GOWANUS BAY AND CANAL
BROOKLYN, NEW YORK

HYDROLOGY, HYDRAULICS, HYDRODYNAMIC AND WATER QUALITY APPENDIX

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1. Introduction

Mathematical models of the Gowanus Bay and Canal watershed and its receiving waters were used to simulate water quality conditions in the Gowanus Bay and Canal Ecosystem Restoration Study. Watershed models simulated hydrologic conditions, sewer system hydraulics, and wet-weather discharges to receiving waters. A receiving water model of Gowanus Bay and Canal was used to simulate hydrodynamic and water quality conditions in the study area. The System-Wide Eutrophication Model (SWEM), developed by the New York City Department of Environmental Protection (DEP), was used to develop water quality boundary conditions in Upper New York Bay.

1.1 Description of Study Area and Vicinity

A comprehensive watershed-based approach is being employed by the Gowanus Bay and Canal Ecosystem Restoration Study to identify and investigate pollutant sources originating in the watershed and their impact on water quality and/or designated uses. In a natural or non-urban setting, the watershed would be delineated as the topographic watershed tributary to the waterbody, although accounting for man-made diversions or other factors. In the case of Gowanus Bay and Canal, the watershed tributary to the waterbody is mostly the sewershed of combined and separated sewer systems that service the watershed and discharge to Gowanus Bay and Canal during wet weather. Since the sewershed does not reflect the actual topographic watershed of Gowanus Bay and Canal, the study area of the Gowanus Bay and Canal Ecosystem Restoration Study encompasses Gowanus Bay and Canal, the corresponding sewershed, and adjacent parks and undeveloped properties that drain to Gowanus Bay and Canal via overland runoff. Figure 1-1 illustrates the Gowanus Bay and Canal Ecosystem Restoration Study area, including both the watershed and the sewershed.

INSERT FIGURE 1-1 Gowanus Bay and Canal Ecosystem Restoration Study Area

The Gowanus Bay and Canal study area is designated as all waters extending from the northern head-end terminus of Gowanus Canal at Butler Street in Brooklyn, New York and terminating to the south where Gowanus Bay converges with the Upper New York Bay at the Breakwater terminal in Red Hook and 37th Street on the southern shore. The study area includes four turning basins that are perpendicular to the canal: the 4th Street

Basin, 6th Street Basin, 7th Street Basin and 11th Street Basin. A fifth turning basin at 1st Street is documented on several maps; however, this basin no longer exists.

The watershed portion of the study area includes the Red Hook, Carroll Gardens, Boerum Hill, Park Slope, Windsor Terrace, and Gowanus neighborhoods of western Brooklyn within Community Districts 6 and 7. This area is serviced by combined sewer systems of the Red Hook and Owls Head Water Pollution Control Plants (WPCPs). Small portions of separately sewered areas serviced by the Red Hook and Owls Head WPCPs are also in the study area, as well as areas adjacent to the waterbody that have private drainage systems.

1.2 Designated Uses and Water Quality Standards

Gowanus Canal is located in and primarily subject to regulation by the State of New York. Gowanus Canal is also within the Interstate Environmental District and is subject to water quality regulation by the Interstate Environmental Commission. Waterbody uses must also be consistent with the fishable/swimmable goals of the Clean Water Act. The following describes water quality use designations, water quality standards, and other considerations pertinent to Gowanus Canal use evaluations.

Gowanus Canal is designated in the Official Compilation of Codes, Rules and Regulations of the State of New York as a Class SD waterbody. The best usage of Class SD waters is fishing. This classification may be given to those waters that, because of natural or man-made conditions, cannot meet the requirements for primary or secondary contact recreation and fish propagation. Water quality standards specific to Class SD waters require that dissolved oxygen concentrations shall not be less than 3.0 mg/L at any time. Since there is no recreational use classification for Gowanus Canal, there are no numerical recreational use water quality standards applied to the waterbody.

Downstream of Gowanus Canal, Gowanus Bay and Upper New York Bay are designated as Class I waters. The best usages of Class I waters are secondary contact recreation and fishing. These waters shall be suitable for fish propagation and survival. The State of New York defines secondary contact recreation as recreational activities where contact with the water is minimal and where ingestion of the water is not probable. Secondary contact recreation includes, but is not limited to, fishing and boating. Numerical water quality standards for Class I waters are specified for dissolved oxygen, and total and fecal coliform. The water quality standards require that dissolved oxygen concentrations shall not be less than 4.0 mg/L at any time. Total coliform must have a monthly geometric mean of less than 10,000 MPN/100 mL from a minimum of five examinations. Fecal coliform must have a monthly geometric mean of less than 2,000 MPN/100 mL from a minimum of five examinations. Table 1-1 summarizes dissolved oxygen and coliform water quality standards applied to Gowanus Canal and its surrounding waters.

Table 1-1 New York State Numeric Surface Water Quality Standards (Saline)

Class	Dissolved Oxygen	Coliform	
		Total	Fecal
SD	>3.0 mg/L	N/A	N/A
I	>4.0 mg/L	Monthly geometric mean <10,000 per 100 mL	Monthly geometric mean <2,000 per 100 mL

The State of New York has narrative criteria and water quality standards to protect aesthetics in all waters of the State; these standards are applied equally to all water classifications. The narrative water quality standards address floatables, settleable solids, odors and other aesthetics that primarily affect aesthetic waterbody uses. They limit the following water quality parameters: taste-, color-, and odor-producing toxic and other deleterious substances; turbidity; suspended, colloidal and settleable solids; oil and floating substances; garbage, cinders, ashes, oils sludge and other refuse; and phosphorous and nitrogen. They are applied to water conditions as well as discharges and are worded with several variations. In all cases, with the exception of phosphorous and nitrogen, narrative water quality standards apply a limit of "no" or "none."

1.3 Existing Waterbody Uses

Gowanus Bay and Canal was fully developed for maritime commerce in the middle of the 19th century. While it remains an active industrial area, the waterbody is transitioning to lighter commercial uses, and water-dependent uses have diminished from historic levels. In addition, recreational uses such as private boating, fishing/crabbing, and diving occur. Public access to the waterbody is limited to street-ends and boat launches.

There are many active industrial and maritime uses in Gowanus Bay and Canal. The area north of the Hamilton Avenue Bridge is home to smaller-scale maritime commerce uses, including the following properties that generate barge traffic:

- Bayside Fuel Oil on the west side of the canal, between Sackett and Union Streets;
- Ferrara Concrete on the west side of the canal, on Bond Street;
- Bayside Fuel Oil on the west side of the canal, on Smith Street; and,
- Greco Concrete on the west side of the canal, on Smith Street.

Recreational boating includes both motorboats and hand-powered boats on Gowanus Canal. A limited number of tie-ups and docks for motorboats are located near Carroll Street. In addition, canoeing by the Gowanus Dredgers Canoe Club, a local recreation and advocacy organization, is done by launching from over a deteriorated bulkhead at the end of 2nd Street on the western shore of the canal. Recreational fishing and crabbing occurs mostly from bridges south of 9th Street.

The Urban Divers, a local environmental advocacy and educational organization, conducts public environmental education programs on Gowanus Canal, including private water quality testing. Some members of the group also scuba dive in the canal and have produced underwater video footage.

2.0 Hydrology and Hydraulic Analysis

Historical alterations made to the Gowanus Bay and Canal watershed have altered its size, imperviousness, and water quality composition. Prior to urbanization, the original Gowanus Creek watershed was characterized by natural areas that were developed into the present neighborhoods upland of and surrounding Gowanus Bay and Canal. The size and location of the watershed has been altered by physical changes made to topography and the construction of sewer systems that overflow to Gowanus Canal during wet weather. The current watershed, which is approximately 1,985 acres, is served by sewer systems that have replaced the natural overland pathway of runoff. Runoff is conveyed much more quickly and directly to the waterbody without attenuation by surrounding wetlands that have been completely eliminated. The following section describes the selection of a design condition for evaluating alternatives, watershed characteristics such as land uses and sewer systems, and the hydrologic mathematical model used to simulate watershed discharges to Gowanus Bay and Canal.

2.1 Climatology

Gowanus Bay and Canal is an estuarine system that is primarily influenced by boundary waters and watershed influences. The watershed for the study area is urbanized and served by combined and separated sewers that discharge to the waterbody on a regular basis during wet weather. Water quality conditions are highly influenced by wet weather events that affect aquatic life, recreational, and aesthetic uses of the waterbody. The DEP is currently conducting long-term combined sewer overflow (CSO) control planning for Gowanus Bay and Canal and has selected a design condition that represents average conditions in Gowanus Bay and Canal. This approach is in accordance with federal CSO Control Policy (USEPA 1995a) and as such is well suited to evaluate water quality and ecological conditions in an estuarine waterbody for long-term planning.

Mathematical modeling analyses are being conducted for the Gowanus Bay and Canal watershed to characterize point-source discharges to the canal. Watershed modeling is conducted to simulate the sewer system and changes to the system associated with engineering alternatives. Receiving water modeling is conducted to simulate receiving water responses and to evaluate existing conditions and projected conditions expected with implementation of alternative scenarios. A critical component for assessing the attainability of water use goals is the selection of a representative condition for which criteria and standards can be evaluated. Once the representative condition is selected, a series of simulations of alternative scenarios can be executed. Projected water quality conditions can then be compared to water quality standards and criteria to assess the attainment and protection of waterbody uses.

Water quality conditions in Gowanus Canal are primarily influenced by combined sewer and stormwater discharges during wet weather. There is no singular recommendation for selecting a wet weather design condition in state and federal regulations, policy or guidance. The federal CSO Control Policy does not specify a design condition for evaluating use and standards attainment. However, the Presumption Approach described in the CSO Control Policy guidance document (EPA, 1995a) requires performance measures of controls for a "system-wide annual average basis."

To develop a representative New York City "annual average" design condition for which to evaluate water quality impacts and attainment of standards and uses, long term precipitation records from local rainfall gages were analyzed. Using precipitation data recorded by the National Weather Service from 1970 through 2002 at John F. Kennedy (JFK) International Airport, the following long term statistics were evaluated:

- Annual total rainfall depth;
- Annual total number of storms;
- Annual average storm volume;
- Annual average storm intensity;
- Annual total duration of storms;
- Annual average storm duration; and,
- Annual average time between storms.

These statistical analyses were performed both on an annual basis and on a monthly basis (i.e., using only January data, using only February data, etc.). The analyses identified several calendar years as being representative of an average precipitation year. Although the selection of a design year is somewhat arbitrary, the analysis of JFK rainfall records indicated that 1988 was representative of overall long-term average conditions in terms of total depth of rainfall and storm duration and includes critical rainfall conditions during July (recreational) and November (shellfish) periods. The rainfall characteristics for 1988 related to total rainfall depth, average intensity, number of storms and average duration are shown on Table 2-1. The table compares the values for 1988 to the long-term median and also shows the return period for both conditions. As shown on Table 2-1, a return period of 2.0 years would represent median conditions. The table indicates that, for both annual rainfall depth and duration, the 1988 conditions have return periods of just over 2 years conditions slightly more severe than median (50 percentile) conditions. The 1988 period has somewhat fewer storms than the median, but the storms were more intense (intensity return period of 11.3 years). Because intensity can significantly impact CSO discharges and certain water quality parameters, using 1988 JFK rainfall conservatively represents a more severe condition than the median.

Table 2-1. Comparison of Annual 1988 and Long-Term Statistics JFK Rainfall Record (1970-2002)

Rainfall Statistic	1988 Statistics	Long-Term Median (1970-2002)
Annual Total Rainfall Depth (inches) Return Period (years)	40.7 2.6	39.4 2.0
Average Storm Intensity (in/hr) Return Period (years)	0.068 11.3	0.057 2.0
Annual Average Number of Storms Return Period (years)	100 1.1	112 2.0
Average Storm Duration (hours) Return Period (years)	6.12 2.1	6.08 2.0

These results are also presented graphically for volume, intensity and duration on Figures 2-1 through 2-3. The figures show the temporal variation of each rainfall parameter for the period of 1970 through 2002 (33 years). The figures show each individual year (1988 indicated), the average for the period of record, the median for the period of record, and plus/minus the standard deviation. The figures demonstrate that for both volume and duration, 1988 is close to the long-term average and median values. The average storm intensity for 1988, however, is greater than one standard deviation from the mean. Therefore, the use of 1988 as a design rainfall year will be conservative with regard to water quality impacts since CSOs and stormwater discharges are driven primarily by rainfall intensity.

It is also important that the selected rainfall design year include a critical period, preferably during the summer months, to protect recreational and aquatic life uses.

Therefore, an analysis of long term monthly rainfall statistics was performed to assess the variability of 1988 rainfall on a monthly basis. Rainfall depth, intensity, storm duration, and time between storms (averages and standard deviations) were calculated for each month. Results indicated that while 1988 is average in terms of rainfall depth, July 1988 was a very wet month. Total storm depth (6.7 inches), total hours of rainfall (71), and average intensity for July (0.14 in/hr) are greater than the long term average plus one standard deviation. The results also indicate that the average time between storms for July 1988 is below one standard deviation from the long-term mean indicating more frequent storm events during July 1988. The results of the monthly analysis are summarized in Table 2-2 and Figures 2-4 through 2-7. The figures show the yearly statistics for four rainfall parameters with the long-term mean and standard deviation for the month of July. As shown, the July 1988 condition for volume, intensity and duration is greater than one standard deviation above the mean of the average July condition.

INSERT Figure 2-1 Total Storm Volume Analysis for Long-Term JFK Annual Record

INSERT Figure 2-2 Average Storm Intensity Analysis for Long-Term JFK Annual Record

INSERT Figure 2-3 Average Storm Duration Analysis for Long-Term JFK Annual Record

Table 2-2. Comparison of July 1988 and July Long-Term Statistics JFK Rainfall Record (1970-2002)

Rainfall Statistic	July 1988	Long-Term July Median (1970-2002)
Total Rainfall Depth (inches)	6.7	2.9
Average Storm Duration (hr)	71	34
Average Intensity (in/hr)	0.14	0.08
Average Time Between Storms (hr)	48.7	81.0

INSERT Figure 2-4 Total Storm Volume Analysis for Long-Term JFK July Record

INSERT Figure 2-5 Average Storm Intensity Analysis for Long-Term JFK July Record

INSERT Figure 2-6 Total Storm Duration Analysis for Long-Term JFK July Record

INSERT Figure 2-7 Average Time Between Storms Analysis for Long-Term JFK July Record

Another method for evaluating the characteristics of 1988 rainfall is to compare calculated discharge volumes (CSO and stormwater) to long-term probability distributions of calculated discharge volumes using the historical rainfall record. Using a calibrated, rainfall-runoff watershed model known as RAINMAN (HydroQual, 2000) developed as a simplified version of EPA's SWMM model, - DEP performed an analysis for four upper East River sewer districts (Hunts Point, Tallman Island, Bowery Bay and Wards Island). Long-term probability volumes were calculated for CSO and stormwater discharges for three periodic conditions: 1) annual basis; 2) seasonal bathing season basis (May through September); and 3) monthly basis. The results for annual statistics and seasonal statistics, representing the high recreation period (May to September), are shown on Figure 2-8. The plotted points on the figures show the long-term probability distributions for the historical rainfall record while the horizontal line shows the statistic for 1988 conditions. The upper two panels are annual CSO and stormwater volumes compared to 1988. The lower two panels represent CSO and stormwater volumes for the bathing season (May through September). As shown, the 1988 condition is generally near the long-term 50th percentile discharges for the specified periods.

INSERT Figure 2-8 Calculated Upper East River Annual and Seasonal CSO/Stormwater Discharges Using JFK Rainfall, 1970-2002

Similarly, monthly CSO and stormwater discharge conditions were evaluated for 1988. Table 2-3 summarizes the monthly 1988 volume discharge percentiles compared to the long-term July distributions and the approximate return periods for each month. As shown, the July 1988 condition, which is within the bathing season, represents a 90th percentile condition; a condition which would have a return frequency of 10 years. Similarly, November 1988 represents a 95th percentile condition, which would have a return frequency of 20 years. Therefore, although the 1988 JFK rainfall record is representative overall, it also contains critical periods during July and November that make it well suited to evaluating alternatives for a waterbody with significant CSO and stormwater discharges that affect aquatic life, recreational and aesthetic uses.

Table 2-3. JFK 1988 Monthly Statistics Compared to the Long-Term (1970-2002) Distributions		
Month	**Discharge Volume (Percentile)**	**Return Period (Years)**
January	50	2.0
February	80	5.0
March	25	1.3
April	15	1.2
May	84	6.3
June	16	1.2
July	90	10.0
August	40	1.7
September	50	2.0
October	80	5.0
November	95	20.0
December	15	1.2

JFK 1988 was also selected as the design condition from these years because this year was previously modeled for the New York/New Jersey Harbor Estuary by the DEP. JFK 1988 has been adopted by the Harbor Estuary Program for evaluating water quality conditions in the New York/New Jersey Harbor Estuary. It has also been selected by the New Jersey Department of Environmental Protection as its design condition specified in permits for long-term CSO control planning. Using an average precipitation year to develop long-term CSO control plans and evaluate compliance with water quality standards is an approach that has been taken by other major municipalities such as Washington, DC and Boston, MA.

2.2 *Watershed Land Uses*

Land use in the immediate vicinity of Gowanus Bay and Canal is generally dominated by industrial uses along its upper reaches, with scattered commercial, institutional and vacant land uses scattered along the waterfront in the vicinity of and south of the

the Gowanus Expressway. Further south and west of the Gowanus Expressway, Hess Oil operates a fuel storage facility in the vicinity of Bryant and Court Streets. This facility extends from Clinton Street east to Smith Street and Gowanus Canal. In addition, several automotive and truck repair facilities are present along the Gowanus Canal waterfront, extending north from the Hess facility.

Located at the intersection of Smith and 5^{th} Streets, is a six-acre parcel of New York City-owned property, which was designated a "Public Place" by the New York City Board of Estimate in 1974. This parcel, which was previously occupied by a coal gasification plant, was declared an Inactive Hazardous Waste Site by the New York State Department of Environmental Conservation (NYSDEC) due to the presence of solvents, coal tar

Pathmark shopping center is the New York City Department of Sanitation (DSNY) Brooklyn District 6 Garage, which is located at the intersection of 2nd Avenue and 14th Street.

Several large industrial and institutional operations are located south of the Gowanus Expressway and Hamilton Avenue along the Gowanus Canal waterfront. The New York City Department of Transportation (DOT) operates an asphalt plant on the south side of the canal immediately west of Hamilton Avenue. Adjacent to the DOT facility is the DSNY Hamilton Avenue Marine Transfer Station also on the south side of the canal. South of the DSNY facility along Hamilton Avenue, are two large commercial uses, specifically a Home Depot and Jetro, a retail supermarket catering to the food service industry. To the east of 3rd Avenue, land uses are mixed residential and industrial. Waterfront uses to the south are dominated by large scale industrial and transportation uses. Many of these uses are waterfront uses including the New York City Economic Development Corporation (NYCEDC) South Brooklyn Marine Terminal, which extends from 29th to 39th Street, and currently includes a 90-acre auto terminal as various wharf structures and piers including the Continental Terminals. The Bush Terminal Docks are located further south of the assessment area, along Upper New York Bay.

Generalized land uses in the watershed of Gowanus Bay and Canal are presented on Figure 2-9. The relative distribution of land uses in the waterbody's watershed and riparian area is summarized in Table 2-4. Land uses in the entire watershed are 45 percent residential, 4 percent park, and the remaining is a mix of public facilities and institutions, commercial, manufacturing and transportation. In general, riparian areas are dominated by warehousing, commercial and heavy industrial uses along its length. Farther inland, residential neighborhoods dominate land uses.

Table 2-4. Gowanus Canal Land Use Summary by Category	
Land Use Category	**Watershed Area**
Residential	45.3 %
Park and Recreation	4.4 %
Mixed Use*	51.3 %
Δ "Mixed Use" includes public facilities, institutional, commercial, manufacturing, transportation and vacant land uses.	

INSERT Figure 2-9 Gowanus Bay and Canal Watershed Land Uses

2.3 *Watershed Discharge Characteristics*

Freshwater streams draining the watershed once fed Gowanus Creek with a constant supply of freshwater that emptied into the tidal marsh and mud flats of Gowanus Bay. The urbanization of the watershed and construction of combined and separated sewers has eliminated these freshwater streams such that the watershed of Gowanus Bay and Canal has no freshwater sources other than CSOs and stormwater discharges. Direct overland runoff from undeveloped areas immediately adjacent to the waterbody still occurs, but is insignificant in terms of magnitude and impact when compared to combined sewer and stormwater discharges.

Gowanus Bay and Canal was the receiving waterbody for most of the discharges generated in the upland areas of this fast-growing environment prior to urbanization. Sewer-system construction followed urbanization for conveying sewage and street runoff from upland areas towards Gowanus Canal. In 1947, the Gowanus pump station was constructed at the head end of the present-day canal to eliminate one of the largest raw sewage discharges into the canal. Originally, the Gowanus pump station conveyed sanitary and combined sewage into a major trunk sewer (called the Bond-Lorraine sewer after the streets it follows) that eventually discharged to Buttermilk Channel in Upper New York Bay. After the Red Hook Water Pollution Control Plant (WPCP) was constructed and began operation in 1987, sewage conveyed by the Bond-Lorraine sewer was redirected to a new interceptor sewer under Columbia Street for treatment at the Red

Hook WPCP. The Red Hook WPCP currently services all areas north and west of Gowanus Bay and Canal. The Owls Head WPCP was constructed and began operation in 1952; it currently services all areas east of Gowanus Bay and Canal.

The NYSDEC is the permitting authority in New York State for regulating the discharges of pollutants from point sources into the waters of the state. It administers the State Pollution Discharge Elimination System (SPDES) program with regulatory authority for WPCP, CSO, stormwater, and other discharges. NYSDEDC permits CSOs discharging to Gowanus Canal through the corresponding Red Hook and Owls Head WPCP permits (SPDES numbers NY0027073 and NY0026166, respectively). Starting with its 1988 WPCP SPDES permits, the DEP was required to conduct a Shoreline Survey every two years. This program conducted water- and land-based surveys of all New York City shorelines to identify, characterize, and document all discharges to New York Harbor waters on a by-WPCP-service-area basis. DEP uses this program to identify illegal sanitary connections to storm sewers and to eliminate illicit dry-weather discharges. CSOs, stormwater discharges, highway drains, industrial discharges, etc. were all identified and mapped during the program, including those for Gowanus Bay and Canal in the Red Hook and Owls Head WPCP service areas.

There are ten SPDES-permitted Red Hook WPCP CSO discharges to Gowanus Bay and Canal within the study area. However, as described below, recent DEP field investigations revealed that one outfall (RH-032) is actually a stormwater discharge. There are two other documented stormwater discharges from the Red Hook service area. Similarly, there are seven SPDES-permitted Owls Head WPCP CSO discharges to the study area. As described below, one outfall was recently identified as a stormwater discharge rather than a CSO. There are two other documented stormwater discharges from the Owl's Head service area. Major sewer system components such as pump stations and force mains, major trunk sewers, regulators, CSO outfalls, and associated drainage area delineations are shown on Figure 2-10. Stormwater drainage areas and discharge points are also shown on Figure 2-10, using the numbering system employed by the DEP Shoreline Survey.

FIGURE 2-10 Major Sewer System Components Red Hook and Owls Head Drainage Areas

Red Hook WPCP Service Area

The Red Hook WPCP is permitted and rated for a design dry-weather flow of 60 MGD. The Red Hook WPCP recorded a daily average sanitary flow of 27 MGD for calendar year 2003. During wet weather, the SPDES permit required the Red Hook WPCP to be physically capable of receiving a minimum of 120 MGD through the WPCP headworks, a minimum of 120 MGD through primary treatment works, and a minimum of 90 MGD through secondary treatment works.

Within the Gowanus Bay and Canal sewershed, the Red Hook WPCP service area includes the Gowanus and Nevins Street pump stations. The Nevins Street pump station has a capacity of 2.2 MGD and receives underflow from several regulators (R-22, -23, -24, and -25). The Nevins Street pump station force main conveys combined sewage to a major trunk sewer of the Gowanus pump station. Following implementation of the 201 Facilities Plan in 1985, the rated capacity of the Gowanus pump station was 20.2 MGD. Up to this capacity, the Gowanus pump station conveyed combined sewage to the Columbia Street interceptor via a force main located within the Gowanus Canal Flushing Tunnel. However, in the 1990s, the force main experienced repeated failures and the flow was eventually routed back to the Bond-Lorraine sewer. In August and September 2001, the Gowanus pump station upgraded to new pumps having a capacity of 28.5 MGD. Flows exceeding this capacity are discharged to Gowanus Canal at outfall RH-034.

The Bond-Lorraine Sewer is a 72-inch brick sewer that receives force main flow from the Gowanus pump station and has other tributary combined sewered areas west of the canal. The DEP conducted sewer cleaning and television inspections of the Bond-Lorraine sewer in 2001 and 2004 (Gannett Fleming, 2004). The inspections revealed sediment accumulations and pipe diameter restrictions that limit its conveyance capacity. The Bond-Lorraine sewer has three relief points that discharge to Gowanus Canal.

Recent field inspections conducted by the DEP of the Gowanus Canal sewershed determined that CSO outfall RH-039 is currently closed and no longer discharges to the canal. Similar inspections of RH-032 indicated that it is not connected to a combined sewer and it is actually a stormwater discharge. Additionally, field inspections of stormwater outfall RH-615 revealed that it does not receive any flows and has no dry- or wet-weather discharge. Regulator locations, drainage areas, outfall locations, and SPDES numbers for the Red Hook WPCP service area are summarized in Table 2-5. Similarly, stormwater drainage areas, outfall locations, and SPDES numbers are summarized in Table 2-6.

Table 2-5. Red Hook WPCP CSO Discharges to Gowanus Bay and Canal

Regulator or Relief	Regulator Location	Combined Sewer Outfall	Outfall Location	Outfall Size	Combined Sewer Area (Acres)
Bond/Lorraine Relief	Lorraine St. & Hicks St.	RH-030	Hicks St.	42" diameter	86
Bond/Lorraine Relief	Lorraine St. & Smith St.	RH-031	Creamer St	72" diameter	70
RH-25	Nevins St. & Douglass St.	RH-033	Douglass St.	3'2" x 3'8"	5
Gowanus P.S.	Douglass St.	RH-034	Butler St.	Equivalent of 216" diameter	658
Bond/Lorraine Relief	Bond St. & 4th St.	RH-035	Bond St.	48" diameter	88
RH-22	Nevins St. & President St.	RH-036	President St.	18" diameter	10
RH-23	Nevins St. & Sackett St.	RH-037	Sackett St.	18" diameter	7
RH-24	Nevins St. & Degraw St.	RH-038	Degraw St.	12'0" x 5'2.5"	10
Bond/Lorraine Relief	NA	RH-039*	Douglass St.	3'2" x 3'8"	0
Total Combined Sewer Area (Acres)					**933**

* Outfall closed according to field inspection

Table 2-6. Red Hook WPCP Stormwater Discharges to Gowanus Bay and Canal			
Stormwater Outfalls	Outfall Location	Outfall Size	Stormwater Sewer Area (Acres)
RH-032*	W. 9th St.	12" diameter	2
RH-614	Columbia St.	36" ellipse	96
RH-615	10' n/o Union St. Bridge	8" diameter	0
Total Stormwater Drainage Area			98
* Stormwater outfall according to field inspection			

Owls Head WPCP Service Area

The Owls Head WPCP is permitted and rated for a design dry weather flow of 120 MGD. The Owls Head WPCP recorded a daily average sanitary flow of 97 MGD for calendar year 2003. The SPDES permit for the Owls Head WPCP requires that during wet weather the WPCP be physically capable of receiving a minimum of 240 MGD through the WPCP headworks, a minimum of 240 MGD through primary treatment works, and a minimum of 180 MGD through secondary treatment works. During wet-weather conditions, the 3rd Avenue interceptor, which conveys flows to a downstream regulator (OH-7D), becomes surcharged and CSOs are generated at tipping locations along the interceptor.

Recent field inspections conducted by the DEP of the Gowanus Bay and Canal sewershed identified that CSO outfall OH-009 is closed and no longer discharges to the canal. Similar inspections indicated that OH-008 is actually a stormwater discharge. Field investigations revealed a relief on the Third Avenue sewer at 23rd Street with an outfall located at 23rd Street on Gowanus Bay. This outfall did not appear to have a SPDES number at the time of the writing of this report, and as such is referred to herein as OH-CSO. Owls Head regulator locations, drainage areas, outfall locations, and SPDES numbers are summarized in Table 2-7. Owls head stormwater drainage areas, outfall locations, and SPDES numbers are summarized in Table 2-8.

Table 2-7. Owls Head WPCP CSO Discharges to Gowanus Bay and Canal					
Regulator, Relief, or Tipping	**Regulator Location**	**Combined Sewer Outfall**	**Outfall Location**	**Outfall Size**	**Combined Sewer Area (Acres)**
Tipping	3rd Ave. & Carroll St.	OH-005	5' s/o Carroll St. Br.	42" dia.	34
Tipping	3rd Ave. & 19th St.	OH-006	19th St. (North side)	36" dia.	306
2nd Ave PS	3rd Ave. & 7th St.	OH-007	end of 2nd Ave.	78" dia.	339
Tipping	NA	OH-009*	5th St.	78" dia.	0
Tipping	NA	OH-022*	Gowanus Bay / 32nd St.	6' x 4'	0
Bush TerminalPS	2rd Ave. & 28th St.	OH-023	Gowanus Bay / 28th St.	10" dia.	59
Tipping	3rd Ave. & 23rd St.	OH-CSO	23rd St.	42" x 24" Oval	0
Total Combined Sewer Area					**738**
* Outfall closed according to field inspection					

Table 2-8. Owls Head WPCP Stormwater Discharges to Gowanus Bay and Canal			
Stormwater Outfall	**Outfall Location**	**Outfall Size**	**Stormwater Sewer Area (Acres)**
OH-008*	E. 9th St.	12" dia.	8
OH-601	22nd St.	3' x 4' egg	22
OH-602	30' south of Gowanus Expressway	18" dia.	10
Total Stormwater Sewer Area			**40**
* Stormwater outfall according to field inspection			

The DEP Shoreline Survey Program has identified several other point-source discharges to Gowanus Bay and Canal. None of these is permitted by a regulatory authority and none has dry-weather discharges. They were classified by the Shoreline Survey Program as permitted industrial, and general or direct discharges that are most likely storm drains from privately owned properties with an insignificant discharge compared to CSO and stormwater.

The overland runoff drainage area immediately adjacent to Gowanus Bay and Canal represents non-point source discharges to the waterbody. Runoff from the privately owned properties almost entirely represents this discharge category and totals approximately 176 acres. These areas are relatively flat and undeveloped areas with high levels of perviousness and low slopes draining towards Gowanus Bay and Canal. Although not specifically investigated during this study, non-point source runoff is most likely insignificant as compared to CSO and stormwater.

The transformation of Gowanus Creek into Gowanus Canal and the urbanization of its watershed have affected the size and location of the watershed from that depending on topography to a sewershed. The total watershed drainage area of Gowanus Bay and Canal is 1,985 acres and represents about 5 percent of Brooklyn's entire 43,690-acre drainage area. The current watershed of Gowanus Canal is approximately 84 percent combined sewers, 7 percent stormsewers, and 9 percent unsewered (producing non-point source runoff). Watershed areas are summarized by category in Table 2-9.

Table 2-9. Gowanus Bay and Canal Watershed Summary

Source Category	Drainage Area (Acres)	Percent of Watershed
Point Sources		
CSO	1,671	84
Stormwater	138	7
Non-Point Sources	176	9
Total Watershed	**1,985**	**100**

Previous model analyses indicated that CSOs currently constitute the majority of discharges to the Gowanus Bay and Canal study area (70 percent, by volume). Approximately 59 percent, by volume, of the CSO discharges are at the Gowanus Pump Station (RH-034). An additional 24 percent are at outfall OH-007, halfway downstream between the head end and Hamilton Avenue. Discharges occur approximately 50 times a year at the Gowanus Pump Station with decreasing frequency at other outfalls.

2.4 Hydrologic (Watershed) Modeling

Mathematical watershed models are used for simulating rainfall, runoff, sewer system flow and hydraulic conditions, and point-source discharges of combined and separated sewer systems. Hydraulic watershed modeling is particularly useful for characterizing sewer systems and evaluating engineering alternatives on a performance basis. The watershed models are also used for calculating point source discharges and pollutant loadings in receiving water models. The following generally describes the tools employed for watershed modeling of the Gowanus Bay and Canal Ecosystem Restoration Study area.

Two hydraulic watershed models were employed to perform Gowanus Bay and Canal watershed simulations: one for the Red Hook WPCP service area and one for the Owls Head WPCP service area. The total combined sewer service areas simulated for these WPCPs are approximately 3,000 acres for Red Hook and 9,600 acres for Owls Head; a portion of each is in the Gowanus Bay and Canal watershed. The service areas simulated with the watershed models are shown on Figure 2-11.

INSERT Figure 2-11 Major Sewer System Components of Red Hook and Owls Head Watershed Models

The hydraulic modeling framework used in this effort is based on the EPA's Storm Water Management Model (SWMM). This comprehensive mathematical model has both design and planning capabilities. EPA describes SWMM as being a dynamic rainfall-runoff simulation model, primarily but not exclusively for urban areas, and suitable for single-event or long-term simulations. The model is composed of several separate modules, or blocks, for simulating hydrology, sanitary flow, flow routing, storage, and treatment. These blocks can be run in sequence or independently. Flow routing is performed for surface and sub-surface conveyance and groundwater systems. SWMM solves the complete St. Venant (dynamic flow) equations during hydraulic calculations in the sewer network, which includes modeling backwater effects, flow reversal, surcharging, looped connections, pressure flow, and tidal outfalls. It is a time-variable model capable of calculating flow and hydraulic grade lines within the sewer system network and at discharge points.

There are several software vendors marketing proprietary versions of similar watershed modeling packages. One such modeling package, called InfoWorks an urban watershed model developed by Wallingford Software in the United Kingdom was used for conducting watershed modeling of the two WPCP service areas. The software package uses a state-of-the-art graphical user interface with greater flexibility and enhanced access to resources for constructing a model as compared to SWMM. Post-processing tools are provided for quickly analyzing model calculations.

The watershed models of the Red Hook and Owls Head WPCP services areas were constructed using information and data compiled from the DEP's as-built designs, WPCP data, previous and ongoing planning projects, regulator improvement programs, and infiltration/inflow analysis projects to construct the models. The information required included invert and ground elevations of manholes, pipe dimensions, pump station characteristics, and regulator configurations and dimensions. The models were calibrated to flow and hydraulic elevation data collected in field investigations during dry and wet weather and using receiving water tidal data or predictions.

In each of the WPCP service areas, the models simulate WPCP headworks, interceptors, branch interceptors, major trunk sewers, and sewers greater than 60 inches in diameter. Control structures such as pump stations, diversion chambers, tipping locations, reliefs, regulators and tide gates are simulated. Separately sewered areas are also simulated in separate models to calculate stormwater discharges to receiving waters. All CSO and stormwater outfalls permitted by the State of New York are represented in the models. The models have been calibrated and validated to flow and hydraulic elevation data collected during the Inner and Outer Harbor CSO Facility Planning Projects as well as more recent data collected in the past several years for facility planning. Field verifications were conducted by the DEP during its USA Project and ongoing facility planning projects to confirm and re-measure system components where data or information gaps existed.

Watershed models were a critical component in waterbody/watershed planning being conduced by the DEP and the USACE. Conceptual alternative scenarios representing no-action and other alternatives were simulated for the design condition (1988 JFK rainfall). Tidally influenced discharges were calculated on a time-variable basis. Pollutant concentrations selected from field data and best professional judgment were assigned to the sanitary and stormwater components of the combined sewer discharges to calculate

characteristics such as land uses and best management practices (BMPs) to influence runoff quantity and quality, and routing patterns. InfoWorks can be used for characterizing both storm-sewer and combined-sewer systems. The software incorporates full solution modeling of backwater effects and reverse flow, open channels, trunk sewers, complex pipe connections and complex ancillary structures.

InfoWorks features excellent pre- and post-processing capabilities that facilitate interfacing in terms of model input, revisions during calibration and validation processes, and model output. InfoWorks provides full interactive views of data using geographical plan views, longitudinal sections, spreadsheet-style grids and time-varying graphs. A three-dimensional junction view gives improved visual presentation of manholes. The model uses automatic computation time stepping to optimize run time, and uses a four-

Runoff Volume Model

A subcatchment is divided into pervious and impervious areas. For impervious areas, the assumptions include an initial rainfall volume loss (to represent depression storage) and no rainfall infiltration so that subsequent rainfall translates into runoff. In pervious areas, the initial rainfall loss is again assumed but rainfall infiltration into the ground is then calculated according to a user-selected algorithm. For this analysis, the frequently used Horton equation was employed. This empirical formula, derived from infiltrometer/small catchment studies, represents the potential infiltration as a function of time when the rainfall rate exceeds the potential infiltration rate. This approach establishes the antecedent soil moisture conditions for each rainfall event so that the runoff volumes can be estimated accordingly.

Runoff Routing Model

InfoWorks incorporates a non-linear reservoir routing model. Subcatchments are modeled as idealized rectangular areas with the slope of the subcatchment perpendicular to the width. Each subcatchment is divided into pervious and impervious subareas. Flow from one subarea moves directly to a node and does not travel over the other subarea. Subcatchments are analyzed as spatially lumped, non-linear reservoirs. Routing is performed separately for each of the sub-areas according to a non-linear equation that accounts for the subcatchment characteristics (width, slope, reservoir storage depth, and roughness).

Hydraulic Routing Model

A sewer is represented in the model as a link of defined length between two nodes. The type of boundary condition between the link and a node may be either as an outfall or as head loss. The gradient of a conduit is defined by invert levels at each end of the link and does not preclude discontinuities in node elevations or negative gradients.

A variety of predefined cross-sectional shapes may be selected for both closed pipes and open channels. Circular pipes are defined by one dimension (diameter) and all others by the height and width; in the case of open channels the height will be to the top of the channel lining. Non-standard cross-sectional shapes may be modeled by defining a nondimensional height/width relationship. Many sewers in New York City are of non-standard cross-sectional shapes such as horseshoe and flat top round bottom (FTRB).

Two different values of hydraulic roughness may be assigned for a conduit: one for the bottom third of the conduit and one for the remainder. A permanent depth of sediment that restricts a sewer's hydraulic capacity can be defined in the invert of the conduit: no erosion or deposition is considered.

The governing hydraulic model equations are the Saint-Venant equations. This pair of equations, which represent the conservation of mass and momentum, contain a conveyance term for which the user can select either the Colebrook-White or the Manning expression. The solution of the Saint-Venant equations is obtained using a four-point implicit numerical scheme. As a result, InfoWorks is generally more numerically stable than the EPA SWMM model, which uses an explicit numerical solution procedure.

2.4.2 Watershed Model Application to Study Area

Watershed modeling of the Gowanus Bay and Canal watershed is achieved through the use of InfoWorks watershed models for the Red Hook and Owls Head WPCP service areas. These two watershed models both employ the InfoWorks modeling framework as applied to all permitted outfalls and major conduits, including all conduits with diameters of 60 inches or more, as documented in City inflow/infiltration maps or as-built drawings. Watershed characteristics, such as area and percent imperviousness, were developed using available graphical information system (GIS) sources pertaining to land use and surface contours, as well as available aerial photographs, as well as information available from previous studies, such as the USA Study as well as previous watershed modeling studies.

The Red Hook WPCP service area is roughly 3,000 acres, serviced by combined sewers. Overall, the Red Hook watershed model consists of 279 nodes (representing manholes, pump stations, outfalls, and the WPCP) and 54 subcatchments (representing drainage areas for each of the regulators within the service area). The overall, drainage-area-weighted average percent imperviousness for the Red Hook service area is about 60 percent. Impervious and pervious areas were assigned depression storage values of 0.03 and 0.1 inches, respectively, and surface roughness values of 0.02 and 0.3, respectively.

Similarly, the Owls Head WPCP service area is roughly 9,400 acres, also serviced by combined sewers. The Owls Head watershed model consists of 359 nodes and 138 subcatchments with an overall percent imperviousness of about 61 percent. Impervious and pervious areas were assigned depression storage values of 0.004 and 0.04 inches, respectively, and surface roughness values of 0.014 and 0.2, respectively. The model networks for these two service areas are shown together on Figure 2-11, and Table 2-10 presents a summary of catchment characteristics by regulator.

The sewer-system components tributary to the Gowanus Bay and Canal watershed area are presented in Figure 2-10. Overall, this drainage area is roughly 2,000 acres, with about half contributed from the Red Hook service area and the other half from the Owls Head service area. Tables 2-2 through 2-5 list the CSO and stormwater outfalls discharging to the study area from each service area.

Table 2-10. Combined Drainage Area Characteristics By Regulator, Red Hook and Owls Head WPCPs

Table 2-10. Combined Drainage Area Characteristics By Regulator, Red Hook and Owls Head WPCPs					
RED HOOK			OWLS HEAD		
Regulator	Drainage Areas (acre)	Impervious Portion (%)	Regulator	Drainage Areas (acre)	Impervious Portion (%)
RH-10	7.24	30	OH-6B	210.26	53
RH-21	9.27	50	OH-2	56.38	52
RH-25	5.11	50	Bush Trmnl PS	55.9	56
RH-9	45.33	53	OH-7	1564.35	65
RH-11	37.3	53	OH-8	244.35	56
RH-034 (Gowanus PS)	657.91	56	OH-8B	151.32	56
RH-2	409.24	56	Avenue V PS	735.53	57
RH-16	7.45	58	OH-8A	446.06	61
RH-12	165.49	58	OH-1	795.71	58
RH-20	1148.29	60	OH-5	8.42	60
RH-3	18.56	61	OH-3	482.54	64
RH-7	2.88	61	OH-9C	2268.19	60
RH-17	97.13	64	OH-9A	554.03	63
RH-5	6.51	64	OH-9B	471.48	62
RH-15	27.99	65	OH-6C	1224.77	63
RH-6	3.02	67	OH-4	140.76	67
RH-18	15.56	67			
RH-18A	17.42	67			
RH-13	89.17	70			
RH-22	9.83	70			
RH-23	7.44	71			
RH-19A	40.26	73			
RH-19	1.74	73			
RH-26	136	75			
RH-14	3.2	79			
RH-24	9.99	80			
RH-8	4.17	86			
Total	**2991**	**60***	**Total**	**9410**	**61***
*Weighted average					

Measured Data to Support Model Calibration

Model calibration is achieved through an iterative process wherein actual, measured system inputs (such as rainfall) are used as model forcing functions in a simulation, the resulting model output is compared against actual, measured system outputs (such as system flows), and model parameters (such as subcatchment imperviousness) are then adjusted and the process repeated until model simulation results match measured system outputs (such as water depth or flow). Support of this model calibration process involves measuring field conditions (e.g., sedimentation levels in sewers, tidal elevations, etc.), forcing functions (e.g., sanitary flows, rainfall data, etc.), and system output (e.g., flow monitoring in the collection system, at the WPCP, and where possible, at outfalls).

