5. RIVER MODEL DESCRIPTION AND ADAPTATION

The selection of the MIT-Dynamic Network Model for water quality analysis of the lower Hackensack River was presented earlier in Chapter 2. This chapter provides a detailed description of the model and it elaborates upon the adaptation of the model to the lower Hackensack River Estuary.

5.1 River Model (MIT-DNM) Description

MIT-DNM is a one-dimensional, transient flow and water quality model designed for both riverine and estuarine systems of variable cross-sectional area. The model is organized around two basic components: hydrodynamic and water quality/ecology. The flow regime in the system under investigation is simulated through the use of the hydrodynamic component of the model. The flows thus generated are internally fed to the water quality/ecology component for the simulation of water quality variations in the aquatic system. In this latter component, a set of coupled and uncoupled mass conservation equations are solved numerically, using a finite element computational scheme, to generate the temporal and spatial distribution of variables of concern in the waterbody.

The governing equations for one-dimensional unsteady flow in a variable area channel are the continuity equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \tag{5.1}$$

and the longitudinal momentum equation:

$$\frac{\partial}{\partial t}(AU) + \frac{\partial}{\partial x}(QU) = -gA\frac{\partial h}{\partial x} - g\frac{Q|Q|}{AC^2 R_h} - \frac{gAd_c}{\rho}\frac{\partial \rho}{\partial x} \tag{5.2}$$

in which:

- x = distance along the longitudinal axis
- t = time
- h = elevation of water surface with respect to a horizontal datum
- Q = cross-sectional discharge
- q = lateral inflow per unit length of channel
- U = Q/A = average cross-sectional velocity in the channel
- g = acceleration of gravity
- A = cross-sectional area of channel
- C = $(1.49/n)R_h$ = Chezy roughness coefficient (n = Manning's)
- R_h = hydraulic radius of channel
- p = density of water
- d_c = distance from surface to centroid of the cross section

The basic component of a water quality model is a statement of conservation of mass. Essentially, the model consists of a sequence of conservation of mass equations, one for each water quality constituent. The one-dimensional conservation of mass equation may be written as

$$\frac{\partial}{\partial t}(AC) + \frac{\partial}{\partial x}(QC) = \frac{\partial}{\partial x}\left(AE_L \frac{\partial C}{\partial x}\right) + A\left(\frac{r_i}{\rho} + \frac{r_e}{\rho}\right) \tag{5.3}$$

in which:

- C = concentration of water quality constituent
- E_L = longitudinal dispersion coefficient
- r_i = time rate of internal addition of mass of substance per unit volume by transformation or reaction processes
- r_e = time rate of external addition of mass of substance per unit volume by addition of substance across the lateral, free surface and bottom boundaries of the system

The adapted model utilizes Equations 5.1 and 5.2 to define spatially-varying flow depths and discharges, and a set of equations similar to Equation 5.3 is utilized to model CBOD, NBOD and DO distribution in the river reaches under consideration.

Model algorithms allow dissolved oxygen to be addressed at two levels of complexity. The primary approach models the influence of carbonaceous and nitrogenous oxygen demands on dissolved oxygen kinetics. The latest version of this model (Najarian et al., 1981) utilizes a phenomenological approach to incorporate the dynamic impact of phytoplankton (chlorophyll a) on dissolved oxygen concentrations in an aquatic environment. A more complex ecological model allows the dynamic simulation of the nitrogen cycle in its interactions with phytoplankton and zooplankton. In the present study, the calculation of the DO variation is achieved by the solution of three mass conservation equations, each written for CBOD, NBOD and DO. These equations are:

$$\frac{\partial}{\partial t}(AL) + \frac{\partial}{\partial x}(QL) = \frac{\partial}{\partial x}\left(AE_L \frac{\partial L}{\partial x}\right) - K_1 AL \tag{5.4}$$

$$\frac{\partial}{\partial t}(AN) - \frac{\partial}{\partial t}(QN) = \frac{\partial}{\partial x}\left(AE_L \frac{\partial N}{\partial x}\right) - K_2 AN \tag{5.5}$$

$$\frac{\partial}{\partial t} A(DO) + \frac{\partial}{\partial x} Q(DO) = \frac{\partial}{\partial x}\left(AE_L \frac{\partial (DO)}{\partial x}\right) - 4.57K_2 AN - K_1 AL + K_a A\left[(DO)_s - (DO)\right] + (P-R) \tag{5.6}$$

in which:

- L = Ultimate CBOD concentration
- N = NBOD concentration
- K_1 = CBOD decay coefficient
- K_2 = NBOD decay coefficient
- DO = concentration of dissolved oxygen
- K_a = surface reaeration coefficient
- $(DO)_s$ = saturation concentration of dissolved oxygen
- $(P-R)$ = rate of net oxygen contribution due to algal metabolism

It must be noted that, for each pound of NBOD decay, there is a potential consumption of 4.57 pounds of DO in the receiving water. Also, the model rate coefficients, K_1, K_2, K_a, and (P- R), are all temperature dependent.

In aquatic systems, the variation in the diurnal DO concentration is caused by differences of the photosynthetic rates and respiratory processes at various times during a day. Thus, using available scientific information, it is possible to generate a time-varying net DO evolution during a diurnal cycle due to algal activity in a quasi-steady environment. Within MIT-DNM, a diagnostic model relates the observed steady state chlorophyll a concentrations to the time-varying rate of oxygen evolution in the environment.

In a study by Najarian et al (1981) a detailed derivation of a phenomenological model for DO diurnal variation was derived. The study used the model to relate the chlorophyll a concentrations in the lower Mohawk River to diurnal DO concentration variation. The daily photosynthetic generation of DO per unit of chlorophyll a concentration can be computed as follows:

$$DO = 2.2632 \times 10^{-5} \times 10^{(0.0275T - 0.07)} \frac{(\text{gms of } O_2/l)_{\text{evolved}}}{(\mu g \text{ chl } \underline{a}/l)_{\text{biomass}} \times \text{day}} \quad (5.7)$$

where T is the water temperature in degrees Celsius. Table 5.1 shows the net hourly generation of DO in the environment as percent of the total daily DO evolution in the system.

MIT-DNM is designed to simulate the temperature variations in an aquatic equation. Ambient temperature changes in a waterbody are due to both natural and euthropagenic causes. Solar and atmospheric radiation and evaporation are the primary factors affecting ambient water temperatures. Heat rejection from power plants or other industrial discharges constitute the man-made factor affecting water temperatures.

Table 5.1 - Time-Varying Percentage of Total Daily DO Production due to Photosynthesis

Time Interval (hrs)	Percent DO evolution Summer	Winter
0:00-1:00	-4.167	-4.167
1:00-2:00	-4.167	-4.167
2:00-3:00	-4.167	-4.167
3:00-4:00	-4.167	-4.167
4:00-5:00	-4.167	-4.167
5:00-6:00	-4.167	-4.167
6:00-7:00	-2.857	-1.667
7:00-8:00	-0.215	3.333
8:00-9:00	2.417	8.333
9:00-10:00	5.055	13.333
10:00-11:00	7.692	13.333
11:00-12:00	10.329	8.333
12:00-13:00	10.329	5.000
13:00-14:00	7.692	3.333
14:00-15:00	5.055	1.667
15:00-16:00	2.417	0.000
16:00-17:00	0.439	-1.667
17:00-18:00	-0.881	-3.333
18:00-19:00	-2.198	-4.167
19:00-20:00	-4.167	-4.167
20:00-21:00	-4.167	-4.167
21:00-22:00	-4.167	-4.167
22:00-23:00	-4.167	-4.167
23:00-24:00	-4.167	-4.167

Temperature variations are computed in the model by using the conservation of energy equation:

$$\frac{\partial}{\partial t}(AT) + \frac{\partial}{\partial x}(QT) = \frac{\partial}{\partial x}(AE_L \frac{\partial T}{\partial x}) + \frac{\theta_n b}{\rho c} \tag{5.8}$$

in which:

T = water temperature
O_n = time rate of net heat input per unit area of water surface
pc = (density) x (specific heat of water)
b = width of water surface

In equation 5.8, the last term represents a source of the external type (i.e., the net rate at which heat is transferred across the water surface by the combined processed of long and short wave radiation, evaporation and convection).

The applicability of MIT-DNM to waterways like the lower Hackensack River is well documented in the published literature (e.g. Najarian et al., 1984, Najarian et al., 1980). This model has been shown to accurately reproduce the hydrodynamic and water quality/ecological regime of a number of similar estuarine systems.

5.2 River Model Schematization

To properly account for the variations in river morphology and to incorporate the impacts of these variations on flow velocities and water quality processes, the adaptation of the MIT-DNM model to the lower Hackensack River was conceptualized as consisting of nine reaches (see Figure 5.1).

Reach I extends from the Communipaw Avenue (Routes 1 & 9) Bridge in Jersey City to the confluence of Berry's Creek in Secaucus, a distance of 5.8 miles. The boundary of the reach was located about 1.3 miles upstream from Newark Bay to eliminate the effects of the lower Passaic River, which also discharges into Newark Bay. Two tide gages were anchored to bulkheads on the western bank of the lower

Hackensack River near the bridge (station H1, H1A), while water quality data was collected at two depths from the center of the bridge (station W1). **This hydraulic and water quality data station is the most critical location inasmuch as it represents the ocean boundary of the model.** The instream water quality monitoring station W2 is located within this reach. This reach of the River contains the deepest and widest sections of the entire Hackensack River. Depths here vary from twenty to sixty feet and widths vary from 700 feet to 2,000 feet in the widest section of the River. A navigational channel maintained by the U.S. Army Corps of Engineers is located along the center of the river. The channel is 400 feet wide with a depth of 30 feet at mean-low-water (MLW). The reach has two power plants along its shores, several CSO's and two tributaries discharging into the River. Penhorn Creek is a minor tributary located on the eastern bank of the River with a tide gate control structure. The Sawmill Creek tributary, located on the western bank of the River, is intimately tied to an extensive area of tidal marshes and mudflats. **About 40% of the tidal volume entering the lower Hackensack Estuary is stored in these marshes and mudflats.** Several major landfills are also located within the Sawmill River basin.

Tidal flows entering this reach of the river from Newark Bay can exceed 60,000 cubic feet per second (cfs). The schematization of this reach was complicated in accounting for the tidal storage within the Sawmill Creek Basin. The MIT-DNM model schematization allows the specification of such embayment storage areas. The technique adopted in the model incorporates the storage volume in the solution of the continuity equation while it is excluded in the solution of the momentum equation. A detailed explanation of this technique is provided in the MIT-DNM User's Manual (Harleman et al., 1977).

Reach II extends from Berrys Creek to the confluence of Berry's Creek Canal in Secaucus, a distance of about 0.9 miles. Depths in this reach of the river vary from 20 feet to 30 feet and widths vary from 500 feet to 2,000 feet. This reach has commercial and industrial development along its eastern bank and tidal marshes along the western bank. The New Jersey Turnpike acts as a drainage divide between the main channel and the tidal marshes. A tide gage (H3) and water quality monitoring station (W3) are located near the downstream end of this reach.

Reach III extends along the main channel of the River, from Berry's Creek Canal to the confluence of Overpeck Creek, a distance of 5.2 miles. Depths in this reach vary between 15 feet to 40 feet, while the widths vary between 400 feet to about 1,000 feet. This reach of the River has five tidal tributaries located on both banks. These include Mill Creek, Cromakill Creek, Bellman's Creek, Moonachie Creek and Losen Slofe, respectively. Three STP's (BCUA, Secaucus and North Bergen) and one power plant are located within this reach of the River. Tidal marshes occupy the major portions of both banks of the River. Due to the presence of several STP's including BCUA, and PSE&G's power plant, this reach of the river is the most environmentally critical reach of the entire Hackensack River. Smaller tidal flows (about 5,000 cfs) in this reach tend to compound the problem of water quality.

