IPRenewal NPEmails

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Sent: Monday, November 22, 2010 9:31 AM
To: Stuyvenberg, Andrew
Subject: Indian Point
Attachments: Cover Letter to Supplemental Report.pdf; Analysis of Closed-Loop Cooling Salinity Levels.pdf

<<Cover Letter to Supplemental Report.pdf>> <<Analysis of Closed-Loop Cooling Salinity Levels.pdf>>
Mr. Stuyvenberg:

Dara Gray asked that I forward the attached to you. This was filed with the Administrative Law Judges at the New York Department of Environmental Conservation who are handling the Indian Point SPDES Renewal and Water Quality Certification Proceedings. A hard copy will follow by mail. If you have any difficulty with the attachments, please let me know.

All the best,

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November 19, 2010

Maria E. Villa, Administrative Law Judge
Daniel P. O'Connell, Administrative Law Judge
New York State Department of Environmental Conservation
Office of Hearings and Mediation Services, 1st Floor
625 Broadway
Albany, NY 12233-1550

Re: <u>Indian Point SPDES Proceeding – Supplement to TRC Environmental Corporation's September 1, 2009 Report Entitled "Cooling Tower Impact Analysis for the Entergy Indian Point Energy Center, Westchester County, New York</u>

Dear Judges Villa and O'Connell:

In accordance with your order, dated November 14, 2008, Entergy Nuclear Indian Point 2, LLC, Entergy Nuclear Indian Point 3, LLC and Entergy Nuclear Operations, Inc. (collectively, "Entergy") submitted to this Tribunal and all parties to the SPDES Proceeding certain reports, including reports by (1) TRC Environmental Corporation ("TRC") entitled "Cooling Tower Impact Analysis for the Entergy Indian Point Energy Center, Westchester County, New York," dated September 1, 2009 (the "2009 TRC Report"); and (2) Enercon Services, Inc. ("Enercon"), entitled "Economic and Environmental Impacts Associated with Conversion of Indian Point Units 2 and 3 to a Closed-Loop Condenser Cooling Water Configuration" (the "2003 Closed-Loop Cooling Report") and "Engineering Feasibility and Costs of Conversion of Indian Point Units 2 and 3 to a Closed-Loop Condenser Cooling Water Configuration," submitted on February 12, 2010 (the "2010 Closed-Loop Cooling Report"). While underscoring the serious challenges facing the construction and operation of closed cycle cooling, the 2010 Closed Cycle Cooling Report evaluated the conceptual placement of two hybrid closed cycle cooling towers at Indian Point, and included a biological appendix that provided entrainment-related data associated with closed cycle cooling under an assumption of year-round operations.

Using an air quality modeling methodology consistent with methods recommended by the U.S. Environmental Protection Agency and the New York State Department of Environmental Conservation ("NYSDEC" or the "Department"), the 2009 TRC Report analyzed, among other things, the expected particulate emissions (as PM-10 & PM-2.5) from cooling towers, if they could be located at Indian Point. The results of that analysis indicated that operation of the towers would result in ground level particulate concentrations that would exceed applicable PM-

10 and PM-2.5 Significant Impact Levels ("SILs") and/or National Ambient Air Quality Standards ("NAAQS"). *See* 2009 TRC Report, pp. 3-13 to 3-24. As a result, TRC concluded that the towers "will cause an adverse air quality impact to the surrounding community such that obtaining a required construction and operating air emissions permit pursuant to 6 NYCRR Part 201 and 231 would not be possible." 2009 TRC Report, p. 1-4.[1]

Since submission of the TRC and Enercon Reports, Entergy's consultants have continued to refine their analysis of the relationship between Hudson River salinity levels and particulate emissions for hybrid cooling towers at Indian Point. To that end, attached is a supplemental report by Enercon, with input from Applied Science Associates, Inc. ("ASA"), TRC and a team of biologists, including ASA Analysis and Communications, Inc. ("ASAAC"), entitled "Analysis of Closed-Loop Cooling Salinity Levels, Indian Point Units 2 & 3" (the "Supplement"). While the Supplement and its technical analyses speak for themselves, several important conclusions are apparent, and warrant highlighting for this Tribunal:

- **The highly variable salinity levels in the Hudson River are frequently substantially higher than the average (constant) value used in the 2010 Enercon and 2009 TRC Reports**. ASA evaluated historic salinity data for the Hudson River in the vicinity of Indian Point and determined that, although the average, constant salinity value used was correct, large natural variation in salinity levels occur, resulting in salinity levels that are frequently substantially higher than those utilized in the 2009 TRC and 2010 Enercon Reports.

- **Actual expected salinity level peaks lead to correspondingly greater particulate emissions – and a larger number of exceedances and/or violations of air quality standards – than previously reported in the 2009 TRC Report.** TRC utilized the updated salinity information provided by ASA to re-analyze the potential emissions of PM-10 and PM-2.5 from the cooling towers, if located at Indian Point. TRC concluded that particulate emissions are greater given the actual expected salinity levels in the Hudson River, as distinct from the previously assumed average, constant salinity.

- **Changes in operations of cooling towers reduce, but do not eliminate, the exceedances and/or violations of applicable air quality standards.** Enercon evaluated

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[1] On October 16, 2009, Department Staff served Entergy with its initial discovery with regard to the 2009 TRC Report ("Department's Discovery Request"). In the Department's Discovery Request, Department Staff sought additional information regarding, among other things, the use of certain "annual average salinity level" data for the Hudson River by TRC. See Department Discovery Request, p. 7. Entergy responded to this and all other requests in the Department's Discovery Request on February 19, 2010 ("Entergy's Response").

whether operating the cooling towers so as to minimize salinity concentrations in the water within the tower (*i.e.*, reducing the number of times water is cycled through the tower before being discharged back to the Hudson River, thus reducing particulate emissions) might alleviate air quality exceedances and/or violations. However, even at reduced concentrations within the cooling towers by using additional Hudson River makeup flow, air quality exceedances and/or violations persist.

- **If operated to avoid air quality exceedances and/or violations, cooling tower use is severely constrained.** TRC analyzed whether compliance with air quality standards could be achieved by limiting the operation of cooling towers to certain periods of the year (i.e., the cooling towers would not operate during periods of high river salinity). TRC concluded that, in order to comply with applicable SILs, cooling towers could be operated no more than 13% of the year. TRC also concluded that, in order to comply with applicable NAAQS, cooling towers could be operated no more than 42% of the time. As noted in the Supplement, the SILs are the limiting factor in the Indian Point region; therefore, cooling towers could be operated no more than 13% of the year. This would mean cooling towers would operate no more than 47 days per year, i.e., just about a month and a half each year.

- **Limited cooling tower operation results in limited reductions in entrainment.** Finally, the biological team, including ASAAC, evaluated the reductions in entrainment associated with the restricted use of cooling towers required as a result of the need to operate in compliance with applicable air quality requirements. That analysis indicates that (i) if operated in order to comply with SILs, cooling towers could achieve an annual reduction in numbers entrained of 26.7% from baseline conditions, and (ii) if operated in order to comply with NAAQS, cooling towers would achieve a reduction in numbers entrained of 57.4% from baseline conditions. As noted in the Supplement, the SILs are the limiting factor in the Indian Point region; therefore, cooling towers could be operated no more than 13% of the year, achieving a corresponding 26.7% reduction in numbers entrained.

- **Consequently, cooling tower performance does not come close to cylindrical wedgewire screens, in terms of entrainment reductions.** Because operating cooling towers in compliance with applicable air quality laws would result in significantly lower entrainment reductions, the Supplement also revisits the comparison of alternative technologies presented in Enercon's "Evaluation of Alternative Intake Technologies at Indian Point Units 2 and 3," submitted on February 12, 2010 (the "2010 Alternatives Report"). As indicated in Appendix D, Table 1 of the Supplement, ASAAC compared the performance of closed-cycle cooling (limited as required to comply with applicable air quality laws) to 2-mm cylindrical wedgewire screens, as well as to current operations.

> That comparison indicates that, on an annual basis assuming simultaneous installation (in a manner contrary to reasonable expectations and the 2010 Enercon Reports): (1) cylindrical wedgewire screens achieves a 74.1% reduction in numbers entrained over baseline conditions; (2) closed-cycle cooling achieves a 26.7% reduction over baseline conditions; and (3) current operations at Indian Point achieves a 17.3% reduction over baseline conditions. Thus, measured in entrainment reductions, cylindrical wedgewire screens substantial outperform closed cycle cooling on an annual basis, among other circumstances.

* * *

In light of these findings, it is increasingly indisputable that air quality is a severely limiting, if not dispositive, issue with regard to the availability of closed-cycle cooling at Indian Point, and therefore appropriate for trial this spring as proposed in our recent response, dated November 4, 2010, to this Tribunal.[2] Moreover, even if closed-cycle cooling were determined to be an available technology at Indian Point, the Supplement underscores that closed-cycle cooling is not, and cannot reasonably be considered, the "best" technology available under 6 NYCRR §704.5, because it is outperformed – on an annual and a cumulative (*i.e.*, over the operating life of the technology) basis – by cylindrical wedgewire screens.

Thank you for your attention to this matter, and please do not hesitate to contact me with any questions regarding this submission.

Respectfully submitted,

Elise N. Zoli/Kmc

Elise N. Zoli

cc: Service List
Andrew Stuyvenberg, Nuclear Regulatory Commission

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[2] Entergy appreciates that the Supplemental Report may prompt additional discovery requests on the Supplemental Report. Nevertheless, there is ample time to complete any remaining discovery in due course in order to move forward with a trial on air quality impacts next Spring.

ANALYSIS OF CLOSED-LOOP COOLING SALINITY LEVELS INDIAN POINT UNITS 2 & 3

Prepared for
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November 2010

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Executive Summary

This report describes supplemental analyses and closed-loop operational scenarios for compliance with regulatory requirements for air emissions. The updated make-up flow rates to reduce closed-loop cooling salinity are presented along with the corresponding emissions of particulate matter, based on the recent Applied Science Associates, Inc. (ASA) salinity analysis.

In the 2003 Report "Economic and Environmental Impacts Associated with Conversion of Indian Point Units 2 and 3 to a Closed-Loop Condenser Cooling Water Configuration" (2003 Closed-Loop Cooling Report), the salinity of a closed-loop system for Indian Point Energy Center (IPEC) was determined to be 7.2 practical salinity units (psu), employing a constant (average) factor for Hudson River salinity of 1.8 psu. This salinity level was the basis for the air quality analyses of cooling tower particulate emissions performed by TRC Companies, Inc. (TRC) in 2009. The recent ASA salinity analysis has indicated that, although the 1.8 psu average is correct, the Hudson River salinity is highly variable and often significantly greater than 1.8 psu for extended periods of time. As a result, if installed, a closed-loop system at IPEC would not be able to maintain 7.2 psu, as previously evaluated by TRC.

This report evaluates how a closed-loop system would need to operate, given the recent salinity information provided by ASA and the associated air quality analyses performed by TRC. As detailed below, and summarized in the results section of this report, there is an essential trade-off between closed–loop cooling operation and air quality, given prevailing salinity conditions of the Hudson River. According to TRC, the closed-loop cooling system cannot reasonably be expected to comply with air quality standards if operated for substantial periods of time (including most of the summer months) given the expected Hudson River salinity values. As a result, previous assumptions about closed-loop cooling operations and configurations (contained in both the 2003 Closed-Loop Cooling Report and the "2010 Engineering Feasibility and Costs of Conversion of Indian Point Units 2 and 3 to a Closed-Loop Condenser Cooling Water Configuration" (2010 Closed-Loop Cooling Report)) require updating.

Closed-loop cooling requires make-up water to replace water lost in evaporation and drift from the cooling towers, and to allow blowdown from the closed-loop system to maintain water quality within the system. As defined in the 2010 Closed-Loop Cooling Report, the IPEC closed-loop cooling system would draw its make-up water from the service water (SW) discharged from each Unit, which reflects the salinity of the Hudson River. According to TRC, Hudson River water salinity is the primary contributing factor to emissions. The evaluated mechanism for controlling air emissions is to limit salinity in the system through alteration of the cooling tower operations, specifically cycles of concentration, or reverting to once-through cooling (bypassing the cooling towers). Theoretically, if the River salinity is sufficiently low, it can be used for closed-loop cooling; however, as the ASA salinity analysis shows, River salinity is high for extended periods of time. This salinity effectively constrains cooling tower operations, requiring the closed-loop system to revert to once-through cooling in order to avoid exceeding the $PM_{2.5}$ national ambient air quality standards (NAAQS) and $PM_{2.5}$ Significant Impact Levels (SIL).

TRC evaluated the exceedance of the PM_{10} and $PM_{2.5}$ NAAQS and SIL that would result from operation of closed-loop cooling at IPEC. TRC determined that to avoid exceeding the $PM_{2.5}$ NAAQS with 1.5 cycles of concentration, the Hudson River salinity would have to be 0.846 psu or less. The limiting ground level concentration in the Westchester County $PM_{2.5}$ non-attainment area is the SIL; to avoid exceeding the $PM_{2.5}$ SIL with 1.5 cycles of concentration, TRC determined that the Hudson River dissolved solids would have to be 0.175 psu or less. These values represent make-up water salinity (i.e., Hudson River water salinity), which is the primary contributing factor to emissions.

TRC's analysis provided the basis for determining the operating profiles for closed-loop cooling based upon the Hudson River salinities (i.e., cooling tower make-up water salinities). In order to avoid exceeding the $PM_{2.5}$ NAAQS or $PM_{2.5}$ SIL under any meteorological condition, a "$PM_{2.5}$ NAAQS No Exceedance" and a "$PM_{2.5}$ SIL No Exceedance" scenario was run to determine how often IPEC would be forced to revert from closed-loop to once-through operation. While no detailed design work on a system that would allow switching from closed-loop to once-through operation at IPEC has been performed, operating constraints would likely limit the switch to a seasonal basis; however, this Report conservatively assumes the switch between closed-loop and once-through operation would be determined on a weekly basis (although impractical for actual Station operation). In addition, the closed-loop cooling configuration described in the 2003 and 2010 Closed-Loop Cooling Reports would have to be revised to accommodate switching between closed-loop cooling and once-through cooling (bypassing the cooling towers). The need to switch between once-through and closed-loop cooling may have substantial design, construction, operational, and cost ramifications.

In order to avoid exceeding the $PM_{2.5}$ NAAQS and $PM_{2.5}$ SIL, operation of closed-loop cooling would be expected to occur no more than 43% and 13% of the year, respectively. Operation of closed-loop cooling 43% of the time would result in reductions in entrainment, entrainment losses, and equivalent age 1 losses of 57.4%, 63.8%, and 56.6%, respectively; moreover, the $PM_{2.5}$ SIL would still be exceeded. Operation of closed-loop cooling 13% of the year would result in reductions in entrainment, entrainment losses, and equivalent age 1 losses of 26.7%, 41.4%, and 38.5%, respectively. For comparison, the reductions in equivalent age 1 losses for cylindrical wedgewire screens would be approximately 89.8%, as presented in Attachment 6 of the 2010 "Evaluation of Alternative Intake Technologies at IPEC Units 2 and 3" (2010 Alternative Technologies Report). Likewise, the reductions in equivalent age 1 losses associated with the existing technology and operational suite employed by Entergy (i.e., Ristroph screens and fish handling and return systems, as well as flow reductions due to variable and dual speed pumps and maintenance outages) are approximately 33.8%.

1 Introduction

1.1 Purpose

In the 2003 Report "Economic and Environmental Impacts Associated with Conversion of Indian Point Units 2 and 3 to a Closed-Loop Condenser Cooling Water Configuration" (2003 Closed-Loop Cooling Report) [Ref. 6.1], the salinity[1] of a closed-loop system for Indian Point Energy Center (IPEC) was determined to be 7.2 practical salinity units (psu), employing a constant (average) factor for Hudson River salinity of 1.8 psu. This salinity level was the basis for the air quality analyses of cooling tower particulate emissions performed by TRC Companies, Inc. (TRC) in 2009. The recent Applied Science Associates, Inc. (ASA) salinity analysis has indicated that, although the 1.8 psu average is correct, the Hudson River salinity is highly variable and often significantly greater than 1.8 psu for extended periods of time. As a result, if installed, a closed-loop system at IPEC would not be able to maintain 7.2 psu, as previously determined and evaluated by TRC.

This report describes supplemental analyses and closed-loop operational scenarios for compliance with regulatory requirements for air emissions. The updated make-up flow rates to reduce closed-loop cooling salinity are presented along with the corresponding emissions of particulate matter, based on the recent ASA salinity analysis.

1.2 Scope

This report evaluates how a closed-loop system would need to operate, given the recent salinity information provided by ASA (Appendix F) and the associated air quality analysis performed by TRC (Appendix C). As detailed below, and summarized in the conclusions section of this report, there is an essential trade-off between closed–loop cooling operation and air quality, given prevailing salinity conditions of the Hudson River. According to TRC, the closed-loop cooling system cannot reasonably be expected to comply with $PM_{2.5}$ national ambient air quality standards (NAAQS) and $PM_{2.5}$ Significant Impact Levels (SIL) if operated for substantial periods of time (including most of the summer months) given the Hudson River salinity values. As a result, previous closed-loop cooling operations and configurations (contained in both the 2003 Closed-Loop Cooling Report [Ref. 6.1] and the 2010 Engineering Feasibility and Costs of Conversion of Indian Point Units 2 and 3 to a Closed-Loop Condenser Cooling Water Configuration (2010 Closed-Loop Cooling Report) [Ref. 6.1]) require updating.

[1] For the purposes of this report, the term "salinity" is used to conservatively represent the sum of total dissolved solids (TDS) and total suspended solids (TSS), which, when measured may yield values greater than simply measuring salinity alone.

2 Salinity Analysis Inputs

2.1 Salinity Data

2.1.1 2003 Closed-Loop Cooling Report Salinity Data

Attachment 5 of the 2003 Closed-Loop Cooling Report [Ref. 6.1], reflected a closed-loop salinity of 7.2 psu (7200 ppm), based on an assumed average salinity level of 1.8 psu (1800 ppm) obtained from the 1974 Economic and Environmental Impacts of Alternative Closed-Cycle Cooling Systems for Indian Point Unit 2 [Ref. 6.5]. Closed-loop salinity was used as a design consideration for cooling tower component selection, and was used to evaluate the salt deposition around the two round hybrid cooling towers [Ref. 6.4].

2.1.2 ASA Hudson River Salinity Data

A long-term data set of Hudson River salinity in the vicinity of Indian Point was determined and provided by ASA, as documented in Appendix F. The data set consisted of 10 years of modeled Hudson River salinity data for the period 2000 – 2009 in 1-hr increments. Table 2.1 shows the average and maximum continuous Hudson River salinity in psu for the interpolated 10-yr data (Table 5.8 of Appendix F). Appendix F further describes ASA's analysis of the Hudson River salinity data. The average data recovery rate (i.e., percentage of data that is measure over a given period of time) for the ten year period analyzed (2000-2009) was 97.2% as shown in Appendix F, and represents an extremely robust data set.

Table 2.1 Continuous 10-Year Hudson River Salinity Data (2000 – 2009)

Month	10-Year Data *Average (psu)*	10-Year Data *Maximum (psu)*
January	1.11	6.77
February	1.59	6.96
March	1.08	5.84
April	0.51	4.51
May	0.75	6.60
June	1.17	6.07
July	2.45	7.27
August	3.14	7.55
September	3.90	7.67
October	3.14	7.66
November	1.76	7.63
December	1.06	7.26
Average Annual	1.81	6.82*

*Average of the monthly maxima.

2.2 Service Water Flow Description

For this analysis and consistent with 2010 Closed-Loop Cooling Report, Service Water (SW) flows were utilized as make-up flow for the closed-loop cooling system. IPEC supplied seven years (2001-2007) of measured SW intake flow data to ASA Analysis & Communication, Inc. (ASAAC) in millions of gallons per day (MGD); the Unit 2 data includes Unit 2 service water (SW) and Unit 1 river water (RW) flow, and the Unit 3 data includes Unit 3 SW flow. This data was initially supplied for the Biological Assessment included in Attachment 6 of the 2010 Evaluation of Alternative Intake Technologies at IPEC Units 2 and 3 (2010 Alternative Technologies Report) [Ref. 6.3].

Table 2.2 shows the monthly and annual average historic flows for the Stations in gallons per minute (gpm). The monthly and average historic SW flows were used because coincident data (2000 – 2009) was not available.

Table 2.2 Average Historic SW Flow Rates (2001-2007)

Month	Unit 2[1] *(gpm)*	Unit 3[2] *(gpm)*	Total *(gpm)*
January	27,947	18,000	45,947
February	28,668	18,000	46,668
March	28,507	16,524	45,031
April	28,924	16,443	45,367
May	29,123	17,774	46,897
June	29,757	18,471	48,228
July	32,201	20,868	53,069
August	34,304	22,561	56,865
September	33,644	20,675	54,319
October	31,239	18,685	49,924
November	28,932	17,913	46,845
December	29,628	18,000	47,628
Average Annual[3]	30,251	18,668	48,919

[1] Unit 2 flow includes Unit 2 SW flow and Unit 1 RW flow.

[2] Unit 3 flow includes Unit 3 SW flow.

[3] The average annual historic (2001-2007) SW flow rate is a weighted average determined using the number of days in each month with respect to the number of days in one year.

2.3 Meteorological Data

Site wet-bulb temperature[2] governs the amount of evaporation from the cooling towers during operation. Since closed-loop salinity is concentrated by evaporation, it is necessary to accurately define monthly variations in evaporation for the closed-loop cooling salinity level analysis. Although wet-bulb temperature is not measured directly by site meteorological instruments, wet-bulb temperature was calculated using the measured dry bulb temperature and dew point temperature data obtained from IPEC.

The eight years of IPEC meteorological data (2001-2008) utilized in the 2010 Closed-Loop Cooling Report [Ref. 6.2] was also utilized for this analysis. A thorough review was conducted to ensure that the data set was uniform with no erroneous values. The average data

[2] Wet-bulb temperature is a meteorological measurement that incorporates both moisture content and temperature of the ambient air.

recovery rate for the eight year period analyzed (2001-2008) was 97.2% as shown in Attachment 4, Table 4-1 of the 2010 Closed-Loop Cooling Report [Ref. 6.2], and represents an extremely robust data set.

2.4 Closed-Loop Design

As discussed in the 2010 Closed-Loop Cooling Report [Ref. 6.2], conversion of both Units 2 and 3 to closed-loop cooling would necessitate the installation of two 100% capacity round hybrid cooling towers and the associated piping and equipment. Under the identified configuration, the new circulating water pumps (CW) for each Unit would draw suction from a modified discharge canal to provide water to cooling tower supply pipelines. In its modified configuration, the discharge canal would no longer serve its once-through cooling function to return circulating water to the Hudson River, but instead would become a new circulating water reservoir / pump pit. The new Unit 2 pump house would be located on the discharge canal between the Unit 1 and Unit 3 turbine generator buildings. The new Unit 3 pump house would be located on the discharge canal along the Hudson River bank. Although the existing CW pumps would no longer be required for closed-loop operation, SW flow would still be maintained through the existing intake structures. The discharge from the SW systems would be used after a conversion to closed-loop cooling for make-up water to the cooling towers.

In short, in order to convert to closed-loop cooling, multiple modifications to the discharge canal would be required. The existing discharge canal would need to be modified to serve as a reservoir/pump pit for the new circulating water pumps that would supply the cooling towers. The new reservoir would communicate between Units 2 and 3 and provide some operational flexibility, whereby the reserve volume would act as a buffer against flow disruptions and equipment failure.

Additional make-up flow for the closed-loop cooling system could be required to provide additional dilution during periods of high closed-loop salinity. One or more make-up pump(s) could be designed to supply the required flow to the cooling tower reservoir. The necessity for additional pumping capacity and resultant flow is discussed in Section 3.1.

3 Method of Analysis

3.1 Additional Make-Up Cases

Closed-loop cooling requires make-up water to replace water lost in evaporation and drift from the cooling towers, and to allow blowdown from the closed-loop system to maintain the water quality in the closed-loop system. As defined in the 2010 Closed-Loop Cooling Report [Ref. 6.2], the IPEC closed-loop cooling system would draw its make-up water from the SW discharged from each Unit, which reflects the salinity of the Hudson River. The mechanism for controlling air emissions is to limit salinity in the system through alteration of the cooling tower operations, specifically cycles of concentration.

The make-up flow provided by historic SW discharge is substantial (see Section 2.2); however, based upon the salinity analysis performed by ASA, SW discharge alone would not adequately reduce the closed-loop salinity in times of increased Hudson River salinity. In an attempt to limit closed-loop salinity, a control logic was chosen using SW discharge and additional make-up water used in instances of high closed-loop cooling salinity. The control logic analyzed is as follows:

1) If closed-loop salinity is less than the selected setpoint[3], then utilize the SW discharge flow rate only as closed-loop make-up.

2) If closed-loop salinity is greater than the selected setpoint, then utilize the SW discharge and additional make-up flow as closed-loop make-up.

Note that if the River salinity is low enough, it can be used for closed-loop cooling; however, as the ASA salinity analysis shows, River salinity is high for extended periods of time. This salinity effectively constrains cooling tower operations, requiring the closed-loop system to revert to once-through cooling in order to avoid exceeding the $PM_{2.5}$ NAAQS and $PM_{2.5}$ SIL.

Figure 3.1 illustrates the closed-loop cycle for one Unit.

[3] The salinity setpoint is a selected point at which additional make-up flow is initiated to counteract high closed-loop salinity levels. The setpoints are selected to minimize make-up flow requirements at the given salinity level, based on the trended analysis discussed in Appendix A. The selected setpoints are documented in Table A.1 of Appendix A.