Ideally, measurements of all these various system inputs and outputs are made simultaneously for a number of different wet-weather events representing a range of conditions. In practice, measurements are typically not available for all locations or all parameters for the same time period. As described below, a number of data-collection efforts were taken to provide measurements for use in the calibration process. Where discrepancies from earlier data-collections were found, subsequent measurements and/or field inspections were conducted to provide resolution.

Watershed Characteristics

The watershed characterizations performed during the initial stages of the USA project were used for developing inputs for the urban watershed model. The regulator drainage areas were further divided into subcatchments based on distribution of land uses. Individual subcatchments were then assigned to the corresponding manholes in the sewer system model. Discrepancies existed between drainage area characterizations performed by HydroQual and the Inner Harbor study characterization performed by Hazen and Sawyer. A comprehensive review of drainage areas to individual regulators was performed to reconcile these discrepancies, and the GIS-based maps were revised to reflect the resulting changes.

In addition to the combined sewer areas included in the Red Hook and Owls Head InfoWorks model networks, two distinct areas were identified in the watershed characterization. The separately sewered drainage areas (e.g., OH-008) were modeled in such a way that sanitary flows from these areas were provided as input to the combined sewer model. Storm water from these areas was modeled using InfoWorks, and the flows were assigned to a storm water outfall in the vicinity or to a receiving water model segment as appropriate. The areas adjacent to the receiving water were modeled in InfoWorks as direct drainage areas and the flows were assigned to an appropriate receiving water model segment.

Field Inspections

During the model setup process, the inflow and infiltration drawings, as-built drawings, shoreline surveys, and field notes from previous studies revealed several discrepancies in terms of how certain regulators and outfalls were represented in earlier hydraulic models (both XP-SWMM and InfoWorks). HydroQual and Hazen & Sawyer coordinated a field inspection program in 2003 to verify the sewer system details and reconcile these discrepancies. A total of 6 regulators and 13 outfalls discharging to the Gowanus Bay and Canal study area were inspected by Savin Engineers, P.C. during dry-weather periods in January, February, May, and June of 2003. Based on these inspections, the Owls Head outfalls OH-022 and OH-009 and the Red Hook outfall RH-039 were found to be closed, and the drainage areas corresponding to OH-008 and RH-032 have been separated so that these two outfalls were reported as storm outfalls. These changes were made to the models.

In addition to the above inspections, information compiled by DEP was used in the models to reflect site-specific conditions. These conditions include:

1. Modification of GPS capacity to reflect changes in capacity during the periods chosen for model calibration and validation;
2. Inclusion of sediment deposition data compiled by D&B in the Bond-Lorraine Sewer that reduces its capacity;
3. Throttling at the treatment plants, particularly, the Red Hook plant to reflect the maximum flows that reached the plant during the calibration and validation periods; and
4. Modification of the force main from GPS to reflect its intermittent working condition and the consequent routing of flow through Bond-Lorraine Sewer during the calibration and validation periods.

Flow Monitoring at WPCPs and Pump Stations

Flow measurements are typically recorded hourly at the WPCPs and at the pump stations. Analysis of the flow data determined that the data were reasonably reliable and accurate and, as a result, flow measurements at these locations were suitable for model calibration and validation purposes.

Sanitary and wet-weather flow rates during the calibration and validation periods were developed by reviewing total WPCP inflow records. Sanitary flow rates and diurnal patterns were developed using records during dry days preceding and following wet-weather events. Wet-weather capacity and dynamics were developed through analysis of plant records during wet weather. The real-time control (RTC) capability of the InfoWorks model was used to characterize the dynamic operations in the sewer system, such as throttling at the plants and operation of tide gates. Table 2.11 lists the wet-weather events for which the Red Hook and Owls Head models were calibrated, as well as the corresponding dry- and wet-weather flows developed for each event.

Table 2-11. Red Hook and Owls Head WPCP Watersheds, Model Calibration Events

Calibration Events	Sanitary/Dry-Weather Inflow (MGD)	Maximum Wet-Weather Inflow (MGD)
RED HOOK WPCP		
10/2/89	37	95
8/1/95 - 1/3/96	36	110
2/20/98 -4/27/98	33	115
10/25/01 - 12/31/01	30	110
3/13/03 - 5/12/03	30	110
1999 (annual average WPCP flow)	31	115
OWLS HEAD WPCP		
10/28/1995 - 11/17/1995	120	240
11/25/1996 - 12/9/1996	122	240
12/11/1996 - 12/22/1996	122	240
1999 (annual average WPCP flow)	103	240

Flow Monitoring Within the Collection System

Depth-of-flow and velocity measurements were recorded at strategic locations during monitoring periods. Flow rates were to be calculated using the depth and velocity measurements. Depth data often proved to be more reliable and accurate than velocity data, which tended to have difficulties due to fouled or blocked probes, flow reversal due to tide or surcharge, inappropriate probe mounting location, and non-uniform velocity distribution due to boundary layer. Therefore, assessment of model calibration at the collection-system monitoring locations focused on the depth data.

For Red Hook, flow and water-depth data compiled in previous studies were used for model calibration. Flow and water depths were monitored at three locations in 1989 and at eight locations in 1995 as part of the Inner Harbor Study (Hazen and Sawyer, HydroQual). Data was also monitored for the Gowanus and Nevins Street pump stations and at two combined sewer locations as part of the Gowanus pump station upgrade during various periods in 1998, 2001, and 2003 (Dvirka and Bartilucci). Because model simulations were not providing satisfactory results with respect to runoff generation, percent impervious values documented in previous studies were targeted for calibration through additional short-term monitoring at five locations selected to characterize runoff from particular land uses (commercial, industrial, and low-density residential) to provide data needed to reconcile the percent imperviousness values. This additional short-term monitoring was conducted in April and May of 2003. The hourly inflow data at the Red Hook and Owls Head WPCPs compiled by DEP were also used for this hydraulic model calibration. A summary of the monitoring locations and periods is presented in Table 2-12.

Table 2.12 Red Hook Flow Monitoring Locations

Meter	Conduit	Location	Monitoring Period
CS-02	72"	Wolcott St & Conover St	1989, 1995
CS-09	78"	Hamilton Ave & Union St	1995, 2003
CS-12	Jct 90" / 66"	Columbia St & Amity St	1995
CS-20	162"	Plymouth St & Gold St	1989, 1995
CS-20a	156"	Gold & Nassau St	2003
CS-20b	48"	Bedford Ave & Lexington Ave	2003
CS-20c	48"	Nostrand Ave & Lexington Ave	2003
Weir R-09	On Weir	Hamilton Ave & Union St	1995
Weir R-20	On Weir	Plymouth St & Gold St	1989, 1995
R01-R02	54"	Downstream R-01 & R-02	1995
R10-R11	66"	Between R-09 & R-10	1995
Nevins PS	18"	Nevins Street PS	2003
Gowanus PS	Influent	Gowanus PS	1989, 1998, 2001
Gowanus PS	Effluent	Gowanus PS	1998, 2001
Red Hook WPCP	Influent	Red Hook WPCP	1995-2003

Note: The following monitoring periods were used for calibrations:
10/2/1989; 8/1/1995-1/3/1996; 2/20/1998-4/27/1998; 10/25/2001-12/31/2001; 3/13/2003-5/12/2003

For Owls Head, only data monitored in 1995 and 1996 as part of the Inner Harbor Study were available to support the hydraulic model calibration. Six locations were monitored in 1995 and 13 locations were monitored in 1996, though data obtained at two locations in 1996 were not reliable and were omitted from the original documentation and from the calibration effort. In addition to depth and flow data, deposition was also measured. Table 2-13 summarizes the locations, along with measurements relating to the deposition of solids (sedimentation) in the sewers.

Table 2-13. Owls Head Flow Monitoring Locations

Meter[1]	Conduit[2]	Deposition (ft)	Location
OH-9	8'x8.5'	0.89	Downstream R-01 @Shore Rd/92nd St
OH-R1	11'	0.94	Upstream R-01 @Shore Rd/92nd St
OH-R6A	10" cast iron (was 30" egg)	0.125	Upstream R-6A @1st Ave/63rd St
OH-R7A	9'	0.667	Upstream R-7A @1st Ave/between 48th & 49th St
OH-R7B	5' egg	0.45	Upstream R-7B @1st Ave/49th St in easement
OH-R7C	2.5' egg	0.21	Upstream R-7C @1st Ave/50th St
M1	7'	0	Downstream R-9A @Bath Ave & 17th Ave
M2	14.5'x8' box	0	Upstream R-9A @Bath Ave & 17th Ave
M3	7'	0.50	Upstream R-9A @Bath Ave & 17th Ave
M4	13'x6' box	0	Downstream R-9C @60th St & 17th Ave (upper weir)
M5	14'x7' box	0	Downstream R-9C @60th St & 17th Ave (lower overflow)
M6	13'	0	Downstream R-9C @60th St & 17th Ave (to R-06)
M7	12'	0	Upstream R-9C @60th St & 17th Ave (upper)
M8	12'	0	Upstream R-9C @60th St & 17th Ave (lower)
M9	13'	0.58	Upstream R-9C @60th St & 17th Ave (from R-08)
M10	12.5'x8' box		B/W R-06 & WPCP @Near 64th St & 1st Ave
M11	9'x9' horseshoe		B/W R-05 & WPCP @Bay Ridge Ave & Shore Rd
M12	15'	0	R-6C TG Chamber @Near 64th St & 1st Ave
M61	13'	1.833	Downstream R-9C @60th St & 15th Ave (to R-06)

Notes:
(1) Shading refers to unusable data
(2) Unless otherwise stated, sewers are circular with diameters shown.

Tidal Data

Tides can significantly affect the CSO discharge characteristics at outfalls. Most of the outfalls in New York City have tide gates that prevent water from getting into the sewer system. During wet events, the hydraulic head at the outfall must be greater than the tide level for an overflow to occur. For Red Hook, the tide data observed at Battery were used. For the Bay Ridge area in Owls Head, tide data at the Battery were corrected with a 20 minute lag time (per NOAA tide tables) and used in the hydraulic model.

Rainfall Monitoring

Continuous climatological data recorded by the National Climatic Data Center is available at three locations in New York City: Central Park (CPK), La Guardia Airport (LGA), and JFK Airport (JFK). CPK and JFK are adjacent to the watershed area tributary to Gowanus Canal (CPK is about 6.5 miles north of the Gowanus Canal and JFK is 4.3 miles southeast of the canal). CPK data was used for Red Hook watershed modeling, and JFK for the Owls Head modeling. Where available, the precipitation data collected by DEP at the Paerdegat Pump Station is used to supplement the CPK/JFK data.

2.4.3 Watershed Model Calibration and Validation

The accuracy and performance of a computer model is best measured by its ability to reproduce actual conditions it is attempting to simulate. Firstly, a calibration and verification process involves a selection of several simulation periods (events) for which data is available or has been collected. It is also important to select periods that are representative of the conditions that the model will simulate such as either typical or extreme rainfall events, or both, in addition to normal and/or seasonal dry weather conditions. A calibration process can have several selected periods such that model parameters are selected and adjusted to reasonably reproduce actual data within acceptable and justifiable model parameter ranges. As results of the calibration process, several sets of model parameters can be generated to reasonably simulate individual events but may need to be combined to simulate various conditions that the model will be used to analyze. Therefore, verification periods are simulated once a final set of model calibrated parameters has been selected. The accuracy and performance of the model can then be assessed by its ability to independently simulate verification periods without adjusting model parameters.

As discussed previously, the InfoWorks model consists of three submodels: a runoff volume submodel, a runoff overland routing submodel, and a hydraulic submodel. The runoff volume submodel calculates the volume of runoff entering the collection system. The overland routing submodel determines the rate of flow entering sewers. The hydraulic submodel combines flows from different subcatchments and redistributes the flow based on the configuration of hydraulic structures in the sewer system. The three submodels were calibrated and verified using precipitation and hydraulic data discussed previously.

Imperviousness has been suggested as a good single indicator of the extent of urbanization as far as urban stormwater impacts are concerned. Therefore, calibration of the runoff parameters (specifically the percent imperviousness) can be achieved by comparing the computed and monitored runoff volumes. The runoff overland routing submodel and the hydraulic submodel are usually calibrated together using the monitored data at some significant locations.

In summary, the InfoWorks model was calibrated in three ways: (a) Comparison of modeled and monitored runoff volumes; (b) Water depth calibration at available locations; and (c) Flow calibration at pump stations and plant inflows.

An example calibration result is provided as follows. A comparison of modeled and monitored water depths at six monitoring locations in the Red Hook drainage area are shown in Figure 2-13. The results correspond to an event observed on September 22-23, 1995 with a total rain of 0.83 inches. There is a good agreement between modeled and monitored depth data and the results are similar for other calibration events.

Figure 2-13 Red Hook Watershed Model Calibration (September 22-23, 1995)

Similar comparison between the monitored and modeled inflows to the Red Hook treatment plant is shown in Figure 2-14 for the entire month of September 1995. Comparisons between measured and model-calculated flows are favorable.

Figure 2-14 Red Hook Watershed Model Calibration (WPCP Inflow)

3.0 Receiving Water Analysis

Gowanus Canal is a tidal waterbody located in the western portion of Brooklyn, New York and is a tributary to the Gowanus Bay portion of Upper New York Bay. The headwaters of the canal are located at Butler Street in the Carroll Gardens section. The canal extends approximately one mile southward to a drawbridge at Hamilton Avenue and is generally bounded by Third Avenue to the west, Smith Street to the east, and Butler Street to the north. Downstream of that it broadens into Gowanus Bay and Upper New York Bay for another mile. The canal has a north-south orientation and features several turning basins perpendicular to the main channel that typically extend one block. The drawbridge at Hamilton Avenue defines two distinct reaches of the canal. The reach upstream of the bridge is narrow, bulkheaded and shallow with water quality greatly influenced by CSO and stormwater discharges. The bulkheaded downstream reach quickly broadens and deepens into Gowanus Bay, and water quality is heavily influenced by New York Harbor conditions. The following is a present-day description of the physical and water quality characteristics of Gowanus Canal as well as its existing uses.

Physical Waterbody Characteristics

Gowanus Canal is approximately 8,500 feet long, 100 feet wide, with a depth ranging from 4 to 16 feet at mean low water (MLW). South of Hamilton Avenue, the canal transitions into Gowanus Bay. In this region, the waterbody is approximately 2,900 feet long, 100 to 2,200 feet wide, with depths between 16 and 35 feet MLW. Beyond Gowanus Bay is Upper New York Bay.

As previously mentioned there are four basins oriented perpendicular to the canal: the 4th Street Basin, 6th Street Basin, 7th Street Basin, and 11th Street Basin. A fifth basin is mapped at 1st Street, however it is entirely filled. Each of these basins are not part of the main navigational channel and experience limited maritime traffic. The basins are primarily used for turning vessels in the canal to reverse their direction during transit. The basins are predominately deep at their intersection with the main channel of the canal. However, the basins become increasingly shallow moving away from the channel and several basins have exposed sediments during low tide. This can be observed in Figure 3-1A, which illustrates Gowanus Bay and Canal depths measured during a bathymetric survey in July 2003. A comparison of Gowanus Bay and Canal depth profiles measured in 1989 and 2003 is presented in Figure 3-1B.

INSERT FIGURE 3-1A Gowanus Bay and Canal Bathymetry in July 2003
INSERT FIGURE 3-1B Gowanus Bay and Canal Depth Profiles

There are five street-level bridges and two elevated bridges crossing Gowanus Canal. The elevated bridges, the Gowanus Expressway and a subway, cross the canal but do not restrict vessel traffic. The City of New York operates all five bridges, four of which are drawbridges crossing over the canal at Hamilton Avenue, 9th Street, Union Street, and 3rd Street. The one retractable bridge located at Carroll Street is the oldest of only four bridges of its type in the nation.

Tributary to Upper New York Bay, the estuarine Gowanus Canal system experiences a semi-diurnal tidal cycle varying between 5 and 7 feet. There is no freshwater inflow other than CSO and stormwater discharges during wet weather events. The lack of freshwater inflow created a stilling effect on pollutant discharges that allows heavy organic material and grit to settle to the bottom of the waterbody. A sediment mound that is exposed at low tides has formed at the head end of the canal due to historical CSO discharges. Naturally, the lack of freshwater flow and its narrow configuration makes Gowanus Canal water quality dependant on tidal flushing with Gowanus Bay and Upper New York Bay waters.

Regular maintenance dredging of the canal by the USACE ended in 1955. The last dredging project conducted by the USACE for navigational purposes was performed in 1971 when portions of Gowanus Bay and Canal were dredged. At that time, 73,708 cubic yards of dredged material was removed from waters between 28th Street and the Hamilton Avenue Bridge. The upper reaches of the Gowanus Canal were once dredged by the DEP in 1975. The canal was again dredged by the DEP in August and September 1998 as part of the Gowanus Canal Flushing Tunnel reactivation efforts. This dredging activity was limited to a small section of the head end at Butler Street where 1,100 cubic yards of material was removed to facilitate construction.

The Gowanus Canal Flushing Tunnel currently provides artificial circulation of harbor water from New York Harbor to the head end of Gowanus Canal. The Bureau of Sewers of the Borough of Brooklyn originally constructed the Gowanus Canal Flushing Tunnel, which began operation on June 21, 1911. The Gowanus Canal Flushing Tunnel was designed with a relatively flat slope to convey water between Upper New York Bay at

Buttermilk Channel and Gowanus Canal to improve water quality conditions in the canal. It was originally intended to operate such that canal water was pumped to Buttermilk Channel. The 12-foot-diameter tunnel is circular in shape, brick-lined, and 6,280 feet long. Starting at the canal, the tunnel pathway begins beneath Butler Street, and passes beneath its pumping facility before turning in a westward direction at Butler Street. It then proceeds under Butler Street west under Hoyt Street, then south under Hoyt Street do Degraw Street, then west under DeGraw Street to its outlet at Buttermilk Channel. The Flushing Tunnel route is shown on Figure 2-10. The pumping facility occupies DEP property immediately adjacent to the canal and the Gowanus Pump Station and consists of a motor drive, propeller, and gate chamber. The propeller is the primary pumping mechanism that is similar in design to that of a ship's propeller. It was operated until the mid-1960's, moving about 325 million gallons of harbor water per day in either direction between Buttermilk Channel and the canal. The Flushing Tunnel was shut down in the 1960's due to mechanical failures. DEP restored the pumping facility and Flushing Tunnel as part of the Inner Harbor CSO Facility Plan and the system was reactivated on March 5, 1999. It currently conveys an average 150 MGD of harbor water to Gowanus Canal.

Current Water Quality Conditions

Water quality conditions in Gowanus Bay and Canal have been extensively characterized by DEP's field investigations associated with the Gowanus Canal 201 Facilities Plan, the Inner Harbor CSO Facility Planning Project, the Harbor Survey, and the USA Project. Additional data was also collected by the USACE. The DEP's monitoring projects started in 1982 and some are still ongoing at the time of the writing of this report. Figure 3-2 shows the locations of receiving water monitoring sampling stations in Gowanus Bay and Canal. Observations of low dissolved oxygen, high coliform bacteria, poor water clarity, floatables, and odors have been well documented by the DEP. These conditions regularly persisted during and following wet weather events when CSOs and stormwater discharges occurred. These data programs showed that aquatic life, aesthetic, and recreational uses were often impaired.

INSERT FIGURE 3-2 Receiving Water Monitoring Locations in Gowanus Bay and Canal

In 1982, the Gowanus Canal 201 Facility Plan Water Quality Study established that water quality was significantly impaired. This was further reinforced by the findings of the Inner Harbor CSO Facility Planning Project, which conducted surveys from May through September 1989. Dry and wet weather surveys of the canal and special studies characterized water quality and sediment conditions and identified causes of impairments. Dissolved oxygen was typically measured as being hypoxic or anoxic throughout the waterbody, especially at the head-end terminus following wet weather discharges. High coliform bacteria, total suspended solids (TSS), biochemical oxygen demand (BOD), etc. were also observed following wet weather events. An example of average dissolved oxygen and fecal coliform concentrations typically found in Gowanus Bay and Canal prior to the reactivation of the Gowanus Canal Flushing Tunnel can be seen in Figure 3-3. Figure 3-3 also shows the NYSDEC SD standard for dissolved oxygen and the benchmarks applicable to fecal coliforms. Floatables were easily recognizable throughout the waterbody with noticeable odors and poor water clarity. The effects of the wet weather events persisted for several days following the events.

INSERT FIGURE 3-3, Gowanus Bay and Canal Conditions Before the Reactivation of the Gowanus Canal Flushing Tunnel

Analyses of the dissolved-oxygen depressions observed in Gowanus Canal indicate that the primary cause of the problem in the upper reaches of the canal is CSO dischargein conjunction with the limited hydraulic flushing of the canal. Figure 3-4 presents the components of the dissolved-oxygen deficits throughout Gowanus Bay and Canal, as determined using the modeling analyses described in later sections of this report. At the head of Gowanus Canal where the largest dissolved oxygen deficits were calculated, CSOs together contribute up to about 70 percent of the total deficit, with CSO discharges from the Gowanus Pump Station alone accounting for up to 67 percent of the total deficit. Stormwater discharges, background (Upper New York Bay) dissolved-oxygen deficits, and residual sediment oxygen demand account for the remaining 30 percent of the deficit. Farther from the head, the influence of CSO lessens while the boundary with Upper New York Bay becomes more dominant, as shown in Figure 3-4.

INSERT FIGURE 3-4, Dissolved Oxygen Deficit Contributors Prior to the Reactivation of the Gowanus Canal Flushing Tunnel

3.1 *Receiving Water Modeling*

Mathematical hydrodynamic and water quality models are used for simulating water quality responses to watershed, atmospheric and boundary influences. The model serves as a valuable tool to evaluate aquatic life and recreational uses, benefits of abating watershed impacts, and implementing ecosystem restorations and innovative technologies.

The Gowanus Bay and Canal Receiving Water Model is a three-dimensional, time-variable, coupled hydrodynamic/water-quality model. The following generally describes the tools employed for the receiving water modeling of the Gowanus Bay and Canal Ecosystem Restoration Study area.

The model domain extends throughout Gowanus Canal and into Gowanus Bay. The computational grid employs an orthogonal-curvilinear coordinate or boundary-fitted system that represents the complex and irregular shorelines, turning basins in the canal, and marine terminals. The model uses a vertical sigma-coordinate system that is scaled to the local water column depth and segments the water column into 10 vertical layers. The model has 20 by 54 horizontal grid cells with resolutions from 150 meters in the Gowanus Bay to about 30 meters in the Gowanus Canal. The model is linked to a time-variable watershed model that calculates wet weather pollutant loadings. Figure 3-6 presents the segmentation scheme developed for Gowanus Canal.

INSERT: Figure 3-6 Gowanus Bay and Canal Receiving Water Model Segmentation

The hydrodynamic model, ECOM-3D (Estuarine and Coastal Ocean Model, three-dimensions), describes the movement of water and calculates the volume and velocity of water at any time and location. The water quality model, RCA, uses this volume and velocity information along with additional water quality input information and kinetic equations to calculate receiving water concentrations for different types of pollutants. The following sections describe the calibration and validation processes of the hydrodynamic and water quality models.

Investigations concluded that water quality in Gowanus Canal did not support aquatic life, aesthetics or recreational uses at all times, and recommended that the existing but inactive Gowanus Canal Flushing Tunnel be returned to service.

In response to the recommendations of the above investigations, the existing Gowanus Canal Flushing Tunnel was reactivated in March 1999 to improve flushing and water quality in the canal. The Flushing Tunnel delivers Upper New York Bay water with higher dissolved oxygen concentrations and improves the canal's assimilative capacity for pollutant discharges. The artificial circulation also provides for a flushing action that minimizes sedimentation at the head end. Odors are reduced and water clarity is improved. Data collected by the Harbor Survey and DEP's post reactivation monitoring of the canal indicated that waterbody dissolved oxygen is greatly improved with concentrations routinely measured above 3.0 mg/L. Coliform bacteria concentrations are also reduced. An example of average dissolved oxygen and fecal coliform concentrations found in Gowanus Bay and Canal after the reactivation of the Gowanus Canal Flushing Tunnel can be seen in Figure 3-5. However, the Flushing Tunnel has been shut down on several occasions for maintenance. Data collected during these periods indicate that water quality quickly degrades to the former impaired condition.

INSERT FIGURE 3-5, Gowanus Bay and Canal Conditions After the Reactivation of the Gowanus Canal Flushing Tunnel

In summary, CSOs and stormwater discharges are primary causes of periodic waterbody use impairments. Discharges of TSS, BOD, settleable solids, and floatables induce nuisance conditions in Gowanus Canal and to a lesser extent in Gowanus Bay. These nuisance conditions include odors and depressed dissolved oxygen in the water column that reaches anoxic conditions in summertime due to BOD and sediment oxygen demand, which is sustained by CSO settleable solids discharges. Elevated coliform bacteria concentrations and noticeable floatables in Gowanus Canal are common occurrences. Noticeable odors are still caused by sediments exposed at low tides and chemical/biological reactions within the sediment and overlying water during hypoxic or anoxic conditions that release hydrogen sulfide and methane gas. The sediment mound is a burden on dissolved oxygen in overlying waters and has no habitat value. Water clarity is poor especially following wet weather events. Floatables discharged by the CSOs and storm sewers are noticeable and represent an aesthetic nuisance condition throughout Gowanus Canal and Bay.

3.2 *Hydrodynamic Model Calibration*

ECOM-3D formulates the conservation of momentum, salt, heat, and mass in their most basic forms and predicts the actual variations in circulation patterns and the salinity and temperature structures. In ECOM, differential equations are used that account for local variations of a parameter, changes due to non-linear advective and turbulent diffusion, pressure effects due to the three-dimensional differences of density (i.e., salinity and temperature), and the temporal and spatial changes in the free surface height (tides, wind-induced setup or setdown, etc.).

The Gowanus Canal hydrodynamic model was calibrated against two sets of data collected during the summer of 1989. One dataset, collected from the previous modeling efforts of Gowanus Bay and Canal (Hazen & Sawyer, 1990), covers monitoring stations within the Gowanus Bay and Canal. The second set of data was part of DEP's annual Harbor Survey database and is mainly for Gowanus Bay. Figure 3-7 depicts station locations for the data set used in the hydrodynamic analysis of Gowanus Bay and Canal.

INSERT: Figure 3-7 Gowanus Bay and Canal Data Sampling Stations Used for Hydrodynamic Analysis

The hydrodynamic model was calibrated by adjusting bottom friction and horizontal eddy diffusion coefficients to reproduce measured tidal elevations, current velocities, salinities and temperatures at different locations inside the model domain. The calibrated value of HORCON, the horizontal eddy diffusion coefficient, was set to 0.2 in the model domain. The minimum friction coefficient was set to 0.0025.

The following sections describe the model boundary forcing and the calibration of temperature, salinity, water elevation, and dye data.

3.2.1 *Boundary Forcing*

The boundary forcing functions of the hydrodynamic model of the Gowanus Canal consist of:

- water surface elevation along open-water boundaries in the Upper Bay;

- three-dimensional fields of temperature and salinity along the open boundaries;

- meteorological information consisting of wind speed and direction, shortwave solar radiation (if available), cloud cover, air temperature, atmospheric vapor pressure and relative humidity to compute surface wind stress and heat flux; and

- freshwater inflows from combined sewer overflow, stormwater, and direct surface runoff.

The details of these boundary conditions are described in this section. The forcing data used for the calibration of the model covering the period from June to September 1989 is shown in Figure 3-8. This period was chosen for calibration of the model because relatively extensive hydrographic survey data were available within Gowanus Bay and Canal.

INSERT: Figure 3-8 Boundaries for Gowanus Bay and Canal Hydrodynamic Calibration

Water Surface Elevations

In order to simulate tidal elevations in the Gowanus Bay and Canal, hourly sea surface elevation data were extracted from the results of the System-Wide Eutrophication Model (SWEM) 1989 simulation. This sea-surface elevation includes the fluctuation of sea level due to tides and meteorological forcing in New York Harbor. A uniform value of hourly data was assigned at the six open boundary grid cells in Gowanus Bay.

Salinity and Temperature

The Upper New York Harbor experiences significant variations of temperature and salinity throughout the year. Depending on the volume of the discharge from the Hudson River, the Harbor's salinity can decrease to about 10 parts per thousand (ppt) or increase to about 25 ppt. Hourly temperature and salinity boundary conditions were also extracted from the SWEM 1989 simulation results. This allowed the model to have time variable vertical temperature and salinity forcing data at its open boundaries (Figure 3-8).

Meteorological Data

Two major boundary forcing parameters applied to the water surface are wind stress and heat flux. Wind stress is computed from wind speed and wind direction. Heat flux computation requires the specification of air temperature, relative humidity, barometric pressure, shortwave solar radiation and cloud cover. Hourly meteorological data were obtained from NOAA for JFK Airport, N.Y. (Figure 3-9).

INSERT: Figure 3-9 Meteorological Conditions for Gowanus Bay and Canal Hydrodynamic Calibration

Fresh Water Inflow

The runoff volumes due to combined sewer overflows and stormwater runoff were obtained from the InfoWorks watershed models, as described above. Hourly rainfall data from the National Weather Service gages at Central Park and JFK Airport were used as model input to generate CSO and stormwater volumes. The resulting outflows were distributed throughout the domain at the locations shown in Figure 3-7. The bottom panel of Figure 3-9 shows the total flow from combined sewer overflows during the calibration period. As indicated in Figure 3-9, CSO discharges result in large total flows during rain events over the simulation period. Fresh water inflow temperatures were assigned to equal the daily water temperature measured at Battery (Figure 3-9).

3.2.2 Tidal Elevations Calibration

Tidal-stage data at two different locations were available for model calibration: one near the mouth of Gowanus Bay and the other at the head of the Gowanus Canal. These gauging stations are shown in Figure 3-7. Hourly elevation data at these stations are compared with computed values. Figure 3-10 compares the computed surface elevations with field data over a period of five days, July 18 to 22, 1989. In the figure, symbols depict observations while solid lines depict the computed elevations. The figure demonstrates good agreement between the model results and the data. The timing and heights of high and low waters were well reproduced by the model.

INSERT: Figure 3-10 Tidal Elevations for Gowanus Bay and Canal Hydrodynamic Calibration

3.2.3 Temperature and Salinity Calibration

Four surveys of temperature and salinity data were available from the previous Gowanus Canal CSO studies (Hazen & Sawyer, 1990): June 13-16, July 6-9, August 15-18, and September 25-29, 1989. Four sets of temperature and salinity data were collected during wet-weather conditions. The locations of these sampling stations are shown in Figure 3-7. For each sampling period, model computed temperature and salinity were compared with data for 15 days (Figure 3-11 through 3-18). Model versus data comparisons of water temperature for these four sampling periods yielded reasonably good agreement in temporal and spatial variation of the water temperature. The model also captured the level of thermal stratification of the water column. However, the model-calculated salinity did not reproduce observed data for periods of no-discharge from CSO or stormwater, except during the June 12-26 period. An analysis comparing data from the CSO-study and Harbor-Survey datasets revealed that the salinity measurements conducted during the CSO study were not accurate. In spite of this, as shown on Figures 3-15 through 3-18, the model did show good agreement with the observed timing and vertical stratification of salinity during CSO and stormwater discharge periods. As the salinity data demonstrates, Gowanus Bay and Canal are generally a vertically well-mixed system due to the lack of a continuous source of freshwater. Though, the transient inputs of freshwater from CSO and stormwater outfalls at various locations in Gowanus Bay and Canal generate temporary stratifications in salinity in the receiving waters during wet-weather periods.

INSERT: Figure 3-11 Temperature Calibration, June 1989
INSERT: Figure 3-12 Temperature Calibration, July 1989
INSERT: Figure 3-13 Temperature Calibration, August 1989
INSERT: Figure 3-14 Temperature Calibration, September 1989
INSERT: Figure 3-15 Salinity Calibration, June 1989
INSERT: Figure 3-16 Salinity Calibration, July 1989
INSERT: Figure 3-17 Salinity Calibration, August 1989
INSERT: Figure 3-18 Salinity Calibration, September 1989

3.2.4 Dye Study Calibration

A dye study was conducted on July 18, 1989. As part of the study, a total mass of 15 lbs of Rhodamine dye was released at the head of the Canal near the Gowanus Pumping Station. Dye concentrations in the Bay and Canal were measured from July 18 through July 21. Figure 3-7 shows the sampling locations for the dye studies. The hydrodynamic model was configured to simulate the dye release study with the same total mass of dye. The dye was released at all depths at the head of the Canal. Results of the model simulation of the dye release are shown in Figures 3-19 and 3-20. The model captures the time-of-maximum concentration and the vertical distribution of the dye well. This dye simulation provided one crucial calibration parameter, the Smagorinsky formulation constant (HORCON) that was applied for all subsequent simulations of the hydrodynamic study.

INSERT: Figure 3-19 Dye Calibration July 1989 (1 of 2)
INSERT: Figure 3-20 Dye Calibration July 1989 (2 of 2)

3.3 Hydrodynamic Model Validation

After the model was calibrated, the model was tested by simulating another condition for which observed data were available. The model calculations matched the data for this "validation" condition. For this study, the selected validation condition was calendar year 1999. Model inputs were set up for this period in the same way as they were for the calibration periods: boundary conditions for sea-surface elevation, temperature and salinity; and meteorological forcing data (Figure 3-21 and Figure 3-22). The 1999 period encompassed the reactivation of the Gowanus Canal Flushing Tunnel. Hence, model inputs incorporate additional flows from the Gowanus Canal Flushing Tunnel for the period subsequent to its reactivation in March of that year, along with the 1999 CSO and stormwater discharge flows generated by the watershed models. The Gowanus Canal Flushing Tunnel draws harbor water from Buttermilk Channel, near Governors Island, and discharges at the head of Gowanus Canal. Hourly flows for the Gowanus Canal Flushing Tunnel were calculated from a pumping rate curve that is a function of tidal elevations and have an average value of 7.5 m^3/sec (171 MGD). Tidal elevations for this calculation were set equal to the 1999 observed tidal elevations at the Battery. The calculated flows used as model input for the 1999 validation period can be seen on the bottom panel of Figure 3-21.

INSERT: Figure 3-21 Gowanus Bay and Canal Hydrodynamic Validation Input (1 of 2)
INSERT: Figure 3-22 Gowanus Bay and Canal Hydrodynamic Validation Input (2 of 2)

Temperature and salinity data measured at various locations in Gowanus Bay and Canal were compared with model computed values (Figure 3-23 and 3-26, respectively). The top panels of Figure 3-23 and 3-25 depict the assigned values of the Flushing Tunnel flow temperature and salinity, respectively. The figures represent 34-hour low-pass filtered values of temperature and salinity. The model captures the annual temperature trends in Gowanus Bay and Canal as well as the vertical thermal stratification levels. In the upstream reach of the Canal, the water column became well mixed as soon as the Flushing Tunnel flows entered the system (Figure 3-23 and 3-24). Salinity also shows the same vertically mixed pattern (Figure 3-25 and 3-26). The impact of the intermittent wet-weather CSO and stormwater inflows are transient when the Gowanus Canal Flushing Tunnel is operating.

INSERT: Figure 3-23 Gowanus Bay and Canal Temperature Validation Results (1 of 2)
INSERT: Figure 3-24 Gowanus Bay and Canal Temperature Validation Results (2 of 2)
INSERT: Figure 3-25 Gowanus Bay and Canal Salinity Validation Results (1 of 2)
INSERT: Figure 3-26 Gowanus Bay and Canal Salinity Validation Results (2 of 2)

3.4 Water Quality Model Calibration

The water quality model, RCA, simulates ten constituents, including salinity, ammonia (NH_3), outfall suspended solids, background suspended solids, hydrogen sulfide (H_2S), biochemical oxygen demand (BOD), dissolved oxygen (DO), total and fecal coliforms, and enterococcus bacteria. The primary parameters of concern in the water quality model calibration are dissolved oxygen and total coliform bacteria. The Gowanus Bay and Canal water quality model was calibrated against wet weather survey data collected during four events in the summer of 1989 . Table 3-1 presents a list of the calibration events with a summary of rainfall statistics.

Table 3-1 Water-Quality Model Calibration Events				
	Central Park Gage		JFK Airport Gage	
Date	Rainfall Depth (inch)	Maximum Rain Intensity (inch/hr)	Rainfall Depth (inch)	Maximum Rain Intensity (inch/hr)
June 12-16, 1989	2.31	0.76	1.80	0.58
July 6-9, 1989	0.16	0.14	0.25	0.20
August 15-25, 1989	0.92	0.41	0.32	0.12
September 25-28, 1989	0.80	0.20	0.87	0.21

Note:
Calibrations used Central Park gage for Red Hook watershed model and JFK gage for Owls Head watershed model.

The following sections describe the effect of temperature in the model kinetics, initial conditions, boundary conditions, point sources loadings, transport of pollutants, and the calibration of dissolved oxygen and total coliform bacteria.

Temperature Effect

Time-variable temperature is calculated in the hydrodynamic model and linked to the water quality model. Temperature is employed in the model to calculate dissolved oxygen saturation concentrations and to adjust model kinetic coefficients to real time temperatures. Temperature correction coefficients for the major kinetic reactions are summarized in Table 3-2.

Table 3-2 Temperature-Correction Coefficients		
Kinetic Reaction	Parameter	Temperature Correction Coefficient
Coliform Die-off	Kb	1.070
Dissolved Oxygen Reaeration	Ka	1.024
Photosynthesis	P	1.066
Respiration	R	1.080
Labile Decay Rate in Sediment	XK1	1.100
Refractory Decay Rate in Sediment	XK2	1.150
H_2S Oxidation	Ks	1.047
BOD Oxidation	Kd	1.047

Initial Conditions

Initial conditions are the concentrations assigned within each model cell for all model systems (constituents) at the start of a model simulation. These concentrations can be set equal to available data at the particular simulation starting time. Another method of assigning initial conditions is to run the model and use the calculated seasonal concentrations as initial conditions.

Boundary Conditions

Boundary conditions refer to the concentrations found in the waters sitting just outside of the model domain. These concentrations vary in time and provide mass gradients that can cause pollutant mass to leave or enter the model domain across the interface with the boundary. Water quality conditions outside of the model domain can have significant effects on the concentrations calculated within the model. Boundary conditions can be calculated by a separate time-variable mathematical model, which simulates water quality conditions outside of the waterbody in question, and by using data at the boundary. In the case of Gowanus Canal model, the boundary location is at the convergence of Gowanus Bay with the Upper New York Bay. DEP's System-Wide Eutrophication Model (SWEM), which simulates water quality for the entire New York -New Jersey Harbor and New York Bight region, can be used as a tool to calculate water quality conditions in Upper New York Bay. Hence, SWEM results can be inputted as boundary conditions for the Gowanus Bay and Canal model.

Point Source Loadings

As shown in the introduction to this section, point source pollutants have been identified as being the major contributor to the water quality impairments found in Gowanus Bay and Canal (NYSDEC, 2002). In the Gowanus Bay and Canal watershed, point source loadings originate from the combined sewer system, and/or from storm sewer discharges. These discharges are the source of high organic-content solids and coliforms, which ultimately promote low dissolved oxygen conditions, high coliform concentrations, and formation of sediment mounds with high sediment oxygen demand (SOD). InfoWorks, the watershed model discussed in previous sections, was used to generate both dry-weather overflows and wet-weather discharges from combined-sewer overflows and storm water discharges. Mass loads into the model were calculated by applying stormwater and sanitary concentrations to the calculated discharge volumes. These sanitary and stormwater concentrations, which were developed and adopted for the New York City's Department of Environmental Protection (DEP) Use and Standard Attainment (USA) project, are shown in Table 3-3.

Table 3-3 Sanitary and Stormwater Pollutant Concentrations

Parameter	Sanitary	Stormwater
TSS (mg/L)	115.0	60.0
BOD (mg/L)	120.0	15.0
DO (mg/L)	1.0	4.0
Total Coliform (MPN/100 mL)	1.50E+07	2.0E+05
Fecal Coliform (MPN/100 mL)	2.70E+06	0.35E+05

Transport of Pollutants

The results of the hydrodynamic model provide the water quality model with the water transport and dispersive information required to simulate the transport of pollutants. The dispersive information includes horizontal, lateral, and vertical mixing. As discussed above, the ECOM-3D hydrodynamic model was calibrated to reproduce observed tidal elevations and limited observations of salinity and dye profiles. When used in the water-quality model, the dispersive information provided by ECOM-3D produced pollutant stratification in areas where the observed data showed less or no stratification. The water quality calibration process revealed that extra mixing was required to reproduce the observed data. For areas from Hamilton Avenue to Gowanus Bay, the ECOM-3D-calculated horizontal and lateral dispersions were scaled up by factors of five and 25, respectively, and the vertical dispersion was set to a minimum of 5.0E-4 m^2/day for the entire water body.

3.4.1 Dissolved Oxygen Calibration

Dissolved oxygen concentrations in Gowanus Bay and Canal are kinetically reduced by algal respiration, oxidation of biochemical oxygen demand (BOD) and sulfides, and by sediment oxygen demand. Dissolved oxygen concentrations are kinetically increased by atmospheric reaeration and algal photosynthesis. Dissolved oxygen concentrations are also influenced by boundary conditions and point source loadings. The following sections summarize the analyses performed to calibrate the Gowanus Canal model for dissolved oxygen.

Dissolved Oxygen Reaeration

Dissolved oxygen is exchanged at the air-water interface. When the water column dissolved oxygen concentration is less than the naturally occurring dissolved oxygen saturation concentration, oxygen is added to the water column from the atmosphere. The dissolved oxygen saturation concentration is calculated for the surface water in the model as a function of temperature and salinity. Oxygen is removed from the water column by reaeration when the water is supersaturated with oxygen.

The aeration coefficient is calculated internally in the model as a function of the oxygen transfer coefficient as follows:

$$K_a = K_l / H$$

Where: K_a is the volumetric aeration coefficient [1/day],
K_l is the oxygen interfacial transfer coefficient [ft/day], and
H is the depth of the model surface segment layer [ft].

The oxygen transfer coefficient was developed as a function of wind speed and surface conditions, and is spatially assigned in the model. A conservative estimate assuming a low wind speed would yield a K_l of 1.0 ft/day. A K_l of 0.2 ft/day was assigned to segments from the canal's head to Hamilton Avenue. This reduced value was the result of calibration efforts and can be justified by field observations of grease slicks on the water surface in the upstream reaches of the Canal. A K_l of 0.6 ft/day was assigned to segments from Hamilton Avenue to 23rd Street, and a K_l of 1.0 ft/day was assigned to segments from 23rd Street to the mouth of Gowanus Bay. The rates that are stated above are for 20 °C and are temperature corrected in the model as previously described.

Nitrification

Nitrification is a biological process in which *nitrosomonas* bacteria oxidize ammonia nitrogen present in the water column. The nitrifying bacteria are sensitive species that generally do not exist in highly polluted water bodies such as Gowanus Canal. Ammonia and nitrate data collected in the canal support the assertion that the nitrifying bacteria are not present in Gowanus Bay and Canal. The water quality calibration did not include nitrification in Gowanus Bay and Canal. This did not by any extent significantly influence the calculation of dissolved oxygen concentrations.

