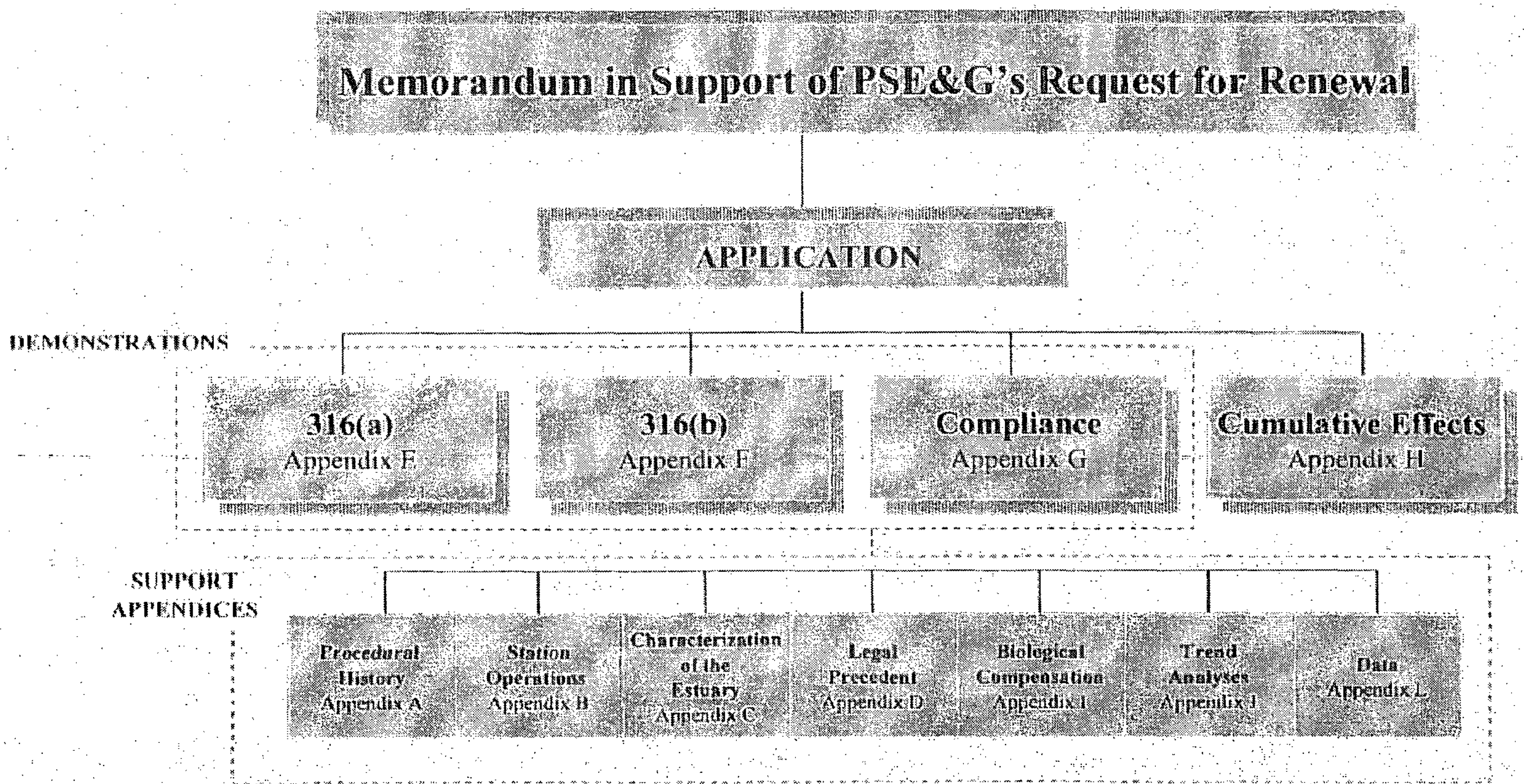
FOREWORD

This Appendix is one part of a larger submission by Public Service Electric and Gas Company (PSE&G) to the New Jersey Department of Environmental Protection (NJDEP). The submittal is in support of the renewal of the New Jersey Pollutant Discharge Elimination System (NJPDES) Permit for the Salem Generating Station (Station). The relationships amongst the several parts of the submittal are shown in the attached figure. The present Appendix is highlighted.

The submittal is built on seven Appendices (A, B, C, D, I, J, L) that provide the legal, regulatory, and factual basis for the Demonstrations. Three Demonstrations make up the bulk of the filing: the 316(a) Demonstration assessing the thermal discharge, the 316(b) Demonstration assessing the effects of Salem's cooling water intake, and the Demonstration of Compliance with the 1994 Permit. The Cumulative Effects Analysis assesses the potential for impacts on the indigenous community of the Delaware Estuary related to all stresses from the Station.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APPENDIX E

§316(a) DEMONSTRATION

SPONSOR: DR. CHARLES C. COUTANT
DR. E. ERIC ADAMS
PSE&G RENEWAL APPLICATION
SALEM GENERATING STATION
PERMIT NO. NJ0005622
4 MARCH 1999

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APPENDIX E
§316(a) VARIANCE DEMONSTRATION

SPONSORS: DR. CHARLES C. COUTANT
AND DR. ERIC E. ADAMS
PSE&G RENEWAL APPLICATION
SALEM GENERATING STATION
PERMIT NO. NJ0005622
4 MARCH 1999

APPENDIX E
§316(a) VARIANCE DEMONSTRATION

EXECUTIVE SUMMARY

Purpose

Appendix E presents PSE&G's Clean Water Act Section 316(a) Demonstration in support of its New Jersey Pollutant Discharge Elimination System (NJPDES) Permit Renewal Application requesting reissuance of its variance from otherwise applicable thermal effluent limitations under the New Jersey Department of Environmental Protection (NJDEP) Surface Water Quality Standards (NJAC 7:9B-1.14(c) 11) for the Salem Generating Station on the Delaware Estuary. In accordance with Section 316(a) of the Clean Water Act, the Demonstration is required to provide persuasive evidence that the Station's thermal discharge is "protective of the balanced, indigenous population" (BIP) or community (BIC) of the Delaware Estuary. The objective of this Demonstration is to satisfy all decision criteria for a Type III demonstration described in the Environmental Protection Agency's 1977 Draft Section 316(a) Technical Guidance. The Demonstration includes an extensive hydrothermal analysis of the Station's thermal plume to characterize potential thermal exposures of organisms in the Estuary, a predictive biothermal analysis using all available data on thermal requirements of aquatic species designated as representative and important (RIS), and a retrospective analysis of population abundance of RIS in the Estuary from pre-operation to the present. This is one of three companion Demonstrations in PSE&G's Permit Renewal Application, the others being the Clean Water Act Section 316(b) Demonstration (Appendix F) related to the impacts of Salem's cooling-water intake, and the Compliance Demonstration (Appendix G) related to specific conditions of the Station's existing NJPDES permit.