Reach IV, the tidal Overpeck Creek, is a tributary to the main Hackensack River. This reach extends from the mouth of the tidal Overpeck to the tidal dam located below the New Jersey Turnpike, a distance of 0.9 miles. The Overpeck Creek tidal dam prevents tidal flows to reach the upper Overpeck Creek. Freshwater from the Overpeck Creek basin is discharged at the dam to the tidal Overpeck. This reach is fairly shallow with depths about 10 feet below MLW and is about 300 feet wide. The major environmental significance of this reach is the location of PSE&G's cooling water intake to its Bergen power plant, about half mile from the mouth of the Overpeck. The plant diverts about 1,000 cfs of cooling water from the Creek and discharges it to the main River at elevated temperatures close to 100°F, under peak summer conditions.

Reach V in the lower Hackensack River extends from the mouth of the Overpeck Creek to the head of tide at Oradell Dam, a distance of 8.9 miles. Depths in this reach of the River are shallow and they vary between 5 feet to 15 feet, while the widths change from 50 feet to 300 feet. This section of the River drains the most densely populated residential areas in Bergen County. Two major tributaries, Coles Brook and Hirshfeld Brook drain into this reach of the River. Several CSO's from the cities of Ridgefield Park and Hackensack discharge into this reach. The head of tide at Oradell Dam, is the northern terminus of the lower Hackensack River Basin and study area. Observed flow and water quality at this station served as the upstream boundary of the modeled system. Two tidal monitoring stations (H5 and H6) and two water quality monitoring stations (W5 and W6) are located within this reach.

Reaches VI, VIII and IX represent the Berry's Creek Canal system with two of its upper tributaries. They extend from the Hackensack River to its upstream terminus at Moonachie Avenue. These reaches extend over 3.2 miles, 0.3 miles and 0.7 miles, respectively. Their depths vary from about 5 feet to 15 feet, while the widths change from 100 feet to 300 feet, respectively. The land use within these reaches are primarily tidal marshes, with extensive commercial/industrial areas located at the northern end. Two STP's discharge into the Berrys Creek System.

Reach VII, Berrys Creek, extends from its mouth at the Hackensack River to Berrys Creek Canal at its northern end, a distance of 1.8 miles. Extensive construction at its upper end, restricts flows between the Creek and the Canal. Accordingly, an asssumption was made that Berrys Creek and Berrys Creek Canal were not hydraulically connected. The watershed draining into Berrys Creek is primarily a tidal marsh.

The system of nine reaches described above was schematized by numerically specifying irregular cross-sectional geometries, based on the latest sounding information of the U.S. Army Corps of Engineers. This data was supplemented with NOAA charts and detailed cross-sectional information taken in Reach III by Ocean Surveys, Inc., in 1989 for plume studies of BCUA's discharge. Storage areas and volumes in the tidal marshes and mudflats, constituting overbank areas for model schematization were obtained from high resolution 200 scale contour maps. These maps were available from both the U.S. Army Corps of Engineers and the Hackensack Meadowlands Development Commission. This data was converted to a common datum (N.G.V.D.), and the enitre network was schematized to a format compatible with the MIT-DNM. Figure 5.2 shows a typical cross-sectional schematization of the lower Hackensack River, while Figure 5.3 shows the bottom profile of Reachs I, II, III & V, the main stem of the River from Newark Bay to Oradell Dam.

The model's numerical solution allows the user specification of both the computational mesh spacing (δx) and the computational time step (δt). The specification of the computational mesh spacing (δx) is based on spatial variations in channel cross-sectional geometry within a specific reach. Larger δx values are specified in reaches with uniform cross-sections, while smaller values are specified in shallow, dendritic reaches of the network. Table 5.2 shows the specification of computational mesh spacing (δx) for the entire network.

Table 5.2 - Specification of Hydraulic Computational Meshpoints (δx)

Reach No.	δx (feet)	Length (feet)	Reach Description
1	500.0	30,340	Kearney Point to Berry's Creek
2	500.0	4,850	Berry's Creek to Berry's Creek Canal
3	500.0	27,500	Berry's Creek Canal to Overpeck Creek
4	100.0	4,500	Overpeck Creek
5	500.0	47,015	Overpeck Creek to Oradell Dam
6	500.0	16,700	Berry's Creek Canal
7	500.0	9,720	Lower Berry's Creek
8	250.0	1,720	East Branch, Upper Berry's Creek
9	400.0	3,700	West Branch, Upper Berry's Creek

The specification of the integration time step (δt) is predicated both on the numerical stability of the models solution technique, and transport characteristics of both the hydraulic and water quality variables adopted in the modeling procedure. While specification of a smaller time step has the benefit of increased model accuracy, the major disadvantage is the increased computation time. A suitable compromise should be reached between these two variables to determine the selection of an optimum time step. **Based on several iterations of both the hydraulic and water quality components of the model, a hydraulic time step (δt) of 3.5 minutes and water quality time step (δt) of 30 minutes were found to be the most adequate time intervals for simulation purposes.**

5.3 Hydraulic and Water Quality Model Calibration and Verification

The proper description of network topology and channel geometry schematization constitutes the first step in model adaptation to the lower Hackensack River tributary system. The second step consists of calibrating model governing parameters with field observed data and verifying the model by comparing its output with a second set of independent field data. The two components of the model - hydraulic and water quality - must be properly calibrated and verified independently. However, as the water quality component of the model calls for the output of its hydraulic component, it is imperative that the hydrodynamics of the system be first rigorously calibrated and subsequently verified. For simulation of hydrodynamics of saline estuarine systems, it is important to account for varying density gradients. In the MIT-DNM model, hydrodynamic simulations are coupled with salinity simulations to account for the density effects on tidal hydraulics. Thus, all hydrodynamic simulations in the lower Hackensack River Study were conducted concurrently with salinity as a modeled variable for the entire network.

The system of interest here, consists of nine coupled reaches as described in Section 5.1. The one-dimensional flows and water surface elevations are first computed to provide the necessary hydrodynamic parameters for the solution of the mass conservation equations and energy equation. The parameters of interest are the flows, salinity, temperature, and concentrations of C-BOD, N-BOD, DO, in the lower Hackensack River.

For the purpose of model calibration and verification, the extensive data base collected in the lower Hackensack River during the Spring and Summer of 1988 was adopted. Data was collected during four independent events in April, July and August, 1988, as shown in Figure 3.1. The periods April 11-20 and July 11-16 were used for model calibration and verification under ambient (no storm) conditions, while the periods July 16-25 and August 23-30 were used for model calibration and verification under wet (storm) conditions. During the period July 11-25 data was collected continuously for fifteen days to reflect both a dry (no storm) period and wet (storm event) period in the Hackensack River. Hence, results of the dry weather model verification period (July 11-20) and the wet weather model calibration period (July 20-25) are presented together in a single section of the report.

For the purpose of model calibration (dry event), the data collected during the period April 12-22, 1988 was utilized. No significant rainstorm occurred during this period resulting in negligible land surface runoff. Thus, the observations represent true ambient conditions in the lower Hackensack River Basin. The mean flow over Oradell Dam, the major upstream boundary during the ten day period was 8 cfs. This is about 8% of the long-term average flow of 99 cfs. The data collected during this period was used to calibrate the hydrodynamic and water quality component of the model.

For model verification (dry event) and model calibration (wet event), the data collected during the period July 11-25, 1988 were utilized. A large rainstorm coincided with this period of field observation. A total rainfall volume of 1.57 inches occurred on July 20 at Neark Airport resulting in a moderate peaking of hydrographs in the major tributaries except at Oradell Dam. The flow at this location was detained by the Hackensack Water Company (HWC) to augment water supply at their Oradell Reservoir. The lateral flows and runoff pollutant loadings resulting from the storm event which occurred in the basin during the period of monitoring were computed using the SWMM-4 runoff model. The details of the SWMM-4 model were described in detail in Chapter 4. Thus, the model verification period included a period of ten days under ambient summer conditions, followed by a five day wet-event with a severe (97%) rainfall event.

The hydraulic and water quality verification of the model was achieved by keeping the model governing parameters specified during the calibration process unchanged. Here, a final review of all these parameters was made and checked against literature review values to ensure that no **strenuous tuning** of the model to fit the data occurred.

For model verification (wet event), the data collected during the period August 23-30, 1988 was adopted. A moderate storm event (93%) of 1.09 inches occurred during August 23-24 and lasted a period of ten hours with 1.02 inches falling over a mere three hours. Flow at Oradell Dam, the freshwater boundary of the system, was about 9 cfs, 8% of the long-term average flow. The methodology adopted for model validation was similar to that adopted during the first storm event survey of July 20-25. All the hydraulic and water quality rate coefficients specified during the previous calibration and verification of the model remained invariant during this period.

5.3.1 Hydraulic Calibration of the Model (Dry Event, April 12-22, 1988)

Specifications of Initial Conditions

A consistent set of initial water surface elevations, flows and salinities were specified in all reaches of the lower Hackensack River system. As the model was applied in unsteady mode, these initial conditions were generated by exercising the model with flow conditions which preceded the field monitoring program by five days. The results of the model run provided a truly consistent description of the desired flows and water surface elevations throughout the system of interest prior to a storm.

Specification of Boundary Conditions

For hydraulic computations in the network of interest, four boundary conditions must be specified. The first boundary condition to be specified are tidal elevations and salinity concentrations at node 1, the ocean boundary, shown in Figure 5.4(a) and 5.5(a). These tidal elevations and salinities were observed 1.3 miles upstream of Newark Bay during the April calibration period. The other boundary conditions are at Oradell Dam, node 5, Overpeck Creek Dam at node 10 and the upstream flow into Berry's Creek at node 9 (see Figure 5.1). At these three locations, observed hydrographs were specified for the duration of the data collection effort.

In addition to these boundary conditions, time-varying hydrographs are specified to represent inflows to the system from other tributaries within the network. Observed lateral inflows are specified to represent effluent discharges from all STP's within the boundaries of the system under investigation. Finally, provision is made to account for cooling water recirculation at the three power plants operated by PSE&G.

Results of Hydraulic Calibration

With the specified initial and boundary conditions discussed above, the MIT-DNM was exercised in real-time to simulate transient hydrodynamic conditions for a period of ten continuous days in the lower Hackensack River network. The hydraulic calibration of the adapted model was achieved by adjusting the bottom friction factor "n" and the Taylor dispersion parameter "m". Table 5.3 shows the spatial variation of Manning's "n" coefficient arrived at during this calibration effort. High values were assigned for those reaches of the modeled streams where dendritic river banks and elongated mid-stream islands exist. A single value of m=40 was used for the Taylor dispersion multiplier.

Figure 5.5 shows the results of the hydraulic calibration. This figure shows the observed and computed tidal elevations within the main stem of the River, at river miles 7.4 and 13.8, respectively. The figure shows an excellent match between model predictions and field observations in both the phases and amplitudes of the tidal variations.

Figures 5.6(b), 5.7(a) and 5.7(b) show the observed and computed salinity concentrations at river miles 5.1, 7.4 and 10.9, respectively. The results show an excellent match between observed and computed salinity concentrations at all three locations.

The modeling results show a strong longitudinal salinity gradient between the mouth of the estuary (15 ppt) and the upper reaches, with salinities in the 5 ppt range. The successful calibration of the hydrodynamic and salinity regimes of the system indicates the models ability to accurately mimic the advection and dispersion properties unique to the lower Hackensack River network.

Table 5.3 - Description of Manning's "n" for the Network

Reach No.	Length (ft)	Manning's (n)
1	30,340	0.035
2	4,850	0.035
3	27,460	0.035
4	4,500	0.035
5	47,015	0.040
6	16,700	0.040
7	9,720	0.040
8	1,720	0.040
9	3,700	0.040

5.3.2 Water Quality Calibration of the Model (Dry Event, April 12-22, 1988)

The water quality component of MIT-DNM was next calibrated using the previously calibrated model hydrodynamics, and the comprehensive water quality database generated during the April 12-22, 1988 survey. This period reflected typical ambient conditions in the lower Hackensack River Basin with no rainfall during the entire ten days. Air temperature varied between 40°F and 60°F, while ambient water temperature varied between 45°F to 55°F in the lower reaches of the river. Elevated temperatures around 62°F were observed in the vicinity of PSE&G's Bergen Power Plant. A detailed description of the collected April data is contained in a separate report prepared by GTC.