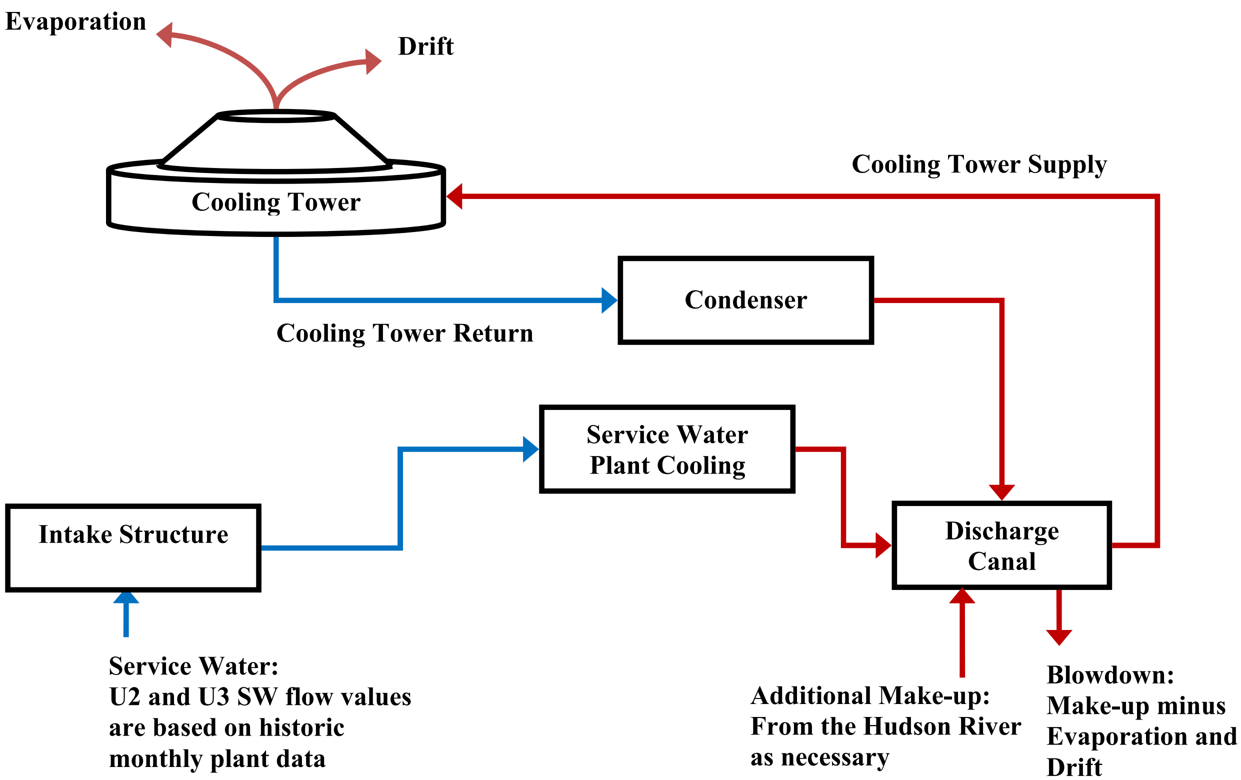

Figure 3.1 Closed-Loop Design

The river water salinity is added to the closed-loop system through the SW flow and additional make-up flow, as required. Salinity is removed from the closed-loop system through blowdown and drift[4] although the salinity lost from the closed-loop system from drift is negligible[5]. Salinity is concentrated in the closed-loop system through evaporation.

Hybrid cooling-tower operation was selected to minimize evaporation, and thereby reduce closed-loop salinity and make-up water flow requirements. SPX provided two data points for evaporation rates for hybrid cooling tower operation (Appendix E). These data points were used to create a correlation between the evaporation rates of a round hybrid cooling tower and the ambient wet-bulb temperature. Appendix E includes a chart from SPX illustrating the linear nature of the relationship between evaporation and wet-bulb temperature. The meteorological data described in Section 2.3 was used to determine the monthly average wet-

[4] Drift is liquid water that is carried away from the cooling towers through the exhaust air stream. Drift droplets have the same concentration of solids as the water flowing through the cooling tower.

[5] The amount of flow and salt lost to drift is only 14 gpm or approximately 0.04% of the make-up flow for the closed-loop system. Therefore, the salinity lost from the closed-loop system through drift is not included in this analysis.

bulb temperature at IPEC because coincident data (2000 – 2009) was not available. This monthly average wet-bulb temperature was input into the correlation derived from the SPX data to determine the monthly and annual average evaporation rates. Table 3.1 shows the monthly and annual average evaporation rates used in the salinity analysis.

Table 3.1 Monthly Average Evaporation

Month	Evaporation Rate *Average (%)*	Evaporation Rate *Average (gpm)*
January	0.80	11,144
February	0.80	11,161
March	0.87	12,187
April	1.01	14,114
May	1.12	15,738
June	1.25	17,566
July	1.30	18,218
August	1.29	18,058
September	1.22	17,055
October	1.08	15,174
November	0.98	13,774
December	0.86	11,976
Average Annual[1]	1.05	14,696

[1] The average annual evaporation rate is a weighted average determined using the number of days in each month with respect to the number of days in one year.

3.2 1.5 Cycles of Concentration

As discussed in the 2010 Closed-Loop Cooling Report, Hudson River water currently used in the Stations' circulating water systems must also be used for the circulating water in a closed-loop system[6]. Evaporation in the cooling tower would increase the concentration of dissolved solids in the circulating water, as compared to the Hudson River water. The number of times the dissolved minerals in the circulating water are concentrated, versus the level in the Hudson River water (i.e., the cycles of concentration), is an important parameter for cooling tower operation. Since the intake salinity at IPEC varies dramatically based on freshwater discharge to the Hudson River as well as other meteorological and oceanographic influences, the number of cycles of concentration would be dependent on the current intake salinity. The higher the salt content of the makeup water, the fewer cycles of concentration that can be employed to maintain the amount of dissolved solids in the circulating water below the design value.

When designing cooling towers, SPX prefers to limit the closed-loop TDS concentration (i.e., salinity) to 5000 ppm (5 psu) or less (Appendix E). Based on ASA's updated Hudson River

[6] As a result of the considerable unknowns, costs, and the numerous permits required, using recycled wastewater is considered infeasible, as discussed in Section 7.1.2 of the 2010 Cooling Tower Report.

salinity analysis (Appendix F), salinity in the vicinity of IPEC peaks as high as 7.67 psu, thus requiring additional make-up flow to moderate the effects of increased Hudson River salinity. The most practical flow scenario would utilize 1.5 cycles of concentration for the closed-loop system, meaning that the concentration of TDS in the circulating water would be 1.5 times that of the incoming Hudson River water. This make-up flowrate was selected based on the recommendation of SPX for saltwater towers[7]. The flowrate required to achieve 1.5 cycles of concentration is equivalent to the historic Unit 2 and Unit 3 service water flowrates. The evaporation and drift flow rates would be determined as described in Section 3.1.

[7] The water quality in saltwater cooling towers is typically 1.5 cycles of concentration, meaning the concentration of TDS in the circulating water would be 1.5 times that of the incoming water. Saltwater/brackish cooling towers are limited by material and thermal performance degradation at levels above 1.5 cycles of concentration and the biological impact of increased water usage at levels below 1.5 cycles of concentration.

4 Updated Salinity Calculation

The updated salinity analysis provides the monthly and annual closed-loop salinity levels based on an updated make-up flow operational scenario to reduce closed-loop cooling salinity in accordance with air quality requirements. The need to decrease the closed-loop salinity is balanced against the goal of not increasing the flow to a value that would significantly diminish closed-loop flow reductions. Table A.1 provides the salinity setpoint (i.e., the selected setpoint at which additional make-up flow is initiated to counteract high closed-loop salinity levels) selections, based on the trended analysis discussed in Appendix A. These setpoint values were selected in an attempt to minimize both the salinity and make-up flow required.

The closed-loop flow and salinity loop is illustrated in Figure 3.1. The initial salinity level within the closed-loop system (T_1) is based on an assumed initial salinity value[8] and the volume of water within the closed-loop system for both Units, shown in Equation 1.

$$T_1 = V \times S_{C1} \qquad (1)$$

where,

T_1 = Initial salt content in the closed-loop system (psu × gallons)

V = Volume of water in the closed-loop system (gallons)

S_{C1} = Initial salinity of the water in the closed-loop system (psu)

The second, and subsequent closed-loop salinity values, are calculated using Equation 2.

$$T = T_L - S_C \times B + S_N \times M \qquad (2)$$

where,

T = Salt content in closed-loop system (psu × gallons)

T_L = Previous salt content in closed-loop system (psu × gallons)

S_C = Previous salinity of the water in the closed-loop system (psu)

B = Blowdown volume (gallons)

S_N = Salinity of the Hudson River water (psu)

M = Make-up volume (gallons)

[8] Using an iterative process, the starting closed-loop cooling salinity is assumed to be the average closed-loop salinity calculated for each setpoint and make-up flowrate; the average closed-loop salinity is used as a representative value and has a negligible impact on the overall calculation.

The closed-loop salinity values calculated using Equation 2 were reviewed and, if during a given week the closed-loop salinity would result in a value exceeding the $PM_{2.5}$ NAAQS or $PM_{2.5}$ SIL limits (Appendix C), the system was switched to once-through operation. For the purposes of this analysis, the switch from closed-loop to once-through cooling was conservatively determined on a weekly basis (i.e., if the closed-loop salinity value would exceed the $PM_{2.5}$ NAAQS or $PM_{2.5}$ SIL limits at any time in a given week, once-through operation was utilized instead of closed-loop operation). However, switching between closed-loop and once-through cooling may only be feasible (if at all practicable) on an infrequent period (such as a seasonal basis).

5 Results

The updated salinity analysis on the 10-year Hudson River data provided by ASA returned values greater than the 7.2 psu defined in the 2003 and 2010 Closed-Loop Cooling Reports. Analyses were done over a range of make-up pump flowrates as well as 1.5 cycles of concentration to determine if make-up pumps would be able to eliminate exceedance of the $PM_{2.5}$ NAAQS and $PM_{2.5}$ SIL. Each of these analyses was calculated in the manner described in Section 4 and was then utilized by TRC to determine the potential exceedance for each scenario.

TRC evaluated the exceedance of the PM_{10} and $PM_{2.5}$ NAAQS and SIL that would result from operation of closed-loop cooling at IPEC. As discussed in Appendix C, the $PM_{2.5}$ NAAQS is 5.8 micrograms per cubic meter above the ambient background levels; to avoid exceeding the $PM_{2.5}$ NAAQS, the Hudson River dissolved solids would have to be 0.846 psu or less. When this value is concentrated 1.5 times, the maximum cooling tower salinity would be approximately 1.269 psu. The limiting ground level concentration in the Westchester County $PM_{2.5}$ non-attainment area is the SIL of 1.2 micrograms per cubic meter; to avoid exceeding the $PM_{2.5}$ SIL, the Hudson River dissolved solids would have to be 0.175 psu or less. When this value is concentrated 1.5 times, the maximum cooling tower salinity would be approximately 0.263 psu. Limiting the cooling tower salinity to below 0.263 psu theoretically would allow the closed-loop cooling system to operate at IPEC without exceeding the $PM_{2.5}$ SIL limit under any meteorological condition.

In order to avoid exceeding the $PM_{2.5}$ NAAQS or $PM_{2.5}$ SIL under any meteorological condition, a “$PM_{2.5}$ NAAQS No Exceedance” and a “$PM_{2.5}$ SIL No Exceedance” scenario was run to determine how often IPEC would be forced to revert from closed-loop to once-through operation. While a conceptual design has been created for a fully closed-loop system (2003 and 2010 Reports), the detailed design for a system that would allow switching from closed-loop to once-through operation at IPEC has not been performed. The consistent circulating water flow to the main condenser is necessary to serve as a heat sink (i.e., a mechanism for heat removal) for turbine exhaust steam, turbine bypass steam, and other flow. Switching between closed-loop and once-through cooling would be complicated by the start-up and realignment of components necessary for each cooling system and the operational need to maintain a consistent circulating water flow to the main condensers with the Stations in service. This would likely require a shutdown of each Unit to accomplish the switchover. Based on these engineering considerations, and operational considerations input from IPEC personnel, switching between closed-loop and once-through cooling for any potential system may only be feasible (if at all practicable) on an infrequent period (such as a seasonal basis). Limited to a seasonal switch between closed-loop and once-through cooling, IPEC would be forced to operate entirely in once-through cooling mode over the 10-year period analyzed by ASA (Appendix F) to avoid exceeding $PM_{2.5}$ SIL (based on a maximum basin salinity of 0.263 psu determined by TRC).

In order to calculate a theoretical best case scenario (i.e., maximize closed-loop operation time while avoiding exceeding $PM_{2.5}$ NAAQS or $PM_{2.5}$ SIL), although impractical for actual Station operation, this report conservatively assumes the switch between closed-loop and once-through operation could be accomplished on a weekly basis. The 10-year Hudson River salinity data was reviewed and if during a given week the closed-loop salinity would exceed the $PM_{2.5}$ NAAQS or $PM_{2.5}$ SIL, the system was switched to once-through operation. Appendix B includes the average annual percentage of once-through run time (bypassing the cooling tower) that would be required to avoid exceeding the air quality standards[9]. As shown in Appendix B, in order to avoid exceeding the $PM_{2.5}$ NAAQS, operation of closed-loop cooling would be expected to occur no more than 43% of the time; in order to avoid exceeding the $PM_{2.5}$ SIL, operation of closed-loop cooling would be expected to occur no more than 13% of the time.

The data in Appendix A and Appendix B was utilized by ASAAC to determine reductions in entrainment[10], entrainment losses[11], and equivalent age 1 losses[12] for each scenario that did not exceed $PM_{2.5}$ NAAQS and $PM_{2.5}$ SIL. Table 5.1 summarizes the results provided by TRC and ASAAC in Appendix C and Appendix D, respectively by presenting the potential exceedance of $PM_{2.5}$ NAAQS and $PM_{2.5}$ SIL for each closed-loop cooling make-up scenario and the associated percent reduction in entrainment, entrainment losses, and equivalent age 1 losses.

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[9] The cooling tower make-up flow would be equal to the historic SW flowrates and the once-through flow would be equal to the historic SW and CW flowrates for both Units 2 and 3 as used by ASAAC in the 2010 Alternative Technologies Report.

[10] Entrainment refers to the eggs, larvae, and older life stages of fish that are drawn through a cooling water system.

[11] Entrainment loss refers to the eggs, larvae, and older life stages of fish that do not survive being drawn through a cooling water system.

[12] Equivalent age 1 refers to the number of fish at different ages that are equivalent one-year-old fish using estimates of the probabilities that fish entrained at various ages would survive to age 1. Equivalent age 1 loss refers to the equivalent age 1 fish that do not survive being drawn through a cooling water system.

Table 5.1 IPEC Salinity Analysis
Air Quality Exceedance and Entrainment Reductions

Case	Air Quality Exceedance[2]		Entrainment Reductions[3]		
	$PM_{2.5}$ SIL	$PM_{2.5}$ NAAQS	Entrainment	Entrainment Loss	Equivalent Age 1 Loss
(Make-Up Capacity[1])	*(Exceedance)*	*(Exceedance)*	*(Average % Reduction)*		
SW Only (1.5 Cycles[4])	YES	YES	N/A	N/A	N/A
SW + 10,000 gpm	YES	YES	N/A	N/A	N/A
SW + 25,000 gpm	YES	YES	N/A	N/A	N/A
SW + 50,000 gpm	YES	YES	N/A	N/A	N/A
SW + 100,000 gpm	YES	YES	N/A	N/A	N/A
SW + 152,000 gpm	YES	YES	N/A	N/A	N/A
SW + 304,000 gpm	YES	YES	N/A	N/A	N/A
SW + 456,000 gpm	YES	YES	N/A	N/A	N/A
SW + 608,000 gpm	YES	YES	N/A	N/A	N/A
SW + 760,000 gpm	YES	YES	N/A	N/A	N/A
SW + 912,000 gpm	YES	YES	N/A	N/A	N/A
SW + 1,064,000 gpm	YES	YES	N/A	N/A	N/A
SW + 1,216,000 gpm	YES	YES	N/A	N/A	N/A
SW + 1,367,000 gpm[5]	YES	YES	N/A	N/A	N/A
$PM_{2.5}$ NAAQS No Exceedance[6]	YES[7]	NO	57.4	63.8	56.6
$PM_{2.5}$ SIL No Exceedance[6]	NO	NO	26.7	41.4	38.5

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.
[2] The Air Quality Exceedance data is provided by TRC in Appendix C.
[3] The Entrainment Reduction data is provided by ASAAC in Appendix D.
[4] The flowrate required to achieve 1.5 Cycles of Concentration is equivalent to the historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates.
[5] Maximum make-up flowrate determined using minimum SW flowrate (33,000 gpm) and sufficient make-up capacity to produce 700,000 gpm per Unit.
[6] The "No Exceedance" case reverts from closed-loop operation to once-through operation, bypassing the cooling tower, on a weekly basis in order to avoid exceeding the $PM_{2.5}$ NAAQS and $PM_{2.5}$ SIL, as described in Appendix B.
[7] Although the "$PM_{2.5}$ NAAQS No Exceedance" case would not exceed the $PM_{2.5}$ NAAQS, the $PM_{2.5}$ SIL would be exceeded.

As discussed above, in order to avoid exceeding the $PM_{2.5}$ NAAQS and $PM_{2.5}$ SIL, operation of closed-loop cooling would be expected to occur no more than 43% and 13% of the year, respectively (see Appendix B). Table 5.1 shows that operation of closed-loop cooling to avoid exceeding the $PM_{2.5}$ NAAQS would result in reductions in entrainment, entrainment losses, and equivalent age 1 losses of 57.4%, 63.8%, and 56.6%, respectively; moreover, the $PM_{2.5}$ SIL would still be exceeded. Table 5.1 also shows that operation of closed-loop cooling to avoid $PM_{2.5}$ SIL would result in reductions in entrainment, entrainment losses, and equivalent age 1 losses of 26.7%, 41.4%, and 38.5%, respectively. For comparison, the reductions in equivalent age 1 losses for cylindrical wedgewire screens would be approximately 89.8%, as presented in Attachment 6 of the 2010 Alternative Technologies Report [Ref. 6.3]. Likewise, the reductions in equivalent age 1 losses associated with the existing technology and operational suite employed by Entergy (i.e., Ristroph screens and fish handling and return systems, as well as flow reductions due to variable and dual speed pumps and maintenance outages) are approximately 33.8% [Ref. 6.3].

In order to accommodate switching between closed-loop cooling and once-through cooling (bypassing the cooling towers), the closed-loop cooling configuration discussed in Section 2.4 would have to be revised. The need to move between once-through and closed-loop cooling may have substantial design, construction, operational, and cost ramifications.

6 References

6.1 Enercon Services, Inc. Economic and Environmental Impacts Associated with Conversion of Indian Point Units 2 and 3 to A Closed-Loop Condenser Cooling Water Configuration. June 2003.

6.2 Enercon Services, Inc. Engineering Feasibility and Costs of Conversion of Indian Point Units 2 and 3 to a Closed-Loop Condenser Cooling Water Configuration. February 2010.

6.3 Enercon Services, Inc. Evaluation of Alternative Intake Technologies at Indian Point Units 2 & 3. February 2010.

6.4 TRC Environmental Corporation. Cooling Tower Impact Analysis for the Entergy Indian Point Energy Center Westchester County, New York. Lyndhurst, NJ. September 2009.

6.5 Consolidated Edison Company of New York. Economic and Environmental Impacts of Alternative Closed-Cycle Cooling Systems for Indian Point Unit 2. December, 1974.

Appendix A: Setpoint Selection

The updated salinity analysis using the 10-year Hudson River data from ASA (documented in Appendix F) returned closed-loop salinity values greater than the 7.2 psu defined in the 2003 and 2010 Closed-Loop Cooling Reports [Refs. 6.1 and 6.2]. As discussed in Section 1, this report provides supplemental analyses and evaluates the closed-loop operational scenarios that determine compliance with regulatory requirements for air emissions. There is an essential trade-off between closed–loop cooling operation and air quality, given the prevailing salinity conditions in the vicinity of IPEC. The evaluated mechanism for controlling air emissions is to limit salinity in the closed-loop cooling system through alteration of the cooling tower operations. One method for altering cooling tower operations is to vary the amount of make-up flow supplied to the closed-loop system.

The updated closed-loop cooling make-up flow control logic described in Section 3 of this evaluation relies upon the selection of an acceptable salinity setpoint. The salinity setpoint is a selected point at which additional make-up flow is initiated to counteract high closed-loop salinity levels. Hudson River salinity varies considerably, resulting in a series of peak salinity values occurring throughout the 10-year period. Additional make-up flow would be utilized leading up to and during peak salinity periods in order to reduce maximum closed-loop salinity. During non-peak conditions, providing additional make-up flow would not be required to mitigate the effect of these peak events.

As a result of the analysis described in Section 4, several setpoint values produce identical maximum closed-loop salinity values. Setpoint values were then chosen to minimize the make-up flow necessary (i.e., minimize potential biological effect) at the lowest 24-hr maximum closed-loop salinity. Table A.1 summarizes the 24-hr maximum salinity values (i.e., the maximum 24-hour average salinity), the maximum instantaneous salinity values, the average salinity values, and the make-up flowrates for a given make-up capacity at the selected salinity setpoints over the 10-year Hudson River data provided by ASA.

Table A.1 IPEC Salinity Analysis

Case *(Make-Up Capacity)*	Closed-Loop System Salinity 24-Hr Max *(psu)*	Max *(psu)*	Average *(psu)*	Make-Up Flow[1] *Average (gpm)*	Selected Setpoint *(psu)*
1.5 Cycles of Concentration[2]	11.01	11.05	2.60	48,918	See Note 4
SW + 10,000 gpm	10.28	10.33	2.59	49,029	10
SW + 25,000 gpm	9.63	9.69	2.57	49,545	9
SW + 50,000 gpm	9.04	9.11	2.51	51,123	8
SW + 100,000 gpm	8.51	8.59	2.50	52,124	8
SW + 152,000 gpm	8.26	8.34	2.50	52,675	8
SW + 304,000 gpm	7.96	8.05	2.41	62,570	7
SW + 456,000 gpm	7.84	7.93	2.40	66,771	7
SW + 608,000 gpm	7.78	7.87	2.40	70,661	7
SW + 760,000 gpm	7.74	7.83	2.40	74,381	7
SW + 912,000 gpm	7.72	7.81	2.39	77,910	7
SW + 1,064,000 gpm	7.70	7.79	2.39	81,320	7
SW + 1,216,000 gpm	7.68	7.77	2.39	84,612	7
SW + 1,367,000 gpm[3]	7.67	7.76	2.39	87,764	7

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.
[2] The flowrate required to achieve 1.5 Cycles of Concentration is equivalent to the historic Unit 2 and Unit 3 service water flowrates.
[3] Maximum make-up flowrate determined using minimum SW flowrate (33,000 gpm) and sufficient make-up capacity to produce 700,000 gpm per Unit.
[4] No salinity setpoint was selected as no additional make-up flow is utilized for this scenario. The flowrate required to achieve 1.5 Cycles of Concentration is equivalent to the historic Unit 2 and Unit 3 service water flowrates.

Table A.1 values range from a 24-hr maximum salinity value of 11.01 psu for an average annual make-up flowrate of 48,918 gpm (1.5 Cycles of Concentration) to a 24-hr maximum salinity value of 7.67 psu for an average annual make-up flowrate of 87,764 gpm (SW + 1,367,000; essentially once-through cooling make-up capacity). As the scenario of SW + 1,367,000 is essentially once-through cooling, the 7.67 psu is representative of the maximum Hudson River salinity reported by ASA in Table 5-4 of Appendix F. All of the tabulated maximum salinity values are greater than the 7.2 psu presented in the 2003 Closed-Loop Cooling Report [Ref. 6.1]. The required make-up flow varies by month, as detailed in Appendix B.

As described in Section 3.1, a salinity setpoint is a selected salinity value in psu at which additional make-up flow is initiated to counteract high closed-loop salinity levels. Additional make-up flow above the historic SW flow would not be added to the closed-loop system until the setpoint value was reached within the closed-loop system. To determine an acceptable salinity setpoint, the analysis described in Section 4 of this evaluation was run and summary tables of the analysis are provided in Table A.2 through Table A.15. Each table provides salinity and flow information over a range of salinity setpoints.

Several setpoint values result in identical maximum closed-loop salinity values. This was due to one of two scenarios: (1) no additional make-up flow was available to further dilute the closed-loop salinity (i.e., the maximum make-up flow was reached) or (2) the closed-loop salinity was equal to the Hudson River salinity. These tables also indicate that the average make-up flow rate decreases with an increase in setpoint values. Based on these trends, the highlighted values are chosen as the setpoint values. This selection minimizes the closed-loop salinity at the lowest make-up flow rate (i.e., maximizes the potential biological benefits).