History

This 316(a) Demonstration reconfirms, through reanalysis and incorporation of the latest information, the conclusions drawn from a series of analyses performed during the past thirty years of the effects of the thermal component of Salem's discharge on aquatic resources. These analyses include those previously conducted for U.S. Atomic Energy Commission (AEC) project licensing (1966-1968), Delaware River Basin Commission (DRBC) project approval (1968-1970), AEC National Environmental Policy Act Impact Statement Process (1970-1973), Salem's first Section 316(a) Demonstration to EPA (1974), supplements to the initial 316(a) Demonstration (1975, 1978, 1979), NJDEP draft and final NJPDES permits (1990-1994), and DRBC's revised approval of Station operation (1995). In addition, the NJDEP contracted for a technical peer review and reanalysis of PSE&G's 316(a) and 316(b) Demonstrations (1986-1989). Each of these analyses has concluded that the Station's thermal discharge does not cause appreciable harm to aquatic populations or communities in the immediate discharge area, the broader region inclusive of the thermal plume or elsewhere in the Delaware Estuary. The NJDEP's contractor (Versar, Inc.) concluded in 1989 that biological effects from the Station's thermal discharge were "small and localized and not a major source of impact"

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and, therefore, the thermal discharge and plume "do not need to be reduced to protect the balanced, indigenous populations."

Presentation of Most Recent Information
The present Demonstration includes numerous and significant advances in both data and analytical techniques, while based solidly on prior information. First, thermal exposures to aquatic organisms potentially affected by Salem's thermal plume were quantified with the most sophisticated, comprehensive monitoring program ever performed and enhanced computer models. Monitoring characterized the size and shape of the thermal plume and measured actual temperatures and other environmental features of the Estuary. There was extensive enhancement and validation of computer models for hydrothermal analyses supported by the new monitoring data, improved plume modeling schemes to allow projections of plume characteristics under normal and extreme conditions of the environment and Station operations, and improved definition of natural environmental variability. The Station's thermal plume was compared to natural thermal plumes in summer from channels that drain marshes at ebb tide (Salem River and Alloway, Hope and Mad Horse Creeks).

Second, the predictions of potential biological effects related to the Station's thermal discharge were improved by including new biological data on thermal responses of organisms, development of confidence intervals for biological source information, and using new quantitative analysis techniques for evaluating organism survival while they transit the thermal plume. Retrospective evaluations of the BIP/BIC in the Estuary were augmented by several years of additional data on population status of RIS, additional analyses applying current fishery management stock assessment techniques, and new methods for analyzing the composition of fish assemblages in terms of species richness, density and turnover from pre-operational years to the present. Finally, the decision criteria for a 316(a) Demonstration described in the 1977 Draft Section 316(a) Technical Guidance were augmented by concepts included in EPA's recent (1998) Ecological Risk Assessment guidelines.

Conclusions
The expanded monitoring and analyses included in this Demonstration further support the conclusion that Salem's thermal discharge does not cause appreciable harm to the Delaware Estuary's balanced indigenous community of aquatic populations. The thermal and hydraulic characteristics of the Estuary near Salem have been characterized in greater detail than ever before by extensive monitoring and a suite of sophisticated and state-of-the-art numerical models to document the rapid dissipation of heat to levels generally tolerated by aquatic life. Beyond about 500 ft. from the point of the discharge, which is largely uninhabitable because of high discharge velocities, the temperatures in the plume are within the range of variation normally seen at marsh outlets to the Estuary. The overall characterization of the plume is essentially similar to previous submittals.

*

Even under extremely warm environmental conditions, most organisms would not show even local or short-duration damages under the conservative predictive evaluations. Based on reasonable worst-case evaluations, some other organisms, notably opossum shrimp, bay anchovy and juvenile weakfish, could be affected by passage through the Salem thermal plume for a short period in warm summers. However, examination of actual data from the Estuary shows that no biological species important to the ecosystem or human use has declined in abundance as a result of the Station's thermal discharge. To the contrary, most fish species are increasing in abundance, reflecting active compensation for any localized effects. No nuisance aquatic organisms have been stimulated. No species that structure the habitat for other aquatic life have been harmed. No migrations have been blocked. There are no detrimental impacts from the interactions of temperature and chemicals in the Estuary of concern to the NJDEP or DRBC. Because the current satisfactory status of RIS animals reflects interactions of all features of the environment, there have been no harmful cumulative impacts from all Station effects and other environmental factors. All criteria for a successful 316(a) Demonstration, including comparable criteria derived from EPA guidance for Environmental Risk Assessment, have been met.

Relationships to Other Parts of the Submittal
This appendix (Appendix E; 316(a) Variance Demonstration) relies on several other source documents in this submittal (Foreword). The regulatory requirements for a successful 316(a) Demonstration are further explained in Appendix A (Procedural History) and Appendix D (Legal Appendix). The history of previous similar analyses and their regulatory contexts is also described in these two appendices, as well as in this appendix. The Station, including the cooling water system and projected operation during future years of the requested permit, is described in detail in Appendix B (Description of the Station and Station Operating Conditions). The physical and biological ecosystem of the Delaware Estuary that is potentially affected by the thermal discharge is described in Appendix C (Ecosystem of the Delaware Estuary). Appendix C also includes attachments that provide detailed information on each of the RIS. Analyses of the composition of fish assemblages, conducted for both this Demonstration and the 316(b) Demonstration (effects of the Station's cooling-water intake structure), are described in Appendix F (316(b) Demonstration). Current understanding of biological compensation, the process by which populations normally adapt to detrimental effects, if any, is presented in Appendix I (Compensation). This is of largely hypothetical interest for the few thermal effects identified. Population trends of RIS spanning the years from before Salem began operation to the present are detailed in Appendix J (Trends Analysis for Delaware River Estuary Fish Populations). Some data used in the analyses presented in this Demonstration are provided in a separate appendix (Appendix L).

The results of the analyses in this appendix are considered in an evaluation of the cumulative effects of the Station that includes the many environmental factors affecting the BIP/BIC and RIS populations. This cumulative effects analysis is presented in Appendix H (Cumulative Effects).

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I. INTRODUCTION

Appendix E presents PSE&G's Section 316(a) variance demonstration (the Demonstration) for the Salem Generating Station (Salem or the Station). PSE&G shows in this Demonstration that it has satisfied the requirements for obtaining reissuance of its variance from otherwise applicable thermal effluent limitations developed by the New Jersey Department of Environmental Protection (NJDEP) in its Surface Water Quality Standards (NJAC 7.9B-1.14(c)(11), under the authority of Section 316(a) of the 1972 Clean Water Act (CWA) because the Station's thermal discharge is protective of the balanced indigenous population (BIP) of the Delaware Estuary.