The water quality variables selected for model calibration were Temperature, C-BOD, N-BOD and DO. These variables were selected because of their interdependence with the DO dynamics of the lower Hackensack River. Influences of algal dynamics and benthal influences were also incorporated into the calibration effort.

Specification of Initial Condition

Seven water quality sampling stations (W1 through W7) were located in the lower Hackensack River between Newark Bay and Oradell Dam. Field observed data were available at each of the seven sampling stations for the initial period of model simulation. At locations between these stations, linearly interpolated initial conditions were used. This assumption was valid, since no storm event causing local runoff occurred during this period. The specified initial conditions for the network are shown in Table 5.4.

Water Quality Boundary Conditions

Water quality data at six locations are needed to completely define the input boundary conditions of the network. The two major boundaries are located at Newark Bay (node #1) the downstream boundary, and Oradell Dam (node #5) the upstream boundary of the main stem of the estuary. Observed concentrations of Temperature, C-BOD, NH_3-N and DO were specified at these six locations. Similarly, observed water quality concentrations were specified at the major tributaries of the lower Hackensack River. During the April survey, flows entering the estuary from the upstream boundary were about 8 cfs for the entire 10 day duration. Thus, the major source of pollutants from the boundaries were from station W1, the ocean boundary. Figures 5.8(a), 5.10(a) and 5.12(a) show the specification of Temperature, C-BOD, NH_3-N and DO concentrations at the critical boundary station W1.

An additonal input required to model the temperature regime is a time series of meteorologic data for the survey period. Such information includes air temperature, relative humidity, wind speed, and cloud cover. This information was obtained from the Newark Airport NWS Station. Site specific information included an assessment of local shading impacts based on field observations and aerial photographs.

Table 5.4 - Specification of Water Quality Initial Condition (Model Calibration, April 12-22, 1988)

Location	Reach	River Mile	Salinity (ppt)	Temperature (°F)	C-BOD (mg/l)	NH_3-N (mg/l)	DO (mg/l)
W1(ocean boudary)	1	1.4	12.0	50.0	4.0	1.0	8.0
W2	1	5.1	10.0	50.0	7.0	2.5	9.5
W3	2	7.4	8.0	50.0	8.0	3.0	10.0
W4	3	10.9	6.0	60.0	8.0	6.0	6.0
W5	5	13.8	5.0	58.0	6.0	6.0	8.0
W6	5	17.5	2.0	53.0	6.0	1.0	10.0
W7(upstream boundary)	5	22.0	2.0	53.0	6.0	1.0	10.0
Berry's Creek Canal	6	---	10.0	50.0	6.0	2.0	6.0
Berry's Creek	7	---	10.0	50.0	6.0	2.0	6.0
E-Branch Berry's Creek	8	---	10.0	50.0	6.0	2.0	6.0
W-Branch Berry's Creek	9	---	10.0	5.0	6.0	2.0	6.0

MIT-DNM simulates temperature based solely on such meteorologic and thermal loading inputs with no allowance for "adjustable" model coefficients.

The calibration of any dissolved oxygen/water quality model requires the specification of several reaction rate coefficients. These coefficients determine the rates of CBOD de-oxygenation (K_1), nitrification (K_2), and reaeration (K_a). Two elements of the intensive survey data, the benthal oxygen uptake rate (SOD) and the chlorophyll a concentration, are also utilized by the model in a manner similar to the above rate coefficients. Initial estimates for K_1 and K_2 were obtained through a review of both literature sources (EPA, 1985) and previous model studies conducted for streams in New Jersey. The reaeration rate is internally calculated by MIT-DNM as a function of several hydrualic parameters according to Harleman et al. (1977) as follows:

$$KDO = \left(KD20\,\frac{V^{0.60}}{H^{1.40}}\right)QT^{(T-20)} \times H \times \frac{\text{Total Topwidth}}{\text{Total Area}} \qquad (4.11)$$

Where:

- v = velocity (fps)
- H = depth (ft)
- T = total topwidth (ft)
- A = total cross-sectional area (ft^2)
- Ka_{20} = user defined coefficient (default=20.8)
- Q_T = Emperical Coefficient

The user defined coefficient (K_{a20}) was chosen to mainatain the K_a rate within the expected range of literature values. The suitability of all model coefficients was scrutinized and, if necessary, adjusted as part of the iterative model calibration process. A listing of the final model calibration coefficients is shown in Table 5.5.

These coefficients are all listed for 20°C. Within the model, all coefficients were adapted to the observed field temperatures based on the standard Arrhenius equation.

Table 5.5 - Model Rate Coefficients Adopted for April Calibration

Model Coefficient	Reach	Model Input
Oxidation Rate of Ultimate C-BOD (K_1 - 1/day)	1 - 9	0.2
Nitrification Rate (K_2 - 1/day)	1 - 9	0.1
Sediment Oxygen Demand* (mg/l/d)	1 - 6	0.1
Chlorophyll a (ug/l)*	1	30 - 50
	2	50
	3	80
	4	80
	5	60 - 100
	6 - 9	20
Reaeration Coefficient (K_a - 1/day)	1	40
	2	40
	3	80
	4	50
	5	10
	6-9	20

* Based on data collected in 1988.

Specification of the Point and Non-Point Sources

In addtion to the pollutant loads entering the lower Hackensack River from the boundaries of the system, other point and non-point loads entering the different reaches of the river need to be included as inputs to the model. These source/sink terms include benthic loads, effects of algal respiration, marsh impacts, impacts from landfills, pollutant loads from major treatment plants and industrial sources.

To account for impact of benthic loads, detailed experiments were conducted at several locations along the main Hackensack River and its tributaries. These experiments were conducted over a one year period and the detailed methodology was presented in Chapter 3. The results indicate that during the month of April, no discernible Sediment Oxygen Demand was evident in the entire network. This is possibly due to the relatively cool temperatures prevalent during the April 1988 survey. The SOD rates adopted for each reach are shown in Table 5.5.

The methodology for simulating algal respiration was explained in detail in Section 5.1. Algal concentrations between 30-100 microgram/m^3 were observed during the April survey at several locations along the river. The response of algal dynamics on the DO regime is to produce a diurnal DO variation based on the algorithm discribed in Section 5.1. No net daily change in DO concentrations occur due to either algal respiration or photosynthesis. However, a diurnal DO cycle is generated, based on the specified concentration of chlorophyll-a in the water column. The specification of chlorophyll-a during model calibration are shown in Table 5.5.

The impact due to landfills was analyzed in detail together with the comprehensive marsh study conducted in 1988 and 1989. The deatils of these studies are contained in Volume II of this report. The results indicate that several landfills located in the Upper Sawmill Creek Basin, (Figure 2.6) are a significant source of both BOD and NH_3-N. These loads were computed to be between 2,000-4,000lbs/day of both BOD_5 and NH_3-N. These values were included in the model as point loads into the main Hackensack River along Reach I. Several previous studies, including the Northeast 208 Plan, have generated landfill pollutant loadings for all the landfills in the basin. **These loads were generated from a single mean, national loading rate referenced in EPA's Areawide Assessment Manual, Volume II.** In the current study, pollutant loadings for the landfills were generated by the field data collected in the Sawmill

Creek Basin containing two major landfills. The loading rates thus generated were extrapolated to the other landfills as shown in Table 2.5.

Point sources discharges from all the major STP's entering the lower Hackensack River were monitored during the April Survey. In addition, thermal load contributions from PSE&G's power plant at Bergen was continuously monitored. Pollutant loads from other industries and thermal loads from two other power plants were obtained from Discharge Monitoring Reports (DMR) of NJDEP. These loads are presented in detail in Table 5.6.

Table 5.6 - Model Calibration: Location and Effluent Concentrations of all Major STP's and Point Sources during April 1988 Survey

Inflow No.	Discharge	Location Reach No.	Flow (mgd)	Temp (°F)	$CBOD_5$ (mg/l)	NH_3-N (mg/l)	DO (mg/l)
1	BCUA	III	62	58	40	15	8
2	N. Bergen Central	III	4	58	28	7	7
3	Secaucus	III	2.3	58	120	20	2
4	N. Arlington	I	1.7	58	96	13	2
5	Woodridge	IX	0.7	58	42	17	6
6	PSE&G (Berg.)	III	633*	75*	---	--	--
7	PSE&G (J. City)	I	835*	75*	---	--	--
8	PSE&G (Kearney)	I	---	---	---	--	--
9	Henkel Corp.	IX	1.5	58	25	--	--

* Time Varying Values

Adopting the initial and boundary conditions, and other point source loads, as model input, the water quality component of the model was exercised for the April 12-22, 1988 period. A water quality time step (δt) of 30 minutes was used for model simulations. During the process of model calibration, salinity was included as a variable in both the hydrodynamic and water quality simualations. This variable is essential in modeling estuarine systems due to its affect both on the density and the saturation value of dissolved oxygen.

Results of Water Quality Calibration

The model calibration process commenced with assigning literature reported reaction coefficients and then tuning these parameters to the values listed in Table 5.5.

The calibration of the temperature regime of the system is an important component of the study for two compelling reasons; first, the biological rate constants that determine the rates of BOD and N-BOD decay are functions of temperature; and second, to accurately assess the impact of the thermal load from the three power plants owned by PSE&G on the stream DO concentrations. Figures 5.8 and 5.9 show the temporal variation of temperature at river miles 5.1 (Station W2), 10.9 (Station W4) and 17.5 (Station W6), respectively.

These figures indicate the model's ability to predict the temperature regime of the system. The results indicate a good match between model predictions and field observations at three stations, 12.4 miles apart. The model predicts very well both the magnitude and temporal variation of temperature at the three locations. It is interesting to note that although the temperature of the water entering the lower Hackensack River from Newark Bay (Station W1) is around 50°F, the temperature at river mile 10.9 (Station W4) is around 60°F. This increment in temperature is due to the impact of PSE&G's Bergen Power Plant located around river mile 13.0.

Figure 5.10 shows model computed and field observed concentrations of ultimate C-BOD and NH_3-N concentrations, at the same locations. Here again, the model is able to predict the observed data at all three locations fairly well. Similar to the temperature observations, low values of 3 mg/l for BOD_5 and 1 mg/l for NH_3-N concentrations were observed at the ocean boundary (Station W1). These concentrations increased to around 8 mg/l for BOD_5 and 5 mg/l for NH_3-N at Station W4. These increased concentrations may be due to the discharges from several treatment plants and other sources within this reach.

Figures 5.11 and 5.12 show the model generated and field observed concentrations of DO at the three sampling locations. An accurate simulation of DO in the River remains the critical component in this study. This is primarily due to the fact that the discharge permit limitations of BCUA's treatment plant are predicated on the DO regime of the River.

The simulations indicate a good match between model predictions and field observed DO concentrations at all three stations. The data shows diurnal variations of around 2 mg/l. This variation is very well simulated by the model, based on the observed concentrations of chlorophyll-a and the algal algorithm within the model.

The model calibration presented above shows a reliable and rigorous simulation of the nutrient and Dissolved Oxygen regime of the lower Hackensack River and its tributaries. Thus, it has been demonstrated that the adopted model can simulate the transient hydraulics, temperature and water quality regimes in the lower Hackensack River without unrealistic "tuning" of model rate coefficients.

5.3.3 Hydraulic Verification of the Model (Dry and Wet Event, July 11-25, 1988)

The MIT-DNM was exercised during the period July 11-25, 1988. The comprehensive database collected during this period represented a different seasonal and hydrologic characteristics of the lower Hackensack River, from the April 1988 survey. Air temperatures varied between 70° and 90°F, while water temperatures in the vicinity of PSE&G's thermal discharge often exceeded 100°F. Furthermore, a severe rainstorm of 1.57 inches in total volume occurred during July 19-20, 1988. Several thunderstorms occurred during the following days resulting in a total rainfall volume of 5.49 inches between July 19-21.