Table A.2 IPEC Closed-Loop Cooling Salinity Analysis at 1.5 Cycles of Concentration[1]

Setpoint	**Closed-Loop System Salinity**			**Make-Up Flow[2]**	**SW Only**	**Additional Make-Up**
(psu)	*24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	*Average (gpm)*	*Average (gpm)*	*Average (gpm)*
2	11.01	11.05	2.60	48,918	48,918	0
3	11.01	11.05	2.60	48,918	48,918	0
4	11.01	11.05	2.60	48,918	48,918	0
5	11.01	11.05	2.60	48,918	48,918	0
6	11.01	11.05	2.60	48,918	48,918	0
7	11.01	11.05	2.60	48,918	48,918	0
8	11.01	11.05	2.60	48,918	48,918	0
9	11.01	11.05	2.60	48,918	48,918	0
10	11.01	11.05	2.60	48,918	48,918	0
11	11.01	11.05	2.60	48,918	48,918	0
12	11.01	11.05	2.60	48,918	48,918	0

[1] No salinity setpoint was selected as no additional make-up flow is utilized for this scenario. The flowrate required to achieve 1.5 Cycles of Concentration is equivalent to the historic Unit 2 and Unit 3 service water flowrates.
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.3 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 10,000 gpm

Setpoint	**Closed-Loop System Salinity**			**Make-Up Flow**[1]	**SW Only**	**Additional Make-Up**
(psu)	*24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	*Average (gpm)*	*Average (gpm)*	*Average (gpm)*
2	10.28	10.33	2.45	52,991	48,918	4,073
3	10.28	10.33	2.46	52,296	48,918	3,378
4	10.28	10.33	2.48	51,489	48,918	2,571
5	10.28	10.33	2.50	50,836	48,918	1,918
6	10.28	10.33	2.52	50,403	48,918	1,486
7	10.28	10.33	2.54	50,028	48,918	1,110
8	10.28	10.33	2.56	49,580	48,918	662
9	10.28	10.33	2.58	49,251	48,918	333
10	**10.28**	**10.33**	**2.59**	**49,029**	**48,918**	**111**
11	10.98	11.00	2.60	48,918	48,918	0
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.4 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 25,000 gpm

Setpoint	**Closed-Loop System Salinity**			**Make-Up Flow**[1]	**SW Only**	**Additional Make-Up**
(psu)	*24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	*Average (gpm)*	*Average (gpm)*	*Average (gpm)*
2	9.63	9.69	2.31	58,907	48,918	9,989
3	9.63	9.69	2.34	57,104	48,918	8,186
4	9.63	9.69	2.38	55,028	48,918	6,111
5	9.63	9.69	2.42	53,482	48,918	4,565
6	9.63	9.69	2.45	52,425	48,918	3,508
7	9.63	9.69	2.49	51,367	48,918	2,449
8	9.63	9.69	2.53	50,309	48,918	1,391
9	**9.63**	**9.69**	**2.57**	**49,545**	**48,918**	**627**
10	10.00	10.01	2.59	49,049	48,918	131
11	10.98	11.00	2.60	48,918	48,918	0
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.5 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 50,000 gpm

Setpoint (psu)	**Closed-Loop System Salinity** *24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	**Make-Up Flow**[1] *Average (gpm)*	**SW Only** *Average (gpm)*	**Additional Make-Up** *Average (gpm)*
2	9.04	9.11	2.20	68,546	48,918	19,628
3	9.04	9.11	2.24	64,722	48,918	15,804
4	9.04	9.11	2.29	60,541	48,918	11,623
5	9.04	9.11	2.35	57,570	48,918	8,653
6	9.04	9.11	2.40	55,406	48,918	6,488
7	9.04	9.11	2.45	53,079	48,918	4,162
8	**9.04**	**9.11**	**2.51**	**51,123**	**48,918**	**2,206**
9	9.05	9.11	2.56	49,736	48,918	818
10	9.99	10.01	2.59	49,051	48,918	133
11	10.97	11.00	2.60	48,918	48,918	0
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.6 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 100,000 gpm

Setpoint (psu)	**Closed-Loop System Salinity** *24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	**Make-Up Flow**[1] *Average (gpm)*	**SW Only** *Average (gpm)*	**Additional Make-Up** *Average (gpm)*
2	8.51	8.59	2.10	87,387	48,918	38,470
3	8.51	8.59	2.15	79,195	48,918	30,277
4	8.51	8.59	2.22	70,838	48,918	21,920
5	8.51	8.59	2.29	65,095	48,918	16,177
6	8.51	8.59	2.35	60,400	48,918	11,482
7	8.51	8.59	2.43	55,631	48,918	6,713
8	**8.51**	**8.59**	**2.50**	**52,124**	**48,918**	**3,207**
9	9.00	9.02	2.56	49,752	48,918	835
10	9.98	10.01	2.59	49,056	48,918	138
11	10.97	11.00	2.60	48,919	48,918	1
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit SW, Unit 1 RW,2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.7 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 152,000 gpm

Setpoint (psu)	**Closed-Loop System Salinity** *24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	**Make-Up Flow**[1] *Average (gpm)*	**SW Only** *Average (gpm)*	**Additional Make-Up** *Average (gpm)*
2	8.26	8.34	2.05	106,639	48,918	57,721
3	8.26	8.34	2.11	93,595	48,918	44,677
4	8.26	8.34	2.19	81,020	48,918	32,102
5	8.26	8.34	2.26	72,383	48,918	23,465
6	8.26	8.34	2.34	64,782	48,918	15,864
7	8.26	8.34	2.42	57,703	48,918	8,785
8	**8.26**	**8.34**	**2.50**	**52,675**	**48,918**	**3,757**
9	8.99	9.02	2.56	49,764	48,918	846
10	9.96	10.01	2.59	49,059	48,918	142
11	10.96	11.00	2.60	48,919	48,918	1
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.8 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 304,000 gpm

Setpoint (psu)	**Closed-Loop System Salinity** *24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	**Make-Up Flow**[1] *Average (gpm)*	**SW Only** *Average (gpm)*	**Additional Make-Up** *Average (gpm)*
2	7.96	8.05	1.99	161,973	48,918	113,055
3	7.96	8.05	2.06	133,883	48,918	84,965
4	7.96	8.05	2.15	109,406	48,918	60,488
5	7.96	8.05	2.23	92,023	48,918	43,106
6	7.96	8.05	2.32	75,599	48,918	26,681
7	**7.96**	**8.05**	**2.41**	**62,570**	**48,918**	**13,652**
8	8.02	8.05	2.50	53,136	48,918	4,218
9	8.96	9.02	2.56	49,800	48,918	882
10	9.93	10.01	2.59	49,073	48,918	155
11	10.94	11.00	2.60	48,920	48,918	2
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.9 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 456,000 gpm

Setpoint (psu)	**Closed-Loop System Salinity** *24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	**Make-Up Flow**[1] *Average (gpm)*	**SW Only** *Average (gpm)*	**Additional Make-Up** *Average (gpm)*
2	7.84	7.93	1.97	216,661	48,918	167,743
3	7.84	7.93	2.04	172,827	48,918	123,909
4	7.84	7.93	2.13	136,707	48,918	87,789
5	7.84	7.93	2.22	110,463	48,918	61,545
6	7.84	7.93	2.31	85,151	48,918	36,234
7	**7.84**	**7.93**	**2.40**	**66,771**	**48,918**	**17,853**
8	8.00	8.03	2.50	53,187	48,918	4,269
9	8.93	9.02	2.56	49,832	48,918	915
10	9.93	10.01	2.59	49,087	48,918	169
11	10.96	11.00	2.60	48,920	48,918	2
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.10 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 608,000 gpm

Setpoint (psu)	**Closed-Loop System Salinity** *24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	**Make-Up Flow**[1] *Average (gpm)*	**SW Only** *Average (gpm)*	**Additional Make-Up** *Average (gpm)*
2	7.78	7.87	1.96	270,915	48,918	221,998
3	7.78	7.87	2.03	211,076	48,918	162,158
4	7.78	7.87	2.13	163,496	48,918	114,578
5	7.78	7.87	2.21	128,303	48,918	79,385
6	7.78	7.87	2.30	94,168	48,918	45,250
7	**7.78**	**7.87**	**2.40**	**70,661**	**48,918**	**21,744**
8	8.00	8.03	2.49	53,237	48,918	4,319
9	8.90	9.02	2.56	49,869	48,918	951
10	9.93	10.01	2.59	49,098	48,918	180
11	10.95	11.00	2.60	48,920	48,918	2
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.11 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 760,000 gpm

Setpoint	Closed-Loop System Salinity			Make-Up Flow[1]	SW Only	Additional Make-Up
(psu)	*24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	*Average (gpm)*	*Average (gpm)*	*Average (gpm)*
2	7.74	7.83	1.95	324,888	48,918	275,970
3	7.74	7.83	2.02	248,721	48,918	199,803
4	7.74	7.83	2.12	189,904	48,918	140,986
5	7.74	7.83	2.21	145,852	48,918	96,934
6	7.74	7.83	2.30	102,801	48,918	53,884
7	**7.74**	**7.83**	**2.40**	**74,381**	**48,918**	**25,463**
8	7.99	8.03	2.49	53,275	48,918	4,357
9	8.90	9.02	2.55	49,894	48,918	977
10	9.93	10.01	2.59	49,109	48,918	191
11	10.95	11.00	2.60	48,921	48,918	3
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.12 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 912,000 gpm

Setpoint	Closed-Loop System Salinity			Make-Up Flow[1]	SW Only	Additional Make-Up
(psu)	*24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	*Average (gpm)*	*Average (gpm)*	*Average (gpm)*
2	7.72	7.81	1.95	378,473	48,918	329,555
3	7.72	7.81	2.02	286,163	48,918	237,245
4	7.72	7.81	2.12	216,133	48,918	167,215
5	7.72	7.81	2.21	163,169	48,918	114,251
6	7.72	7.81	2.30	111,231	48,918	62,313
7	**7.72**	**7.81**	**2.39**	**77,910**	**48,918**	**28,992**
8	7.98	8.03	2.49	53,320	48,918	4,402
9	8.89	9.02	2.55	49,932	48,918	1,014
10	9.93	10.01	2.59	49,121	48,918	203
11	10.95	11.00	2.60	48,921	48,918	3
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.13 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 1,064,000 gpm

Setpoint	**Closed-Loop System Salinity**			**Make-Up Flow**[1]	**SW Only**	**Additional Make-Up**
(psu)	*24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	*Average (gpm)*	*Average (gpm)*	*Average (gpm)*
2	7.70	7.79	1.94	432,155	48,918	383,237
3	7.70	7.79	2.01	323,387	48,918	274,470
4	7.70	7.79	2.11	242,066	48,918	193,149
5	7.70	7.79	2.20	180,226	48,918	131,308
6	7.70	7.79	2.29	119,454	48,918	70,536
7	**7.70**	**7.79**	**2.39**	**81,320**	**48,918**	**32,402**
8	7.97	8.03	2.49	53,390	48,918	4,472
9	8.85	9.02	2.55	49,964	48,918	1,046
10	9.93	10.01	2.59	49,132	48,918	214
11	10.94	11.00	2.60	48,922	48,918	4
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.14 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 1,216,000 gpm

Setpoint	**Closed-Loop System Salinity**			**Make-Up Flow**[1]	**SW Only**	**Additional Make-Up**
(psu)	*24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	*Average (gpm)*	*Average (gpm)*	*Average (gpm)*
2	7.68	7.77	1.94	485,384	48,918	436,466
3	7.68	7.77	2.01	360,452	48,918	311,534
4	7.68	7.77	2.11	267,939	48,918	219,021
5	7.68	7.77	2.20	197,029	48,918	148,111
6	7.68	7.77	2.29	127,572	48,918	78,655
7	**7.68**	**7.77**	**2.39**	**84,612**	**48,918**	**35,694**
8	7.96	8.03	2.48	53,416	48,918	4,499
9	8.88	9.02	2.55	49,988	48,918	1,070
10	9.93	10.01	2.59	49,144	48,918	227
11	10.96	11.00	2.60	48,922	48,918	5
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table A.15 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 1,367,000 gpm

Setpoint	**Closed-Loop System Salinity**			**Make-Up Flow[1]**	**SW Only**	**Additional Make-Up**
(psu)	*24-Hr Max (psu)*	*Max (psu)*	*Average (psu)*	*Average (gpm)*	*Average (gpm)*	*Average (gpm)*
2	7.67	7.76	1.94	538,248	48,918	489,330
3	7.67	7.76	2.01	396,892	48,918	347,975
4	7.67	7.76	2.11	293,260	48,918	244,343
5	7.67	7.76	2.20	213,480	48,918	164,562
6	7.67	7.76	2.29	135,450	48,918	86,532
7	**7.67**	**7.76**	**2.39**	**87,764**	**48,918**	**38,846**
8	7.95	8.03	2.48	53,455	48,918	4,537
9	8.92	9.02	2.55	50,017	48,918	1,099
10	9.93	10.01	2.58	49,157	48,918	239
11	10.96	11.00	2.60	48,923	48,918	5
12	11.01	11.05	2.60	48,918	48,918	0

[1] Make-up flowrate based on closed-loop system logic and historic Unit 2 SW, Unit 1 RW, and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Appendix B: Monthly Make-Up Flowrates

The updated salinity analysis using the 10-year Hudson River data from ASA (documented in Appendix F) returned greater make-up flowrates than the SW flows used for the 2010 Alternative Technologies Report [Ref. 6.3] (see Case 15 of Attachment 6). As discussed in Section 3 of this evaluation, the updated closed-loop cooling make-up flow control logic relies upon the selection of an acceptable salinity setpoint. As discussed in Appendix A, several salinity setpoint values result in the identical maximum closed-loop salinity values while the average make-up flow rates decrease with an increase in setpoint values. The selection of setpoints in Appendix A minimizes the closed-loop salinity at the lowest make-up flow rate (i.e., maximizes the potential biological benefits). Based on these setpoint values, Table B.1 through Table B.14 show the average monthly and annual make-up flow rates required to minimize salinity. As discussed in Section 5, the make-up flowrate for closed-loop cooling would be based on 1.5 cycles of concentration (i.e., historic SW flow only).

Per TRC (Appendix C), the maximum salinity value that could be run through the closed-loop cooling system and not exceed the air quality standards would be 0.263 psu. In order to avoid exceeding the air quality standards, a scenario was run to determine how often IPEC would be forced to revert from closed-loop operation to once-through operation. While no detailed design work on a system that would allow switching from closed-loop to once-through operation at IPEC has been performed, operating constraints would likely limit the switch to a seasonal basis; however, this Report conservatively assumes the switch between once-through and closed-loop operation would be determined on a weekly basis (although impractical for actual Station operation). The 10-year Hudson River salinity data was reviewed and, if during a given week the closed-loop salinity would exceed the $PM_{2.5}$ NAAQS or $PM_{2.5}$ SIL, the system was switched to once-through operation. Table B.1 includes the average percentage of once-through run time (bypassing the cooling tower) that would be required to avoid exceeding the air quality standards. Note that the cooling tower make-up flow would be equal to the historic SW flowrates and the once-through flow would be equal to the historic SW and CW flowrates for both Units 2 and 3.

Table B.1 IPEC Closed-Loop Cooling Salinity Analysis at 1.5 Cycles of Concentration[1]

Month	Make-Up Flow[2] Average (gpm)	SW Only Average (gpm)	Additional Make-Up Average (gpm)	Once-Through Run Time $PM_{2.5}$ SIL Average (%)	Once-Through Run Time $PM_{2.5}$ NAAQS Average (%)
January	45,947	45,947	0	92%	39%
February	46,668	46,668	0	92%	72%
March	45,031	45,031	0	76%	57%
April	45,367	45,367	0	58%	29%
May	46,897	46,897	0	78%	25%
June	48,227	48,227	0	88%	43%
July	53,069	53,069	0	94%	73%
August	56,865	56,865	0	100%	83%
September	54,319	54,319	0	99%	91%
October	49,925	49,925	0	96%	82%
November	46,845	46,845	0	82%	59%
December	47,628	47,628	0	85%	38%
Annual Average	48,918	48,918	0	87%	57%

[1] No salinity setpoint was selected as no additional make-up flow is utilized for this scenario (see Appendix A). The flowrate required to achieve 1.5 Cycles of Concentration is equivalent to the historic Unit 2 and Unit 3 service water flowrates.
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.2 IPEC Closed-Loop Cooling Salinity Analysis Flow Rate = SW + 10,000 gpm[1]

Month	Make-Up Flow[2] Average (gpm)	SW Only Average (gpm)	Additional Make-Up Average (gpm)
January	45,947	45,947	0
February	46,668	46,668	0
March	45,031	45,031	0
April	45,367	45,367	0
May	46,897	46,897	0
June	48,227	48,227	0
July	53,069	53,069	0
August	57,003	56,865	138
September	55,318	54,319	998
October	50,134	49,925	209
November	46,845	46,845	0
December	47,628	47,628	0
Annual Average	49,029	48,918	111

[1] A setpoint of 10 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.3 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 25,000 gpm[1]

Month	Make-Up Flow[2] *Average (gpm)*	SW Only *Average (gpm)*	Additional Make-Up *Average (gpm)*
January	45,947	45,947	0
February	46,668	46,668	0
March	45,031	45,031	0
April	45,367	45,367	0
May	46,897	46,897	0
June	48,227	48,227	0
July	53,149	53,069	80
August	58,448	56,865	1,583
September	58,446	54,319	4,127
October	51,409	49,925	1,484
November	47,093	46,845	248
December	47,642	47,628	13
Annual Average	49,545	48,918	627

[1] A setpoint of 9 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.4 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 50,000 gpm[1]

Month	Make-Up Flow[2] *Average (gpm)*	SW Only *Average (gpm)*	Additional Make-Up *Average (gpm)*
January	45,947	45,947	0
February	46,669	46,668	1
March	45,031	45,031	0
April	45,367	45,367	0
May	46,952	46,897	55
June	48,227	48,227	0
July	53,919	53,069	850
August	63,083	56,865	6,218
September	65,907	54,319	11,588
October	56,002	49,925	6,078
November	48,307	46,845	1,462
December	47,788	47,628	160
Annual Average	51,123	48,918	2,206

[1] A setpoint of 8 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.5 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 100,000 gpm[1]

Month	**Make-Up Flow[2]** *Average (gpm)*	**SW Only** *Average (gpm)*	**Additional Make-Up** *Average (gpm)*
January	45,947	45,947	0
February	46,670	46,668	2
March	45,031	45,031	0
April	45,367	45,367	0
May	46,956	46,897	58
June	48,227	48,227	0
July	54,048	53,069	979
August	65,413	56,865	8,548
September	72,912	54,319	18,593
October	58,195	49,925	8,271
November	48,660	46,845	1,815
December	47,807	47,628	179
Annual Average	52,124	48,918	3,207

[1] A setpoint of 8 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.6 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 152,000 gpm[1]

Month	**Make-Up Flow[2]** *Average (gpm)*	**SW Only** *Average (gpm)*	**Additional Make-Up** *Average (gpm)*
January	45,947	45,947	0
February	46,672	46,668	4
March	45,031	45,031	0
April	45,367	45,367	0
May	46,959	46,897	61
June	48,227	48,227	0
July	54,077	53,069	1,008
August	66,219	56,865	9,354
September	77,742	54,319	23,423
October	59,098	49,925	9,173
November	48,731	46,845	1,886
December	47,809	47,628	180
Annual Average	52,675	48,918	3,757

[1] A setpoint of 8 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.7 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 304,000 gpm[1]

Month	Make-Up Flow[2] *Average (gpm)*	SW Only *Average (gpm)*	Additional Make-Up *Average (gpm)*
January	46,287	45,947	341
February	47,071	46,668	403
March	45,031	45,031	0
April	45,367	45,367	0
May	47,537	46,897	640
June	48,305	48,227	77
July	59,920	53,069	6,851
August	93,857	56,865	36,992
September	122,536	54,319	68,217
October	88,197	49,925	38,272
November	56,971	46,845	10,126
December	49,147	47,628	1,519
Annual Average	62,570	48,918	13,652

[1] A setpoint of 7 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.8 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 456,000 gpm[1]

Month	Make-Up Flow[2] *Average (gpm)*	SW Only *Average (gpm)*	Additional Make-Up *Average (gpm)*
January	46,294	45,947	347
February	47,138	46,668	470
March	45,031	45,031	0
April	45,367	45,367	0
May	47,561	46,897	664
June	48,312	48,227	84
July	60,658	53,069	7,590
August	103,711	56,865	46,846
September	148,211	54,319	93,892
October	99,100	49,925	49,175
November	59,680	46,845	12,836
December	49,590	47,628	1,962
Annual Average	66,771	48,918	17,853

[1] A setpoint of 7 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.9 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 608,000 gpm[1]

Month	Make-Up Flow[2] *Average (gpm)*	SW Only *Average (gpm)*	Additional Make-Up *Average (gpm)*
January	46,301	45,947	354
February	47,160	46,668	492
March	45,031	45,031	0
April	45,367	45,367	0
May	47,551	46,897	654
June	48,312	48,227	84
July	61,227	53,069	8,158
August	112,694	56,865	55,829
September	172,513	54,319	118,194
October	109,090	49,925	59,166
November	62,115	46,845	15,270
December	49,998	47,628	2,370
Annual Average	70,661	48,918	21,744

[1] A setpoint of 7 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.10 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 760,000 gpm[1]

Month	Make-Up Flow[2] *Average (gpm)*	SW Only *Average (gpm)*	Additional Make-Up *Average (gpm)*
January	46,321	45,947	375
February	47,209	46,668	541
March	45,031	45,031	0
April	45,367	45,367	0
May	47,578	46,897	681
June	48,315	48,227	88
July	61,734	53,069	8,666
August	120,981	56,865	64,116
September	196,203	54,319	141,884
October	118,417	49,925	68,492
November	64,437	46,845	17,593
December	50,438	47,628	2,809
Annual Average	74,381	48,918	25,463

[1] A setpoint of 7 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.11 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 912,000 gpm[1]

Month	Make-Up Flow[2] *Average (gpm)*	SW Only *Average (gpm)*	Additional Make-Up *Average (gpm)*
January	46,315	45,947	368
February	47,227	46,668	559
March	45,031	45,031	0
April	45,367	45,367	0
May	47,612	46,897	715
June	48,333	48,227	106
July	62,242	53,069	9,173
August	128,616	56,865	71,751
September	219,324	54,319	165,004
October	127,110	49,925	77,185
November	66,541	46,845	19,697
December	50,713	47,628	3,085
Annual Average	77,910	48,918	28,992

[1] A setpoint of 7 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.12 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 1,064,000 gpm[1]

Month	Make-Up Flow[2] *Average (gpm)*	SW Only *Average (gpm)*	Additional Make-Up *Average (gpm)*
January	46,376	45,947	429
February	47,190	46,668	522
March	45,031	45,031	0
April	45,367	45,367	0
May	47,589	46,897	691
June	48,350	48,227	123
July	62,722	53,069	9,653
August	136,045	56,865	79,180
September	241,751	54,319	187,431
October	135,350	49,925	85,425
November	68,667	46,845	21,822
December	50,965	47,628	3,337
Annual Average	81,320	48,918	32,402

[1] A setpoint of 7 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.13 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 1,216,000 gpm[1]

Month	**Make-Up Flow[2]** *Average (gpm)*	**SW Only** *Average (gpm)*	**Additional Make-Up** *Average (gpm)*
January	46,355	45,947	409
February	47,235	46,668	567
March	45,031	45,031	0
April	45,367	45,367	0
May	47,633	46,897	735
June	48,340	48,227	113
July	62,957	53,069	9,888
August	143,189	56,865	86,324
September	263,629	54,319	209,310
October	143,549	49,925	93,624
November	70,461	46,845	23,616
December	51,224	47,628	3,596
Annual Average	84,612	48,918	35,694

[1] A setpoint of 7 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Table B.14 IPEC Closed-Loop Cooling Salinity Analysis
Flow Rate = SW + 1,367,000 gpm[1]

Month	**Make-Up Flow[2]** *Average (gpm)*	**SW Only** *Average (gpm)*	**Additional Make-Up** *Average (gpm)*
January	46,376	45,947	429
February	47,305	46,668	637
March	45,031	45,031	0
April	45,367	45,367	0
May	47,632	46,897	735
June	48,354	48,227	127
July	63,634	53,069	10,565
August	149,805	56,865	92,940
September	284,811	54,319	230,491
October	150,857	49,925	100,933
November	72,033	46,845	25,188
December	51,640	47,628	4,012
Annual Average	87,764	48,918	38,846

[1] A setpoint of 7 psu was selected to minimize salinity (see Appendix A).
[2] Make-up flowrate based on closed-loop system logic and historic Unit 2 and Unit 3 SW flowrates used in Case 15 of Attachment 6 to the 2010 Alternative Technologies Report.

Appendix C: TRC Analysis

Determination of Maximum Basin Salinity to achieve PM Air Quality Compliance

The closed-loop cooling tower air quality impact analysis as prepared in 2009 (Ref. 7.4) assumed a basin salinity of 7200 ppm (based upon an average Hudson River salinity of 1800 ppm with four cycles of concentration). The maximum $PM_{2.5}$ ground level concentration during hybrid operation was calculated to be 32.9 micrograms/cubic meter. The $PM_{2.5}$ national ambient air quality standard (NAAQS) is 35 micrograms per cubic meter. The representative background concentration of $PM_{2.5}$ for Westchester County is 29.2 micrograms per cubic meter, leaving a maximum available air quality contribution by the closed cycle cooling towers of 5.8 micrograms/cubic meter (35 - 29.2 = 5.8). In order for the particulate emissions from the cooling towers to be limited to a value that would result in impacts that would not exceed the 5.8 micrograms per cubic meter value, the maximum basin dissolved solids concentration is calculated as:

$$7200 \text{ ppm} \times (5.8 \text{ micrograms/cubic meter})/(32.9 \text{ micrograms/cubic meter}) = 1269 \text{ ppm}$$

Similarly, the limiting ground level concentration in the Westchester County $PM_{2.5}$ non-attainment area is the Significant Impact Level (SIL) of 1.2 micrograms per cubic meter. In order for the particulate emissions from the cooling towers to be limited to a value that would result in impacts that would not exceed the 1.2 micrograms per cubic meter value, the maximum basin dissolved solids concentration is calculated as:

$$7200 \text{ ppm} \times (1.2 \text{ micrograms/cubic meter}) / (32.9 \text{ micrograms/cubic meter}) = 263 \text{ ppm}$$

For practical cooling tower operation, the minimum basin cycling is assumed to be 1.5 times the concentration of the Hudson River water. For compliance with the $PM_{2.5}$ NAAQS the maximum Hudson River dissolved solids would be 846 ppm (1269/1.5 = 846 ppm). Similarly, to achieve the $PM_{2.5}$ SIL, the Hudson River dissolved solids would be 175 ppm (263/1.5 = 175 ppm).