Under Section 316(a) of the CWA, a permittee may obtain a variance upon establishing, to the satisfaction of the permitting agency, that its thermal discharge, combined with other potential impacts on the aquatic biota, will assure protection and propagation of the BIP in and on the receiving water body (EPA 1973). The concepts of BIP, or balanced indigenous community (BIC) as it is also called in the federal regulations [40 CFR 125.71(c)], and Section 316(a) variance requirements are more fully developed in Appendix D.

As discussed further in Appendix A, and in Sections II, V, and VI of Appendix E, this 316(a) Demonstration reconfirms, through reanalysis and incorporation of the latest information, the conclusions drawn from the numerous analyses of the thermal component of Salem's discharge performed over the past thirty years. The history of those analyses and their regulatory context are discussed in Section II.A below. Every analysis during the thirty-year period has concluded that the Station's discharge does not cause appreciable harm to aquatic populations or communities in the immediate discharge area, the broader region inclusive of the thermal plume created by the discharge, or elsewhere in the Delaware Estuary.

Section 316(a) does not include specific, formal standards for the format and content of a variance demonstration; however, draft USEPA regulatory guidance (EPA 1977 Draft Interagency 316(a) Technical Guidance Manual and Guide for Thermal Effects Sections of Nuclear Facilities Environmental Impact Statements) describes three alternative 316(a) variance demonstration types that can be considered:

- A Type I, or "absence of prior appreciable harm", demonstration involves a retrospective approach. The Type I retrospective approach allows an existing permittee to base its 316(a) variance request on completed field studies of thermal discharge impacts that have shown "no appreciable harm" in the past. Type I is intended for cases where the regulating agency already has significant knowledge with respect to the facility, and requires only moderate amounts of supplemental data.
- A Type II, or "representative important species" (RIS), demonstration involves a predictive approach. It calls for predictive analyses of potential impacts to the BIP related to the permittee's thermal discharge. A Type II demonstration can

apply to either new or existing discharge sources. A Type II demonstration for a Section 316(a) variance may be employed when the regulatory authority decides that the nature of the discharge warrants more detailed evaluation beyond that provided by a Type I demonstration. The predictive analyses are usually based on scientific literature concerning laboratory studies and evaluations of the biology, ecology and physiology of the RIS. The premise of a RIS demonstration is that detailed quantitative analysis of data on selected representative aquatic species properly substitutes for full-scale studies on all species present in the receiving water body. A Type II demonstration assesses the potential effects of a permittee's thermal discharge over a range of projected facility operating conditions. In addition to information on the RIS, Type II demonstrations include qualitative analyses of broader aspects of the ecosystem.

- A Type III, or "alternative", demonstration may be utilized on a case-specific basis. Neither Section 316(a) of the Clean Water Act nor the federal regulations, nor related agency guidance specifies the precise parameters of a Type III demonstration. Rather, the scope and conditions of a Type III demonstration are designed on a site-specific basis to meet the circumstances presented by a given case, consistent with the criteria of Section 316(a). A Type III demonstration is usually a combination of Types I and II, and thus may include both retrospective and predictive components.

This Demonstration is a Type III demonstration. It presents available empirical data, including water body-wide monitoring data and extensive results from hydrothermal and biological modeling studies, buttressed by a variety of predictive analyses used to assess the potential biological impacts to RIS of the Station's thermal plume under projected Station operating conditions. Figure I-1 provides a map of the Section 316(a) process followed for this Type III demonstration.

At each step of both the retrospective and predictive analyses undertaken by PSE&G, conservative assumptions were applied to ensure that the results of this Demonstration fully consider the range of "reasonable worst case" conditions of Station operation and thermal discharge impact. Because of this conservative bias applied throughout, this Demonstration provides analyses of potential operating conditions and thermal discharge impacts that exceed expectations of actual occurrence.

The remaining sections of Appendix E (Sections II through VI) present the history of the various regulatory reviews of the Station's thermal discharge, and the specific scientific information upon which this Demonstration is based. The content of each Section of Appendix E is summarized below.

Section II briefly summarizes the regulatory review history of the Station's thermal plume and the effects of the plume on the Estuary's biota. This includes the previously cited reviews by the DRBC, AEC, USEPA, and NJDEP. A more detailed discussion of the regulatory history of the Salem Station's thermal plume is provided in Appendix A.

Section II also discusses in brief the legal and regulatory standards applicable to a Section 316(a) variance determination. A more detailed discussion of these standards is provided in Appendix D.

Section III provides a brief description of the Station, including its location, design, and operational characteristics. A more detailed Station description is provided in Appendix B.

