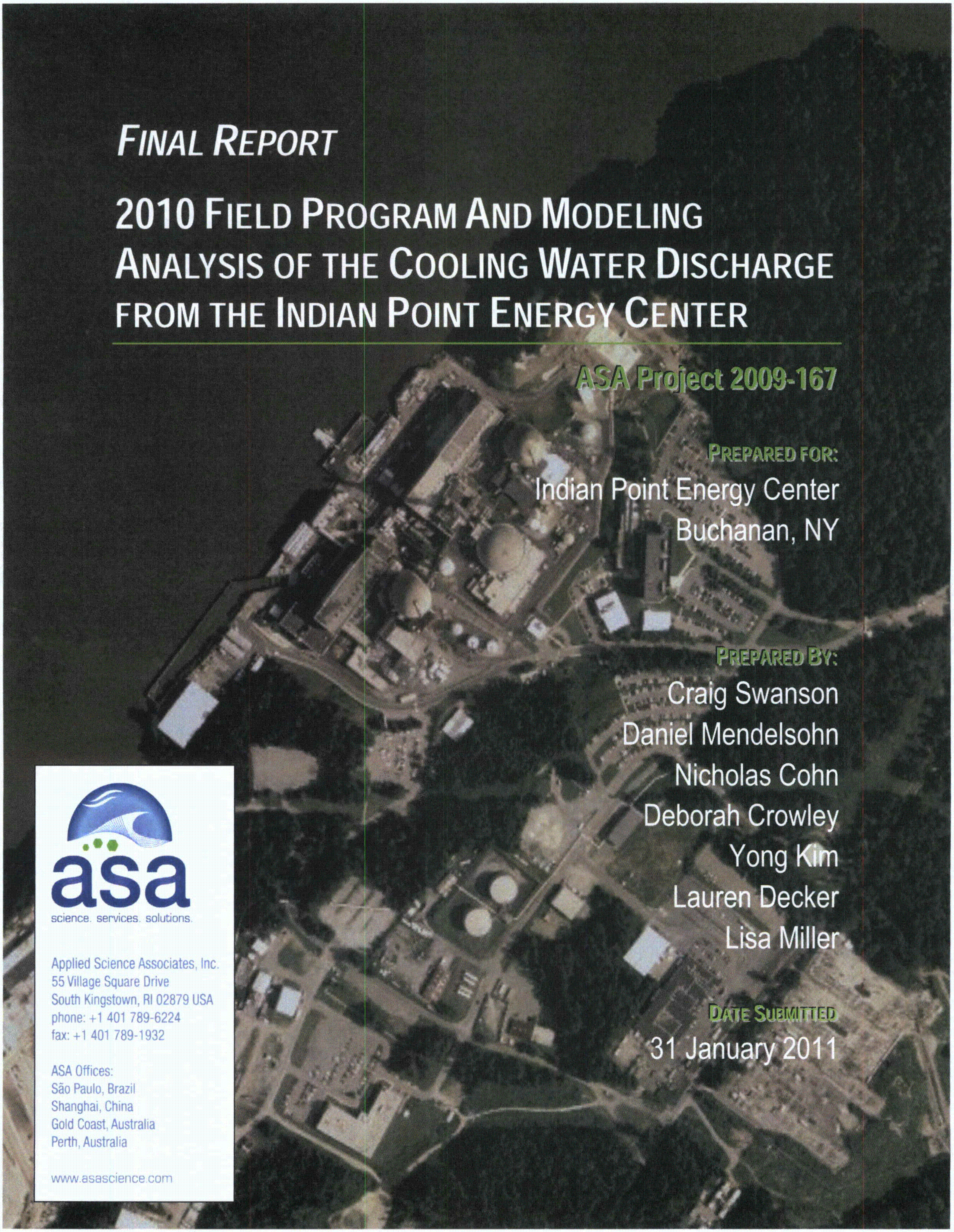

FINAL REPORT

2010 FIELD PROGRAM AND MODELING ANALYSIS OF THE COOLING WATER DISCHARGE FROM THE INDIAN POINT ENERGY CENTER

ASA Project 2009-167

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ASA 2010 Field Program and Modeling Analysis of the IPEC Discharge

EXECUTIVE SUMMARY

The Indian Point Energy Center (IPEC) consists of two operating nuclear power plants, referred to as Units 2 and 3, owned respectively by Entergy Nuclear Indian Point 2, LLC and Entergy Nuclear Indian Point 3, LLC (collectively, Entergy). IPEC is located along the eastern side of the Hudson River (River) in the village of Buchanan, New York, approximately 42 miles upstream of the Battery (located at the southern tip of Manhattan and defined as the mouth of the River). IPEC uses a once-through cooling water system that discharges heated water to the River through a common discharge canal, subject to and with the benefit of a New York State Department of Environmental Conservation- (NYSDEC) issued State Pollutant Discharge Elimination System (SPDES) permit, which contains thermal discharge conditions and limitations, i.e., *6 NYCRR Part 704.2(b)(5): Special Thermal Criteria for Estuaries of Portions of Estuaries: parts (i), (ii), (iii) & (iv) (Thermal WQS).*

To evaluate IPEC's compliance with the Thermal WQS, a triaxial study was conducted in late summer and early fall of 2009 that consisted of a combination of field work, data analysis and numerical modeling. A review and preliminary analysis of the field program and dataset derived from that program (Swanson, et al. (2010a) was submitted to NYSDEC on 12 February 2010. A full report documenting the triaxial study (Swanson et al., 2010b) was submitted to NYSDEC on 22 March 2010 that described the field program, the thermal modeling approach and the model results that showed IPEC was in compliance with the Thermal WQS. NYSDEC Staff requested additional validation of the thermal model and results, employing summer 2010 field data.

In response, Applied Science Associates, Inc. (ASA) and Normandeau Associates Inc. (NAI) designed and performed the summer 2010 triaxial thermal study. The field survey consisted of long term, high resolution, fixed station temperature, current and salinity observations as well as two days of mobile surveys that captured currents, temperature and salinity profiles in the River at various stages of the tide. The observations were used to assess the environmental conditions in the River and the extent of the IPEC thermal plume, as well as to validate the hydrothermal numerical model used in the previous study and documented in Swanson et al. (2010b).

Specifically, the 2010 Field Program was performed to monitor River temperatures, salinities and currents at various locations in the River from 20.9 mi south of IPEC (downstream) to 9.5 mi north of IPEC (upstream) during a 10-week period from 5 July through 10 September 2010. These data were analyzed, along with other publicly available River and meteorological observations, to first assess the dynamics of the thermal plume resulting from the IPEC discharge, and then to understand the response of the plume to various environmental forcing factors, such as tides, water temperature, salinity and currents, as well as meteorological conditions.

The long term, fixed mooring field program used an extensive array of thermistors (i.e., 348 thermistors on 66 moorings), three fixed Acoustic Doppler Current Profilers (ADCPs) and eight Conductivity / Temperature / Depth (CTD) sensors. The relative contributions of different forcing mechanisms, including River flow, tide and salt-induced estuarine circulation, cause substantial temporal and spatial variability and were captured by these instruments. Bi-directional tidal flow with a period of 12.42 hours was dominant with the distinctive signal of the bi-weekly spring-neap cycle observed. The combined effect of River flow and salt intrusion resulted in estuarine circulation, where the surface flow was stronger during ebb while the bottom flow was stronger during flood. The vertical temperature stratification was most evident near the IPEC discharge with higher temperatures restricted to the near surface.

A model validation effort was performed using the calibrated model described in Swanson et al. (2010b). Both qualitative and quantitative methods that represent the industry standard, provided confidence in model results. The approach used is described in detail in Swanson et al. (2010b). Specifically, the time series of observations vs. model predictions showed that the model captured accurately both the surface elevation variations and currents with respect to phase and amplitude. The model was able to successfully simulate the current velocities with respect to the important tidal signals in the River. Most importantly, the model was able to reproduce the spatial and temporal variation in River temperature.

The model temperature results for the validation period were post-processed to determine if the IPEC thermal discharge was in compliance with NYSDEC Thermal WQS. The first analysis of the results consisted of determination of any occurrence of an estuary temperature (beyond the mixing zone) greater than 90°F. The mixing zone for IPEC is defined as a formula, by an equation that describes the accelerated mixing of the thermal discharge based on the head differential across the discharge structure, within which temperatures greater than 90°F are necessarily authorized.. The results of the 90°F analysis showed that the surface area coverage was predominantly semi-diurnal (tidally driven) and peaked at 15 ac on 25 July and averaged 4 acres (ac). The typical variation over a tidal cycle ranges from 0 to 4-5 ac. These areas are similar to the 2005 extreme environmental condition results (Swanson et al., 2010b). This surface area also compares favorably with a calculation of a maximum of 23 ac that is based on the locations of six fixed thermistor stations that each recorded a surface (1-ft depth) temperature greater than 90°F. Temperatures greater than 90°F were observed at a 4-ft depth for three stations closer to the discharge and at one station closest to the discharge (down to 15 ft). The area coverage for temperatures greater than 90°F complies with the NYSDEC Thermal WQS by definition, based on the IPEC permit condition of a formulaic inferred mixing zone.

To test compliance to the other Thermal WQS the 8 through 30 July period results were processed to determine the natural ambient temperature close to IPEC. Following the procedure described in the earlier modeling report (Swanson et al., 2010b), i.e., running the model without any thermal discharges, the results showed that the surface ambient temperature during this period was always under 83°F, which is the ambient threshold at which the allowable plume temperature rise is limited to 1.5°F versus 4°F. Therefore, only the spatial extent of the cross sectional area and surface width of the 4°F temperature rise isotherm were calculated to determine compliance for the period and not the 1.5°F extents.

The model results for the period showed that the 4°F temperature rise covered less than 8% of the River vertical cross sectional area at the transects at all times during the simulation period, and generally covered less than 2% of the cross sectional area compared to the cross section area limit of 50%. The model results also showed that the surface extent of the 4°F temperature rise was less than 24% across the River at all times, and generally less than 10% compared to the surface width limit of 67%. Thus the model results show that IPEC was in compliance with the dimensional criteria in the Thermal WQS for the 2010 study period, as it was during the 2009 calibration period and the extreme environmental condition period (Swanson et al., 2010).

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1 INTRODUCTION

The Indian Point Energy Center (IPEC) consists of two operating nuclear power plants, referred to as Units 2 and 3, respectively owned by Entergy Nuclear Indian Point 2, LLC and Entergy Nuclear Indian Point 3, LLC (Entergy). IPEC is located along the eastern side of the Hudson River (River), approximately 42 miles upstream of the Battery (located at the southern tip of Manhattan and defined as the mouth of the River) in the village of Buchanan, New York. IPEC uses a once-through cooling water system that discharges heated water to the River, through a common discharge canal, subject to and with the benefit of a New York State Department of Environmental Conservation- (NYSDEC) issued State Pollutant Discharge Elimination System (SPDES) Permit which includes thermal discharge limitations.

To establish IPEC's compliance with New York State thermal water quality standards, set forth in 6 NYCRR section 704 (Thermal WQS), a triaxial study of the thermal structure in the River was conducted in late summer and early fall of 2009 that consisted of a combination of field work, data analysis and numerical modeling. A review and preliminary analysis of the field program and dataset derived from that program (Swanson, et al., 2010a) was submitted to NYSDEC on 12 February 2010. A full report documenting the triaxial study (Swanson et al., 2010b) was submitted to NYSDEC on 22 March 2010 that described the field program, the thermal modeling approach, and the evaluation that showed IPEC was in compliance with the Thermal WQS. NYSDEC Staff requested additional validation of the Thermal Report results during the summer period of 2010.

In response, Applied Science Associates, Inc. (ASA) and Normandeau Associates Inc. (NAI) designed and performed the summer 2010 triaxial thermal study. The field survey consisted of long term (early July to mid September), high resolution, fixed temperature, current and salinity observations as well as two days of mobile surveys that captured currents, temperature and salinity profiles in the River at various stages of the tide. The observations were employed in the state-of-the-art, boundary fitted computer hydrothermal model that previously had been provided to NYSDEC Staff.

This report documents that work. Chapter 1 introduces the thermal issues and provides a chronology of relevant previous work performed by ASA for IPEC. Chapter 2 describes the field data sources used in the 2010 summer field program, both public (web-based sources) as well as the IPEC-funded River monitoring. Characterization of the 2010 observations from both public and IPEC sources is described in Chapter 3, including discussions of water level, temperature, salinity, currents, meteorology, as well as IPEC and other plant operations. Model results for the validation period (8 through 30 July) are described in Chapter 4. Determination that IPEC's thermal discharge was in compliance with the Thermal WQS for the summer 2010 period (8 through 30 July) is presented in Chapter 5. Conclusions are summarized in Chapter 6 and references are listed in Chapter 7. The appendices provide extensive documentation of the data collected during the 2010 field program.

2 2010 FIELD MONITORING

Temperature, salinity, water level and current data were collected by NAI during the summer of 2010 (early July to mid-September) through a combination of measurements taken at fixed locations and mobile surveys. In addition, data collected by NAI was supplemented by hydrological measurements obtained from public source stations, as described in Section 2.1.

2.1 PUBLIC DATA SOURCES

Public data sources are those maintained by the federal government or institutions that have instruments deployed in the Hudson River to collect physical parameters. These sources typically maintain websites where the data can be downloaded or requested online. The sources include the U.S. Geological Survey (USGS) river data, the Northeast Regional Climate Center (NRCC) / National Weather Service (NWS) meteorological data, the National Oceanographic and Atmospheric Administration National Ocean Service (NOS) river and ocean data, the Stevens Institute of Technology (SIT) river and harbor data, and the Hudson River Environmental Conditions Observing System (HRECOS) river data. The locations of public source stations used in this report are displayed in Figure 2-1 and the following sections describe these data sources.

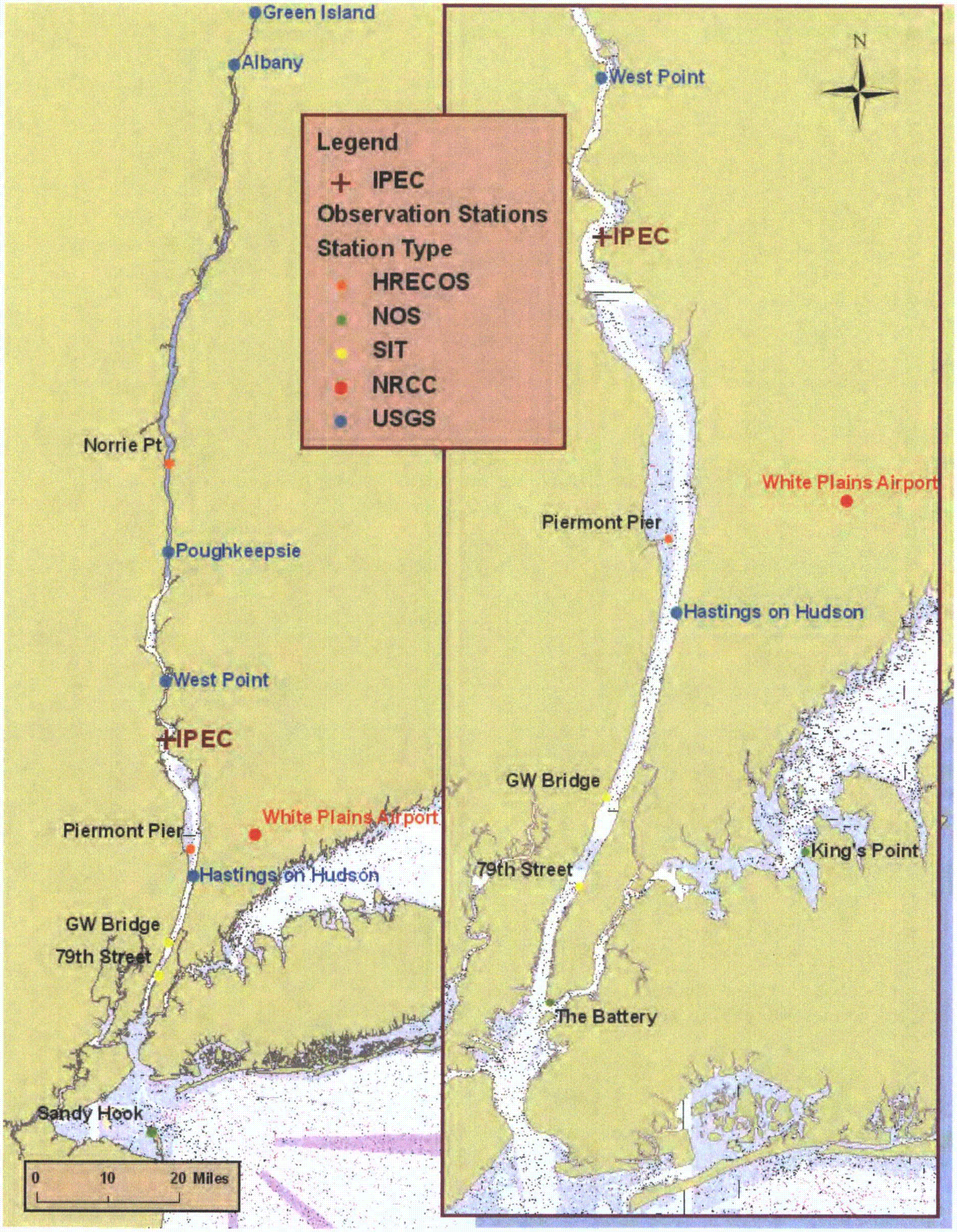

Figure 2-1. Location of public data monitoring locations and IPEC.

2.1.1 USGS Data

The USGS National Water Information System (NWIS) and NWISWeb (http://waterdata.usgs.gov/ny/nwis/) provide both real time and average daily data for many sites in the Hudson River basin. Data include water temperature and/or discharge flow, as well as other parameters, such as water level and salinity (specific conductance) at a number of these sites. Real-time data are time-series data from automated equipment and represent the most current conditions. Measurements are commonly recorded at 15-minute intervals, while daily values are summarized from time-series data for each day for the period of record.

Specifically, the temperature, salinity and water level data used were acquired from two USGS stations along the River, at Hastings and West Point, which are located downstream and upstream of IPEC, respectively. The temperature in the River at IPEC will likely fall between the temperatures measured at these two stations, except for the effect of the IPEC discharge (other thermal discharges do not appear to affect temperatures measured by USGS). USGS temperature and flow data were acquired from the station at Green Island. Data from additional USGS stations were used for model comparisons. Station locations are shown in Figure 2-1. A summary of the stations adapted from the USGS website is provided below:

- Hastings (USGS station 01376304) located 21 mi above Battery at 40°59'16" N, 73°53'15" W referenced to North American Datum of 1927, Westchester County, NY, Hydrologic Unit 02030101, 180 feet from left bank on abandoned Mobil Oil Corporation platform, 0.5 mi southwest of railroad station, at Hastings-on-Hudson. Water temperature, salinity and elevation are measured at a depth of 10 ft below the National Geodetic Vertical Datum of 1929 (approximately mean sea level). The station is located 21 mi downstream of IPEC.

- West Point (USGS station 01374019) located 51 mi above Battery at 41°23'10" N, 73°57'20" W referenced to North American Datum of 1927, Orange County, NY, Hydrologic Unit 02020008, on right bank at South Dock at West Point. Water temperature, salinity and elevation are measured at a depth of 10 ft below the National Geodetic Vertical Datum of 1929 (approximately mean sea level). The station is located 9 mi upstream of IPEC.

- Poughkeepsie (USGS station 01372058) located 75 mi above Battery at 41°39'03" N, 73°56'42" W referenced to North American Datum of 1927, Dutchess County, NY, Hydrologic Unit 02020008, on left bank at IBM pumping station, 2.3 mi south of Poughkeepsie, and 3.5 mi south of the Mid-Hudson bridge. The station is located 33 mi upstream of IPEC.

- Albany (USGS station 01359139) located 143mi above Battery at 42°38'46" N, 73°44'53" W referenced to North American Datum of 1927, Albany County, NY, Hydrologic Unit 02020006, on right bank 0.1 mi upstream from bridge on U.S. Highways 9 and 20 in Albany, and 0.7 mi downstream from railroad bridge. The station is located 101 mi upstream of IPEC.

- Green Island (USGS station 01358000) located 148 mi above Battery at 42°45'08" N, 73°41'22" W referenced to North American Datum of 1927, Albany County, NY, Hydrologic Unit 02020003, on right bank at Green Island, just upstream from Troy lock and dam, and 0.5 mi downstream from 5th branch Mohawk River. Since October 2000, estimated water-discharge data is based on records for Hudson River above Lock 1 near Waterford (01335754) and Mohawk River at Cohoes (01357500). The station is located 106 mi upstream of IPEC.

2.1.2 NRCC/NWS Data

The Northeast Regional Climate Center (NRCC) database (http://www.nrcc.cornell.edu/) includes historical climate data for the northeastern United States as well as continually updated National Weather Service (NWS) weather observations and forecasts. NRCC has also developed models that estimate variables such as solar radiation and evapotranspiration. The closest NWS station to IPEC is the White Plains Airport (HPN) located 18 mi south southeast at 41°4'12" N, 73°43'12" W in Westchester County, NY. A variety of meteorological observations are recorded including air temperature, dew point, wet bulb temperature, pressure, relative humidity, wind speed and direction, and solar radiation. The NRCC station location is shown in Figure 2-1.

2.1.3 NOS Data

The National Oceanographic and Atmospheric Administration National Ocean Service (NOS) maintains real-time sensors in the lower Hudson River, New York Harbor, Long Island Sound, and along the New York and New Jersey coasts primarily measuring water level but frequently also temperature and salinity. The three NOS stations collecting temperature data, The Battery, Sandy Hook and Kings Point, are shown in Figure 2-1. Station descriptions are available from http://tidesandcurrents.noaa.gov/ports/index.shtml?port=ny and are summarized below.

- The Battery, NY (NOS Station 8518750) is located at 40°42.0' N, 74°0.8' W. The gage is located on the pier behind the U.S. Coast Guard Inspection Office on State Street, New York City. The station is located 41.5 mi downstream of IPEC.