Photosynthesis and Respiration

Algae suspended in the water column can add oxygen to the water column during periods of sunlight (photosynthesis) and can continuously consume oxygen (respiration). Special studies have been conducted as part of previous field sampling programs to evaluate the rate of oxygen production and respiration in similar waterbodies. These studies determined the amount of oxygen produced at various times in the day at the water surface. Measurements of chlorophyll-a concentrations were also performed to determine relationships between the rate of photosynthesis and chlorophyll-a concentrations. In these studies, samples were collected for measurements of chlorophyll-a concentrations to estimate the rates of photosynthesis and respiration.

Assuming that nutrients are not limiting, the gross production of oxygen by photosynthesis can be expressed as a function of a maximum photosynthesis production rate and an attenuation factor as follows:

$$\text{Photosynthesis} = P_{max} * G(Ia)$$

where Pmax is the maximum production of oxygen at optimum or "saturated" light conditions at water surface, and G(Ia) is the light attenuation factor over depth. The maximum photosynthesis rate, P_{max}, is represented as follows:

$$P_{max} = A_{op} * G_{max} * P(t)$$

where A_{op} is the ratio of oxygen to chlorophyll-a (mg O_2/ug chl-a), G_{max} is the maximum phytoplankton growth rate (day^{-1}), and P(t) is the phytoplankton chlorophyll-a concentration (ug/L). A_{op} and G_{max} were set in the model to 0.3 mg O_2/ug chl-a and 3.0/day, respectively (Thomann/Mueller). Chlorophyll-a was spatially set to constant values throughout the calibration simulation. Chlorophyll-a concentrations used in the calibration were extracted from data collected in the canal and from SWEM-calculated results at the boundary. A data-extracted chlorophyll-a concentration of 2.0 ug/L was assigned to segments between the head of the canal and Hamilton Avenue. A 5.0 ug/L chlorophyll-a concentration, also extracted from data, was assigned for segments from Hamilton Avenue to 23rd Street. An average chlorophyll-a concentration of 8.5 ug/L was extracted from SWEM results at the segment that represents Gowanus Bay and was assigned to segments from 23rd Street to Gowanus Bay.

The light attenuation factor, G(Ia), reduces the photosynthesis effect at lower depth. It is a function of the fraction of day that experiences sunlight, the depth of the water segment, light saturation intensity, total available solar radiation at the water surface, and the light extinction coefficient. The hydrodynamic model provides the depth of water. The light saturation intensity, which is the light intensity at which phytoplankton grow at a maximum rate, was set to 300 langleys/day. The fraction of day and the total available solar radiation assigned for each day of the calibration period were retrieved from SWEM, which uses LaGuardia Airport meteorological records.

A light extinction coefficient of 1.34/m was set for the entire model domain throughout the calibration simulation. This value was extracted from summer 1989 SWEM results at the segment representing Gowanus Bay and Canal. This value was later compared to secchi depth data collected in the canal and found to be in excellent agreement.

Respiration is algae's utilization of dissolved oxygen. The algal respiration rate is based on the simple assumption that the respiration rate is proportional to the production of oxygen at optimum light conditions (P_{max}):

$$\text{Respiration} = P_{max} * G$$

where G is a proportionality constant (dimensionless) converting the maximum photosynthetic effect to respiration. According to research literature, G is approximately 0.1, and can range from 0.05 to 0.20. A constant value of 0.085 was used in the model during calibration.

Sediment Oxygen Demand and Diagenesis

Particulate solids are discharged by dry weather overflows, CSOs and stormwater discharges. These particulate solids settle to the bottom sediments of Gowanus Bay and Canal, and promote a series of chemical reactions that utilize dissolved oxygen in the aerobic sediment layer and the water column. As oxygen is depleted in the sediment layer, anaerobic reactions begin. Sediment reactions produce hydrogen sulfide, which either oxidizes in the aerobic layer of the sediment or migrates up from the sediment into the water column. The entire process is known as diagenesis. Physical indicators that such reactions are occurring in receiving waters are strong odors of hydrogen sulfide and sediment mounds at discharge points. Both indicators are apparent in Gowanus Canal. Previous CSO studies in similar tributaries of New York Harbor have shown that diagenesis plays an important role in receiving water dissolved oxygen kinetics.

Modeling of total suspended solids (TSS) was separated into outfall and background components to distinguish between the heavier, more-settleable solids discharged from sewers and the lighter, less-settleable solids suspended in receiving waters. A constant settling rate of 50.0 ft/day was used for sewer-outfall solids, while a settling rate of 1.0 ft/day was used for background (receiving-water) solids. Prior to simulating the calibration period, the settled solids system was brought to equilibrium by "spinning" the model for several years.

The conversion of particulate solids to reactive carbon which aerobically and anaerobically decays in the sediment was based on information developed in other study areas. The factors that were employed to evaluate the reactive carbon in the sediment were the measure of volatile portion in the total suspended solids (VSS/TSS), particulate carbon portion of the volatile solids (POC/VSS), and the reactive carbon portion of the particulate carbon (RC/POC). The VSS/TSS, POC/VSS, and RC/POC ratios were estimated from previous studies and set to 0.64, 0.50, and 0.70, respectively, which yields a reactive carbon to TSS ratio of 0.22.

In the model, reactive carbon settled to the sediment was separated into rapidly decaying (labile) and slowly decaying (refractory) carbon classes. Analyses of sediment diagenesis during the calibration effort resulted in the use of a ratio of 0.50 for the labile to refractory classes of reactive carbon. Labile materials were set to decay at a rate of 1.00/day, while the refractory materials were set to decay at a rate of 0.001/day.

Once the model calculates total diagenesis based on the reactive carbon settled to the sediment it further fractionates diagenesis between SOD and hydrogen sulfide flux. It calculates the SOD and sulfide fractions using a SOD model developed by Di Toro et al (Di Toro, 1990). In this model, mathematical relationships calculate the SOD and hydrogen sulfide flux fractions using an iterative process that takes into account the

In the surface layer of the water column, the model allows for volatilization of H_2S to the atmosphere. The volatilization rate is calculated internally in the model as a function of H_2S transfer coefficient as follows:

$$K_{AS} = K_{LS}/H$$

where K_{AS} in (1/day) is the volatilization rate, K_{LS} in (m/day) is the transfer coefficient of H_2S, and H in (m) is the depth of the model surface segment layer. A K_{LS} value of 2.0 m/day was used for all water segments in the model.

BOD Oxidation

The biochemical oxygen demand (BOD) oxidation rate (Kd) is the rate at which microorganisms utilize oxygen dissolved in the water column during the process of consuming organic matter. The model kinetics uses ultimate BOD in its calculations and a value of 3.0 was chosen for the ratio of the ultimate BOD to the five-day BOD (BOD5). The oxidation rate used during the calibration was 0.30/day.

Boundary Conditions

As previously mentioned, time-variable boundary conditions in Gowanus Bay can be provided via a link to SWEM. However, Gowanus Bay and Canal boundary conditions for the calibration period were extracted from Inner Harbor CSO Facility Planning Project data at station G5 in Gowanus Bay. Except for times when data was available, an average summer value was specified throughout the entire calibration period. Table 3-4 summarizes summer average values used for boundaries conditions for the Gowanus Canal model calibration.

Table 3-4 Summer-Average Concentrations Used As Boundary Conditions

Parameter	Summer Average (Geometric Mean for Coliform)
Dissolved Oxygen (mg/L)	5.7
Background Solids (mg/L)	15.0
BOD5 (mg O_2/L)	1.65
Ammonia (mg/L)	0.40
Total Coliform (cells/100 mL)	4,000

chemical reaction velocities responsible for oxygen uptake in sediments. Furthermore, the total SOD in the model is divided into a carbonaceous fraction and a nitrogenous fraction. Hence, these chemical reaction velocities become important and sensitive calibration parameters for the water quality model's overall dissolved oxygen calibration. The reaction velocity for the carbonaceous SOD fraction, 'k_C'. was set to 2.0 m/day, and the nitrogenous SOD reaction velocity, 'k_N' was set to 0.15 m/day. These values are consistent with laboratory and field measurements reported in Di Toro's model development studies.

Initial sediment oxygen demand (SOD) for all segments in the model were set to 1.50 g O_2/m^2-day. This initial SOD value was based on sediment sampling surveys performed during the summer of 1989 and long-term simulations of SOD in the model. The model also accounts for SOD resulting from algal settling and settled solids not originating from CSO or stormwater sources by adding an additional 1.0 g O_2/m^2-day to calculated SOD.

Hydrogen Sulfide Oxidation

Highly organic sediments subjected to anaerobic conditions in the water column are a source of hydrogen sulfide (H_2S) to the overlying water. Some of this sulfide is biochemically oxidized in the water column to form sulfuric acid. The remaining sulfide is released to the atmosphere as hydrogen sulfide gas. The three components of the hydrogen sulfide kinetic calculations are mass flux from the sediment to the water column, oxidation in the water column, and volatilization to the atmosphere at the water surface.

H_2S mass flux from the sediment is a function of sediment diagenesis. The rate at which H_2S is diffused into the water column is dependent on the dissolved oxygen concentration in the water column, sediment diagenesis, and sediment oxygen demand. The calibration of the mass flux from the sediment was discussed in the sediment oxygen demand section.

The rate at which the sulfide is oxidized in the water column is called the sulfide oxidation rate (Ks). Laboratory analyses conducted in previous studies indicated that this rate is higher than most other rates and that it can exceed 1.5/day. A K_S value of 2.0/day was used in the calibration of the model. The half-saturation coefficient for H_2S oxidation (K_{H_2S}) was set to 1.0 mg/L.

Initial Conditions

Initial conditions were determined by performing a four-month model run using average concentrations extracted from data collected in June 1989 as initial conditions. The results at the end of this model run were then inputted and used as initial conditions for the calibration simulations.

Point Source Loadings

Point-source loadings for dissolved oxygen include any dry-weather overflows (DWOs) and wet weather discharges from combined and storm sewers. Point-source discharges were generated by the InfoWorks model. Wet weather pollutant loadings were based on the mixture of sanitary and stormwater in the overflow discharge and therefore dependent on the concentrations assigned to these discharges. The assigned concentrations, as discussed above and shown in Table 3-3, were applied together with the volumetric discharges from InfoWorks to produce the pollutant mass loadings used during the calibration of Gowanus Canal model. Table 3-5 presents pollutant mass loads discharged into Gowanus Bay and Canal during the four wet-weather calibration events.

Table 3-5 Gowanus Bay and Canal Calibration Loads

Period	Total Volume (MG)	Total Coliform (lbs)	TSS (lbs)	BOD (lbs)	Dissolved Oxygen (lbs)
June 12–16, 1989	40	3.89E8	20,497	7,153	1,218
July 6–9, 1989	6	3.49E7	2,864	872	180
August 15–25, 1989	31	3.16E8	16,641	5,793	992
September 25–28, 1989	74	1.18E9	40,408	16,533	2,221
June-September, 1989	562	7.37E9	305,467	116,180	17,457

3.4.2 Dissolved Oxygen 1989 Calibration Results

Temporal comparison of calculated and observed dissolved oxygen concentrations during the four-month (June - September 1989) calibration period, along with reported rainfall, is shown on Figure 3-27. Station locations are shown in Figure 3-2. Figures 3-28 through 3-31 show the predefined calibration events individually. The model reasonably reproduces increased dissolved oxygen concentrations during wet weather events resulting from higher dissolved oxygen in the wet weather discharge as compared to receiving water measured concentrations. Following the events, dissolved oxygen is depressed due to its uptake during the biochemical breakdown of the discharged pollutants. Dissolved oxygen concentrations then return to pre-event conditions once the labile component of the discharged carbon is extinguished or is reduced to steady state levels.

INSERT: Figure 3-27 Dissolved Oxygen Calibration, Summer 1989
INSERT: Figure 3-28 Dissolved Oxygen Calibration, June 1989
INSERT: Figure 3-29 Dissolved Oxygen Calibration, July 1989
INSERT: Figure 3-30 Dissolved Oxygen Calibration, August 1989
INSERT: Figure 3-31 Dissolved Oxygen Calibration, September 1989

These comparisons indicate that the model generally predicts Gowanus Bay and Canal dissolved oxygen concentrations during and following wet-weather events with a reasonable degree of accuracy. The model did have difficulty reproducing unusual surface/bottom inversions observed occasionally at data station G3. Though the model does reproduce the movement of oxygen-laden water in the salt wedge from Upper New York Bay, the magnitude and exact location of the inversion is not always matched. However, the model does reproduce the low dissolved-oxygen levels observed in the Canal during the critical July and August periods.

Total Coliform Calibration

Total coliform bacteria is discharged to Gowanus Bay and Canal during dry weather overflows and wet weather discharges from combined and storm sewers. Coliform bacteria are also present in the waters surrounding Gowanus Bay and Canal and can influence coliform concentrations found in the Bay and Canal. Coliform concentrations in the nearby waters are due to CSO and storm water discharges into the Upper New York Harbor, including the East River and its tributaries. The following sections summarize the analyses performed to calibrate the Gowanus Bay and Canal model for total coliforms bacteria.

Total Coliform Die-Off Rate

The kinetic portion of the model describes the loss of bacteria due to first order die-off rate. This die-off rate is comprised of three mechanisms: a base mortality rate, death due to salinity, and death due to solar radiation. The effect of solar radiation on the total death rate is generally small during and following wet weather events and is not included in the model. The overall death rate varies with water temperature.

The base mortality rate used in the model was 0.8/day, and the salinity loss rate used was 0.6/day (for 100% saline water.) The total die-off rate used in the model is expressed as:

$$Kb = (0.8 + 0.6 * SAL/33.7) * 1.07^{(T-20)}$$

where Kb is the coliform die-off rate (per day), T is temperature (degrees celsius), and SAL is salinity (ppt).

Die-off rates calculated by the model during the calibration averaged 1.27 for all segments at all depths and ranged from 0.72 to 2.10.

Boundary Conditions

As previously mentioned, SWEM hourly results for the calibration period of summer 1989 were not available. Hence, Gowanus Canal boundary conditions for total coliform, were extracted from Inner Harbor CSO Facility Planning Project data at station G5 in Gowanus Bay for the calibration period. Similar to dissolved oxygen boundary conditions, a summer geometric mean value was used throughout the entire calibration period except for times when data was available. Boundary conditions were set equal to the data whenever data were available. Summer total and fecal coliform geometric mean values used for boundaries conditions during the Gowanus Bay and Canal model calibration were 4,000 MPN and 571 MPN, respectively.

Point Source Loadings

Point source loadings for total coliforms included dry weather overflows (DWOs), and wet weather discharges from combined and storm sewers. Overflow discharges were generated by the InfoWorks model. Concentrations corresponding to sanitary and storm sources were assigned for each discharge according to the relative proportion of each for each outfall. The assigned concentrations, as discussed in previous sections and shown in Table 3-3, were applied during the calibration of Gowanus Bay and Canal model. Table 3-5 shown in the previous section also presents coliform pollutant loads discharged into Gowanus Bay and Canal during the four wet-weather calibration events.

3.4.3 Total Coliform 1989 Calibration Results

Temporal comparisons of calculated and observed total coliform concentrations for the summer 1989 calibration period are shown on Figure 3-32. Station locations are shown in Figure 3-2. Figures 3-33 through 3-36 show the comparisons during selected four events for calibration. The model reasonably reproduces increased coliform concentrations during wet weather events resulting from coliform loading from the wet weather discharges. Following the event, coliform concentrations are reduced due to die-off and wash away of coliforms.

These comparisons indicate that the model predicts the Gowanus Bay and Canal elevated levels of coliforms during and following wet-weather events with a reasonable degree of accuracy.

INSERT: Figure 3-32 Total Coliform Calibration, Summer 1989
INSERT: Figure 3-33 Total Coliform Calibration, June 1989
INSERT: Figure 3-34 Total Coliform Calibration, July 1989
INSERT: Figure 3-35 Total Coliform Calibration, August 1989
INSERT: Figure 3-36 Total Coliform Calibration, September 1989

3.5 Water Quality Model Validation

In order to assure that the Gowanus Bay and Canal Model accurately simulates the effect of the Gowanus Canal Flushing Tunnel, which draws water from Upper New York Bay into the head of Gowanus Canal, the model was validated by comparing model results to dissolved oxygen data collected after the reactivation of the Flushing Tunnel in March 1999. Dissolved oxygen was measured to track the benefits of reactivating the Flushing Tunnel; pathogens were not measured under this monitoring program . The validation simulation was performed for calendar year 1999, which included periods for which the Gowanus Canal Flushing Tunnel was not active.

The validation simulation was performed using the rates and constants developed during the model calibration. Initial conditions for dissolved oxygen were extracted from DEP's Harbor Survey dataset for station G5. The boundary conditions were also extracted from available Harbor Survey data collected during 1999. Pollutant loadings included CSO and stormwater discharges as per InfoWorks results and assigned concentrations for sanitary and storm water used in the calibration process. InfoWorks computed no dry-weather overflows during the validation period; this was confirmed by the lack of evidence supporting the existence of DWOs in Gowanus Bay and Canal and the fact that, by 1999, DEP had already taken corrective measures to eliminate DWOs.

The Gowanus Canal Flushing Tunnel enhances the circulation and exchange of Gowanus Bay and Canal waters by continuously forcing water from Buttermilk Channel (Upper New York Bay) into the head end of the Canal. This improves water quality in the Canal. Since Upper New York Bay is the source of the introduced water, water quality conditions in the Upper New York Bay have a significant impact on water quality in Gowanus Canal when the Gowanus Canal Flushing Tunnel is in operation. Gowanus Canal Flushing Tunnel flows and their associated pollutant mass loadings were included in the validation run. Gowanus Canal Flushing Tunnel flows were calculated from a tidally influenced semi-diurnal function of the existing pumping rates as previously discussed in the hydrodynamic section. Due to maintenance procedures, the Gowanus Canal Flushing Tunnel was shut down various times during 1999. The validation simulation of 1999 mimics these maintenance events by turning the flow function on and off at the appropriate times. In order to generate loadings associated with the Gowanus Canal Flushing Tunnel, monthly dissolved oxygen values were extracted from water quality data collected in Buttermilk Channel during the post-Gowanus Canal Flushing Tunnel reactivation monitoring. Monthly values for months which had no Buttermilk Channel dissolved oxygen data, were assigned using data from the nearest available sampling location, Harbor Survey Station E1. Similarly, all other necessary parameters for load calculation were also extracted from Harbor Survey Station E1.

Temporal comparison of calculated and observed dissolved oxygen concentrations during the validation period, calendar year 1999, is shown on Figure 3-37. Station locations are shown in Figure 3-2. As depicted in Figure 3-37 dissolved oxygen concentrations prior to the reaction of the Gowanus Canal Flushing Tunnel are mostly influenced by wet-weather events. Dissolved oxygen can become depressed after CSO and stormwater discharges and take some time to recover to normal ambient levels even in the winter months when higher ambient dissolved concentrations can be expected. However, it was apparent from both the data and the consistent model results, that dissolved oxygen concentrations in 1999 became highly dependant on the Gowanus Canal Flushing Tunnel operation. The model reasonably reproduced the increased dissolved oxygen concentrations measured during the post-reactivation sampling surveys. Sharp depressions in the calculated dissolved oxygen concentrations post the Gowanus Canal Flushing Tunnel during 1999 can be linked to times when the Gowanus Flushing Tunnel was shut down for maintenance activities. Following the maintenance shutdowns dissolved oxygen concentrations returned to levels consistent with concentrations found in the Upper New York Harbor. During the summer months higher ambient temperatures can decrease dissolved oxygen saturation levels and increase other chemical and biochemical reaction rates which further deplete oxygen from the water column. Comparison of dissolved oxygen levels in the New York Harbor and Buttermilk Channel to those found in Gowanus Bay and Canal during the summer months indicate that the observed lower dissolved oxygen concentrations are consistent with the boundary conditions at Gowanus Bay and the Gowanus Canal Flushing Tunnel water quality. Furthermore, the reactivation of the Gowanus Canal Flushing Tunnel seems to have significantly attenuated dissolved oxygen depressions associated with wet-weather events in Gowanus Canal and Bay.

INSERT: Figure 3-37 Dissolved Oxygen Validation, Calendar Year 1999

3.6 Receiving Water Model Sedimentation Calculations

As mentioned above, the RCA water-quality model is capable of tracking total suspended solids (TSS) from both outfall and background sources. The model reports the results as fluxes in grams solids per meter square-day (g/m^2-day). The total annual flux of solids from the water column can be converted to sedimentation rates by utilizing the following equation (DiToro, 2001);

$$\varpi = Jss / \rho_s (1-\phi)$$

where: ϖ is the sedimentation rate (cm/yr), Jss is the solids flux from water column to the sediments (g/cm^2-yr), ρ_s is the sediment's solids density (g/cm^3), and ϕ is the sediment porosity (unitless).

Sedimentation calculations for Gowanus Bay and Canal used sediment porosity and sediment solids density values consistent with those commonly found in CSO impacted locations in New York Harbor. These values are summarized in Table 3-6.

Table 3-6: Sedimentation Constant Parameters

Parameter	Typical CSO Sediment Deposit Value	Units
Sediment Porosity	0.8	Unitless
Sediment Solids Density	1.2	(g/cm^3)

4.0 No-Action Alternative

The Gowanus Bay and Canal Ecosystem Restoration Study No-Action alternative takes into account ongoing projects that are currently scheduled for implementation and that may impact the physical conditions and water quality within the study area. The New York City Department of Environmental Protection's (DEP) Gowanus Canal Waterbody/Watershed Facility Plan is, therefore, included in the No-Action Alternative. The multi-faceted approach of the DEP's Gowanus Canal Waterbody/Watershed Facility Plan incorporates several cost-effective engineering solutions with demonstrable positive impacts on water quality, including increased dissolved oxygen concentrations, decreased coliform concentrations, and reductions in the deleterious aesthetic consequences of CSO discharges, such sediment mounds, nuisance odors and floatables. The Plan also maximizes utilization of the existing collection system infrastructure and treatment of combined sewage at the Red Hook WPCP.

4.1 No-Action Alternative Components

The components of the No-Action Alternative for Gowanus Bay and Canal are summarized as follows:

1. Gowanus Canal Flushing Tunnel modernization;
2. Gowanus pump station reconstruction;
3. Bond-Lorraine sewer improvements;
4. Rehabilitate/reconstruct OH-007; and,
5. Periodic waterbody floatables skimming

The Gowanus Canal Flushing Tunnel will be modernized, reducing down time and improving overall operation. The main elements of the modernization is replacing the Flushing Tunnel pumping system and improving conveyance in the Flushing Tunnel.

After evaluating several configurations, installation of vertical axial flow pumps was determined to provide the highest capacity and the flexibility and redundancy lacking in the existing system. Three submersible, vertical, axial flow pumps will be installed in parallel within the existing motor pit, which will serve as a wet well. Each pump will have a design capacity of 69,500 gpm (100 MGD) at a head of 16 feet when operated at full speed (500 rpm), and will discharge through a 54-inch diameter concrete tube equipped with 54-inch Tideflex rubber check valve to prevent backflow. Variable frequency drives will adjust the speed of the pumps in synchrony according to the available submergence at the pumps, which will be controlled according to the hydraulic draw-down in the Flushing Tunnel and the tide level at Buttermilk Channel. Two spare pumps will be stored on site.

The existing restriction formed in the Gowanus Canal Flushing Tunnel by the Columbia Street interceptor will be partially alleviated by rerouting the force main to exit the Flushing Tunnel approximately 100 feet east of Columbia Street. This will result in an increase in cross-sectional area of approximately 100 percent, which will significantly reduce, though will not eliminate, the head loss through this restriction. Reducing the hydraulic limitations in the Flushing Tunnel will facilitate an estimated peak capacity of approximately 252 MGD during high tide in Buttermilk Channel, and an average flow rate of 215 MGD throughout the typical daily tidal cycle. Although these flow rates do not meet the design flow of the existing system (300 MGD), the peak flow of the proposed system will exceed the actual peak flow of the existing system by approximately 30 percent, and the average daily flow of the proposed system will exceed the existing average daily flow by approximately 40 percent. Additionally, the modernized system will have built-in redundancy and will not require shutdown for maintenance or repairs.

The Gowanus pump station reconstruction will include increasing the pump station capacity from 20.2 MGD to 30 MGD and adding floatables screening. The reconstruction will replace the non-functional force main in the Gowanus Canal Flushing Tunnel and increase its force main capacity. It will also optimize flow in the Flushing Tunnel through the elimination of a constriction where the Columbia Street interceptor passes through the Flushing Tunnel.

Bond-Lorraine sewer improvements will include cleaning, repairing the structural constriction, and adjusting a relief weir. The structural constriction between Bond Street at 4th Street and Smith Street at Huntington Street will be repaired by either restoring the pipe diameter to 72 inches or by constructing a new sewer. The relief weir for outfall RH-035 will also be raised one foot

Rehabilitating and possibly reconstructing Owls Head outfall OH-007 will include cleaning and rehabilitating the trap basin upstream of the outfall at a negligible cost. The DEP will conduct post-implementation monitoring to assess the effectiveness of the alternative. The DEP will also further evaluate reconstructing the trap basin to provide improved access to the chamber after the cleaning is performed.

The interim containment boom located at Sackett Street in Gowanus Canal will be removed upon completion of the Gowanus pump station reconstruction. The DEP will conduct periodic waterbody floatables skimming in the canal to minimize all floatables in the canal. The DEP will dispatch its tributary skimmer vessels to the canal periodically following wet weather events, especially those that induce discharges in excess of the floatables screening capacity of the Gowanus Pump Station. Floatables discharged by CSOs and stormwater outfalls will be collected by skimmer vessels.

Locations of the selected alternatives for the waterbody/watershed facility plan are shown on Figure 4-1. The total cost of the selected alternatives costs will be in addition to the DEP's $11.1 million actual cost of implementing the Gowanus Canal elements of the Inner Harbor CSO Facility Plan.

INSERT: Figure 4-1 Locations of No-Action Alternative Components

4.2 Projected Benefits for the No-Action Alternative

The calibrated mathematical models described in the previous sections were used to simulate the conceptual scenario representing the No-Action Alternative for the design condition. This design condition, which has been established by DEP for city-wide planning purposes, consists of 1988 conditions including the 1988 JFK rainfall record and climatology as well as associated model boundary conditions, together with 2045 projections for sanitary (dry-weather) flow and the design wet-weather treatment capacity at both the Red Hook and Owls Head WPCPs. The following discusses the projected water quality benefits associated with the No-Action Alternative as determined from the analysis and interpretation of mathematical models results.

Implementation of DEP's Gowanus Canal Waterbody/Watershed Facility Plan (No-Action Alternative) will have both sewer system performance benefits as well as water quality benefits. The various components of the plan will reduce CSO discharges, improve aesthetic conditions, and enhance habitat consistent with regulatory and stakeholder use goals.

The Gowanus Canal Flushing Tunnel modernization will eliminate shut downs and will increase the amount of Upper New York Bay water being conveyed from Buttermilk Channel to the head end of Gowanus Canal. This will improve circulation and water quality and aesthetic conditions in the canal.

The Gowanus Pump Station Reconstruction will increase pump station capacity, restore force main flow, and add floatables screening. The upgrade in pump station capacity will increase the flow routed via the force main to the Columbia Street interceptor and will reduce the frequency and volume of CSO discharges from the Pump Station (RH-034) to the head end of the canal by 43 percent compared to the prior condition. Restoring the force main allows the pumped flow to bypass the Bond-Lorraine sewer and to directly enter the Columbia Street Interceptor. This will relieve hydraulic conditions in the Bond-Lorraine sewer (where the pumped flow is otherwise diverted) and will substantially reduce existing discharges at the RH-035 outfall. In addition to this reduction in discharges, floatables screening will provide treatment of virtually all CSO discharges to the canal at RH-034 during an average precipitation year. Overall, this will increase wet weather CSO capture, maximize treatment, and improve water quality and aesthetic conditions in the canal.

Making improvements to the Bond-Lorraine sewer will restore conveyance capacity in the sewer. Cleaning and repairing the sewer, combined with adjusting the relief weir of RH-035, will increase wet weather CSO capture, maximize treatment, and improve water quality and aesthetic conditions in the canal.

Rehabilitating and possibly reconstructing Owls Head outfall OH-007 will restore the floatables- and settleable solids-controlling function of the trap basin upstream of the outfall. This will provide a level of floatables and settleable solids control and improve water quality and aesthetic conditions in the canal. The DEP will also conduct periodic waterbody floatables skimming in Gowanus Canal to minimize floatables in the canal and to improve aesthetic conditions in the canal.

The benefits of the No-Action Alternative (which is comprised of DEP's selected Gowanus Canal Waterbody/Watershed Facility Plan) can be quantified on a performance basis. Table 4-1 summarizes the calculated CSO discharges in the Gowanus Bay and Canal Ecosystem Restoration Study area for the No-Action Alternative. Model results predict that the Gowanus Pump Station upgrades significantly reduce CSOs in the assessment area.

Table 4-1 Gowanus Bay and Canal Summary of Projected Discharges for No-Action Alternative [1]

Outfall	Discharge Volume (MG)	Percent of Total CSO	Number of CSO Discharge Events
CSO			
RH-034	106.68	44.7	44
OH-007	75.84	31.8	47
OH-CSO	27.17	11.4	36
OH-006	14.58	6.1	31
RH-031	9.14	3.8	11
RH-035	0.19	0.1	4
RH-036	1.56	0.7	19
OH-023	1.01	0.4	5
OH-005	0.99	0.4	5
RH-038	0.94	0.4	13
RH-037	0.50	0.2	12
RH-033	0.21	0.1	8
Total CSO	238.81	100	47
Stormwater			
OH-601	122.00	N/A	N/A
OH-008	8.37	N/A	N/A
OH-602	7.27	N/A	N/A
RH-032	1.54	N/A	N/A
OH-009	N/A	N/A	N/A
OH-022	N/A	N/A	N/A
RH-039	N/A	N/A	N/A
Total Stormwater	139.18	N/A	N/A
Total Discharge	**377.99**	N/A	N/A

Note:

(1) Projection condition reflects representative annual precipitation record (JFK, 1988) and sanitary flows projected for year 2045 at Red Hook WPCP (43 MGD) and Owls Head WPCP (119 MGD).

The implementation of the No-Action Alternative (DEP's Gowanus Canal Waterbody/Watershed Facility Plan) is expected to result in the highest fish and aquatic life uses that can be reasonably attained. The No-Action Alternative will assure compliance with current Class SD dissolved oxygen standards for fish survival within Gowanus Canal. Full numerical achievement of higher levels of uses appears to be unattainable. The No-Action Alternative will improve conditions above those currently achieved. With the Flushing Tunnel in service and operating without disruption, Gowanus Canal can be considered to support a fish-survival level of water quality and generally higher levels of uses most of the time.

Figure 4-2 depicts profiles of the model-predicted average and minimum dissolved oxygen conditions along the centerline of the Gowanus Bay and Canal, and the applicable NYSDEC standards for the two waterbodies. As shown, the annual average dissolved oxygen conditions for the No-Action Alternative are above the NYSDEC standards in both the Bay and Canal. However, the standards require that dissolved oxygen concentrations be "never-less-than" the limiting standards, and a closer look at the minimum dissolved oxygen concentrations profile shows that excursions of water quality standards are projected to occur occasionally in some locations of Gowanus Bay. The following discussions address how frequently water-quality excursions can be expected to occur and provide a comparison with water quality standards to analyze the potential for attainment of higher levels of use protection.

INSERT: Figure 4-2 Gowanus Bay and Canal Dissolved Oxygen Projections for No-Action Alternative

Figure 4-3 presents a frequency analysis for compliance with water-quality standards under the No-Action Alternative. Each of the three panels represents compliance with a different dissolved-oxygen standard; the top panel with Class SD (never less than 3.0 mg/L), the middle panel with Class I (never less than 4.0 mg/L), and the bottom panel with Class SB/SC (never less than 5.0 mg/L). In each case, the "compliance" values represent the percentage of time that the minimum-calculated dissolved oxygen values meet or exceed the water-quality standard. At this time, Gowanus Canal is subject to Class SD standards, while Gowanus Bay is subject to Class I standards.

The top panel of Figure 4-3 shows that the applicable the Class SD dissolved oxygen standard (never-less-than 3.0 mg/L) will be met 100 percent of the time within both

Gowanus Canal and Gowanus Bay. The best usage of Class SD waters is fishing, hence, compliance with this standard suggests that fish survival and fishing activities will be protected for Gowanus Canal as well as Gowanus Bay.

The second panel of Figure 4-3 presents a comparison of model-projected minimum dissolved oxygen to the Class I dissolved oxygen standards (never less than 4.0 mg/L). This comparison shows that the No-Action Alternative is expected to achieve Class I standards in Gowanus Bay with the exception of the region where Gowanus Bay converges with Gowanus Canal, where a minimum compliance of 98.8 percent is projected. In addition, the model results also show the upper reaches of the Canal, from the head end to approximately Hamilton Avenue, will also meet Class I dissolved oxygen standards. Although Gowanus Canal is considered to be Class SD and Class I standards are not applicable, water quality is expected to be correspondingly protective of the Class I uses throughout the Canal for at least 93% of the time. The best usages of Class I waters are secondary contact recreation and fishing. This classification also requires that the waters shall be suitable for fish propagation and survival. The projected compliance with dissolved oxygen standards above the minimum of 98.8% in Gowanus Bay suggests that fish propagation and survival will be protected almost all of the time for an average precipitation year.

The third panel of Figure 4-3 presents a comparison of model-projected minimum dissolved oxygen to Class SB/SC standards. Class SB/SC waters provide for uses including primary and secondary contact recreation and fishing, as well as fish propagation and survival. Projected compliance with Class SB/SC standards is limited to a maximum of approximately 90% at the boundaries (Upper New York Harbor and Buttermilk Channel) and for this reason the head of Gowanus Canal and the convergence of Gowanus Bay with the New York Harbor are also limited to this value. It should be noted that even at the most critical dissolved oxygen location in the Canal, approximately 7,000 feet from the head end, compliance with Class SB/SC standard is expected for about 75 percent of the time. Hence, protection of aquatic life consistent with Class SB/SC classification can also be expected for most of the time in an average-precipitation year.

INSERT: Figure *4-3 Gowanus Bay and Canal NYSDEC Dissolved Oxygen Compliance Projections for No-Action Alternative*

Since there is no recreational use classification of Gowanus Canal, there are no numerical recreational-use water-quality standards applied to the waterbody. However, as previously mentioned, the Class I designation is intended to protect secondary recreation activities, and standards protecting this use are applicable to Gowanus Bay. The State of New York defines secondary contact recreation as recreational activities where contact with the water is minimal and where ingestion of the water is not probable. Secondary contact recreation includes, but is not limited to, fishing and boating. Numerical water quality standards for Class I waters for total and fecal coliform require that total coliform must have a monthly geometric mean of less than 10,000 MPN/100 mL from a minimum of five examinations, and fecal coliform must have a monthly geometric mean of less than 2,000 MPN/100 mL from a minimum of five examinations.

Figure 4-4 presents compliance with various standards of the projected total coliform concentrations under the No-Action Alternative. The top panel of Figure 4-4 presents compliance with secondary contact recreation standards; the middle and bottom panels present compliance with primary contact recreation standards (median and upper limit, respectively). Although primary contact standards are not applicable to Gowanus Bay and Canal, Class SB/SC is intended to protect primary recreation activities. The State of New York defines primary contact recreation as recreational activities where the human body may come in direct contact with ambient water to the point of complete body submergence. Primary contact recreation includes, but is not limited to, swimming, diving, water skiing, skin diving, and surfing. Numerical water quality standards for Class SB/SC waters require that total coliform must have a monthly median value of less than 2,400 MPN/100 mL from a minimum of five examinations, and more than 20 percent of the samples from a minimum of five examinations must be less than 5,000 MPN/100 mL, and fecal coliform must have a monthly geometric mean of less than 200 MPN/100 mL from a minimum of five examinations.

As shown in the top panel of Figure 4-4, the model projections suggest that protection of secondary contact recreation will be achieved by the No-Action Alternative all of the time for an average precipitation year in both Gowanus Canal and Gowanus Bay. This satisfies the standards applicable for Gowanus Canal.

The middle and lower panels of Figure 4-4 show that the No-Action Alternative is expected to result in 100 percent compliance with primary contact coliform standards (both median and upper limit) during an average precipitation year.

INSERT: Figure 4-4 Gowanus Bay and Canal NYSDEC Total Coliform Compliance of No-Action Alternative

The narrative water quality standards address floatables, settleable solids, odors and other aesthetics that primarily affect aesthetic waterbody uses. The No-Action Alternative will not be compliant with the "no" or "none" limits for some of these parameters. However, the levels of aesthetic use attained by the No-Action Alternative (that is, DEP's selected Waterbody/Watershed Facility Plan) represent a cost-effective plan for achieving the highest reasonably attainable aesthetic uses. Reductions in the expected volumes of CSO discharges with the implementation of the No-Action Alternative will correspond to similar reductions in discharged floatables, suspended solids and seattleable solids to Gowanus Bay and Canal.

With respect to floatables, beyond the reduction of CSO discharges, the screening of discharges from the Gowanus Pump Station (RH-034, which represents the largest CSO by volume in the assessment area) and improvements to OH-007 (the second largest CSO by volume) will further significantly reduce floatables discharges.

With respect to settleable solids, analyses of the projected sedimentation of seattleable solids indicate that a significant reduction in sedimentation and the accumulation of sediment at the bottom of the canal can be expected, particularly for the areas located near the head of Gowanus Canal (in the vicinity of the RH-034 outfall and the outlet of the Gowanus Canal Flushing Tunnel.) The reduction of sedimentation can be attributed to a combination of factors. The reduction in discharged CSO volumes will also decrease the amount of setleable solids discharged into the canal. In addition, the flushing action of the upgraded Gowanus Canal Flushing Tunnel will increase horizontal velocity profiles and will thereby help to reduce settling in the canal itself. The resulting transport of solids will result in a more even distribution of settleable solids within the Canal and Bay and will also help to transport solids into the open waters beyond the assessment area.

The model-projected pattern of sedimentation under the No-Action Alternative is shown Figure 4-5. The calculated sedimentation rate for the areas near the head end of the Canal for the No-Action Alternative is roughly 7 mm/yr and as much as nearly 9 mm/yr for areas approximately 3,500 feet from the head.

INSERT: Figure 4-5 Gowanus Bay and Canal No-Action Alternative Sedimentation

REFERENCES

Community Board Six, Borough of Brooklyn, New York City. http://www.brooklyncb6.org

Community Board Seven, Borough of Brooklyn, New York City. http://www.brooklyncb7.org

Di Toro D.M., Paquin P.R., Subburamu K., and Gruber D.A. (1990). Sediment Oxygen Demand Model: Methane and Ammonia Oxidation. J. Environ. Engr. ASCE, 116(5):945-986

Di Toro, D.M. 2001. *Sediment Flux Modeling*, New York: John Wiley & Sons, Inc., pp 624.

Dvirka and Bartilucci Consulting Engineers, 2004. Gowanus Facilities Upgrade, Final Draft Facility Plan. Prepared for the New York City Department of Environmental Protection, January 2004.

ENSR Consulting, 1999. East River Repowering Project at the East River Generating Station, New York, NY, September 1999.

Gannett Fleming, Inc., 2004. Gowanus Bond-Lorraine Sewer System Sewer Cleaning and TV Inspection. Prepared for Dvirka and Bartilucci Consulting Engineers, Woodbury, NY for the New York City Department of Environmental Protection, July 2004.

Gowanus Canal Community Development Corporation, http://gowanus.org/, 2002.

Gowanuscanal.com, http://www.southbrooklyn.net/gowanus/, 1999.

Hagstrom Map Company, Inc. 1998. *New York City 5 Borough Atlas*. 5th Edition. Maspeth, NY: The Langenscheidt Publishing Group.

Hazen and Sawyer, P.C., 1983. Gowanus Canal 201 Facilities Plan, Volumes 1, 2 and 3. Prepared for The City of New York Department of Environmental Protection, December 1983.

Hazen and Sawyer, P.C., 1990. Inner Harbor CSO Facility Planning Project, Draft Task Report 2.4, 3.4, and 4.2, Receiving Water Conditions. Prepared for The City of New York Department of Environmental Protection, Bureau of Heavy Construction, June 1990.

Hazen and Sawyer, P.C., 1992. Outer Harbor CSO Facility Planning Project, Draft Report, Task 2.2 Sewer System Monitoring, Task 2.3 Rainfall Monitoring, Task 3.3 Pumping Station and Treatment Plant Performance. Prepared for The City of New York Department of Environmental Protection. Bureau of Environmental Engineering, September 1992.

Hazen and Sawyer, P.C., 1994. Outer Harbor CSO Facility Planning Project, Facilities Planning Report. Prepared for The City of New York Department of Environmental Protection, Bureau of Environmental Engineering, December 1994.

Hazen and Sawyer, P.C., 2001. Final Report on Water Quality and Biological Improvements After Reactivation of the Gowanus Canal Flushing Tunnel, NYSDEC Permit No. 2-6102-00128/00002. Prepared for The City of New York Department of Environmental Protection, Bureau of Environmental Engineering, March 2001.

HydroQual, Inc., 1993. Final Report - Sources, Fate and Control of Floatable Materials in New York Harbor. Prepared for the City of New York Department of Environmental Protection, Bureau of Environmental Engineering, December 1993.

HydroQual, Inc., 1995. Floatables Pilot Program, Final Report - Evaluation of Non-Structural Methods to Control Combined and Storm Sewer Floatable Materials. January 1995.

HydroQual Environmental Engineers and Scientists, P.C., 1997. City-Wide CSO Floatables Plan, Draft. Prepared for The City of New York Department of Environmental Protection, Bureau of Environmental Engineering, June 1997.

HydroQual Environmental Engineers and Scientists, P.C., 2000. "A Simplified Modeling Approach for Simulating Rainfall-Runoff, Projecting Pollutant Loads and Analyzing Treatment Performance." Presented by W. McMillin at the International Conference on

Stormwater and Urban Water Systems Modeling, Toronto, Canada, February 4, 2000. Abstract available at http://www.hydroqual.com/Papers/wmcmillin/03/a_wem 03.htm

National Oceanographic and Atmospheric Administration. *Tide Tables, High and Low Water Predictions, East Coast of North and South America.* National Ocean Service, Estuarine and Ocean Physics Branch, 6001 Executive Boulevard, Rockville, MD 20852. (Published annually and available at www.co-ops.nos.noaa.gov/tide_pred.html).

New York City Department of City Planning. July 1990. *Zoning Handbook, A Guide to New York City's Zoning Resolution.*

New York City Department of City Planning. 1992. *New York City Comprehensive Waterfront Plan: Reclaiming the City's Edge.*

New York City Department of City Planning, City Planning Commission. 1994. continuously updated. *Zoning Resolution, The City of New York.*

New York City Department of City Planning. Fall 1994. *Plan for the Brooklyn Waterfront.*

New York City Department of City Planning. Fall 1996. *Recreation and Open Space in New York City, Brooklyn.*

New York City Department of City Planning. September 2002. *The New Waterfront Revitalization Program.*

New York City Department of City Planning, in conjunction with the Department of Citywide Administrative Services. November 2002. *Gazetteer of City Property 2002.*

New York City Department of City Planning, *Coastal Zone Boundary*, 1986.