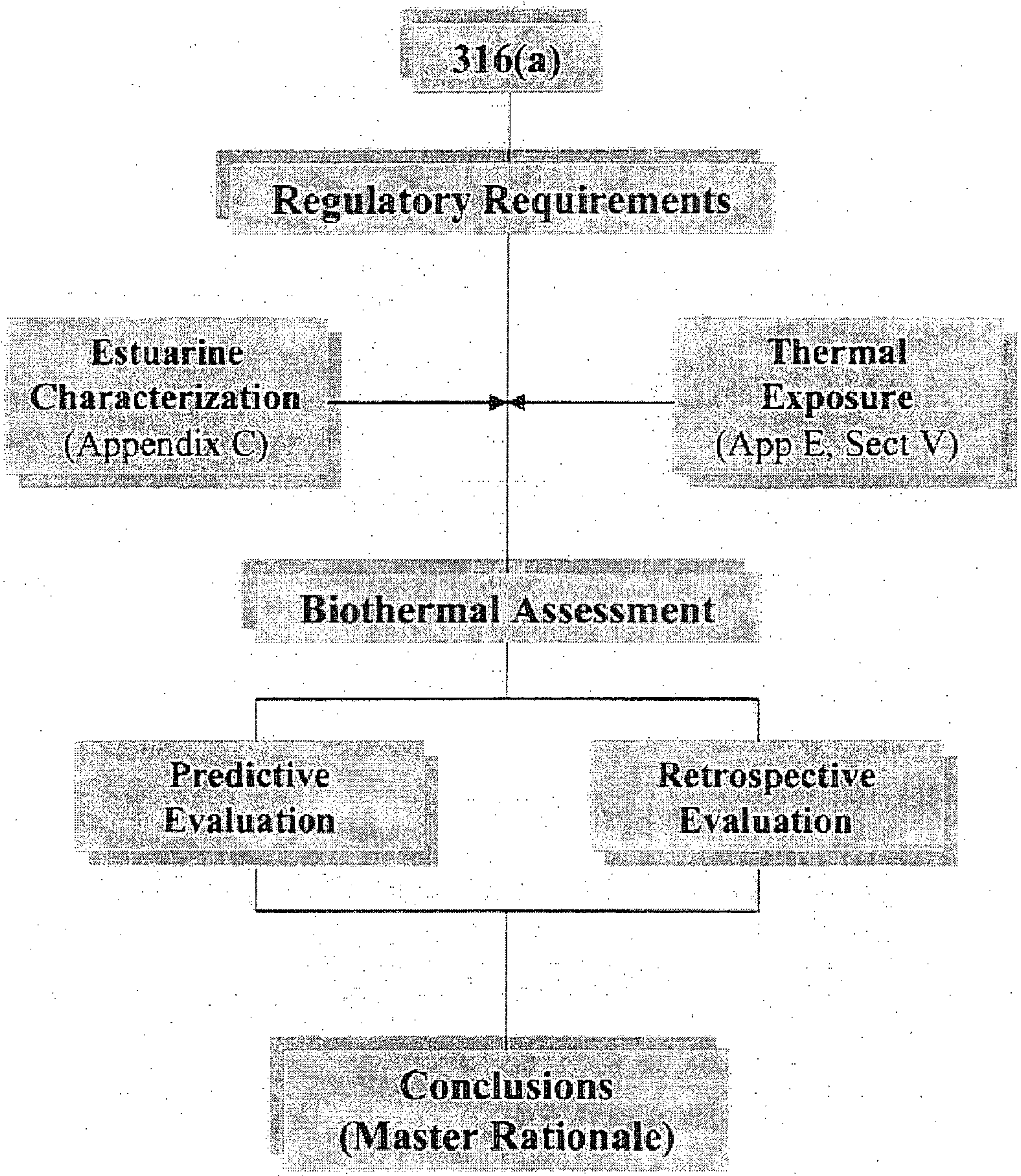
Section IV provides a summary description of the Delaware Estuary ecosystem, which is set out in more detail in Appendix C.

Section V characterizes the Station's thermal plume. It includes a description of hydrothermal monitoring programs, a discussion of prior characterizations of the thermal plume, a description of the hydrothermal modeling methods used in support of this Demonstration, and the results of those modeling efforts.

The hydrothermal monitoring and modeling methods used to characterize the thermal plume for this Demonstration are supported by the latest scientific knowledge available. Furthermore, a conservative approach was adopted for the hydrothermal modeling effort to address the inherent uncertainties associated with predicting hydrothermal plume characteristics.

Section VI presents the biothermal assessment of the Station's thermal plume. It includes the following components: a history of past biothermal assessments of the Station's plume; a discussion of biothermal assessment methodology; a discussion of temperature-related factors affecting aquatic communities; and a discussion of the Type III assessment approach including decision criteria based on EPA draft guidance utilized for this Demonstration. Section VI also discusses the continuing applicability of the Station's prior Section 316(a) variance to the thermal discharge and the nature of the aquatic community, the application of current best scientific methods for impact assessment, and the latest knowledge about biothermal effects of the Station's discharge.

The biothermal assessment concludes that the effects of the thermal plume do not cause appreciable harm to the BIC in the Estuary. Furthermore, the Station's discharge does not result in excessive heat shock, growth of nuisance organisms, impairment of zones of passage or reproduction, adverse impact on threatened or endangered species, or destruction of unique habitat. The extensive additional evidence developed for this Demonstration shows that the premises underlying the 1994 NJDEP determination to grant a 316(a) variance for the Station are essentially unchanged. This premise is more fully developed in Appendix D.



E Figure I-1. Schematic of the 316(a) Demonstration presentation.
Starting with Regulatory Requirements, fed by Estuary and Thermal Exposure information, two parallel assessment methodologies lead to the Master Rationale (conclusions).

II. REGULATORY BACKGROUND AND STANDARDS FOR A §316(A) DECISION

II.A. Salem's §316(a) Regulatory History

II.A.1. Introduction

The history of regulatory agency consideration of the thermal discharge at the Station is more than three decades long. Throughout this period, Station operations have remained essentially the same. PSE&G has demonstrated, to the United States Atomic Energy Commission (AEC), the Delaware River Basin Commission (DRBC), the United States Environmental Protection Agency (EPA), and later to the New Jersey Department of Environmental Protection (NJDEP), that the thermal discharge for the once-through cooling water system at the Station adequately assures the protection and propagation of a balanced, indigenous population (BIP) or community (BIC) in the Delaware Estuary.

II.A.2. Pre-Clean Water Act Permitting

II.A.2.a. United States Atomic Energy Commission Construction Licensing

In December 1966, PSE&G applied to the AEC for a permit to construct a nuclear generating station. In January 1968, PSE&G amended its application to name Artificial Island as the location at which Salem would be built. The AEC authorized construction of the Station in September 1968. As a condition of its authorization, the AEC required PSE&G to initiate baseline environmental monitoring of the Estuary.

II.A.2.b. 1968 Application for Delaware River Basin Commission Project Approval

In January 1968, contemporaneous with its application to the AEC to construct the Station, PSE&G applied to the DRBC for project approval of the Station's cooling-water system. PSE&G retained Pritchard-Carpenter Consultants to perform thermal discharge studies in connection with the design of the cooling-water system, to recommend a discharge configuration, and to estimate the dimensions of the thermal plume associated with the recommended configuration. PSE&G also retained Ichthyological Associates, Inc. (IA) to perform detailed baseline biological monitoring surveys and to assess the potential effects of the Station.

The DRBC thoroughly analyzed the proposed operation of the Station's cooling water system and its potential effects on the Estuary, and on October 27, 1970, approved PSE&G's application and issued Docket No. D-68-20 CP (the Salem Docket) for the Station. The DRBC concluded that "[t]he proposed project will not have any adverse effect on the water resources of the [Delaware] basin, nor will it substantially impair or conflict with the [DRBC's] Comprehensive Plan." Based on its determinations, the DRBC established a heat dissipation area (HDA) extending to a one-mile radius from the ends of the circulating water discharge pipes in order to accommodate the thermal plume, consistent with then-applicable DRBC Water Quality Regulations, Zone 5 standards for temperature (DRBC 1968).