- Sandy Hook, NJ (NOS Station 8531680) is located at 40°28.0' N, 74°0.5' W. The gage is located at the south end of U.S.C.G small pier in a tide house with NOS sign at U.S. Coast Guard Base Fort Hancock in Sandy Hook. The station is located 55 mi south of IPEC.

- Kings Point, NY (NOS Station ID: 8516945) is located at Latitude: 40°48.6' N, 73°45.8' W. The gage is located on the sailing center dock of the U.S. Merchant Marine Academy on Steamboat Avenue in Kings Port. The station is located 32 mi south of IPEC.

2.1.4 SIT Data

The Stevens Institute of Technology (SIT) maintains real-time sensors in support of its New York Harbor Observing and Prediction System (NYHOPS) that encompasses the lower Hudson River Estuary, the New York / New Jersey Harbor Estuary, the East River, Raritan Bay, Long Island Sound and the coastal waters of New Jersey. The two SIT stations collecting temperature data, the George Washington Bridge and 79th Street, are shown in Figure 2-1. Water level, temperature, dissolved oxygen, turbidity, conductivity, and pH are collected at these sites. No detailed information about the specific sites was found on the SIT Urban Ocean Observatory website http://hudson.dl.stevens-tech.edu/maritimeforecast/PRESENT/data.shtml. However, temperature data from these locations were analyzed as part of the study.

2.1.5 HRECOS Data

The Hudson River Environmental Conditions Observing System (HRECOS) maintains real-time sensors in the Hudson River Estuary from Schodack Island to the New York / New Jersey Harbor. There are six sites along the River but only the two southern HRECOS stations, Norrie Point and Piermont Pier that are within the lower River, are of interest and shown in Figure 2-1. Measurements, collected at 15-minute intervals, include dissolved oxygen, turbidity, stage, temperature, salinity, pH, chlorophyll, colored dissolved organic matter, and blue-green pigments. The Norrie Point site, at River Mile (RM) 85, is located at the Hudson River Research Reserve's headquarters and operated by its staff. The Piermont Pier site, at RM 25, is located at the northern boundary of the Piermont Marsh Reserve site and is operated by Columbia University's Lamont Doherty Earth Observatory. Specific information (metadata) can be found at http://hudson.dl.stevens-tech.edu/hrecos/d/ and is repeated below:

- Norrie Point (41°49'54.8" N 73°56'29.8" W) is a bedrock outcropping into the main stem of the Hudson River adjacent to a cove. The depth at the sampling location ranges from approximately 3 to 11 ft. YSI 6600 dataloggers are deployed at Norrie Point approximately 11 ft off the bottom in a perforated four-inch aluminum tube that is vertically mounted to a piling at the end of a dock. The datalogger contains sensors for temperature, conductivity, pH, dissolved oxygen, turbidity, chlorophyll a, and depth. The depth sensor at Norrie Point is vented to the atmosphere for more precise depth readings. The station is located 48.5 mi upstream of IPEC.

- The Piermont Pier sampling station, in Piermont NY (41° 2' 35.0" N 73° 53' 45.9" W), is situated on the end of a mile long pier stretching into the Hudson River. The pier is open to the public and regularly used for recreational purposes. It is located just north of the NERRS Piermont Marsh where approximately 30 MGD of secondarily treated sewage is discharged from Orangetown and Rockland County. The local tidal range varies between 3 and 5 feet and the river bottom is characterized by thick mud and rocks. A submersible YSI 6600 multi-probe sonde is deployed in a perforated PVC tube encasing mounted to the pier. The installed sensors monitor chlorophyll, dissolved oxygen, salinity, turbidity, water temperature, water level and pH. The station is located 16.5 mi downstream of IPEC.

2.2 IPEC River Monitoring Data

An extensive field program was designed jointly by NAI and ASA to acquire in-River temperature, current velocity, water level and salinity data with which to evaluate the characteristics of the thermal discharge in the River from IPEC. A long-term (July – mid-September 2010) deployment of moored instruments was conducted in the River. Thermistors were used to measure temperature, Acoustic Doppler Current Profilers (ADCPs) were used to measure current velocities and water level, and Conductivity-Temperature-Depth (CTD) instruments were used to measure salinity and temperature. Locations of the thermistor, ADCP and CTD monitoring stations, are shown in Figures 2-2 to 2-4 (north, in vicinity of, and south of IPEC, respectively) as a series of plan views of the River with numbered locations for the thermistor and CTD stations. Figure 2-5 displays the location of transects used for the mobile intensive surveys, which acquired cross River temperature, salinity, and current velocity data during select tidal events during the 2010 summer survey period.

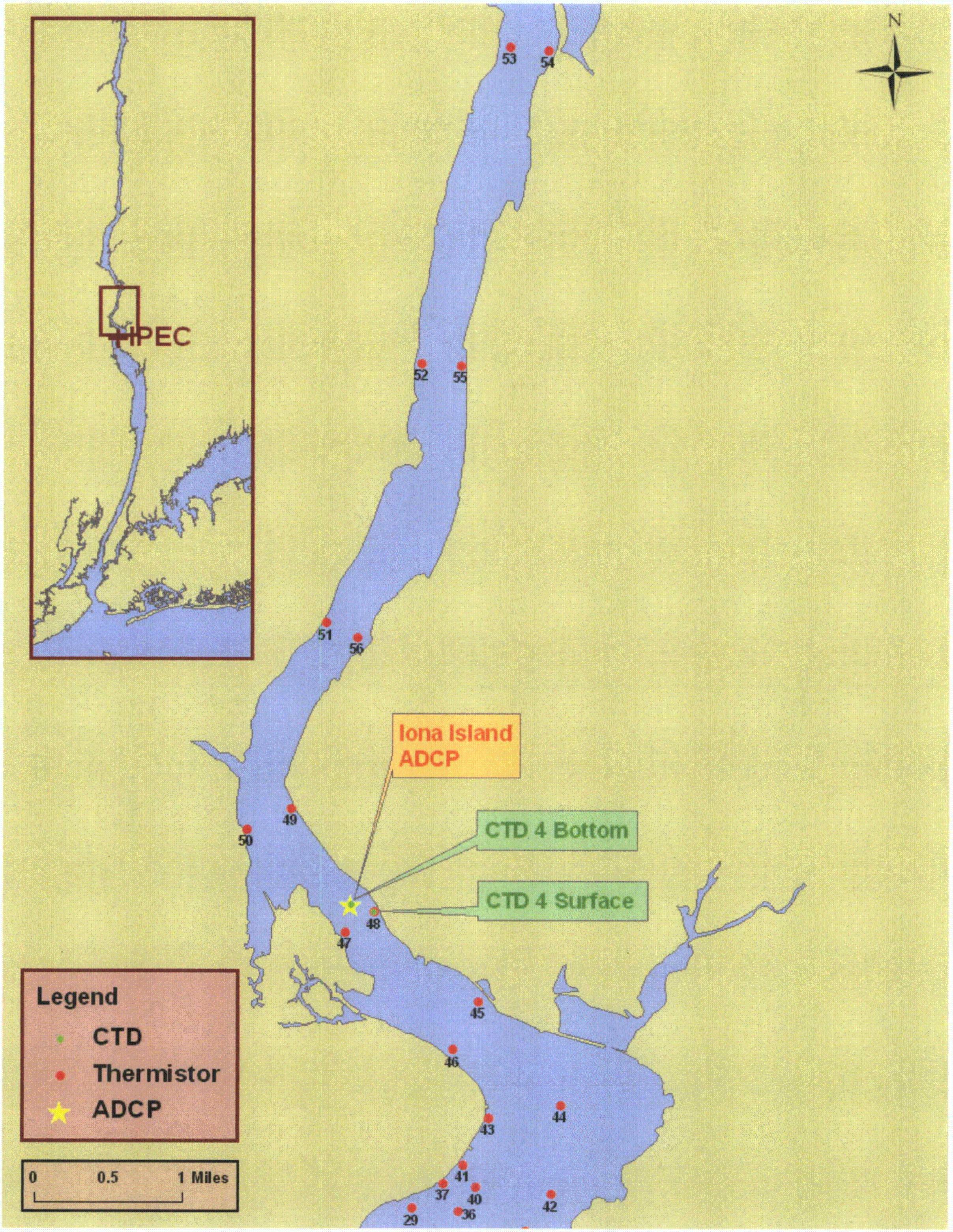

Figure 2-2. Location of IPEC moored thermistor, ADCP and CTD monitoring stations in section of River north of IPEC.

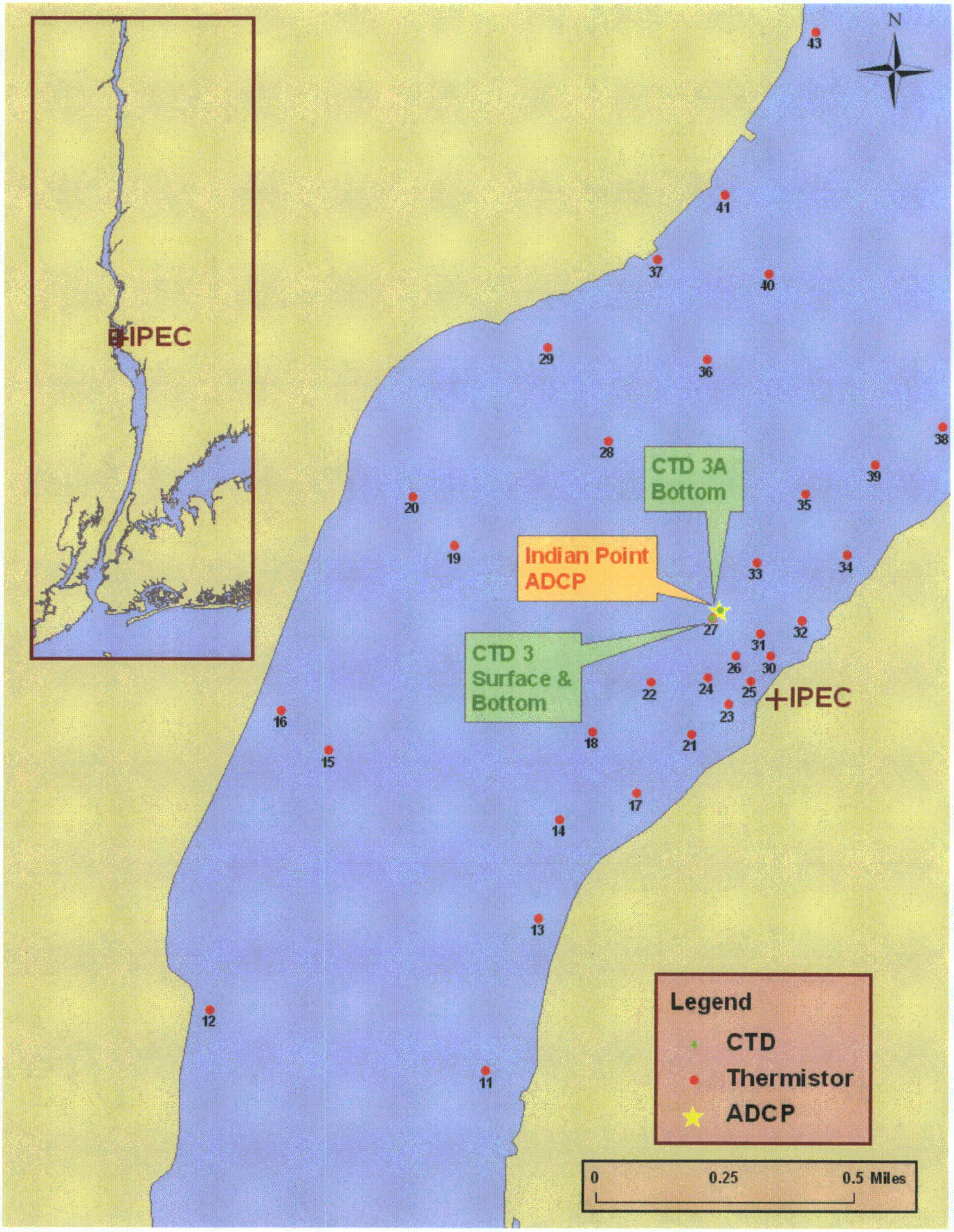

Figure 2-3. Location of IPEC moored thermistor, ADCP and CTD monitoring stations in section of River near IPEC.

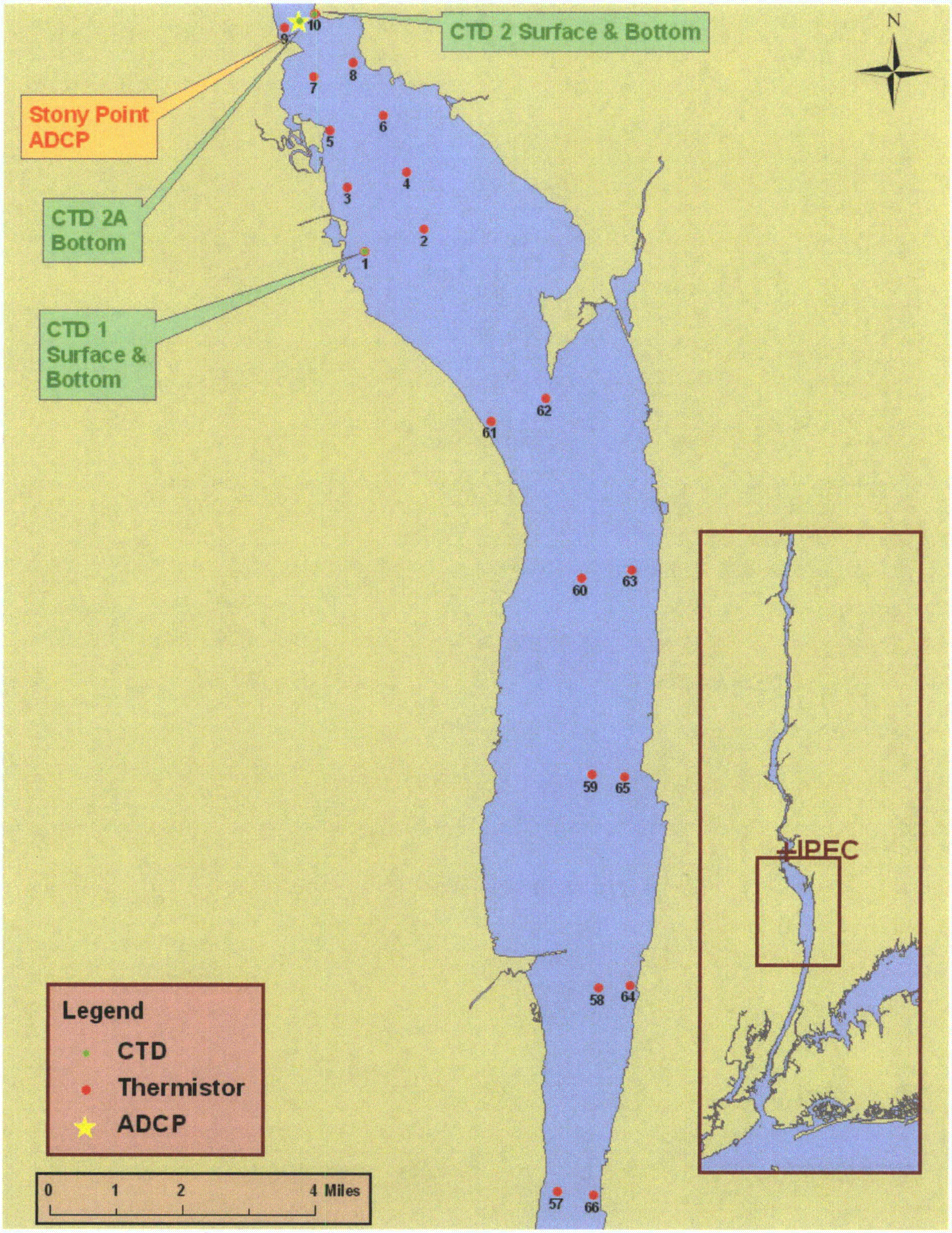

Figure 2-4. Location of IPEC moored thermistor, ADCP and CTD monitoring stations in section of River south of IPEC.

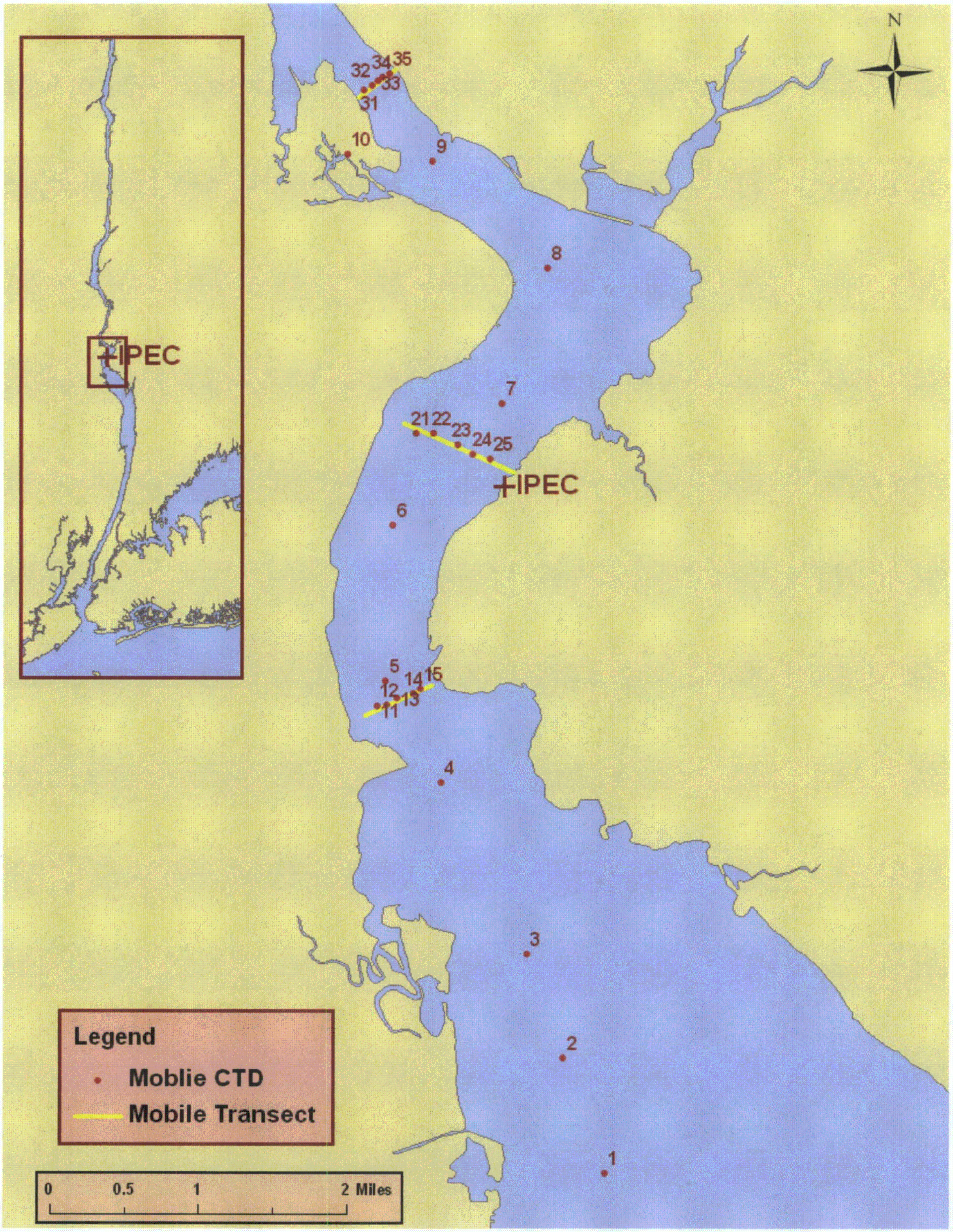

Figure 2-5. Location of IPEC CTD profiling stations and mobile survey transects for thermistor and ADCP measurements.

2.2.1 Thermistor Deployment Description and Data Processing

Sixty six (66) moored thermistor strings (Onset TidbiT v2 temperature loggers and Onset Hobo U20 series temperature and water level loggers) were deployed by NAI starting on 5 July 2010 and ending deployed by 9 July 2010. The strings had between three and six thermistors affixed at various depths as described below. Fixed thermistor moorings were checked and their data downloaded weekly through the period. The thermistors were deployed until early September, with the last thermistor retrieved on 10 September 2010.

The geographic area of the River covered by this fixed thermistor array was from 9.5 mi north of Indian Point to 20.9 mi south of IPEC (at RM 41.7), and designed to encompass the thermal conditions in the area of influence of IPEC. Figures 2-2 to 2-4 show a plan view of the station locations of the thermistor moorings in the River. Along the River, there are two station pairs, one on each side of the River, that are designed to capture the along- and cross-River temperature variations.

The thermistor stations for the 2010 field program were increased from the 50 stations used in the 2009 study (Swanson et al., 2010b) to 66 stations to capture a larger area of the River thermal dynamics. Six stations were added to the north (upstream) of IPEC end and 10 stations to the south (downstream).

Fifty moored strings consisting of up to six thermistors, each mounted along a line between a surface float and bottom anchor were deployed at stations 1 - 50 as shown in Figures 2-2 to 2-4. The surface thermistors were located between 1 and 1.3 ft below the surface. The bottom thermistors were located 1 ft above the anchors and ranged from 26 to 101 ft deep. The remaining four thermistors were distributed either at approximately 5, 15 and 25 feet below the surface and equidistant between the 20 foot and bottom thermistor, when depths at the deployment location permitted. If depths were too shallow (less than 35 ft) to accommodate six thermistors, fewer thermistors were deployed.

The 16 additional 2010 moored strings consisted of three thermistors, each mounted along a line between the surface float and bottom anchor. The surface thermistors were located between 1 and 1.3 ft below the surface. The bottom thermistors were located 1 ft above the anchors. The remaining thermistors were located approximately 15 ft below the surface.