The period for model verification, therefore, represented a ten day period (July 11-20) under ambient summer conditions, including a wet (storm) event for a period of five days (July 20-25). Several minor storm events occurred during the ten day period without contributing significant runoff to the river. The storm event that occurred on July 20, 1988, resulted in a total rainfall volume of 1.57 inches, which is a 97% storm event. Thus, the model verification effort conducted during July 11-25, 1988 represents conditions in the river both under ambient Summer (dry) conditions and a severe storm (wet) conditions.

The methodology adopted for model verification was identical to that used during model calibration, with the exception of the storm event of July 20, 1988. the storm event resulted in extensive stormwater runoff from the entire watershed below Oradell Dam and contributions from several CSO's. Pollutant loads from the land surface runoff during the storm event were computed by the calibrated and verified runoff model SWMM-4. These loads were included in the river model based on the segmentation presented in Figures 4.1 and 4.2.

Specifications of Initial Conditions

A consistent set of intial water surface elevations, flows and salinities were specified in all reaches of the lower Hackensack River system during the July verification period. These initial conditions were generated by applying the model for five days preceding the field monitoring program.

Specifications of Boundary Conditions

Observed tidal elevations and salinity concentrations were specified at node 1, the ocean boundary, shown in Figure 5.13(a) and 5.15(a). The other boundary conditions are at Oradell Dam, node 5, Overpeck Creek Dam at node 10 and the upstream flow into Berry's Creek at node 9 (Figure 5.1). At these three locations, observed hydrographs and pollutographs were specified.

In addition to these boundary conditions, time-varying hydrographs are also specified to represent inflows to the system from all sub-basins in the watershed. Observed lateral inflows are specified to represent effluent discharges from all STP's within the boundaries of the system under investigation. Finally, provision is made to incorporate cooling water recirculation at the three power plants operated by PSE&G.

During the period of model calibration, there was no land surface runoff due to the absence of any rainfall. During the July data collection period however, several storms occurred in the basin between July 19-21, 1988. This resulted in extensive runoff from the entire watershed and all major CSO's. Thus, an accurate estimate of the contribution of stormwater runoff and pollutant loads resulting from these storm events was essential for a proper verification of the river model. These loads were computed from the previously calibrated and verified runoff model SWMM-4, details of which were presented in Chapter 4.

Results of Hydraulic Verification

With the specified initial and boundary conditions discussed above, the MIT-DNM was exercised in real-time to simulate hydrodynamic conditions for a period of fifteen days in the lower Hackensack River network. The hydraulic verification of the adapted model was tested by maintaining the bottom friction factor "n" and the Taylor dispersion parameter "m" to the values generated during model calibration. Table 5.3 shows the spatial variation fo Manning's "n" coefficient arrived at during this calibration and verification effort. High values were assigned for those reaches of the modeled streams where dendritic river banks and elongated mid-stream islands exist. A single value of m=40 was used for the Taylor dispersion multiplier.

The results of the hydraulic verification are shown in Figures 5.14(a) and 5.14(b). The figures show the observed and computed tidal elevations within the main stem of the River, at river miles 13.8 and 17.5, respectively. These figures show the computed tides to closely follow the observations in both tidal amplitude and phase.

Figures 5.15(b), 5.16(a) and 5.16(b) show the observed and computed salinity concentrations at river miles 5.1, 7.4 and 17.5, respectively. The results show an excellent match between observed and computed salinity concentrations at all three locations. These results indicate that the model adequately describes the salt dynamics in the lower Hackensack River Estuary.

The modeling results show a strong longitudinal salinity gradient between the mouth of the estuary (20 ppt) and the upper reaches, with salinities in the 5 ppt range. Higher ocean salinity concentrations (20 ppt) occurred during the July survey than during the April 1988 survey, when salinities were in the 15 ppt range. This is a result of large freshwater inflows discharging into Newark Bay from both the upper Hackensack and Passaic River basins during the Srping of 1988. Figures 5.16 and 5.17 indicate a reduction in salinity of 5 ppt over a period of about five days,beginning on July 21, 1988. This is the result of storm events that occurred during the period July 19-21. The model's ability to reproduce this trend at all locations is a validation of the estimates of stormwater runoff entering the river from the entire watershed computed by the SWMM-4 model. The successful verification of the hydrodynamic and salinity regimes of the system indicates the models ability to accurately reproduce the advection and dispersion processes unique to the lower Hackensack River.

5.3.4 Water Quality Verification of the Model

The water quality component of MIT-DNM was next verified using the previously calibrated model hydrodynamics, and the comprehensive water quality data the collected in July 11-25, 1988 survey. This period reflected both ambient conditions withour significant rainfall during the first ten day period followed by a wet period in the lower Hackensak River Basin. Atmospheric temperatures varied between 70°F and 100°F, while ambient water temperatures varied between 70°F to 90°F in the lower reaches of the river, while elevated temperatures around 100°F were observed in the vicinity of PSE&G's Bergen Power Plant. A detailed description of the collected water quality data is contained in a separate report prepared by GTC. The water quality variables selected for model verification were Temperature, C-BOD, N-BOD and DO.

Specification of Initial Condition

Seven water quality sampling stations (W1 through W7) were located in the lower Hackensack River between Newark Bay and Oradell Dam. Field observed data were available at each of the seven sampling stations at the start time of the model. At locations between these stations, linearly interpolated initial conditions were used. This assumption is valid, since no storm event constituting local runoff occurred prior to model initiation. The specified initial conditions are shown in Table 5.7.

Water Quality Boundary Conditions

Water quality data at six locations are needed to completely define the input boundary conditions of the network. The two major boundaries are located at Newark Bay (node #1) the downstream boundary, and Oradell Dam (node #5) the upstream boundary of the main stem of the estuary. Observed concentrations of Temperature, C-BOD, NH_3-N and DO were specified at these six locations.

Similarly, water quality concentrations were specified using SWMM at all sub-basins of the lower Hackensack River. During the July survey, flows entering the estuary from the upstream boundary were about 2 cfs for the entire 15 day duration. Thus, the major source of pollutants from the boundaries were from station W1, the ocean boundary. Figures 5.18(a), 5.19(a) and 5.21(a) show the specification of

Temperature, C-BOD, NH_3-N and DO concentrations at the boundary station W1.

An additional input required to model temperature was a time series of meteorologic data for the survey period. Such information includes air temperature, relative humidity, wind speed, and cloud cover. This information was obtained from the NWS Station at Newark Airport.

Table 5.7 - Specification of Water Quality Initial Condition (Model Verification July 11-26, 1988)

Location	Reach	River Mile	Salinity (ppt)	Temperature (°F)	Ultimate C-BOD (mg/l)	NH_3-N (mg/l)	DO (mg/l)
W1(ocean boudary)	1	1.4	20.0	80.0	4.0	1.0	2.0
W2	1	5.1	16.0	80.0	2.0	3.0	3.0
W3	2	7.4	14.0	80.0	2.0	5.0	4.0
W4	3	10.9	14.0	90.0	5.0	5.5	3.0
W5	5	13.8	10.0	90.0	5.0	6.0	2.0
W6	5	17.5	3.0	80.0	8.0	1.0	8.0
W7(upstream boundary)	5	22.0	3.0	80.0	8.0	1.0	8.0
Berrys Creek Canal	6	---	10.0	80.0	4.0	0.5	6.0
Berrys Creek	7	---	10.0	80.0	4.0	0.5	6.0
E-Branch Berrys Creek	8	---	10.0	80.0	4.0	0.5	6.0
W-Branch Berrys Creek	9	---	10.0	80.0	4.0	0.5	6.0

The coefficients of CBOD de-oxygenation (K_1), nitrification (K_2), and reaeration (K_a) obtained during model calibration remained unchanged during model verification. Two elements of the intensive survey data, the benthal oxygen uptake rate (SOD) and the chlorophyll a concentration, are also utilized by the model.

A listing of the final model verification coefficients is shown in Table 5.8. These coefficients are all listed for 20°C. Within the model, all coefficients were adapted to the observed field temperatures based on the standard Arrhenius equation.

Table 5.8 - Model Rate Coefficients for July Verification

Model Coefficient	Reach	Model Input
Oxidation Rate of Ultimate C-BOD (K_1 - 1/day)	1 - 9	0.2
Nitrification Rate (K_2 - 1/day)	1 - 9	0.1
Sediment Oxygen Demand* (mg/l/d)	1	2.0
	2 - 5	1.0
	6 - 9	0.1
Chlorophyll a (ug/l)*	1	30 - 50
	2	50
	3	60
	4	50
	5	60 - 100
	6 - 9	20
Reaeration Coefficient (K_a)	1	40
	2	40
	3	80
	4	50
	5	10
	6-9	20

* Based on data collected in 1988.

Specification of the Point and Non-Point Sources

In addition to the pollutant loads entering the lower Hackensack River from the boundaries of the system, other point and non-point loads entering the different reaches of the River need to be included as inputs to the model. These source/sink terms include benthic loads, effects of algal respiration, marsh impacts, impacts from landfills, pollutant loads from major treatment plants and industrial sources and significant pollutant contributions resulting from stormwater runoff.

The results indicate that unlike the April survey, during the month of July, Sediment Oxygen Demand was evident along the main river channel (see Part II of report). This is possibly due to the relatively warm temperatures prevalent during the July 1988 survey. The SOD rates adopted for each reach are shown in Table 5.7.

The methodology for simulating algal respiration was explained in detail in Section 5.1. Algal concentrations between 30-100 microgram/m^3 were observed at several locations along the river. The specification of chlorophyll-a during model verification are shown in Table 5.7.

The impact due to landfills was analyzed in detail together with the comprehensive marsh study conducted in 1988 and 1989. The results indicate that, similar to the April survey, the landfills in the Upper Sawmill Creek Basin, provided a significant source of both BOD and NH_3-N. These loads were computed to be between 2,000-4,000 lbs/day of both BOD_5 and NH_3-N. These values were input as point loads into the main Hackensack River along Reach I.

Point sources discharges from all the major STP's entering the lower Hackensack River were monitored during the July Survey. In addition, thermal load contributions from PSE&G's power plant at Bergen was continuously monitored. Pollutant loads from other industries and thermal loads from two other power plants were obtained from DMR reports of NJDEP. These loads are presented in detail in Table 5.9.

Table 5.9 - Model Verification: Location and Effluent Concentrations of all Major STP's and Point Sources during July 1988 Survey

Inflow No.	Discharge	Location Reach No.	Flow (mgd)	Temp (°F)	$CBOD_5$ (mg/l)	NH_3-N (mg/l)	DO (mg/l)
1	BCUA	III	62	58	40	15	8
2	N. Bergen Central	III	4	58	28	7	7
3	Secaucus	III	2.3	58	120	20	2
4	N. Arlington	I	1.7	58	96	13	2
5	Woodridge	IX	0.7	58	42	17	6
6	PSE&G (Berg.)	III	633*	75*	---	---	--
7	PSE&G (J. City)	I	835*	75*	---	---	-
8	PSE&G (Kearney)	I	---	---	---	---	--
9	Henkel Corp.	IX	1.5	58	25	---	--

* Time Varying Values

Unlike the April survey, where the stormwater contribution from overland runoff was negligible, the July survey resulted in pollutant contributions associated with large rainfall events. A major series of storm events that occurred between July 19-21 contributed 5.49 inches of rainfall over the entire watershed. These storm events contributed significant pollutant loads via land surface runoff into the entire lower Hackensack River network. The magnitudes of these loads were computed using the previously calibrated and verified SWMM-4 model. The SWMM-4 model was also used to computed pollutant loads from the enitre CSO network within the basin.

Adopting the initial and boundary conditions, and other point source loads, as model input, the water quality component of the model was exercised for the July 11-25, 1988 time period. A water quality time step (δt) of 200 seconds was used for model simulations. During the process of model calibration, salinity was included as a variable in both the hydrodynamic and water quality simualations.