Note that the threshold river concentrations that would enable the closed-cycle cooling towers to achieve air quality standards compliance are also independent of the maximum river salinity. It is very important to note when the closed cycle cooling towers operate at or below these threshold river salinities, there would be no exceedance of either the $PM_{2.5}$ NAAQS or the $PM_{2.5}$ SIL, depending upon which target compliance threshold salinity is being considered. The river salinity thresholds for PM_{10} standards and SIL compliance are also provided in the Table C.1 for the hybrid operation.

Table C.1 Hudson River Salinity Thresholds for Hybrid Operation

			% of Year Operating OTC to achieve NO AQ Impacts	
	Applicable Threshold (ug/m^3)	Maximum River[1] Salinity (psu)	OTC	CCC
$PM_{2.5}$ AAQS	5.8	0.846	57	43
$PM_{2.5}$ SIL	1.2	0.175	87	13
PM_{10} AAQS	90	13.131	0	100
PM_{10} SIL	5	0.729	59	41

[1] Base condition - basin salinity of 7.2 psu with a maximum concentration of 32.9 micrograms per cubic meter

Appendix D: ASAAC - Biological Assessment of Closed-Loop Cooling Flow Scenarios

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BIOLOGICAL ASSESSMENT OF CLOSED-LOOP
COOLING FLOW SCENARIOS
11/19/2010

This report evaluates the entrainment reductions associated with expected makeup flow rates for closed-loop cooling necessary to meet applicable air quality requirements, in a manner consistent with the entrainment reduction analysis performed in the Alternatives Assessment (Enercon 2010). The biological assessment in Enercon 2010 examined two potential cooling tower flow alternatives. In Alternative 15, historical service water flows were assumed to be sufficient to provide all makeup water to the cooling towers, thus no additional flow beyond service water would be required. In alternative 15.5, service water flows were set to the maximum levels for Units 2 and 3 (15,000 gpm at Unit 2 and 18,000 gpm at Unit 3) as an upper bound on potential cooling water use for closed-loop technology.

Subsequent to the submission of the Alternatives Assessment, continued refinement of Hudson River salinity levels occurred, and indicated that it would not be possible to meet air quality standards when operating in closed-loop mode during periods of high river salinity. The revised analysis contemplated a cooling system in which the units would operate in once-through mode during high salinity periods, and in closed-loop mode when salinity is low enough to allow operation without exceeding applicable air quality requirements. These modes were quantified as projected monthly service water flows while in closed-loop mode, plus some percent of the time each month when the operation would be in once-through mode in order to meet the PM2.5 SIL or PM2.5 NAAQS.

Month	Historical Service Water Flow Units 1,2,3 2001-2007 (gpm)	Fraction of time in once-through mode (Provided by Enercon)	
		PM2.5 SIL	PM2.5 NAAQS
Jan	45,947	0.92	0.39
Feb	46,668	0.92	0.72
Mar	45,031	0.76	0.57
Apr	45,367	0.58	0.29
May	46,897	0.78	0.25
Jun	48,227	0.88	0.43
Jul	53,069	0.94	0.73
Aug	56,865	1.00	0.83
Sep	54,319	0.99	0.91
Oct	49,925	0.96	0.82
Nov	46,845	0.82	0.59
Dec	47,628	0.85	0.38
Annual	48,918	0.87	0.57

The biological assessment of these new operating modes was conducted by estimating expected monthly entrainment in historical years 2001-2007 as the weighted average of monthly entrainment under Closed-Loop alternative 15.5, scaled to the expected monthly flow during closed-loop operation, and monthly entrainment under Current Technology alternative 1:

$$E_{smyC} = (1 - f_m)\frac{F_{mC}}{F_{15.5}}E_{smy15.5} + f_m E_{smy1}$$

where:

E_{smyC} = Number entrained of species *s* in month *m* in year *y* under the closed-loop scenario

$E_{smy15.5}$ = Number entrained of species *s* in month *m* in year *y* under alternative 15.5 (closed-loop with maximum service water flow)

E_{smy1} = Number entrained of species *s* in month *m* in year *y* under alternative 1 (current technology)

f_m = fraction of time that once-through cooling would be used in month *m*

F_{mC} = average total flow rate during closed-loop operation during month *m*

$F_{15.5}$ = average total flow rate during closed-loop operation for alternative 15.5

Similar calculations were performed for entrainment losses (L_{smyC}) and equivalent age 1 losses ($L1_{smyC}$), lost yield (Y_{smyC}), and production forgone (P_{smyC}). The values for $E_{smy15.5}$, $L_{smy15.5}$, $L1_{smy15.5}$, $Y_{smyC15.5}$, $P_{smyC15.5}$, E_{smy1}, L_{smy1}, $L1_{smy1}$, Y_{smyC1} , and P_{smyC1} had been calculated previously as part of the Alternatives Assessment.

As calculated in the Alternatives Assessment, the monthly entrainment numbers, losses, and equivalent age 1 losses were summed over the year to produce an annual total, and then compared to the appropriate baseline values (E_{syB}, L_{syB}, $L1_{syB}$) to estimate the percent reduction:

$$E_{syC} = \sum_{m=1}^{12} E_{smyC}$$
$$\% \, Reduction_{syC} = 100 \left\{ \frac{E_{syB} - E_{syC}}{E_{syB}} \right\}$$
$$\% \, Reduction_{yC} = \sum_s \% \, Reduction_{syC}$$
$$\% \, Reduction_{C} = \sum_y \% \, Reduction_{yC}$$

To assess total lost yield, the production forgone (P_{smyC}) was converted to expect lost yield and added to the direct estimate of lost yield. This was done both with and without inclusion of striped bass production foregone, which are the top predator species in the ecosystem and represent a large majority of the total lost yield.

$$\text{Total Lost Yield} = \sum_s Y_{smyC} + 0.1R \sum_s P_{smyC}$$

where 0.1 = trophic transfer ratio
R = ratio of striped bass lost yield to production forgone (0.323 for entrainment, 0.509 for impingement)

A cumulative life cycle analysis was performed to compare the cumulative performance of the baseline, current technology, 2-mm wedgewire screens, and closed-loop alternatives (operated to meet the PM2.5 SIL and the PM2.5 NAAQS) through the end of the license renewal period (2033 for Unit 2 and 2035 for Unit 3). For the 2-mm , for consistency with Enercon 2010wedgewire screens, it was assumed that screens would be operational at Unit 2 in 2013 and Unit 3 in 2015, for consistency with Enercon 2010.

RESULTS

Annual entrainment with 2-mm wedgewire screens would be substantially less than with either closed-loop cooling alternative. With 2-mm wedgewire screens, estimated average annual entrainment is 438 million fish, but entrainment with the closed-loop cooling alternatives were 999 million when operated to meet the PM2.5 SIL, and 560 million if operated to meet the PM2.5 NAAQS (Table 1). Operation to meet the PM2.5 SIL would only reduce entrainment slightly from that using current technology (1139 million) because the units would operate in once-through mode most of the time. The average % reduction for closed-loop cooling was 26.7 for the SIL and 57.4 for the NAAQS, in comparison to 74.1 for the 2-mm wedgewire screen option.

Annual entrainment loss with 2-mm wedgewire screens would be substantially less than with either closed-loop cooling alternative. With 2-mm wedgewire screens, estimated average annual entrainment loss is 262 million fish, but entrainment loss with the closed-loop cooling alternatives were 589 million when operated to meet the PM2.5 SIL, and 390 million if operated to meet the PM2.5 NAAQS (Table 2). Operation to meet the PM2.5 SIL would only reduce entrainment loss slightly from that using current technology (646 million) because the units would operate in once-through mode most of the time. The average % reduction for closed-loop cooling was 41.4 for the SIL and 63.8 for the NAAQS, in comparison to 80.3 for the 2-mm wedgewire screen option.

Annual equivalent age 1 entrainment loss with 2-mm wedgewire screens would be substantially less than with either closed-loop cooling alternative. With 2-mm wedgewire screens, estimated average annual equivalent age 1 entrainment loss is 0.27 million fish, but entrainment loss with the closed-loop cooling alternatives were 2.53 million when operated to meet the PM2.5 SIL, and 2.02 million if operated to meet the PM2.5 NAAQS (Table 3). Operation to meet the PM2.5 SIL would only reduce equivalent age 1 entrainment loss slightly from that using current technology (2.64 million) because the units would operate in once-through mode most of the time. The average % reduction for closed-loop cooling was 38.5 for the SIL and 56.6 for the NAAQS, in comparison to 89.8 for the 2-mm wedgewire screen option.

Estimates of annual lost yield for 2-mm wedgewire screens were also much lower than those for closed-loop cooling. Total lost yield for the wedgewire screens ranged from 13,637 to 15,262 kg, depending on whether striped bass production forgone is included in the calculation of indirect lost yield (Table 4). In contrast, total lost yield ranged from 84,805 to 92,248 for PM2.5 SIL, and from 60,758 to 65,796 for PM2.5 NAAQS. The forgone catch ranged from 4,433 to 4,924 fish for the wedgewire screens, 27,008 to 29,252 fish for the SIL alternative, and 19,350 to 20,869 fish for the NAAQS.

The cumulative analysis through 2035 indicated that installing 2-mm wedgewire screens on the original schedule proposed (2013 and 2015) would reduce numbers entrained from what would occur with current technology by 14,726 million, while closed-loop cooling operated to meet air quality requirements would reduce entrainment by only 1,978 million (SIL), or 4,614 million (NAAQS) (Table 5 for 0% discount rate). Entrainment losses would be reduced by 8,056 million with wedgewire screens, 986 million (SIL) or 2,176 million (NAAQS) with closed-loop cooling. Equivalent age 1 losses would be reduced by 50 million with wedgewire screens, 3 million (SIL) or 6 million (NAAQS) with closed-loop cooling. Lost fishery yield would be reduced by 1.63 million kg using 2-mm wedgewire screens, but only by 0.13 (SIL) or 0.26 (NAAQS) with closed-loop cooling.

If non-zero discount rates, which are used in economic analyses to express future costs or benefits at current equivalent value, are used for the cumulative analysis, the total losses and incremental reductions are smaller but the 2-mm wedgewire screen alternative continues to be the best alternative. Results for a 3% discount rate are presented in Table 6, and those for a 7% discount rate in Table 7.

Table 1. Annual number of fish entrained under Baseline conditions, Current technology, 2-mm wedgewire screens, and under Closed Cycle Cooling operated to meet standards PM2.5 SIL and PM2.5 NAAQS.

	Entrainment Numbers (million)								
	Baseline-0	Current Tech - 1		2-mm WWS - 4		CC - PM2.5 SIL		CC - PM2.5 NAAQS	
Year	#	#	Ave % Red	#	Ave % Red	#	Ave % Red	#	Ave % Red
2001	2,087	1,863	20.1	690	78.1	1,581	7.1	746	27.7
2002	765	733	13.2	244	75.4	674	20.2	450	51.0
2003	1,184	1,087	16.7	423	74.2	947	17.3	525	52.7
2004	1,511	1,438	12.9	676	67.2	1,245	48.4	688	76.2
2005	830	800	21.3	306	72.5	711	58.5	394	79.7
2006	619	597	17.2	233	74.0	559	16.8	405	56.4
2007	1,533	1,456	19.5	493	77.4	1,278	18.3	713	58.1
Average	1,219	1,139	17.3	438	74.1	999	26.7	560	57.4

Table 2. Annual entrainment loss under Baseline conditions, Current technology, 2-mm wedgewire screens, and under Closed Cycle Cooling operated to meet standards PM2.5 SIL and PM2.5 NAAQS.

	Entrainment Loss (million)								
	Baseline-0	Current Tech - 1		2-mm WWS - 4		CC - PM2.5 SIL		CC - PM2.5 NAAQS	
Year	#	#	Ave % Red	#	Ave % Red	#	Ave % Red	#	Ave % Red
2001	2,095	612	37.3	256	84.1	542	6.9	320	27.6
2002	767	566	33.1	197	78.8	527	13.3	377	44.6
2003	1,197	585	34.4	241	81.0	532	56.7	356	74.2
2004	1,514	923	32.6	464	74.2	832	77.4	538	88.7
2005	840	451	34.0	193	79.7	410	71.3	256	85.6
2006	620	479	33.1	195	78.8	460	47.3	360	71.0
2007	1,539	903	38.7	288	85.1	819	17.2	526	54.8
Average	1,224	646	34.7	262	80.3	589	41.4	390	63.8

Table 3. Annual equivalent age 1 entrainment loss under Baseline conditions, Current technology, 2-mm wedgewire screens, and under Closed Cycle Cooling operated to meet standards PM2.5 SIL and PM2.5 NAAQS.

	Equivalent Age 1 Entrainment Loss (million)								
	Baseline-0	Current Tech - 1		2-mm WWS - 4		CC - PM2.5 SIL		CC - PM2.5 NAAQS	
Year	#	#	Ave % Red	#	Ave % Red	#	Ave % Red	#	Ave % Red
2001	2.26	1.25	36.7	0.19	90.0	1.18	7.4	0.90	23.1
2002	2.69	2.32	30.7	0.27	88.7	2.24	13.1	1.80	34.9
2003	3.91	2.73	35.1	0.31	93.7	2.63	48.8	2.15	65.4
2004	3.03	2.47	33.5	0.32	86.9	2.36	71.9	1.85	81.2
2005	3.20	2.78	31.3	0.20	92.1	2.66	68.4	2.13	80.3
2006	2.22	1.95	31.3	0.25	85.7	1.90	45.5	1.57	66.3
2007	5.58	4.95	37.8	0.38	91.3	4.72	14.7	3.73	44.6
Average	3.27	2.64	33.8	0.27	89.8	2.53	38.5	2.02	56.6

Table 4. Annual lost fishery yield and catch under Baseline conditions, Current technology, 2-mm wedgewire screens, and under Closed Cycle Cooling operated to meet standards PM2.5 SIL and PM2.5 NAAQS.

	Baseline	Current	2mm WW	Closed Cycle PM2.5 SIL	Closed Cycle PM2.5 NAAQS	
Direct LY (kg)	240,068	90,617	13,470	84,617	62,651	
Indirect LY (kg)	25,909	8,958	1,792	8,268	5,838	With SB PF
Total LY	265,977	99,575	15,262	92,885	68,488	With SB PF
Indirect LY (kg)	1,968	825	167	759	526	Without SB PF
Total LY	242,036	91,442	13,637	85,376	63,177	Without SB PF
Direct Catch	76,567	28,872	4,383	26,957	19,947	
Indirect Catch	7,816	2,702	541	2,494	1,761	With SB PF
Total Catch	84,383	31,574	4,924	29,451	21,708	With SB PF
Indirect Catch	594	249	50	229	159	Without SB PF
Total Catch	77,161	29,121	4,433	27,186	20,106	Without SB PF

Table 5. Cumulative (2013 through 2035) number entrained (million), entrainment loss (million), equivalent age 1 loss (million), and total lost yield (million kg) for Baseline, Current technology, 2-mm wedgewire screens, and under Closed Cycle Cooling operated to meet standards PM2.5 SIL and PM2.5 NAAQS. Discount rate = 0%

Alternative	Year Installed	Number Entrained #	Number Entrained Incremental Reduction	Entrainment Loss #	Entrainment Loss Incremental Reduction	Equivalent Age 1 Loss #	Equivalent Age 1 Loss Incremental Reduction	Total Lost Yield #	Total Lost Yield Incremental Reduction
Baseline	2011	26,807	-	26,938	-	72	-	5.32	-
Current Technology	2011	25,060	1,748	14,203	12,735	58	14	2.01	3.31
2-mm WW	2013/15	10,333	14,726	6,147	8,056	8	50	0.38	1.63
CC -PM2.5 SIL	2029	23,082	1,978	13,217	986	55	3	1.88	0.13
CC -PM2.5 NAAQS	2029	20,446	4,614	12,027	2,176	52	6	1.75	0.26

Note: Incremental reduction for WW and CC alternatives calculated from Current Technology.

Table 6. Cumulative (2013 through 2035) number entrained (million), entrainment loss (million), equivalent age 1 loss (million), and total lost yield (million kg) for Baseline, Current technology, 2-mm wedgewire screens, and under Closed Cycle Cooling operated to meet standards PM2.5 SIL and PM2.5 NAAQS.

Discount rate = 3%

Alternative	Year Installed	Number Entrained #	Number Entrained Incremental Reduction	Entrainment Loss #	Entrainment Loss Incremental Reduction	Equivalent Age 1 Loss #	Equivalent Age 1 Loss Incremental Reduction	Total Lost Yield #	Total Lost Yield Incremental Reduction
Baseline	2011	19,826	-	19,922	-	53	-	3.94	-
Current Technology	2011	18,533	1,293	10,504	9,419	43	10	1.49	2.45
2-mm WW	2013/15	7,814	10,719	4,640	5,864	7	36	0.30	1.19
CC -PM2.5 SIL	2029	17,335	1,198	9,901	603	41	2	1.41	0.08
CC -PM2.5 NAAQS	2029	15,836	2,697	9,225	1,279	39	4	1.33	0.15

Note: Incremental reduction for WW and CC alternatives calculated from Current Technology.

Table 7. Cumulative (2013 through 2035) number entrained (million), entrainment loss (million), equivalent age 1 loss (million), and total lost yield (million kg) for Baseline, Current technology, 2-mm wedgewire screens, and under Closed Cycle Cooling operated to meet standards PM2.5 SIL and PM2.5 NAAQS.

Discount rate = 7%

Alternative	Year Installed	Number Entrained		Entrainment Loss		Equivalent Age 1 Loss		Total Lost Yield	
		#	Incremental Reduction	#	Incremental Reduction	#	Incremental Reduction	#	Incremental Reduction
Baseline	2011	13,872	-	13,939	-	37	-	2.76	-
Current Technology	2011	12,967	904	7,349	6,590	30	7	1.04	1.71
2-mm WW	2013/15	5,661	7,306	3,352	3,997	5	25	0.23	0.81
CC -PM2.5 SIL	2029	12,364	603	7,043	307	29	1	1.00	0.04
CC -PM2.5 NAAQS	2029	11,674	1,294	6,731	618	28	2	0.97	0.08

Note: Incremental reduction for WW and CC alternatives calculated from Current Technology.

Appendix E: SPX Information

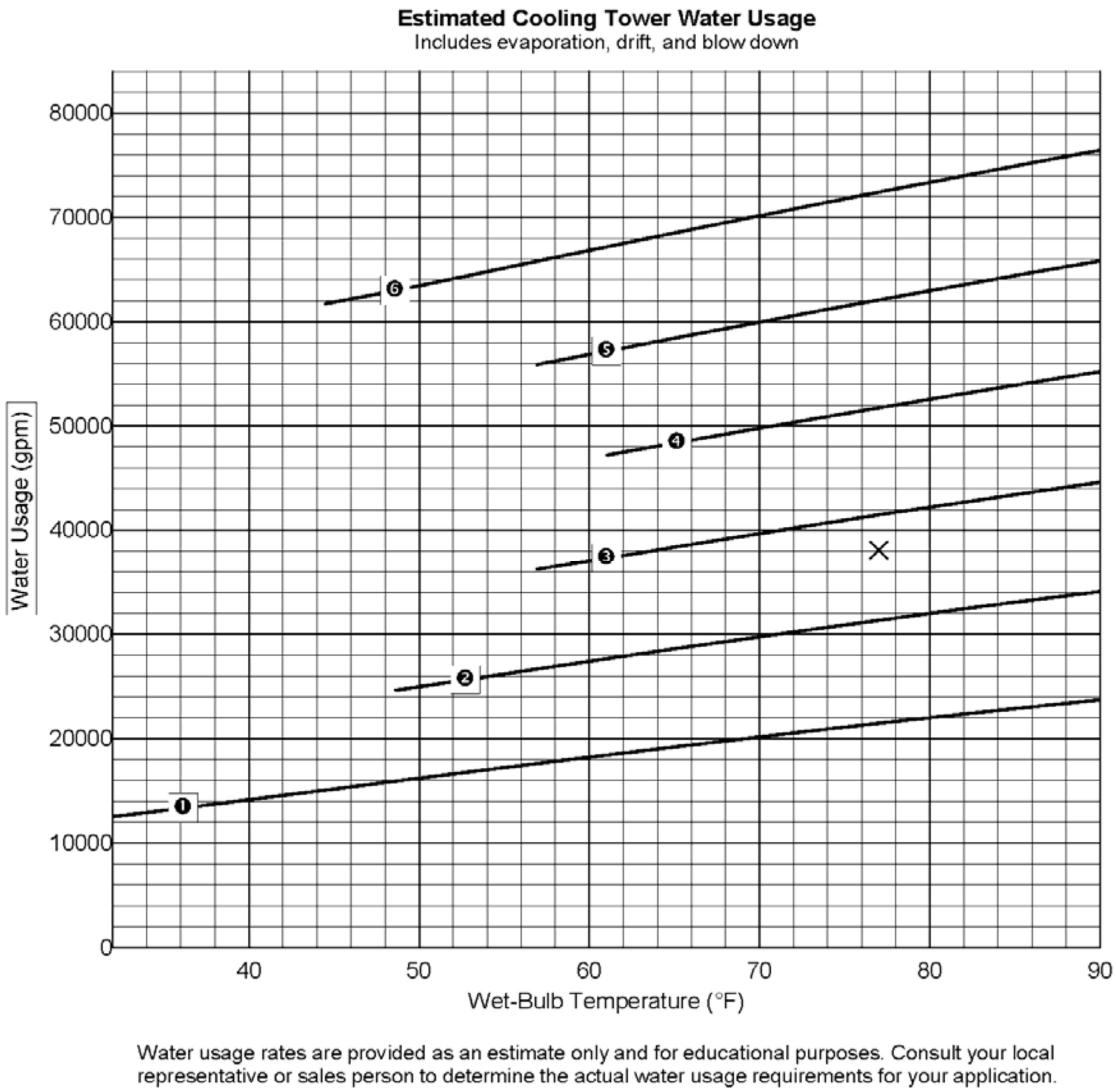

Figure E.1 Example Curve Illustrating Linear Relationship between Wet-Bulb Temperature and Water Usage

From: John.Arntson@marleyct.spx.com
Sent: Friday, May 23, 2003 4:35 PM
To: sbeaver@enercon.com
Cc: JIM.VANGARSSE@marleyct.SPX.COM
Subject: Revised Performance Data

Tower Type:
Counterflow, forced draft, plume abated (hybrid) with low noise fans & sound attenuation baffles.

Tower Geometry:
OD= 524.8 ft
Overall Ht. = 168 ft.
ID exit cone: 241.4 ft.
No. fans (wet section) = 44 (Motor output power = 300 HP)
No. fans (dry section)= 44 (Motor Output Power = 350 HP)

Wet Section Data:
Flow = 700,000 gpm
Plan area of fill: 121660 ft2
Fill Type: 6 ft. PVC low fouling film (MCT FC-18)
DE type / drift rate: Cellular PVC (MCT TU-12)/ drift rate .001%
Distribution system: FRP headers/PVC pipes
Nozzles: High efficiency polyproplyene

Dry Section Data:
Flow= 245,000 gpm
Element type: 4 row/ 2 pass
Tube type: 1" OD Titanium
Fin Type: 2.25" OD Aluminum fins @ 11 fins/in ("L" fin)
Tube length = 49 ft.
No. tubes/ bundle = 218
No. bundles = 264

Thermal Data:
Wet design condition: (77 WBT, 89 CWT, 109 HWT)
HP (motor output wet section) = 270 HP, evaporation rate = 1.67%, Vexit= 1233 fpm

Hybrid Operation@ plume abatement design point(27 WBT @ 90 % RH)
HP (MOP wet section) = 300 HP, evaporation rate = .81%, CWT = 59 °F, Vexit=2260 fpm
HP (MOP dry section)= 350 HP

Note: evaporation rate at summer conditions with dry section in operation will be approx. 1.47%. CWT= 88 ° F approx.

Pumping Head:

Main Pumps:
700,000 gpm @ 45 ft. TDH

Booster Pumps:
245000 gpm @ 26 ft

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SPX Cooling Technologies
Balcke | Hamon Dry Cooling | Marley

PREFERRED COOLING TOWER WATER CONDITION LIMITS

NOTE: Biological treatment and control of Legionella and other potentially health-threatening bacteria is essential. Consult a competent water treatment expert or service company.

pH	6.5 to 9.0 (special materials may be required beyond these limits)
Temperature	125° F (51.7° C) maximum, or up to 180° F (82.2° C) with special materials
Langelier Saturation Index	0.0 to 1.0 recommended; higher allowed if scale is controllable.
M-Alkalinity	100 to 500 ppm as $CaCO_3$
Silica	150 ppm as SiO_2 maximum (scale formation)
Iron	3 ppm maximum (staining and scale contributor)
Manganese	0.1 ppm maximum (staining and scale contributor)
Sulfides	Greater than 1 ppm can be corrosive to copper alloys, iron, steel, and galvanized steel. See table below for limits with film fill.
Ammonia	50 ppm maximum if copper alloys present; lower limits apply for film fill - see table.
Chlorine / bromine	1 ppm free residual intermittently (shock), or 0.4 ppm continuously maximum. Excess can attack sealants, accelerate corrosion, increase drift, and embrittle PVC.
Organic solvents	These can attack plastics and promote bio-growth. Trace amounts may be acceptable, depending on the solvent.
TDS	Over 5000 ppm can affect thermal performance and be detrimental to wood in alternately wet/dry zones such as fan deck and louver face.