Consistent with NAI's extensive experience in performing triaxial thermal surveys, the thermistors were set to acquire temperature data instantaneously every five minutes during the deployment period. The Onset TidbiT specification sheet lists an accuracy of 0.36°F. Each data record consisted of date, time, water temperature, instrument serial number, latitude, longitude, and depth.

Raw data were received from NAI and had been quality assured through NAI's own extensive procedures. Additional measures were used by ASA to identify any additional extraneous outliers as described in Swanson et al. (2010b) and summarized below. ASA's quality assurance involved calculation of data differences between adjacent data records, both forward and backward in time, where the distribution of the magnitude of these differences was determined, and data identified as statistical outliers were flagged. The data were then filtered with a 1-hr centered running average (1-hr boxcar filter) and subsampled to hourly values to aid in understanding the significant processes affecting the temperature variations, including tidal effects, meteorological forcing and ocean water intrusion, by removing the very short term influences, e.g., barge traffic, etc.

Time series for each of the thermistors on each of the 66 hourly subsampled thermistor stations are presented in Appendix A for the individual thermistor periods of deployment. The corresponding statistics (minimum, maximum, mean, median, and standard deviation) for each thermistor are presented in Appendix B.

2.2.2 ADCP Deployment Description and Data Processing

Continuous three-dimensional water velocity measurements throughout the entire water column were made using three bottom-mounted Acoustic Doppler Current Profilers (Teledyne RD Instruments Workhorse Sentinel ADCP 600 or 1200 kHz). Near Indian Point, one ADCP was moored in the deeper part of the channel on the east side of the River (41° 16′ 14.82″ N, 73° 57′ 30.00″ W) approximately 1000 ft offshore of the IPEC discharge. The ADCP was deployed in on 8 July 2010 and retrieved 68 days later on 14 September 2010. A second bottom-mounted ADCP was located across the River from Iona Island (41° 18′ 29.53″ N, 73° 58′ 20.16″ W) in the deepest part of the channel closer to the east shore approximately 3.3 mi north of IPEC. This ADCP was deployed and retrieved on the same days as the ADCP at Indian Point (8 July to 14 September). A third ADCP was located near Stony Point (41° 14′ 50.67″ N, 73° 58′ 12.95″ W) at about 45 ft deep in the deeper part of the channel closer to the west shore approximately 2 mi south of IPEC. This ADCP was deployed on 1 July 2010 and retrieved on 14 September 2010. ADCP locations are shown in Figures 2-2 through 2-4.

Each ADCP was mounted facing upward in a gimbaled tripod and deployed with a submerged surface buoy line attached by an acoustic release (Benthos Model 875). Water velocity measurements were averaged over 5 minute intervals (ensembles) at 3.3 ft vertical increments throughout the whole water column, with measurements starting approximately 10 ft above the bed. Data were initially reviewed in WinADCP software provided by Teledyne RD Instruments and then exported to Matlab data files by NAI. The data was subsequently processed according to the same routine as the thermistor data processing as described in Section 2.2.1.

For the later analysis, the magnitudes of the current velocities recorded from the ADCPs were rotated to along-channel direction to more clearly show the flow in the up and downstream directions. The Iona Island ADCP data were rotated 45 degrees west of north, IPEC ADCP data were rotated 50 degrees east of north and the Stony Point ADCP data were rotated 50 degrees west of north.

2.2.3 CTD Deployment Description and Data Processing

Long-term moored observations of salinity were conducted at surface and bottom at four stations, which include Haverstraw Bay (CTD1), Stony Point (CTD2), Indian Point (CTD3), and Iona Island (CTD4) shown in Figures 2-2 through 2-4. A total of 14 CTD sensors (either RBR, Inc. XR-420CT or Onset, Inc. U24 models) were mounted on either ADCP frames or stationary thermistor chains. The data were then filtered and sub-sampled in the same manner as the other data..

2.2.4 Mobile Survey Description and Data Processing

In order to capture cross River variability two intensive mobile surveys were completed. The two days of deployment corresponded to spring (13 July) and neap (3 August) tide conditions. During each day three cross river transects were sampled four times over a complete tidal cycle, approximately corresponding to times of high water slack, ebb tide, low water slack, and flood tide.

The transect locations corresponded to the moored ADCPs at Stony Point, Indian Point, and Iona Island shown in Figure 2-5. Temperature measurements were taken in the surface layer using seven thermistors at 3.3-ft depth increments. Currents were measured using a boat mounted ADCP (Sontek ADP 1MHz). Results from the mobile temperature surveys are presented in Appendix C as vertical cross sections that include relevant fixed thermistor temperatures. The results from the mobile ADCP data are presented as vertical cross sections of contoured speed in Appendix D.

In addition, CTD profiles using a RBR CT-420CT instrument were completed at a total of 25 stations to provide high resolution measurements in the vertical. A total of five CTD profiles for each transect, as shown in Figure 2-4, were completed in the same time frame as the other mobile surveys. A separate NAI vessel that collected the CTD profiles was different from that used for the continuous ADCP and temperature transect surveys to facilitate synoptic data acquisition, and the deployment once again consisted of two separate days of deployment (13 July and 3 August) for the same four phases of the tide. Additionally, ten points where chosen along the axis of the River between Iona Island and Stony Point to resolve longitudinal variation.

CTD profiles at each of the 25 locations provided temperature and specific conductivity (which was converted to salinity) from the surface to the bottom of the water column. NAI completed its own systematic quality control and quality assurance on the data. ASA further processed the data by eliminating any additional outliers at the surface and bottom layer, and only the CTD profile obtained during the down cast was analyzed to eliminate instrument-induced interference by mixing the water. Vertical profiles of salinity and temperature are presented in Appendix E.

3 Characterization Of 2010 Observations

Temperature, salinity, water level and current data from various sources, as described in Section 2, were used to characterize the River based on the type of observation. The discussion below describes the tidal nature (Section 3.1), thermal structure (Section 3.2), salinity structure (Section 3.3), and the currents (Section 3.4) within the River. Additionally, local meteorology (Section 3.5), IPEC plant operations (Section 3.6), and thermal inputs from other power plants (Section 3.7) are discussed in this chapter.

3.1 Water Level

Fixed station ADCPs from the 2010 field study measured water depth every 5 minutes. The mean depth over the period of record was calculated and subtracted from each water depth measurement to determine the change in water level over time. Figure 3-1 displays the water levels from the three fixed station ADCP units, located at Iona Island, Indian Point, and Stony Point. The average tidal ranges were 3.27 ft, 3.46 ft, and 3.44 ft at Iona Island, Indian Point, and Stony Point, respectively.

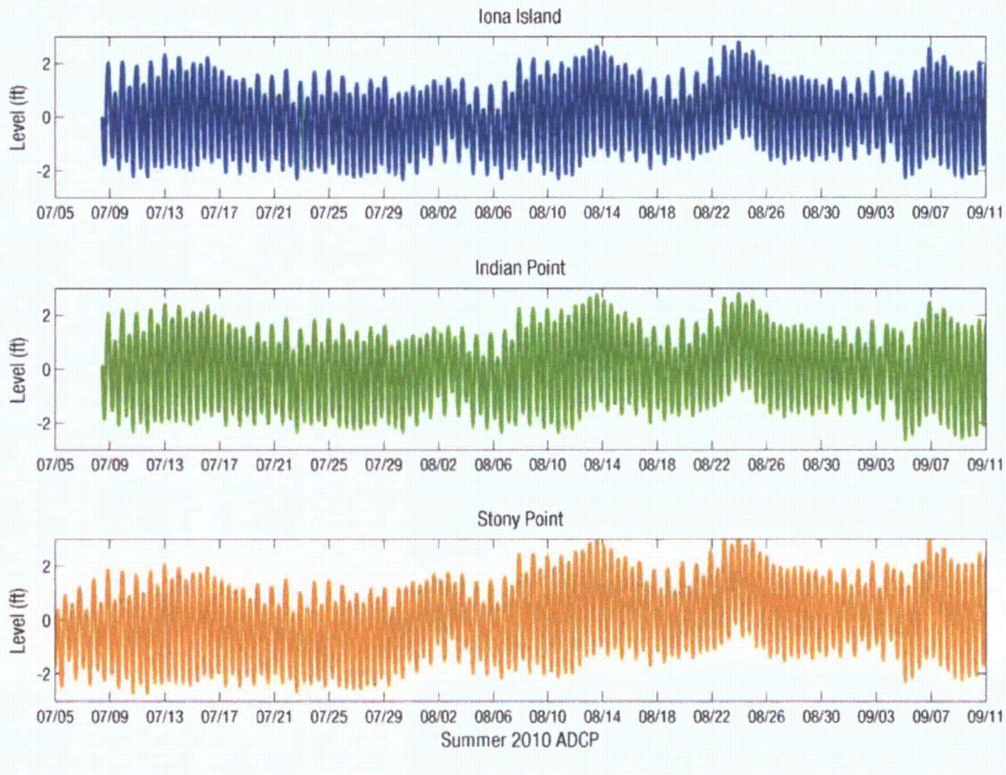

Figure 3-1. Water levels at IPEC ADCP locations for Iona Island (top), Indian Point (middle), and Stony Point (bottom) during 2010 survey period.

The local trend around the Indian Point region based on these values indicated that the tidal range decreased as the tidal wave propagated up the River toward West Point. However, data from a series of USGS/NOS stations, shown in Figure 3-2, indicate that this trend is not consistent throughout the entire river system. At the tip on Manhattan, The Battery (NOS) water level records indicated the average tidal range was 4.76 ft. To the south of the three ADCP stations and north of The Battery, the Hastings station had an average tidal range of 3.83 ft. The West Point station, located to the north of Iona Island had an average tidal range of 3.20 ft. The Poughkeepsie station, located north of West Point at RM 77, had an average tidal range of 3.30 ft. Additionally, the Albany station, located far upriver past West Point at RM 144, had an average tidal range was 5.74 ft, the largest tidal range observed of all of the stations.

Therefore, the data suggests that the tide levels are high at the southern portion of the River near the ocean. Up the River the tidal ranges tend to decrease until the West Point stretch of the River, where the ranges reverse trend and begin to increase to Albany.

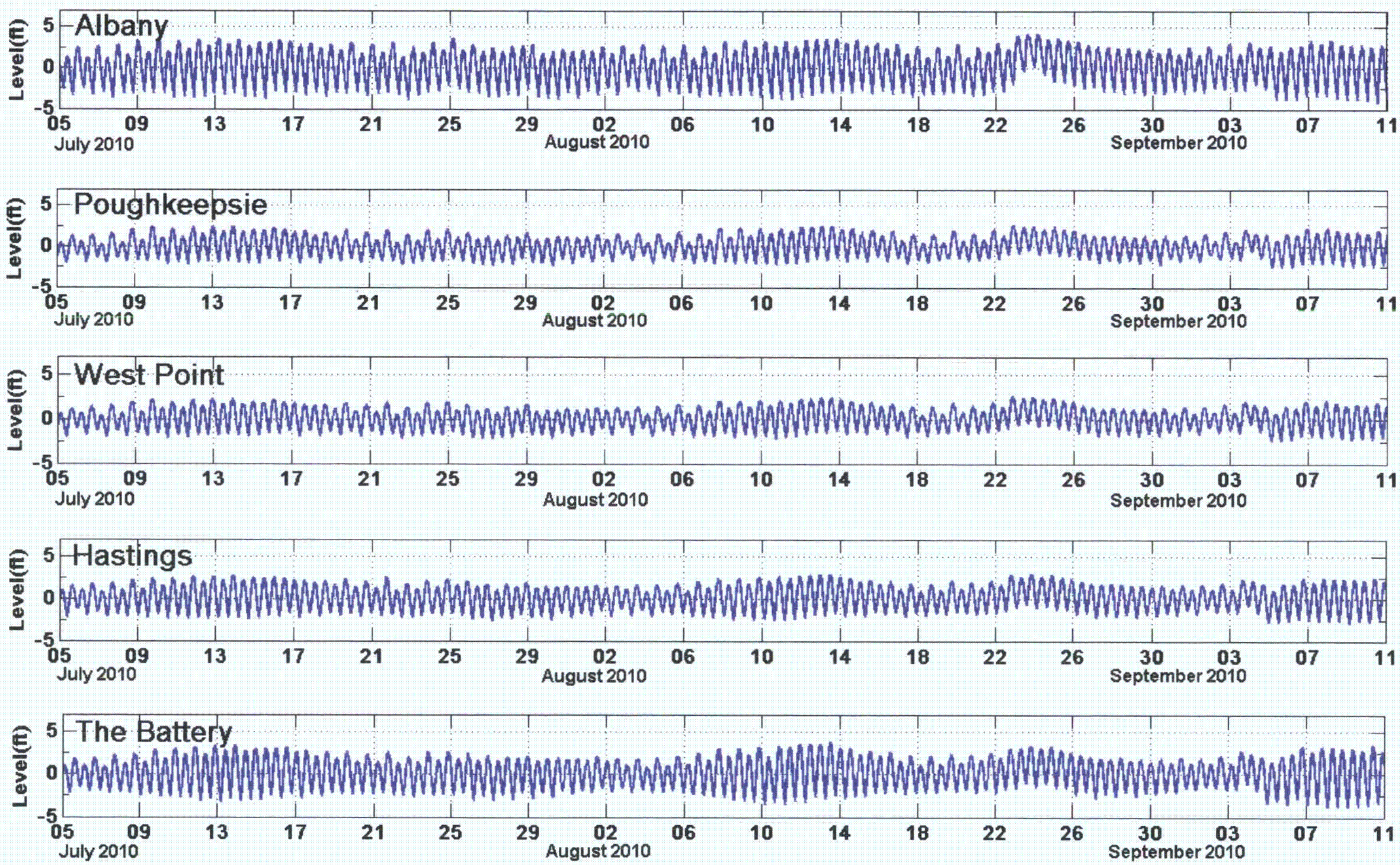

Figure 3-2. Water levels at public stations along the Hudson River for Albany (top), Poughkeepsie (upper middle), West Point (middle), Hastings (lower middle), and The Battery (bottom) during 2010 survey period.

3.2 TEMPERATURE

The temperature conditions in the River during summer 2010 were evaluated by source, i.e., public and IPEC funded studies. The public sources, as identified in Section 3.2.1 included USGS, NOS, SIT and HRECOS data available on the Internet. A temperature characterization based on the IPEC thermistor monitoring program conducted by NAI during the summer of 2010 is presented in Section 3.2.2.

3.2.1 PUBLIC DATA

Throughout the Hudson River, the ambient temperature varies spatially and temporally. Ambient temperatures change along the River, varying primarily due to the effects of mixing of ocean waters intruding up River, and freshwater flow entering the River from upstream tributaries and proceeding down River. The variability of both atmospheric conditions and local river bathymetry, whereby shallow waters heat up considerably faster than deeper regions play a major role in temperature variations. While an extensive field program was implemented during the summer of 2010, a variety of public data sources exist in or are proximate to the study area (as described in Section 2.1) that are available to supplement the NAI-collected data.

North of Indian Point there are four main hydrological stations which help to characterize the near-surface (typically 10 ft depth) river temperature, those being Albany (USGS), Norrie Point (HRECOS), Poughkeepsie (USGS), and West Point (USGS). Figure 3-3 shows the water temperature at these northern locations for the study period. The locations of these stations are shown in Figure 2-1.

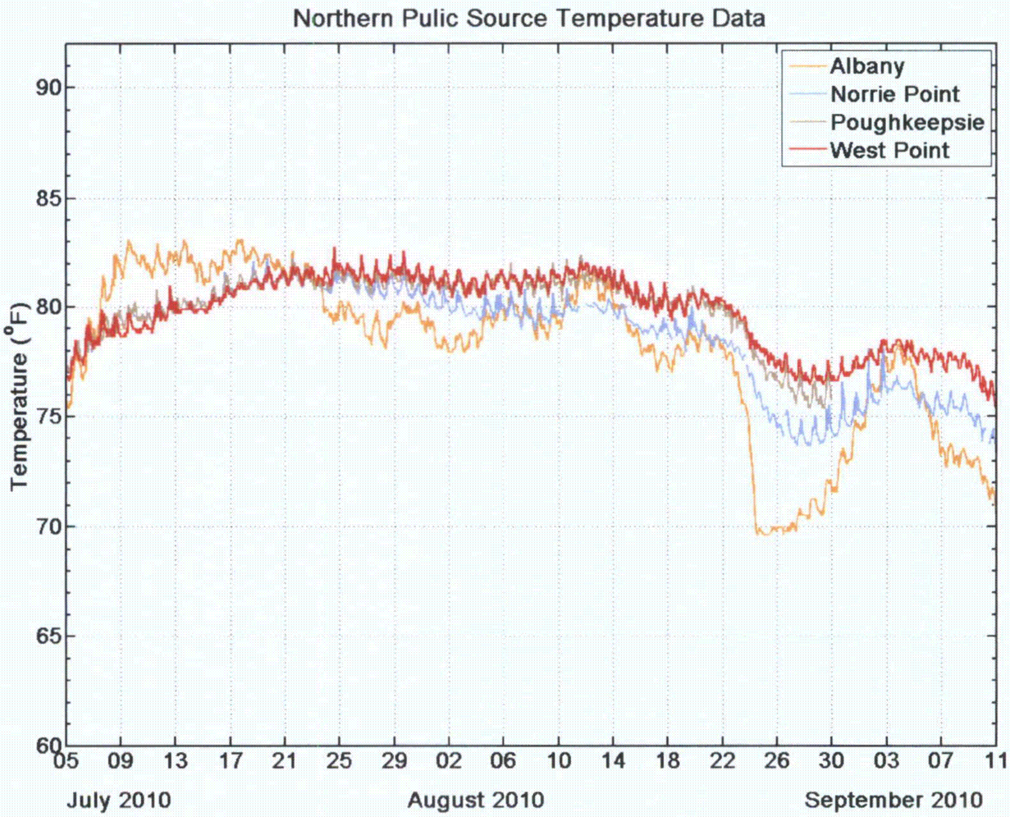

Figure 3-3. Temperatures from public stations located upstream (north) of IPEC during the summer 2010 period.

Albany, the northernmost station, responded quite differently from the other stations presented in Figure 3-3. Albany transitioned from being the coldest station near the beginning of the study period (5 July), with a low of 75.4°F, to being the warmest station of the four for a 10-day period in mid-July, during which the maximum temperature at Albany peaked at 83.1°F on 17 July. Thereafter, the Albany temperature dropped and once again was the coolest of the four stations. Albany remained the coolest, with a few short-lived spikes in temperature, until the end of the study period (mid-September). The minimum temperature at Albany was 69.6°F, observed multiple times between 24 August to 26 August.

In contrast, the Norrie Point, Poughkeepsie and West Point stations all exhibited similar trends, with a slight rise in surface temperatures (~5°F) from 5 July through to 20 July, whereupon temperatures generally plateaued until 13 August. Thereafter temperatures declined gradually over the last month of the study (mid-August to mid September). During this decline through the later part of August and the beginning of September, variations in the temperature between Norrie Point, Poughkeepsie, and West Point became more evident, with the northernmost station (Norrie Point) exhibiting the lowest temperatures and the southernmost station (West Point) exhibiting the warmest temperatures. The maximum observed temperatures for the Norrie Point, Poughkeepsie, and West Point were, respectively, 82.5°F, 82.6°F, and 82.8°F, with these maximums all occurring on 24 July. The minimum temperature recorded at Norrie was 73.2°F and at West Point was 75.4°F, where minimums at both locations occurred multiple times between 11 September and 13 September. The minimum temperature at Poughkeepsie was 75.2°F, which occurred on 28 August. The median values for Norrie, Poughkeepsie, and West Point were 78.4°F, 80.1°F, and 80.2°F, respectively.

South of IPEC the Piermont Pier (HRECOS), Hastings (USGS), and George Washington Bridge (SIT) stations provided water temperature data as shown in Figure 3-4. The locations of these stations are shown in Figure 2-1. The temperatures at these stations showed larger daily variability due primarily to their locations within the estuarine portion of the River than those to the north. Warmer freshwater flowing from upstream (north) occurred during ebb tide, while cooler ocean water moved up the Hudson River during flood tide. In addition, daily heating of shallow waters played a major role in such areas as Haverstraw Bay, located north of the Piermont Pier and Hastings stations. Typically the major peaks have a diurnal signal from daily heating, although temperatures decrease slightly during the flood tide as cooler ocean water propagates up the Hudson River.

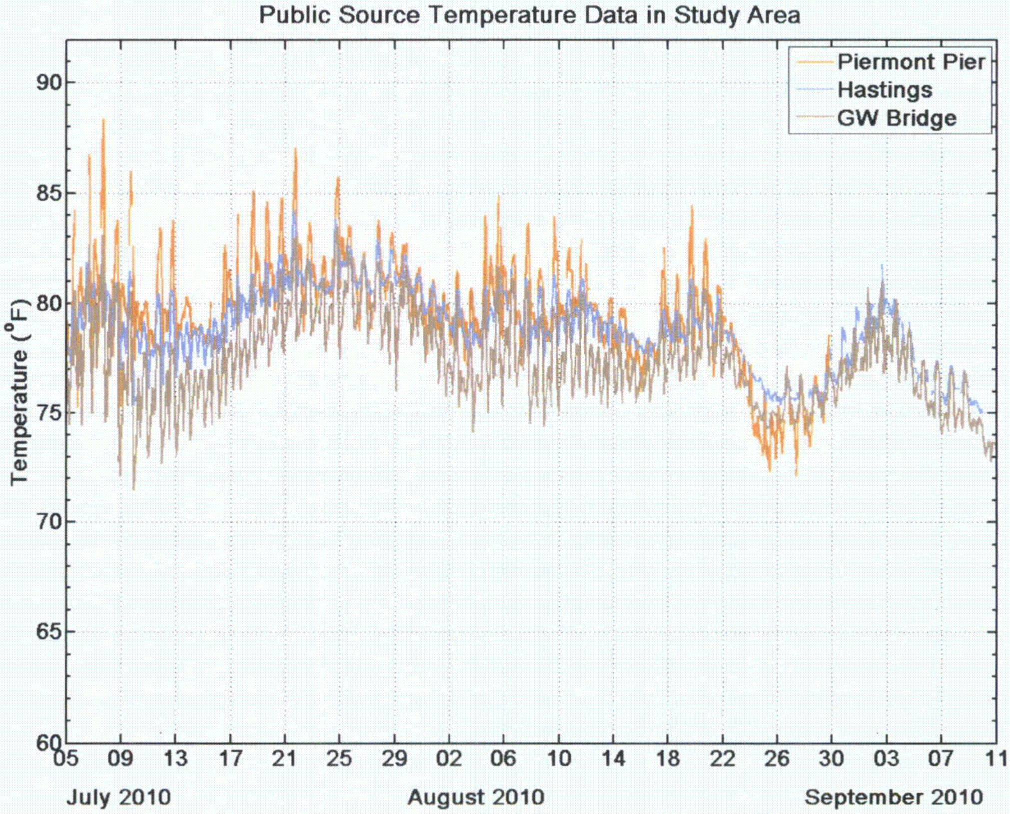

Figure 3-4. Temperatures from public stations located downstream of IPEC in or just south of the study area during the summer 2010 period.