New York City Department of City Planning, *Plan for the Brooklyn Waterfront, New York City Comprehensive Waterfront Plan*, 1994.

New York City Department of City Planning, *Recreation and Open Space in New York City: Brooklyn*, 1996.

New York City Department of City Planning. Fiscal Years 2002/2003. *Community District Needs, Brooklyn.*

New York City Department of City Planning. Fiscal Year 2004. *Community District Needs, Brooklyn.*

New York City Department of Environmental Protection. 1997. CSO Abatement in the City of New York: Report on Meeting the Nine Minimum CSO Control Standards, January 1997.

New York City Department of Environmental Protection, 2001. 2001 New York Harbor Water Quality Report.

New York City Department of Environmental Protection, 2003. Inner Harbor CSO Facility Planning Project, Modified CSO Facility Planning Report, April 2003.

New York City Department of Parks and Recreation. http://www.nycgovparks.org/

New York City Neighborhood Profiles. New York Metro Website. http://www.newyorkmetro.com/ realestate/articles/neighborhoods/carrollboerum.htm

New York State Department of Environmental Conservation, *Tidal Wetland Maps*, 1974.

New York State Department of Environmental Conservation, *New York State Freshwater Wetlands Map - Brooklyn Quadrangle, New York, Kings County*, 1988.

New York State Department of Environmental Conservation, *New York State Freshwater Wetlands Map - Jersey City Quadrangle, New Jersey-New York, Kings County*, 1988.

New York State Department of Environmental Conservation, *New York Harbor Water Quality Survey*, 1998.

New York State Department of Environmental Conservation, *NYSDEC TOGS 1.1.1, Ambient Water Quality Standards and Guidance Values and Groundwater Effluent Limitation*, updated 1998, 1999 and 2000.

New York State Department of Environmental Conservation. 2002. The 2000 Atlantic Ocean Long Island Sound Basin Waterbody Inventory and Priority Waterbodies List. Volume 1: New York City Metropolitan Waters, April 2002.

Richards, Daniel. 1848. Report of the Street Committee of the Common Council, on the Drainage of That Part of the City Lying Between Court-Street and the Fifth Avenue, Warren-Street and Gowanus Bay, November 1848.

Sanborn Map Company, Inc. 1974. *Land use maps, New York*. Prepared for the New York City Department of City Planning, New York City Planning Commission.

Sunset Energy Fleet, LLC., 2002. Article X Application, New York State Public Service Commission, Case 99-F-0478, 2002.

Thomann. R.V. and J.A. Mueller. 1987. *Principles of Surface Water Quality Modeling and Control*. New York: HarperCollins Publishers, pp 644.

U.S. Army Corps of Engineers, New York District. http://www.nan.usace.army.mil/

U.S. Army Corps of Engineers, 2001. Project Management Plan. Gowanus Bay and Canal Brooklyn, New York, Ecosystem Restoration Study. Prepared by U.S. Army Corps of Engineers, New York District, November 2001.

U.S. Army Corps of Engineers, 2003a. Gowanus Canal Benthic Sampling Data Documentation, Gowanus Canal, New York. Prepared by U.S. Army Corps of Engineers, Planning Division, New York District, August 2003.

U.S. Army Corps of Engineers, 2003b. Site Investigation Gowanus Bay and Gowanus Canal, Kings County, NY. Draft Report, Volume 1. Prepared by U.S. Army Corps of Engineers, Baltimore District for U.S. Army Corps of Engineers, New York District, September 2003.

Van Dam. Stephan. 1998-2000. *NY @tlas*.

U.S. Army Corps of Engineers, *Site Investigation Gowanus Bay and Gowanus Canal*, Kings County, New York, Final Report. October 2003.

U.S. Environmental Protection Agency, 1986. Ambient Water Quality Criteria for Bacteria - 1986. EPA 440/5-84-002, January 1986.

U.S. Environmental Protection Agency, 1994. Combined Sewer Overflow (CSO) Control Policy. EPA 830-B-94-001, April 1994.

U.S. Environmental Protection Agency, 1994a. Water Quality Standards Handbook: Second Edition. EPA 823-B-94, August 1994.

U.S. Environmental Protection Agency. 1995a. Combined Sewer Overflows - Guidance for Long-Term Control Plan. EPA 832-B-95-002, September 1995.

U.S. Environmental Protection Agency, 1995b. Combined Sewer Overflows - Guidance for Permit Writers. EPA 832-B-95-008, September 1995.

U.S. Environmental Protection Agency, 1997. Technical Guidance Manual for Developing Total Maximum Daily Loads, Book 2: Streams and Rivers, Part 1: Biochemical Oxygen Demand/Dissolved Oxygen and Nutrients/Eutrophication. EPA 823-B-97-002, March 1997.

U.S. Environmental Protection Agency, 1998. EPA Guidance for Quality Assurance Project Plans, EA QA/G-5. EPA/600/R-98/018, February 1998.

U.S. Environmental Protection Agency, 1999. Combined Sewer Overflows - Guidance for Monitoring and Modeling. EPA 832-B-99-002, January 1999.

U.S. Environmental Protection Agency, 2000. Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Code to Cape Hatteras. EPA-822-R-00-012, November 2000.

U.S. Environmental Protection Agency, 2001. Guidance: Coordinating CSO Long-Term Planning With Water Quality Standards Reviews. EPA-833-R-01-002, July 31, 2001.

U.S. Environmental Protection Agency, 2001a. EPA Requirements for Quality Management Plans, EPA QA/R-2. EPA/240/B-01/002, March 2001.

U.S. Environmental Protection Agency, 2001b. EPA Requirements for Quality Assurance Project Plans, EPA QA/R-5. EPA/240/B-01/003, March 2001.

U.S. Environmental Protection Agency, 2001c. Guidance for Preparing Standard Operating Procedures (SOPs), EPA QA/G-6. EPA/240/B-01/004, March 2001.

U.S. Fish and Wildlife Service. *National Wetland Inventory (NWI) Maps - Brooklyn, N.Y.*, 1977.

U.S. Fish and Wildlife Service, *National Wetland Inventory (NWI) Maps - Jersey City, N.J.*, 1977.

U.S. Geological Survey, *Jersey City Quadrangle, New Jersey-New York, 7.5-Minute Series*, 1967, photo revised 1981.

U.S. Geological Survey, *Brooklyn Quadrangle, New York, 7.5-Minute Series* , 1995.

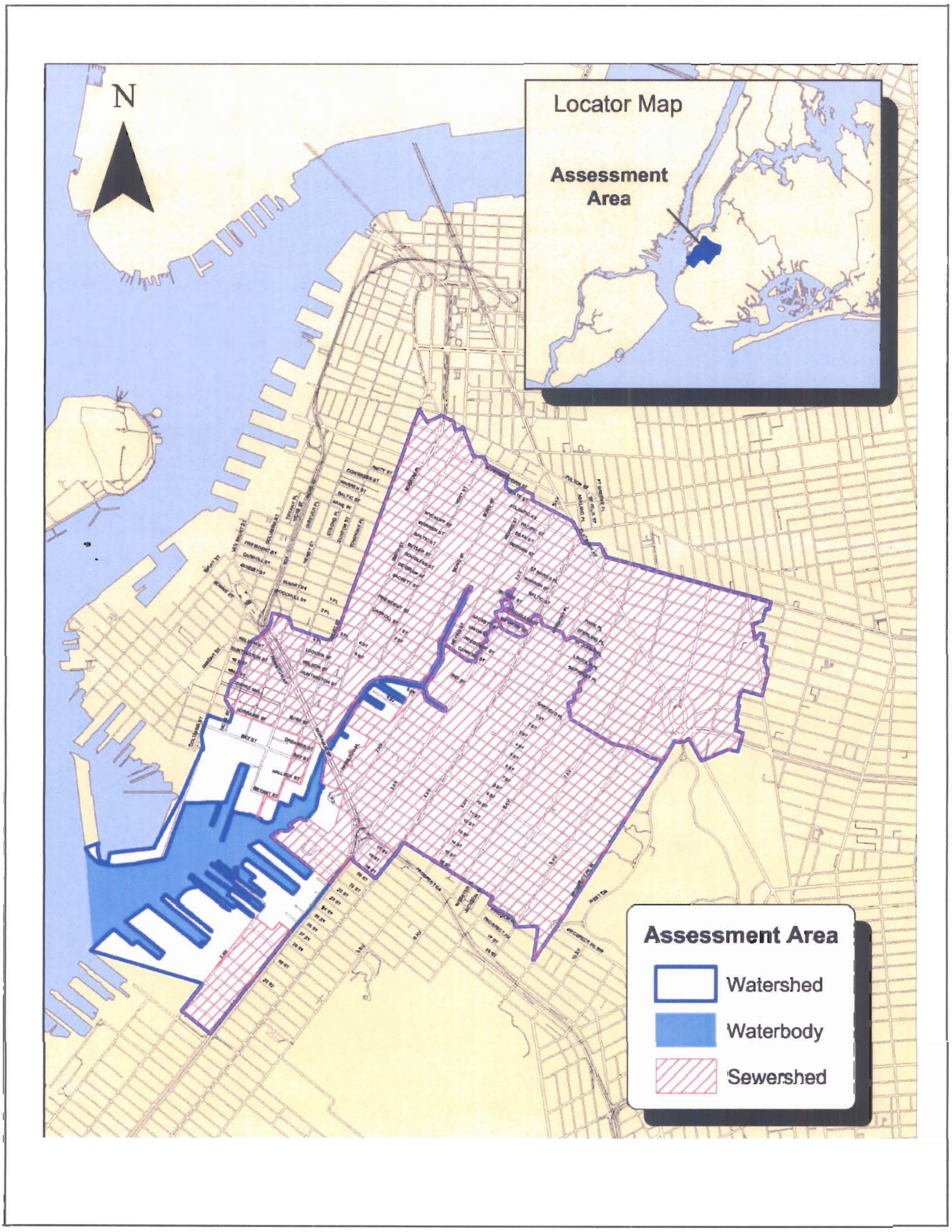


Figure 1-1
Gowanus Bay and Canal Ecosystem Restoration Study Area

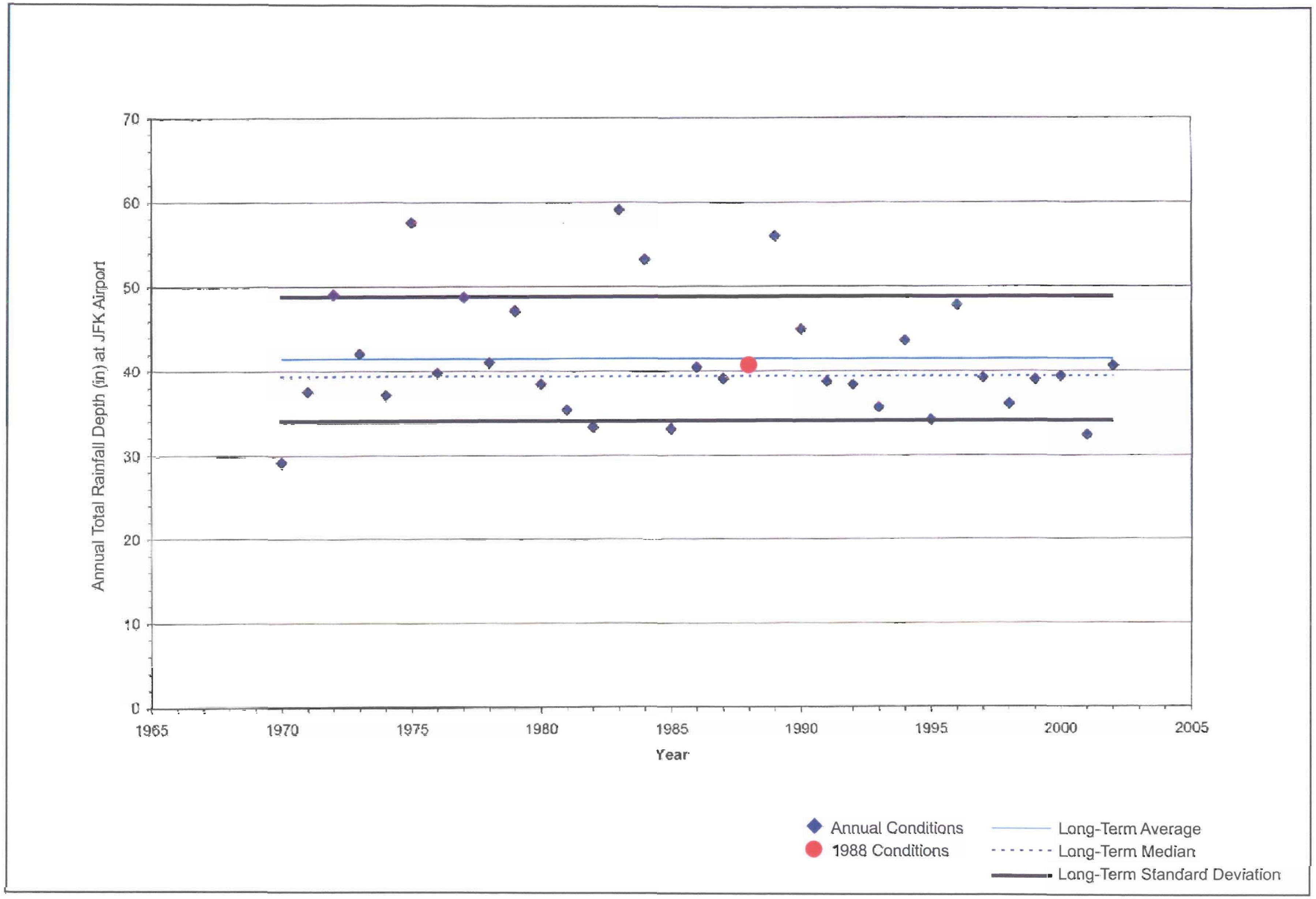


Figure 2-1
Annual Total Rainfall Depth Analysis for Long-Term JFK Record

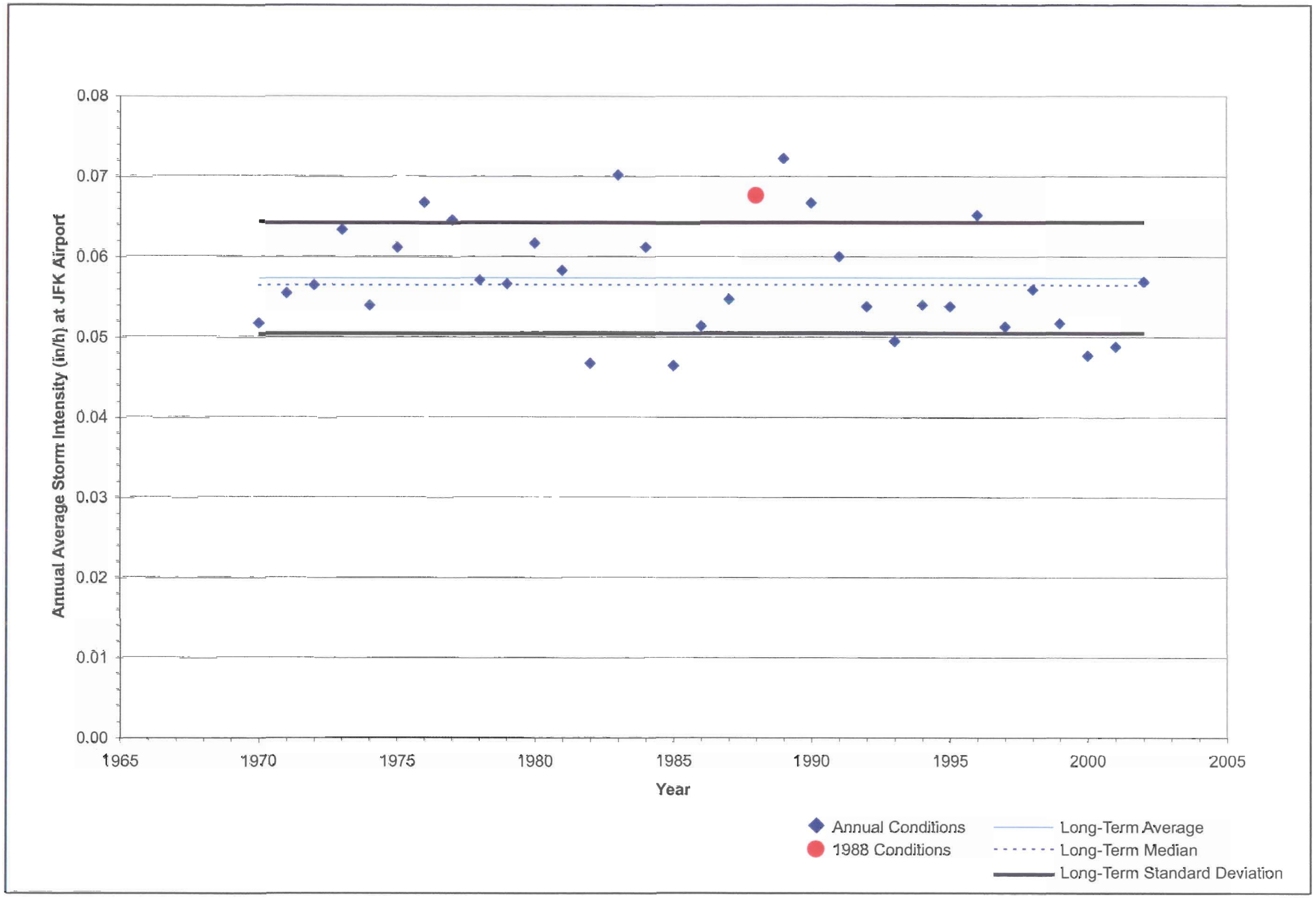


Figure 2-2
Annual Average Storm Intensity Analysis for Long Term JFK Record

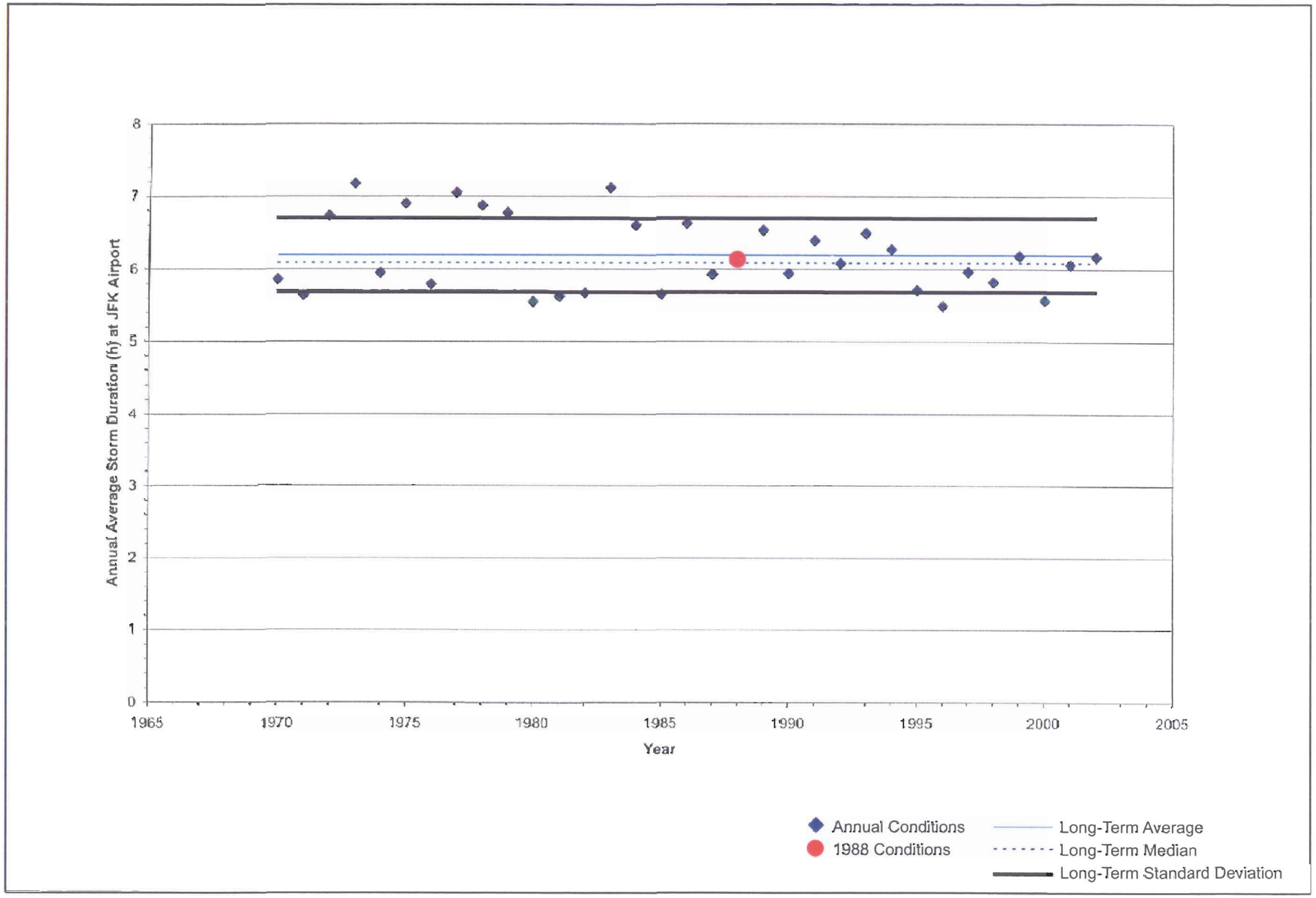


Figure 2-3
Annual Average Storm Duration Analysis for Long-Term JFK Record

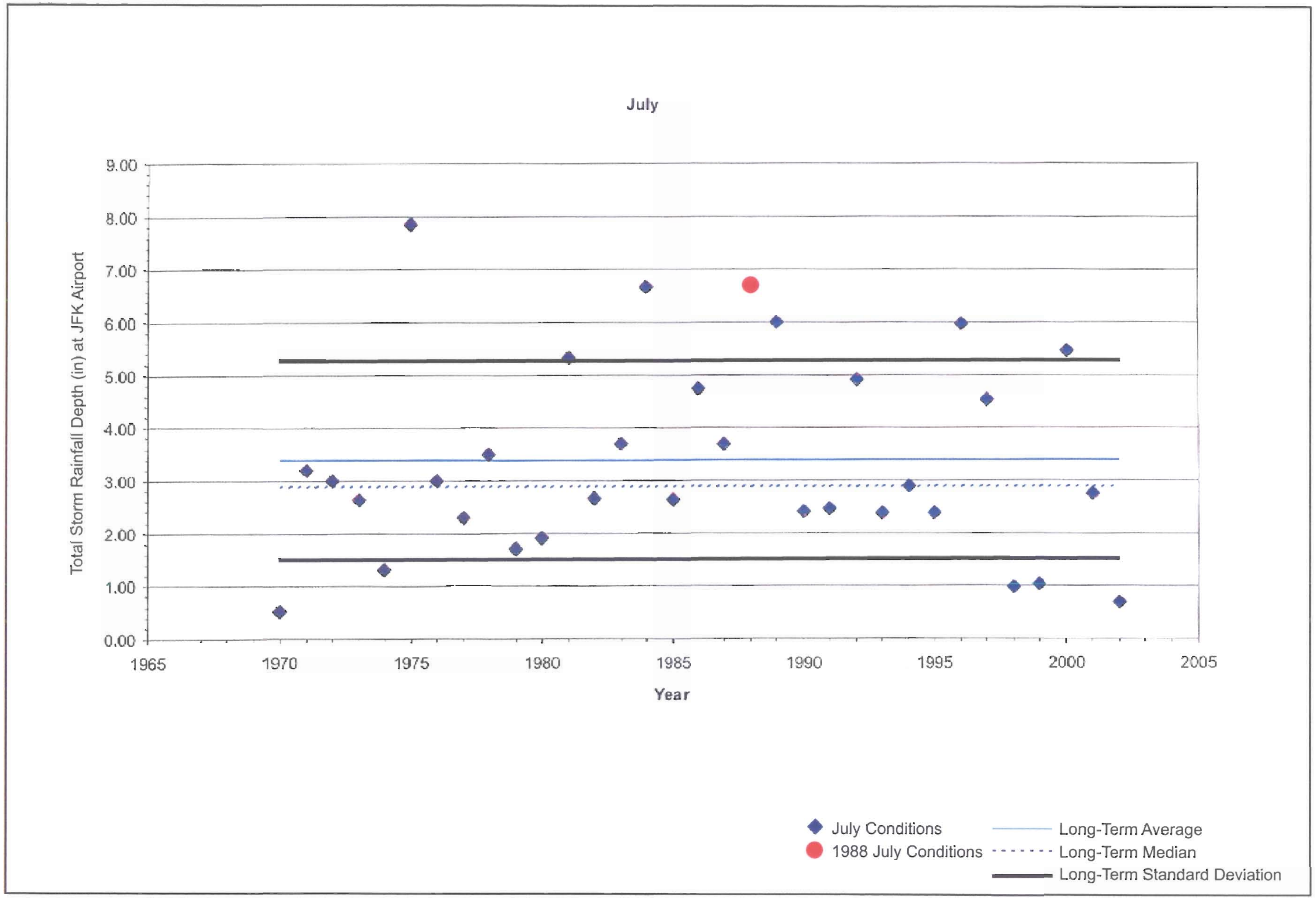


Figure 2-4
Total Storm Rainfall Depth Analysis for Long-Term JFK July Record

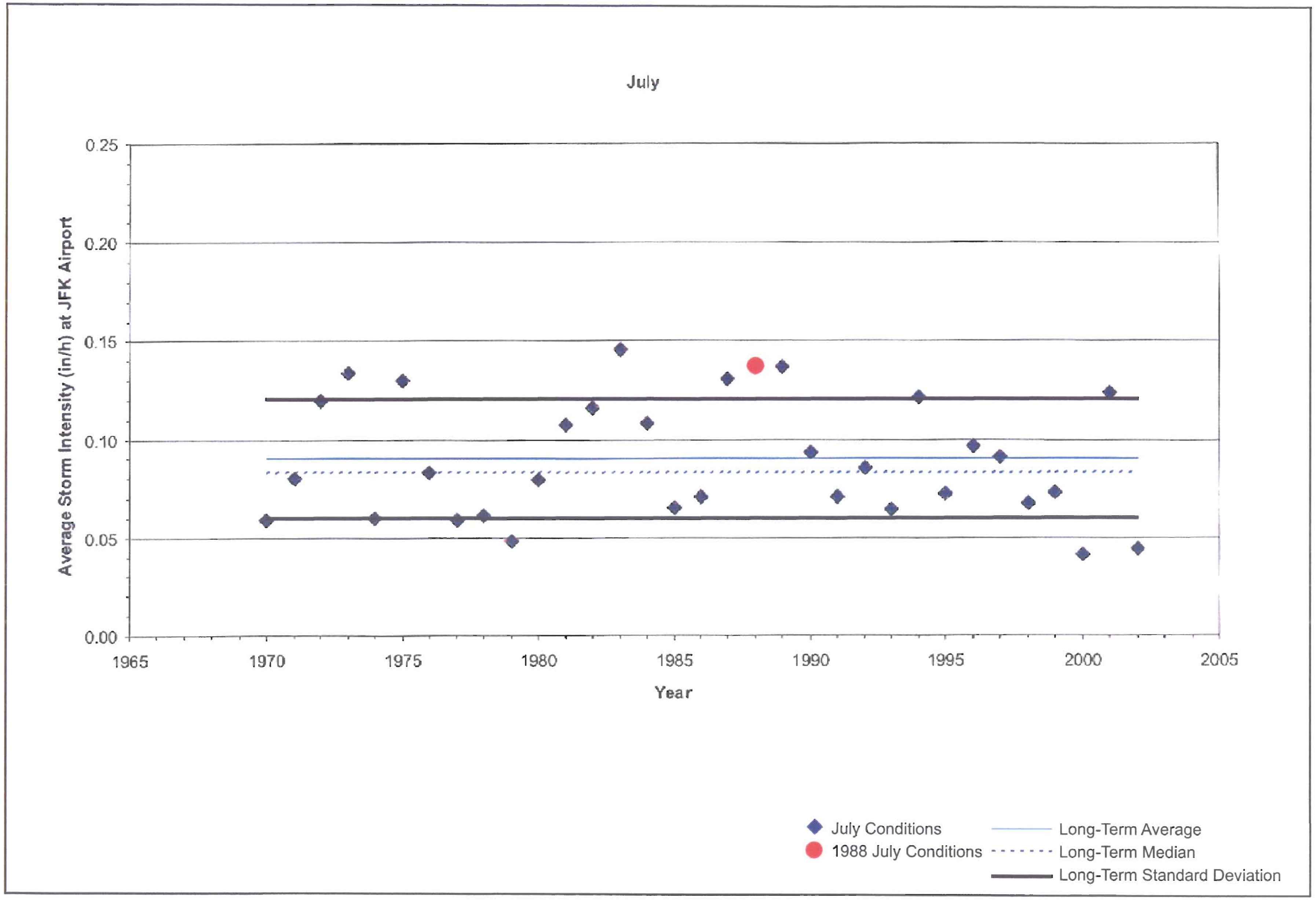


Figure 2-5
Average Storm Intensity Analysis for Long-Term JFK July Record

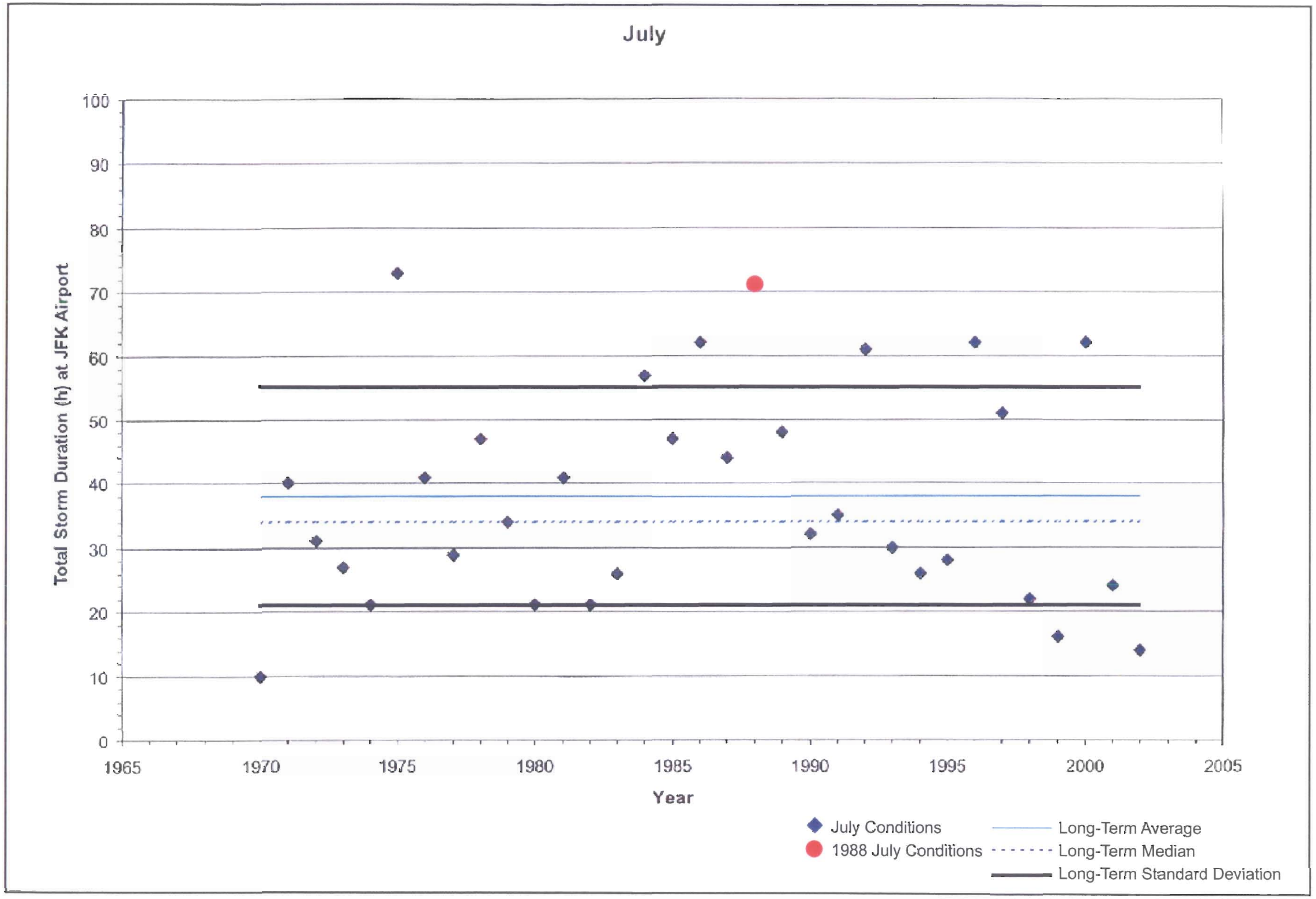


Figure 2-6
Total Storm Duration Analysis for Long-Term JFK July Record

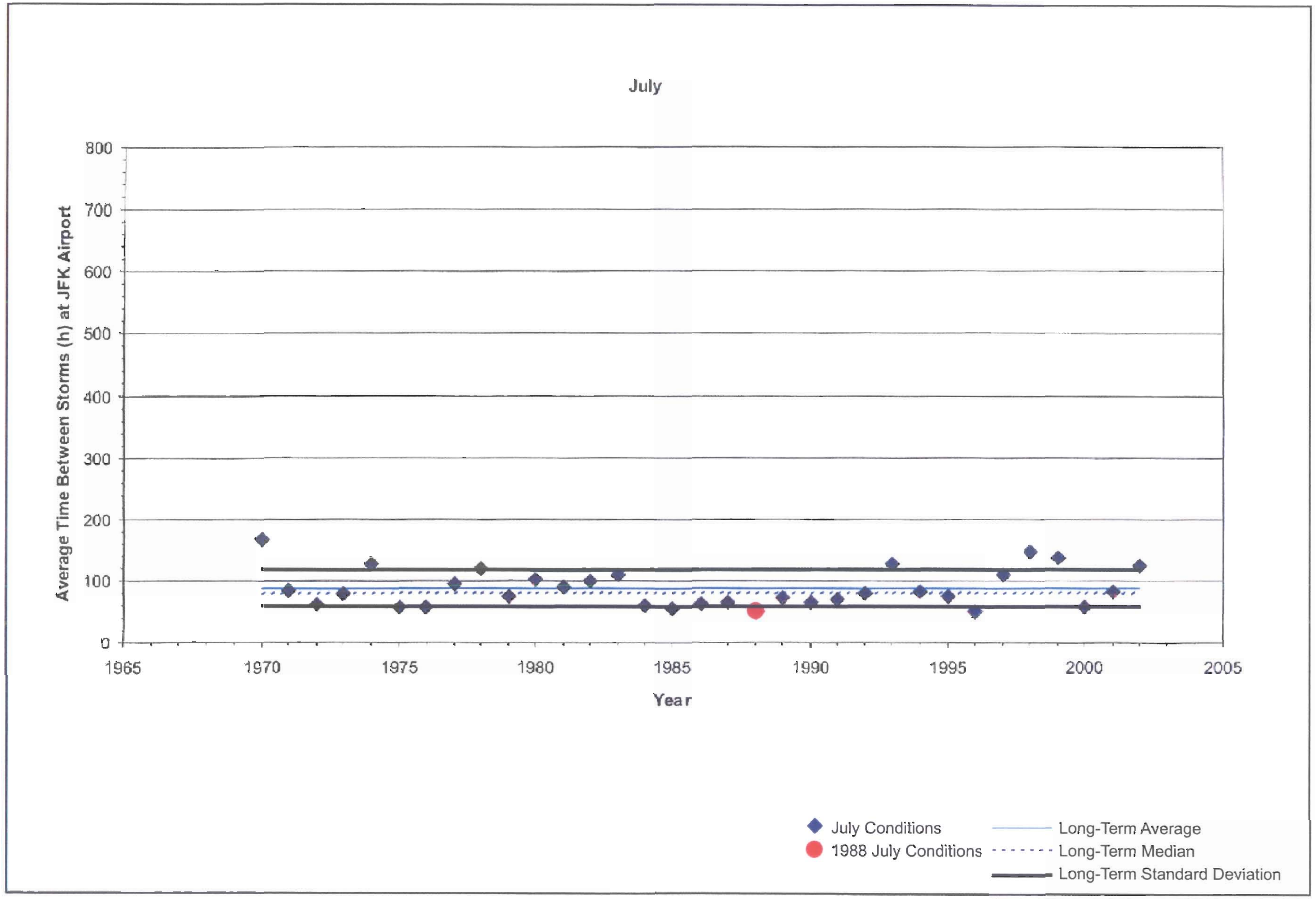
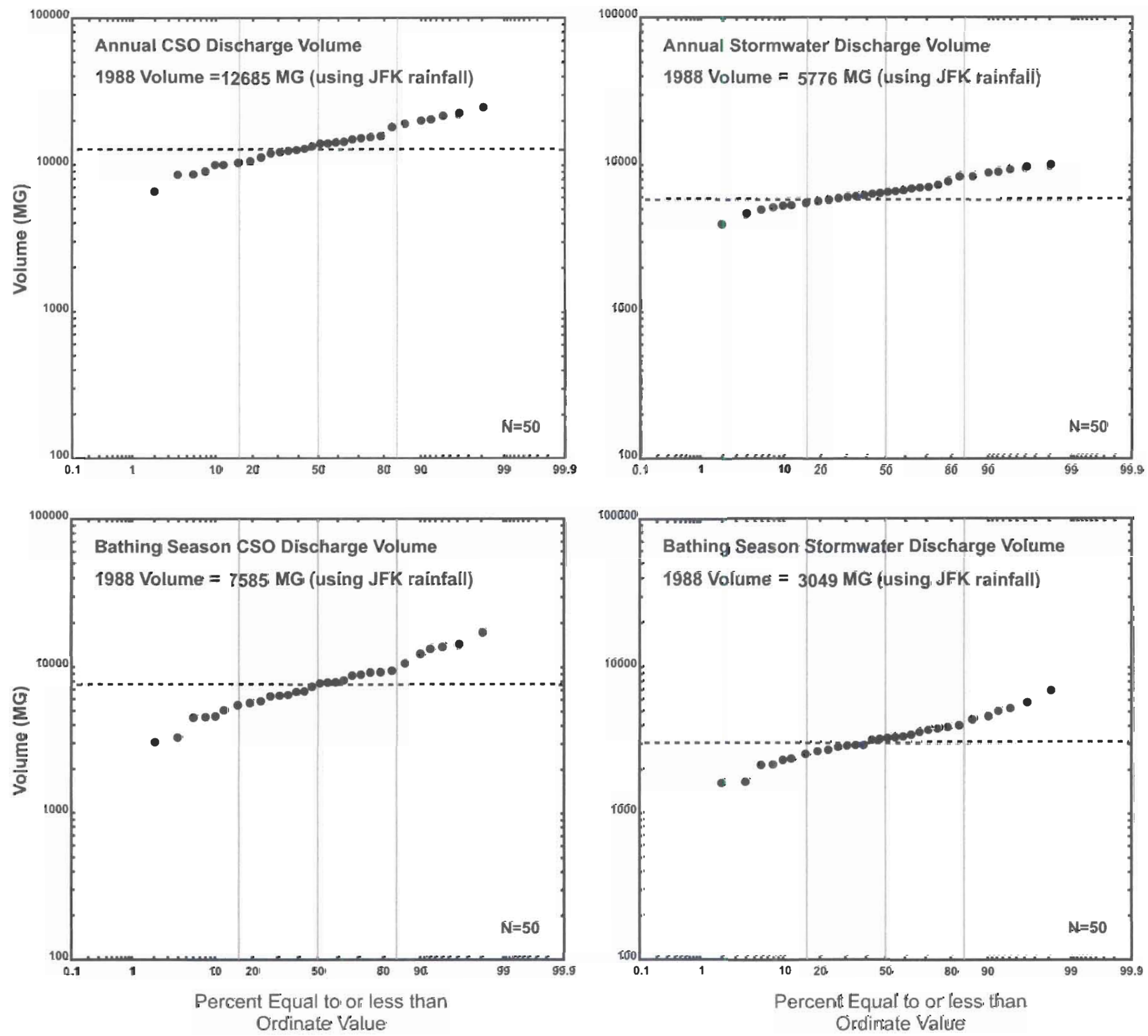


Figure 2-7
Average Time Between Storms Analysis for Long-Term JFK July Record



Note: Frequency = (1-percentile)$^{-1}$

Figure 2-8
Calculated Upper East River Annual and Seasonal CSO/Stormwater Discharges Using JFK Rainfall, 1970-2002