Individual Ions:		MAXIMUM:
Cations:	**Calcium**	800 ppm as $CaCO_3$. (300 ppm with MX75 fill in arid climate)
	Magnesium	Depends on pH and Silica level
	Sodium	No limit
Anions:	**Chlorides**	450 ppm as Cl^- (300 for galvanized towers) upgrades are required for higher chloride levels.
	Sulfates	800 ppm as $CaCO_3$
	Nitrates	300 ppm as NO_3 (bacteria nutrient)
	Carbonates/Bicarbonates	300 ppm as $CaCO_3$ maximum preferred for wood

Fouling Contaminant Limits

Bacteria counts listed below relate to maintaining fill thermal efficiency only.
Biocidal treatment is required for all cooling tower installations. (see NOTE above).

Fill Type	Aerobic Bacteria Heterotrophic Plate Count	Total Suspended Solids (TSS)	Oil and Grease	Sulfides	Ammonia
MC75	10,000 CFU/ml	50 ppm	1 ppm	0.5 ppm	10 ppm
FB20, SNCS ("Coolfilm"), MX75 (crossflow), ClearFlow Modules	100,000 CFU/ml 10,000 CFU/ml	50 ppm 150 ppm	1 ppm	1.0 ppm	15 ppm
DF254, FC18, MCR16, DF381+1' MC75 overlay	1,000,000 CFU/ml 100,000 CFU/ml	50 ppm 150 ppm	5 ppm	1.5 ppm	25 ppm
DF381, Tricklebloc, MCR12, AAFNCS ("Cleanflow")	1,000,000 CFU/ml	250 ppm	10 ppm	2.0 ppm	25 ppm
Splash bar or grid fill	1,000,000 CFU/ml target	No specific limit	10 ppm	N/A	N/A

Note: Any amount of oil or grease is likely to adversely affect thermal performance. Sulfides and ammonia promote bacterial growth which can cause fill fouling; conformance to the limits above will assist in controlling bacteria to the recommended levels.

Drift Effects:

Certain contaminants or treatment chemicals such as surfactants, glycols, biodispersants and antifoams may increase drift rate. When minimizing drift is vital, the circulating water shall have a surface tension of at least 65 dynes/cm and a total organic carbon (TOC) level below 50 ppm. *Reclaim or re-use waters in particular may contain contaminants which increase drift rate either directly or by necessitating the use of treatment chemicals which increase drift rate.*

Miscellaneous Solids and Nutrients

Avoid high efficiency fill (MC75) with water containing bacteria nutrients such as alcohols, nitrates, ammonia, fats, glycols, phosphates, black liquor, or TOC greater than 50 ppm. Clog-resistant fills may be considered for contaminated water, case by case. For all film fills, avoid fibrous, oily, greasy, fatty, or tarry contaminants, which can plug fill.
In general, do not use film fill in Steel Plants, Pulp & Paper Mills, Food Processing Operations, or similar applications unless leaks and contamination by airborne or waterborne particulates, oil, or fibers are extremely unlikely. If film fill is used, biological-growth control must be stringent and diligent.

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Appendix F: ASA - Estimate of Salinity in the Hudson River at Indian Point Energy Center

ESTIMATE OF SALINITY IN THE HUDSON RIVER AT INDIAN POINT ENERGY CENTER

ASA Project Number: 2009-167

PREPARED FOR:

Indian Point Energy Center
Buchanan, NY

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DATE SUBMITTED

19 November 2010

EXECUTIVE SUMMARY

It is necessary to estimate salinity in the Hudson River (River) at the Indian Point Energy Center (IPEC) in order to evaluate environmental effects on air quality during closed cycle cooling operations since make-up water is drawn from the River to replace losses from evaporation, drift and blowdown from the cooling towers. The water quality of the circulating cooling water, measured in part by salinity, is important for use in the design of the cooling tower system to ensure optimal operation and minimal environmental effects on air quality. An analysis of long-term historical measurements of salinity in the River was made to provide an estimate of expected salinity of the makeup water for IPEC.

Direct measurements of salinity are not made at IPEC. Consequently, Applied Science Associates, Inc. (ASA) developed an empirical relationship to estimate salinity at the IPEC intake based on salinity measured at other locations in the River. The data sets used for this analysis consisted of conductivity measurements taken every 15 minutes by the U.S. Geological Survey (USGS) at Hastings-on-Hudson (Hastings), , Tomkins Cove (Tomkins), and West Point. The Hastings station is located 21 mi downstream of IPEC and has been continuously operating since 1992. The West Point station is located 9 mi upstream of IPEC and has been operating since 1991. The Tomkins station was located 1 mi downstream of IPEC, but was discontinued in 2001.

A statistical analysis was performed on the salinity data at each of the USGS stations for the available data. The analysis revealed a decrease in salinity to the north (upriver), from Hastings to Tomkins to West Point. Mean salinity at Hastings was 6.29 psu, Tomkins was 2.09 psu, and West Point was 0.79 psu, consistent with the 90th percentile salinity values of 10.88 psu (Hastings), 4.96 psu (Tomkins) and 2.63 psu (West Point). Hastings and West Point exhibited the lowest salinity, as determined by the mean and 90th percentile values for the periods of record, in April. Low salinity during this time is correlated with high freshwater discharge. The highest mean and 90th percentile values occur in September at these two stations, primarily as a function of lower freshwater discharge. Tomkins, with a significantly shorter period of record, had the lowest average salinity values in January and the highest in August.

A correlation analysis was performed that related the salinity at Tomkins to that at West Point and Hastings. It was found that the West Point data was more highly correlated to Tomkins than Hastings was and therefore used to estimate Tomkins salinity for the long-term decadal period. The model was improved at low salinities by forcing the Tomkins salinity to be equal to the West Point salinity when the Hastings salinity fell below 4.07 psu. This improvement had no effect on higher salinity predictions.

The decadal (2000-2009) salinity time series at IPEC (assumed equivalent to that at Tomkins) was generated to provide a long-term estimate of salinity under a variety of environmental

conditions. This time series is consistent with the analysis period conducted for the extreme environmental conditions in support of the hydrothermal modeling (Swanson et al., 2010).

The model results showed that salinities were typically higher in the summer and fall seasons, consistent with the observations at the USGS stations. Some years (2000, 2001, and 2006) showed extended periods of salinity exceeding 5 psu for three months with peaks exceeding 7 psu. There were also shorter periods when the salinity was zero (2000, 2001, and 2008), usually in the spring season. These variations are primarily due to freshwater entering the River, although there are occasional events (storm surge) that can transport salt from the ocean to the vicinity of the IPEC intake.

A statistical analysis was performed on the hourly-modeled salinity predictions at IPEC for the decadal period 2000 through 2009. The mean salinity over the entire period was 1.80 psu, the minimum 0.07 psu and the maximum 7.67 psu. The median, or 50th percentile, was 0.72 psu, indicating that the salinity distribution is not a normal distribution, but slightly biased to lower salinities. The 90th percentile salinity was 5.23 psu. Salinities between 0 and 0.25 psu were found to occur 30.62% of the time while salinities between 0.25 and 0.50 psu dropped to 12.29% of the time. The large number of low salinities is indicated by the cumulative frequency of occurrence that shows over 50% (54.78%) of the salinities were less than 1.00 psu.

The statistical summary of the 10-yr data set broken down by year showed that 2001 had the highest mean (3.21 psu) and highest median (3.28 psu), 2002 had the highest maximum (7.67 psu) and highest 90th percentile (6.90 psu). Salinities between 0 and 0.25 psu occurred between 12% of the time in 2000 and 42% in 2009 while salinities between 0.25 and 0.50 psu dropped dramatically for all years. The large number of low salinities was indicated by the cumulative frequency of occurrence showed that between 33% (in 2001) and 70% (in 2000) of the salinities are less than 1.00 psu.

The statistical summary of the 10-yr data set broken down by month showed that September had the highest mean (3.84 psu), highest maximum (7.67 psu), highest median (3.70 psu) and highest 90th percentile (7.16 psu), followed by the months of July, August, October and November. The winter and spring months had lower values with April the lowest of any month. Salinities between 0 and 0.25 psu varied between 5% of the time in September and 85% in April, consistent with fluctuations in freshwater discharge to the River. Salinities between 0.25 and 0.50 psu dropped dramatically for most months, indicating an uneven distribution of salinities across the range of values. The large number of low salinities is indicated by the cumulative frequency of occurrence that shows between 18% (in September) and 86% (in April) of the salinities are less than 1.00 psu.

The effect of using linear interpolation to fill the missing hours (2.8% of the total hours) is insignificant when viewed in the context of the 10-yr record as all statistical measures showed a maximum difference of only 0.01 psu when compared to the results of the non-filled data set. The individual years and months exhibited larger differences but were still relatively small.

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1 INTRODUCTION

The Entergy Indian Point Energy Center (IPEC), consisting of two operating nuclear power plants (Units 2 and 3), 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 configuration to cool the system, discharging heated water employed in the cooling process through a discharge canal to the River. The discharge is permitted by the New York State Department of Environmental Conservation (NYSDEC) via a State Pollutant Discharge Elimination System (SPDES) Permit NY0004472. As part of the renewal process NYSDEC directed Entergy to perform a feasibility and alternative technology assessment of the use of closed-loop cooling, i.e., cooling towers.

The purpose of this report is to assess the salinity variation in the waters of the River near IPEC that would be used to supply makeup water to the cooling towers. This makeup water is required to replace water lost by evaporation, drift and blowdown from cooling tower operations. The water quality of the circulating cooling water, measured in part by salinity, is important for use in the design of the cooling tower to ensure optimal operation and minimal environmental effects on air quality. Since the River is an estuary, salt concentration can vary widely based on environmental forcing so that a constant salinity value to assess the environmental effects and plant efficiency is impractical. Therefore, an analysis of historical measurements of salinity from three locations in the River was performed to provide a more appropriate estimate of expected salinity of the makeup water for IPEC.

Direct measurements of salinity are not made at IPEC. Consequently, Applied Science Associates, Inc. (ASA) developed an empirical relationship to estimate salinity entering the IPEC intake based on salinity measured at other locations in the River. The data sets used for this analysis consisted of conductivity measurements taken every 15 min by the U.S. Geological Survey (USGS) at Hastings-on-Hudson (Hastings), Tomkins Cove (Tomkins), and West Point. The Hastings station is located 21 mi downstream of IPEC and has been operating continuously since 1992. The West Point station is located 9 mi upstream of IPEC and has been operating continuously since 1991. The Tomkins station is located 1 mi downstream of IPEC, but was discontinued in 2001. Figure 1 shows the locations of USGS stations in the River relative to IPEC.

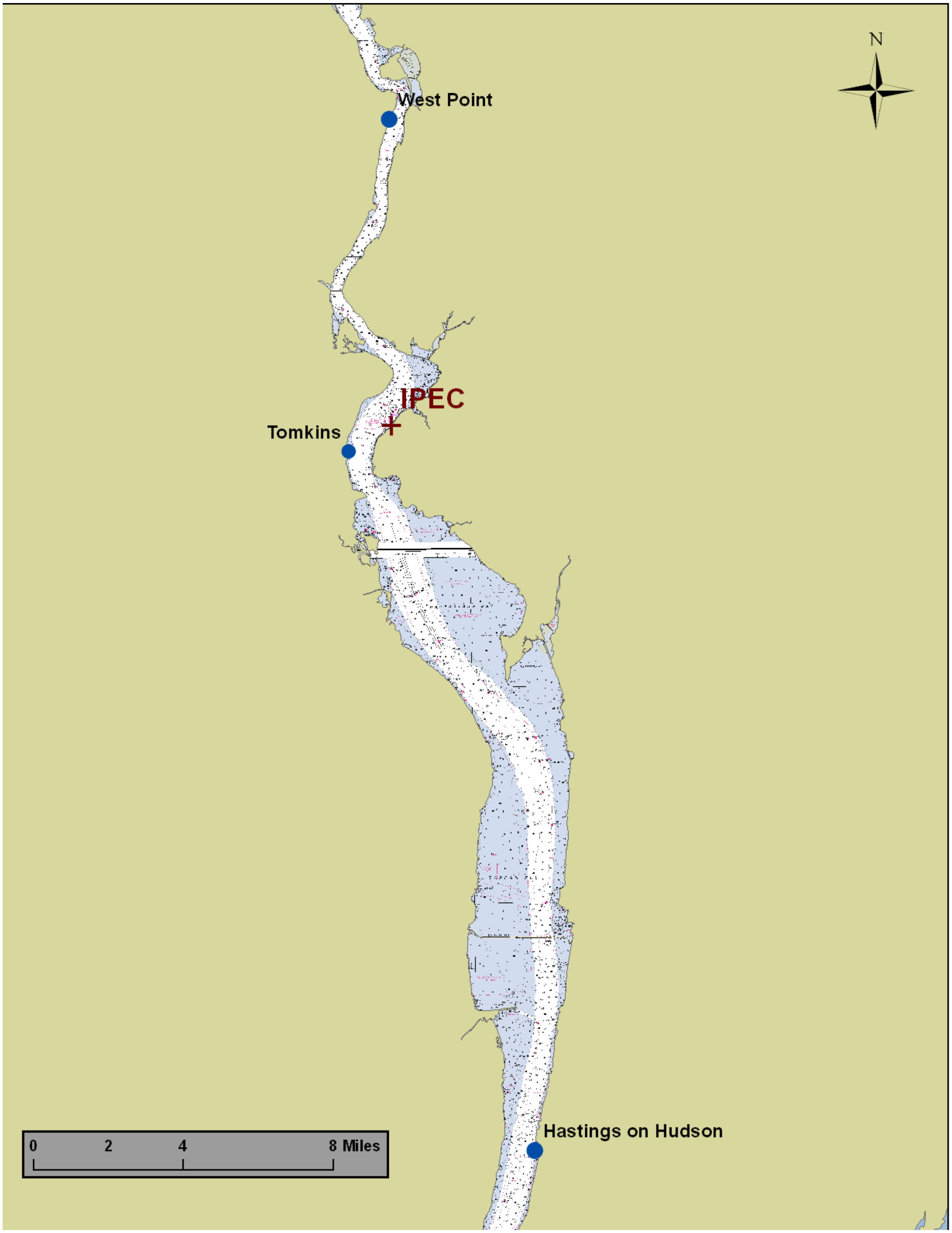

Figure 1-1. Map of a portion of the Hudson River showing the USGS stations used in the present analysis (Hastings, Tomkins, and West Point) in relation to IPEC.

2 USGS Data

Water level, temperature and specific conductivity data is available in 15-min intervals from two long-term stations located in the River. The Hastings station is located 21 mi downstream from IPEC and West Point is located 9 mi upstream of IPEC (Figure 1-1). These stations provide a continuous long-term history of conductivity variations in the River and, although located some distance from IPEC, the observations bound the range of conductivity (and ultimately salinity) at IPEC. A summary of the stations adapted from the USGS website [http://waterdata.usgs.gov/ny/nwis/rt] is provided below:

- Hastings (USGS station 01376304) located 21 mi above Battery at Lat 40°59'16", Long 73°53'15" 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. Specific conductivity is measured at a depth of 10 ft below the National Geodetic Vertical Datum of 1929 (approximately mean sea level). Hastings conductivity data is available from 1 October 1999 to the present (real time).

- West Point (USGS station 01374019) located 51 mi above Battery at Lat 41°23'10", Long 73°57'20" referenced to North American Datum of 1927, Orange County, NY, Hydrologic Unit 02020008, on right bank at South Dock at West Point. Specific conductivity is measured at a depth of 10 ft below the National Geodetic Vertical Datum of 1929 (approximately mean sea level). West Point conductivity data is available from 1 October 1998 to the present (real time).

Additional continuous (15-min interval) USGS data from a now-discontinued station (01374349) at Tomkins was obtained for the period from May 1997 through July 2001. Since metadata did not exist for this station, it is assumed that the instrument depth is 10 ft, consistent with other USGS stations. Since Tompkins is located only 1 mi downstream of IPEC (Figure 1-1) at Lat 41°15'31", Long 73°58'41", it is potentially a good proxy for the salinity at the IPEC intake, despite its location on the opposite side of the River.

3 DATA ANALYSIS

The raw specific conductance data, with units of µS/cm at 25 °C, received from USGS consisted of individual readings taken every 15-min. The data was converted to salinity, with units of Practical Salinity Units (psu), using the relationship:

Salinity = -100*ln(1-(Conductivity/178500))

This equation is based on an analysis conducted by Normandeau Associates, Inc. on properties of water in the River (Texas Instruments, 1976).

The converted salinity data was then filtered with a centered 1-hr moving average and subsampled to every hour. The Tomkins record was analyzed for the period from May 1997 to July 2001. However, longer records were available for the other two USGS stations, so the salinity was analyzed from October 1998 to December 2009 for West Point and from October 1999 to December 2009 for Hastings. The following sections describe the analysis of the individual datasets.

3.1 TOMKINS DATA

The raw specific conductance data received from USGS for the Tomkins station consisted of records every 15-min from 15 May 1997 to 16 July 2001. The data was converted to salinity, filtered with a centered 1-hr moving average and subsampled to an hour. Figure 3-1 displays the time series of the hourly subsampled salinity data. Table 3-1 outlines basic statistics of the Tomkins dataset, broken down by month and year. The data indicates that there is a large range in salinity at Tomkins ranging from 0.09 to 9.27 psu. The maximum salinity reading at Tomkins occurs in August 1999. The mean salinity for the entire record is 2.09 psu and the median (50th percentile) is 1.49 psu. Large difference between the mean and median values indicates that the average is driven up by some high salinity spikes within the river. Additionally, the year-to-year variation is significant with large differences in the 50th and 90th percentile values among the years.

The monthly variation shows lower mean values, between 0.36 and 1.50 psu, from January through June presumably due to increased freshwater discharge. Higher mean values, with a range between 2.56 and 4.07 psu, occur from July through December. Higher salinity is generally indicative of lower freshwater discharge into the River. This general seasonal trend is also apparent in the other statistical measures. For example, the highest 90th percentile values occur in August and September, at 7.22 and 6.49 psu, respectively.

Table 3-1. Statistical summary for the entire Tomkins period of record (15 May 1997 through 16 July 2001) and for each year and month in the record.

Period	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
All	2.09	0.09	9.27	1.49	4.96

Period	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
1997	3.36	0.10	6.71	4.03	5.56
1998	2.12	0.09	6.61	2.04	4.54
1999	2.60	0.13	9.27	1.93	6.54
2000	1.20	0.10	7.99	0.60	3.18
2001	1.29	0.09	6.20	0.74	3.23
Jan	1.47	0.09	4.66	1.31	2.98
Feb	1.24	0.14	4.28	1.11	2.58
Mar	0.92	0.11	7.72	0.18	2.97
Apr	0.36	0.09	2.96	0.17	0.94
May	1.11	0.09	6.20	0.26	3.53
Jun	1.50	0.11	5.27	0.79	3.85
Jul	2.56	0.12	8.25	2.32	5.22
Aug	4.07	0.17	9.27	4.44	7.22
Sep	3.70	0.18	9.00	4.17	6.49
Oct	3.26	0.15	6.68	3.69	5.34
Nov	3.12	0.24	7.99	3.17	5.36
Dec	1.88	0.12	5.90	1.75	3.92

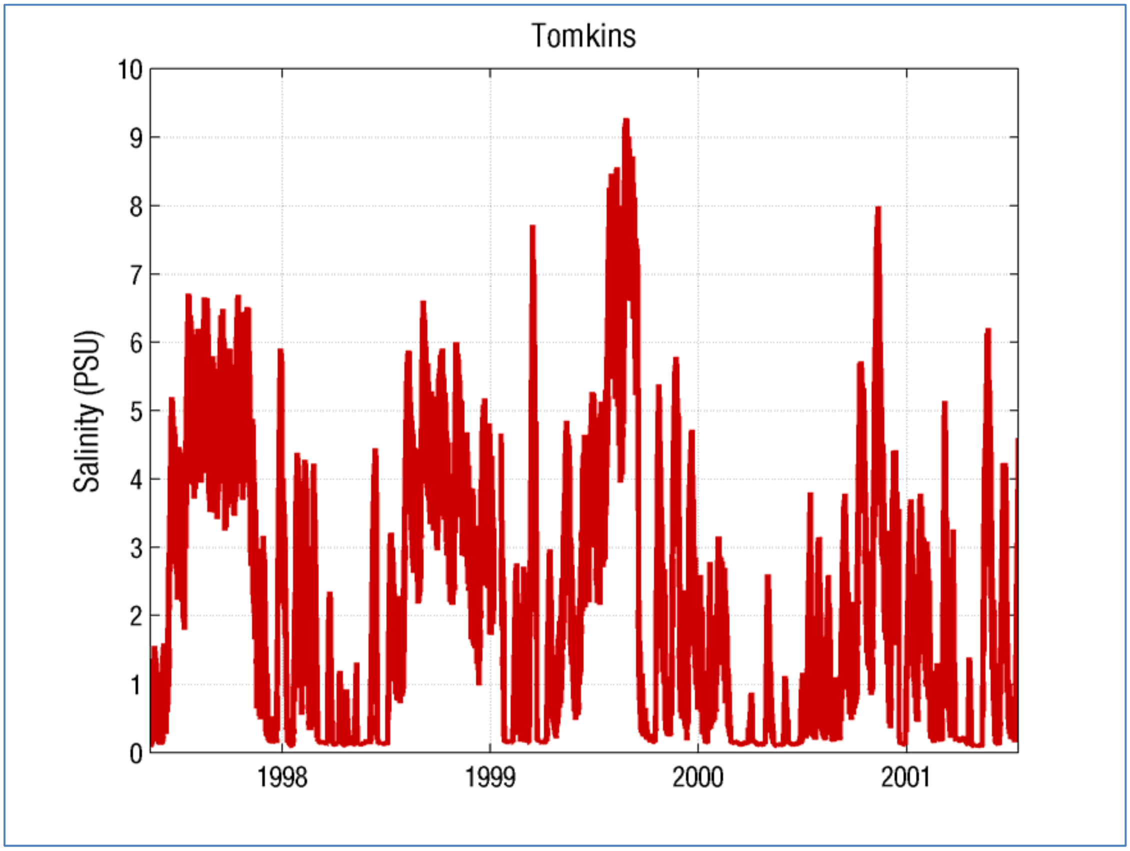

Figure 3-1. Hourly time series at Tomkins for the period of record (15 May 1997 through 16 July 2001).

3.2 Hastings and West Point Data

The raw specific conductance data received from USGS for the Hastings and West Point stations consisted of observations every 15-min extending from 1 October 1998 to 31 December 2009 for West Point and 1 October 1999 to31 December 2009 for Hastings. The data were converted to salinity, filtered with a centered 1-hr moving average and subsampled to an hour. The period used in the model development and calibration, as described in later sections, extended from 1 October 1999 through 16 July 2001 since this period included all three USGS stations. The period used in the subsequent model predictions was the decade 2000 – 2009, consistent with previous ASA analyses (Swanson et al., 2010).

3.2.1 Hastings Data

The Hastings data is shown in Figure 3-2 with summary statistics given in Table 3-2. The salinity variation at Hastings is substantial, indicative of the dynamic processes occurring in the River estuary. The large range in salinity at the site varies from 0.10 psu to a maximum of 19.06 psu in February 2007. The mean salinity for the entire record is 6.29 psu is close to the median (50th percentile) is 6.12 psu, indicative of a normal distribution. The year-to-year variation for the mean ranges from 4.86 psu in 2000 and 7.77 psu in 2001. The 50th percentile values range from 5.19 psu in 2000 and 7.92 psu in 2001 while the 90th percentile values range from 8.28 psu in 2000 to 12.99 psu in 2002.

The monthly variation mean salinity values are the lowest between December and June, due to increased freshwater discharge into the River. The exception occurs in February when the mean salinity at 6.36psu, far exceeding the mean in the other winter and spring months. Higher mean values, ranging between 6.10 and 9.44 psu, are observed from July through November. This trend is also evident from other statistical measures, including the peak 90th percentile monthly value of 12.84, which occurs in September.

Table 3-2. Statistical summary for the entire Hastings period of record (October 1999 through December 2009) and for each year and month in the record.