These three stations generally exhibited similar variation between 75°F and 85°F for most of the study period, until the last week when temperatures dropped to consistently below 75°F. The maximum temperatures at Piermont Pier, Hastings, and GW Bridge were 88.5°F (7 July), 84.7°F (21 July), and 83.4°F (24 July), respectively. The minimum temperatures were 72.2°F (27 August), 72.9°F (multiple times from 11 to 13 September), and 71.5°F (9 July and 13 September and median temperature for the three stations were 79.5°F, 78.7°F, and 77.3°F, respectively.

Further downstream, both in and outside the River proper, there are four additional stations which show general trends from the ocean and provide an understanding for the complex dynamics of the Hudson River estuary. The 79th Street station data, collected by SIT, and data at the Battery, Sandy Hook, and Kings Point, all from NOS, were examined to determine the temperature variability south of the primary study area, as shown in Figure 3-5. While some of these stations are far from IPEC, understanding the Hudson River system by addressing boundary forcing at or near its mouth is necessary.

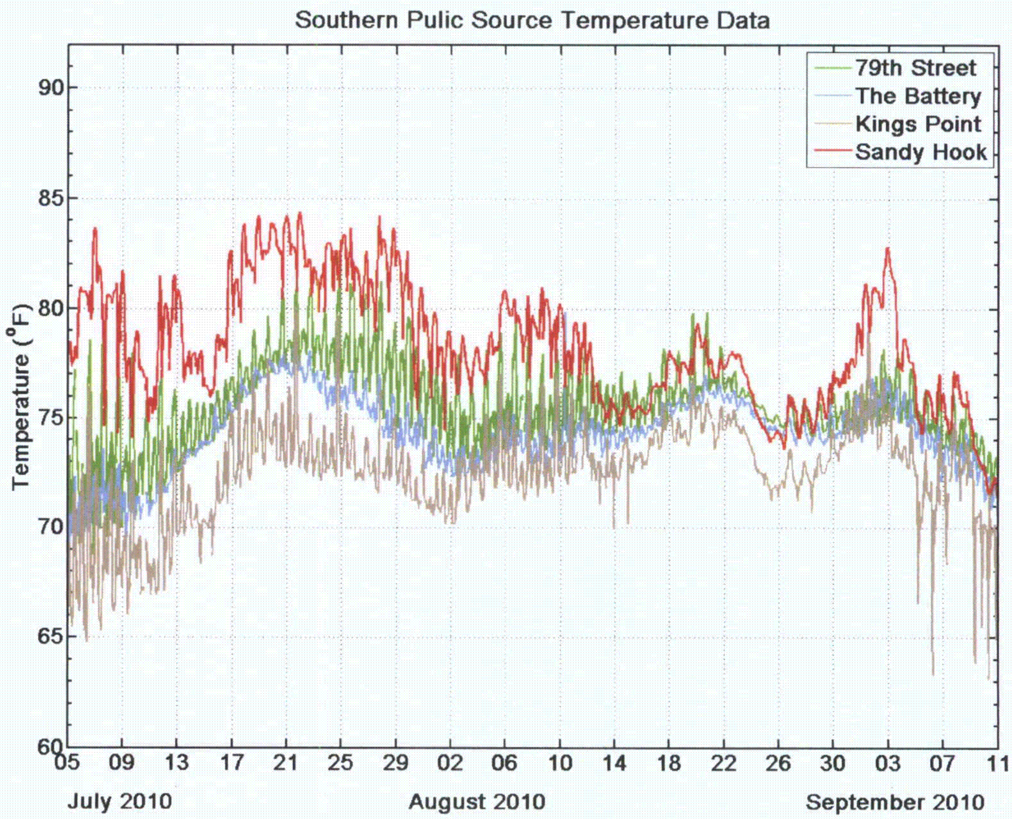

Figure 3-5. Temperatures from public stations to the south of Indian Point during the summer 2010 period.

The 79th Street station is located along the eastern side of the River on Manhattan Island. The NOS stations are located at the southern tip of Manhattan (The Battery), the entrance to outer New York Harbor (Sandy Hook) and in western Long Island Sound near the entrance to the East River (Kings Point), all relatively different water bodies (Figure 2-1). All locations exhibited similar general characteristics, each with a consistent temperature offset: 79th Street with a median of 75.6°F, Sandy Hook with a median of 78.2°F, The Battery with a median of 74.3°F and Kings Point with a median of 72.4°F. The four locations rose in temperature about 10°F during the first half of July, with a slight decline in temperatures thereafter from 20 July to 1 August. A general decline in temperatures was observed from 1 September to the end of the study period. This is generally consistent with observations at other public source stations located further north in the Hudson River.

The maximum temperatures at 79th Street, The Battery, Sandy Hook and Kings Point were 82.4 °F (24 July), 79.9°F (10 August), 84.4°F (21 July), and 80.0°F (21 July), respectively. The minimum temperatures were 68.8 °F (6 July), 69.1°F (12 September), 70.5°F (multiple times from 11 to 13 September), and 63.1°F (10 September), respectively.

3.2.2 IPEC Thermistor Data

Approximately six million, seven hundred and fifty thousand (6,750,000) temperature measurements were made during the deployment from July through mid-September from 318 thermistors located on 66 moorings. Each thermistor data set was processed from 5-min raw data to 1-hr averaged and subsampled to hourly values as described in Section 2.2.2. All data in this analysis are shown hourly to eliminate very short period variations. Time series of all the thermistors are found in Appendix A with one graphic for each of the 66 stations. Statistics (minimum, maximum, mean, median, and standard deviation) for data from each thermistor are found in Appendix B.

To give an overall sense of the variation of temperature from these thermistors, the data were aggregated into minimum and maximum for each 1-hr interval, as shown in Figure 3-6. There was a general heating effect from early to mid-July, then a plateauing through the last week of July and finally a decrease in temperature that persisted to the beginning of September, as seen in both the surface minimum and maximum temperature time series. The minimum temperature of all thermistors, regardless of thermistor depth, exhibited similar temporal trends to the minimum surface temperature variation, although it was observed to be equal to or slightly cooler in general. In addition, there was a more pronounced decrease in the first 10 days of August and decreased temperatures observed around 8 July, 20 August, and 2 September in the overall minimum temperature relative to the minimum surface temperature. The hottest temperature always appeared at the surface, therefore the maximum surface thermistor temperature was identical to the maximum of all thermistors.

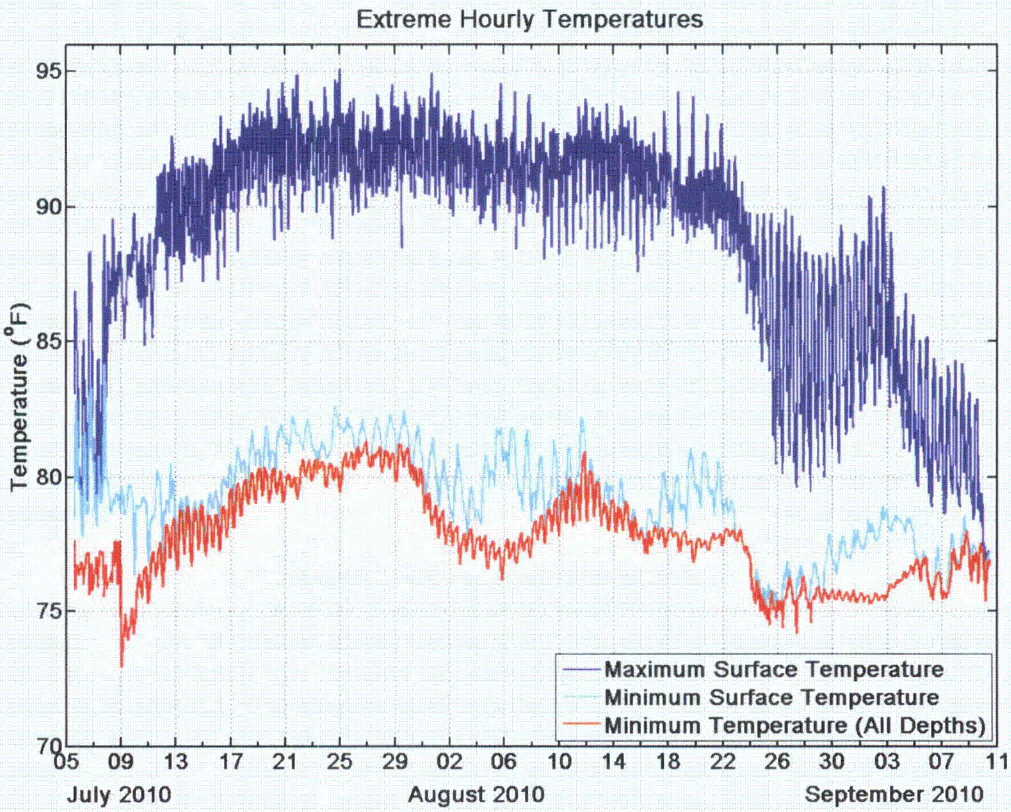

Figure 3-6. Maximum and minimum temperatures of all surface IPEC thermistors and the minimum temperature for all thermistors during the summer 2010 survey period.

The relatively large oscillations shown most clearly in the maximum temperature were caused by the tides with a 12.42-hr period transporting the discharge plume to thermistor station 25. The highest maximum temperature was 95.1°F on 24 July. The lowest minimum surface temperature was 75.0 °F occurring on 24 August. The lowest minimum temperature of all the 318 thermistors was 72.9°F on 9 July.

Figure 3-7 shows the time variation of temperature at all three depths for the most downstream station (66, see Figure 2-4) for the July to September period of deployment. All depths showed a general rise during July, followed by a decline from the beginning of August until September. The surface temperature exhibited a large diurnal (daily) signal while the deeper thermistors more typically exhibited a semi-diurnal (tidal [12.42 hrs]) periodic signal, which is known as the M2 tidal constituent. The diurnal signal at the surface thermistor is probably due to daily heating and cooling from local solar radiation. The trend at the 15-ft depth was consistent with the USGS Hastings station which measures temperature at 10 ft. Note that major gaps in the record are a result of data flagged as unusable by NAI as outlined in Section 2.2.2 (as seen around 12 August for station 66).

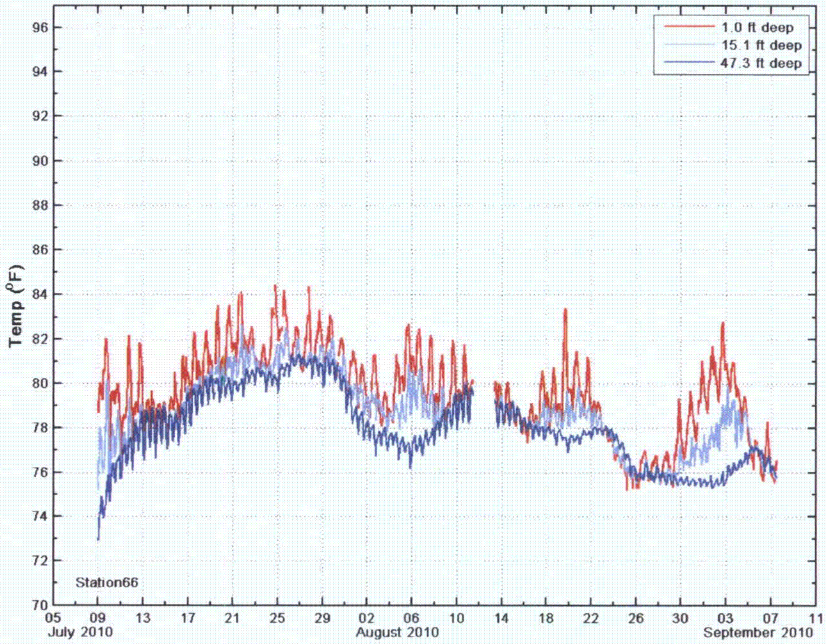

Figure 3-7. Temperatures for all depths at southern boundary (station 66 – RM 20.6) during the summer 2010 survey period.

The maximum surface temperature at station 66 occurred on 24 July (84.5°F) with another major peak (84.1°F) on 21 July, consistent with the elevated temperatures seen in the time series for USGS Hastings, NOS Kings Point, SIT GW Bridge, and HRECOS Piermont Pier. The minimum surface temperature at station 66 was 75.2°F as observed on 25 August. The middle thermistor (15.1 feet) at station 66 peaked at 82.7°F on 21 July and had a minimum temperature of 74.9°F observed on 10 July. The bottom thermistor (47.3 feet) had a maximum of 81.3°F (26 July) and a minimum of 72.9°F (9 July). The median temperatures at station 66, from surface to bottom, were 79.5°F, 78.6°F, and 77.8°F, respectively. A comparison to data from other thermistor stations indicates that the plume from Indian Point never reaches station 66 at the southern boundary of the study area.

Figure 3-8 shows the time variation of temperature at three depths for the most upstream station (54, see Figure 4-2). The general trends were similar to the most downstream station (66) with a rise and plateau in July, followed by a slight drop and recovery, and then a further downward trend from mid August into September. The major difference between this station and the southernmost station was that the shallowest depth showed only a slightly warmer peak (< 0.5°F) than the deeper thermistors. In general there was very little difference in temperature with depth, i.e., a thermally unstratified condition.

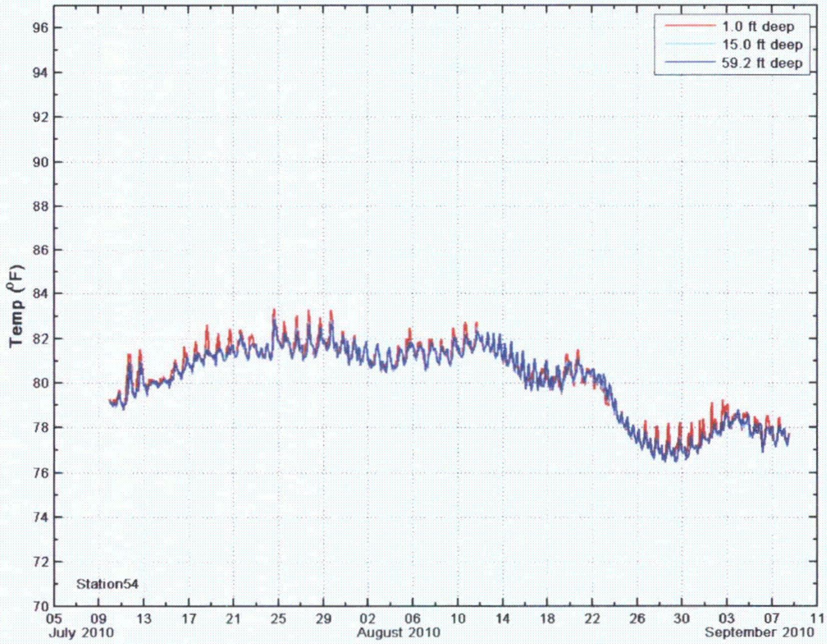

Figure 3-8. Temperatures for all depths at northern boundary (station 54 – RM 50.8) during the summer 2010 survey period.

The maximum temperatures at station 54, from surface to bottom, were 83.3°F, 82.9°F, and 82.9°F, respectively , all which occur on 24 July. The surface and middle thermistors each had minimums on 28 August, with values of 76.7°F and 76.4°F, respectively. The bottom thermistor observed a minimum temperature of 76.5°F (29 August). The median temperatures for all depths were identical at 80.7°F for the summer 2010 period.

From examining the downstream and upstream boundary thermistor station data, it is clear that ambient temperature in the river, particularly at the surface, varies depending on location (along-River and in the vertical) and time, and cannot be considered constant. The boundary thermistor stations (66 and 54) are far from the discharge at IPEC (RM 41.5) and are outside the influence of the plume as shown by the data. Therefore, the major thermal differences between these boundary stations are most likely due to natural influences. For instance, solar insolation warming the volume of shallow Haverstraw Bay, which is the widest part of the River located in the southern portion of the thermistor array, would have likely contributed to the greater degree of thermal stratification at southernmost station 66 compared to northernmost station 54.

Station 25 (Figure 3-9) is located approximately 150 ft from the IPEC discharge structure in the River. As such, station 25 is well within the inferred mixing zone based on the permit requirement of a 1.75 ft head differential across the slot-type openings in the discharge structure which causes a 10 ft/s discharge velocity through the slots into the River. In contrast to the boundary stations 66 (southernmost) and 54 (northernmost), the surface temperatures at station 25 were significantly warmer than at the field program boundaries, with a maximum value of 95.1°F on 24 July. Additionally,

Figure 3-9 shows that there was significant thermal stratification in the water column, which is due to the location within the inferred mixing zone.

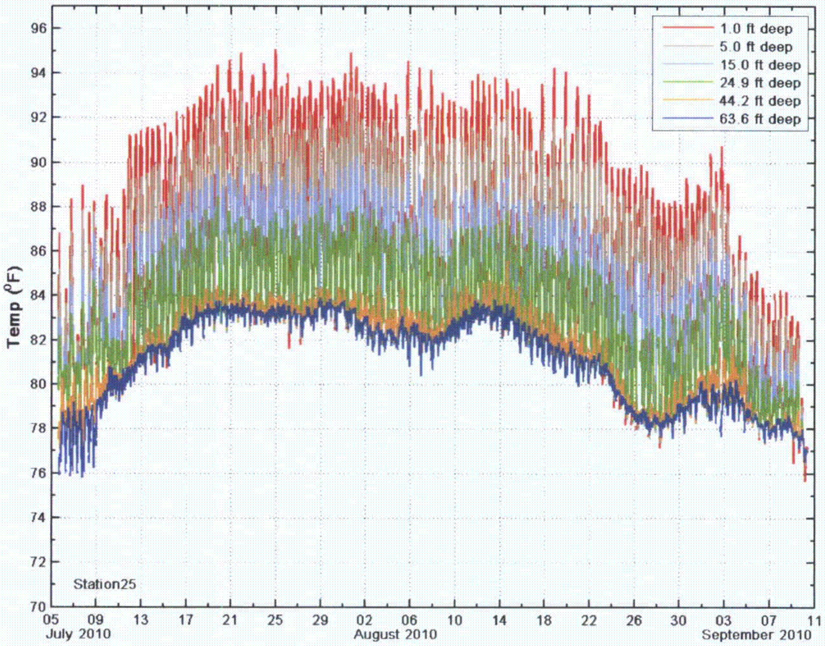

Figure 3-9. Temperatures for all depths at IPEC discharge (station 25 – RM 41.5) during the summer 2010 survey period.

The maximum temperature at the 5ft depth thermistor dropped to 93.2°F (21 July), followed by a maximum of 90.3°F (1 August) at 15 ft depth and 88.5°F (19 July) at 24.9 ft depth. The deeper maxima were 85.6°F (14 August) at 44.2 ft depth and 83.9°F (28 July) at the bottom (63.6 ft). The minimum temperatures from surface to bottom were 75.6°F (10 September), 76.4°F (10 September), 76.7°F (10 September), 76.6°F (10 September), 76.6°F (10 September), and 75.8°F (7 July), respectively. The median temperatures at station 25, from surface to bottom, were 84.3°F, 83.9°F, 83.3°F, 82.9°F, 82.0°F and 81.6°F, respectively during the summer 2010 period. The near surface temperatures at station 25 were significantly higher than those observed at the field program downstream and upstream boundaries, while the maximum and median temperatures at the bottom-most depth at station 25 were only 1°F or less warmer than those observed at the northern boundary (station 54).

There was a large variation in temperature over each tidal cycle due to the short term buildup of heat during slack water conditions that was then transported away from station 25. Interestingly, there were short periods (typically for under 2 hours) between 0300 and 0700 when the surface water cooled to temperatures below the other, deeper thermistors. This is likely a function radiation cooling from the water to the atmosphere, causing surface temperatures to cool faster than deeper waters.

At increasing distance from the IPEC discharge structure, the surface temperatures decreased compared to those observed at station 25. Figure 3-10 shows the temperature records from the six thermistors at station 27, located approximately 920 ft from the structure and 770 ft offshore from station 25 (location of the thermistor stations around the plant are shown in Figure 2-3). Here the maximum surface temperature was 88.5°F (1 August), followed by 88.2 °F (20 July, 5 ft depth), 87.1 °F (30 July, 14.9 ft depth), 86.2 °F (30 July, 24.9 ft depth), 83.8 °F (29 July, 46.6 ft depth), and 83.6°F (22 July) at the bottom while the minimum temperatures were 77.6°F (28 August), 76.5°F (10 September), 76.6°F (10 September), 76.5°F (10 September), 76.3°F (10 September), and 75.6°F (5 July). The median temperatures, from surface to bottom, were 83.1°F, 82.8°F, 82.4°F, 82.1°F, 81.7°F, and 81.4°F, respectively for the summer 2010 period.