Results of Water Quality Verification

The model verification process started with assigning reaction coefficients obtained during model calibration. These values are listed in Table 5.5.

Figures 5.17 shows the temporal variation of temperature at river mile 10.9 (Station W4). These figures indicate the model's ability to predict the temperature regime of the system. A good match between model predictions and field observations at three stations, 12.4 miles apart is achieved. The model predicts very well both the magnitude and temporal variation of temperature at the three locations. It is interesting to note that although the temperature of the water entering the lower Hackensack River from Newark Bay (Station W1) is around 80°F, the temperature at river mile 10.9 (Station W4) is around 100°F. This increment in temperature is due to the impact of PSE&G's Bergen Power Plant located around river mile 13.0.

Figure 5.18 shows model computed and field observed concentrations of ultimate C-BOD and NH_3-N concentrations, respectively. Here again, the model is able to predict the observed data at all three locations fairly well. Similar to the temperature observations, low values of 3 mg/l for BOD and 1 mg/l for NH_3-N concentrations were observed at the ocean boundary (Station W1). These concentrations increased to around 5 mg/l for BOD and 5 mg/l for NH_3-N at Station W4. These increased concentrations are probably due to the discharges from several treatment plants within this reach, including the BCUA's discharge.

Figures 5.19 and 5.20 show the model generated and field observed concentrations of DO at the three sampling locations. An accurate simulation of DO in the River remains the critical component in this study since the discharge permit limitations of BCUA's treatment plant is predicated on the DO regime of the River.

The simulations indicate a good match between model predictions and field observed DO concentrations at all three stations. The data shows diurnal variations of DO around 2 mg/l. This variation is captured very well by the model, based on the observed concentrations of chlorophyll-a and the algal algorithm within the model. Due to the high temperature and nutrient levels present in the middle sections of the River, observed DO concentrations remained at anoxin levels. The model reproduces these concentrations very well in both magnitude and timing at these locations.

The model verification presented above shows a reliable and rigorous simulation of the nutrient and DO regime of the lower Hackensack River and its tributaries. Thus, it has been demonstrated that the adopted model can reproduce the transient hydraulics, temperature and water quality conditions under different hydrologic and seasonal characteristics in the lower Hackensack River network. This was achieved under both ambient (no storm) and wet (storm) hydrologic conditions in the lower Hackensack River, without changing the physical and biological rate coefficients achieved during model calibration.

5.3.5 Hydraulic Verification of the Model (Storm Event, August 24-30, 1988)

The MIT-DNM was exercised once more for the period August 24-30, 1988. The comprehensive database collected during this period, represented a different seasonal and hydrologic characteristic of the lower Hackensack River, to those of April and July 1988 surveys. Air temperatures varied between 70°-90°F, while water temperatures in the vicinity of PSE&G's thermal discharge often exceeded 90°F. Furthermore, a median to severe storm event of 1.02 inches occurred on August 23, 1988.

This exercise of model verification consists of a six day period (August 24-30) under wet (storm) summer conditions. The storm event that occurred on August 23, 1988, resulted in a total rainfall volume of 1.02 inches, a 91% storm event. Thus, the model re-verification effort conducted during August 24-30, 1988 represents conditions in the River under summer conditions with a median to severe storm event.

The methodology for model re-verification was identical to the model verification using July data, with the exception of the storm event of August 23, 1988. The storm event resulted in extensive stormwater runoff from the entire watershed below Oradell Dam with pollutant contributions from several CSO's. Pollutant loads from the land surface runoff during the storm event were computed by the calibrated and verified runoff model SWMM-4.

Specifications of Initial Conditions

A consistent set of intial water surface elevations, flows and salinities were specified in all reaches of the lower Hackensack River system during the August verification period. As the model was exercised in unsteady mode, these initial conditions were generated by exercising the model with flow conditions which preceded the field monitoring program by five days. The results of the model run provided a truly consistent description of the desired flows and elevations throughout the system of interest.

Specifications of Boundary Conditions

For hydraulic computations in the network of interest, four boundary conditions must be specified. Tidal elevations and salinity concentrations were specified at node 1, the ocean boundary, shown in Figures 5.21(a) and 5.22(a). These tidal elevations and salinities were observed 1.3 miles upstream of Newark Bay during the August river survey. The other boundary conditions are at Oradell Dam, node 5, Overpeck Creek Dam at node 10 and the upstream flow into Berrys Creek at node 9 (Figure 5.1). At these three locations, observed hydrographs were specified for the duration of the data collection effort.

In addition to these boundary conditions, time-varying hydrographs were also specified to represent inflows to the system from other tributaries with the network. Observed lateral inflows were specified to represent effluent discharges from all STP's within the boundaries of the system under investigation. Finally, provisions were made to allow for time-varying circulation of flow at the three power plants operated by PSE&G.

During the August data collection period, however, several storms occurred in the basin between August 23-24, 1988. This resulted in extensive runoff from the entire watershed and at all major CSO's. Thus, an accurate estimate of the contribution of stormwater runoff and pollutant loads resulting from these storm events was essential for a proper verification of the river model under wet conditions. These loads were computed from the previously calibrated and verified runiff model SWMM-4, details of which were presented in Chapter 4.

Results of Hydraulic Verification

With the specified initial and boundary conditions discussed above, the MIT-DNM was used to simulate hydrodynamic conditions for a period of five days in the lower Hackensack River network. The hydraulic verification of the adapted model was tested by maintaining the bottom friction factor "n" and the Taylor dispersion parameter "m" to the values generated during model calibration and verification. Table 5.3 shows the spatial variation fo Manning's "n" coefficient arrived at during this calibration and verification effort.

The results of the hydraulic verification are shown in Figure 5.21(b) and 5.21(c). The figures show the observed and computed tidal elevations within the main stem of the River, at river miles 7.4 and 13.8, respectively. These figures show the computed tides to closely follow the observations in both tidal amplitude and phase.

Figure 5.22(b) and 22(c) shows the observed and computed salinity concentrations at river miles 5.1 and 13.8, respectively. The results show an excellent match between observed and computed salinity concentrations at these locations. These results indicate that the model adequately describes the salt dynamics in the lower Hackensack River Estuary.

The modeling results show a strong longitudinal salinity gradient between the mouth of the estuary (20 ppt) and the upper reaches, with salinities in the 6 ppt range. Higher ocean salinity concentrations (20 ppt) occurred during the July and August surveys than observed during the April 1988 survey, where salinities were in the 15ppt range. This is a result of larger freshwater inflows discharging into Newark Bay from both the upper Hackensack and Passaic River basins during the Spring of 1988. The model's ability to reproduce this trend at all locations is a validation of the estimates of stormwater runoff entering the river from the entire watershed computed by the SWMM-4 model.

5.3.6 Water Quality Verification of the Model

The water quality component of MIT-DNM was next verified using the previously calibrated and verified model hydrodynamics, and the comprehensive water quality database generated during the August 24-29, 1988 survey. This period reflected a wet event in the lower Hackensak River Basin with a rainfall volume of 1.02 inches. Atmospheric temperatures varied between 60°F and 90°F, while ambient water temperatures varied between 70°F to 75°F in the lower reaches of the river. Elevated temperatures around 90°F were observed in the vicinity of PSE&G's Bergen Power Plant. A detailed description of the collected data is contained in a separate report prepared by GTC. The water quality variables selected for model verification were Temperature, C-BOD, N-BOD and DO.

Specification of Initial Condition

Seven water quality sampling stations (W1 through W7) were located in the lower Hackensack River between Newark Bay and Oradell Dam. Field observed data were available at these sampling stations at the start time of the model. At locations between these stations, linearly interpolated initial conditions were used. The specified initial conditions for the network are shown in Table 5.10.

Water Quality Boundary Conditions

Identical approach was taken to generate the water quality boundary conditions as thos described earlier for the July 1980 verification simulations. The coefficients of CBOD de-oxygenation (K_1), nitrification (K_2), and reaeration (K_a) obtained during model calibration, remained unchanged during model validation. Two elements of the intensive survey data, the benthal oxygen uptake rate (SOD) and the chlorophyll a concentration, are also utilized by the model in a manner similar to the above rate coefficients.

A listing of the final model validation coefficients is shown in Table 5.11. These coefficients are all listed for 20°C. Within the model, all coefficients were adapted to the observed field temperatures based on the standard Arrhenius equation.

Table 5.10 - Specification of Water Quality Initial Condition (Model Verification August 23-29, 1988)

Location	Reach	River Mile	Salinity (ppt)	Temperature (°F)	Ultimate C-BOD (mg/l)	NH_3-N (mg/l)	DO (mg/l)
W1(ocean boudary)	1	1.4	19.0	75.0	2.0	1.0	3.0
W2	1	5.1	16.0	75.0	2.0	1.0	3.0
W3	2	7.4	13.0	75.0	2.0	1.0	3.0
W4	3	10.9	9.0	75.0	4.0	3.5	2.0
W5	5	13.8	6.0	75.0	5.0	4.0	1.0
W6	5	17.5	2.0	75.0	6.5	3.0	3.0
W7(upstream boundary)	5	22.0	2.0	75.0	6.5	1.0	8.0
Berrys Creek Canal	6	---	10.0	75.0	2.0	2.0	4.0
Berrys Creek	7	---	10.0	75.0	2.0	2.0	4.0
E-Branch Berrys Creek	8	---	10.0	75.0	2.0	2.0	4.0
W-Branch Berrys Creek	9	---	10.0	75.0	2.0	2.0	4.0

Table 5.11 - Model Rate Coefficients for July Verification

Model Coefficient	Reach	Model Input
Oxidation Rate of Ultimate C-BOD (K_1 - 1/day)	1 - 9	0.2
Nitrification Rate (K_2 - 1/day)	1 - 9	0.1
Sediment Oxygen Demand* (mg/l/d)	1	2.0
	2 - 5	2.0-5.0
	6 - 9	1.0
Chlorophyll a (ug/l)*	1	10
	2	10
	3	10
	4	10
	5	20 - 80
	6 - 9	20
Reaeration Coefficient (K_a)	1	40
	2	40
	3	80
	4	50
	5	10
	6-9	20

* Based on data collected in 1988.

Specification of the Point and Non-Point Sources

In addition to the pollutant loads entering the lower Hackensack River from the boundaries of the system, other point and non-point loads entering the different reaches of the river need to be included as inputs to the model. These source/sink terms include benthic loads, effects of algal respiration, marsh impacts, impacts from landfills, pollutant loads from major treatment plants and industrial sources and significant pollutant contributions resulting from stormwater runoff.

The results indicate that unlike the April survey, during the month of August, Sediment Oxygen Demand was evident along the main river channel. This is possibly due to the relatively warm temperatures prevalent during the August 1988 survey. The SOD rates adopted for each reach are shown in Table 5.11.

The methodology for simulating algal respiration was explained in detail in Section 5.1. Algal concentrations between 20-80 microgram/m^3 were observed at several locations along the river. The specification of chlorophyll-a during model verification are shown in Table 5.11.

The impact due to landfills was analyzed in detail together with the comprehensive marsh study conducted in 1988 and 1989. The results indicate that, similar to the April and July surveys, the landfills in the Upper Sawmill Creek Basin, provided a significant source of both BOD and NH_3-N. These loads were computed to be between 2,000-4,000lbs/day of both BOD_5 and NH_3-N. These values were input as point loads into the main Hackensack River along Reach I.

Point sources discharges from all the major STP's entering the lower Hackensack River were monitored during the August Survey. In addition, thermal load contributions from PSE&G's power plant at Bergen was continuously monitored. Pollutant loads from other industries and thermal loads from two other power plants were obtained from DMR reports of NJDEP. These loads are presented in detail in Table 5.12.