Period	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
All	6.29	0.10	19.06	6.12	10.88
1999	5.99	1.30	14.25	5.89	8.47
2000	4.86	0.13	15.02	5.18	8.28
2001	7.77	0.16	15.32	7.92	11.94
2002	7.56	0.72	16.28	7.06	12.99
2003	5.55	0.12	18.50	5.41	9.76
2004	6.59	0.22	16.17	6.48	10.57
2005	6.49	0.12	16.22	6.51	11.29

Period	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
2006	5.75	0.13	15.96	5.67	9.96
2007	7.03	0.12	19.06	7.74	11.04
2008	5.41	0.10	18.43	5.23	10.10
2009	5.94	0.21	14.47	6.02	9.18
Jan	5.36	0.14	16.30	5.34	9.15
Feb	6.36	0.12	19.06	6.53	9.85
Mar	4.92	0.10	15.25	5.19	8.79
Apr	3.43	0.12	13.96	2.87	7.38
May	5.03	0.13	13.97	4.67	8.60
Jun	5.37	0.15	15.84	5.12	8.89
Jul	8.17	0.15	16.28	8.38	11.83
Aug	8.56	1.15	16.02	9.22	12.25
Sep	9.44	0.31	16.28	9.78	12.84
Oct	7.87	0.18	18.43	8.14	11.90
Nov	6.10	0.13	14.49	6.02	10.46
Dec	4.96	0.13	14.47	4.88	8.98

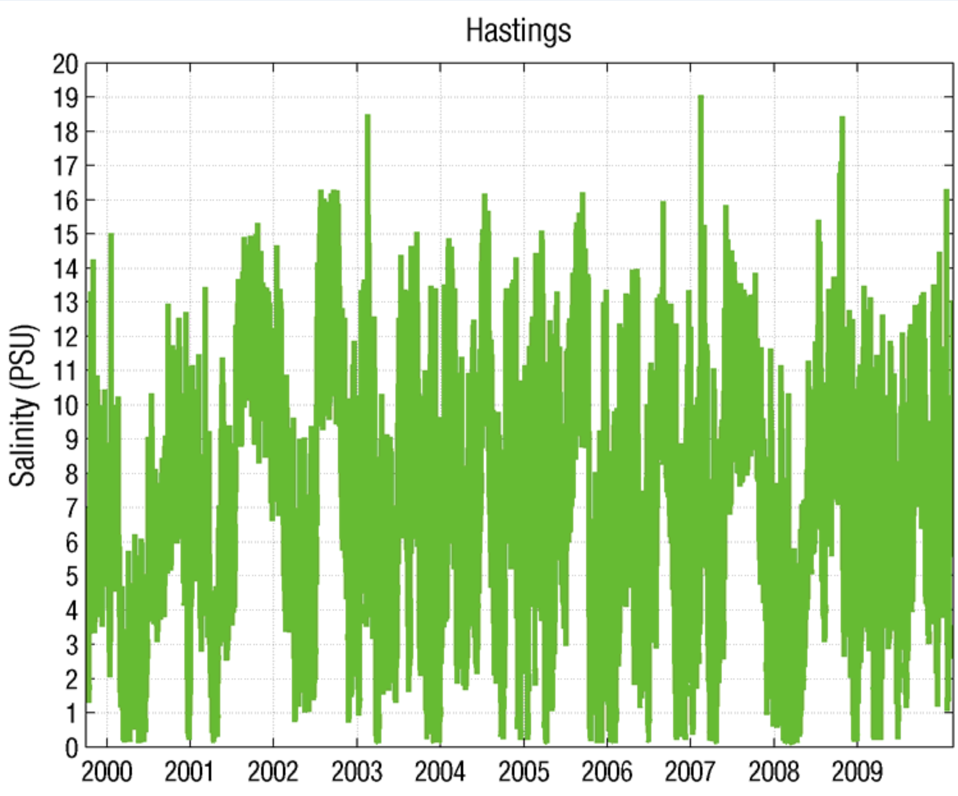

Figure 3-2. Hourly time series at Hastings for the period from 1 October 1999 through 31 December 2009.

3.2.2 West Point Data

The West Point data is shown in Figure 3-3 with summary statistics given in Table 3-3. There is a lower observed salinity variation at West Point relative to the other two USGS stations simply due to its upstream location. The range in salinity at the site varies from 0.07 psu to a maximum of 6.99 psu, which occurs in September of 2003. The mean salinity for the entire record is only 0.79 psu and the median (50th percentile) is 0.17 psu. The year-to-year variation for the mean ranges from 0.36 psu in 2009 and 1.57 psu in 2001. The 50th percentile ranges from 0.13 psu in 2006 and 1.17 psu in 1998 while the 90th percentile values range from 0.54 psu in 2003 to 4.21 psu in 2006.

The monthly variation shows lower means, between 0.19 and 0.78 psu, from December through June, due to increased freshwater discharge into the River with higher means, between 0.78 and 2.03 psu, from July through November indicative of lower discharge. This trend is also generally seen in the other statistical measures such as with the highest 90th percentile value of 4.70 psu occurring in September.

Table 3-3. Statistical summary for the entire West Point period of record (October 1998 through December 2009) and for each year and month in the record.

Period	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
All	0.79	0.07	6.99	0.17	2.63
1998	1.22	0.22	3.06	1.17	2.12
1999	1.03	0.10	6.08	0.34	3.49
2000	0.39	0.10	5.73	0.14	1.00
2001	1.57	0.09	5.29	1.05	3.64
2002	1.44	0.09	6.99	0.37	4.21
2003	0.27	0.10	2.45	0.16	0.54
2004	0.44	0.10	3.24	0.16	1.28
2005	0.77	0.10	4.39	0.20	2.47
2006	0.38	0.08	3.62	0.13	1.14
2007	1.39	0.08	6.94	0.37	3.91
2008	0.59	0.07	4.73	0.15	1.72
2009	0.36	0.10	3.12	0.14	0.99
Jan	0.41	0.08	3.95	0.15	1.14
Feb	0.49	0.10	4.16	0.18	1.35
Mar	0.37	0.10	3.75	0.16	1.08
Apr	0.19	0.08	1.99	0.13	0.29
May	0.33	0.07	3.84	0.12	1.03
Jun	0.42	0.10	3.36	0.14	1.16
Jul	1.03	0.08	4.74	0.60	2.67
Aug	1.77	0.09	6.08	1.36	3.98
Sep	2.03	0.11	6.99	1.44	4.70
Oct	1.37	0.11	6.64	0.68	3.65
Nov	0.78	0.09	5.73	0.21	2.40

Period	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
Dec	0.46	0.09	4.70	0.14	1.46

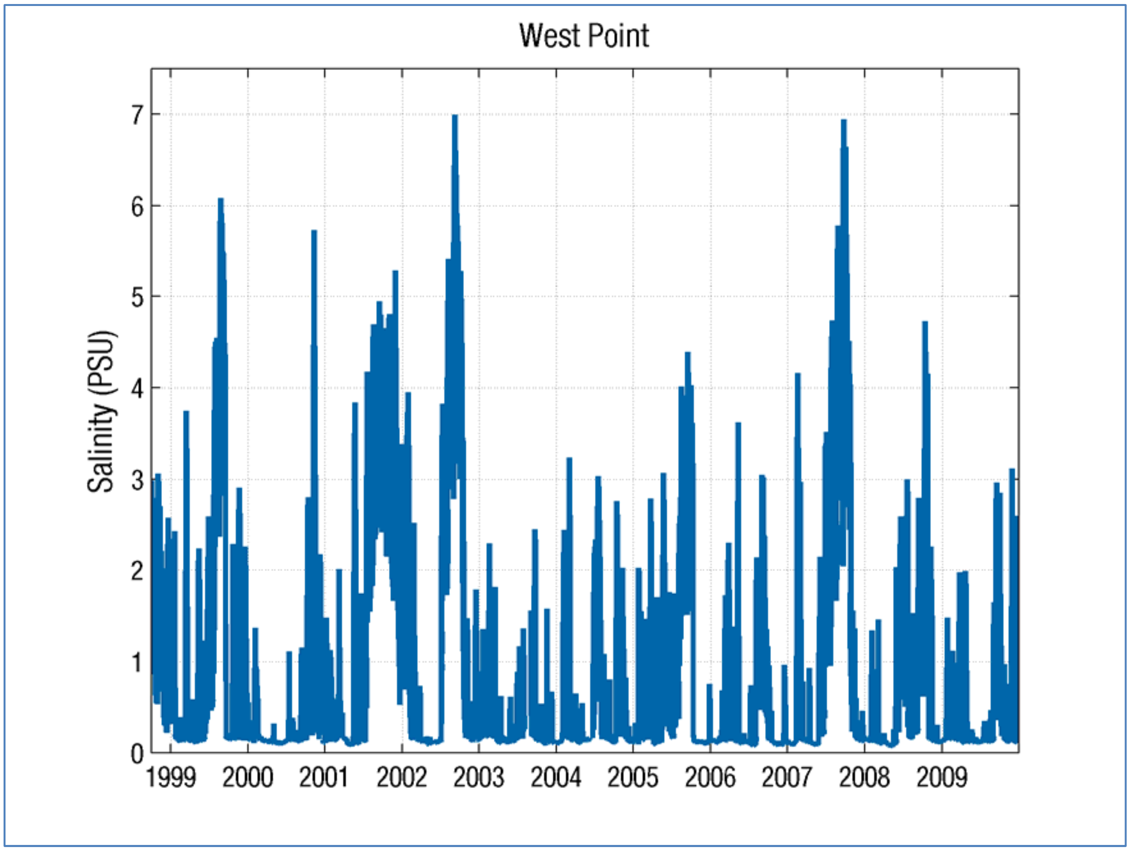

Figure 3-3. Hourly time series at West Point for the period from 1 October 1998 through 31 December 2009.

4 IPEC Salinity Model Development

To estimate the long-term salinity variation in the River at Tomkins (near IPEC), statistical correlations were developed among the USGS station data. An analysis was conducted examining the correlation between both Tomkins and West Point and Tomkins and Hastings USGS stations to assess the relationships among the stations.

4.1 Tomkins vs. Hastings Salinity Correlation

Figure 4-1 shows a scatterplot of the salinities at Tomkins versus Hastings during the October 1999 through July 2001 period when all three data sets overlapped. There is a large variation of salinity at Hastings (0 – 8 psu) when that observed at Tomkins is small (~0.1 psu). However, there is also large variation at Tomkins (0 – 6 psu) when the salinity at Hastings is fixed at 8 psu. The visual best-fit line to the data is a least squares fitted power-law function, as shown superimposed over the data on Figure 4-1. The power-law function has a variance of 0.66 psu^2 and a standard deviation of 0.81 psu.

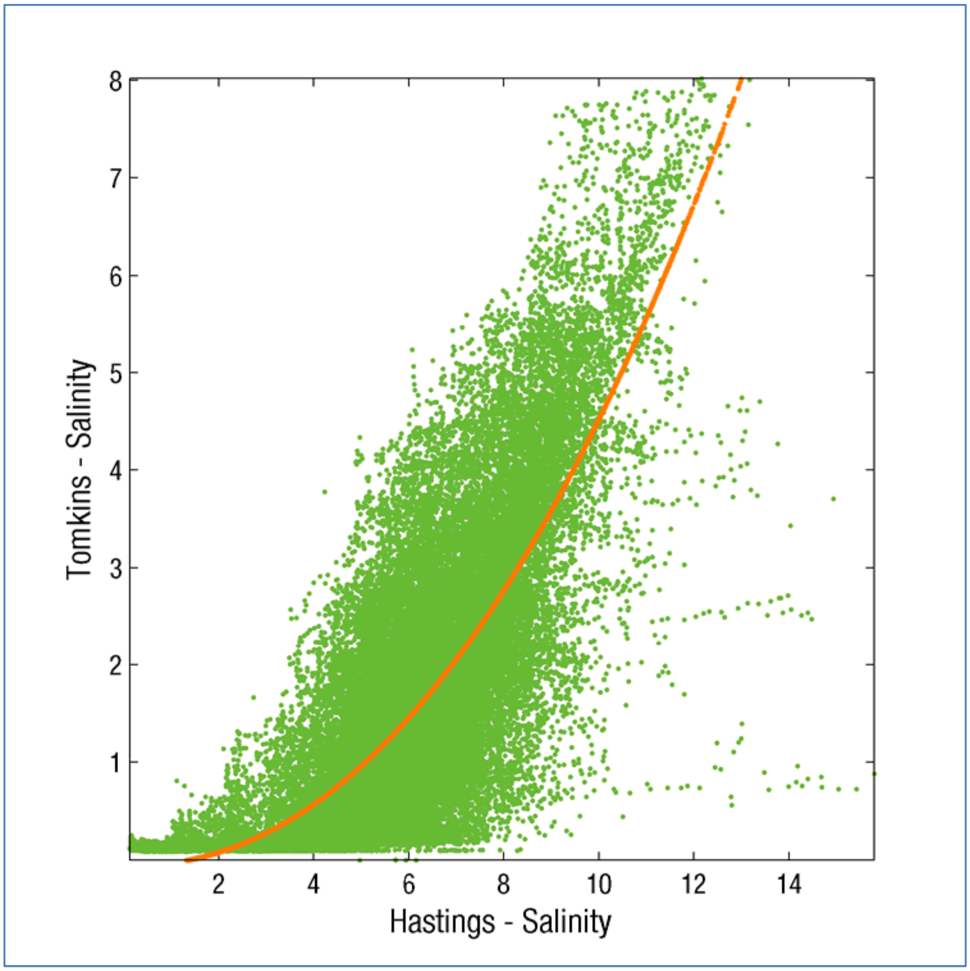

Figure 4-1. Scatterplot of salinity data for USGS stations at Tomkins and Hastings with a power law regression superimposed on the data.

An alternative empirically based approach uses a non-continuous binned relationship between the mean values of salinity at Tomkins averaged over a small range of salinities (the bin width) at Hastings. The bins vary in width from a minimum of 0.084 psu at lowest salinities to a maximum of 0.764 psu at higher salinities (i.e., >5 psu) and are summarized in Table 4-1. The new empirically derived line is superimposed over the data in Figure 4-2. The scatter or fit to the empirical binned function has a variance of 0.60 psu^2 and a standard deviation of 0.78 psu. This new method results in a lower standard deviation and thus a “better fit” as compared to the power law function shown in Figure 4-1. The improvement is seen at the higher Hastings salinities where the Tomkins to Hastings ratio salinity slope decreases to account for the larger scatter in the data.

Table 4-1. Empirically based bin information for Hastings salinity data.

Bin Number	Bin Width (psu)	Bin Max (psu)
1	0.084	0.084
2	0.044	0.128
3	0.059	0.187
4	0.138	0.325
5	0.153	0.478
6	0.187	0.664
7	0.227	0.892
8	0.252	1.144
9	0.304	1.448
10	0.327	1.775
11	0.373	2.148
12	0.420	2.568
13	0.447	3.015
14	0.510	3.525
15	0.537	4.062
16	0.506	4.568
17	0.764	5.332
18	0.406	5.738

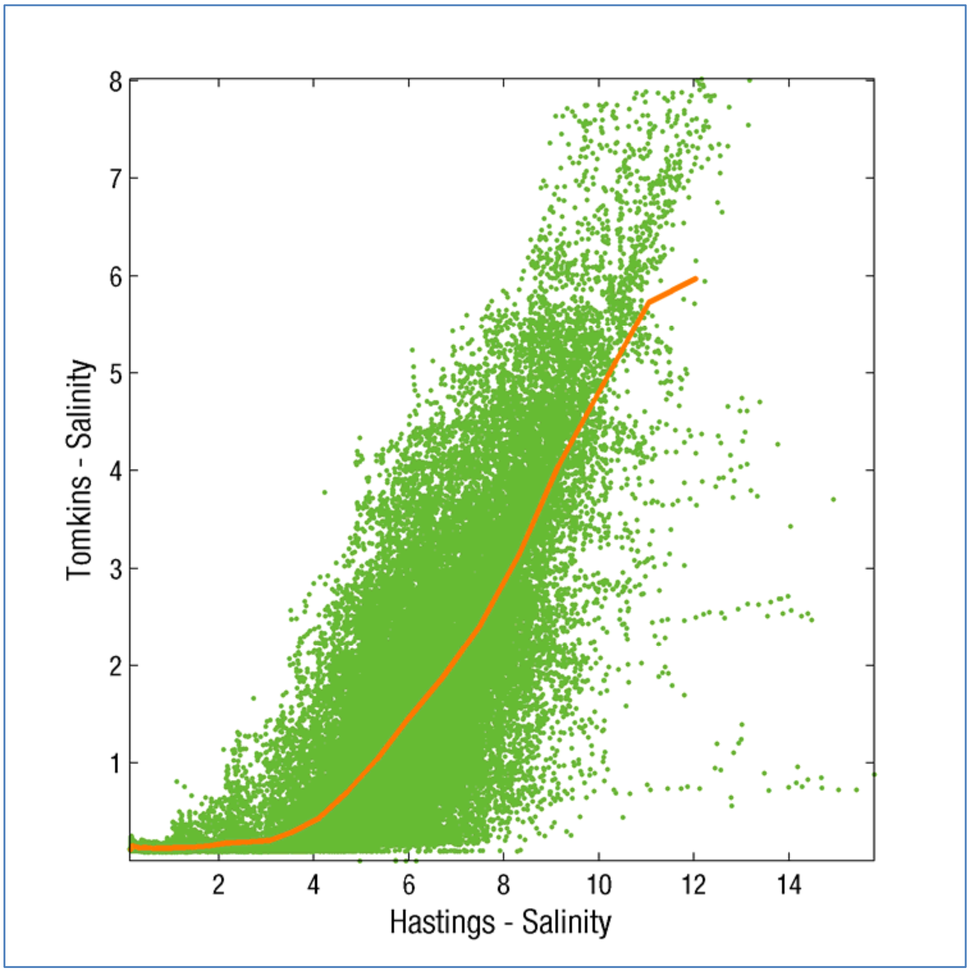

Figure 4-2. Scatterplot of salinity data for USGS stations at Tomkins and Hastings with an empirically based regression superimposed on the data.

4.2 Tomkins vs. West Point Salinity Correlation

The scatterplot of Tomkins versus West Point is shown in Figure 4-3 with the superimposed least squares fitted power-law function. The scatter is much smaller than Hastings as indicated by the variance of 0.23 psu^2 (standard deviation of 0.48 psu). To check the empirically based approach used above, the mean value of salinity at Tomkins was averaged over a small range of salinities (the bin width) at West Point (Figure 4-4). The bins vary in width from a minimum of 0.145 psu at lowest salinities to a maximum of 0.994 psu at the highest salinities (i.e., 11.5 psu) and are summarized in Table 4-2. The scatter is much smaller than at Hasting as indicated by the low variance of 0.18 psu^2, corresponding to a standard deviation of 0.43 psu.

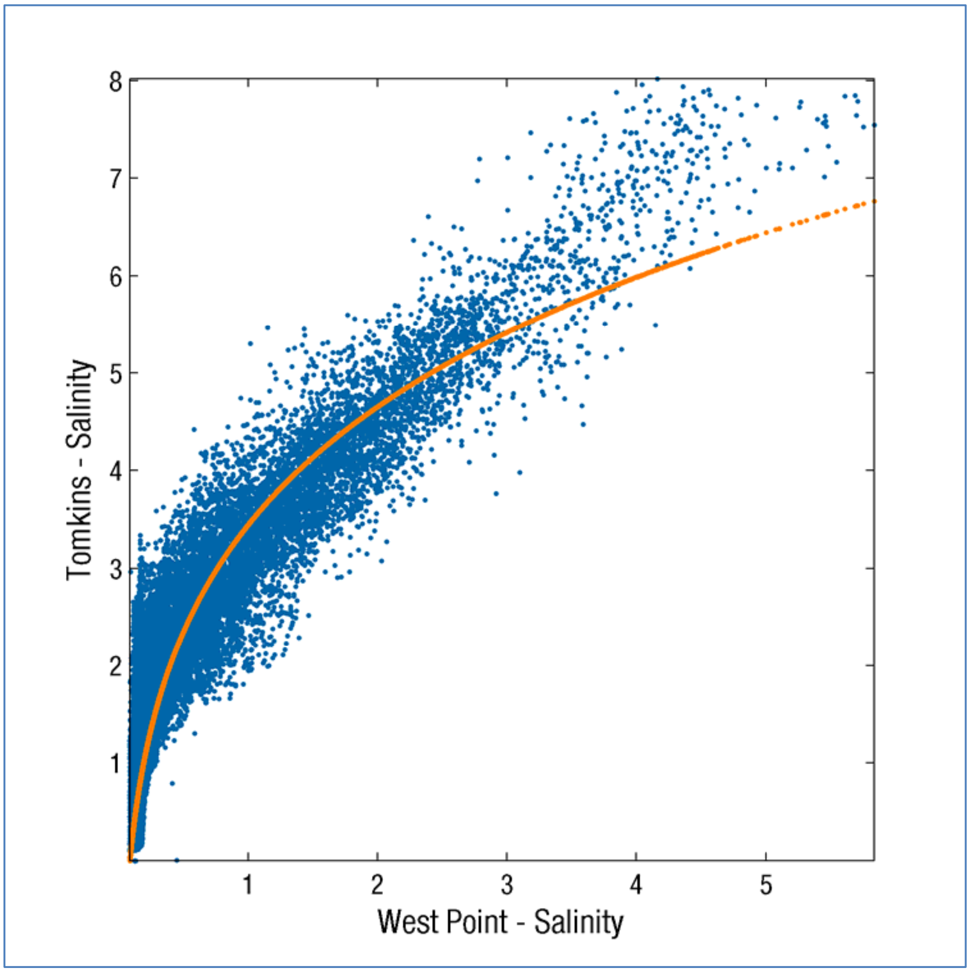

Figure 4-3. Scatterplot of salinity data for USGS stations at Tomkins and West Point with a power law regression superimposed on the data.

Table 4-2. Empirically based bin information for West Point salinity data.

Bin Number	Bin Width (psu)	Bin Max (psu)
1	0.145	0.145
2	0.043	0.187
3	0.141	0.328
4	0.154	0.482
5	0.185	0.667
6	0.230	0.897
7	0.262	1.159
8	0.282	1.441
9	0.344	1.785
10	0.375	2.160
11	0.425	2.585
12	0.479	3.064
13	0.497	3.560
14	0.547	4.107

Bin Number	Bin Width (psu)	Bin Max (psu)
15	0.592	4.699
16	0.633	5.332
17	0.665	5.998
18	0.723	6.721
19	0.774	7.494
20	0.833	8.327
21	0.826	9.153
22	0.940	10.093
23	0.953	11.046
24	0.994	12.040

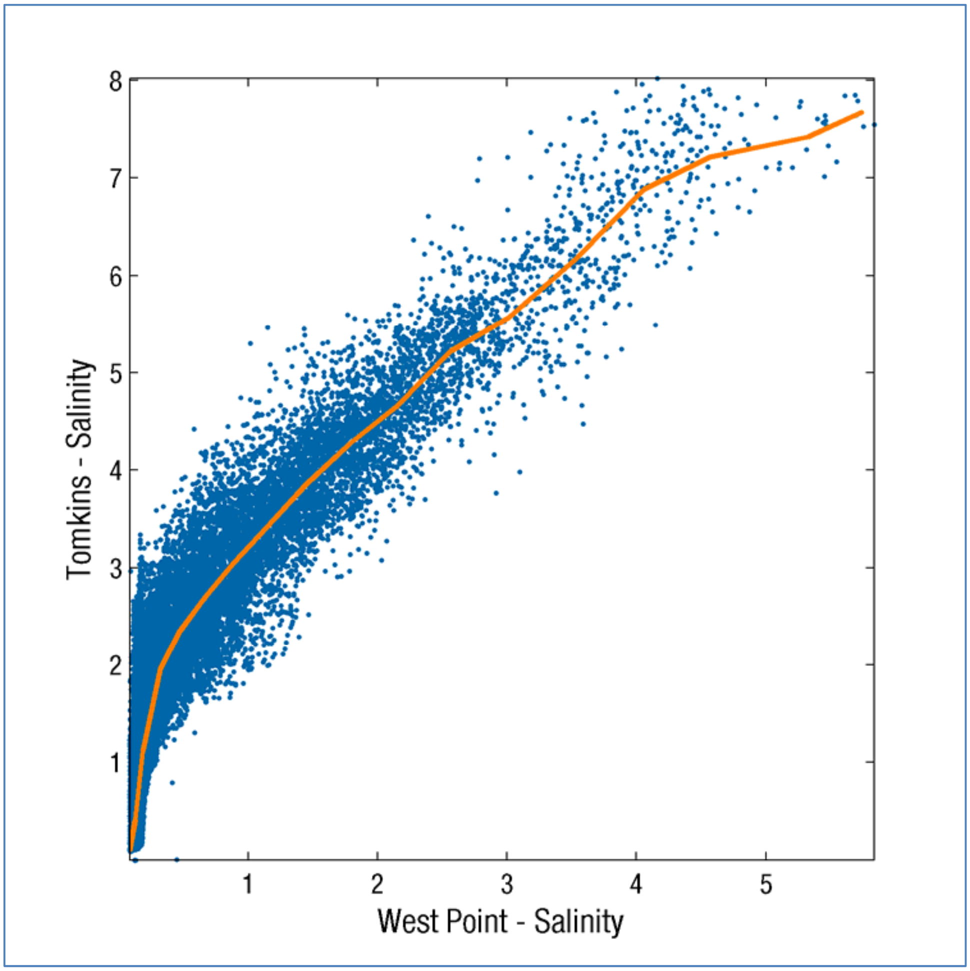

Figure 4-4. Scatterplot of salinity data for USGS stations at Tomkins and West Point with an empirically based regression superimposed on the data.

4.3 IPEC Model Results

Since the Tomkins salinity is well correlated to West Point but not to Hastings, initially only the West Point data was used in estimating Tomkins salinity. However, a comparison of the estimated salinity from the empirically based regression model compared to the observed indicates that when salinities are low at West Point (< 1 psu) the model over predicts Tomkins salinities. However, further testing and analysis showed that, when the salinity at Hastings fell below 4.07 psu, the salinity at both West Point and Tomkins was typically very close to zero. Therefore, in all periods when the Hastings salinity dropped below 4.07psu the Tomkins statistical model was set equal to the West Point salinity. This process prevented unreasonably high model predictions of salinity at Tomkins.

Figure 4-5 shows the salinity time series during the period when salinity observations were reported for all three USGS stations, October 1999 through July 2001. As expected, West Point always had the lowest salinity at any given time, Tomkins salinity was essentially the same or higher than West Point salinity, and Hastings consistently had the highest salinity. During high discharge periods, the salinity recorded at Hastings was very close to that observed at Tomkins and West Point. The empirical model estimate at Tomkins is also shown in Figure 4-5 and tracks the observed data at Tomkins closely.

To see how well the empirical model correlated with the observations on shorter time scales, Figure 4-6 displays a segment of the time series from 30 January through 9 April 2000. During the first month of the period, Hastings salinity is greater than 4.07 psu and the model tracks the Tomkins salinity data well. For the rest of the period the Hastings salinity frequently falls below 4.07 psu and the West Point salinity is essentially zero, thus the model forces the Tomkins salinity to the West Point value. This assumption typically works well except that some small excursions of Tomkins salinity are not captured during this period (e.g., early in March) or that extraneous small (<1 psu) levels are intermittently predicted (early February).