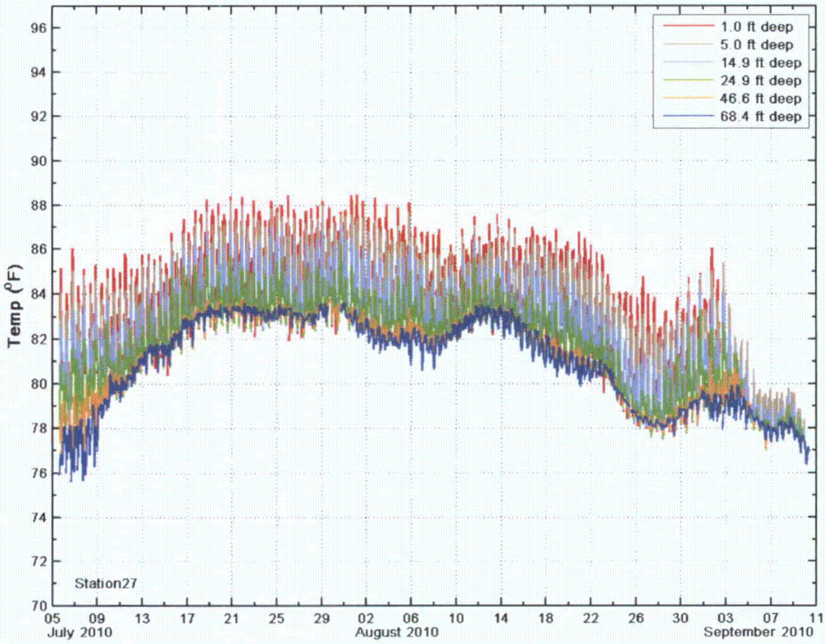

Figure 3-10. Temperatures for all depths near IPEC discharge (station 27 – RM 41.6) during the summer 2010 survey period.

At station 27, the maximum observed temperature decreased by 6.6°F and the median temperature at the surface dropped by 1.2°F relative to station 25. It is evident that the plume disperses quickly away from the discharge canal. Similarly to station 25, there were also short periods (<2 hours, between 0200 and 0700) at station 27 when the surface waters cool to temperatures below the other, deeper thermistors.

Additional thermistor station time series can be found in Appendix A.

A series of surface temperature time series between groups of thermistors were developed to show variation in temperature from north to south and along the eastern and western sides in the study area. Figure 3-11 shows temperatures from selected stations along the western side of the River channel for thermistors from just north of IPEC to the northernmost boundary station. The stations nearest IPEC showed a strong semidiurnal (tidal – 12.4 hrs) signal in the temperature variation although the magnitude of the variation was greatest near IPEC and progressively decreased with distance away. showed Higher temperatures were observed during the day than the night due to solar insolation and warmer air temperatures, thus suggesting the significant role played by radiative heating and cooling.

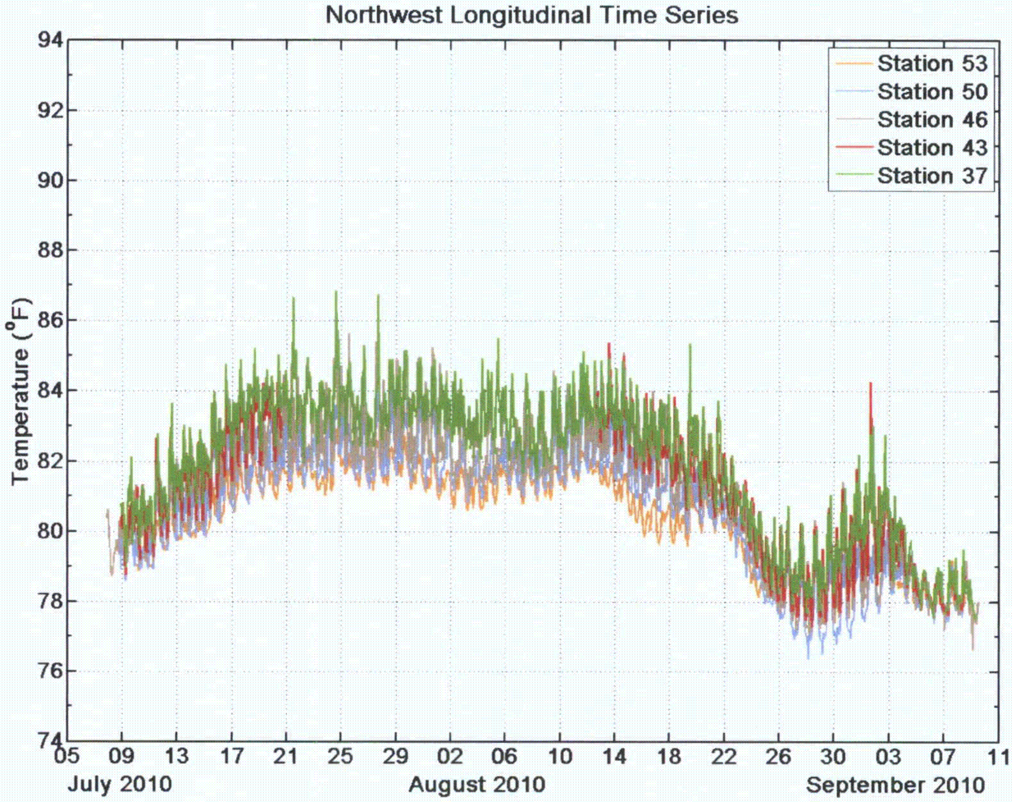

Figure 3-11. Near surface temperatures along western side of River from the northernmost thermistor (station 53 – RM 50.8) to just north of IPEC (station 37 – RM 42.0) during the summer 2010 survey period.

The maximum temperatures ordered by distance away from IPEC (37, 43, 46, 50 and 53) were 86.8°F (24 July), 85.4°F (13 August), 85.6°F (25 July), 84.4°F (11 August), and 82.9°F (24 July), respectively, while the median temperatures were 82.4°F, 80.7°F, 81.6°F, 81.2°F, and 81.1°F, generally consistent with their locations relative to IPEC. The minimum temperatures were 77.5°F (9 September), 77.3 °F (28 August), 76.6°F (9 September), 76.4°F (28 August), and 77.8°F (7 September), respectively. Note that the median temperature for station 43 does not follow the gradually cooling trends of the thermistors from south to north. This is only a function of missing data for late July to early August, as seen in Figure 3-11.

Figure 3-12 shows selected stations along the eastern side of the River channel for thermistors from just north of IPEC to the northernmost boundary station. Similar to the west side, the stations nearest IPEC showed a strong semidiurnal (tidal – 12.4 hrs) period in the temperature variation although the magnitude of the variation was greatest near IPEC and progressively decreased with distance away. The tidal cycle during daylight hours typically showed higher temperatures than the nighttime hours due to solar insolation and warmer air temperatures.

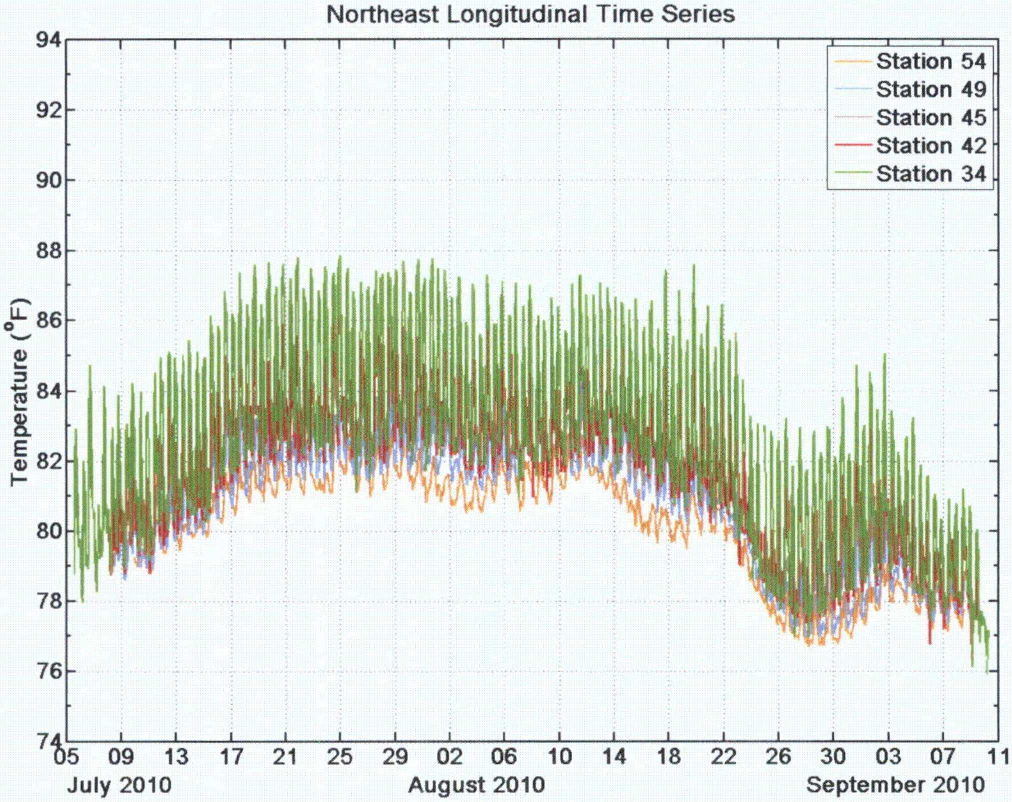

Figure 3-12. Near surface temperatures along eastern side of River from the northernmost thermistor(station 54 – RM 50.8) to just north of IPEC (station 34 – RM 41.9) during the summer 2010 survey period.

The maximum temperatures ordered by distance away from IPEC (34, 44, 45, 49, and 54) were 87.9°F (24 July), 86.3°F (25 July), 85.8°F (24 July), 84.3°F (13 August), and 83.3°F (24 July), respectively, while the median temperatures were 82.4°F, 81.9°F, 81.8°F, 81.2°F, and 80.7°F, consistent with their locations relative to IPEC. The minimum temperatures recorded were 75.9°F (10 September), 77.3°F (27 August), 77.3°F (29 August), 76.7°F (28 August), and 77.3°F (7 September), respectively. Most of the values for the eastern stations were very similar to those for the western stations except for the station closest to IPEC (34), whose maximum was 1.1°F higher than station 37 on the western side.

Figure 3-13 selected stations along the western side of the River channel for thermistors from just south of IPEC to the southernmost boundary station. The stations nearest IPEC showed a stronger diurnal (daily) period in the temperature variation than the northern stations although the magnitude of the variation was greatest near IPEC and progressively decreased with distance away. The southernmost station (57) was significantly cooler with a clear diurnal (daily) period. The tidal cycle during daylight hours typically showed higher temperatures than the nighttime hours due to solar insolation and warmer air temperatures.

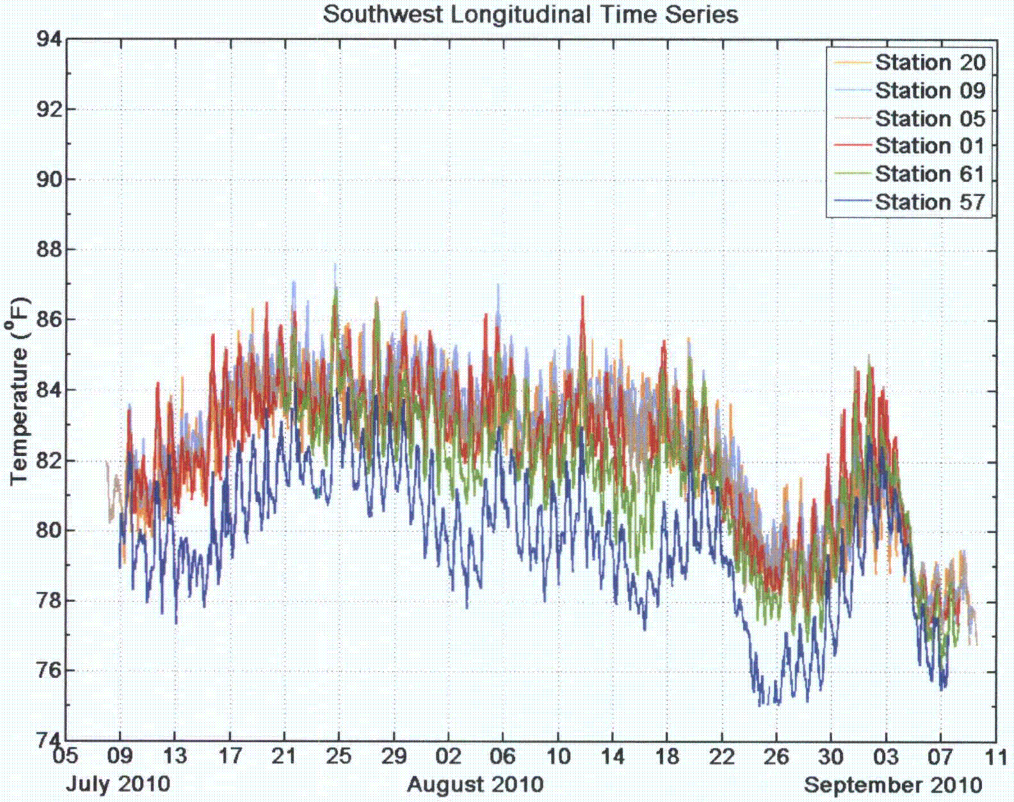

Figure 3-13. Near surface temperatures along western side of River from the southernmost thermistor station 57 – RM 20.6) to just south of IPEC (station 20 – RM 41.5) during the summer 2010 survey period.

The maximum temperatures ordered by distance away from IPEC (20, 09, 05, 01, 61, and 57) were 87.0°F (24 July), 87.6°F (24 July), 86.6°F (27 July), 86.7°F (24 July), 86.9°F (24 July), and 84.4°F (21 July), respectively, while the median temperatures were 82.6°F, 83.0°F, 82.7°F, 82.6°F, 81.8°F, and 79.7°F for the summer 2010 period. The minimum temperatures recorded were 77.3°F (7 September), 77.1°F (9 September), 76.8°F (9 September), 77.3°F (8 September), 76.0°F (7 September),and 77.3°F (24 August), respectively. The closest station (20) to IPEC was not the warmest because the thermal plume primarily traveled downstream on the eastern side of the River on ebb under the influence of the tidal velocities than across-stream. Rather, the highest maximum and median temperatures occurred at station 9, reflective of the geometry of the River tending to orient the ebb plume toward the western side of the River at that location.

Figure 3-14 shows selected stations (locations shown in Figure 2-4) along the eastern side of the River channel for thermistors from just south of IPEC to the southernmost boundary station. The stations nearest IPEC showed a strong semidiurnal (tidal – 12.4 hr) period in the temperature variation similar to the east side northern stations. The magnitude of the variation was clearly greatest near IPEC (17) and progressively and significantly decreased with distance away. The southernmost station (66) was typically cooler with a clear diurnal (daily) period. The tidal cycle during daylight hours typically showed higher temperatures than the nighttime hours due to solar insolation and warmer air temperatures except near IPEC (17).

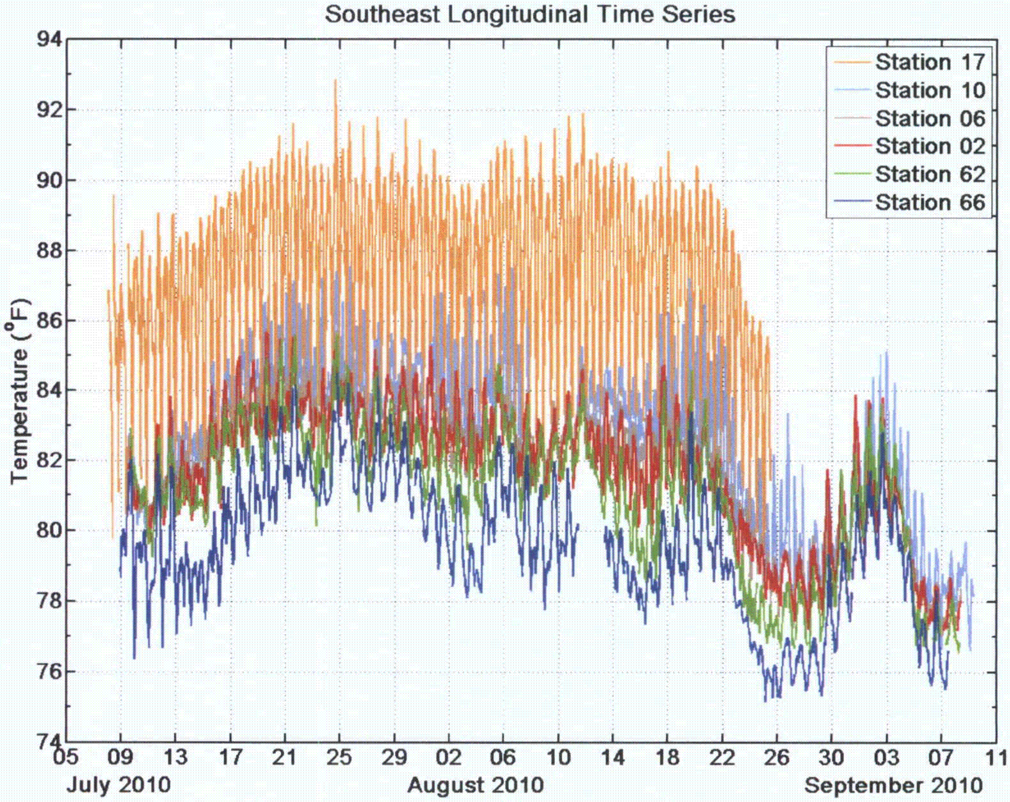

Figure 3-14. Near surface temperatures along western side of River from the southernmost thermistor station 66 – RM 20.6) to just south of IPEC (station 17 – RM 41.2) during the summer 2010 survey period.

The maximum temperatures ordered by distance away from IPEC (17, 10, 06, 02, 62, and 66) are 92.9°F (24 July), 87.5°F (25 July), 85.9°F (20 July), 85.7°F (19 July), 85.6°F (24 July), and 84.5°F (24 July), respectively, while the median temperatures were 87.3°F, 82.8°F, 82.2°F, 82.0°F, 81.5°F, and 79.5°F for the summer 2010 period. The minimum temperatures recorded were 79.3°F (25 August), 76.5°F (6 September), 77.1°F (7 September), 76.9°F (8 September), 76.5°F (28 August),and 75.2°F (25 August), respectively. The closest station (17) to IPEC was the warmest (both maximum and median temperatures) due to its proximity.

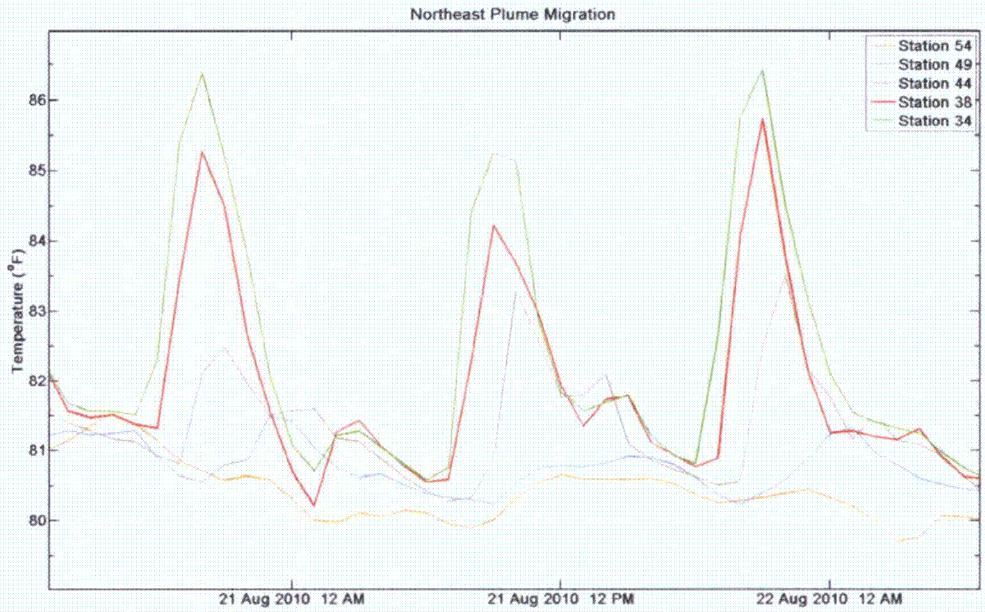

Figure 3-15. Near surface temperatures along the eastern side of the River north of Indian Point between 20 August to 22 August.

From the thermistor records, the location of the plume can be monitored through compartative analysis during short time scales. Areas to the north of IPEC experience increased temperatures only during the flood tide, as shown in Figure 3-15. As the tides turn from ebb to flood, increased temperatures are experienced along the eastern side of the Hudson, just north of the plant. Station 34, located one quarter of a mile north of the discharge at RM 41.85, typically observes a spike in temperature of 3-5°F during the flood tide. Stations further north gradually have lower temperature rises, as seen at stations 38 and 44. Station 49 typically has small temperature rises (< 1°F) during the flood tide, while station 54 hass no discernable spikes in temperature that are directly related to the plume. The major signal at Station 54 is diurnal, with a single major rise and fall of temperatures per day associated with daily heating/cooling. However, tides still impact the region north of station 54, so semi-diurnal signals were evident during some periods of the record which result in dual peaked temperature time series in a single day.

