at the four river stations. At station H1, near the mouth of the Hackensack River, a duplicate tide gage H1A was installed to supplement the data at station H1. This was done to avoid any lapses in the tide data, in the event of instrument malfunction, at station H1, the critical boundary station for adaptation of the river model. A current meter was also installed near Station H1 in the river to measure tidal currents at the boundary station.

Rating curves were generated at each of the tributary stations H8, H9 (see Appendix A-1) and H10 to generate hydrographs at these stations. The development of a rating curve at the tidal barrier in the Overpeck Creek was more complicated due to the automatic operation of these gates. An algorithm was developed to account for this feature and the flows computed accordingly. Flow at station H7, Oradell Dam, was obtained directly from USGS which maintains a permanent gage at this location.

Concurrent to the collection of the hydraulic data, water quality data was collected at these stations during the four sampling periods described previously. Table 3.2 shows the locations and frequencies of the collected water quality data. Data was collected at the ten instream and tributary stations (W1-W10) during the sampling periods April 12-22, July 11-25 and August 23-29, 1988, respectively. Sampling was conducted at 3 hour intervals (night and day) at all stations except for station W1. At this critical boundary station, the sampling interval was reduced to 2 hours.

The accurate and rigorous monitoring of Station W1, the open boundary was an essential component of the study. The results of sampling at this station provided invaluable insight into the contribution of pollutants to the lower Hackensack River from Newark Bay. A two depth (1/2 and 2/3) monitoring protocol was adopted at stations W1, W2, W3, W4 and W5 to provide information regarding possible two layer circulation in the lower Hackensack River and its intimate interaction with

Table 3.2 - Hackensack River Water Quality Sampling Stations

Station	Location	Approximate Miles Upstream of Newark Bay	Qualifier	Sample(1) Retrieval	Parameters Analyzed(2)	Frequency of Sampling (Events/Day)
W1	Rte 1 & 9 Bridge	1.3	Newark Bay Boundary	2 depths	A11	2
W2	Erie Lackawanna Railroad Bridge	5.1	Calib./Verif. /Storm	2 depths	A11	3
W3	Conrail Railroad Bridge	7.1	Calib./Verif. /Storm	2 depths	A11	3
W4	Centre of Hackensack River, opposite Bellmans Cr.	10.8	Calib./Verif. /Storm	2 depths	A11	3
W5	Rte. 46 Bridge	13.7	Calib./Verif. /Storm	2 depthd	A11	3
W6	Old Bridge Road Bridge	18.0	Calib./Verif. /Storm	Single depth	A11	3
W7	Oradell Avenue Bridge	21.7	Calib./Verif. /Storm	Single depth	A11	3
W8	Coles Brook at Main St.	--	Calib./Verif. /Storm	Single depth	A11	3
W9	Overpeck Creek at Bergen Turnpike Bridge	--	Calib./Verif. /Storm	Single depth	A11	3
W10	Berrys Creek at Industrial Avenue Bridge	--	Calib./Verif. /Storm	Single depth	A11	3

(1) 2 depths indicates sampling of 1/3 and 2/3 depths while 1 depth indicates sampling at 1/2 depth

(2) See text for parameters analyzed

Newark Bay. A similar approach adopted by Najarian et al (1983) study in the Passaic River proved to be an important factor in the accurate assessment of pollutant loadings into the lower Passaic River. The data observed at Station W1, however, did **not** show vertical stratification indicating the Hackensack to be a well mixed estuary.

The analysis of water quality was designed primarily to assess variables which directly influence the variation of dissolved oxygen (DO) concentrations in the Lower Hackensack River. Accordingly, the following variables were monitored at instream locations, tributaries, and the boundaries at Newark Bay and Oradell Dam.

(a) Salinity
(b) Temperature
(c) pH
(d) Turbidity
(e) Suspended Solids
(f) Chlorophyll-a
(g) C-$BOD_{5\&20}$
(h) NH_3-N
(i) NO_2-N
(j) NO_3-N
(k) TKN
(l) DO
(m) Organic Phosphate
(n) Orthophosphate
(o) Total Phosphorus
(p) Fecal Coliform

During the data collection effort, it was essential to compute pollutant loads from all other point sources discharging into the River. These point sources consisting of STPs, power plants and dry-weather overflows (DWOs) were monitored during the study. Several samples were taken at each STP during each river survey to supplement the information provided in NJDEP's Discharge Monitoring Reports (DMRs) database. Similar data was collected at three major DWOs located within the system.

The location of PSE&G's thermal power plant at Ridgefield was a critical component of the study. This plant, located about half a mile upstream of BCUA's, discharges about 650 MGD of heated water at temperatures around 100°F into the lower Hackensack River via a discharge channel. Due to the critical nature of this discharge, a separate flow meter and temperature gage were installed at the effluent channel to continuously monitor both the flow and temperature of the heated discharge.

The activity of benthic microphytes were monitored at 5 locations in the tidal River approximately over a one year period. Eight core samples were taken at each location and analyzed by GTC using the core-incubation method. The intent of this design is to account for potential spatial and temporal variability of this important source/sink term. The locations of Benthos monitoring stations correspond with the following water quality sampling stations: W1, W2, W3, W5, W6 (see Figure 3.2).

Long-term rainfall data for the watershed model was obtained at two monitoring stations. One of these stations is designated as a primary station by the National Weather Service (NWS) - Newark Airport. The second station is operated by the Hackensack Water Company near Oradell Dam. In addition to the rainfall data, long-term meteorological data required for the water quality component of the River model was obtained from the Newark Airport Weather Station.

3.2 Watershed Model Data

The adoption of the runoff model (SWMM-4) to the watershed of the lower Hackensack River Basin required the following data:

- Drainage subcatchment morphology for all the CSO and storm sewered areas within the watershed (i.e. drainage basin delineations, land use and soil type descriptions, impervious areas, pipe size and slope data, CSO chamber descriptions, etc.)
- Short-term and long-term rainfall data at several locations within the watershed
- Continuous flow data at selected CSO and storm sewer locations during the observed storm events