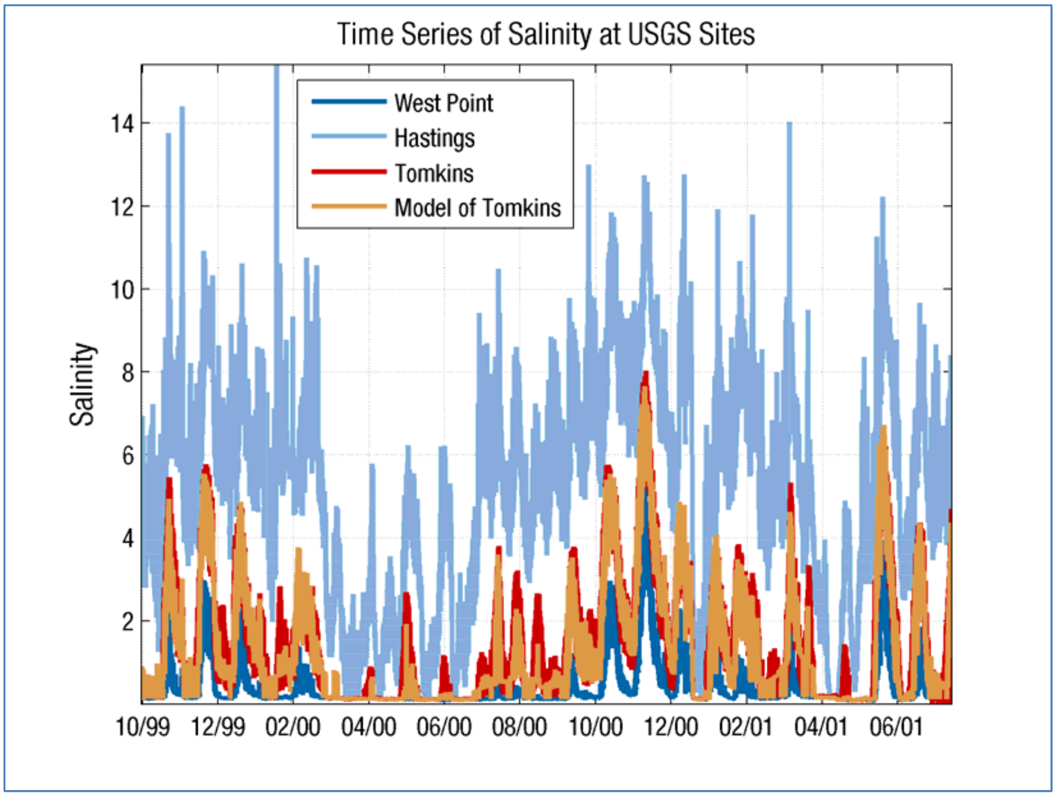

Figure 4-5. Salinity time series of period of record (October 1999 through July 2001).

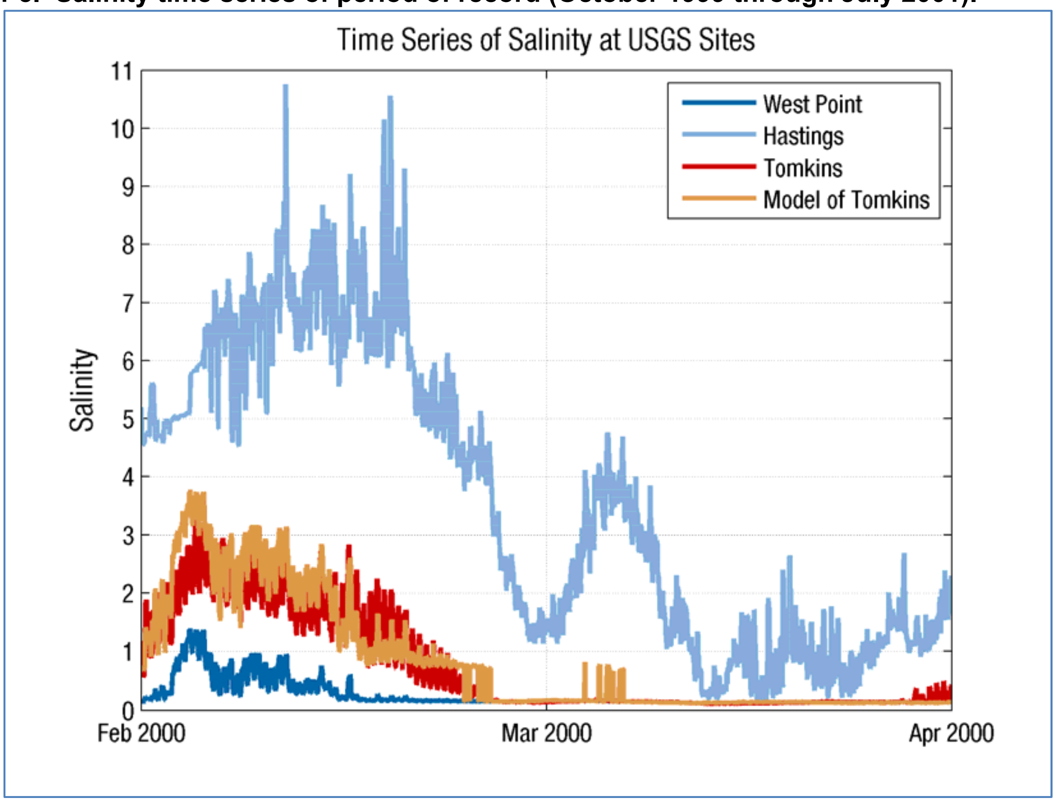

Figure 4-6. Salinity time series of short portion of record (30 January through 9 April 2000) showing ability of model to simulate low salinities at Tomkins.

The resulting time series of hourly salinity at Tomkins, used as a proxy for the IPEC intake, is shown in Figure 4-7 for the 10-year period 2000 – 2009. There is no clear annual cycle although salinities are typically higher in the summer and fall seasons. Some years (2001, 2002, 2005, and 2007) show extended periods of salinity continuously exceeding 4 psu for more than two months with peaks exceeding 7 psu. These variations are primarily due to freshwater entering the River, although there are sometimes events (storm surge) that can transport salt from the ocean to the vicinity of the IPEC intake. The complete 1-hr empirically calculated salinity data set for the 10-yr period is available upon request as an Excel spreadsheet.

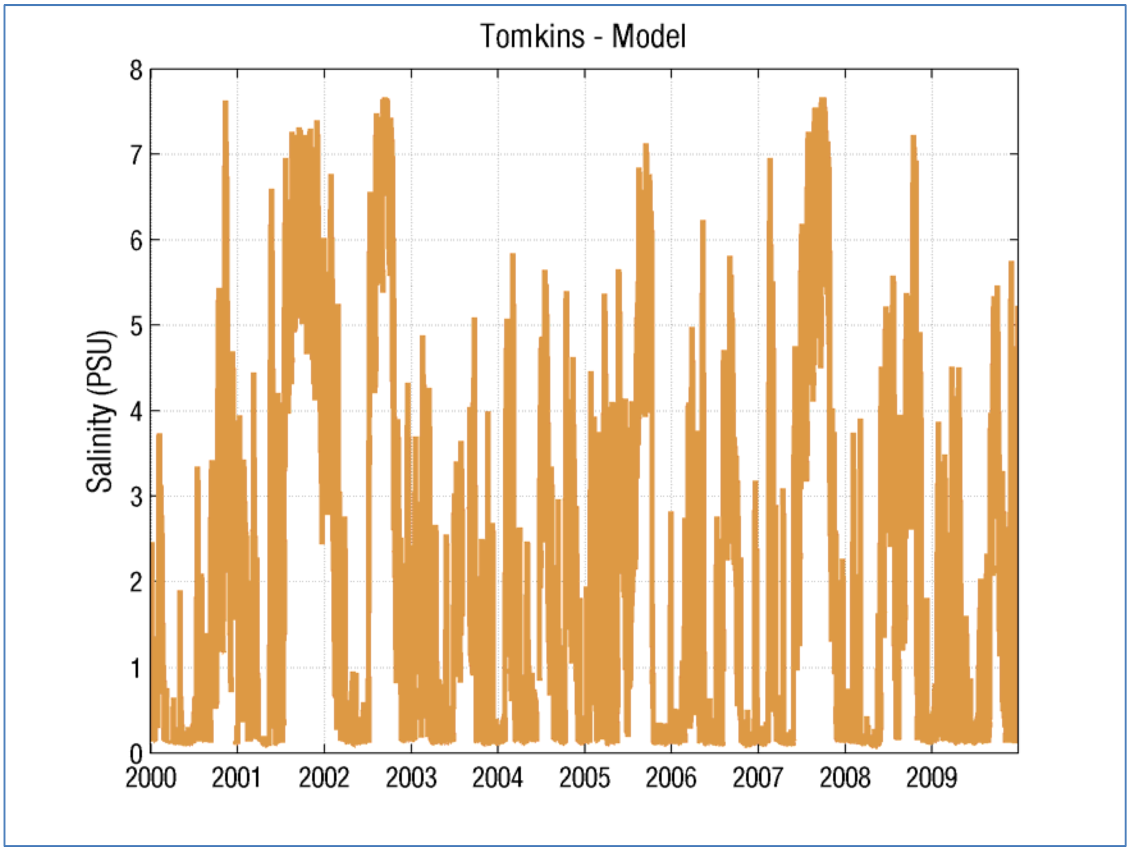

Figure 4-7. Predicted salinity at IPEC (using Tomkins as a proxy) for the period 2000 through 2009.

5 STATISTICAL ANALYSES

Statistics, frequency and cumulative frequency distributions were determined for the hourly-modeled salinity predictions at IPEC (with Tomkins as a proxy) for the decadal period 2000 through 2009. Separate analyses are reported for the entire period, for each of the 10 years and each of the 12 months in the record.

5.1 ENTIRE 2000-2009 ANALYSIS

There were a total of 85,192 hours of data contained in the decadal record (Table 5-1). This value falls below the full 87,672 hours that fall within the period of record from 2000 to 2009 due to a number of missing data points. The missing data points in the original USGS records are likely a function of instrument malfunction, interference, or maintenance.

The mean salinity is seen to be 1.80 psu, the minimum 0.07 psu and the maximum 7.67 psu. The median, or 50th percentile, is 0.72 psu, indicating that the salinity distribution is not a normal distribution, but slightly biased to lower salinities. The 90th percentile salinity, which means that 90% of the salinity values in the record are less than 5.23 psu, while 10% are greater.

Table 5-1. Statistical summary for the entire 10-yr record.

Period	Count (hrs)	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
2000-2009	85,192	1.80	0.07	7.67	0.72	5.23

Figure 5-1 and Table 5-2 document the frequency and cumulative frequency distribution of the entire 10-yr data set. The salinity bin resolution is 0.25 psu (0 – 0.25, 0.25 – 0.50, 0.50 – 0.75, etc). Salinities between 0 and 0.25 psu occur 30.62% of the time while salinities between 0.25 and 0.50 psu drop to 12.29% of the time. The large number of low salinities is indicated by the cumulative frequency of occurrence that shows over 50% (54.78%) of the salinities are less than 1.00 psu. There are no salinity bins above 1.00 psu exceeding a frequency of 3%.

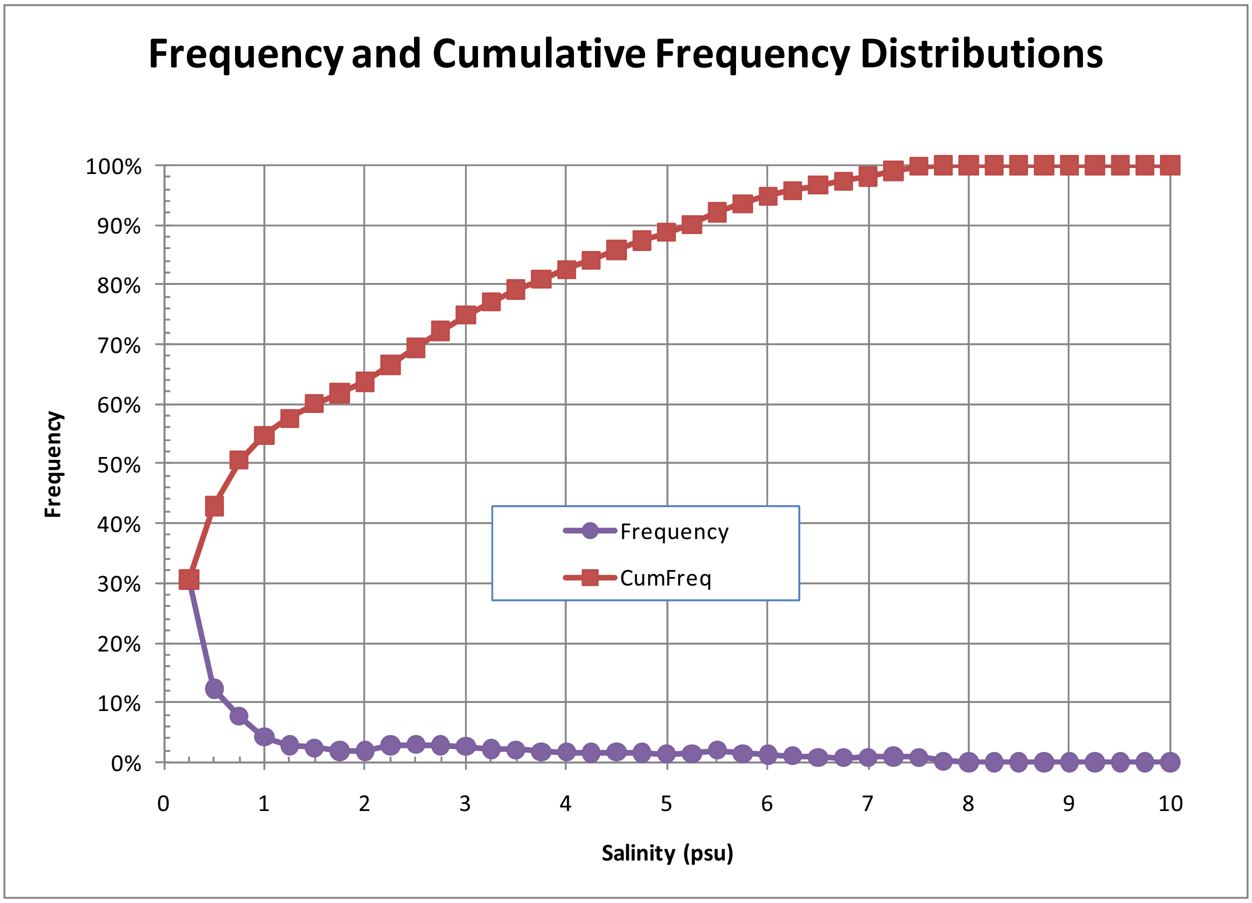

Figure 5-1.Frequency and cumulative frequency distributions for the entire 10-yr record.

Table 5-2. Frequency and cumulative frequency distributions in 0.25 psu bins for the entire 10-yr record.

Minimum Salinity (psu)	Maximum Salinity (psu)	Frequency (%)	Cumulative Frequency (%)
0.00	0.25	30.62%	30.62%
0.25	0.50	12.29%	42.91%
0.50	0.75	7.68%	50.59%
0.75	1.00	4.20%	54.78%
1.00	1.25	2.85%	57.63%
1.25	1.50	2.35%	59.98%
1.50	1.75	1.83%	61.81%
1.75	2.00	1.89%	63.70%
2.00	2.25	2.79%	66.49%
2.25	2.50	2.91%	69.40%
2.50	2.75	2.83%	72.23%
2.75	3.00	2.64%	74.88%
3.00	3.25	2.21%	77.09%
3.25	3.50	2.04%	79.13%
3.50	3.75	1.74%	80.87%

Minimum Salinity (psu)	Maximum Salinity (psu)	Frequency (%)	Cumulative Frequency (%)
3.75	4.00	1.69%	82.56%
4.00	4.25	1.57%	84.13%
4.25	4.50	1.64%	85.77%
4.50	4.75	1.58%	87.35%
4.75	5.00	1.36%	88.71%
5.00	5.25	1.41%	90.12%
5.25	5.50	1.97%	92.10%
5.50	5.75	1.45%	93.55%
5.75	6.00	1.24%	94.79%
6.00	6.25	0.99%	95.78%
6.25	6.50	0.82%	96.60%
6.50	6.75	0.70%	97.30%
6.75	7.00	0.76%	98.07%
7.00	7.25	0.95%	99.02%
7.25	7.50	0.77%	99.79%
7.50	7.75	0.21%	100.00%
7.75	8.00	0.00%	100.00%
8.00	8.25	0.00%	100.00%

5.2 Yearly Analysis for Each Year in 10-yr Record

The statistical summary of the 10-yr data set broken down by year is presented in Table 5-3 and displayed in Figure 5-3. Counts for each year vary from 7,846 (2003) to 8,759 (2001) indicating which years have missing data. Non-leap years have 8,760 hrs while leap years have 8,784 hrs. The data shows that the years 2001, 2002, and 2007 have higher salinities on average, while the years 2000, 2003, and 2009 generally have lower salinities. Highest maximum salinities across the entire data set occur in 2000, 2001, 2002 and 2007, with all exceeding 7.40 psu. The minimum salinities vary for all years between 0.07 and 0.11 psu. The mean is consistently greater than or equal to the median indicating that there are more lower values than higher values. The 90th percentile salinities show values greater than 6 psu during 2001, 2002 and 2007.

Table 5-3. Statistical summary for each year of the 10-yr record.

Period	Count (hrs)	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
2000	8692	1.10	0.10	7.63	0.52	3.20
2001	8759	3.21	0.09	7.40	3.28	6.32
2002	8572	2.75	0.09	7.67	1.94	6.90
2003	7846	0.97	0.10	5.08	0.52	2.46
2004	8458	1.37	0.11	5.84	0.69	3.60
2005	8486	1.96	0.10	7.13	1.10	5.10
2006	8435	1.16	0.08	6.23	0.38	3.43

2007	8705	2.71	0.08	7.67	2.06	6.60
2008	8501	1.56	0.07	7.23	0.55	4.22
2009	8738	1.15	0.11	5.76	0.45	3.19

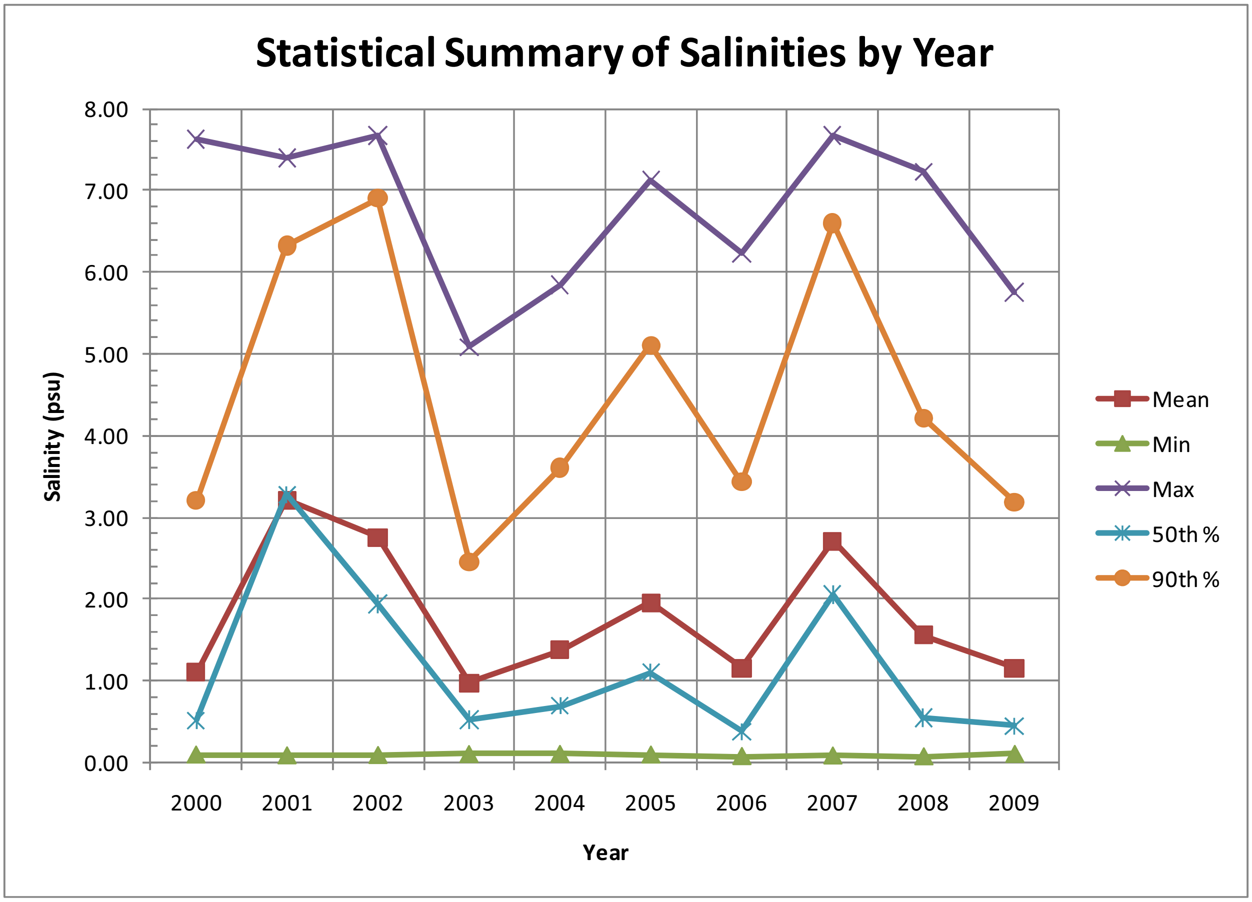

Figure 5-2. Statistical summary by year for the 10-yr period.

Figures 5-3 and 5-4 show the frequency distribution and cumulative frequency distribution, respectively for each year in the 10-yr record. Salinities between 0 and 0.25 psu occur 12% of the time in 2000 and 42% in 2009, while salinities between 0.25 and 0.50 psu occur even less often for all years. Above 1.5 psu, no salinity bins exceed a frequency greater than 5% except for 2009 between 5.50 psu and 6.00 psu. Cumulative frequency distributions indicate that between 33% (in 2001) and 70% (in 2000) of the salinities are less than 1.00 psu.

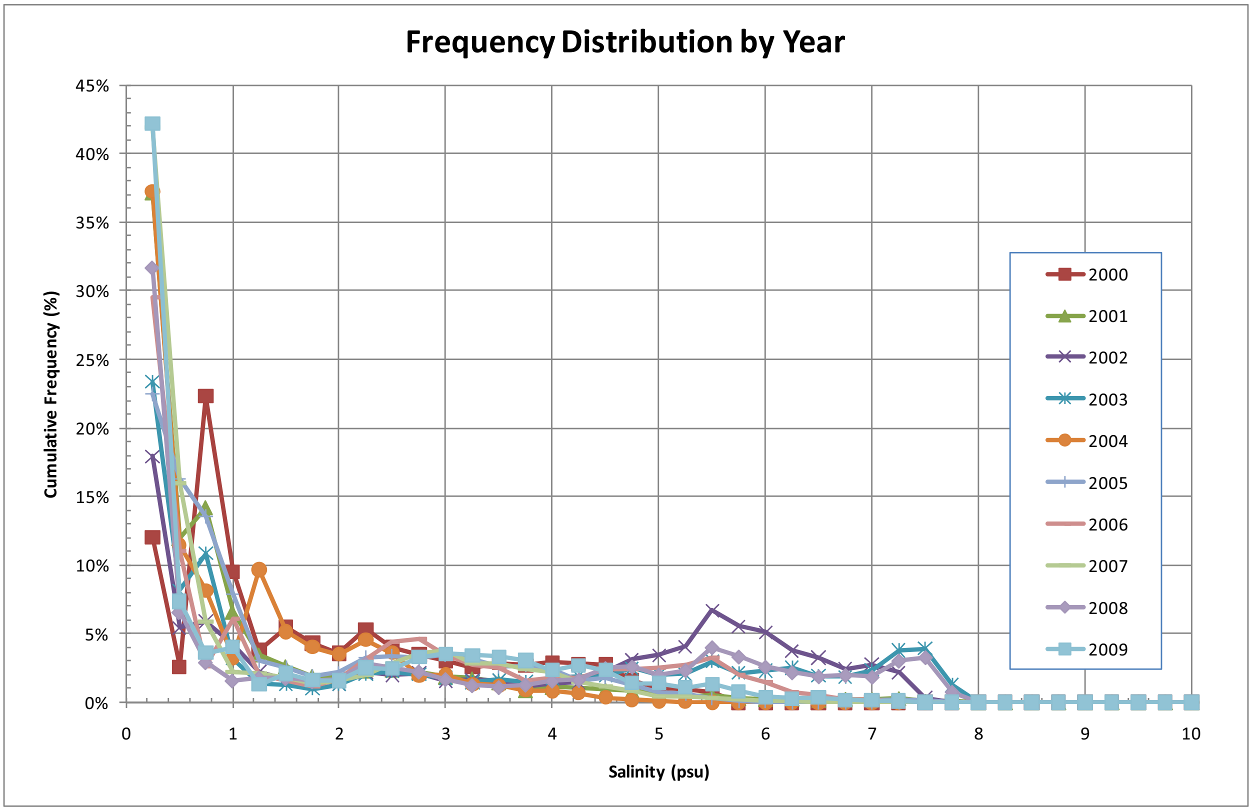

Figure 5-3. Frequency distributions for each year of the 10-yr record.