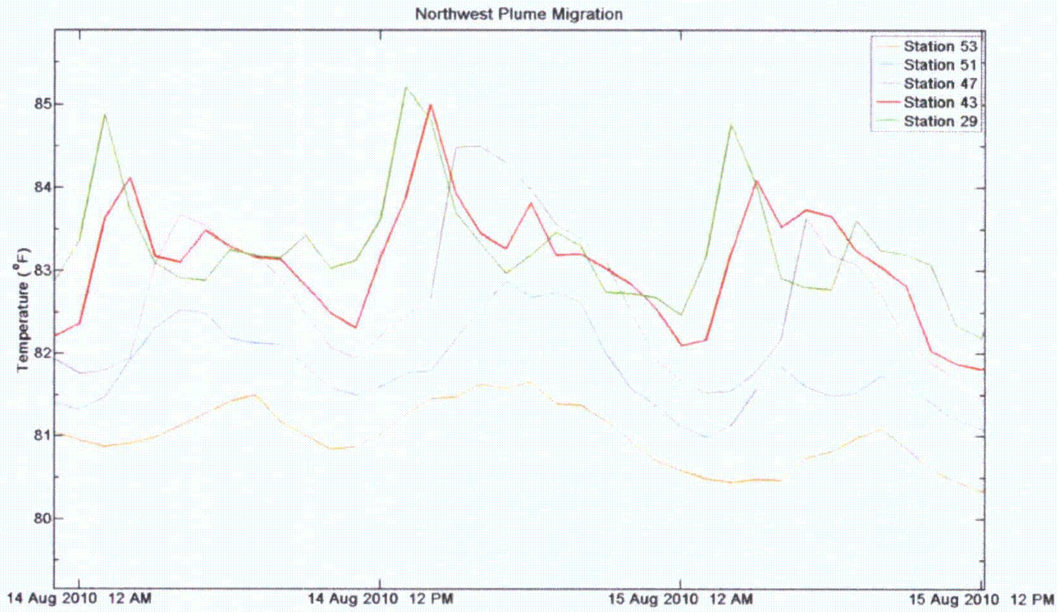

Figure 3-16. Near surface temperatures along the western side of the River north of Indian Point between 14 August to 15 August.

On the opposite side of the river, temperature increases associated with IPEC are less evident. Stations on the western side of the river to the north of IPEC are shown for the period from 14 to 15 August in Figure 3-16. Temperatures are elevated at stations 29 by 1.5-3°F during the flood tide; presumably part of the rise could be a function of warm waters flushed out of shallows to the southwest during the flood tide. Stations further to the north have much smaller rises in temperature during the flood tide. Station 53 generally shows a diurnal signal, with the primary temperature fluctuation from daily heating and cooling of waters from atmospheric forcings. However, some small (< 0.5°F) fluctuations in temperature can occur at station 53 over the course of the tidal cycle. Based on the fact that temperature peaks at station 53 before that of station 51, the increase of temperature at station 53 is not related to the heated water from IPEC.

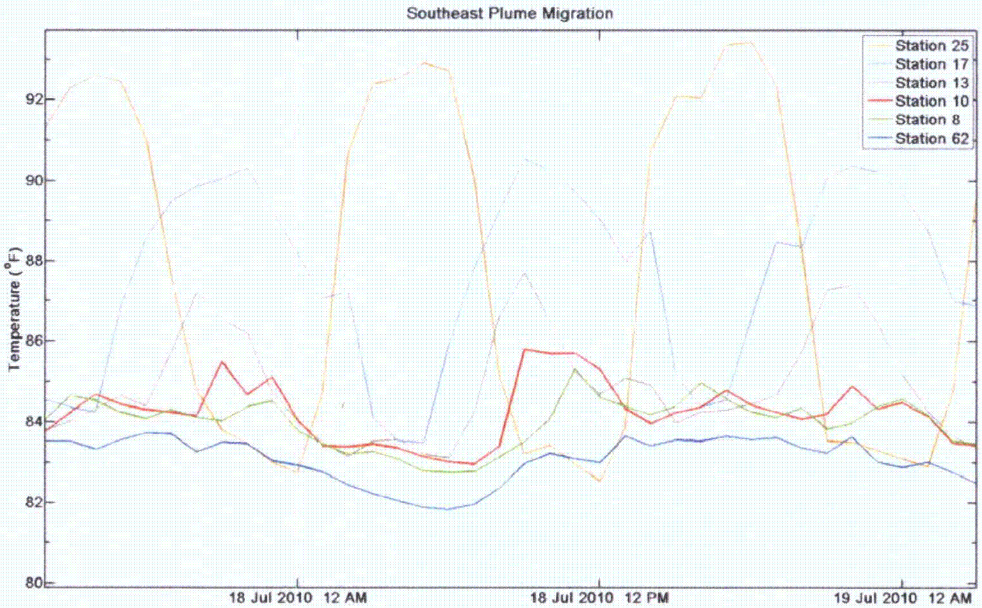

Figure 3-17. Near surface temperatures along the eastern side of the River south of Indian Point between 17 July to 19 July.

To the south, a series of stations were analyzed to understand the range of the thermal plume downstream, as shown for the eastern side of the River in Figure 3-17. At station 25 the temperature rises drastically during slack tides. However, as the tide ebbs, the stations downstream of the plant see a temperature increase. Temperatures at the surface of station 17 generally vary by 3°F during the course of a tidal cycle; these temperature rises quickly dissipate at stations to the south. Small temperature increases are observed during the ebb at station 8, near Stony Point at the northern portion of Haverstraw Bay at river mile 38.75. However at station 62, at the southern portion of Haverstraw Bay, the dominant signal becomes diurnal and there is typically no major discernible signal from the plume.

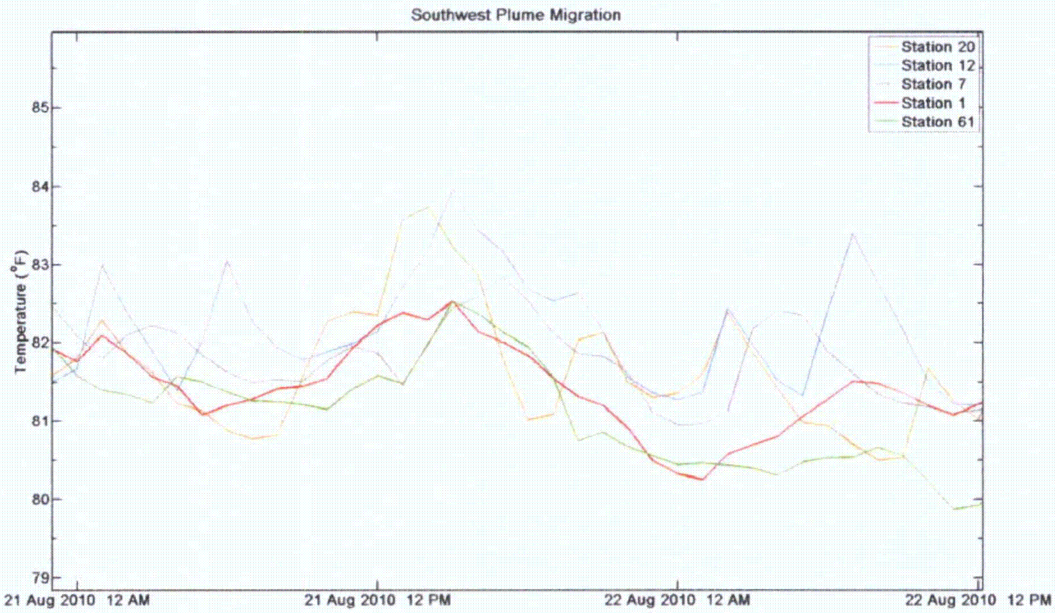

Figure 3-18. Near surface temperatures along the western side of the River south of Indian Point between 21 August to 22 August.

Figure 3-18 shows the complexity of the western side of the river. Station 20 is close to the plant but does not see a major increase over every tidal cycle. However, station 12 to the south sees much more variation and is typically affected by every tidal cycle (flood and ebb). To the south, stations 1 and 61 see some variation during the flood and ebb, although a diurnal signal is more dominant due to the daily warming of Haverstraw Bay.

However at certain times some fairly large spikes are evident in parts of the Haverstraw Bay area. For example, Figure 3-19 shows one such spike at 1600 on 4 August where station 1, the closest station to the Bowline discharge, has noticebly higher temperatures than stations to the north and south.

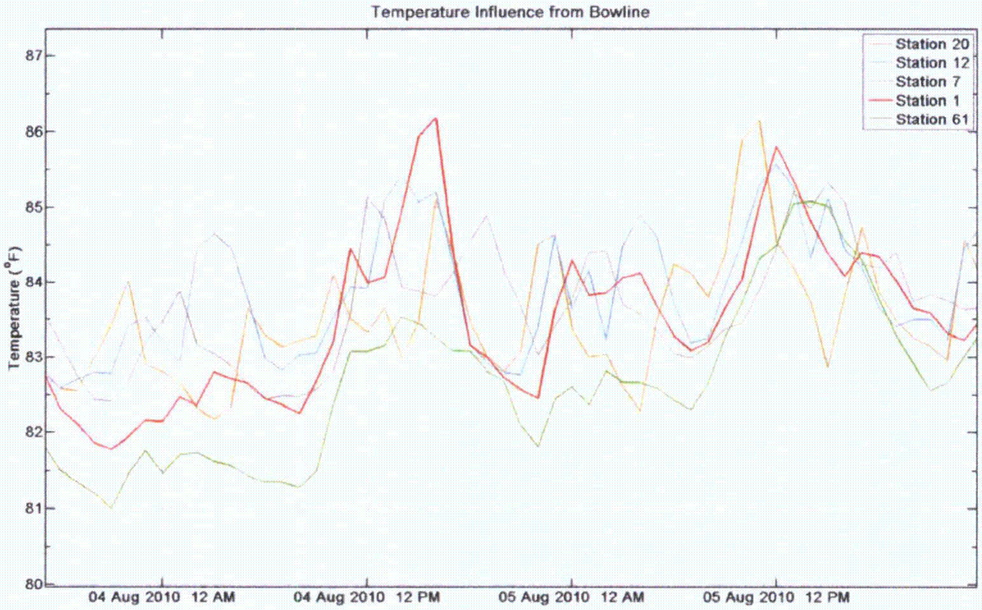

Figure 3-19. Near surface temperatures along the western side of the River south of Indian Point between 3 August to 5 August.

One factor that is important to consider around the Haverstraw Bay area is the influence on water temperatures from the thermal effluent at Bowline Power Station. Bowline is a peaking power station and therefore is not in continuous operation. However, during the summer when there is high energy demand the station is often in operation; these times may correspond to when both air and ambient river temperatures are at their warmest and therefore will contribute to elevating temperatures further, particularly around the Haverstraw Bay region. The spike at station 1 at 1600 on 4 August, as shown in Figure 3-19, is likely a result of thermal discharge from the Bowline plant. The surface temperature at station 1 is about 2.5°F higher during the 4 August peak than station 61, located 3 miles to the south, and approximately 2°F higher than station 7, located 2.85 miles to the north of station 1. As station 61 is also located in Haverstraw Bay, larger temperature rises would have been expected as station 61 during the 4 August period if the spike observed at station 1 was solely natural forcings.

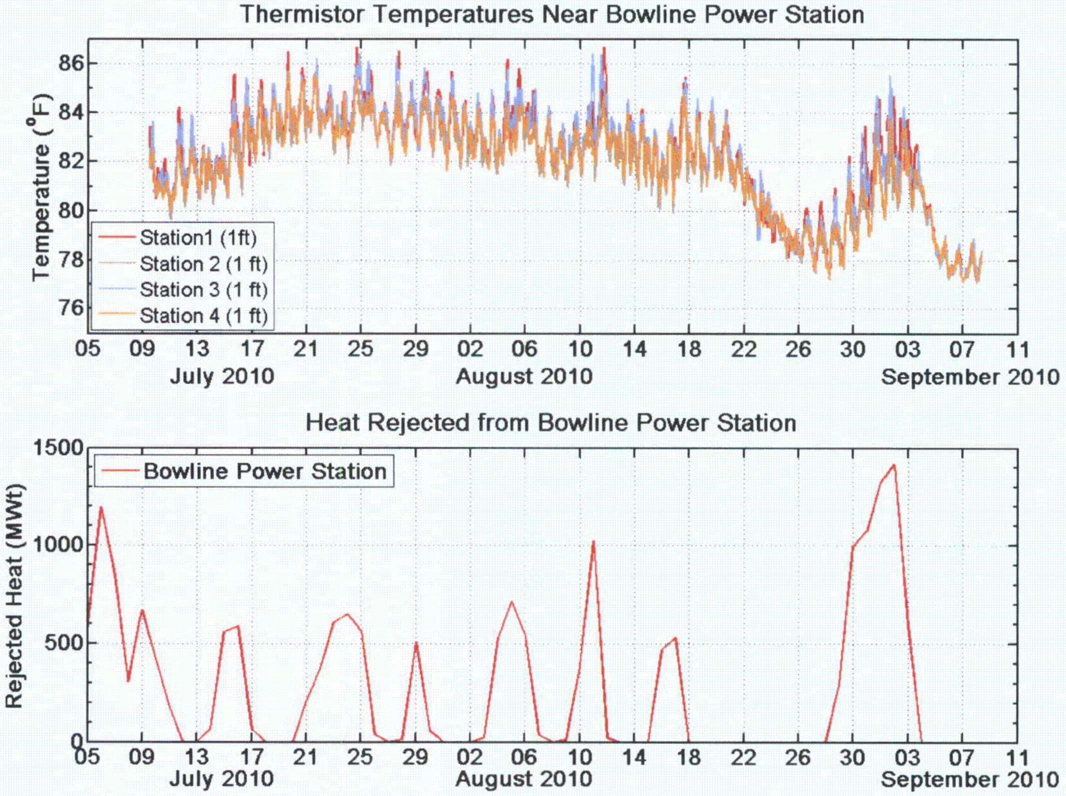

Figure 3-20. Time series of thermistor stations near Bowline Power Station (upper panel) and heat rejected from Bowline Power Station (lower panel) for the 2010 study period.

Figure 3-20 shows the time series of stations near Bowline plotted against the rejected heat output of the Bowline Power Station. From this it is evident that major spikes at stations 1 and 2 regularly occur whenever Bowline is in operation. Elevations in temperature are also evident at stations 3 and 4 on the eastern side of the channel, although to a lesser degree. While more total heat is released by IPEC into the River, any rise above ambient in temperature around Haverstraw Bay is in part the influence of Bowline during its periods of operation.

To better illustrate the downriver variation of temperature, especially as a function of tidal activity, in the River a series of vertical longitudinal section contours of temperature were prepared along the eastern and western sections of the River defined by the eastern and western thermistor stations. The western section consists of 23 thermistors and the eastern section consists of 27 thermistors listed in Table 3-1.

Table 3-1. Thermistor stations used in calculating vertical longitudinal section contours.

Description	Western Section Stations	Eastern Section Stations
Northernmost Boundary	53	54
	52	55
	51	56

Description	Western Section Stations	Eastern Section Stations
	50	49
	47	48
	46	45
	43	44
		42
	40	38
	36	34
		30
IPEC	28	25
		23
		21
	19	17
	15	13
	12	11
	9	10
	7	8
	5	6
	3	4
	1	2
	61	62
	60	63
	59	65
	58	64
Southernmost Boundary	57	66

Figures 3-21 to 3-27 display longitudinal vertical section contours using a color contouring scheme to show general trends vertically through and along the River from River Mile (RM) 20.6 to RM 50.8 on 2 August. In the figures, more weight was given in the interpolation method to lateral thermal mixing than to vertical in order to approximate thermal stratification seen in the River. The open circles indicate locations of thermistors in the water column.

Individual sections at 2-hr intervals from 0800 through 2000 during 3 August were chosen to highlight the east to west and north to south variation along River. The chosen day corresponds with the date of one of the mobile intensive surveys from the 2010 field program and a neap tide. In the figures, darker shades of green represent warmer waters, typically as a result of the IPEC thermal plume, with its discharge located at RM 41.5. Warmer temperatures were prevalent almost all of the time on the eastern section view (lower panel in the figures) as a direct result of the discharge. The western section (upper panel) at RM 41.5 showed temperatures generally warmer than upriver and downriver, but the same elevated heating as on the eastern side was not evident at this location. However, solar radiation, especially around Haverstraw Bay (RM 30), increased the surface temperatures resulting in higher water temperatures.

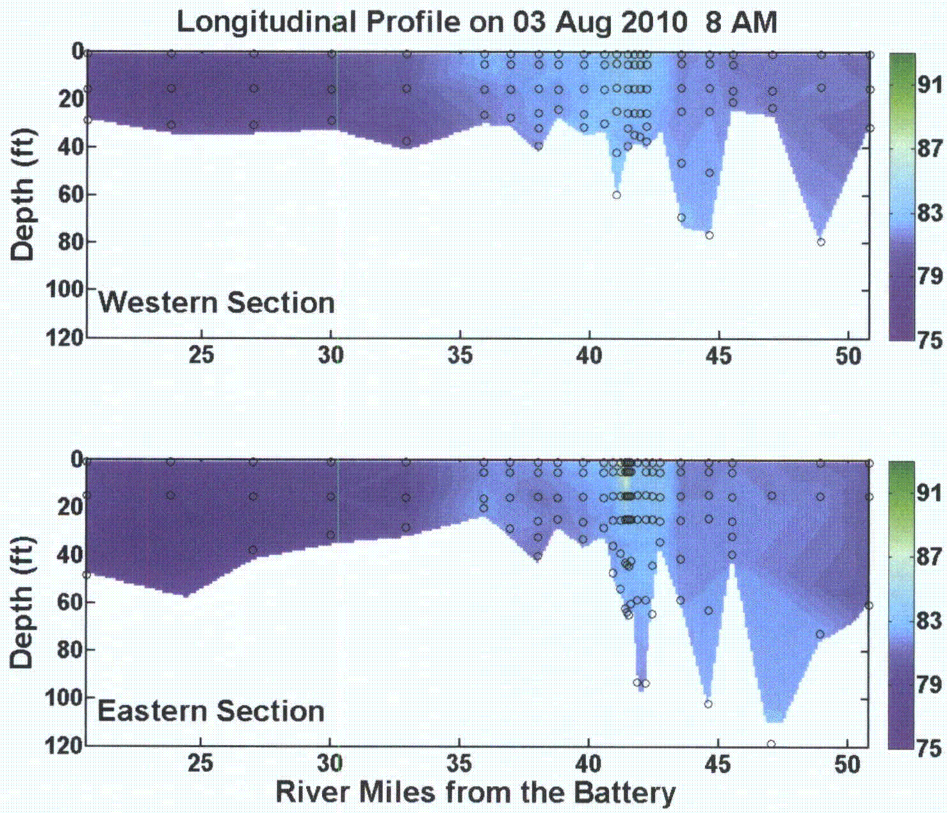

Figure 3-21. Vertical longitudinal section contours of temperature at 0800 on 3 August (corresponding to slack before ebb tide) for all thermistors along western side of River (upper panel) and eastern side of River (lower panel) from southernmost extent (RM 20.6) to northernmost extent (RM 50.8).

Migration of the plume downriver is evident from examination of the longitudinal sectional contours over multiple hours in sequence. Figure 3-21 shows the water temperatures during slack before ebb at 0800 where the coldest temperatures are present on the southern portion of the study area at RVM 21. During this time there was a small area on the eastern side of the River at thermistor station 25 (RVM 41.5) where the river temperatures exceed 90°F, falling within the inferred mixing zone in the River at IPEC. The temperatures observed on the western side of the Hudson are lower than those observed on the east at IPEC.

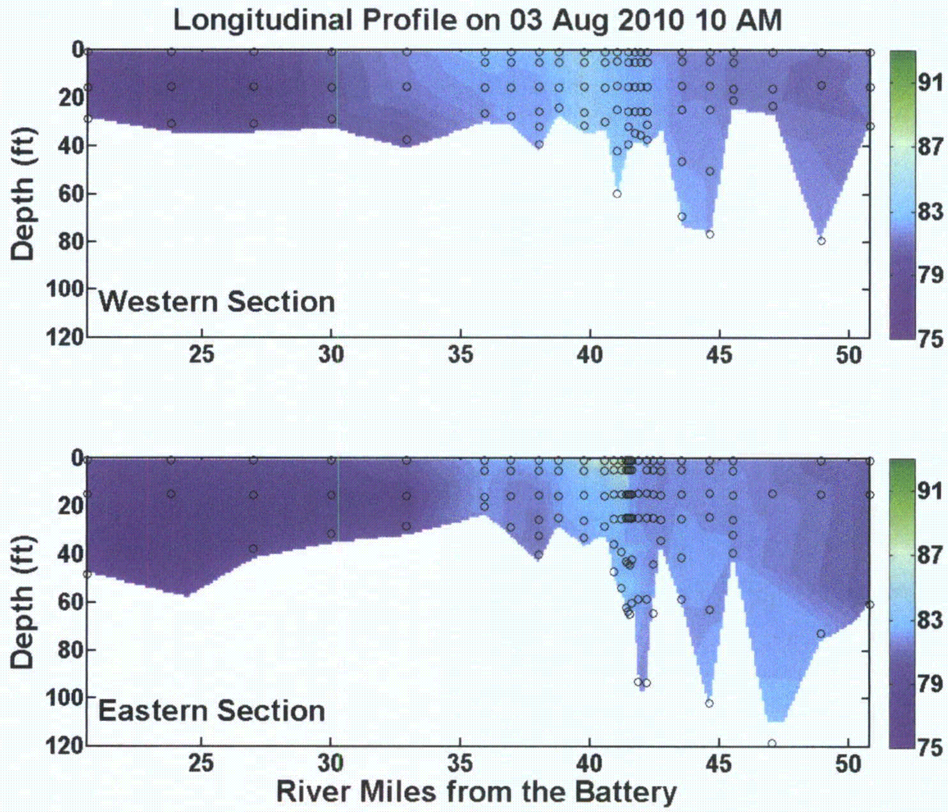

Figure 3-22. Vertical longitudinal section contours of temperature at 1000 on 3 August (corresponding to ebb tide) for all thermistors along western side of River (upper panel) and eastern side of River (lower panel) from southernmost extent (RM 20.6) to northernmost extent (RM 50.8).

During the ebb tide, shown in Figure 3-22 (at 1000), Figure 3-23 (at 1200), and Figure 3-24 (at 1400), the warmer waters flowed toward the south. Increases in temperature near IPEC begin to dissipate and move southward as a result of mixing from both tidal currents and river flow. Throughout the course of the day, there is also radiative heating of surface waters, which leads to increase in observed temperatures. In particular this leads to a warming of the shallow waters around Haverstraw Bay.