II.A.2.c. United States Atomic Energy Commission Environmental Impact Statement Process

The National Environmental Policy Act of 1969 (NEPA) requires that Federal agencies include, in all reports or recommendations on proposals for major federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on the environmental impacts, unavoidable adverse effects, alternatives, and any irreversible or irretrievable commitments of resources involved with the proposed action. This detailed statement is known as an Environmental Impact Statement (EIS). In 1969, the AEC began preparation of an EIS that included an evaluation of the environmental effects of the Station's thermal discharge. In connection with the EIS process, in 1971 PSE&G submitted to AEC an Environmental Report (Salem Nuclear Generating Station, Units 1 And 2, Environmental Report, Operating License Stage, USAEC Docket Nos. 50-272, 50-311, 1971) and a supplement thereto providing information on conditions in the Estuary in the vicinity of the Station, the characteristics of the thermal discharge, and predicted environmental effects.

In April 1973, the AEC issued a final EIS which concluded that the Station's operation would not have a significant impact on the aquatic environment in the Estuary. Based in part on the EIS findings, the U.S. Nuclear Regulatory Commission (USNRC), successor agency to the AEC, issued authorization for Unit 1 to proceed to full-power operation on 6 April 1977, and subsequently issued a full-power operating license for Salem Unit 2 on 20 May 1981.

II.A.2.d. United States Army Corps of Engineers Licensing: 1970 Application under the Rivers and Harbors Act of 1899

In the late 1960s, after PSE&G had applied to the AEC for project approval, the United States Army Corps of Engineers (ACE) began to implement a nationwide program to permit and regulate point-source discharges of pollutants, including heat, into navigable waters, pursuant to authority asserted under the Rivers and Harbors Act of 1899. PSE&G applied to ACE in 1970 for a permit to discharge pollutants, including heat, from the Station.

In 1972, while the Station's application to the ACE for a discharge permit was pending, the Federal Water Pollution Control Act (later the Clean Water Act (CWA)), was enacted. The CWA requires that all point-source dischargers obtain a National Pollutant Discharge Elimination System (NPDES) permit from EPA or from a state agency with delegated permitting authority.

II.A.3. National Pollutant Discharge Elimination System Proceedings For Salem

Following enactment of the CWA, the primary means for regulating thermal discharges shifted to the NPDES permitting process, administered initially by EPA and later by NJDEP after it was delegated permitting authority by EPA in 1982. In 1972, pursuant to

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the CWA, EPA assumed jurisdiction over the permit application that PSE&G had made to ACE the year before. A draft NPDES permit for Salem was issued by EPA on 24 July 1974; PSE&G submitted a Type II demonstration in support of a Section 316(a) variance on 11 November 1974. EPA issued Salem a NPDES permit on 24 February 1975, effective 31 March 1975. PSE&G challenged the thermal effluent limitations in the final permit. In resolving PSE&G's challenge, EPA deferred a decision on PSE&G's Section 316(a) variance request pending PSE&G's submittal of its CWA Section 316(b) Demonstration pertaining to the Station's intake. In addition, compliance with both the EPA thermal effluent limitations and the DRBC thermal water quality standards was stayed; the interim thermal limitations in the 1975 permit remained the operative limits through EPA's issuance of the second NPDES permit for Salem in 1981. NJDEP subsequently issued a NJPDES permit for the Station in 1985; the applicable thermal limitations remained essentially the same through NJDEP's issuance of the 1994 Permit. Those limitations included a maximum daily discharge temperature limit of 110°F (winter), a maximum daily discharge delta-temperature (ΔT) of 27.5°F, and a maximum daily two-unit waste heat limit of 30,600 MBtu/hr.

II.A.3.a. Salem's Section 316(a) Demonstration

Based on an ongoing dialogue with EPA and in response to data requests, PSE&G filed three supplements to its initial November 1974 Section 316(a) Demonstration. These supplements, submitted in 1975, 1978, and 1979, provided new information concerning the potential biothermal effects of the Station's thermal discharge. PSE&G also performed pre-operational and post-operational ecological monitoring in the Estuary in the vicinity of the Station and submitted the results of these studies to appropriate regulatory agencies. The monitoring included the baseline ecological monitoring required by AEC, the 1977-1978 Thermal Modeling Program (One-Unit Operation), and the 1982-1985 Thermal Modeling Program (Two-Unit Operation). In 1982, NJDEP assumed primary responsibility for the NPDES program and the Section 316(a) permit variance requested for Salem.

In April 1986, NJDEP contracted with Martin Marietta Environmental Systems, which later became Versar, Inc. (Versar), to conduct a technical review of PSE&G's Section 316(a) and Section 316(b) Demonstrations. (A Section 316(b) demonstration had been submitted by PSE&G in 1984 in connection with the Station's 1985 NJPDES permit). In 1989, Versar issued a revised report, which concluded that biological effects from the Station's thermal discharge "were small and localized and not a major source of impact" and, therefore, "do not need to be reduced to protect the balanced, indigenous populations." Nonetheless, Versar further concluded that the Station's intake had the potential to cause a long-term adverse environmental impact on five RIS (weakfish, white perch, spot, bay anchovy, and opossum shrimp), and therefore recommended that PSE&G's request for a thermal variance be denied (Versar 1989). RIS are species which are representative, in terms of their biological needs, of a balanced indigenous community or population of shellfish, fish, and wildlife in the body of water into which the discharge is made (40 CFR §125.71(b)).

II.A.3.b. New Jersey Department of Environmental Protection 1990 Draft Permit For Salem Station

In October 1990, NJDEP issued a draft NJPDES Permit (1990 Draft Permit) that proposed, *inter alia*, (1) denying the requested Section 316(a) variance, and (2) imposing thermal discharge limitations that would have required immediate shutdown pending retrofitting for closed-cycle cooling. The proposed denial of a Section 316(a) variance was based on NJDEP's concerns regarding the potential environmental effects of Salem's intake on the five RIS identified by Versar rather than evidence of any environmental effects of the Station's thermal discharge.

Numerous parties, including EPA, submitted comments on the 1990 Draft Permit. PSE&G submitted extensive comments in 1991, including new studies of the thermal plume and a new biothermal assessment based on the results of these plume studies, which concluded, as had all previous studies, that the thermal discharge did not have an adverse impact on aquatic populations in the Estuary. PSE&G's 1991 Comments also included a detailed evaluation of fish abundance trends for RIS utilizing data from field-sampling programs in the Estuary and commercial fisheries data from the period 1966-1990. The data indicated that the trends of abundance for relevant life stages of each of the RIS were either stable or increasing, providing further evidence that the operation of the Station did not have an adverse impact on aquatic life.

II.A.3.c. New Jersey Department of Environmental Protection 1993 Draft NJPDES Permit and 1994 Final NJPDES Permit for Salem Station

In June 1993, NJDEP issued for public comment a new Draft Permit (1993 Draft Permit) that: 1) proposed the Station continue to operate with a once-through cooling system; (2) granted the Station a Section 316(a) variance; and (3) imposed (with certain modifications by NJDEP) as special conditions measures proposed by PSE&G in a March 1993 Permit Renewal Application Supplement, which addressed potential effects of the Station's intake.