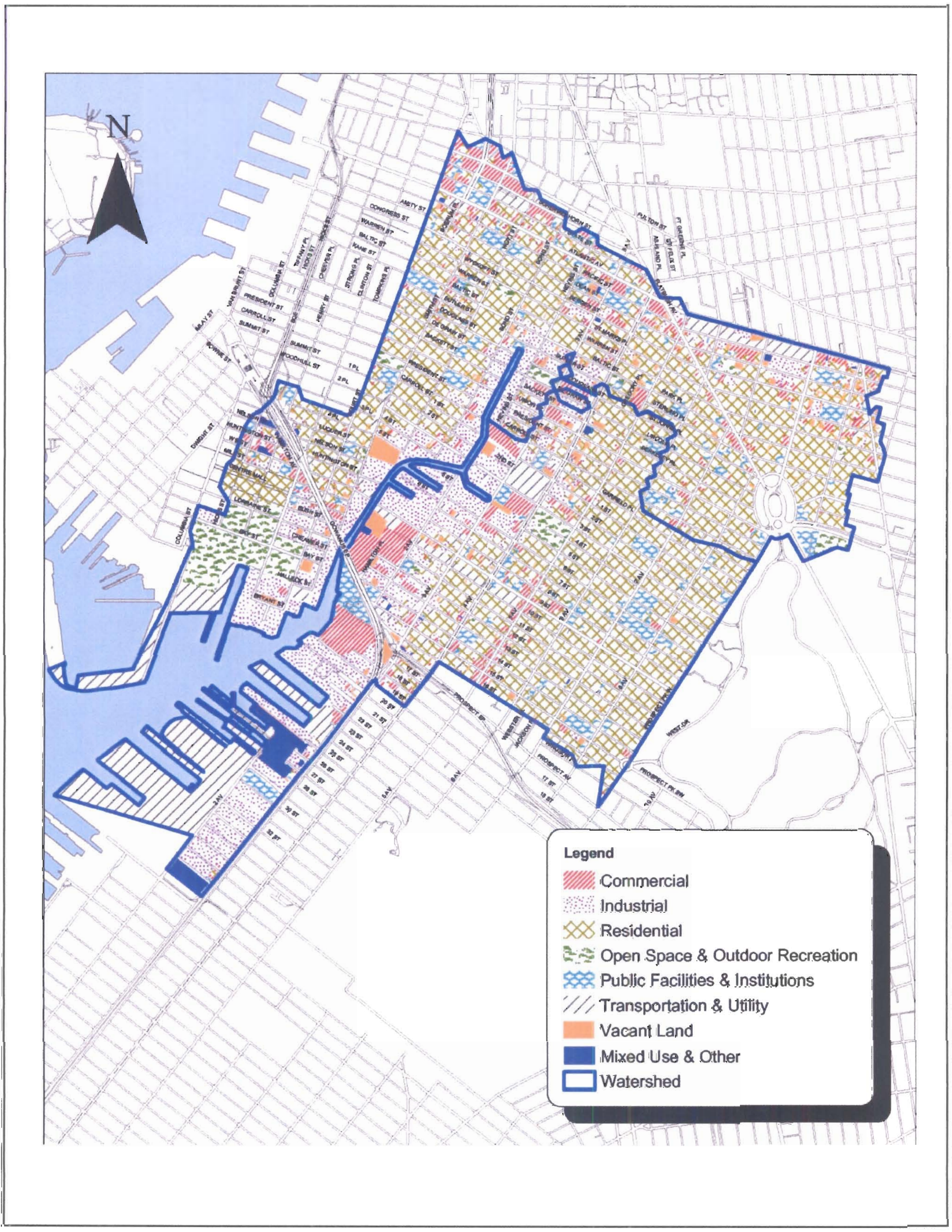


Figure 2-9
Land Uses in the Gowanus Bay and Canal Watershed

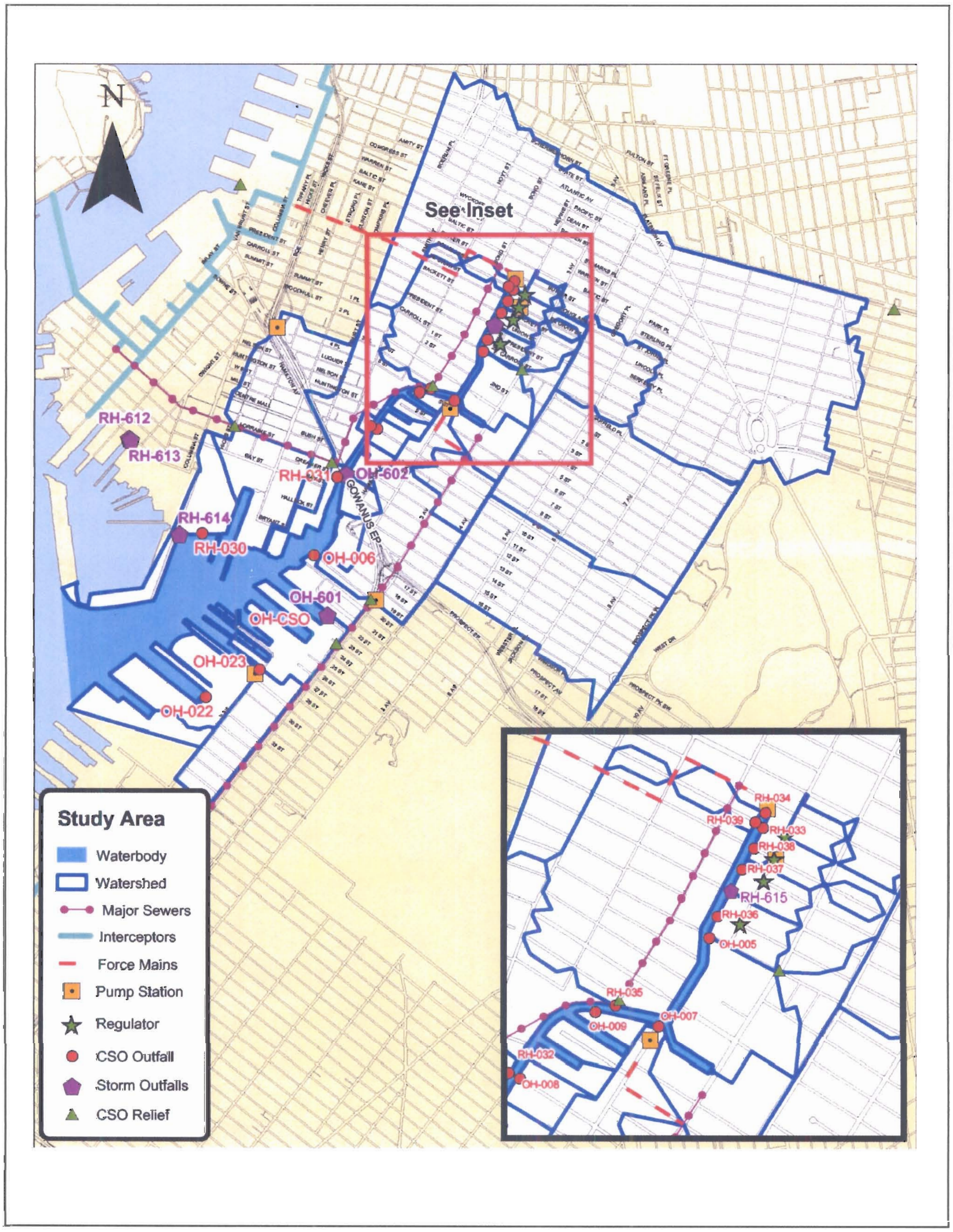


Figure 2-10
Major Sewer System Components Within Gowanus Watershed Area

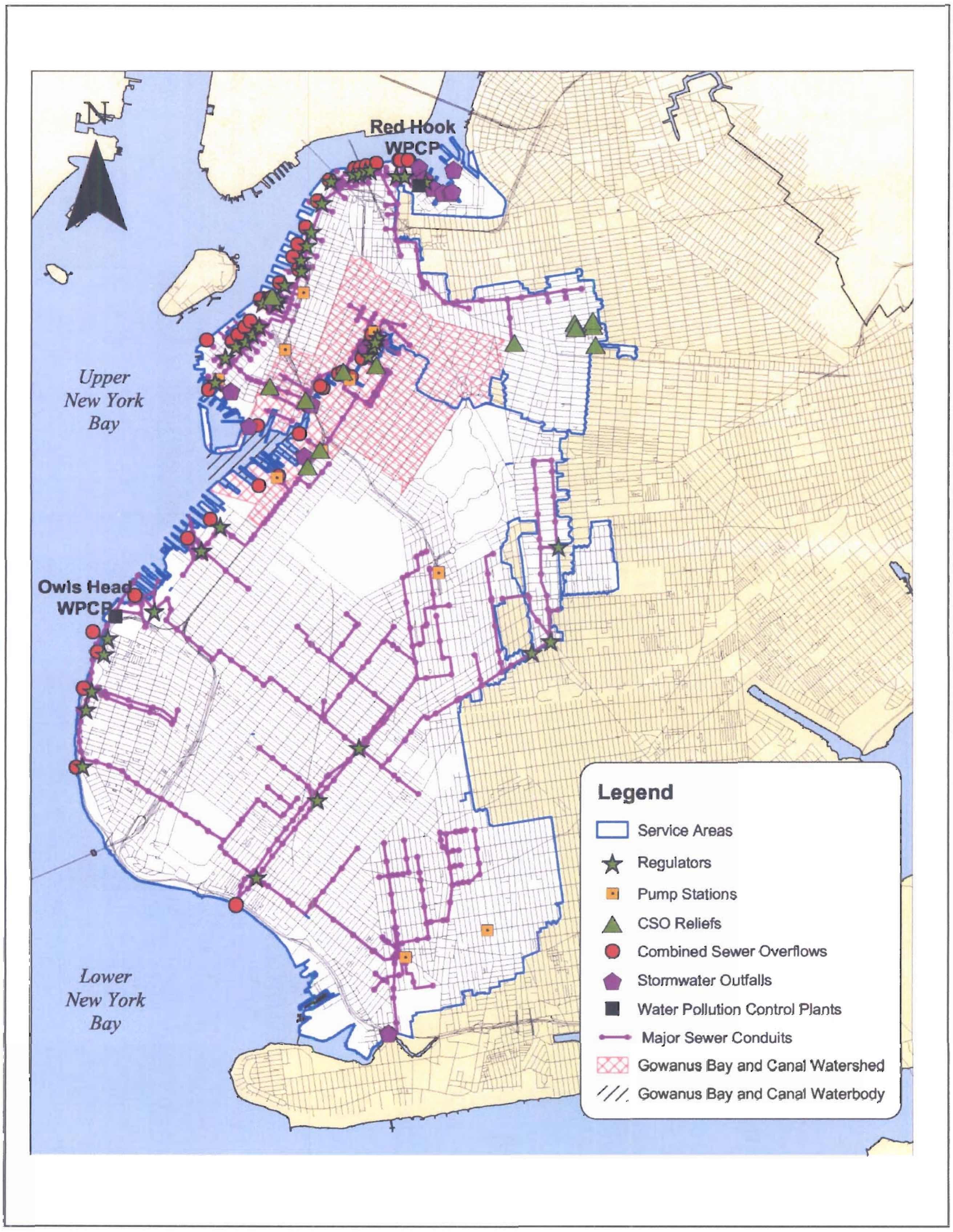


Figure 2-11
Major Sewer System Components of Red Hook and Owls Head Watershed Models

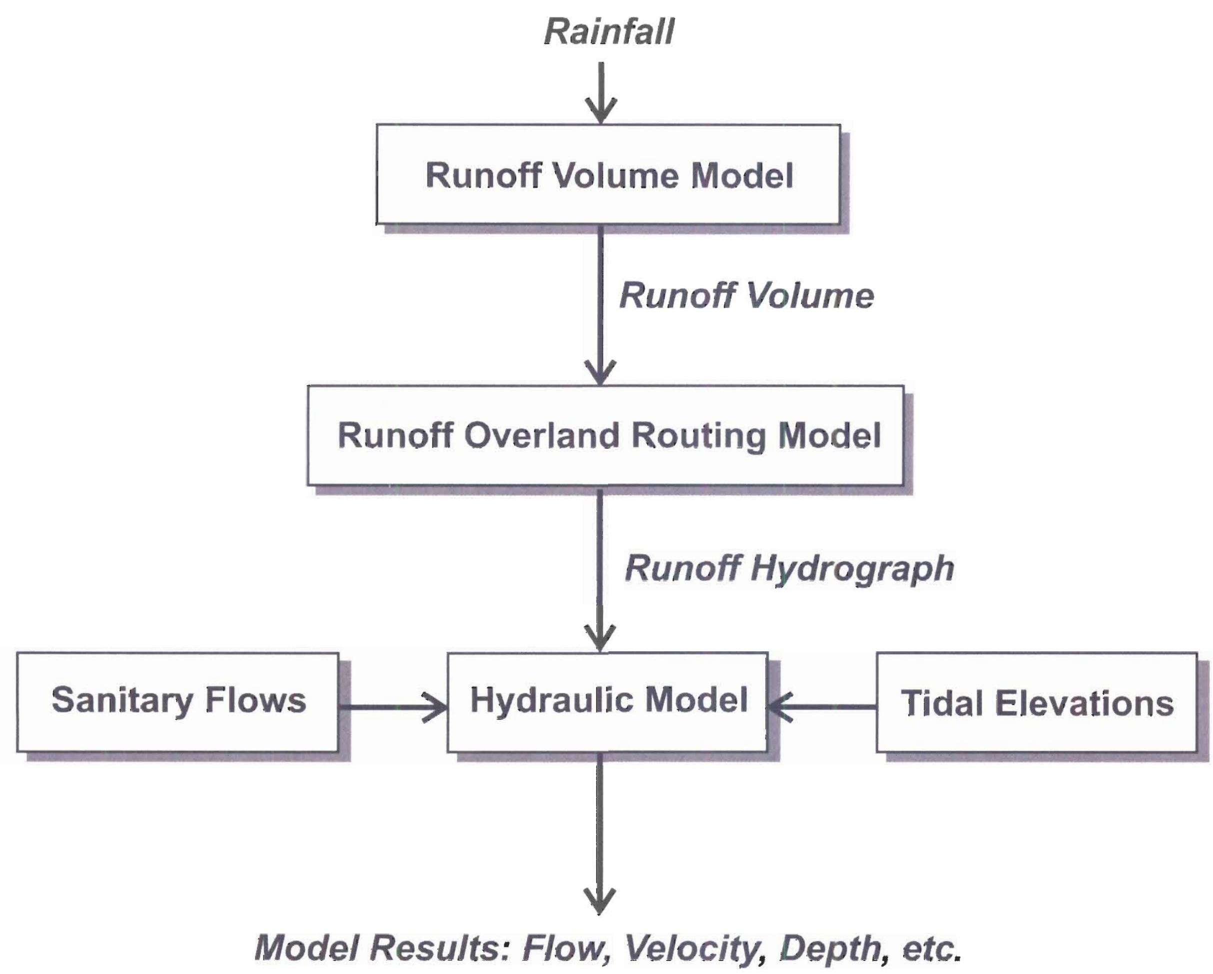


Figure 2-12
Watershed Modeling Schematic

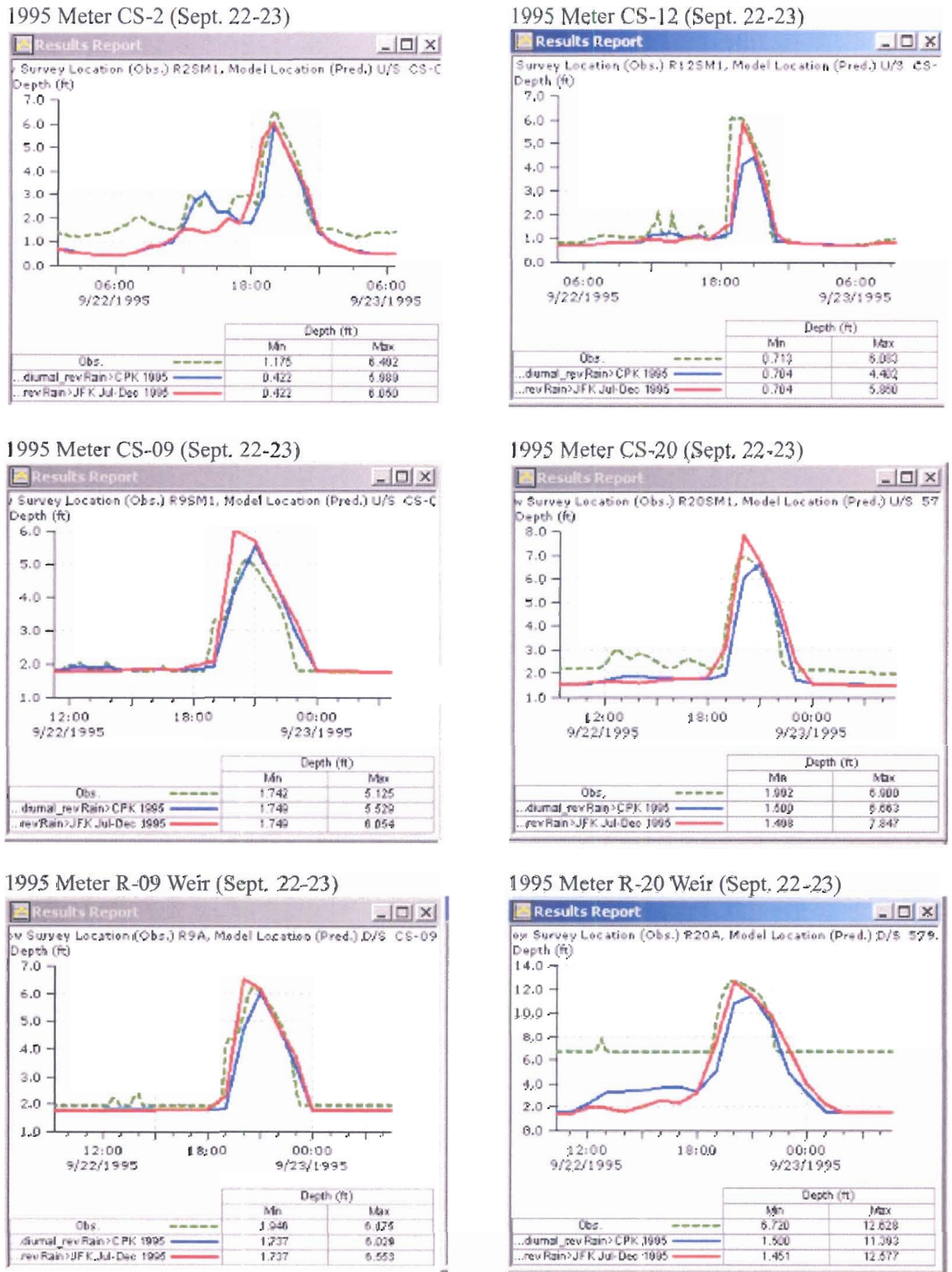
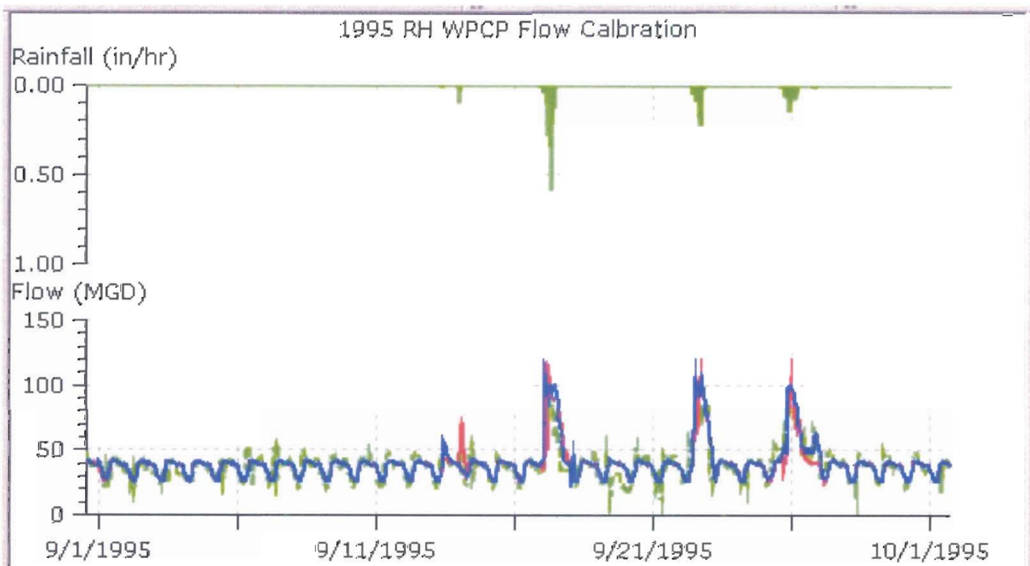


Figure 2-13
Red Hook Watershed Model Calibration (September 22-23, 1995)



	Rainfall			Flow (MGD)		
	Depth (in)	Peak (in/hr)	Average (in/hr)	Min	Max	Volume (US Mgal)
Rain	3.410	0.590	0.005			
Obs.				10.300	90.900	1195.093
...PS>JFK.Jul-Dec 1995				25.565	107.924	1220.845
...J_26.2GPS>CPK 1995				25.547	107.783	1241.305

Figure 2-14
Red Hook Watershed Model Calibration (WPCP Inflow)

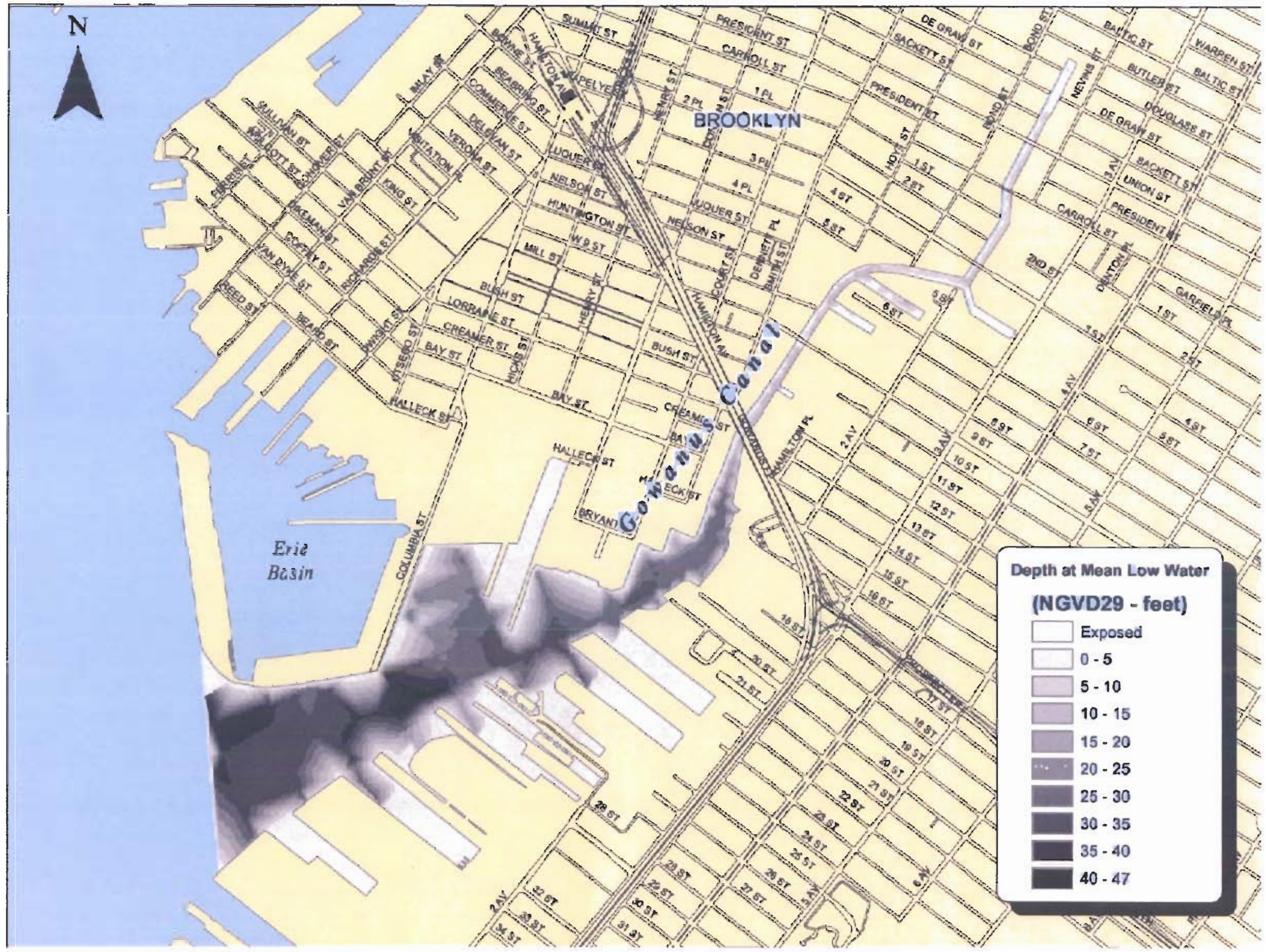


Figure 3-1A
Gowanus Bay and Canal Bathymetry in July 2003

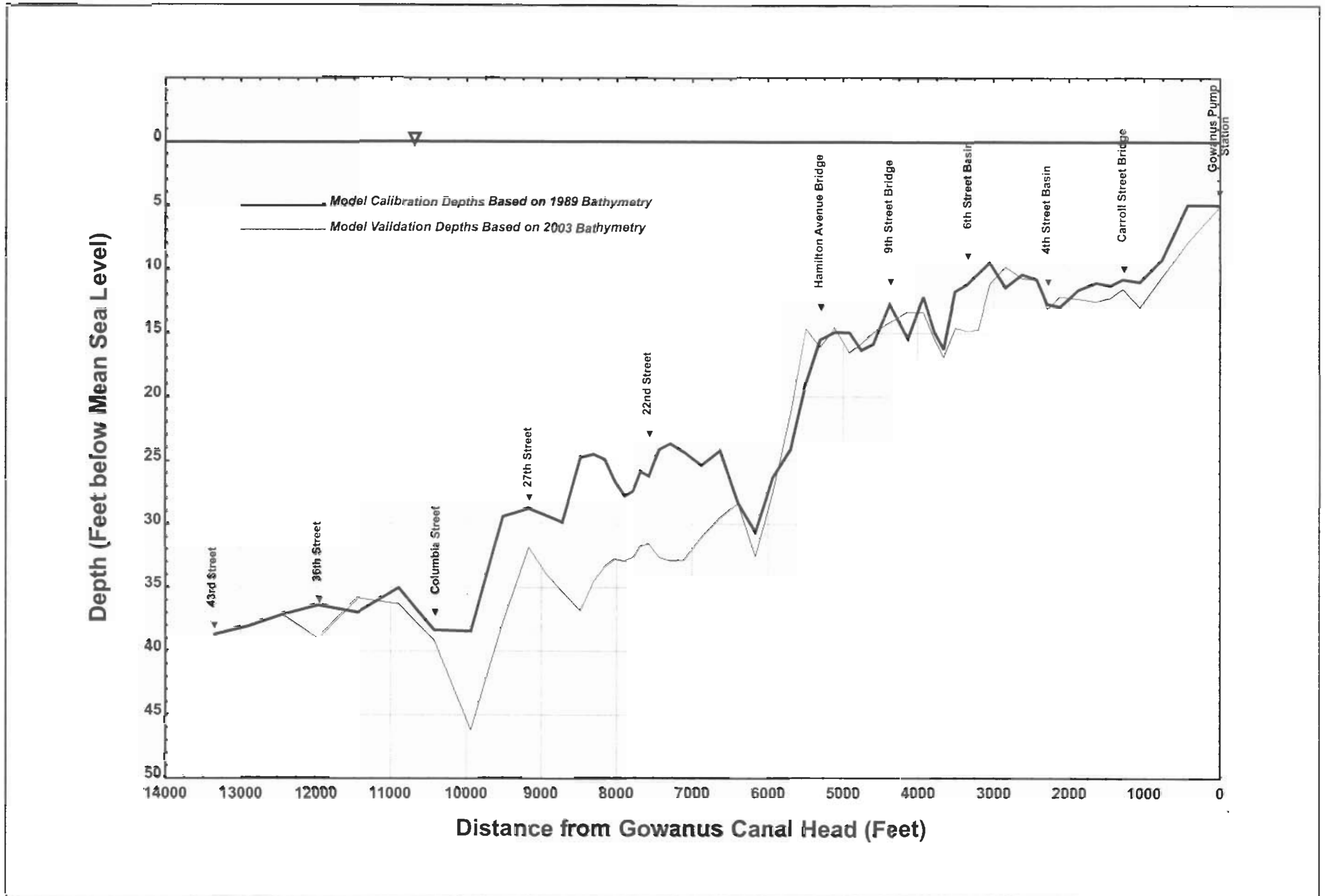


Figure 3-1B
Gowanus Bay and Canal Depth Profiles

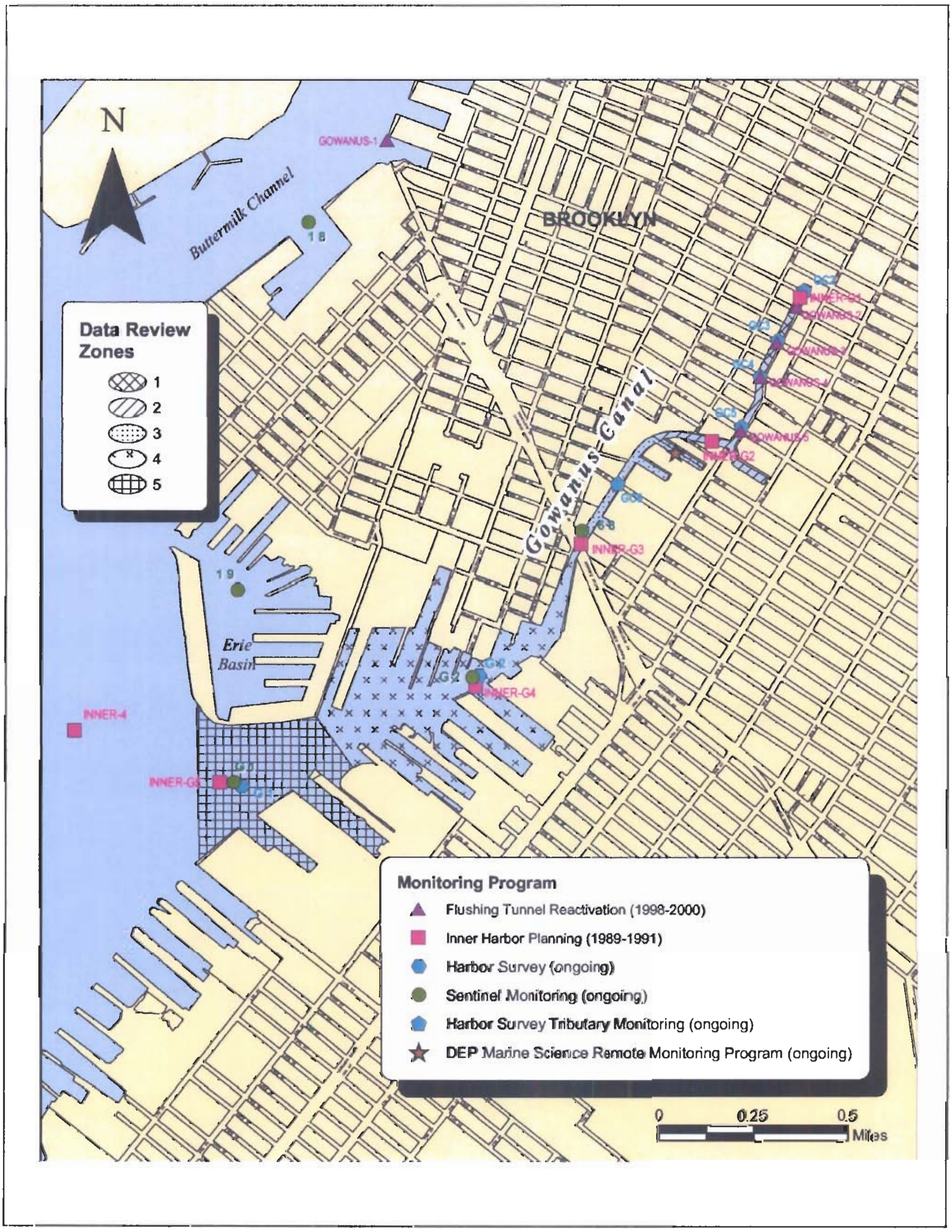


Figure 3-2
Receiving Water Monitoring Locations in Gownaus Bay and Canal

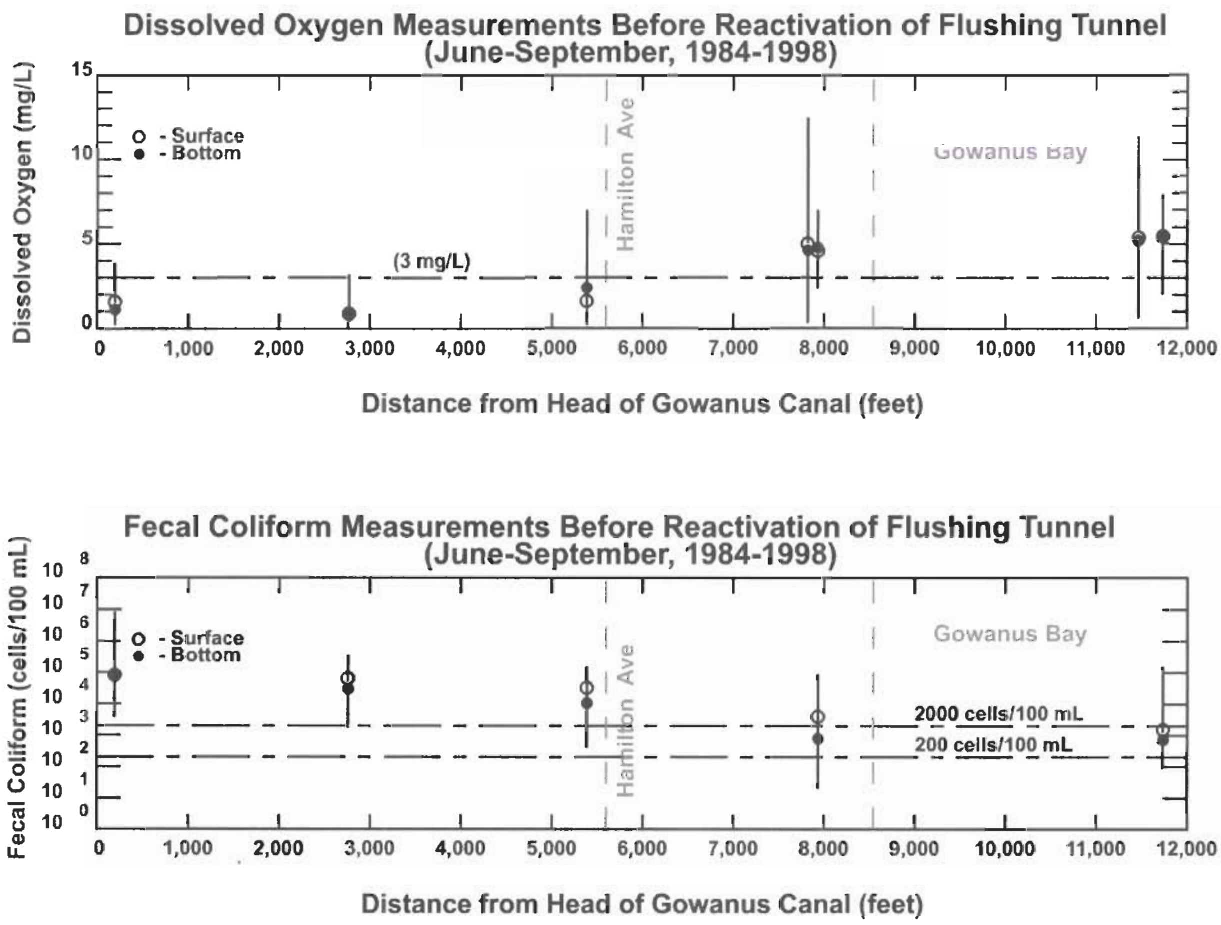


Figure 3-3
Gowanus Bay and Canal Conditions Before the Reactivation
of Gowanus Canal Flushing Tunnel

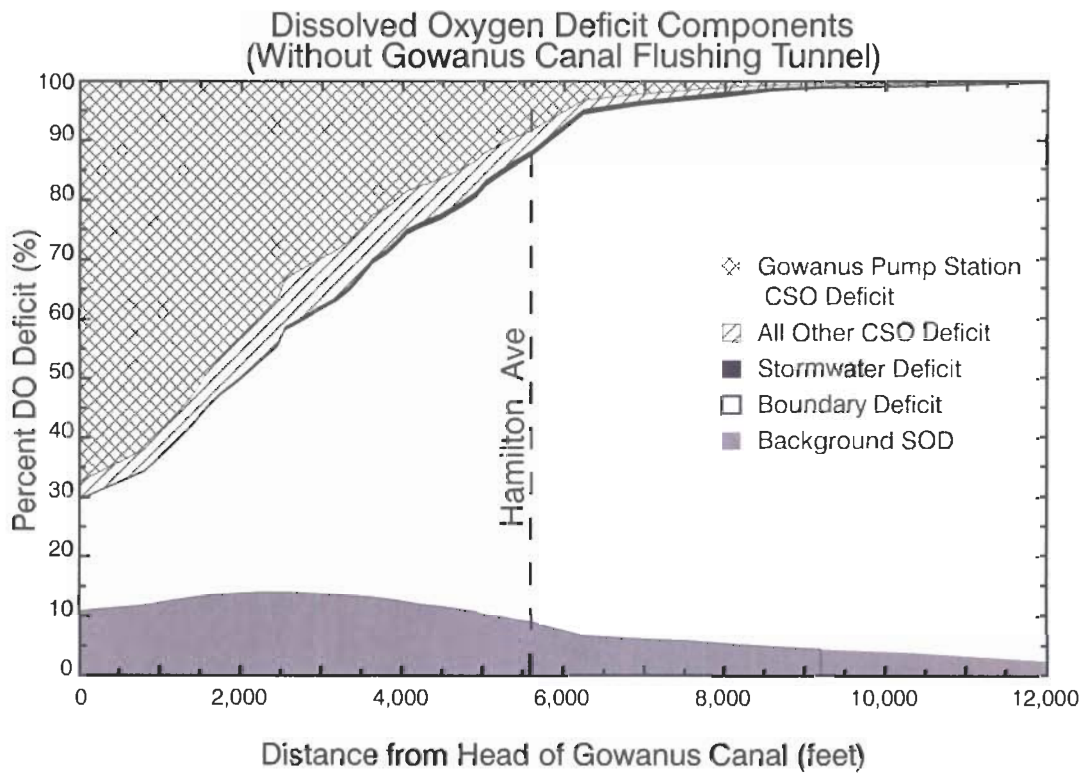


Figure 3-4
Dissolved Oxygen Deficit Components Before
Reactivation of Gowanus Canal Flushing Tunnel

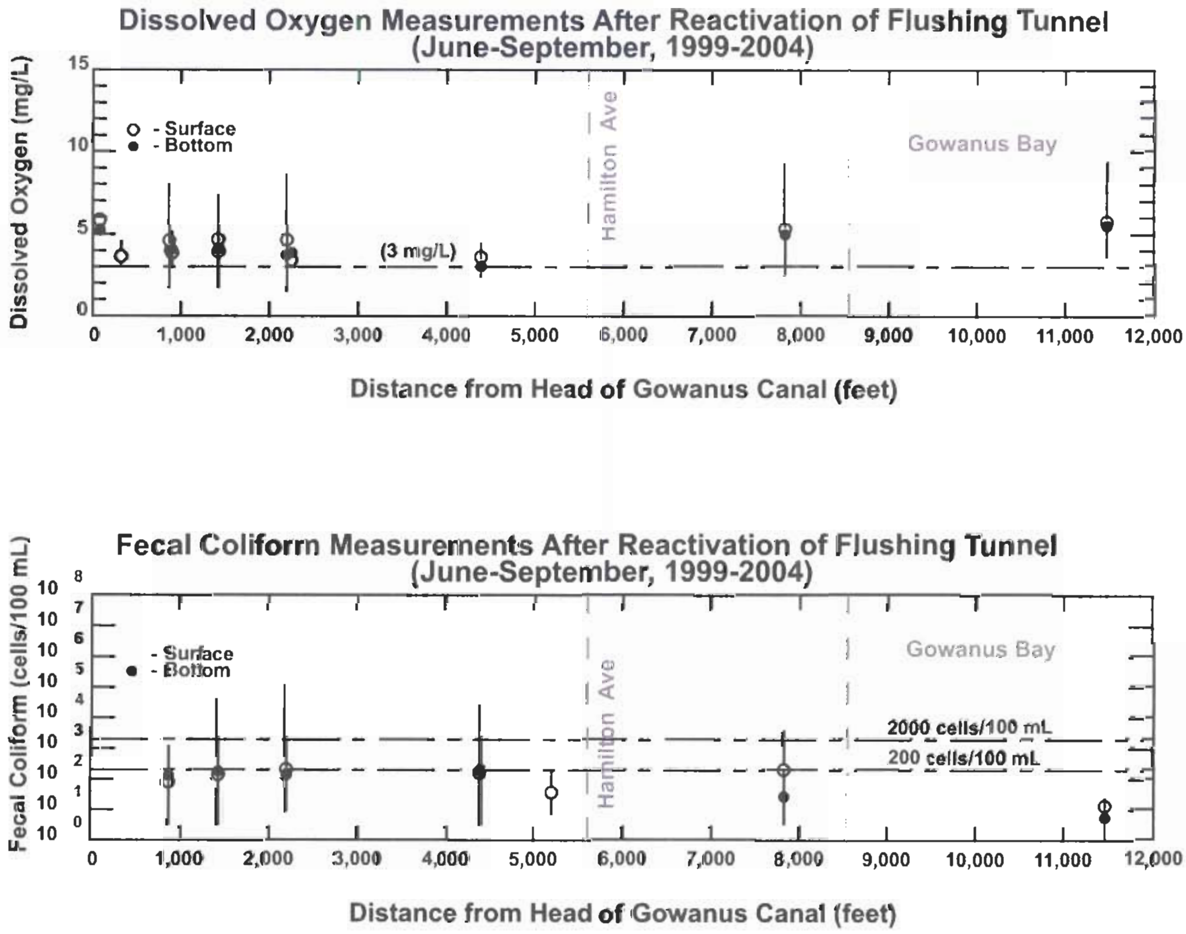


Figure 3-5
Gowanus Bay and Canal Conditions After the
Reactivation of Gownaus Canal Flushing Tunnel

Figure 3-6
Gowanus Bay and Canal Receiving Water Model Segmentation

Figure 3-7
Gowanus Bay and Canal Data Sampling Stations Used for Hydrodynamic Analysis