Table 5.12 - Model Verification: Location and Effluent Concentrations of all Major STP's and Point Sources during August 1988 Survey

Inflow No.	Discharge	Location Reach No.	Flow (mgd)	Temp (°F)	$CBOD_5$ (mg/l)	NH_3-N (mg/l)	DO (mg/l)
1	BCUA	III	62	58	40	15	8
2	N. Bergen Central	III	4	58	28	7	7
3	Secaucus	III	2.3	58	120	20	2
4	N. Arlington	I	1.7	58	96	13	2
5	Woodridge	IX	0.7	58	42	17	6
6	PSE&G (Berg.)	III	633*	75*	---	---	--
7	PSE&G (J. City)	I	835*	75*	---	---	--
8	PSE&G (Kearney)	I	---	---	---	---	--
9	Henkel Corp.	IX	1.5	58	25	---	--
10	Tanaten Chem.		0.5	58	200	---	6
11	Union Textile		0.6	58	1,500	---	6

* Time Varying Values

Unlike the April survey, where the stormwater contribution from overland runoff was negligible, the August survey resulted in pollutants contributions associated with several rainfall events. These storm events contributed significant pollutant loads via land surface runoff into the entire lower Hackensack River network. The magnitudes of these loads were computed using the previously calibrated and verified SWMM-4 model. The SWMM-4 model was also used to computed pollutant loads from the enitre CSO area in the basin.

Adopting the initial and boundary conditions, and other point source loads, as model input, the water quality component of the model was exercised for the August 24-29, 1988 period. A water quality time step (δt) of 30 minutes was used for model simulations. During the process of model verification salinity was included as a variable in both the hydrodynamic and water quality simulations.

Results of Water Quality Model Validation

The model validation process started with assigning literature reported reaction coefficients and then tuning these parameters to the values listed in Table 5.5.

Figure 5.23 shows model computed and field observed concentrations of ultimate C-BOD concentrations. Here again, the model is able to predict the observed data at these locations fairly well. Similar to the temperature observations, low values of 3 mg/l for BOD and 1 mg/l for NH_3-N concentrations were observed at the ocean boundary (Station W1).

Figure 5.24 shows the model generated and field observed concentrations of DO at these sampling locations. An accurate simulation of DO in the River remains the critical component in this study. This is primarily due to the fact that the discharge permit limitations of BCUA's treatment plant is predicated on the DO regime of the River.

The simulations indicate a good match between model predictions and field observed DO concentrations at all three stations. The data shows diurnal variations of DO around 2 mg/l. This variation is captured very well by the model, based on the observed concentrations of chlorophyll-a and the algal algorithm within the model. Due to the high temperature and nutrient levels present in the middle sections of the river, observed DO concentrations remian at anoxia levels. The model reproduces these concentrations well in both magnitude and timing at these locations.

The model validation presented above shows a reliable and rigorous simulation of the nutrient and Dissolved Oxygen regime of the lower Hackensack River and its tributaries. Thus, it has been demonstrated that the adopted model can reproduce the transient hydraulics, temperature and water quality conditions under different hydrologic and seasonal characteristics in the lower Hackensack River network. This was achieved under two wet (storm) hydrologic conditions in the lower Hackensack

River, without changing the physical and biological rate coefficients achieved during model adaptation of the April 1988 monitoring periods.

5.3.7 Review of Model Calibration and Verification

The preceding sections presented the results of the hydraulic and water quality calibration of the adopted MIT-Dynamic Network Model to the Lower Hackensack River Network. The model was calibrated and verified using four independent data sets collected during the spring and summer of 1988. These periods reflected both ambient (no rain) and wet (storm event) conditions in the watershed. The model has been validated under different seasonal and environmental contributions which resulted in pollutant conditions from all point and non-point sources within the system. Thus, the engineering "tool" which has been successfully adapted to the entire lower Hackensack River watershed can now be used to evaluate environmental impacts of various alternatives to achieve realistic water quality objectives in the lower Hackensack Basin.

6. ANALYSIS OF ALTERNATIVES FOR WATER QUALITY ENHANCEMENT

6.1 General Overview

The first five chapters of this report contain the details of the methodology adopted in the generation of a comprehensive water quality management tool (model) for the lower Hackensack River Watershed. The broad details of the adopted methodology were presented in the flowchart shown in Figure 1.2. The following sections describe the application of the developed modeling tool to generate viable alternatives for water quality enhancement in the lower Hackensack River.

6.2 Regulatory Perspective

Chapter 1 presented on the overall objectives of the study. The primary objective of this study is to satisfy the targets set forth in BCUA's modified NJPDES Permit No. NJ0020028 dated January 17, 1985 and the Administrative Consent Order (ACO) executed by NJDEP on May 26, 1988. Paragraph nine of the ACO states:

> "...the objective of the study is to determine what level of treatment above secondary, if any, is required of the BCUA STP to enable the lower Hackensack River to meet water quality standards."

Paragraph 17 of the ACO further elaborates on the alternatives available to BCUA as,

> "...BCUA... agrees to comply with the water quality effluent limits established by the study or alternatively...**discharge to another surface water consistent with the WQM Plan."**

Tables 6.1 and 6.2 show the existing water quality classification of the lower Hackensack River network as defined in NJAC 7:9-4:15 dated August 7, 1989. Table 6.3 shows NJDEP's Current Treatment Level Criteria.

Table 6.1 - Hackensack River Network, Surface Water Classification

River Segment	Classification
Hackensack River:	
- Oradell Dam to Overpeck Creek	SE-1
- Overpeck Creek to Routes 1 & 9 Bridge	SE-2
- Routes 1 & 9 Bridge to Kearney Point	SE-3
Berry's Creek:	
- Entire Length	FW2-NT/SE-2

Table 6.2 - Dissolved Oxygen Concentration Standard for Different Stream Classifications

Classification	DO Concentration Standard
SE-1/FW2-NT	- 24 hour average not less than 5.0 mg/l - Not less than 4.0 mg/l at any time
SE-2	- not less than 4.0 mg/l at any time
SE-3	- not less than 3.0 mg/l at any time

Table 6.3 - NJDEP Treatment Level Criteria

Treatment Level	BOD_5		$CBOD_u$		$NBOD_u$		NH_3-N		Suspended Solids		DO
	30-Day Average	7-Day Average	30-Day Average	7-Day Average	30-Day Average	7-Day Average	30-Day Average	7-Day Average	30-Day Average	7-Day Average	7-Day Average
Secondary	30	45	--	--	--	--	--	--	30	45	--
1	24	36	36	54	130	195	26	39	24	36	4
2	16	24	24	36	50	75	10	15	16	24	6
3	16	24	24	36	20	30	4	6	16	24	6
4	8	12	12	18	10	15	2	3	8	12	6
5	4	6	6	9	5	7.5	1	1.5	4	6	6

NOTE: All criteria are in mg/l.

These tables indicate that for the modeled reaches of the lower Hackensack River, Dissolved Oxygen concentrations must exceed 4.0 mg/l at all times. Additionally, the portion of the River between Oradell Dam and Overpeck Creek must have daily average DO concentrations above 5.0 mg/l. Based on this regulatory framework, and to satisfy the desired water quality objectives of the lower Hackensack River, several mitigation alternatives were investigated during the course of this study. This chapter describes these alternatives and presents the simulation results of these alternatives.

6.3 Selection of Critical Time Period for Alternative Analyses

To evaluate the impact of different alternatives of BCUA's discharge on the DO regime of the lower Hackensack River, the selection of a critical time period for model simulation is essential. The critical periods for model simulations were selected to represent periods of low DO within the different reaches of the River. Low DO concentrations are a result of the complex hydrologic, hydraulic, and meteorologic conditions, and the total pollutant contribution into the lower Hackensack River.

The flow regime in the lower Hackensack River is primarily tidal. The main freshwater inflow into the Estuary is from the small tributaries and BCUA treatment plant discharge. Tidal variations in Newark Bay, the southern terminus of the Hackensack Estuary, do not exhibit any discernible annual (long-term) variations. Due to strict control of let-down flows at Oradell Dam by the Hackensack Water Company, only secondary impacts on lower Hackensack River hydraulics and water quality could be attributed to the headwaters of the Estuary. The demand for water supply is so acute that during the critical Summer months, the let-down flows at the Oradell Dam remain non-existent for long and continuous periods. Thus, tidal variations in Newark Bay, in general, is the primary controlling factor governing the flow regime in the lower Hackensack River.

The selection of suitable meteorologic conditions for instream DO concentration simulations is another important task. This is due to two compelling reasons. First, periods of elevated water temperatures accelerate biological processes resulting in greater reductions of the DO concentrations in the River; and second, such periods coincide with the maximum operation of PSE&G's power plants due to increased consumer demand. The combined impact of these two factors plays a critical role in DO dynamics of the lower Hackensack River. To determine a realistic meteorologic regime for model simulations, an extensive review of the meteorological database at the Newark Airport Weather Station was conducted. Meteorological data was processed and ranked for a thirty year period (1959-1988). The ranking scheme considered both annual and seasonal variations. **This review indicates that the 1988 Summer period was the hottest summer within the last thirty years with an average temperature of 78°F. Air temperatures of 101°F were observed on several days during the Summer of 1988.**

Careful review of the sorted meteorologic data led to the decision to select the Summer of 1988 (June 1 - September 30) to conduct all long-term model simulations. The major reasons for adopting this time period are summarized below:

- The 1988 Summer represents the warmest Summer for the past 30 years

- The long-term average freshwater inflow from the Upper Hackensack River during this period was less than 3.0 cfs

- The extensive hydraulic and water quality database collected within the lower Hackensack River and its tributaries in 1988 provide consistent and realistic database for use in model simulations

- The rainfall volume that occurred during this period, represented median conditions of runoff within the watershed.

- The combination of high river temperatures and low freshwater inflows represented the most critical conditions for the DO regime in the River

6.4 Selection of Hydraulic and Water Quality Boundary Conditions

The selection of the Hydraulic and Water Quality Boundary conditions were similar to that adopted during the model calibration/verification effort. However, the specification of the Boundary Condition at node 1 (ocean boundary) was modified for water quality simulations. This was due to the absence of **continuous** water quality data for the four month simulation. To account for this limitation, an Ocean Boundary condition was specified using the extensive data collected in April, July and August, 1988. The details of this type of Boundary specifications are presented in the MIT-DNM Users Manual (Harleman, et al., 1977) and elaborated in the following sections.

Specifications of Hydraulic Initial Conditions

Similar to the hydraulic calibration and verification of the model, a consistent set of initial water surface elevations, flows and salinities were specified in all reaches of the lower Hackensack River system for the long-term simulations. Realistic and temporally compatible initial conditions were generated by exercising the model with flow conditions which preceded the modeling period by a few days. The results of the model run provided a truly consistent description of the desired instantaneous flows and elevations throughout the system of interest.

Specifications of Hydraulic Boundary Conditions

Similar to hydraulic model calibration and verification for hydraulic computations in the network of interest, four boundary conditions must be specified. Tidal elevations and salinity concentrations were specified at node 1, the ocean boundary. These tidal elevations were observed 1.3 miles upstream of Newark Bay during 1988. The other boundary conditions are at Oradell Dam, node 5, Overpeck Creek Dam at node 10 and the upstream flow into Berry's Creek at node 9 (Figure 5.1). At these three locations, MA7CD10 flows were specified during non-storm conditions. During storm events, the SWMM-4 model was used to compute the stormwater runoff from these boundaries, except at node 5, where observed USGS flows were used.

In addition to these boundary conditions, time-varying hydrographs generated by the SWMM-4 model were specified to represent inflows to the system during storm events from other tributaries and CSO's within the network. Observed lateral inflows were also represented along with effluent discharges from all STP's into the lower Hackensack River and its tributaries. These STP discharges were set at treatment levels consistent with those adopted for BCUA. Finally, provision was made to allow for time-varying circulation of flow at the three power plants operated by PSE&G.