On 20 July 1994, NJDEP issued the Final Permit (the Permit) for the Station. NJDEP made certain modifications from the 1993 Draft Permit in response to comments submitted by EPA, PSE&G, other environmental resource agencies, and various environmental groups. Based on the voluminous record of evidence regarding the thermal plume and its potential biological effects, NJDEP concluded that the continued operation of the Station in accordance with the Permit terms "would ensure the continued protection and propagation of the balanced indigenous population of aquatic life" in the Estuary. It therefore granted the Station a Section 316(a) variance and imposed the same temperature and heat limitations for the Station's discharge that had been imposed by the previous Salem NJPDES permit. EPA later favorably reviewed the 1994 Permit, and remaining disputes with other parties interested in the Permit were resolved.

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II.A.4. Delaware River Basin Commission 1995 Docket Approval

On 30 June 1995 PSE&G submitted an application to the DRBC for approval to revise the DRBC Salem Docket. In the application, PSE&G requested a revision of the Salem Docket Heat Dissipation Area (HDA) and other revisions that would incorporate into the Docket certain requirements of the 1994 NJPDES Permit.

On 27 September 1995, DRBC approved the requested revisions (subject to USNRC and NJPDES conditions), stating that NJPDES permitting requirements supersede the revision approval "insofar as more stringent criteria are imposed." The Revised DRBC Salem Docket approval explicitly recognized in its findings the procedural history of Salem's NJPDES permitting and PSE&G's Section 316(a) Demonstration, and stated that the data collection and analyses performed fully confirmed DRBC's earlier determinations, supported NJDEP's Section 316(a) variance and 316(b) determinations, and ensured protection of all designated uses for Zone 5 of the Delaware River as specified in the DRBC Water Quality Regulations.

II.A.5. Implementation of 1994 New Jersey Pollutant Discharge Elimination System Permit Special Conditions Requirements and Salem's 1999 Permit Application

As part of the Special Conditions of the 1994 Permit, PSE&G was required to develop and implement a comprehensive thermal monitoring program (TMP) as a component of a biological monitoring program. In 1994, PSE&G developed a thermal monitoring program (the Original TMP) as a portion of the Station's Biological Monitoring Work Plan (BMWP) that was reviewed by the Monitoring Advisory Committee (MAC) and approved by NJDEP in 1995. The MAC, established by permit requirement, is a group of independent scientists assembled to review and provide advice related to the Salem monitoring programs. Because of a prolonged Station outage that extended until May 1998, PSE&G was unable to implement the Original TMP. Consequently, PSE&G developed a Modified Thermal Monitoring Program (Modified TMP) which was also reviewed by the MAC and approved by the NJDEP. The results of the Modified TMP are presented within this Appendix (Section V.D.2).

II.B. Legal and Regulatory Standards for a Section 316(a) Variance

II.B.1. Basic Standards Applicable to a Section 316(a) Variance Demonstration

Section 316(a) of the CWA, together with the implementing regulations, guidance, and precedent construing this statutory provision, permits the owner or operator of a point-source discharge to demonstrate that otherwise applicable effluent limitations on the thermal discharge are more stringent than necessary to assure the protection and propagation of a balanced, indigenous population[1] of shellfish, fish, and wildlife in and on the receiving water body. If the owner or operator makes this showing, permit limitations with respect to the thermal component of the source's discharge shall take into account the permittee's demonstration that the interaction of the discharge's thermal component with other pollutants will assure the protection and propagation of the BIP in and on the receiving body of water.[2]

The alternative effluent limitations issued in connection with a Section 316(a) variance preempt any otherwise applicable thermal limitations, whether based on state water quality or other standards. Among the types of effluent limitations for a given thermal discharge that may be determined to be unnecessarily stringent under a Section 316(a) variance request are discharge temperature standards, discharge zones, flow limits, receiving body water temperatures, and technology-based or industry-based limitations.

II.B.2. Burden of Proof

A Section 316(a) variance can be based upon satisfaction of any of the following requirements: (1) the applicant establishes, based on a predictive showing, that the otherwise applicable effluent limitations are unnecessarily stringent for the protection and propagation of an aquatic BIP and the permittee can provide reasonable assurance that the variance requested is protective of a balanced population of aquatic life in the receiving body of water (a "predictive" demonstration); (2) in the case of an operating facility, the applicant establishes that an existing thermal discharge has not previously caused appreciable harm to the BIP and that there have been no material unfavorable changes in the thermal discharge, or in the potentially affected populations, or in any knowledge concerning effects, and where a variance renewal is sought, that no other circumstances are present that might justify nonrenewal (a "retrospective" demonstration); or (3) a combination of (1) and (2) above, as developed on a case-specific basis (40 CFR §125.73; USEPA 1977; USEPA 1975; USEPA 1974). If an applicant satisfactorily demonstrates that it has met any of those Section 316(a) requirements, a thermal effluent limitation variance shall be granted.

The applicant for a Section 316(a) variance bears the burden of proof on these issues. The applicant must provide a reasonable assurance that the BIP will be protected, but need not prove this protection to a mathematical certainty. However, if there is a lack of critical information so as to preclude a reasonable assurance, the applicant's burden has not been met (USEPA 1974). In the case of a Section 316(a) variance renewal, the renewal will include the original terms of variance from thermal effluent limitation standards if there have been no material intervening changes in relevant facts or applicable law, or other compelling justification for a change in terms.

II.B.2.a. Showing of Reasonable Assurance of Protection of the Balanced Indigenous Population (Predictive Demonstration)

In a predictive demonstration, the applicant must show that a discharge will adequately ensure the protection of RIS. Pursuant to the regulations, RIS are species that are representative, in terms of their biological needs, of a balanced indigenous community of shellfish, fish and wildlife in and on the water body. RIS may include: commercially or recreationally valuable species; threatened or endangered species; species that are critical to the structure and function of the ecological system; species that are potentially capable of becoming localized nuisance species; species vital to the food chain; or species that are representative of the thermal requirements of species other than themselves.

In addition, the interaction of the thermal component of the discharge with other impacts—positive and negative—is taken into account. Negative impacts to be considered include the interaction of heat and other pollutants or stresses present in the Estuary. Positive factors include reduction in other pollutants or in other stresses and the benefits of conservation and restoration measures to relevant populations.