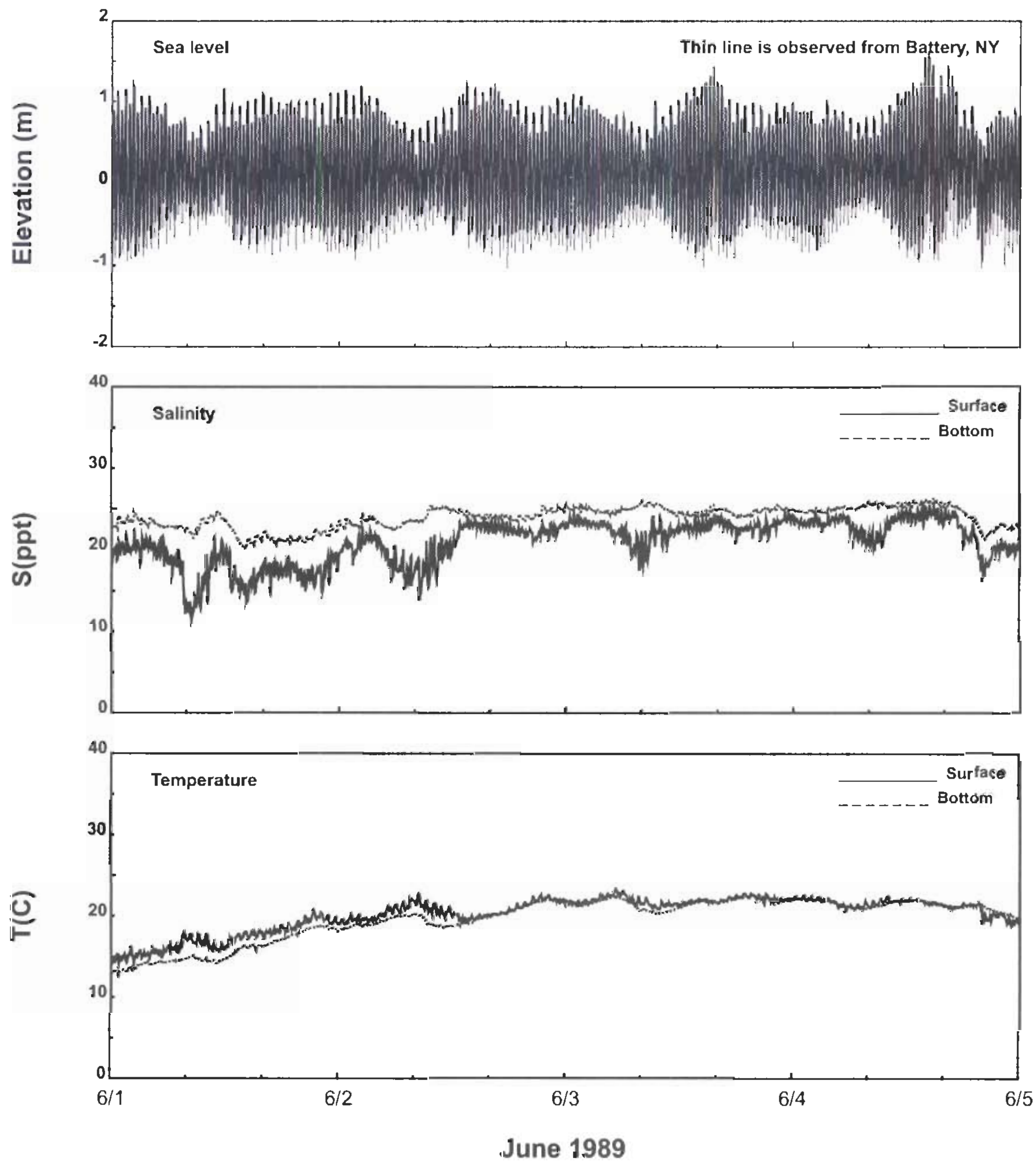


Figure 3-8
Boundaries for Gowanus Bay and Canal Hydrodynamic Calibration

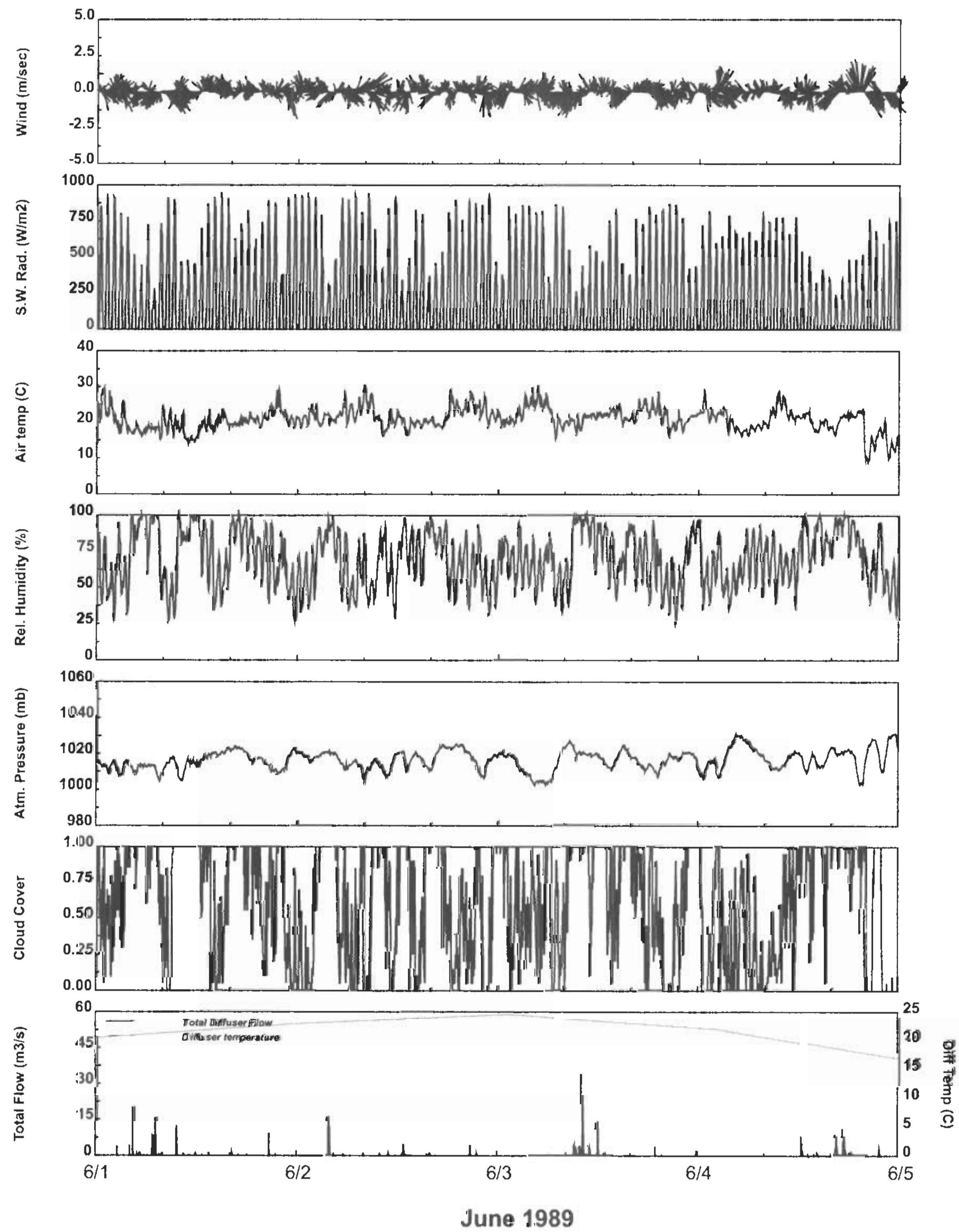


Figure 3-9
Meteorological Conditions for Gowanus Bay and Canal Hydrodynamic Calibration

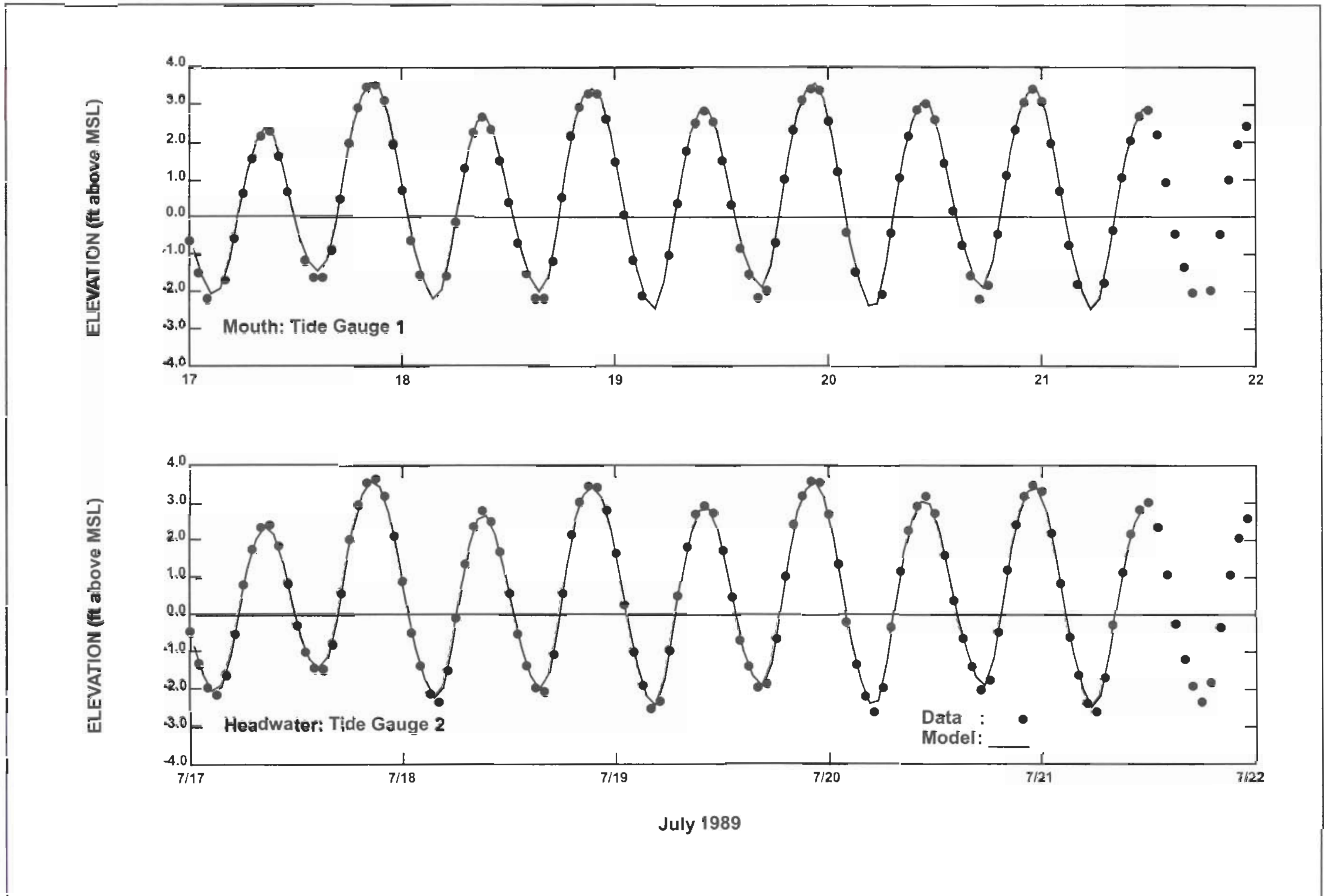


Figure 3-10
Gowanus Bay and Canal Tidal Elevation Calibration

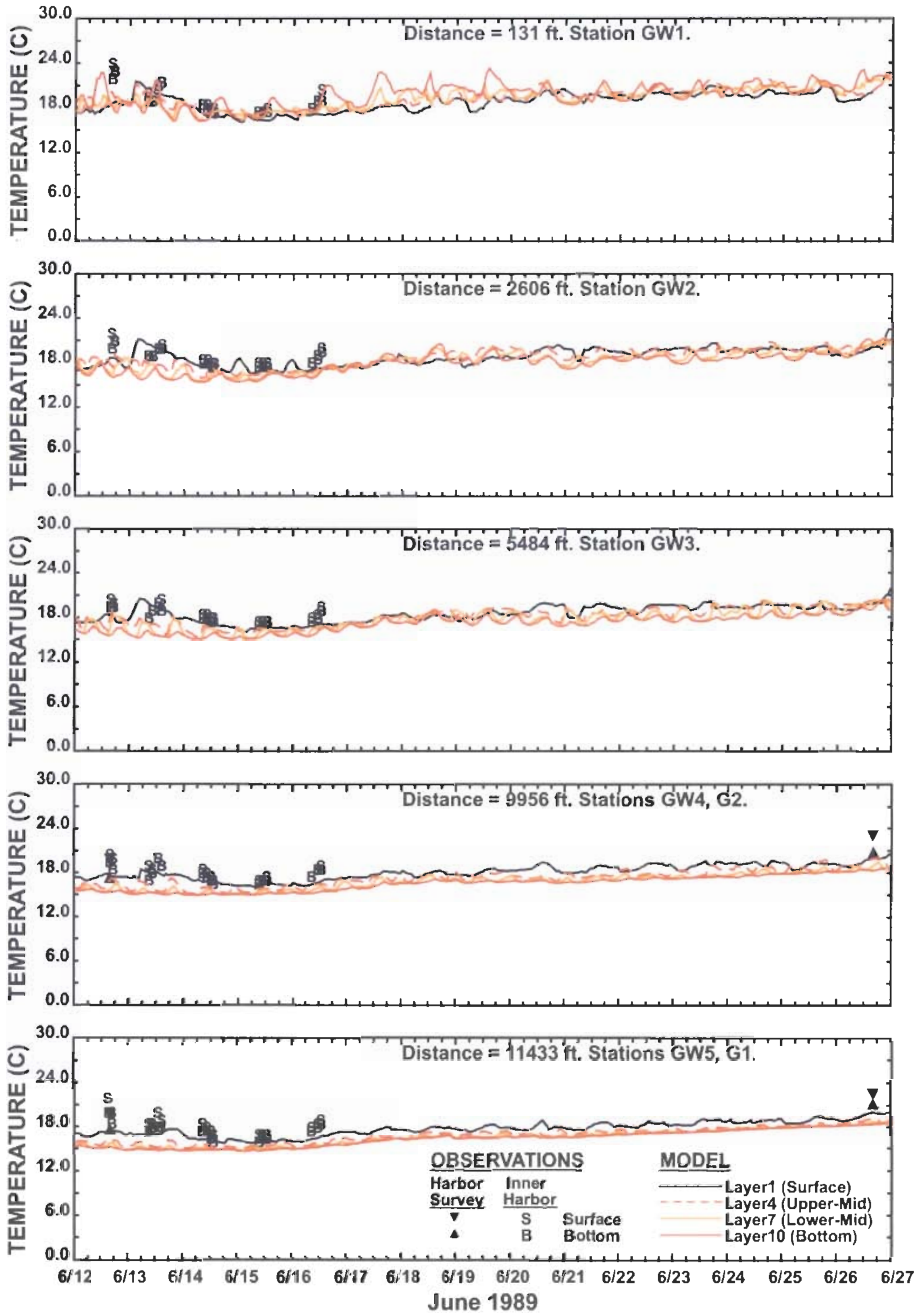


Figure 3-11
Gowanus Bay and Canal Temperature Calibration
June 12-26, 1989

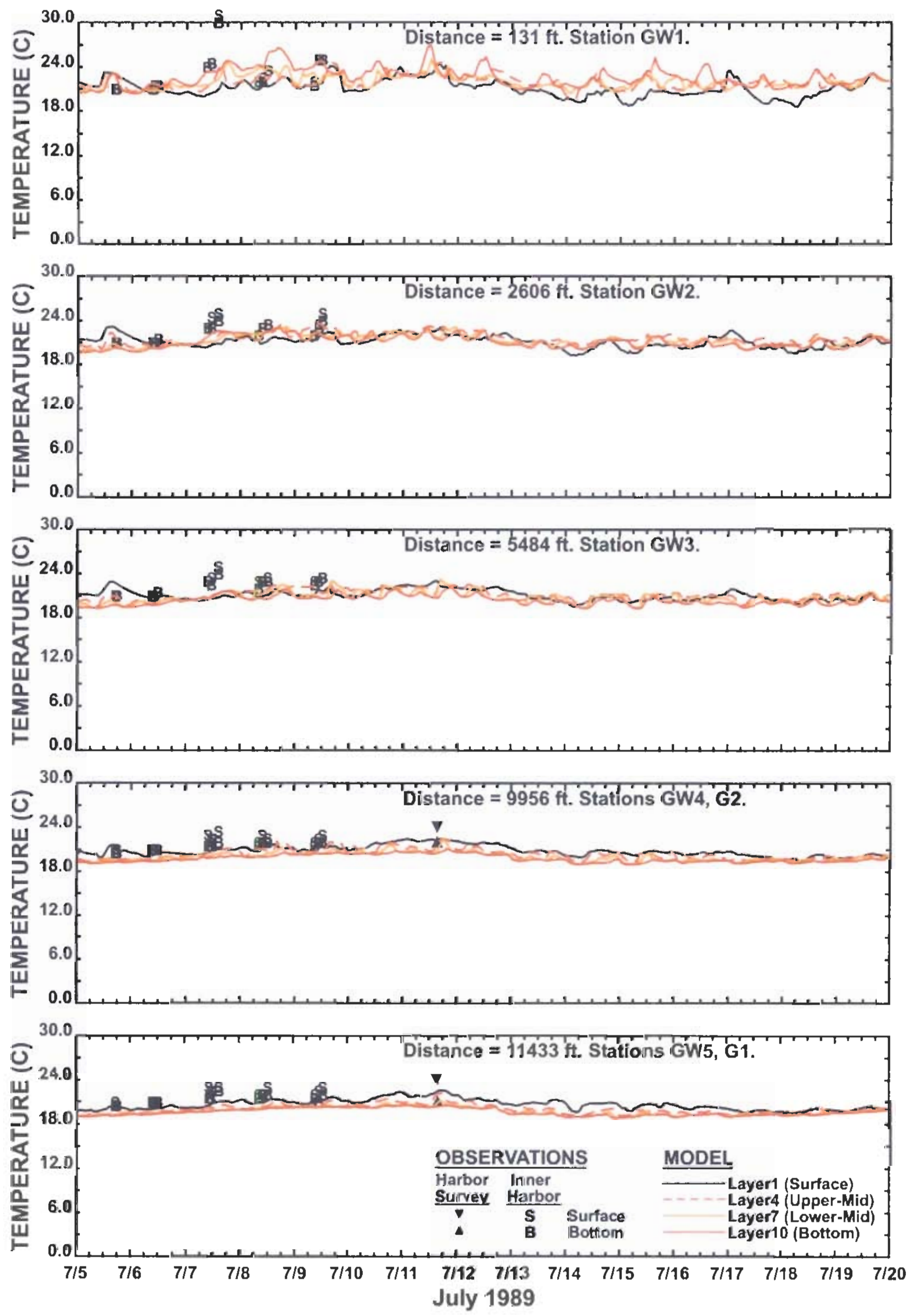


Figure 3-12
Gowanus Bay and Canal Temperature Calibration
July 5-19, 1989

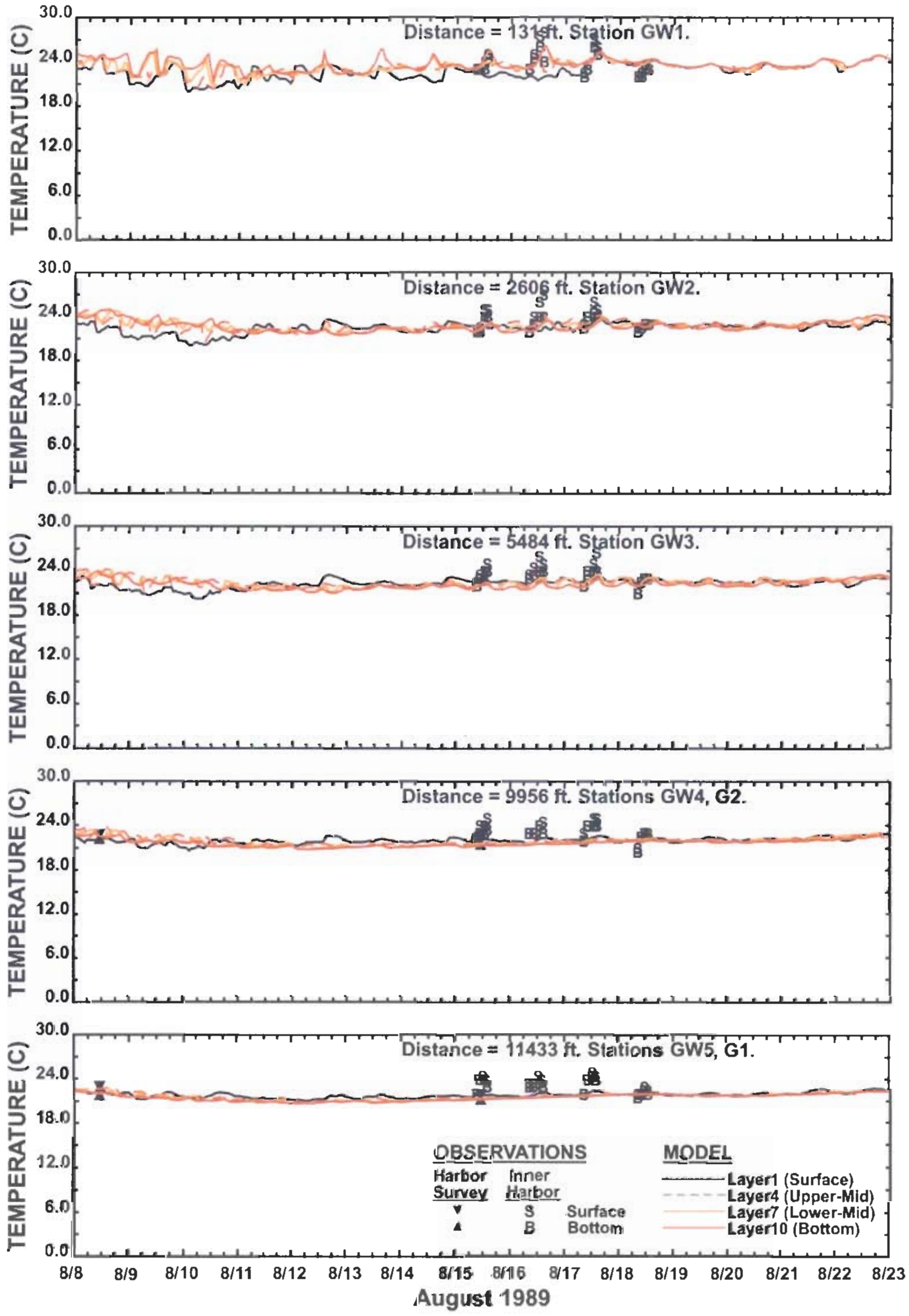


Figure 3-13
Gowanus Bay and Canal Temperature Calibration
August 8-22, 1989

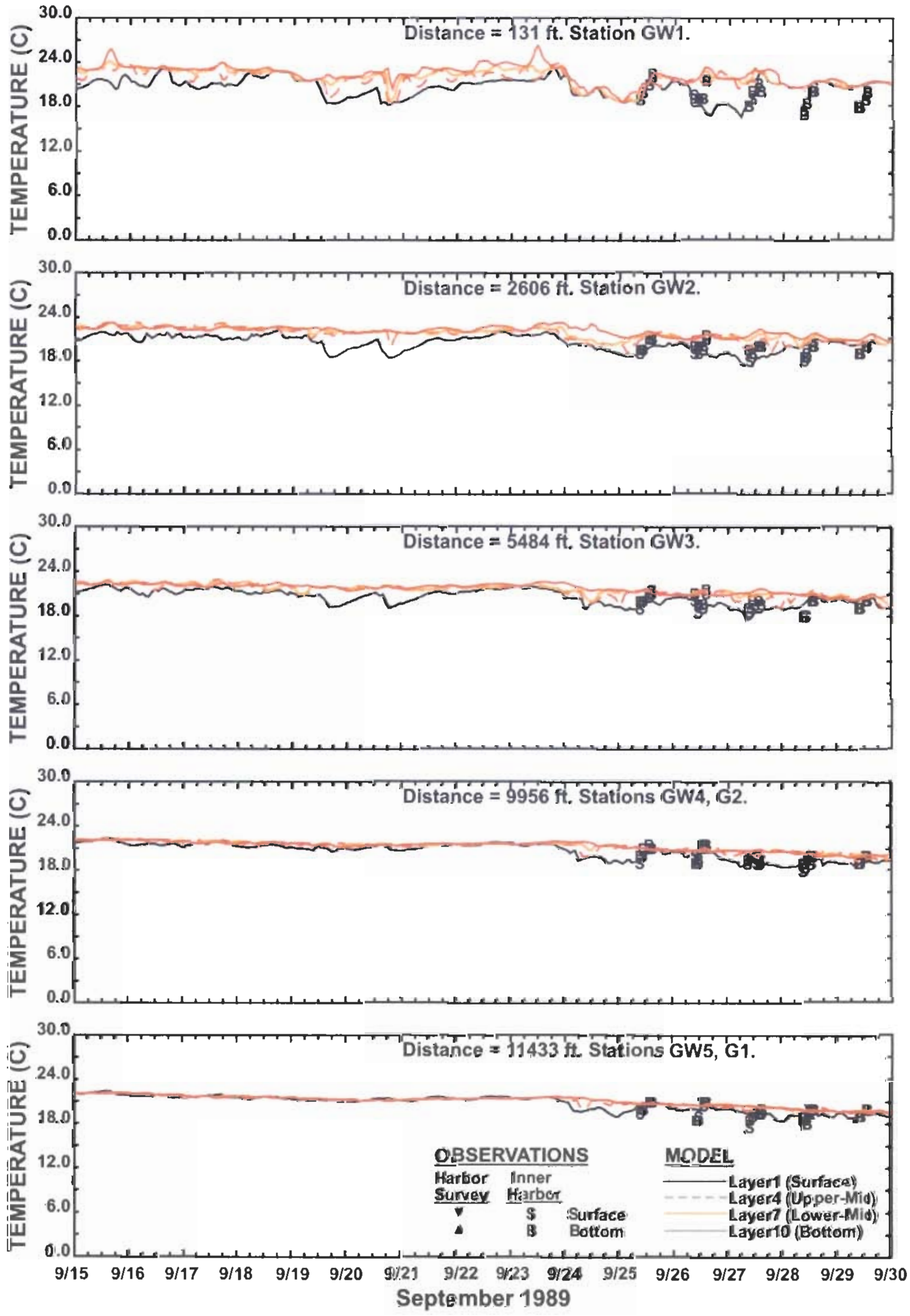


Figure 3-14
Gowanus Bay and Canal Temperature Calibration
September 15-29, 1989

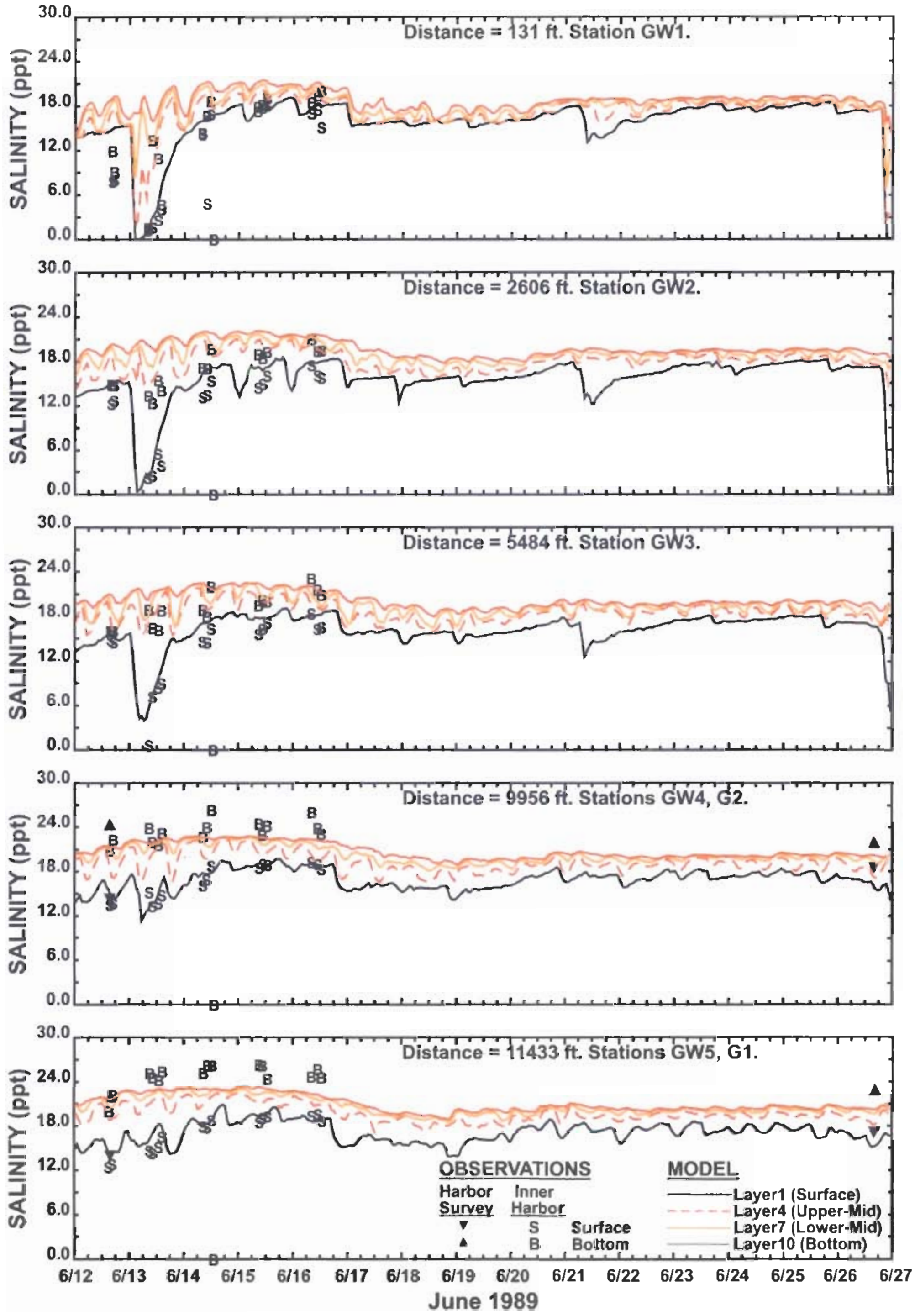


Figure 3-15
Gowanus Bay and Canal Salinity Calibration
June 12-26, 1989

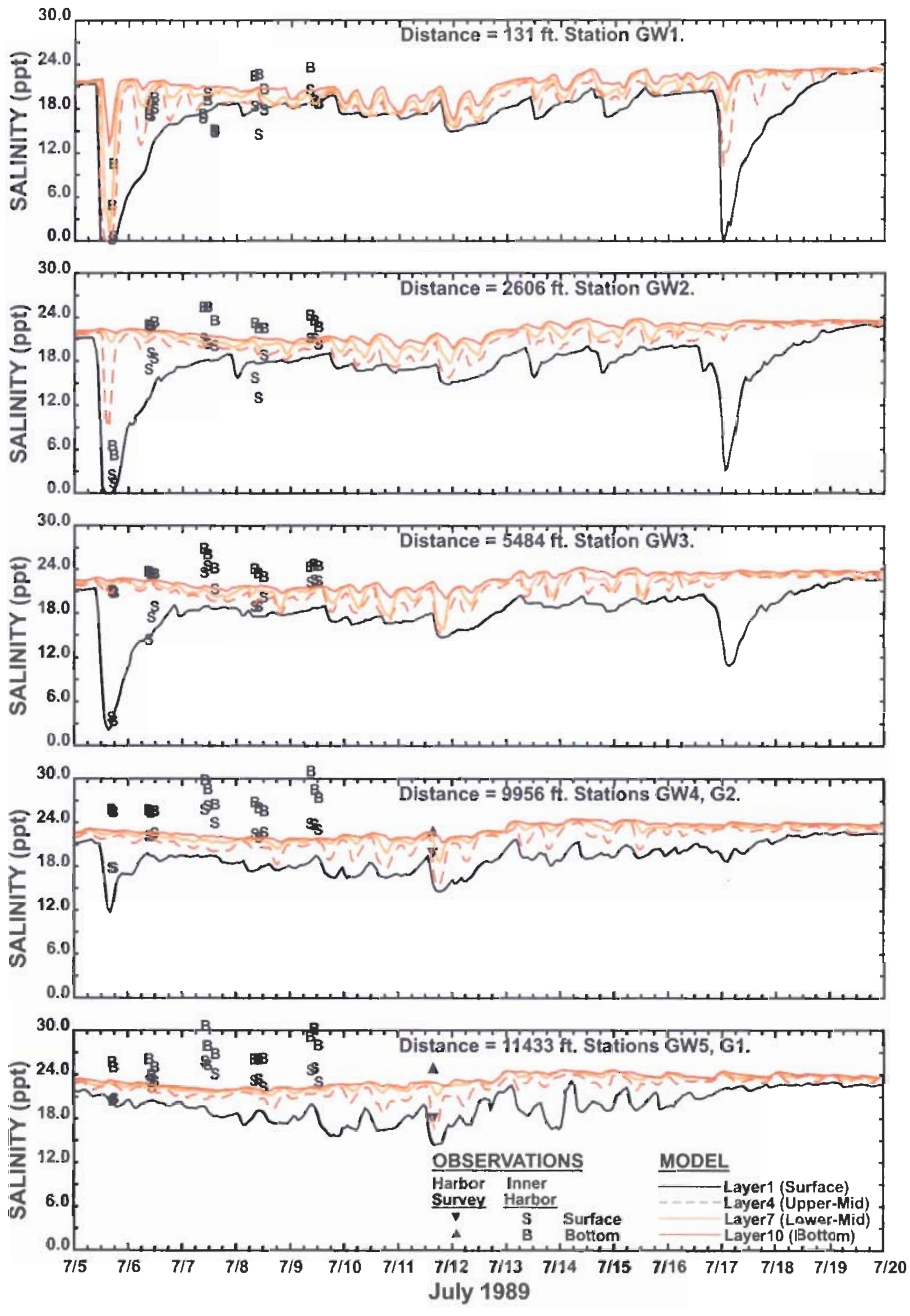


Figure 3-16
Gowanus Bay and Canal Salinity Calibration
July 5-19, 1989

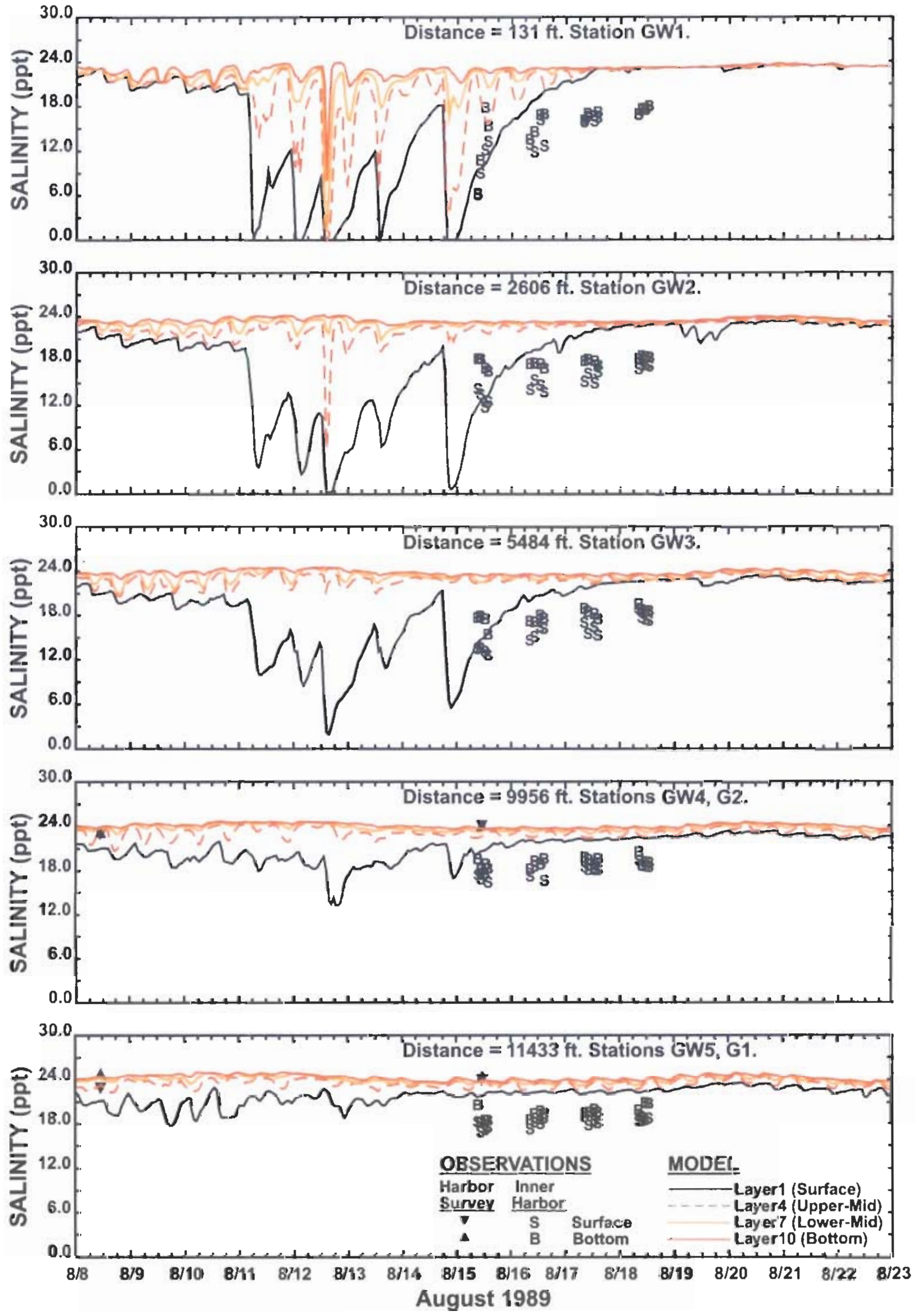


Figure 3-17
Gowanus Bay and Canal Salinity Calibration
August 8-24, 1989

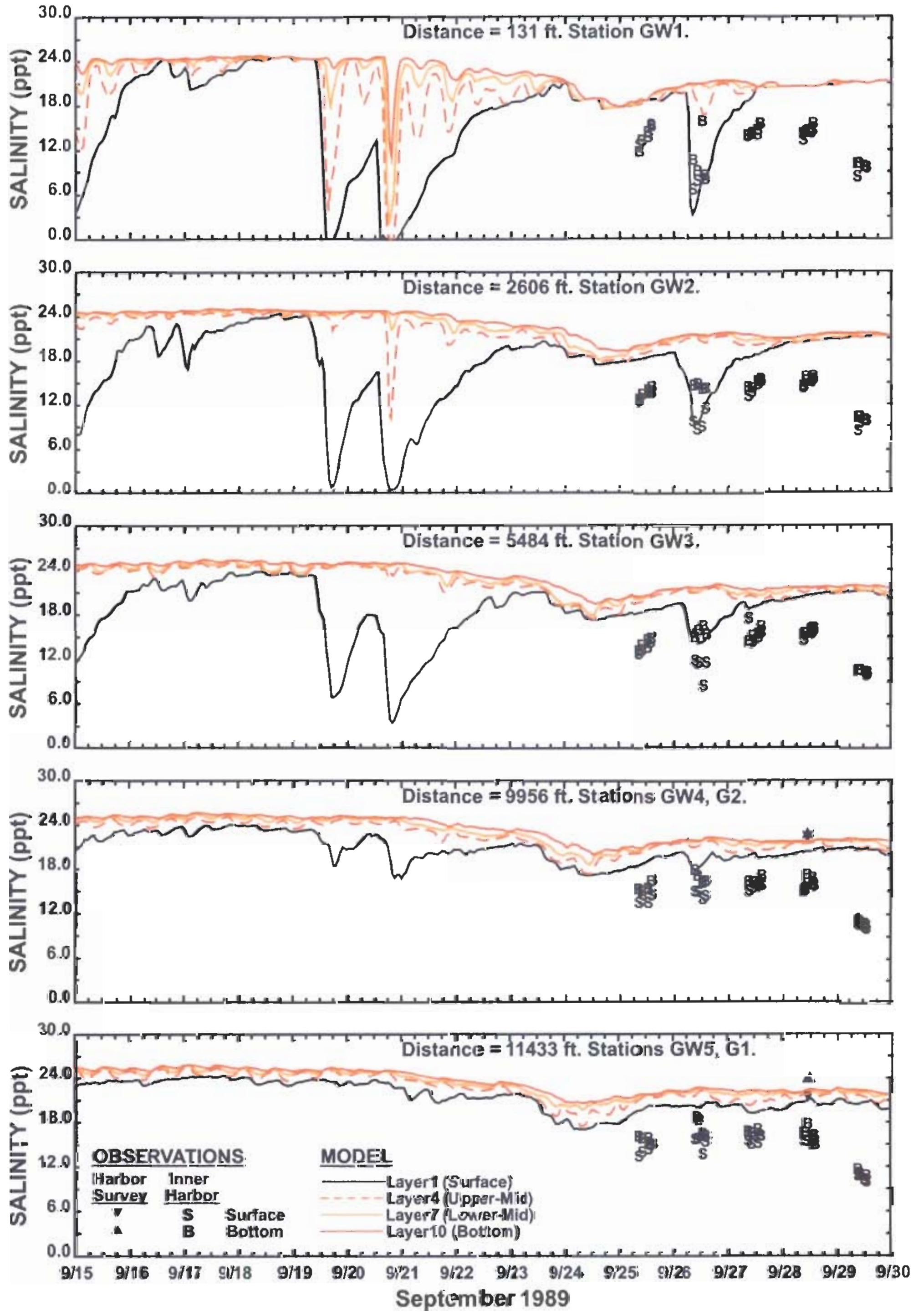


Figure 3-18
Gowanus Bay and Canal Salinity Calibration
September 15-29, 1989

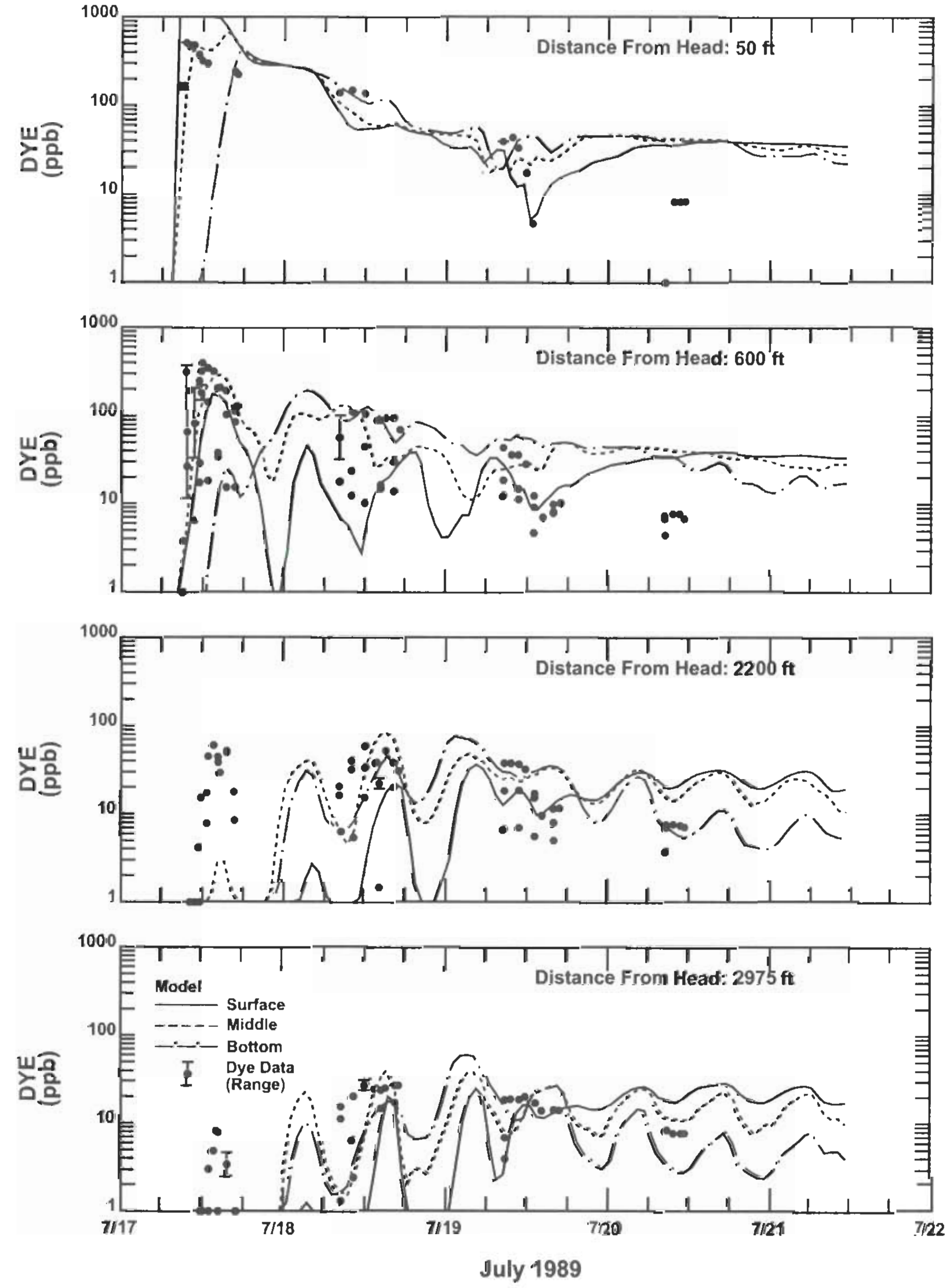


Figure 3-19
Gowanus Bay and Canal Dye Calibration (1 of 2)