Specification of Water Quality Initial Condition

Seven water quality sampling stations (W1 through W7) were located in the lower Hackensack River between Newark Bay and Oradell Dam during the 1988 field monitoring period. Field observed data were not available at these sampling stations for June 1, 1988, the beginning data for simulations. Consistent and synoptic data in the lower Hackensack River was available only during the extensive sampling periods of April, July and August, 1988. Since long-term model simulations were conducted during the period June 1 - September 30, 1988, a decision was made to adopt the water quality data observed in July to represent model initial conditions for the long-term simulations. Although such an assumption resulted in the use of high temperature and low DO concentrations within the River, it provided a more conservative approach to evaluating DO variations in the River during critical conditions. The specified initial conditions, therefore, were identical to the values adopted during model verification (non-storm conditions) as shown in Table 6.4.

Table 6.4 - Specification of Water Quality Initial Condition (Summer 1988 Simulations, June 1 - September 30, 1988

Location	Reach	River Mile	Salinity (ppt)	Temperature (°F)	Ultimate C-BOD (mg/l)	NH_3-N (mg/l)	DO (mg/l)
W1(ocean boundary)	1	1.4	20.0	80.0	4.0	1.0	2.0
W2	1	5.1	16.0	80.0	2.0	3.0	3.0
W3	2	7.4	14.0	80.0	2.0	5.0	4.0
W4	3	10.9	14.0	90.0	5.0	5.5	3.0
W5	5	13.8	10.0	90.0	5.0	6.0	2.0
W6	5	17.5	3.0	80.0	8.0	1.0	8.0
W7(upstream boundary)	5	22.0	3.0	80.0	8.0	1.0	8.0
Berry's Creek Canal	6	---	10.0	80.0	4.0	0.5	6.0
Berry's Creek	7	---	10.0	80.0	4.0	0.5	6.0
E-Branch Berry's Creek	8	---	10.0	80.0	4.0	0.5	6.0
W-Branch Berry's Creek	9	---	10.0	80.0	4.0	0.5	6.0

Water Quality Boundary Conditions

Water quality data at four locations are needed to completely define the input boundary conditions of the network. The two major boundaries are located at Newark Bay (node #1) the downstream boundary, and Oradell Dam (node #5) the upstream boundary of the main stem of the estuary. Temperature and concentrations of, C-BOD, NH_3-N and DO were specified at these six locations. The method of selection of water quality concentrations at these locations were different from those adopted during model calibration and verification. A modified methodology was required since continuous water quality data were not available at these locations for the four month simulation period. The methodology adopted for the respective boundary specifications are described below.

a) **Specification of Newark Bay Boundary - Node #1**

At node #1, the tidal boundary, Temperature and concentrations of C-BOD, N-BOD and DO were specified only during a portion of the flooding tide. These concentrations were more indicative of conditions prevailing in the open waters of Newark Bay during the summer of 1988. MIT-DNM internally computes the water quality concentrations at this boundary during ebb flows. At the onset of the flood flows, the concentrations at this boundary are prescribed by linear interpolation between the values at the end of ebb flow and a maximum or minimum value prescribed as ocean boundary concentrations. The time to attain the specified ocean concentrations was prescribed as 0.3T where T is the tidal period (12.42 hours on the mean). For further details on this type of boundary condition approximation the reader is referred to Thatcher and Harleman (1972), and Harleman et al. (1977).

For the Summer 1988 simulation, the observed water quality data at two depths at node #1, during July 11-25 and August 23-30, 1988, were used to generate long-term Summer ocean boundary conditions. Mean monthly observed conditions at the ocean boundary, averaged over the two depths of observation were adopted for the Summer 1988 simulations. Table 6.5 shows the water quality concentrations specified during flooding tides at the ocean boundary station.

Table 6.5 - Specified Long-Term Flood Flow Water Quality Boundary Concentrations at the Ocean Boundary (Node #1)

Constituent	Concentration*
Salinity	20.0 - 22.0 ppt
Temperature	72.0 - 75.0 °F
Ultimate C-BOD	1.5 mg/l
NH_3-N	1.0 mg/l
DO	3.0 - 5.0 mg/l

* Ranges reflect adjustment for seasonal variation

b) Specification of Upstream boundary at Oradell Dam (node #5) and tributary boundaries

As discussed before, flows at the fall line (head of tide) and tributary boundaries were set at their MA7CD10 values. These data published by USGS, indicate almost zero flow at these locations except during storm events. Water quality data during storm events were computed using the calibrated and verified SWMM-4 model. Thus, in the case of boundary specifications at the above locations, due to the absence of any discernible flow, the pollutant loadings into the River were neglected, except during storm events.

An additional input required in modeling the temperature regime, is the specification of meteorologic conditions during the modeling period. Such information includes air temperature, relative humidity, wind speed, and cloud cover. This information was obtained at three hourly intervals from the comprehensive database at the Newark Airport Weather Station.

The rate coefficients of CBOD de-oxygenation (K_1), nitrification (K_2), and reaeration (K_a) obtained during model calibration and verification, remained unchanged during the long-term simulations. Two elements of the intensive survey data, the benthal oxygen uptake rate (SOD) and the chlorophyll a concentration, were also utilized by the model in a manner similar to the above rate coefficients.

A listing of the model rate coefficients adopted for long-term simulations are shown in Table 6.6. These coefficients are all listed for 20°C. Within the model, all coefficients were adapted to the observed field temperatures based on the standard Arrhenius equation.

Specification of the Point and Non-Point Sources

In addition to the pollutant loads entering the lower Hackensack River from the boundaries of the system, other point and non-point loads entering the different reaches of the River were included as inputs to the model. These source/sink terms consisted of benthic loads, effects of algal respiration, marsh impacts, impacts from landfills, pollutant loads from major treatment plants and industrial sources and significant pollutant contributions resulting from stormwater runoff.

Pollutant contributions due to Benthos, tidal marshes, algal effects and landfills were estimated similar to model calibration and verification. Seasonal adjustments were made for these variables using the data collected during the April, July and August 1988 surveys. The specification of these variables are presented in Table 6.5.

Table 6.6 - Model Rate Coefficients for Summer 1988 Simulations (June 1 - September 30)

Model Coefficient	Reach	Model Input
Oxidation Rate of Ultimate C-BOD (K_1 - 1/day)	1 - 9	0.2
Nitrification Rate (K_2 - 1/day)	1 - 9	0.1
Sediment Oxygen Demand* (mg/l/d)	1	2.0
	2 - 5	1.0
	6 - 9	0.1
Chlorophyll a (ug/l)*	1	30 - 50
	2	50
	3	60
	4	50
	5	60 - 100
	6 - 9	20
Reaeration Coefficient (K_a)	1	40
	2	40
	3	80
	4	50
	5	10
	6-9	20

* Based on data collected in 1988

An important aspect of the specification of point sources is a realistic representation of the discharge of heated water from PSE&G's thermal power plant at Ridgefield. Towards this objective, continuous flow and temperature data were observed at the discharge channel. This data, although representing the conditions prevalent in 1988, may not reflect peak operating conditions of the plant. Thus, the thermal load of PSE&G's Bergen Plant adopted in the alternative analyses may not represent peak operating conditions.

In the case of PSE&G's Hudson Plant, no operational information was available other than sparse data in the Discharge Monitoring Reports compiled at NJDEP. This plant is designed to operate at a higher capacity than the Bergen Plant. Due to the absence of additional data on the Hudson Plant, the operational pattern of the Bergen Plant was adopted for the analyses with adjustment for the flow differences. In the absence of actual and detailed data, the adopted approach provided the means to generate a realistic estimate of the thermal load from the Hudson Plant. Due to large tidal flows present in the vicinity of the Hudson Plant discharge, only marginal increases in river ambient temperature are observed in the vicinity of the discharge. Furthermore, the Hudson Plant discharge has no impact on the critical reach of the lower Hackensack River which lies between Berrys Creek Canal and Overpeck Creek.

Point source pollutants discharged from all STP's were monitored during the April, July and August 1988 monitoring periods. These data were used to estimate average pollutant loads to the River, for the long-term simulations. However, such loads were made consistent with effluent concentrations of BCUA's discharge for the alternative analyses. For example, the analysis with BCUA at Level III, all STP's in the basin were set to Level III treatment and 208 design flows. These loads are presented in Table 6.7.

The purpose of these alternative analyses was to assess water quality impacts on the lower Hackensack River under future conditions within the basin. **Thus, several current point source discharges into the lower Hackensack River (dry weather discharges and overflows, planned diversions of existing STPs) were ignored and eliminated from the long-term simulations.** These assumptions provided a more meaningful representation of future water quality conditions in the lower Hackensack River Basin.

Table 6.7 - Effluent Concentrations Adopted for Major STP's and Point Sources During Summer 1988 Simulations

Inflow No.	Discharge	Location Reach No.	Flow (mgd)	Temp (°F)	$CBOD_5$ (mg/l)	NH_3-N (mg/l)	DO (mg/l)
1	BCUA	III	Q**	75	24	20	2.0
2	N. Bergen Central	III	10	75	16	4	6
3	Secaucus	III	5.12	75	16	4	6
4	PSE&G (Bergen)	III	650*	105*	---	---	---
5	PSE&G (J. City)	I	835*	105*	---	---	---
6	PSE&G (Kearney)	I	---	---	---	---	---
7	Henkel Corp.	IX	1.5	75	25	---	6

* Time Varying Values
**Q - Future Projected Flows (6.5 mgd above 1988 flows)

Adopting the initial and boundary conditions, and other point source loads, as model input, the hydraulic and water quality component of the model was exercised for the June 1 - September 30, 1988 time period. A hydraulic time step (δt) of 200 seconds and water quality time step (δt) of 1,800 seconds were used for model simulations.

6.5 Selection of Alternative Scenarios for Long-Term Simulations, Summer 1988 (June 1 - September 30)

The preceding sections presented the selection of the different model variables for use in the long-term Summer simulations. Using the specified model variables, several alternative simulations of pollutant discharge (scenarios) were conducted to assess the relative impacts of these alternatives on the DO regime of the River. The results of these simulations were compared visually and statistically to evaluate the influence of each of these alternatives on the DO concentration of the River at the most critical station. The location of the critical station was determined by comparing the DO sag at several locations along the river during the Summer 1988 model simulations.

Table 6.8 lists the different alternatives simulated using the Summer 1988 hydraulic and meteorologic conditions, while Table 6.9 lists the critical alternatives considered in the study.

Table 6.8 - Description of Alternative Scenarios Conducted During Summer, 1988 (June 1 - September 30, 1988)

Scenario	BCUA Flow STP(mgd)	BOD_5	NH_3-N	DO
1. Base (Present Condition)	1988 Flows	24	20	2
2. Future No Action Alternative (1988 Flow + 6.5 mgd)		24	20	2
3. BCUA Level II	Same as #2	16	10	6
4. BCUA Level III	Same as #2	16	4	6
5. BCUA Level IV	Same as #2	8	2	6
6. BCUA to Hudson River	---	--	--	--
7. Same as #2 Relocate BCUA Downstream	Same as #2	24	20	2
8. PSE&G - 0% Heat Rejection BCUA as scenario #2	Same as #2	24	20	2
9. PSE&G - 50% Heat Rejection BCUA as scenario #2	Same as #2	24	20	2
10. PSE&G - 0% Heat Rejection BCUA Level III	Same as #2	16	4	6
11. PSE&G - 0% Heat Rejection BCUA to Hudson River	---	--	--	--
12. Same as #2 Without CSOs/landfills/Benthos	Same as #2	24	20	2
13. Same as #2 Assume Newark Bay Pristine	Same as #2	24	20	2

Table 6.9 - Description of Critical Alternative Scenarios Conducted During Summer, 1988 (June 1 - September 30, 1988)

Scenario Number*	Description
2	BCUA and other STP's, including PSE&G, at their future operating levels.
7	BCUA Discharge diverted downstream near Berrys Creek Canal. (All other conditions identical to scenarios #2)
6	BCUA Discharge Diverted to Hudson River (All other conditions identical to scenario #2)
4	BCUA at Level III Treatment - DO @ 6 mg/l - BOD_5 @ 16 mg/l - NH_3-N @ 4 mg/l (All other conditions identical to scenario #2)
11	BCUA Discharge Diverted to Hudson River and PSE&G heat rejection at 0.0 BTU (All other conditions identical to scenario #2)
8	BCUA Discharge under Existing Conditions and PSE&G heat rejection at 0.0 BTU (All other conditions identical to scenario #2)

* From Table 6.8

The simulation of these critical scenarios were conducted to provide valuable insights into the causes of significant DO depletion in the River under severe Summer conditions. Additional scenarios were conducted as described in Table 6.8 to determine the impacts of other management alternatives on the water quality of the lower Hackensack River.