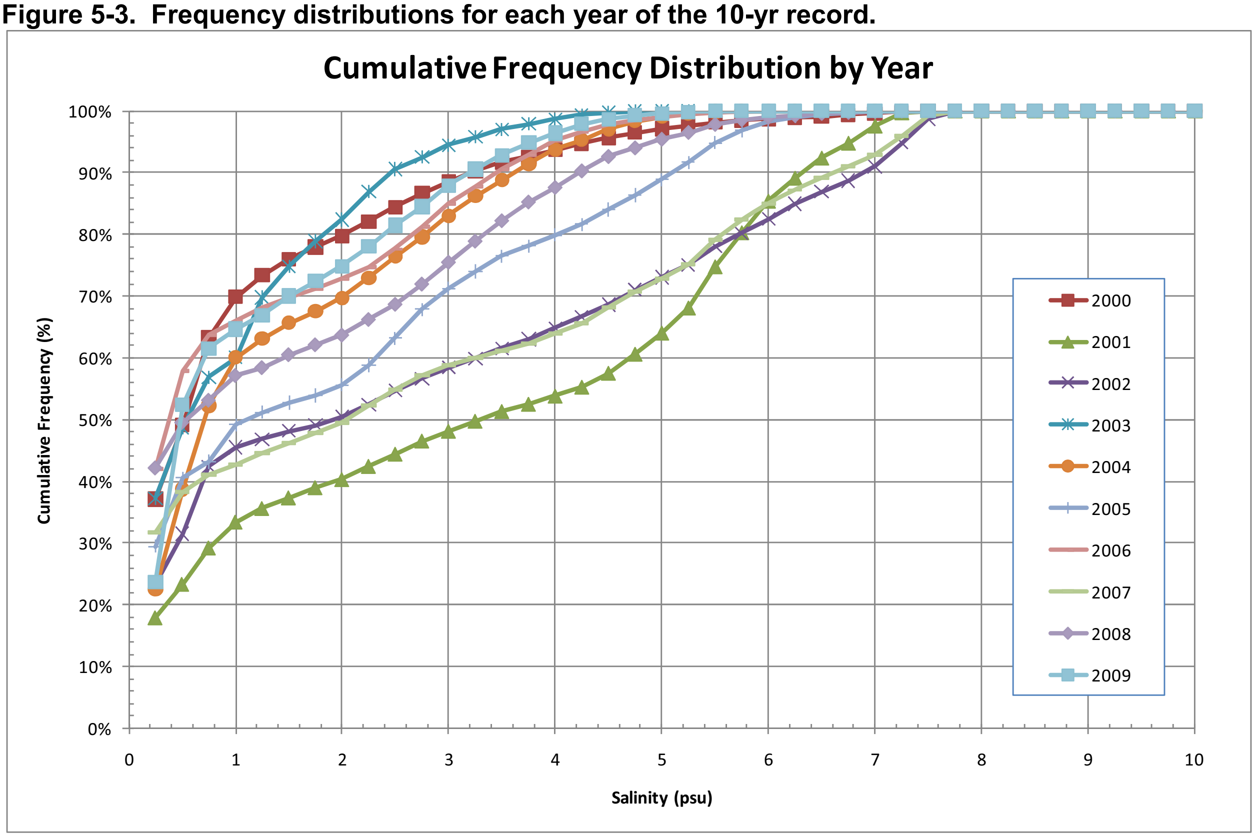

Figure 5-4. Cumulative frequency distributions for each year of the 10-yr record.

5.3 Monthly Analysis for Each Month in 10-yr Record

The statistical summary of the 10-yr data set broken down by month is shown in Table 5-4 and Figure 5-5. Counts for each month vary from 6,698 to 7,440, differing based on years that have fewer days and missing data. February has 672 hrs during non-leap years and 696 hrs during leap years. The data shows that the months of July through October have higher salinities while the other months have lower salinities, with April the lowest. Highest maximum salinities occur between July and December, with all exceeding 7.20 psu while the minimum salinities vary for all months between 0.07 and 0.11 psu. The mean is consistently larger than the median indicating that there are more lower values than higher values. The 90th percentile salinities show values greater than 6 psu during August, September, and October.

Table 5-4. Statistical summary for each month of the 10-yr record.

Month	Count (hrs)	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
Jan	7440	1.11	0.08	6.77	0.39	3.56
Feb	6792	1.59	0.11	6.96	1.09	3.65
Mar	7433	1.08	0.10	5.84	0.63	3.16
Apr	7100	0.52	0.08	4.51	0.13	1.83
May	7276	0.76	0.07	6.60	0.21	2.95
Jun	6698	1.22	0.10	6.07	0.35	3.33
Jul	6804	2.56	0.08	7.27	2.39	5.31
Aug	6739	3.22	0.09	7.55	3.05	6.46
Sep	6939	3.84	0.11	7.67	3.70	7.16
Oct	7422	3.13	0.11	7.66	2.78	6.46
Nov	7200	1.76	0.09	7.63	0.77	5.13
Dec	7349	1.04	0.09	7.26	0.28	3.83

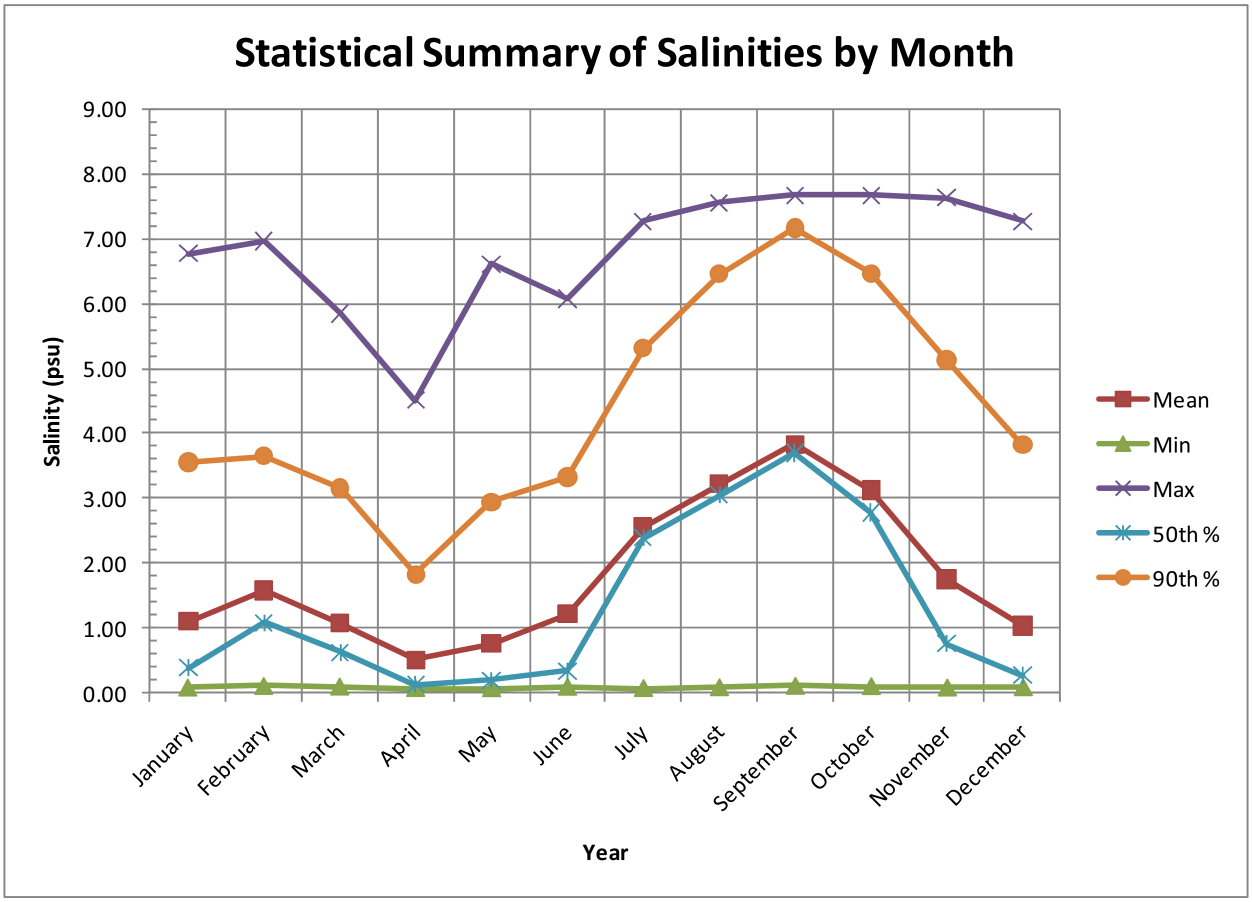

Figure 5-5. Statistical summary by month for the 10-yr period.

Figures 5-6 and 5-7 show the frequency distribution and cumulative frequency distribution, respectively for each month in the 10-yr record. Salinities between 0 and 0.25 psu vary between 5% of the time in September and 85% in April, consistent with freshwater discharge to the River. Generally, there is a dramatic drop for the salinity bin between 0.25 and 0.50 psu for most months. Above 1.5 psu, no salinity bins exceed a frequency greater than 5% except for September for the 7.5-psu bin. Cumulative frequency distributions indicate that between 18% (in September) and 86% (in April) of the salinities are less than 1.00 psu.

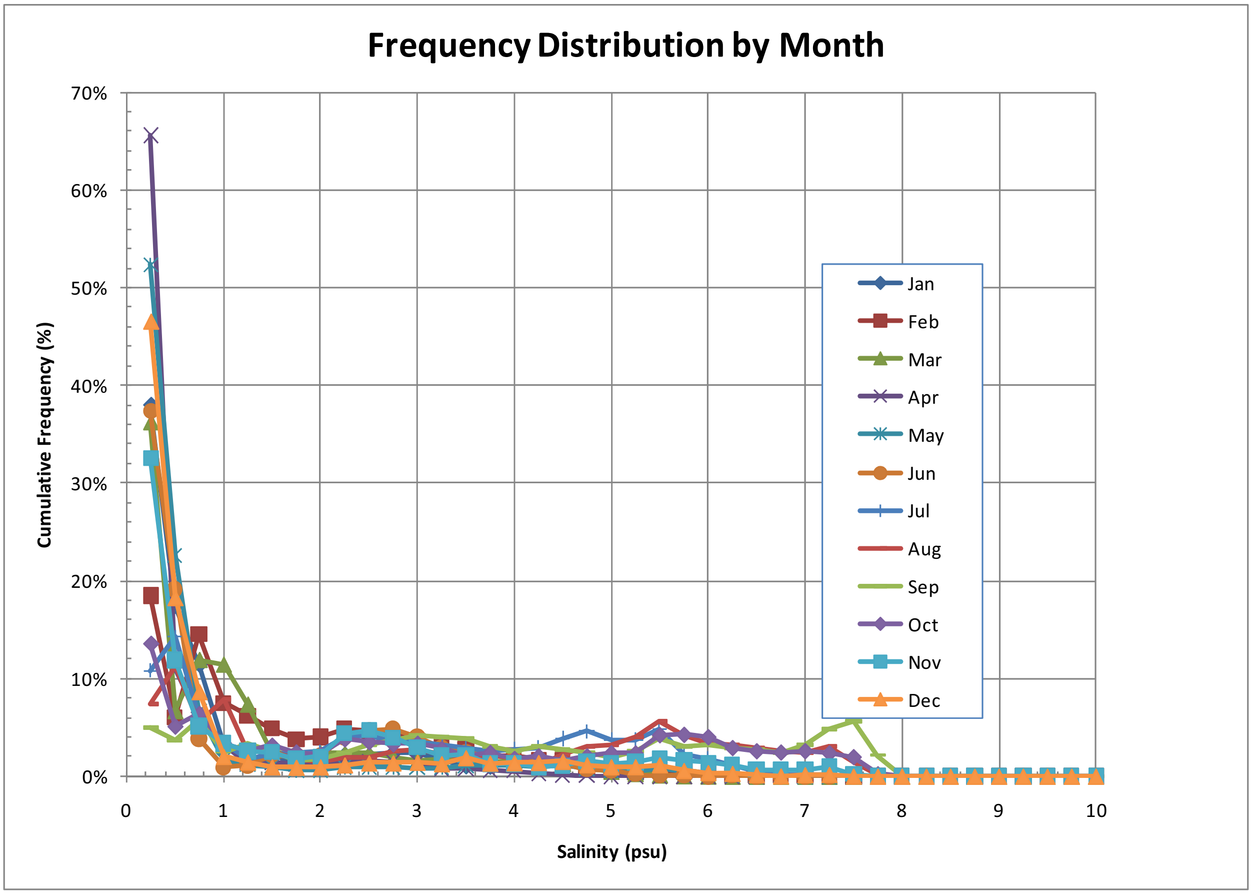

Figure 5-6. Frequency distributions for each month of the 10-yr record.

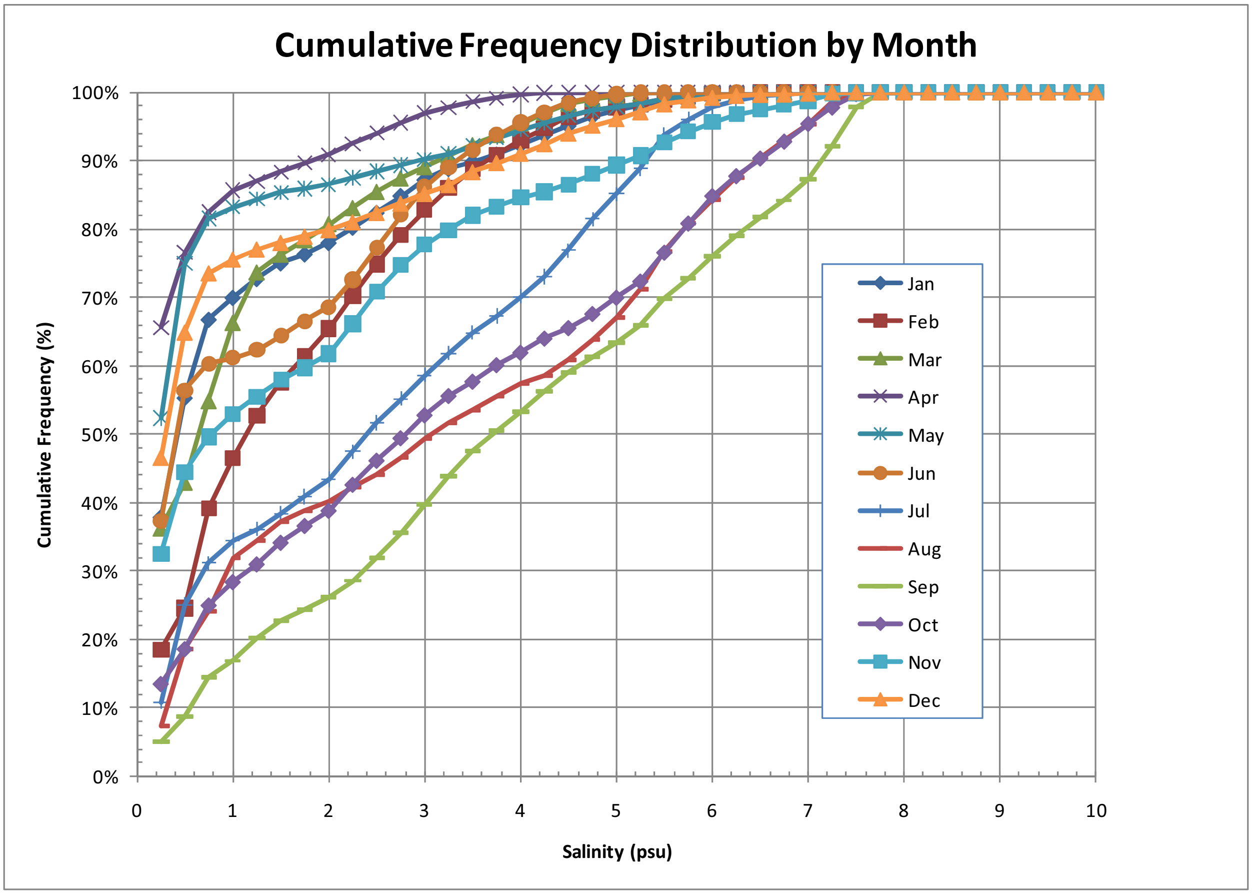

Figure 5-7. Cumulative frequency distributions for each month of the 10-yr record.

5.4 Continuous 10-yr Data Set Analysis

As noted in Section 5.1 there were a total of only 85,192 hrs of data in the 10-yr record of model predictions due to missing data values in the original USGS data records used. Since there are 87,672 hrs in the period 2000 through 2009 a total of 2,480 hrs were missing. In order to provide a continuous time series for subsequent analysis of cooling tower operation the missing values needed to be interpolated from the predictions. An analysis of the missing hours reveals that the largest gap extended for 739 hrs down to 60 1-hr gaps summarized in Table 5-5.

Table 5-5. Summary of data gaps in the 10-yr record.

Start Time	Gap Duration (hr)
8/3/03 15:00	739
6/9/04 23:00	324
6/10/03 10:00	167
7/4/08 0:00	154
7/1/05 19:00	88
4/15/05 8:00	78

Start Time	Gap Duration (hr)
9/20/05 5:00	53
5/28/02 14:00	44
7/23/06 1:00	41
7/27/06 4:00	41
12/17/00 23:00	35
7/17/06 21:00	24
7/22/06 0:00	24
7/25/06 3:00	24
7/19/06 23:00	23
7/26/06 4:00	23
7/21/06 1:00	22
7/16/06 20:00	14
7/18/06 22:00	13
7/16/06 7:00	12
12/15/00 21:00	11
4/14/05 19:00	11
12/14/00 22:00	9
8/1/05 14:00	9
7/15/06 20:00	9
7/17/06 11:00	9
9/6/02 21:00	8
9/24/07 20:00	8
Number of Gaps	
12	7
20	6
17	5
6	4
12	3
27	2
60	1

Since the total number of missing values is only 2.8% of the total hrs in 10 yrs the form of the interpolation would not likely affect overall distribution of salinity values. Therefore a simple linear interpolation was used to estimate the missing values. To check whether the interpolation affected the distribution, the statistical analyses used in previous sections was repeated. The statistical summary for the continuous entire 10-yr record is given in Table 5-6. The only differences from the results in Table 5-1 are a 0.01 psu increase in mean and 50th percentile values and a 0.01 psu drop in 90th percentile value, none of which are significant.

Table 5-6. Statistical summary for the continuous entire 10-yr record.

Period	Count (hrs)	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
2000-2009	87672	1.81	0.07	7.67	0.73	5.22

The statistical summary for each year of the continuous 10-yr record is shown in Table 5-7. The differences of the means compared to Table 5-3 vary from 0 psu in 2001 and 2008 up to a maximum of 0.10 psu in 2003. The largest difference in 2003 is due to the relatively large number of missing hours, greater than 900 hrs. The largest difference in the 50th percentile was also 0.10 psu and the largest difference in the 90th percentile was 0.18 psu, all occurring during 2003.

Table 5-7. Statistical summary for each year of the continuous 10-yr record.

Period	Count (hrs)	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
2000	8784	1.11	0.10	7.63	0.52	3.19
2001	8760	3.21	0.09	7.40	3.28	6.32
2002	8760	2.79	0.09	7.67	2.01	6.97
2003	8760	1.07	0.10	5.08	0.62	2.64
2004	8784	1.34	0.11	5.84	0.68	3.58
2005	8760	1.95	0.10	7.13	1.09	5.12
2006	8760	1.12	0.08	6.23	0.36	3.41
2007	8760	2.74	0.08	7.67	2.08	6.67
2008	8784	1.56	0.07	7.23	0.56	4.19
2009	8760	1.16	0.11	5.76	0.45	3.20

The statistical summary for each month of the continuous 10-yr record is shown in Table 5-8. The difference in the means compared to Table 5-4 vary from 0.00 psu for January, February, March and November up to a maximum of 0.11 psu for July, consistent with the most months with missing data summarized in Table 5-5. The largest difference for the 50th and 90th percentiles occurred in August, consistent with the largest gap in August.

Table 5-8. Statistical summary for each month of the continuous 10-yr record.

Month	Count (hrs)	Mean (psu)	Minimum (psu)	Maximum (psu)	50th Percentile (psu)	90th Percentile (psu)
Jan	7440	1.11	0.08	6.77	0.39	3.56
Feb	6792	1.59	0.11	6.96	1.09	3.65
Mar	7440	1.08	0.10	5.84	0.63	3.15
Apr	7200	0.51	0.08	4.51	0.13	1.80
May	7440	0.75	0.07	6.60	0.19	2.90
Jun	7200	1.17	0.10	6.07	0.35	3.26
Jul	7440	2.45	0.08	7.27	2.30	5.26
Aug	7440	3.14	0.09	7.55	2.76	6.37
Sep	7200	3.90	0.11	7.67	3.77	7.22
Oct	7440	3.14	0.11	7.66	2.79	6.49
Nov	7200	1.76	0.09	7.63	0.77	5.13
Dec	7440	1.06	0.09	7.26	0.29	3.81

6 CONCLUSIONS

An analysis was performed to estimate the variability of salinity at the intakes to IPEC on the River. Long-term (greater than a decade) data records of conductivity were identified for active USGS stations at West Point and Hastings that are located 9 mi upstream and 21 mi downstream of IPEC, respectively. In addition, a discontinued USGS station at Tomkins Cove, located 1 mi south of IPEC, was identified that had a shorter (4-yr) period of record. Since the Tomkins, station was relatively close to IPEC it was used as a proxy for salinity at the IPEC intakes.

A statistical analysis was performed on the hourly salinity data for each period of record for each station. Statistics, including mean, minimum, maximum, 50th and 90th percentile values, along with frequency and cumulative frequency distributions, were calculated. The analysis revealed a decrease in salinity from Hastings to Tomkins and from Tomkins to West Point, consistent with their locations moving upriver. Mean salinity at Hastings was 6.29 psu, Tomkins was 2.09 psu, and West Point was 0.79 psu, consistent with the order of the 90th percentile salinity values of 10.88 psu (Hastings), 4.96 psu (Tomkins) and 2.63 psu (West Point). Hastings and West Point showed the lowest mean and 90th percentile values in April, consistent with high freshwater discharge, and highest mean and 90th percentile values in September, consistent with low freshwater discharge. Tomkins, with a significantly shorter period of record, showed the lowest mean and 90th percentile values in January and the highest in August.

A correlation analysis was performed that related the salinity at Tomkins to salinities at West Point and Hastings. It was found that the West Point data was more highly correlated to Tomkins than Hastings was and thus used to estimate Tomkins salinity for the long-term decadal period. The model was improved at low salinities by forcing the Tomkins salinity to be equal to the West Point salinity when the Hastings salinity fell below 4.07 psu. This improvement had no effect on higher salinity predictions.

The decadal (2000-2009) salinity time series at IPEC (assumed equivalent to that at Tomkins) was generated to provide a long-term estimate of salinity under a variety of environmental conditions. This time series is consistent with the analysis period conducted for the extreme environmental conditions in support of the hydrothermal modeling at IPEC (Swanson et al., 2010).

The model results showed that salinities were typically higher in the summer and fall seasons, consistent with the observations at the USGS stations. Some years (2000, 2001, and 2006) showed extended periods of salinity exceeding 5 psu for three months with peaks exceeding 7 psu. There were also shorter periods when the salinity was near-zero (2000, 2001, and 2008), usually in the spring season. These variations are primarily due to fluctuations in freshwater entering the River, although there are occasional events (storm surge) that can transport salt from the ocean to the vicinity of the IPEC intake.

A statistical analysis was performed on the hourly-modeled salinity predictions at IPEC for the decadal period 2000 through 2009. The mean salinity over the entire period was 1.80 psu, the minimum 0.07 psu and the maximum 7.67 psu. The median, or 50th percentile, was 0.72 psu, indicating that the salinity distribution is not a normal distribution, but slightly biased to lower salinities. The 90th percentile salinity was 5.23 psu. Salinities between 0 and 0.25 psu were found to occur 30.62% of the time while salinities between 0.25 and 0.50 psu dropped to 12.29% of the time. The large number of low salinities is indicated by the cumulative frequency of occurrence that shows over 50% (54.78%) of the salinities were less than 1.00 psu.

The statistical summary of the 10-yr data set broken down by year showed that 2001 had the highest mean (3.21 psu) and highest median (3.28 psu), 2002 had the highest maximum (7.67 psu) and highest 90th percentile (6.90 psu). Salinities between 0 and 0.25 psu occurred between 12% of the time in 2000 and 42% in 2009 while salinities between 0.25 and 0.50 psu dropped dramatically for all years. The large number of low salinities was indicated by the cumulative frequency of occurrence that showed between 33% (in 2001) and 70% (in 2000) of the salinities are less than 1.00 psu.

The statistical summary of the 10-yr data set broken down by month showed that September had the highest mean (3.84 psu), highest maximum (7.67 psu), highest median (3.70 psu) and highest 90th percentile (7.16 psu). July, August, October and November had the next highest values after September. The winter and spring months had lower values with April the lowest of any month. Salinities between 0 and 0.25 psu varied throughout the year, with such low values occurring only 5% of the time in September and as high as 85% in April, directly related to the freshwater discharge to the River while salinities between 0.25 and 0.50 psu dropped dramatically for most months, excepting those with lowest salinities. The large number of low salinities is indicated by the cumulative frequency of occurrence that shows between 18% (in September) and 86% (in April) of the salinities are less than 1.00 psu.

The effect of using linear interpolation to fill the missing hours (2.8% of the total hours) is insignificant when viewed in the context of the 10-yr record as all statistical measures showed a maximum difference of only 0.01 psu when compared to the results of the non-filled data set. The individual years and months exhibited larger differences but were still relatively small.

7 REFERENCES

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