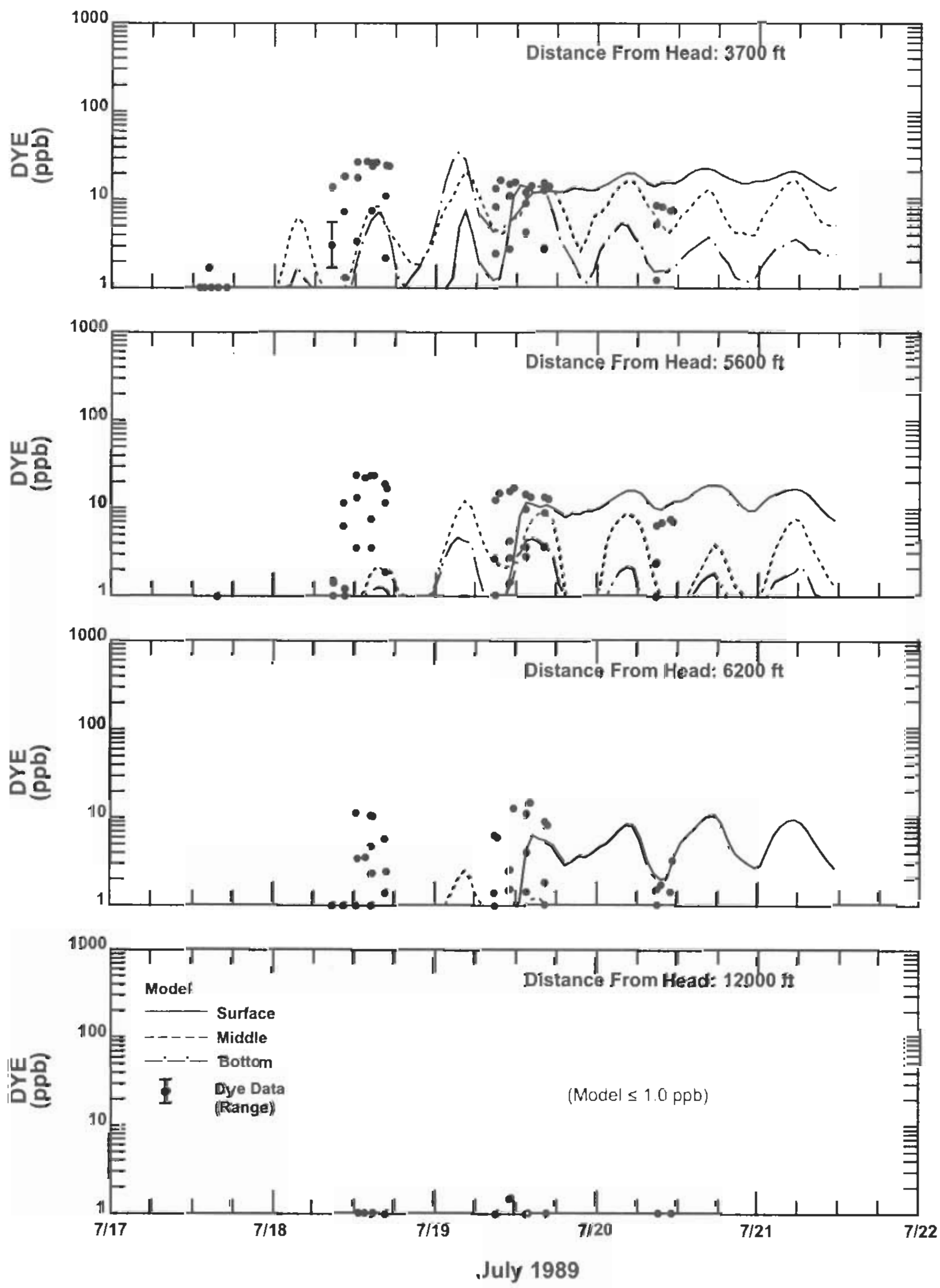


Figure 3-20
Gowanus Bay and Canal Dye Calibration (2 of 2)

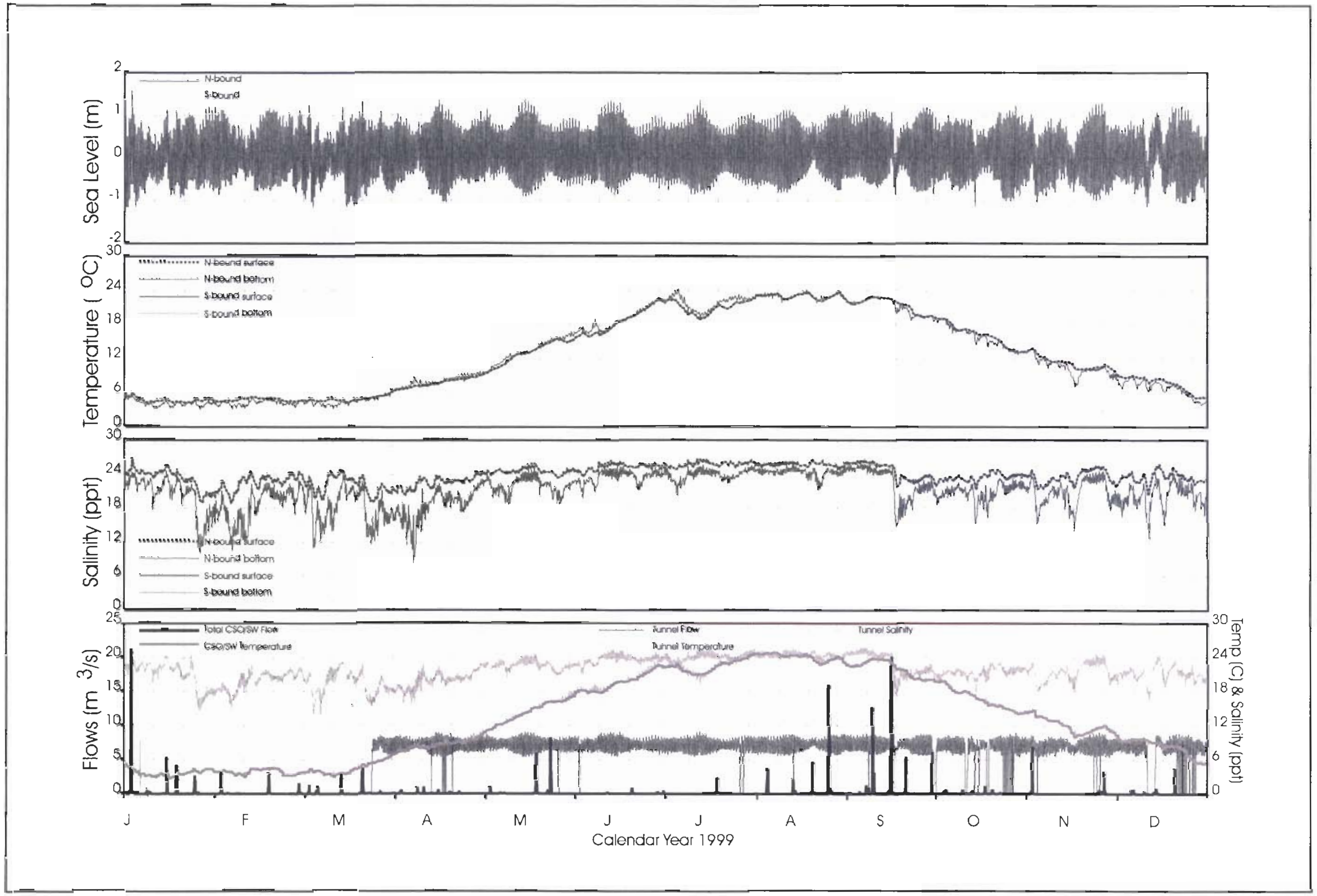


Figure 3-21
Gowanus Bay and Canal Hydrodynamic Validation Input (1 of 2)

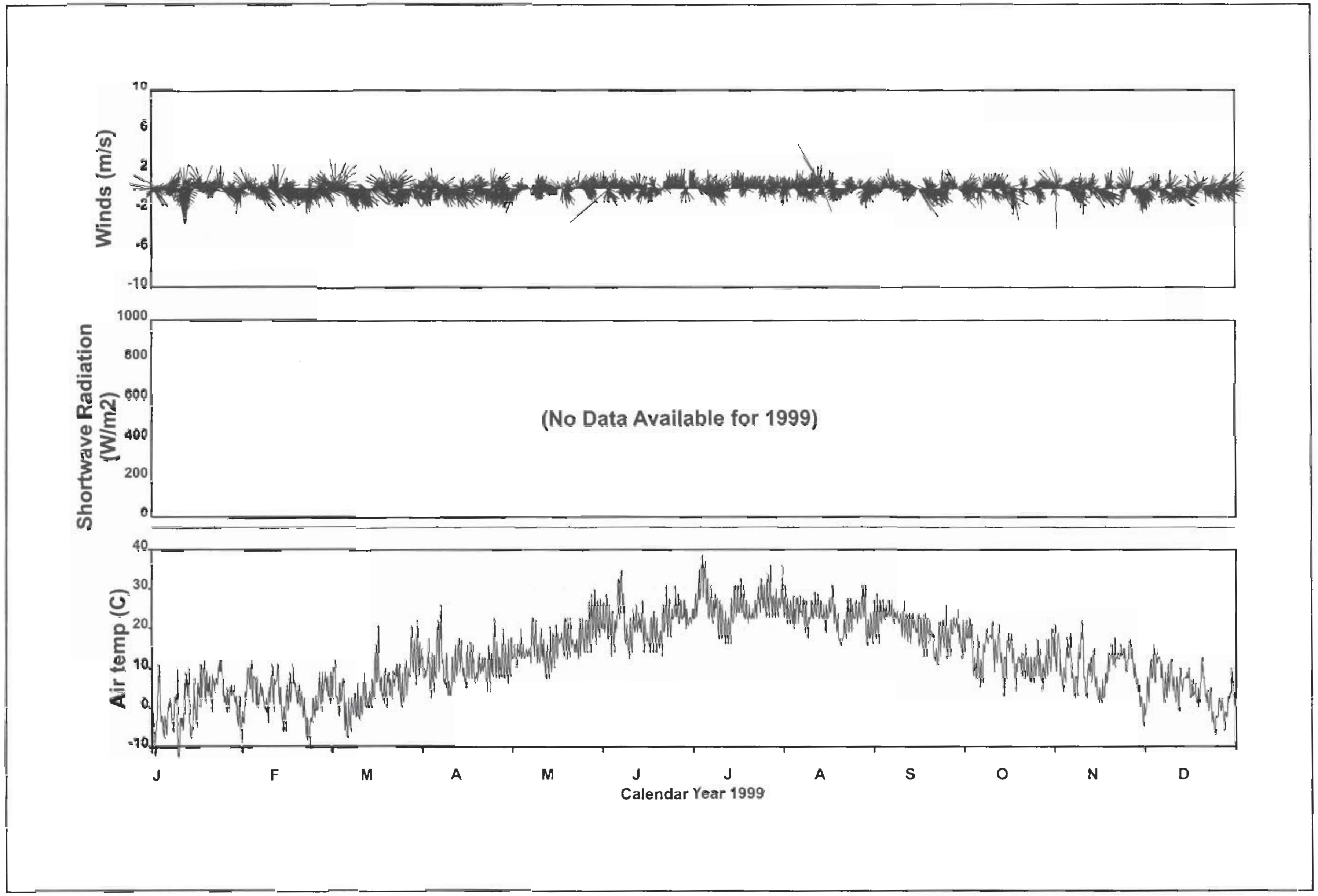


Figure 3-22
Gowanus Bay and Canal Hydrodynamic Validation Input (2 of 2)

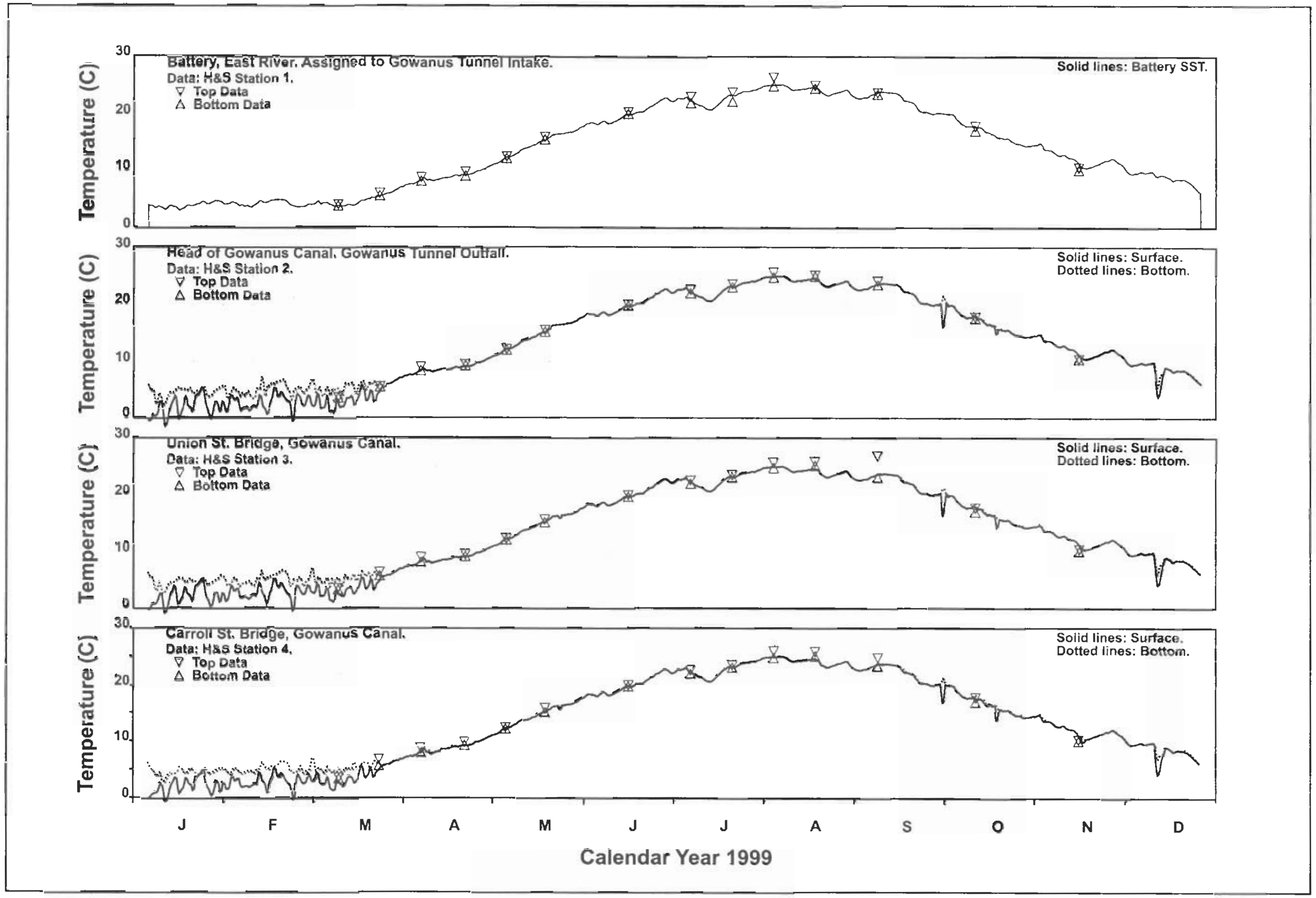


Figure 3-23
Gowanus Bay and Canal Temperature Validation Results (1 of 2)

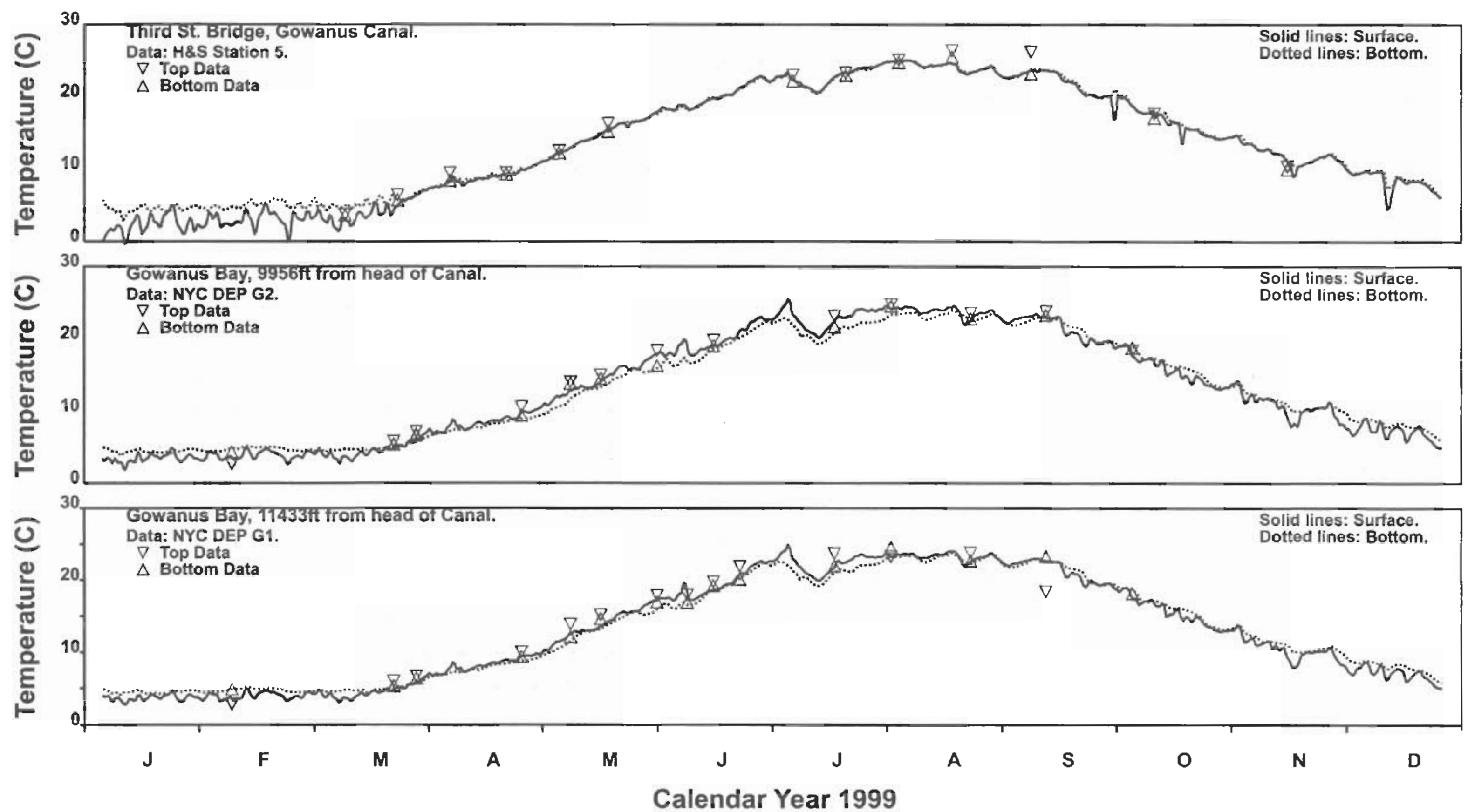


Figure 3-24
Gowanus Bay and Canal Temperature Validation Results (2 of 2)

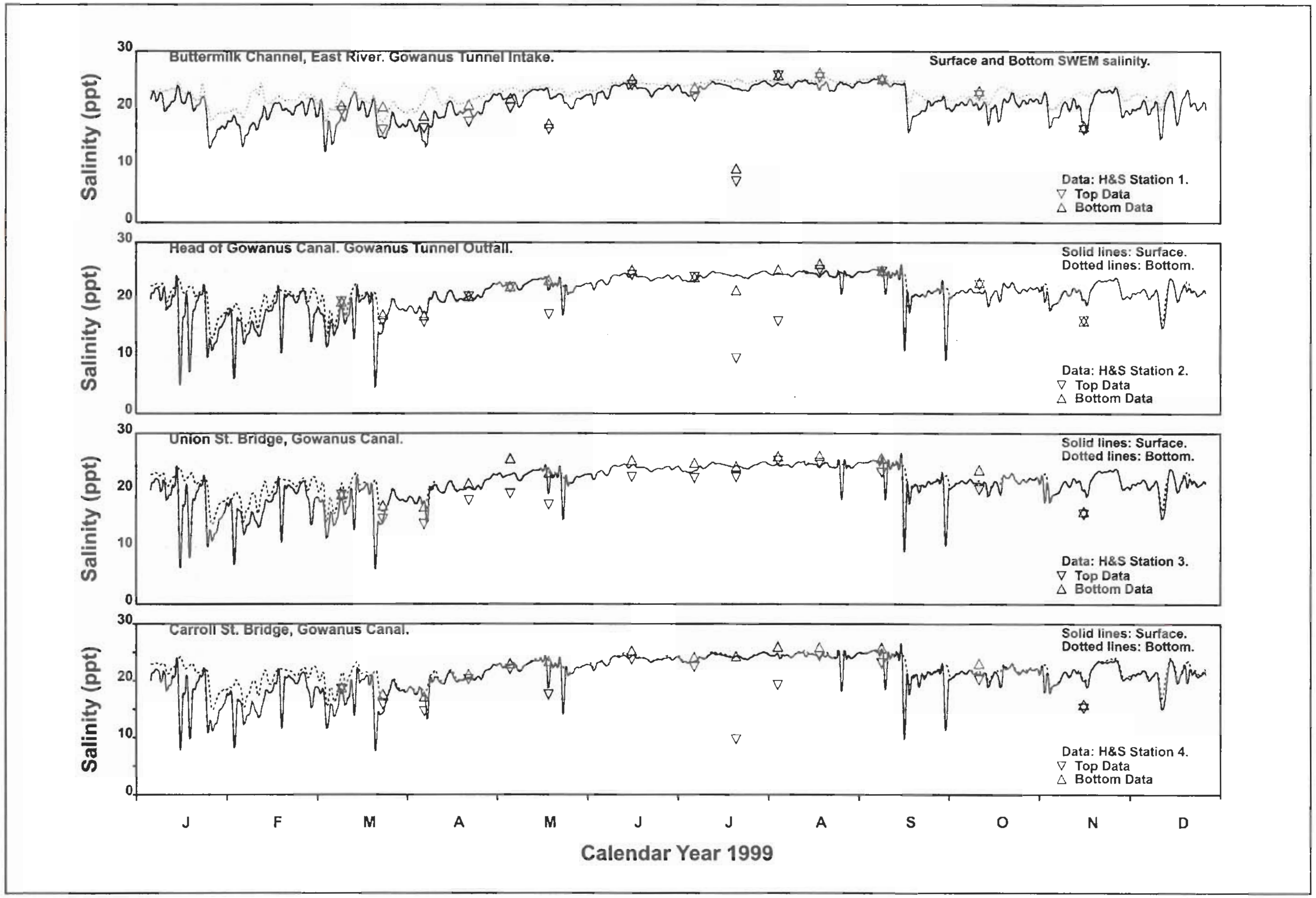


Figure 3-25
Gowanus Bay and Canal Salinity Validation Results (1 of 2)

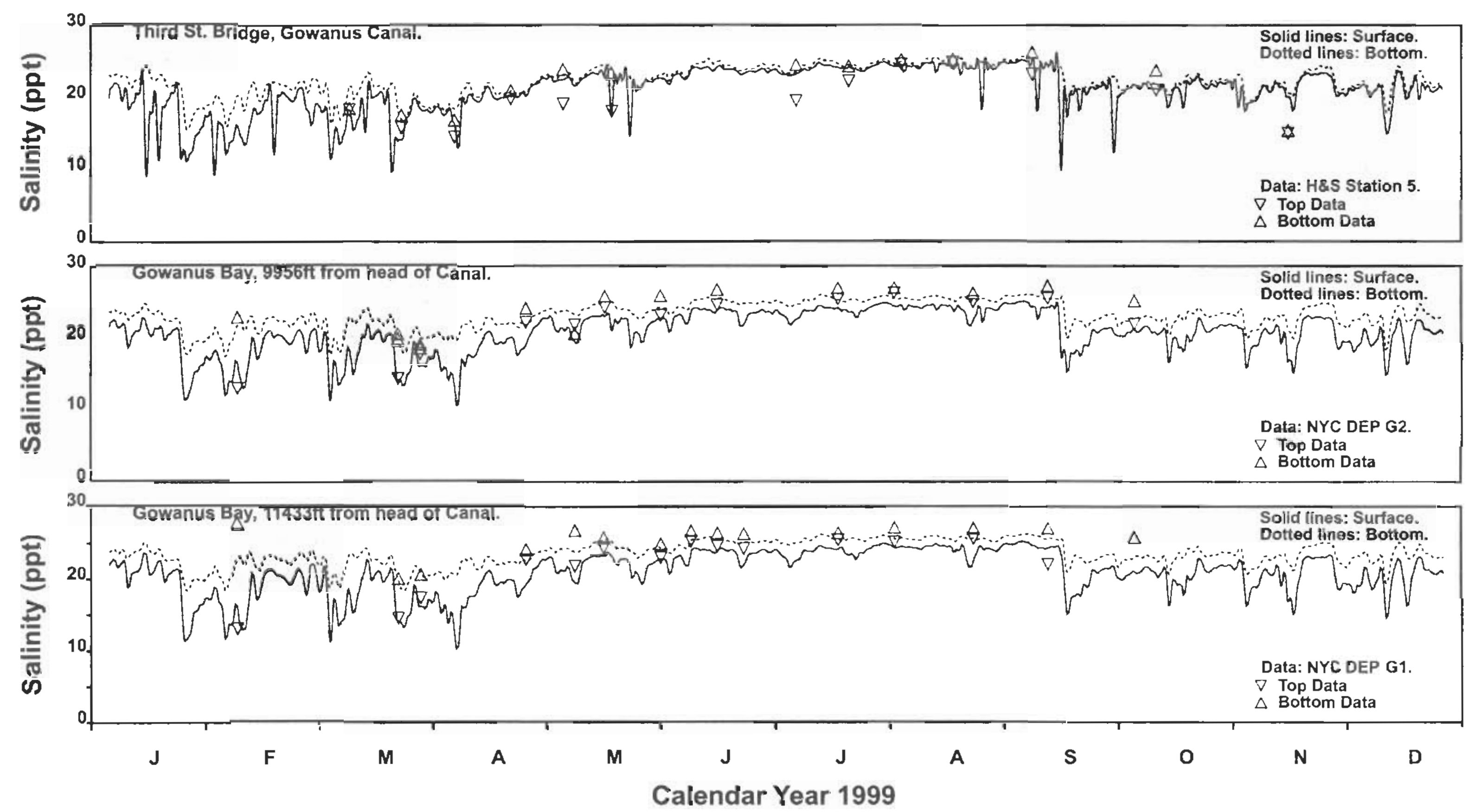


Figure 3-26
Gowanus Bay and Canal Salinity Validation Results (2 of 2)

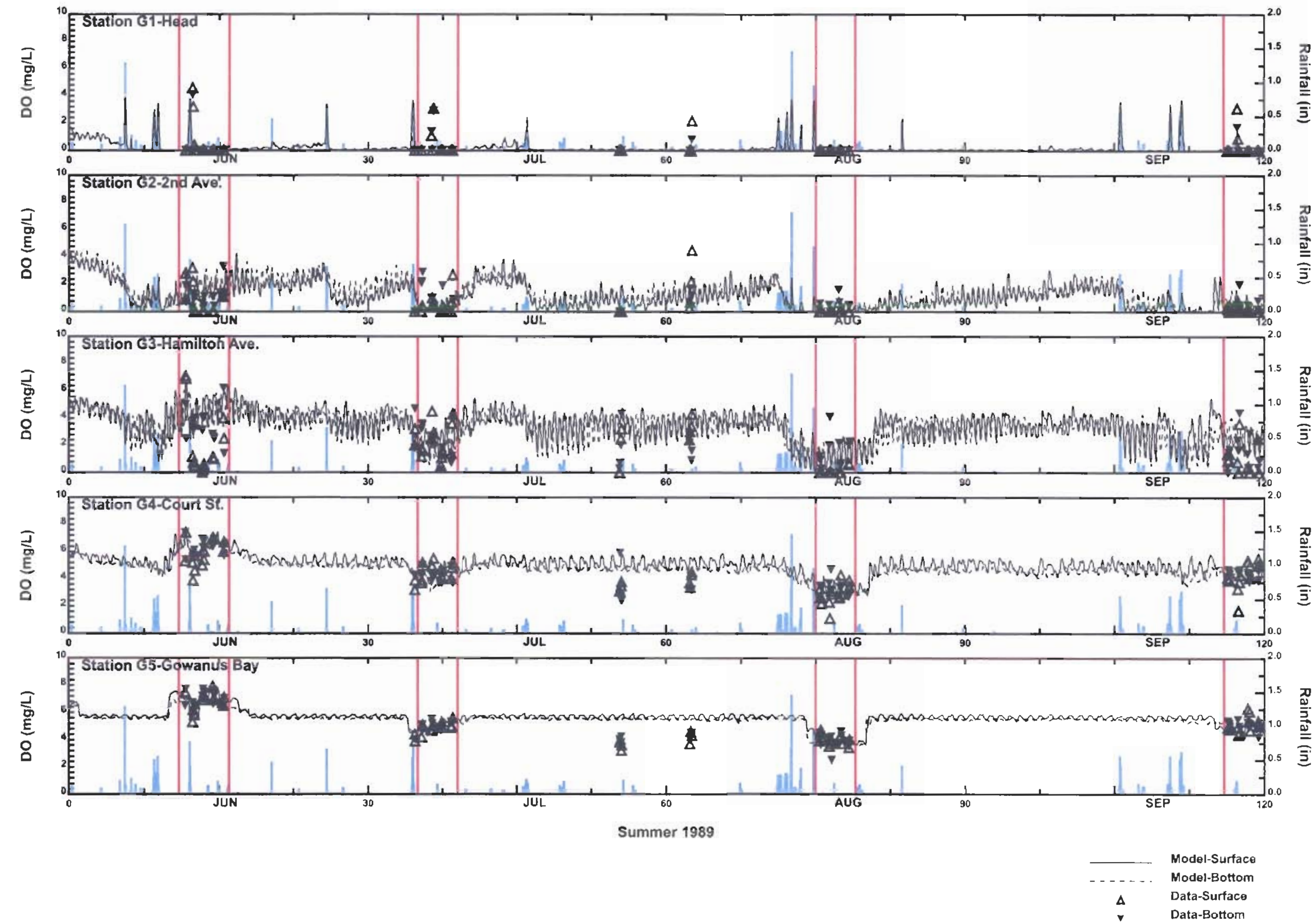


Figure 3-27
Calculated and Observed Dissolved Oxygen Concentrations
Gowanus Calibration: June-Sept 1989

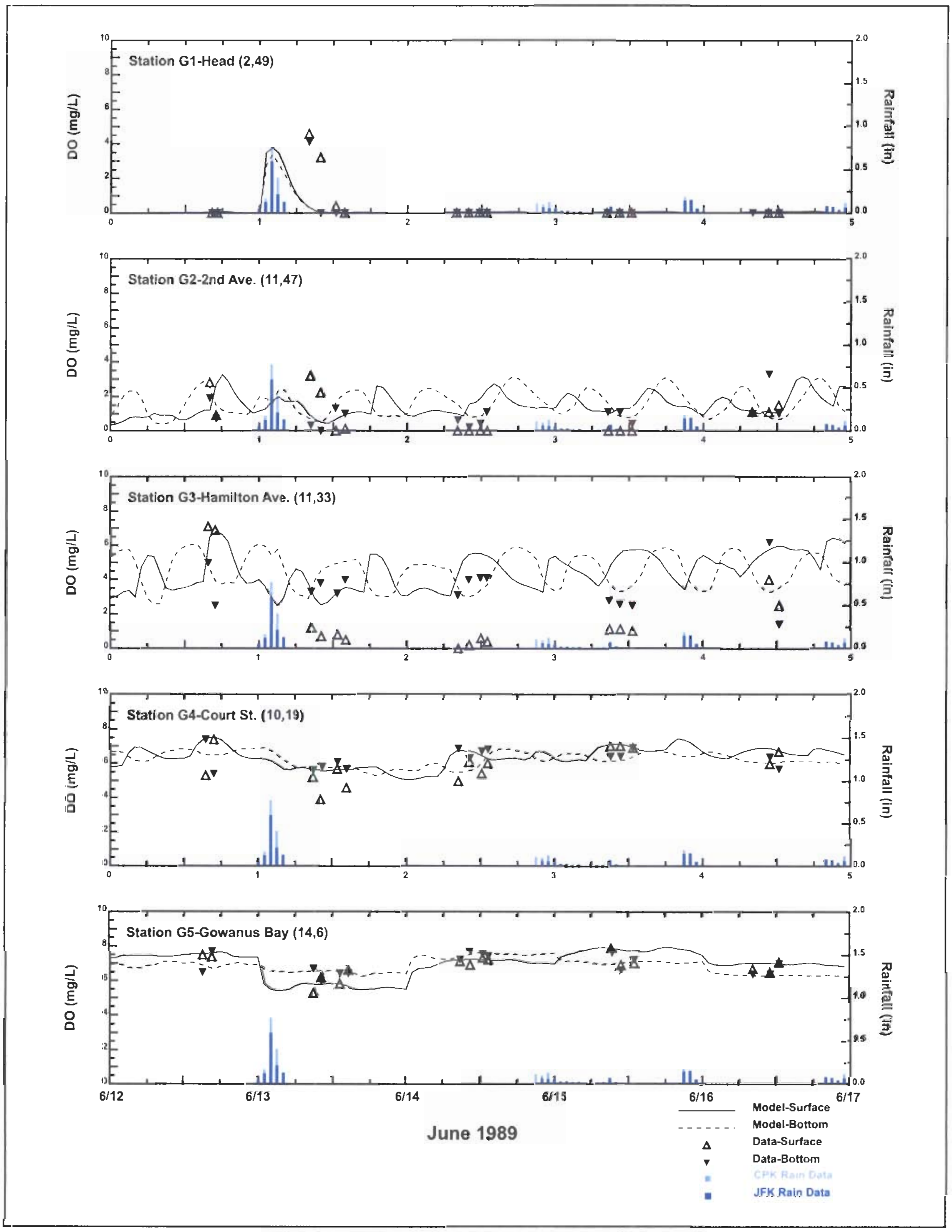


Figure 3-28
Calculated and Observed DO Concentrations
Gowanus Canal Calibration: June 12-16, 1989

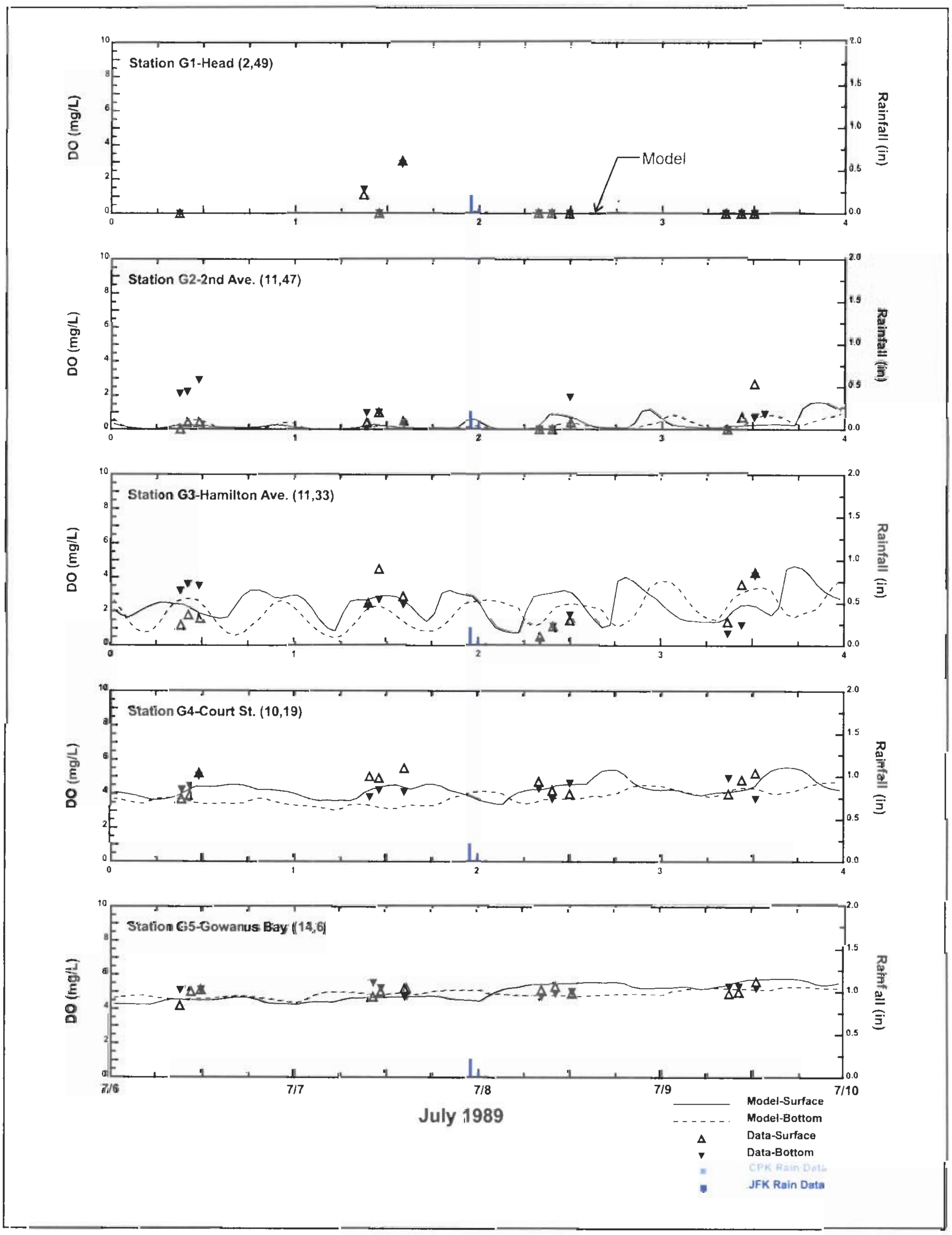


Figure 3-29
Calculated and Observed DO Concentrations
Gowanus Canal Calibration: July 6-9, 1989

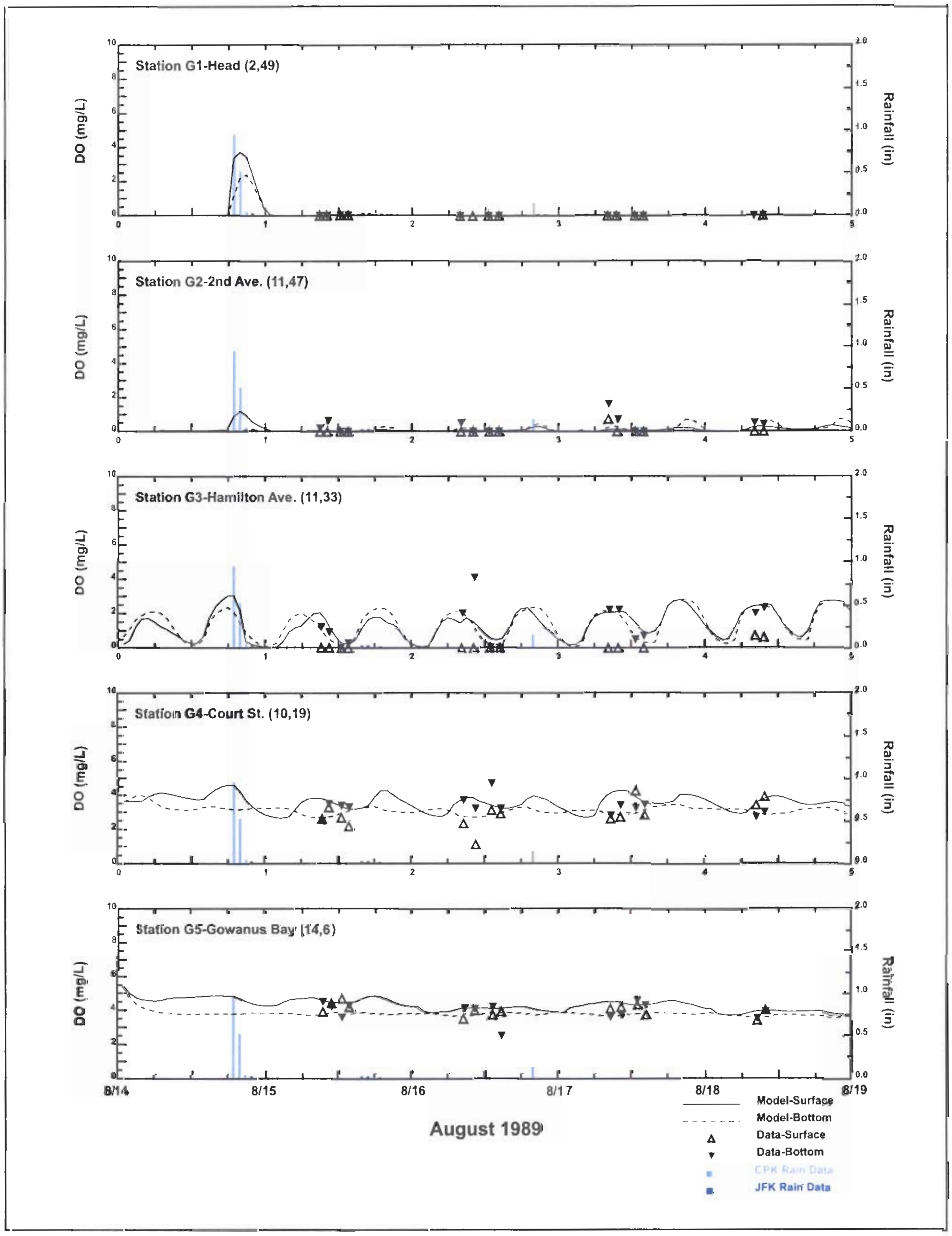


Figure 3-30
Calculated and Observed DO Concentrations
Gowanus Canal Calibration: August 15-18, 1989