II.B.2.b. No Prior Appreciable Harm (Retrospective Demonstration)

In the case of an existing source, a permittee may obtain a Section 316(a) variance upon showing that "no prior appreciable harm" (NPAH) has resulted from an existing thermal discharge and that there have been no material adverse changes in relevant circumstances that would negate the inference that the absence of appreciable harm will continue (40 CFR §125.73(c)). A NPAH demonstration must show either: (1) that no appreciable harm has resulted from the thermal component of the discharge, taking into account the interaction of that thermal component with other pollutants and the additive effect of other thermal sources on the BIP; or (2) if previous harm occurred as a result of the discharge, the desired alternative effluent limitations sought by the applicant as a variance (or appropriate modifications thereof) will nevertheless assure the protection and propagation of a BIP.

There is no universally applicable, precise formulation of the NPAH standard against which to measure the impact of past facility operations. It is clear, however, that harm to individual organisms, in the absence of more extensive harm to populations, community or habitat, is not considered "appreciable harm." The applicant must provide support for a NPAH demonstration through laboratory or field sampling data, modeling, statistical analyses or other sources of evidence. Examples of factors considered in NPAH determinations include a demonstration of the absence of such phenomena as:

- Substantial increase in abundance or distribution of any nuisance species or heat-tolerant community not representative of the highest community development achievable in receiving waters of comparable quality.
- Substantial decrease of indigenous species, other than nuisance species.
- Changes in community structure to resemble a simpler successional stage than is natural for the locality and season in question.
- Unaesthetic appearance, odor, or taste of the receiving body of water.
- Elimination of an established or potential economic or recreational use of the receiving body of water.
- Reduction of the successful completion of life cycles of indigenous species, including those of migratory species.
- Substantial reduction of community heterogeneity or trophic structure.

As indicated by this definition, not every change in flora and fauna is considered "appreciable harm." Moreover, it is not necessary for the applicant to show that every species that would occur under optimal conditions is present, as long as it demonstrates that the community as a whole, and all major components thereof, are intact.

In determining whether or not "prior appreciable harm" has occurred, the permitting agency considers the length of time the applicant has been discharging, the nature of the discharge, and the condition of the water body receiving the discharge. Also, information about the effects of thermal discharge from past operations can serve as the basis for a demonstration of NPAH if there have been no material adverse changes in the nature of the discharge or in the aquatic population.

ENDNOTES

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[1] A biological "population" or "community" is an organized unit to the extent that it has characteristics additional to its individual and population components, and functions as a unit through coupled metabolic transformations. Each population has not only a definite functional unity with characteristic trophic structures and patterns of energy flow, but also a compositional unity in that certain species are likely to occur together.

A "balanced, indigenous population" (BIP) or "balanced, indigenous community" (BIC) typically is characterized by diversity at all trophic levels: stratification, periodicity, metabolism, succession, and development within the limit of natural noncatastrophic conditions; the capacity to sustain itself through cyclic seasonal changes; the presence of necessary food-chain species; and a lack of domination by pollution-tolerant species.

Such a population or community may include historically non-native species introduced in connection with a program of wildlife management, and species whose presence or abundance results from substantial and irreversible environmental modifications. Normally, however, such a community will not include the following populations or species: those resulting from the introduction of pollutants; those introduced and maintained in residence as a result of habitat destruction by human activities; or those that have colonized or established themselves at the expense of endemic communities and are beyond the limit of management intent. Moreover, the population considered in the BIP evaluation is not the local community viewed in isolation, but rather is the entire integrated biological community, of which the immediate and local community may form a relatively small part.

[2] The BIP is adequately protected if the cumulative impact of the thermal discharge, together with all other significant impacts, both positive and negative, is not significantly deleterious to the structure and sustainability of the indigenous biotic community. Under Section 316(a), a thermal discharge will be found "protective" of the BIP if it does not increase undesirable heat-tolerant or other undesirable nonindigenous species to the detriment of the existing community structure and its constituent populations, or otherwise significantly impair the character of and balance among indigenous populations. Moreover, the determination of the significance of a discharge requires that the discharge be compared to other causes of mortality. A discharge will not be considered significant where it poses no greater risk to a population than do other stresses in the natural environment.

III. SALEM STATION

This section of Appendix E describes the Salem Station, a two-unit pressurized water reactor (PWR) nuclear generating facility with a combustion turbine for emergency and peaking power. This section provides a summary description of the Station's location, its components, and its operational characteristics, focusing on those facts most pertinent to the 316(a) Demonstration. Appendix B of this submittal describes the Station in greater detail.

III.A. Location and Site Description

The Salem Generating Station is located in Lower Alloways Creek Township, Salem County, New Jersey, at River Mile 50 on the Delaware River Estuary (the Estuary). Located on a peninsula known as Artificial Island, the Station is bordered by the Estuary on two sides and by extensive marshes and uplands on the other two sides. The Station is on the eastern, or New Jersey, side of the Estuary. It withdraws water from the Estuary for cooling and discharges heated water back into the Estuary.

The Salem Station occupies 220 acres of land and the adjacent Hope Creek Station occupies another 153 acres, with an additional 367 acres of land uncommitted. Land adjacent to the Stations is zoned for industrial and residential/agricultural use, but its wetlands classification restricts development.

In addition to the generating station itself, the Salem site includes associated buildings and structures, an electrical switchyard, parking areas, roads, and equipment storage areas. Riprap and bulkheads protect the shoreline from erosion.

The Estuary is approximately 2.5 miles wide in the vicinity of the Station. Tidal flow past the Station is approximately 400,000 cubic feet per second, or 259,000 million gallons per day.

III.B. Station Description

III.B.1. Design and Electric Rating

The Station consists of two essentially identical Units (1 and 2). They are Westinghouse PWRs, each with a thermal rating of 3,423 megawatts thermal (MWt). The Unit 1 and 2 turbines are rated at a gross output of 1,162 megawatts electric (MWe) per Unit. They are designed to operate continuously at the full thermal power rating as base-loaded electrical generating units.

The Station's generating units were proposed in 1966, and are licensed by the Nuclear Regulatory Commission (USNRC) to operate within specified license conditions. Construction licenses for Units 1 and 2 were issued by the U.S. Atomic Energy Commission (USAEC) on 25 September 1968 and operating licenses were issued on 13 August 1976 and 18 April 1980, respectively. Unit 1 began commercial operation in 1977 and has a license to operate through 30 June 2017. Unit 2 began operation in 1981 and has a license to operate through 13 October 2021.

Electricity at Salem is generated by a steam cycle (Figure III-1). The essential components of this cycle are the reactor (to make heat to produce high-pressure steam), steam generators, several steam turbines (to convert moving steam to mechanical motion), generators (to convert the motion of turning turbines into electricity), condensers (to condense the steam as it leaves the turbines), and pumps and piping for water to return to the steam generators. Heat is released to the environment, the subject of the 316(a) Demonstration, primarily in estuary water used to cool the condensers.