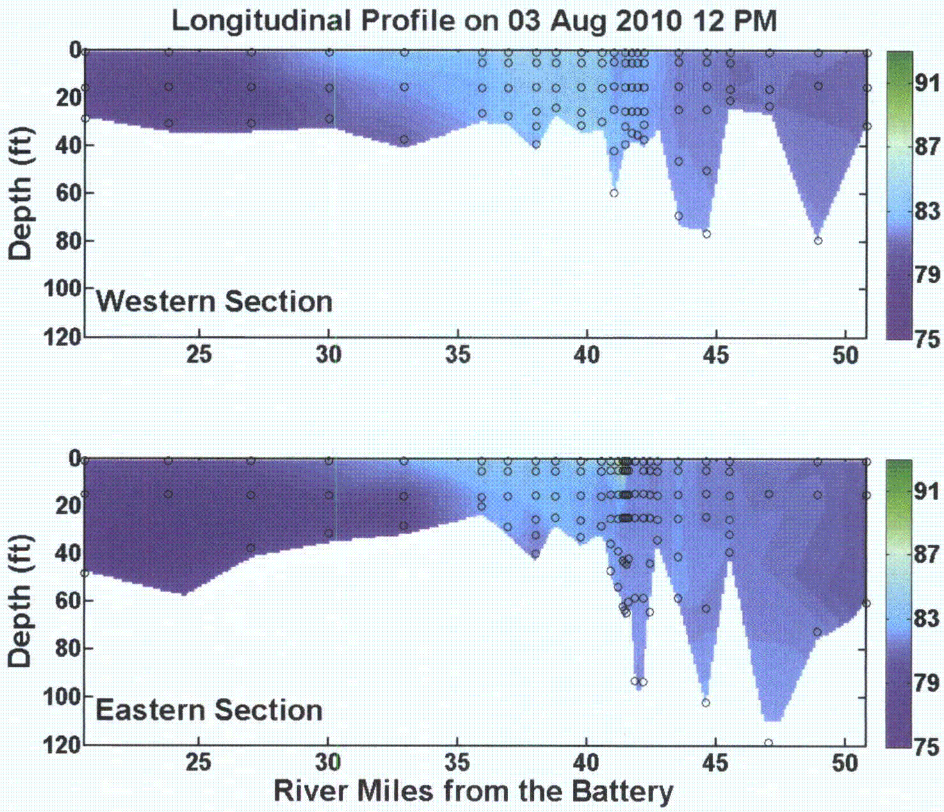

Figure 3-23. Vertical longitudinal section contours of temperature at 1200 on 3 August (corresponding to ebb tide) for all thermistors along western side of River (upper panel) and eastern side of River (lower panel) from southernmost extent (RM 20.6) to northernmost extent (RM 50.8).

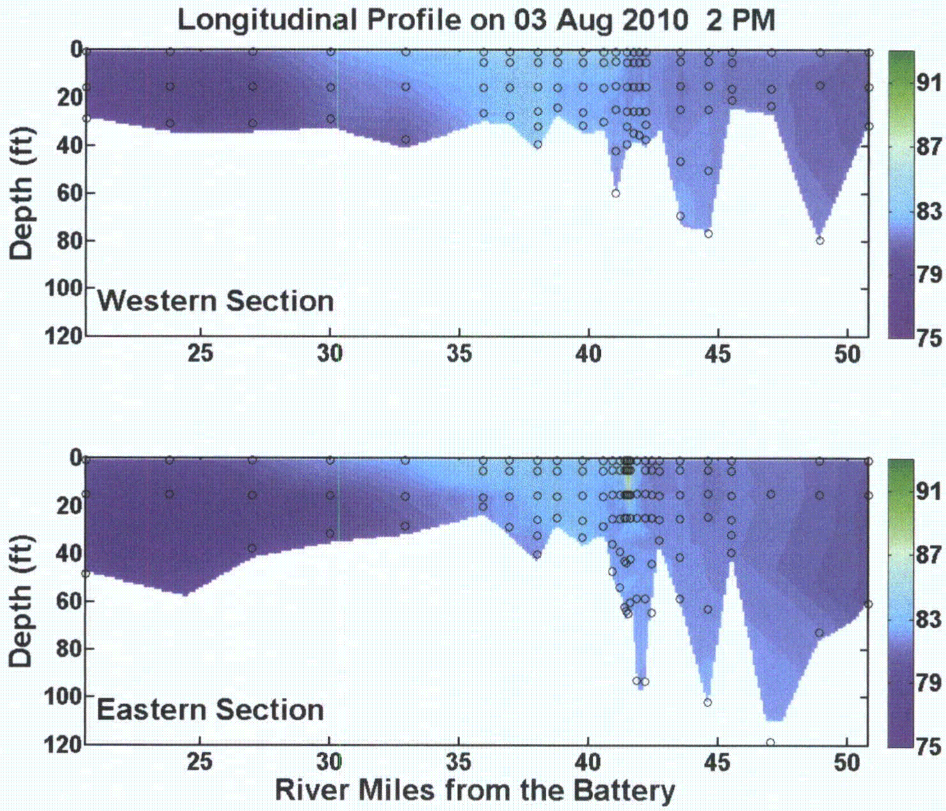

Figure 3-24. Vertical longitudinal section contours of temperature at 1400 on 3 August (corresponding to slack before flood tide) for all thermistors along western side of River (upper panel) and eastern side of River (lower panel) from southernmost extent (RM 20.6) to northernmost extent (RM 50.8).

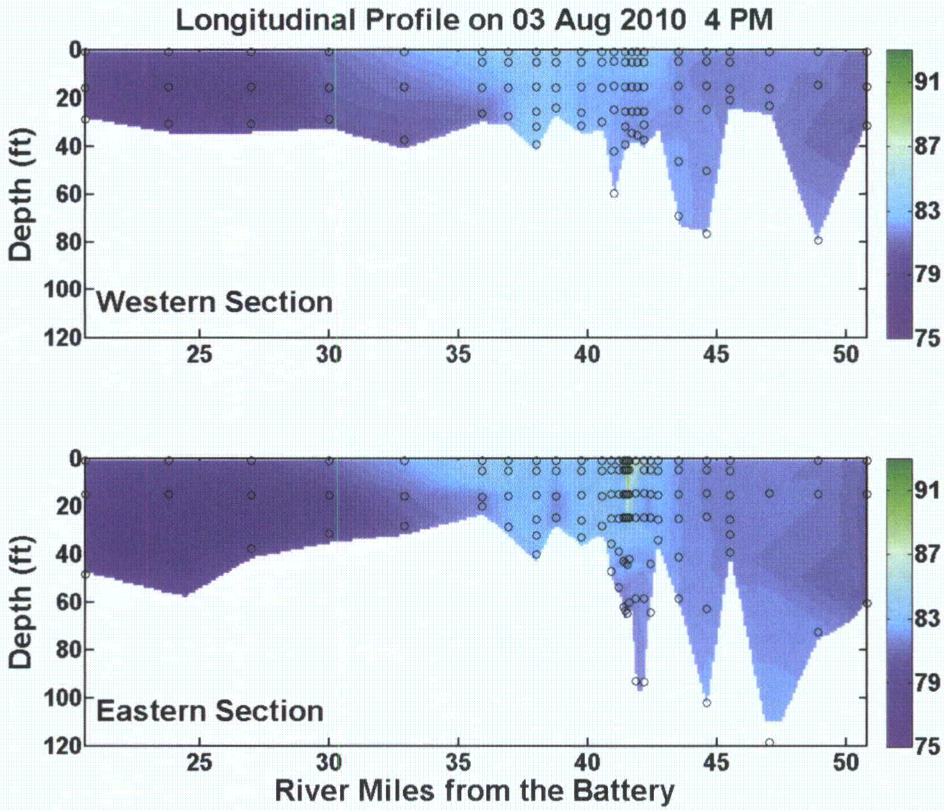

Figure 3-25. Vertical longitudinal section contours of temperature at 1600 on 3 August (corresponding to flood tide) for all thermistors along western side of River (upper panel) and eastern side of River (lower panel) from southernmost extent (RM 20.6) to northernmost extent (RM 50.8).

During flood tide cycle (Figure 3-24 to Figure 3-26), there was an increase in cold water (as depicted by purple) observed in the southern portions of the longitudinal section contours. The colder, saltier water is denser than the fresh warmer waters flowing from the north, so the seawater remains primarily wedged at the bottom. Stratification of temperatures in the water column can be seen especially between river miles 30 and 40 from this phenomenon. While the flood causes decreased temperatures south of IPEC, the flood tide also causes an increase in temperature to the north. As the flood tide progresses during the period represented by these figures, 1200 to 1800 on 3 August 2010, warmer waters from Haverstraw Bay and IPEC move northward due to the current velocities.

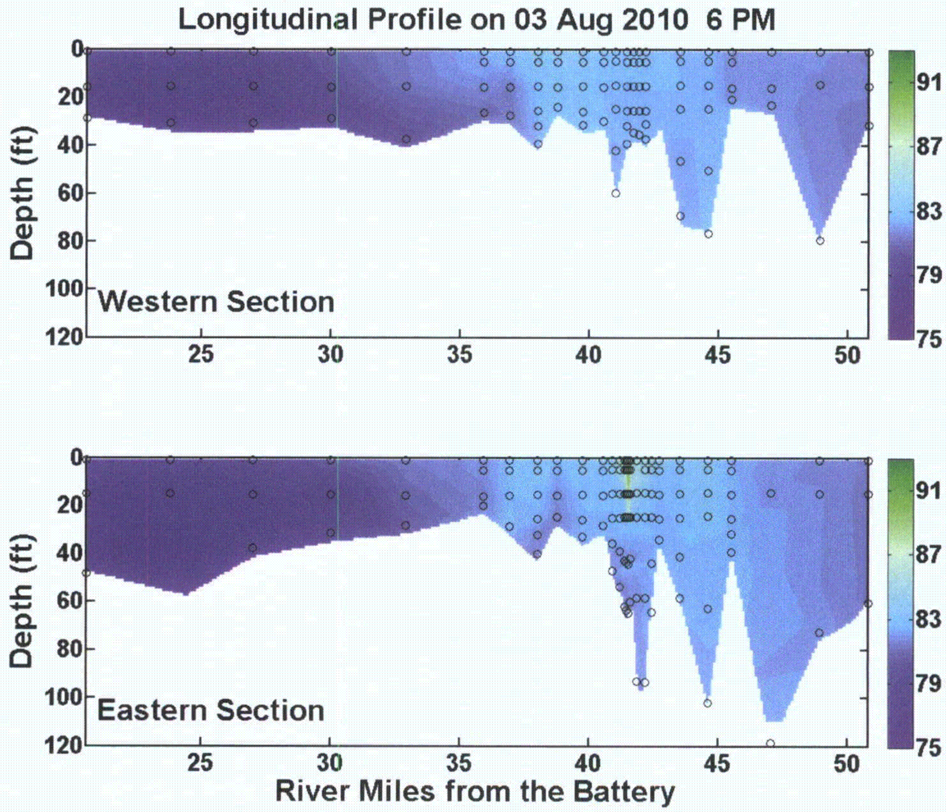

Figure 3-26. Vertical longitudinal section contours of temperature at 1800 on 3 August (corresponding to flood tide) for all thermistors along western side of River (upper panel) and eastern side of River (lower panel) from southernmost extent (RM 20.6) to northernmost extent (RM 50.8).

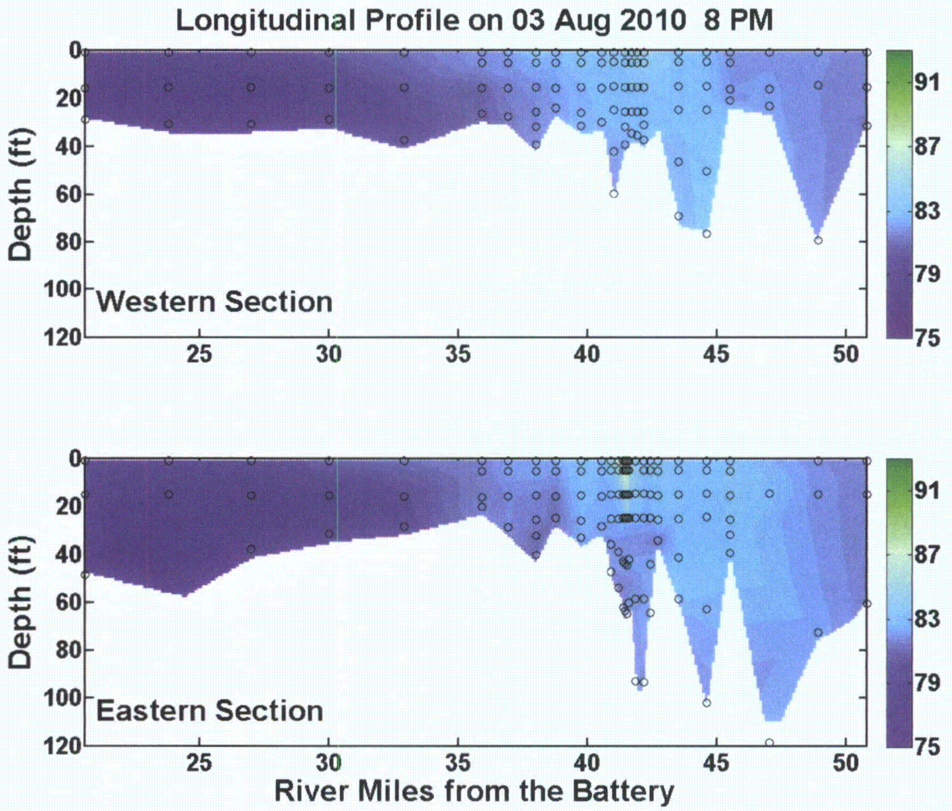

Figure 3-27. Vertical longitudinal section contours of temperature at 2000 on 3 August (corresponding to slack before ebb tide) for all thermistors along western side of River (upper panel) and eastern side of River (lower panel) from southernmost extent (RM 20.6) to northernmost extent (RM 50.8).

Figure 3-27 shows the second slack before ebb tide on 3 August. After this point the cycle described would be expected to continue over again, whereby water temperatures increase to the south during the ebb tide. During the flood tide, temperatures to the north increase, although the cold ocean water results in a decrease in water temperatures to the south. The temperatures also naturally increase throughout the course of the day due to radiative heating, and cool during the nighttime. As is evident from this discussion, the Hudson River is particularly complex because of estuarine dynamics and wide variability in bathymetry, causing significant longitudinal variations in temperature.

The fixed station thermistors could not completely show the cross river variation of temperatures in the River, so fixed station data was supplemented with temperature data from intensive mobile surveys along three transects. Examples of these cross river profiles are shown in Figure 3-28 to Figure 3-30.

At the Indian Point transect, the cross river temperatures generally showed a large spike near the plant on the eastern side of the river, with a decrease in temperatures at about 300 m away from the eastern shoreline. For example, Figure 3-28 shows the transect at Indian Point on 13 July during a flood (spring) tide.

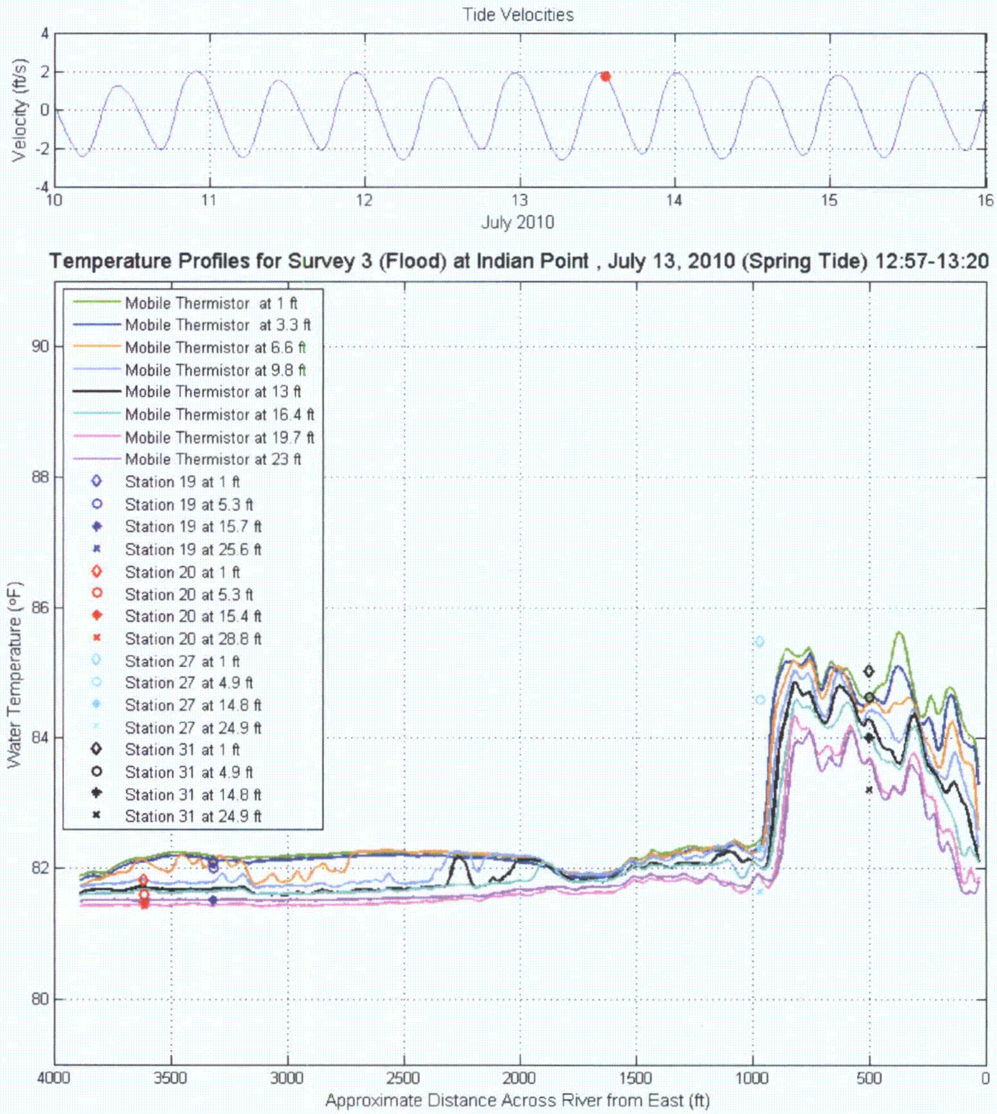

Figure 3-28. Temperature record from mobile survey at Indian Point cross river transect 1257-1320 on 13 July (spring tide) at flood tide, with closest moored thermistor readings included at appropriate cross river distance.

The survey shown in Figure 3-28, shows a strong correlation with the fixed thermistor data that are plotted as various point symbols in the figure. The lines display the continuous measurements from various depths of the mobile temperature sensors. Interestingly, the middle and the western side of the channel show little stratification, as all temperatures from each depth are within 1°F of each other. On the eastern side the heat discharge appears to raise the temperature up by 2 to 3°F all the way to 24.9m depth.

Depending on the location, time of day, and stage of the tide, the vertical stratification can vary significantly within the profiles. Profiles at Iona Island, such as shown in Figure 3-29, generally have similar temperature values between surface and bottom and from east to west, while Stony Point, as shown in Figure 3-30, can exhibit more cross river and vertical variation.

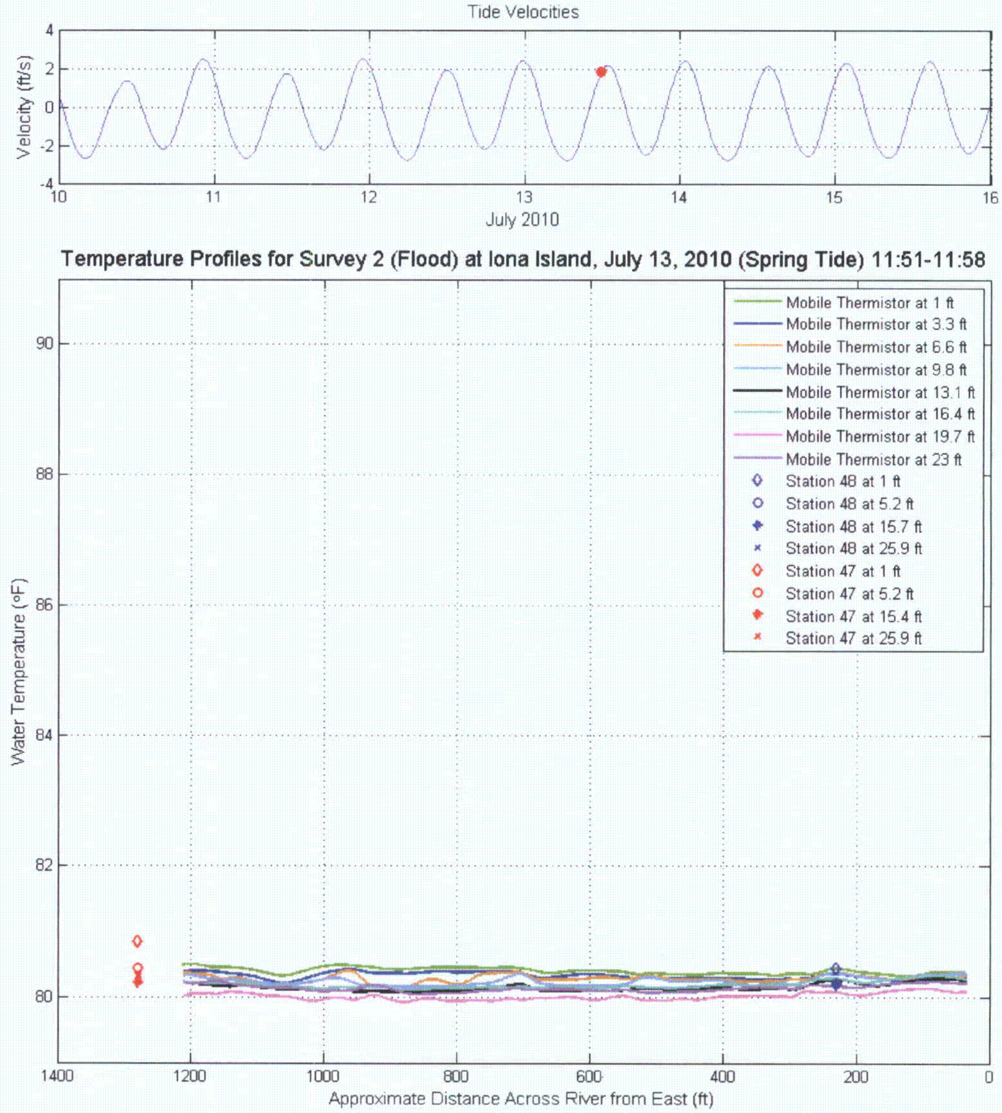

Figure 3-29. Temperature record from mobile survey at Iona Island cross river transect 1151-1158 on 13 July (spring tide) at flood tide, with closest moored thermistor readings included at appropriate cross river distance.