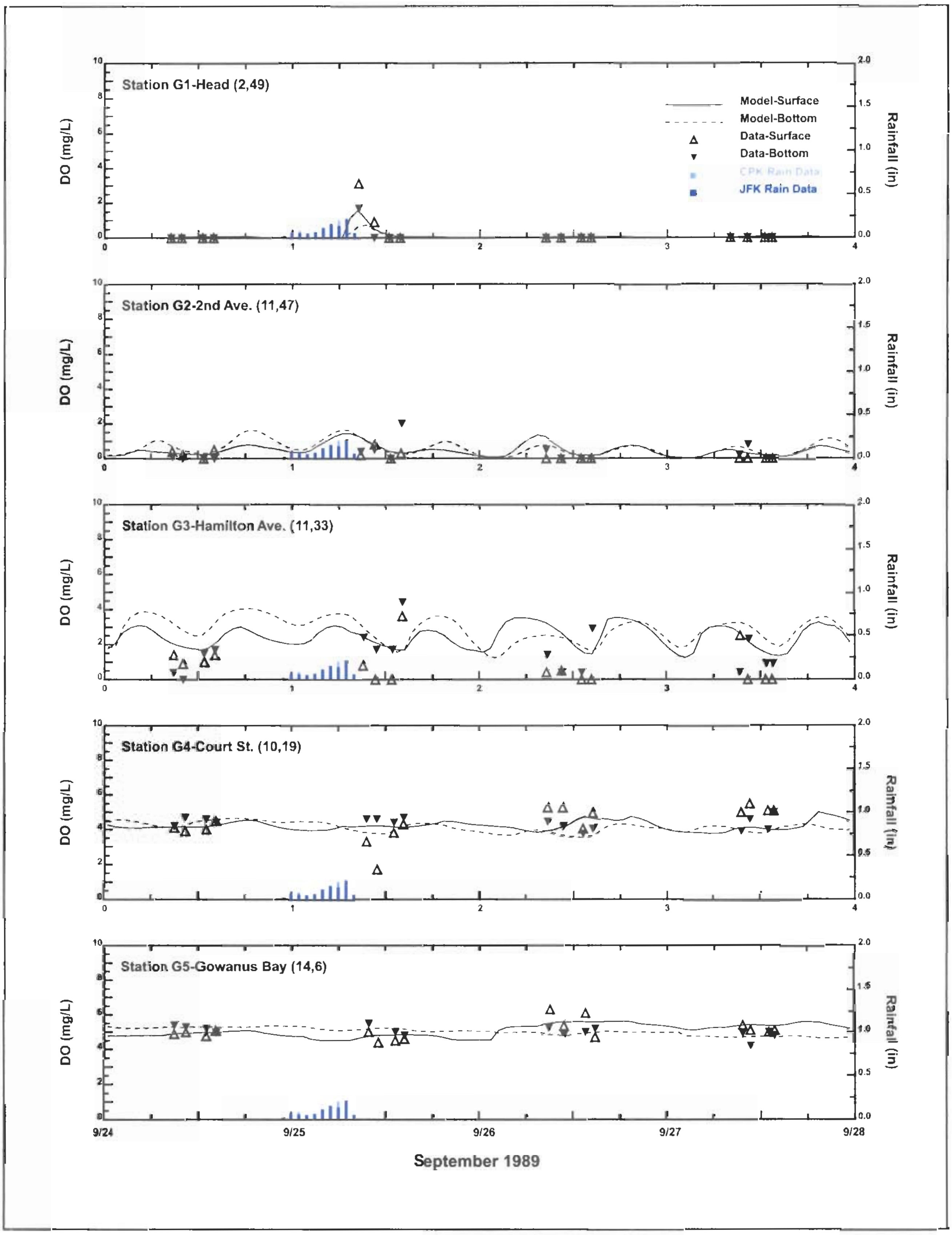


Figure 3-31
Calculated and Observed DO Concentrations
Gowanus Canal Calibration: September 25-28, 1989

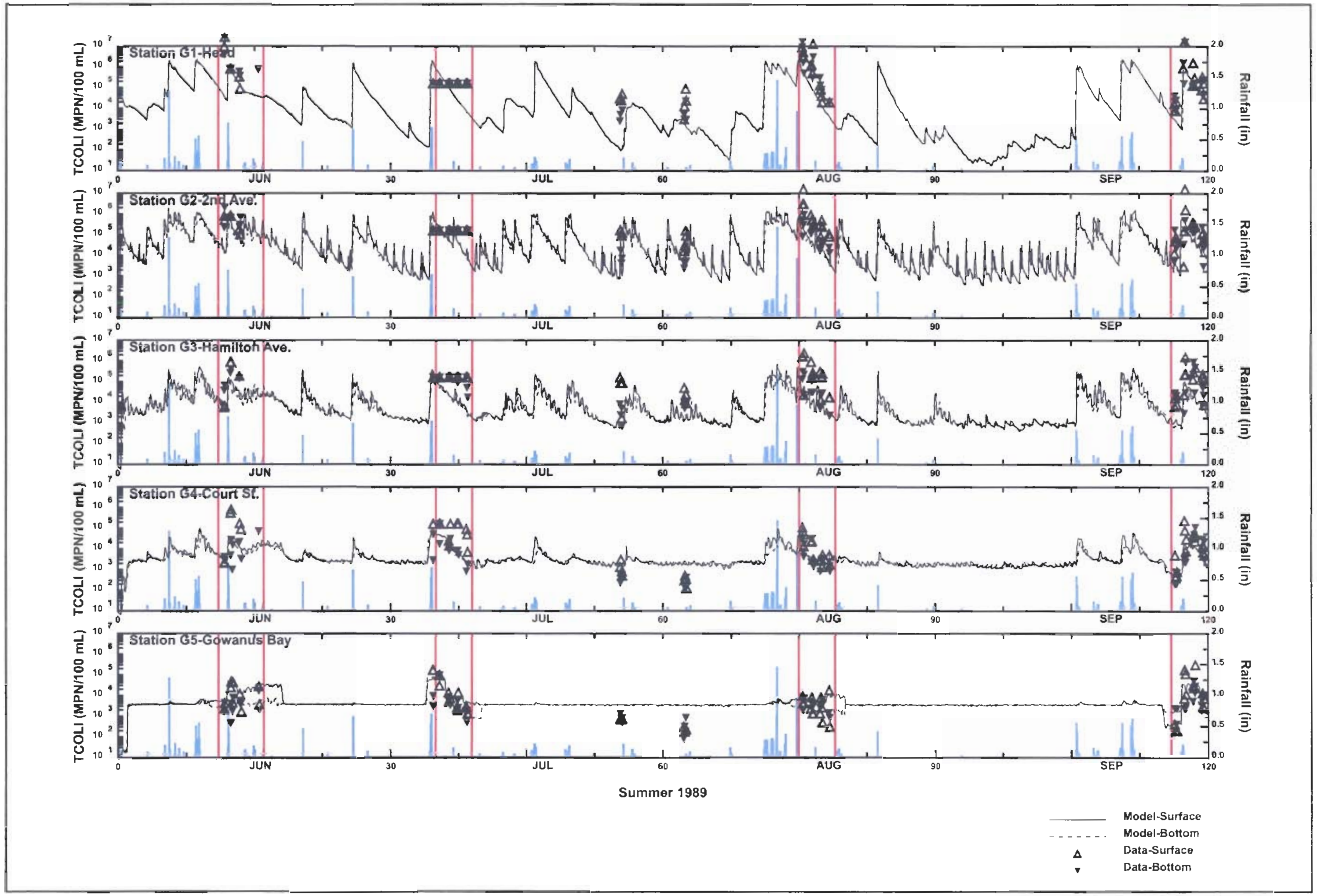


Figure 3-32
Calculated and Observed Total Coliform Concentrations
Gowanus Canal Calibration: June-Sept 1989

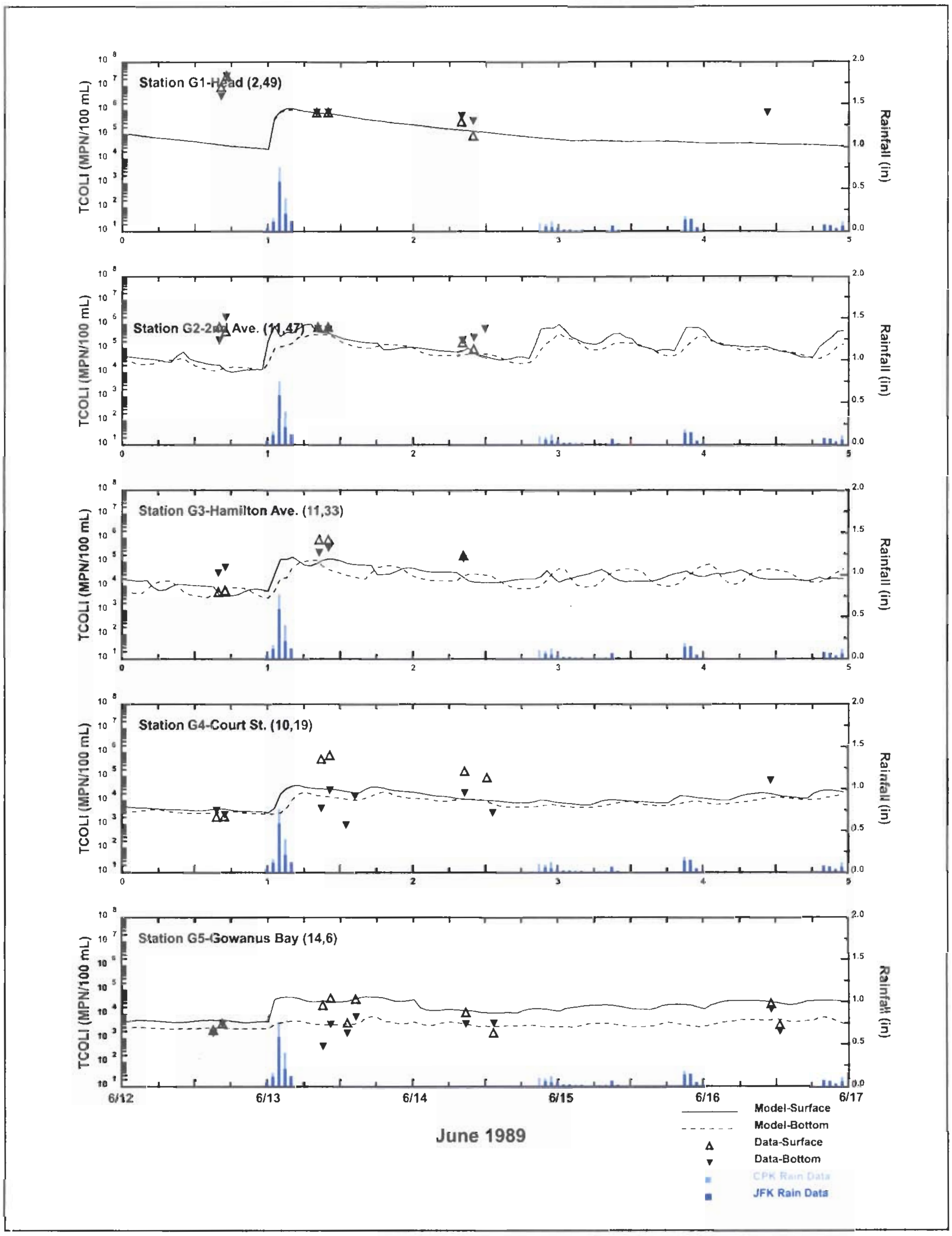


Figure 3-33
Calculated and Observed Total Coliform Concentrations
Gowanus Canal Calibration: June 12-16, 1989

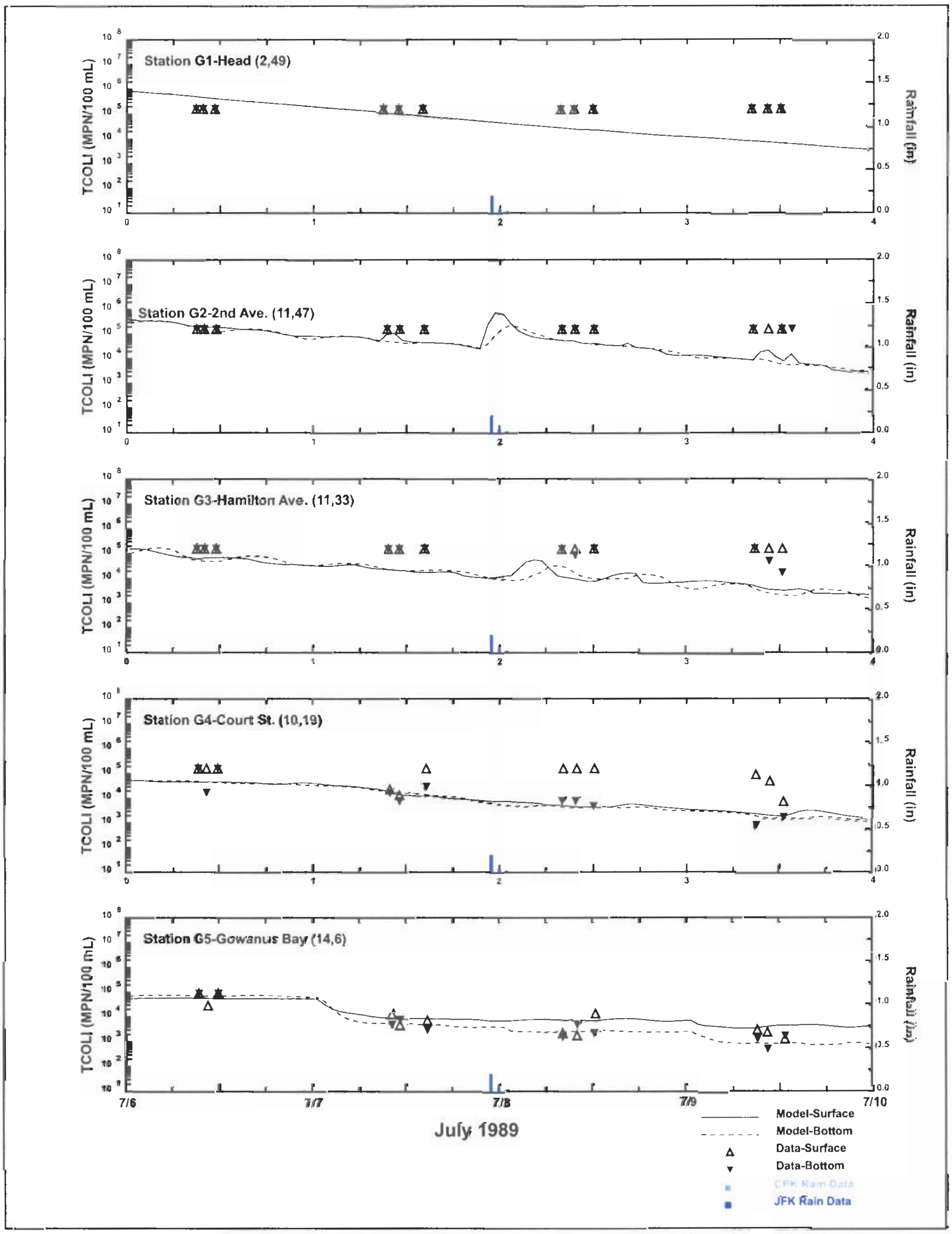


Figure 3-34
Calculated and Observed Total Coliform Concentrations
Gowanus Canal Calibration: July 6-9, 1989

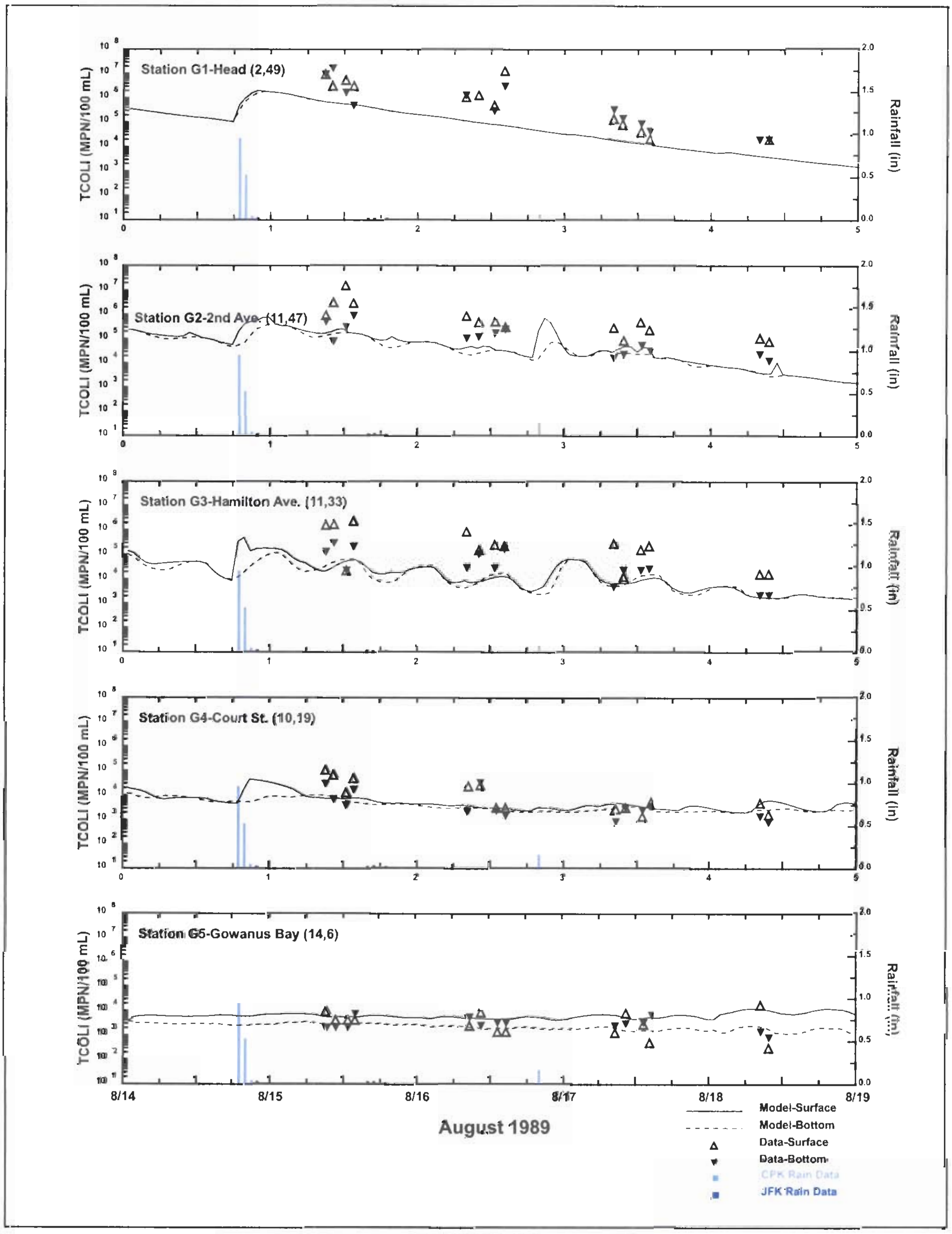


Figure 3-35
Calculated and Observed Total Coliform Concentrations
Gowanus Canal Calibration: August 15-18, 1989

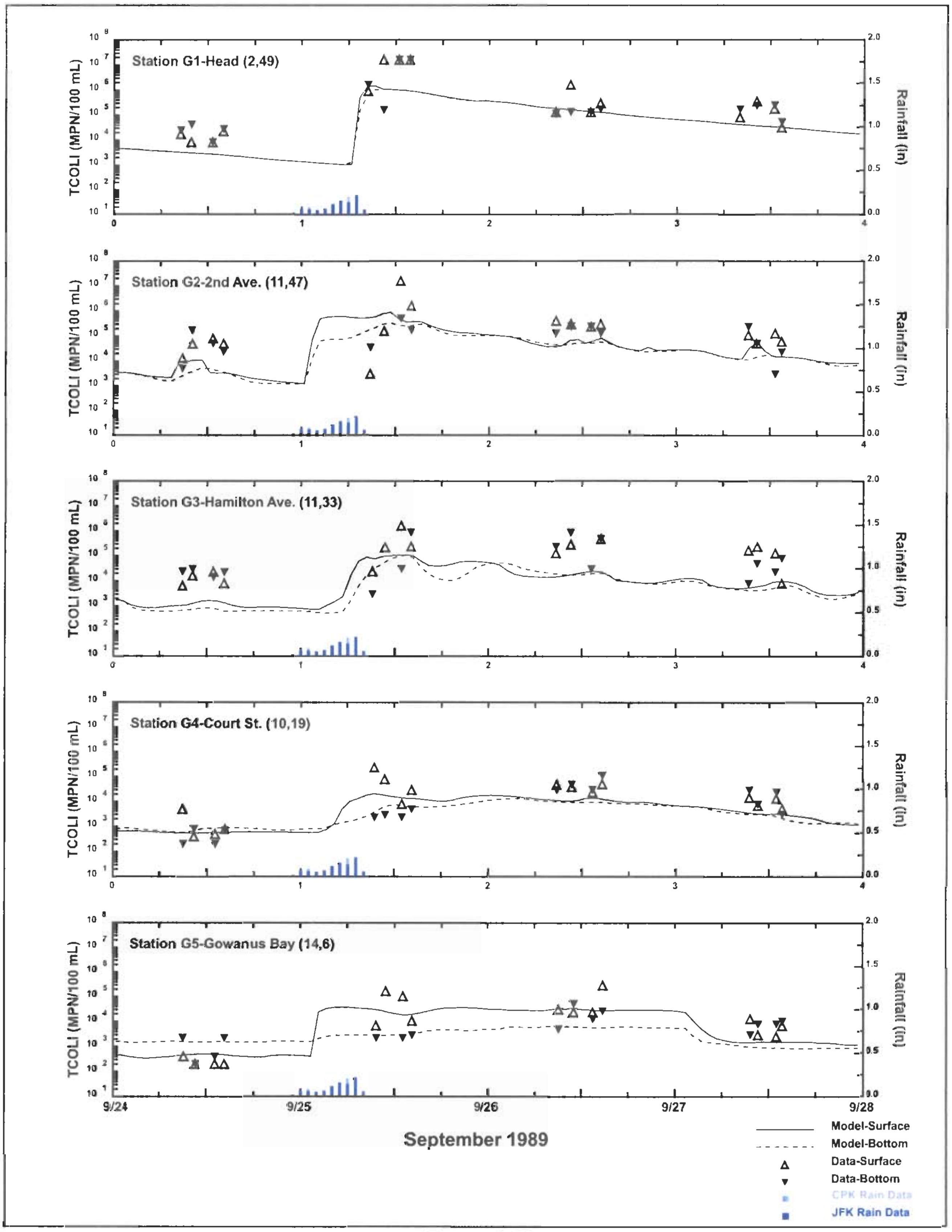


Figure 3-36
Calculated and Observed Total Coliform Concentrations
Gowanus Canal Calibration: September 25-28, 1989

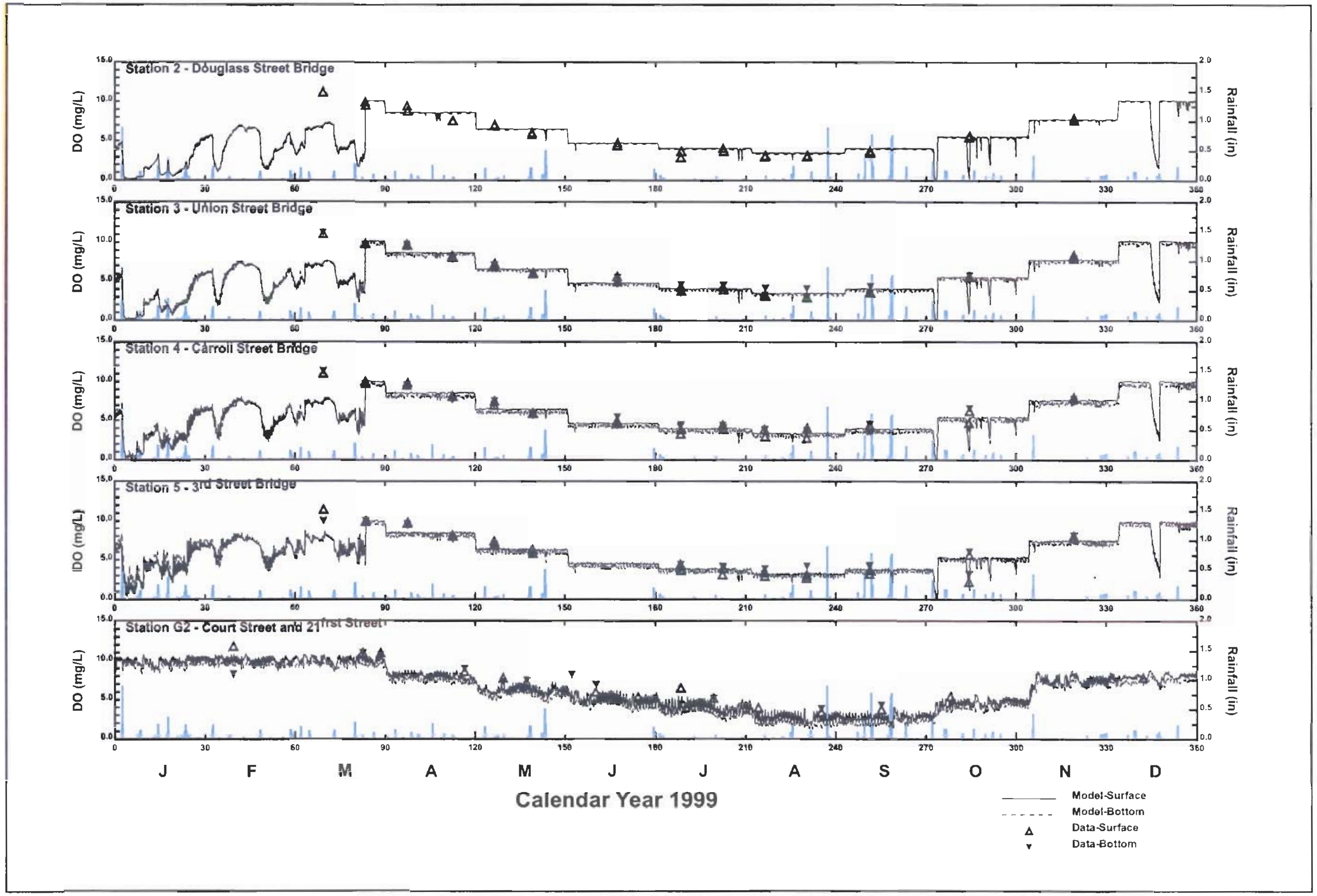


Figure 3-37
Calculated and Observed Dissolved Oxygen Concentrations
Gowanus Canal Validation: Calendar Year 1999

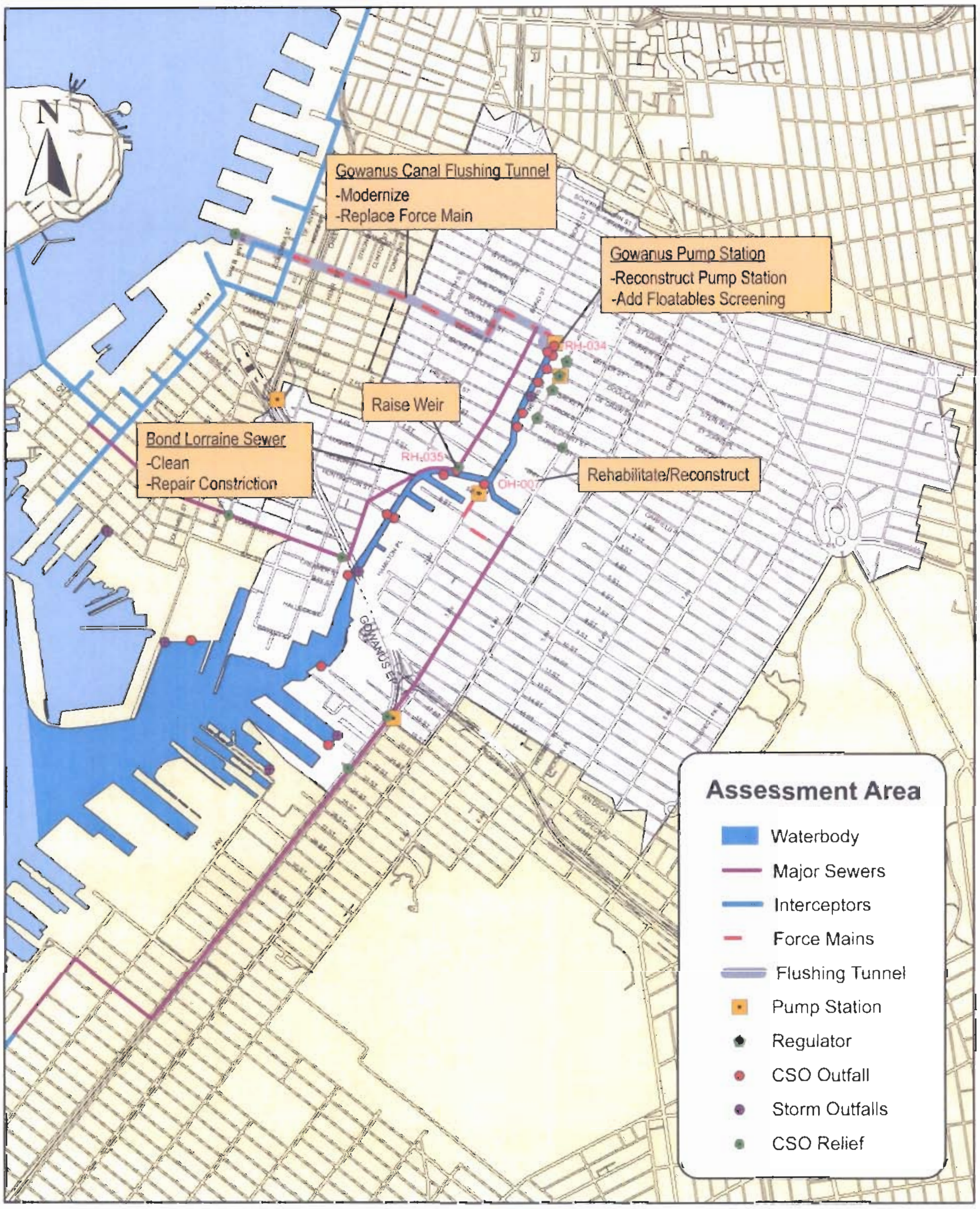


Figure 4-1
Locations of No-Action Alternative Components

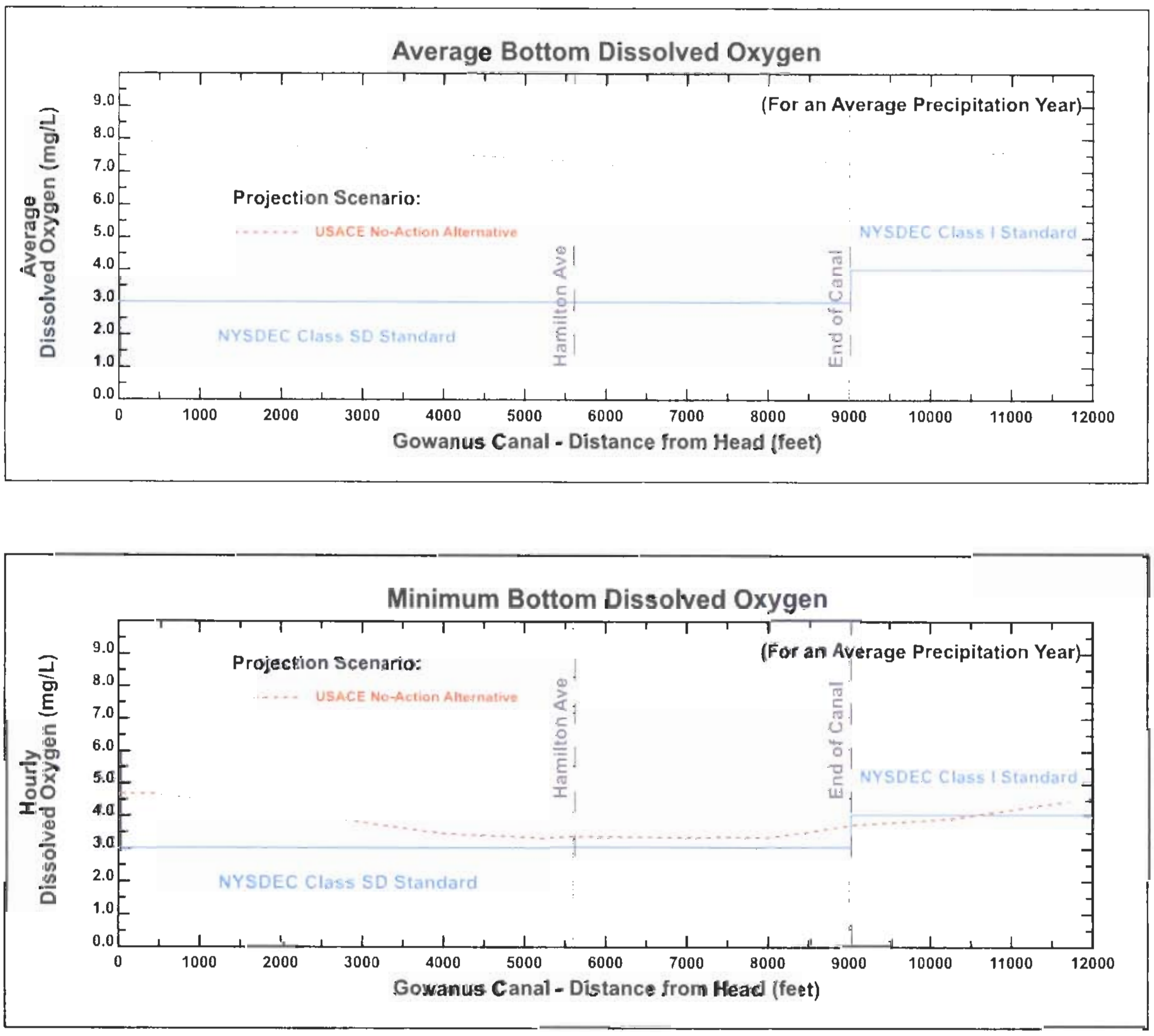


Figure 4-2
Gowanus Bay and Canal Dissolved Oxygen Projections
for No-Action Alternative

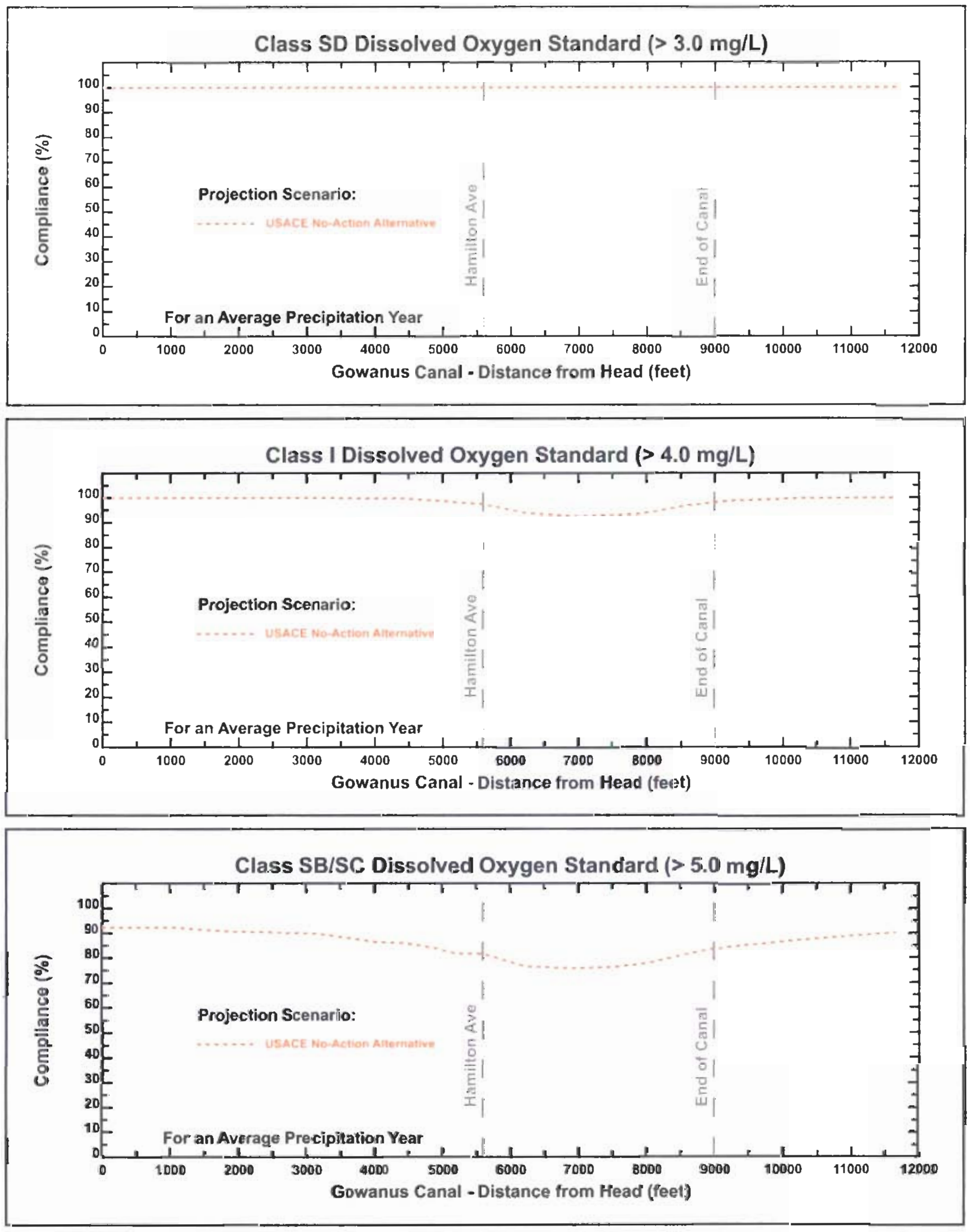


Figure 4-3
Gowanus Bay and Canal NYSDEC Dissolved Oxygen Compliance of No-Action Alternative

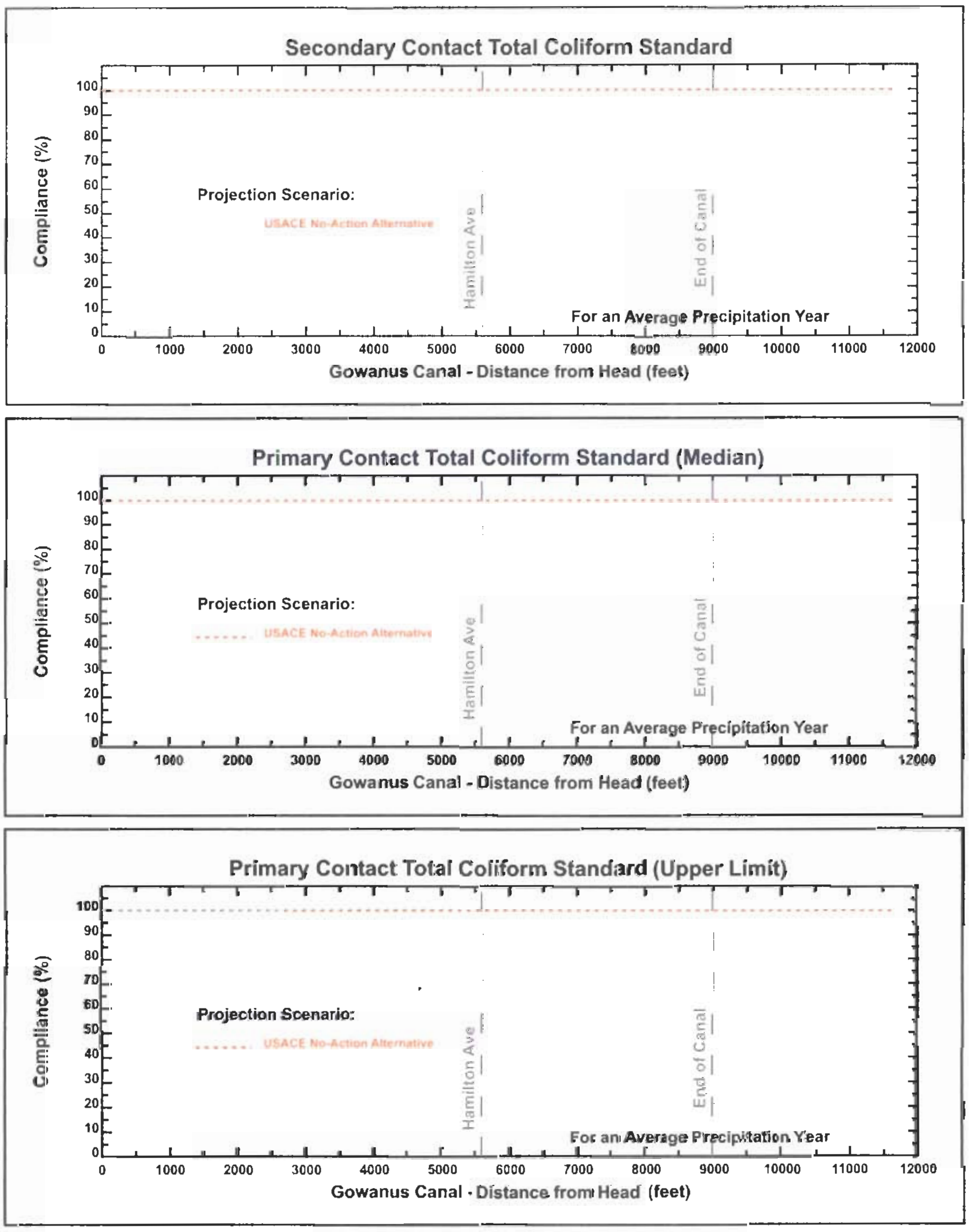


Figure 4-4
Gowanus Bay and Canal NYSDEC Total Coliform Compliance of No-Action Alternative
(Based on Calendar Year)

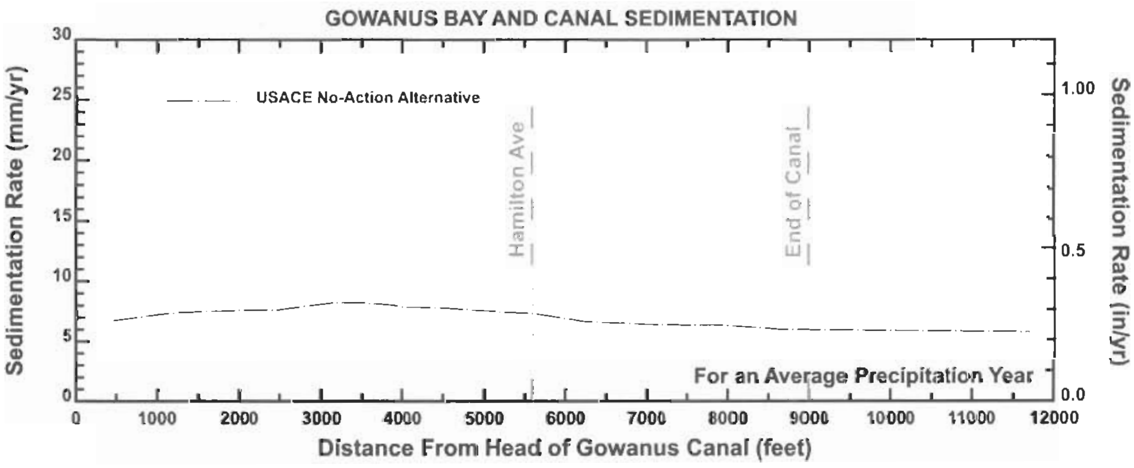


Figure 4-5
Gowanus Bay and Canal No-Action Alternative Sedimentation