A simple statistical technique was adopted to facilitate the comparative analysis of the results of scenario simulations. DO concentrations at the critical reaches of the

River was the basis of the comparison. The technique was designed to assess the extent of improvement on DO concentrations at these critical reaches as a result of implementing a selected alternative. Figure 6.1 and Table 6.10 show the percent of time, within a period of four months, when the established DO standards are violated with each alternative considered.

The results of this simple statistical analysis conducted for the critical station indicate the following:

- With the future no action alternative, the DO standard is violated 21.3% of the time - Curve #6

- Diverting BCUA's discharge downstream below Berrys Creek Canal will result in violation of the DO standard 5.5% of the time - Curve #3

- Diverting BCUA's discharge to the Hudson River will result in violation of the DO standard 3.8% of the time - Curve #2

- Increasing treatment at BCUA STP to level III will result in violation of the DO standard 11.5% of the time - Curve #4

- Diverting BCUA's discharge to the Hudson River **and** eliminating PSE&G's discharge will result in violation of the DO standard 1% of the time - Curve #1

- Maintaining BCUA at its current level and eliminating PSE&G's discharge will result in violation of the DO standard 13.8% of the time - Curve #5

Table 6.10 - Percent DO Violation for the Different Alternatives at the Critical Station

Scenario No.	Description	Percent Violation
1	Present Condition	19
2	Future No Action Alternative	21.3
3	BCUA Level II	13.8
4	BCUA Level III	11.5
5	BCUA Level IV	7.5
6	BCUA Diverted to Hudson River	3.8
7	Relocate BCUA Downstream	5.5
8	PSE&G 0% Heat Rejection	13.8
9	PSE&G 50% Heat Rejection	16.1
10	PSE&G 0% Heat Rejection/BCUA Level III	6.8
11	PSE&G 0% Heat Rejection/BCUA to Hudson	0.8
12	Without CSOs, Landfills and Benthos	13.8
13	Newark Bay Pristine	21.1

All the scenarios discussed above were conducted on the basis that BCUA will be discharging at their future design flows. These flows were 6.5 mgd larger than flows observed during the summer of 1988. Although this assumption is valid during dry summer months, higher flows occur at BCUA's plant during periods of wet weather. These high flows which, at times, exceed 90 mgd are a result of extensive infiltrative and inflow (I/I) within BCUA's collection system. Review of the water quality data of BCUA's discharge during periods of high flow indicate lower concentrations of both BOD and NH_3-N in the effluent. The lower concentrations are the result of dilution by the relatively cleaner stormwater runoff entering BCUA's collection system. Since permit restrictions are based both on flows and concentration, the specification of large flows observed during storm events combined with high concentrations of BOD_5 and NH_3-N observed under dry Summer conditions is unrealistic.

Thus, to analyze the impact of BCUA's discharge during wet years, the period June 1 - September 30, 1989 was selected. During the year 1989, 53.99 inches of rainfall was observed at the Newark Airport weather station. This rainfall has only been exceeded three times during the past 30 years. A total Summer (June-September) rainfall volume of 24.12 inches was observed in the watershed, which was exceeded only twice during the past 30 years. Thus, the year 1989 represents an extreme wet year for model simulations in the lower Hackensack River Watershed.

Simulations for the "wet period" were conducted using the same boundary and meteorological conditions as the 1988 Summer simulations with the following exceptions: a) flow and water quality data for BCUA's discharge were specified based on observed values for the period of simulation and b) air temperatures were specified based on extremes observed during the Summer of 1988. The selection of these boundary conditions yield a conservative set of boundary input conditions for model simulations. The results of these simulations indicate that the DO regime of the river is less impacted during a wet Summer than a dry Summer, using the same meteorological conditions. The results further indicate that although larger flows from BCUA are discharged into the river during wet years, the corresponding large stormwater runoff from the watershed provides added dilution in the receiving water, thus abating the impact of BCUA's discharge.

Since this comparative analysis was conducted over an entire critical summer period, the results reflect the impact due to a large number of storms with different rainfall volumes and intensities. The results indicate that the greatest impact on the DO regime of the lower Hackensack River are during "dry" summers with relatively low I/I in the sanitary sewer system. Although these periods correspond to periods of low discharges from BCUA's STP, the decreasing River flows during dry periods reduces the rate of dilution, thus creating the most critical condition with respect to stream DO concentrations. **Thus, the wasteload allocation for BCUA's STP should be based on Dry Weather Conditions.**

7. CONCLUSIONS

The study presented here describes the overall assessment of point and non-point source impacts on the water quality of the lower Hackensack River. It specifically addresses the relative impact of Bergen County Utility Authority's (BCUA) wastewater treatment plant (STP) discharge on the dissolved oxygen (DO) regime of the lower Hackensack River. To serve the objectives of this study, elaborate engineering "tools" were adapted to the entire lower Hackensack River watershed. These models were developed based on the comprehensive database collected during the years 1988 and 1989.

The realistic water quality impact assessment needed a generalized approach whereby, practically all the significant sources of pollutants which influence the stream water quality were considered. This approach provided a detailed perspective and helped to evaluate BCUA's impacts relative to impacts of other sources of pollutants in the system under investigation.

Two complementary models were employed to satisfy the objectives of this study. The first model, USEPA's Surface Water Management Model(SWMM-4), was adopted to estimate the pollutant loadings to the lower Hackensack River from direct land surface runoff, storm sewers and CSO's. This model was also used to evaluate, on a continuous basis, the anticipated long-term pollutant loads from these sources within the lower Hackensack River Watershed. The second model, MIT-Dynamic Network Model (MIT-DNM), was used to quantify the impact of the point and non-point sources on the water quality of the lower Hackensack River network. Both these models were first calibrated to reflect conditions pertinent to the lower Hackensack basin. To ensure the validity of model calculations, the models were subjected to verification tests using field data which were independent of those used for model adaptation. Adequate verification was achieved as "real time" field observations, were matched with simulated results over continuous intervals of ten days. Thus, it was possible to generate a model capable of assessing both transient (short-term) and mean (long-term) impacts of all discharges on the lower Hackensack River.

A complementary study was conducted to assess the impact of the extensive tidal marshes on the water quality of the lower Hackensack River. This analysis was based on extensive experiments conducted within these marsh areas during 1988 and 1989. The results of this study are contained in Part II of this report.

The results of the marsh study do not indicate a consistent pattern of nutrient exchange between the tidal marshes and the lower Hackensack River. Thus the extrapolation of loading rates generated in the study to the remaining tidal marshes could not be justified. However, the marshes acted as sources of DO into the Lower Hackensack River. This was incorporated into the river modeling effort by increasing the DO reaeration rates in the relevant reaches of the modeled system. Significant pollutant loads from the landfills were observed and assessed during the marsh study conducted in Sawmill creek. These loading rates were then extrapolated to the remaining landfills without leachate collection systems.

The adopted models were then exercised in a continuous mode during a critical Summer period. The Summer of 1988 (June 1 - September 30) was characterized by elevated temperatures and low DO concentrations in the lower Hackensack River. In fact, 1988 Summer period was the warmest season during the past 30 years. The long-term simulations of the model provided a means of assessing trends in long-term DO concentrations under different control alternatives. The results of the different alternative simulations are presented below.

1. The largest pollutant contributor to the lower Hackensack River is Newark Bay, followed by BCUA and several landfills within the watershed. Figure

7.1 and Table 7.1 show the relative distribution of both C-BOD and NH_3-N from different sources.

Table 7.1 - Pollutant Loadings to the Lower Hackensack River During Summer of 1988 (June-September) From its Major Contributors

Major Contributors	$C\text{-}BOD_5$		NH_3-N	
	Tons	%	Tons	%
Newark Bay	6000	67	4085	70
BCUA	1243	14	690	12
Landfills	656	7	623	11
Stormwater	408	4	23	0.6
Benthos	196	2	338	5
Others*	550	6	83	1.4

* STPs, CSOs DWOs

Figure 7.1 indicates that Newark Bay contributes about 67% to 70% of the total pollutant load entering the lower Hackensack River Basin. The large pollutant loads entering the Hackensack River are due to a combination of large tidal flows and high pollutant concentrations prevailing in Newark Bay. The water quality in Newark Bay is governed by the interaction of numerous point and non-point sources discharged through the Passaic, Hudson, Raritan, Arthur Kill, Rahway and other rivers in the vicinity of Newark Bay.

The sources of pollutants presented in Table 7.1 contribute to the overall DO sag in the lower Hackensack River, together with thermal discharges from PSE&G's Power Plant at Ridgefield. The impacts due to these different sources were discussed in Chapter 6.

2. The long-term water quality database generated in 1988 within the lower Hackensack River network indicate extensive degradation of the River water quality above Berry's Creek. Frequent violation of the DO concentration standard was observed along the entire River during the surveys of 1988.

3. The simulations indicate that the section of the River between Berry's Creek and Overpeck Creek is the most stressed reach due to the impact of discharges of several STP's and PSE&G's Bergen Power Plant.

4. The BCUA's discharge effluent and PSE&G's thermal discharge have the greatest impact on the DO concentrations in the section of the River between Berry's Creek and Overpeck Creek.

5. Relocation of BCUA's discharge further downstream from its current discharge point to the vicinity of the confluence of Berrys Creek Canal results in a greater improvement in River DO concentrations than upgrading BCUA's STP to Level III.

6. The severity in the lower Hackensack River DO depletion is <u>greater</u> during dry summer months with lower discharges from BCUA's STP, than during wet Summer months with larger discharges.

The results clearly suggest several viable alternatives for improving the DO regime in the lower Hackensack River. These alternatives include:

1. Relocation of BCUA's STP discharge to a downstream reach of the River.

2. Upgrade BCUA's STP to Level III.

3. Divert BCUA discharge to the Hudson River.

4. Reduce the Heat Rejection from PSE&G's Power Plant at Ridgefield.

The costs associated with each of these viable alternatives are discussed in detail in a Summary Report prepared by Clinton Bogert Associates. Table 7.2 briefly lists these costs.

Table 7.2 - Costs Associated with Different Viable Alternatives

Alternative No.	Description	Present Worth (Million Dollars)
1	Relocate BCUA Downstream	58.8
2	Upgrade BCUA to Level III	150.2
3	Divert BCUA to Hudson River	80.7
4	Eliminate Heat Rejection from the PSE&G Power Plant	99.1

The alternatives considered in this study were designed particularly to select a cost-effective approach to improving the DO regime of the lower Hackensack River. The implementation of any of the management alternatives presented in this study will undoubtedly have impacts on other important water quality or ecological attributes of the system. Some of these important issues needing further analysis include:

a) Impact of BCUA's STP discharge relocation to a point further downstream or to the Hudson River on the marsh ecology of the Hackensack Meadowlands.

b) Impact of BCUA's STP discharge diversion to the Hudson River on the salinity regime of the lower Hackensack.

c) Impact of reduced nutrient discharged from BCUA's STP as a result of plant upgrade to Level III on tidal marshes.

d) Impact of BCUA's STP discharges on the Hudson River water quality.

Sufficient information has been developed in this study to determine the best approach for the resolution of the DO problems in the lower Hackensack River. The selected alternatives represent the results of the comprehensive River Basin Water Quality Study conducted in the lower Hackensack River and their tributaries. Meaningful discussions can now be initiated with the regulatory authorities and a judicious wasteload allocation for BCUA's STP discharge can now be assured. Based upon the selected alternative, analyses will be conducted to determine a seasonal wasteload allocation for the STP.