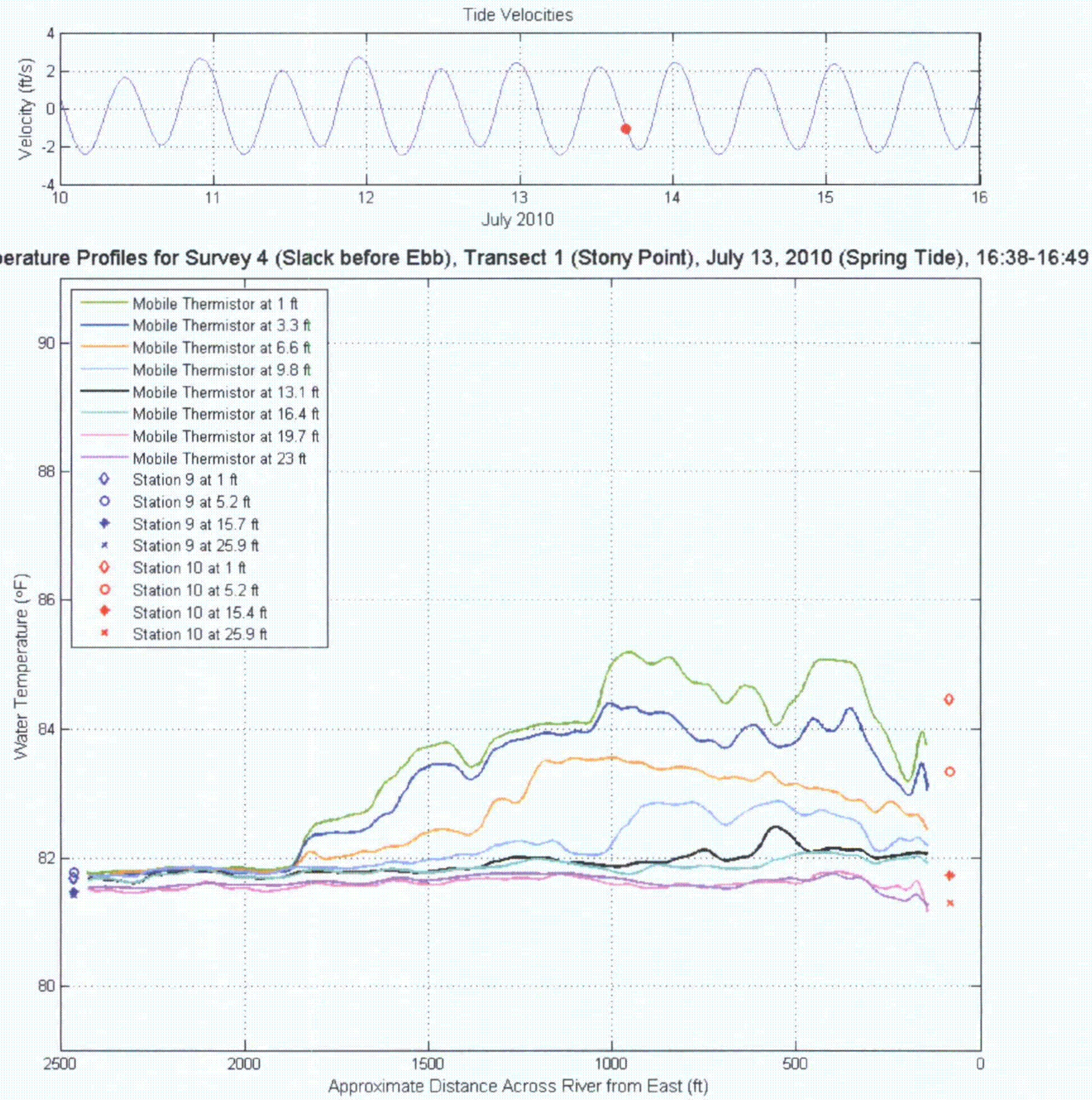

Figure 3-30. Temperature record from mobile survey Stony Point cross river transect 1638-1649 on 13 July (spring tide) at slack before ebb tide, with closest moored thermistor readings included at appropriate cross river distance.

3.3 SALINITY

Salinity was observed by moored instruments at the surface and bottom at four locations: Haverstraw Bay (CTD#1), Stony Point (CTD#2), Indian Point (CTD#3), and Iona Island (CTD#4, see Figures 2-2 through 2-4 for locations). A total of 14 CTDs were installed at the locations, with some CTD locations having multiple sensors at the same depth and location. Instrument malfunction occurred for some salinity sensors, which generated gaps in the individual sensor record. Figure 3-31 shows all of the available salinity data for each location grouped by depth.

Salinity collected at CTD1 in Haverstraw Bay showed bi-weekly variability (i.e., neap-spring cycle) at both surface and bottom overlain with a semi-diurnal cycle from tidal influences, more strongly at the surface than at the bottom (Figure 3-31). Average salinity for the period of record was 5.73 and 4.34 psu for the bottom and surface layer, respectively. The bottom salinity reached a maximum of 9.59 psu on 7 August, while the minimum recorded was 2.70 psu on 31 August. The surface salinity reached a maximum of 7.85 psu on 9 August and a minimum of 1.62 psu on 1 September.

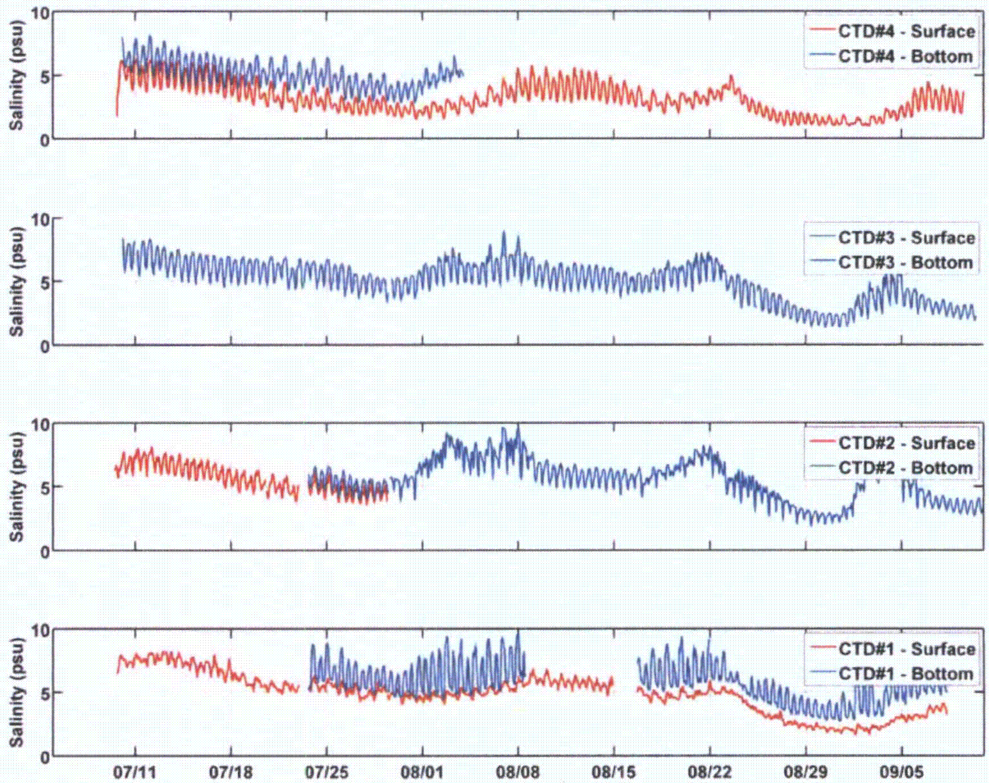

Figure 3-31. Surface and bottom salinities from stationary CTD locations for the 2010 study period. Panels from top (CTD#4) to the bottom (CTD#2) represent the locations from north to south, with the upper middle panel (CTD#2) corresponding to IPEC.

Top-to-bottom salinity difference at CTD1 was minimal (usually less than 1 psu) during ebb, while vertical stratification was above 5 psu during flood. In addition, the daily maximum vertical differences in salinity were typically twice as large during neap (early August and September and mid August) than during spring tide. The closest salinity profile to CTD1 from the mobile survey (mobile CTD station #1 in Figure 2-5) also showed that the top-to-bottom salinity difference was larger during neap (up to 5 psu) than spring (approximately 1 psu), as shown in Figure 3-32. This implies further intrusion of the salt wedge from the ocean and thus more vertical stratification during neap than spring.

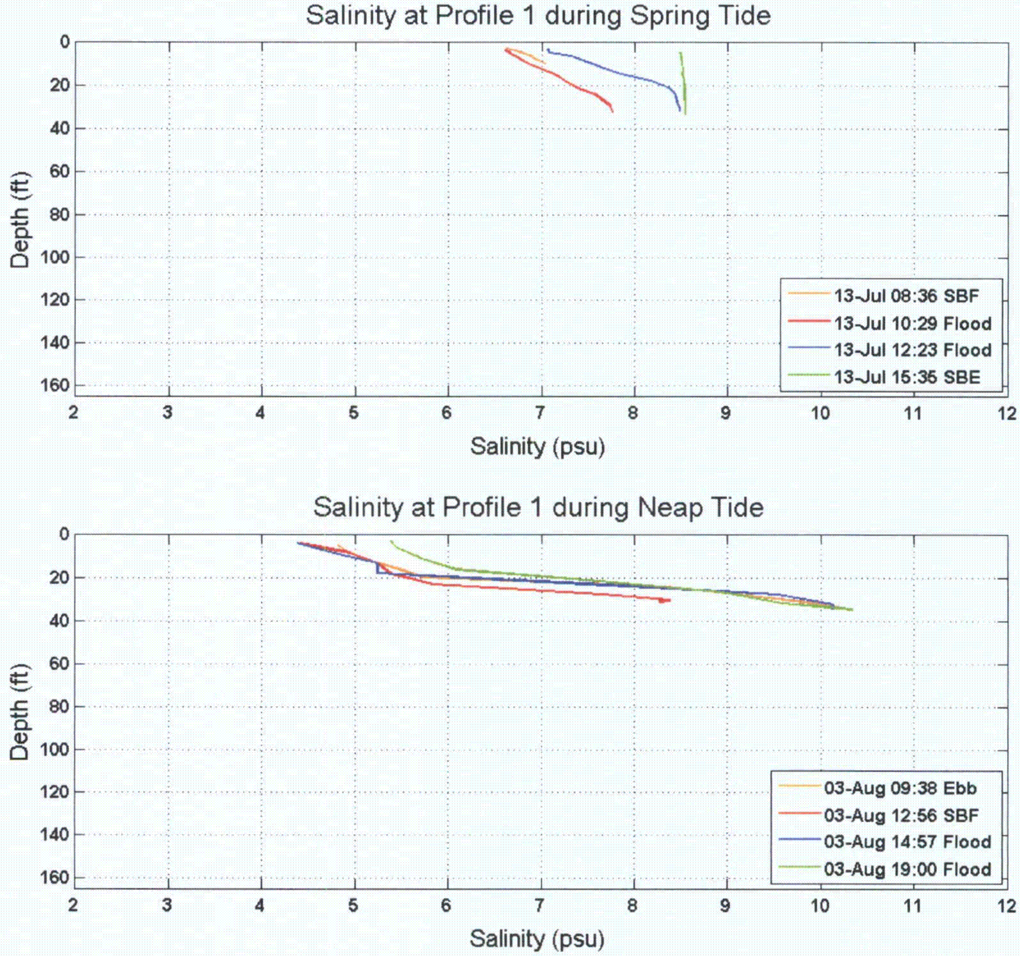

Figure 3-32. Salinity profiles at mobile CTD location 1 on 13 July (upper panel) and 3 August (lower panel.

CTD2 was located at the eastern flank of Stony Point (3.7 mi upstream from CTD1) and showed a slight reduction in salinity from south to north (Figure 3-31) between the two stations. Data collection from the surface layer discontinued after 29 July, but data from the bottom was collected for a period of 52 days (23 July – 14 September). The maximum salinity at the bottom was 9.64 psu on 6 August during a neap tide, and the minimum was 1.84 psu on 29 August during a spring tide (lower middle panel in Figure 3-31). The average salinity for the period was 5.40 psu at the bottom, which was 0.33 psu lower than that at bottom of CTD1. The horizontal salinity gradient was approximately 0.1 psu/mile between the two stations in the northern portion of Haverstraw Bay. The calculated horizontal salinity gradient for this region was larger during spring tide than neap; in addition, there was also less vertical stratification during spring tide than neap tides as a result of increased mixing. Mobile CTD station 12 showed more vertical stratification during neap tide as well (Figure 3-33). Similar to CTD1, daily variability of salinity was larger during neap than spring tide.

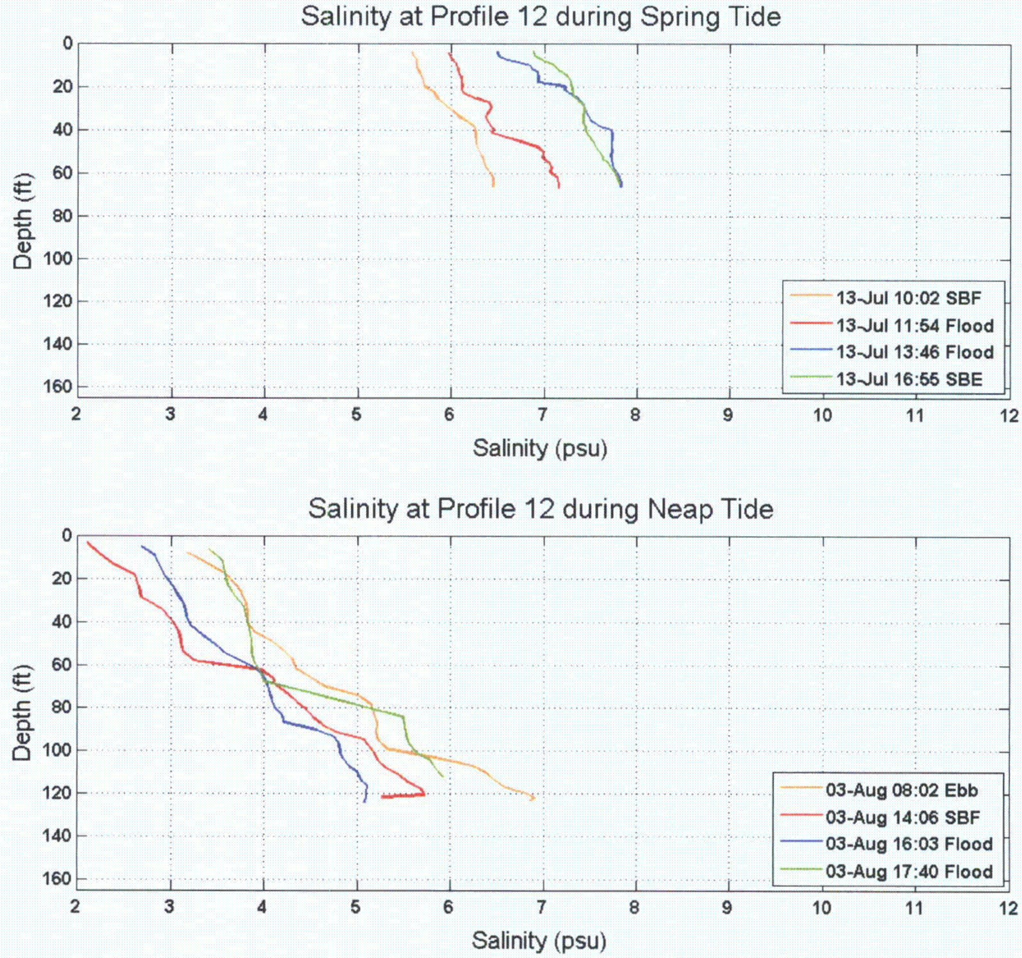

Figure 3-33. Salinity profiles at mobile CTD location 12 on 13 July (upper panel) and 3 August (lower panel.

CTD3 was located in the vicinity of the IPEC discharge (Figure 2-3). The maximum salinity at the bottom was 9.00 psu on 6 August (a neap tide), and the minimum was 1.34 psu on 30 August (a spring tide). The surface salinity reached a maximum of 3.34 psu on 8 August, and a minimum of 0.50 on 19 August. The average salinity was 4.58 psu (bottom) and 2.12 psu (surface) with the bottom at this station 0.82 psu lower than that observed at CTD2. The calculated horizontal salinity gradient between Indian Point and Stony Point was 0.5 psu/mi, which is five times larger than observed at Haverstraw Bay. The horizontal salinity gradient was larger during neap than spring tide, which is opposite to the observations in northern Haverstraw Bay. Such contrasts may be caused by a salt front that was located between Indian and Stony points during neap (18-25 July, 1-8 and 16-25 August, 1-8 September), and moved downstream, south of Stony Point, during the spring tide (25-31 July, 8-16 and 25-31 August). Furthermore, the mobile CTD survey indicated that the vertical stratification at the CTD3 station during neap tide was comparable to the mobile CTD location 25 downstream, as seen in Figure 3-34.

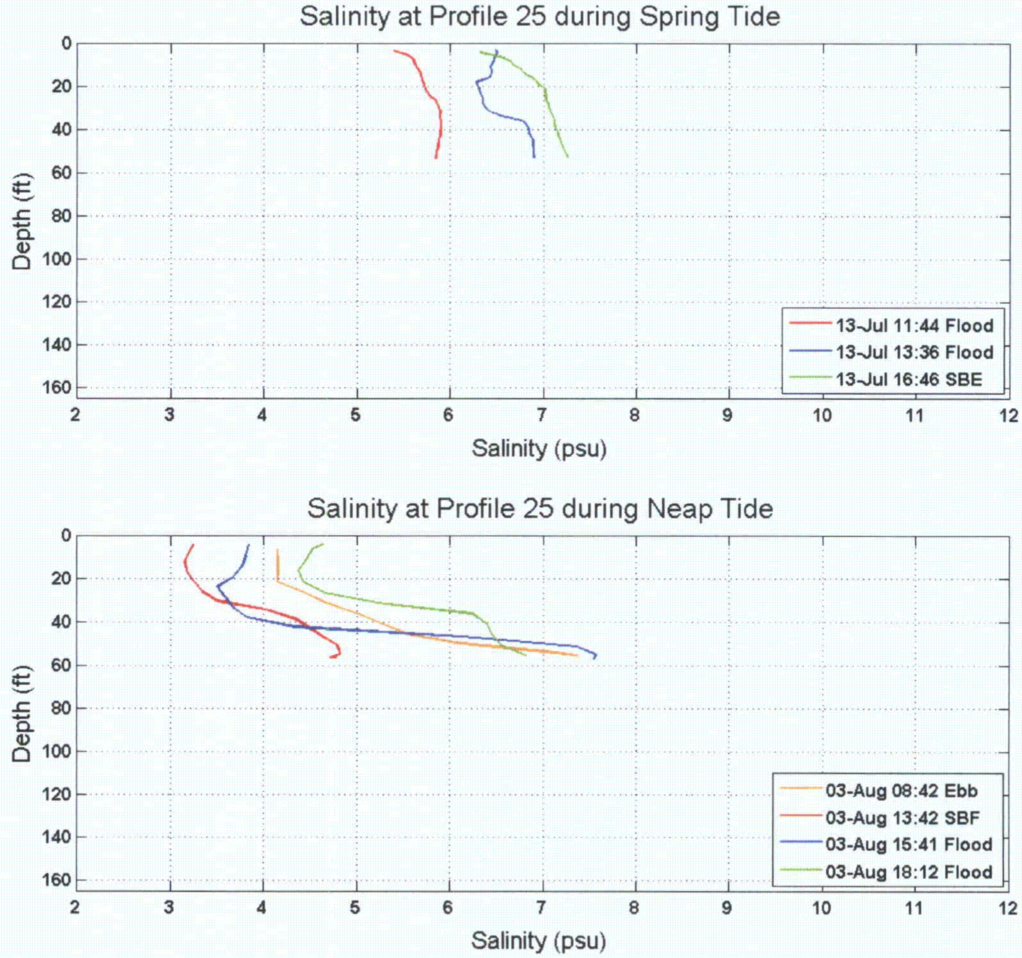

Figure 3-34. Salinity profiles at mobile CTD location 25 on 13 July (upper panel) and 3 August (lower panel.

The farthest upstream moored observation of salinity was located near Iona Island (CTD4 in Figure 2-3). The bottom salinity reached a maximum of 8.13 psu on 12 July, while the minimum recorded was 2.83 psu on 30 July. The surface salinity reached a maximum of 6.23 psu on 11 July and a minimum of 1.01 psu on 2 September. Average salinity for the period of record was 5.07 psu and 3.16 psu for the bottom and surface, respectively. The mobile CTD survey indicated that the vertical stratification during neap tide was comparable to that observed at the stations downstream (Figure 3-35).