In this steam cycle, water contained in a closed loop is pumped at high pressure and temperature through each reactor. Each reactor has four steam generators where the heat from the reactor creates high-pressure steam. The steam leaves the steam generators through pipes to the Station's turbine system; each unit has a main high-pressure turbine plus three low-pressure turbines. Having given up much of its energy moving through the turbines, the steam next travels from the turbines to a condenser. Each Unit possesses a main condenser, inside which the circulating water from the Estuary transits through tubes independent of the feed water system. The Circulating Water System (CWS) provides relatively cool water (from the Estuary), which is pumped from the intake structure to the condensers, and through the tubes. The steam in the condenser cools, condenses, and is pumped to the steam generators as feed water to repeat the cycle. After CWS water passes through the condenser tubes, it is discharged to the Estuary. The CWS is discussed in more detail below and in Appendix B.

Estuary water is also used to remove heat associated with the Service Water System (SWS). The SWS draws water from the Estuary some 400 feet north of the CWS intake structure, using it to cool various heat exchangers and equipment before it is returned to the Estuary via the CWS discharge pipes. The combined discharge of the CWS and SWS is located approximately 500 feet from shore at a depth of about 30 feet. The SWS is discussed in more detail below and in Appendix B.

III.B.2. Circulating Water System and Discharge

III.B.2.a. Pumps

The CWS intake structure for both units is located at the southwestern side of the site, and consists of 12 separate intake bays containing ice barriers, trash racks, traveling screens, and a fish return structure. Each of the twelve intake bays serves a circulating water pump, with six pumps (and bays) servicing each of the two units.

Each of the twelve pumps is an axial-flow Worthington Corporation HIFLO circulating water pump. Total design flow is 1,110,000 gpm through each unit with individual pump design ratings of 185,000 gallons per minute (gpm) at 27 feet total developed head (TDH). However, the average flow per pump is below this design value. Each pump discharges water into an individual 84-inch line for delivery to the main condenser waterboxes.

The main condensers are designed to remove residual heat remaining in the steam and dissipate that heat to the environment. Each unit's condenser contains three interconnected shells. Each shell supports one of the unit's three low-pressure turbines. Each shell is divided into two waterboxes, which are supplied with cooling water from a single pump and piping system (six per unit, twelve total for the Station; Figure III-2). The circulating water passes through the waterboxes to remove heat and is discharged through a network of piping directly to the Estuary.

The six discharge flows from each unit converge into three 120-inch (10-foot) diameter discharge pipes (six total for the Station). Transit time for cooling water from the condenser to the Estuary varies from about two minutes (two pumps operating per discharge pipe) to about seven minutes (one pump operating per discharge pipe). Each discharge pipe has a slightly different length and hence a different transit time. The pumps and piping are designed to discharge water to the Estuary at a velocity of 10.5 ft/sec at a depth of 31 feet below the surface at mean low tide.

III.B.2.b. Discharge Location and Design

The six 120-inch discharge pipes (three from each unit) run along the riverbed from the shoreline toward the middle of the Estuary, and are buried for most of their length. The pipes run for a distance of approximately 500 feet from the Station bulkhead, nearly directly westward beneath the Estuary. At their western end, the pipes discharge nearly horizontally into the Estuary, perpendicular to the dominant flow. West of the discharge point is a rock apron, and beyond that is a dredged area. The outfalls through which the thermal discharge occurs are designated Discharge Serial Numbers (DSN) 481 - 486.

Details of the discharge structure design and present configuration are presented in Exhibit E-1-4.

Features of the discharge that minimize environmental impacts were summarized in a previous filing (DRBC Docket 1970) by Dr. Edward Raney of Cornell University. As an expert in aquatic biology, Dr. Raney testified about the results of field studies, performed under his direction, on the anticipated effects of the Station's discharge. These studies investigated the spatial and temporal characteristics of aquatic life in the Estuary in the vicinity of the Station. Among his conclusions were the following: (1) the design configuration selected was the best available for the site (Ichthyological Associates 1969); (2) the submerged offshore location of the Station's proposed discharge would induce rapid mixing and thereby minimize the zone of elevated temperatures in the discharge plume (DRBC 1969); (3) the proposed offshore location of the Station's discharge would be in an area of dynamic tidal currents and salinity (DRBC 1969); and (4) the thermal plume would not block migration of shad, striped bass, or other migratory fish (DRBC 1969).

III.B.3. Service Water System and Discharge

The Service Water System (SWS) is a safety-related cooling water system that supplies a dependable, continuous flow of cooling water (under normal and emergency conditions) to the nuclear and turbine area heat exchangers. Service Water (SW) is withdrawn from the Estuary through an intake located approximately 400 feet north of the CWS intake.

III.B.3.a. Pumps

The SWS for each unit consists of six vertical turbine-type pumps; six vertical mechanical screens; one mechanical trash rake; six automatic strainers; two intake sump pumps; and associated piping, valves, and instrumentation. Each SWS pump is rated at 10,875 gpm. The actual system flow per pump depends upon system resistance characteristics. The average velocity through the SWS intake structure is less than one foot per second at the design flow of 10,875 gpm.

III.B.3.b. Internal Discharge to the Circulating Water System

During Station start-up, four of the six SW pumps per unit are operated to provide the nominally required 42,000 gpm flow. During normal Station operations, the four pumps nominally provide 41,200 gpm. During Station shut-down, the SWS flow requirement drops to approximately 28,500 gpm. Flow in the SWS flow also varies with intake temperature and cooling system heat load.

Service Water is discharged to the Estuary via connections to the CWS discharge pipes. Intake temperature for the SWS is essentially the same as for the CWS. Transit through the SWS results in an increase in temperature of the SWS from near zero up to 15°F, depending on the need for equipment cooling, with an average temperature increase of 8° to 10°F.

III.B.4. Station Measurement Systems Relevant to Thermal Discharge

The Station contains a variety of measurement systems to monitor various components under all operating conditions. Measurements are made of water temperature, water pressure, flow volume, megawatts electric (MWe), megawatts thermal (MWt), and total residual chlorine (TRC).

III.B.4.a. Temperature

Temperature is measured by resistance temperature devices at the intake structure and within the six discharge pipes at fixed points. Data are recorded by the Station. Exhibit B-1-3 describes the temperature measurement system in more detail.

III.b.4.b. Pressure

Pressure is measured at various locations within the CWS using Bourdon tube pressure gauges. Pressure within the SWS is measured remotely using diaphragm-type strain gauges.

III.B.4.c. Flow Volume

Flow volume is difficult to measure with a high degree of accuracy in a large-diameter pipe. Instead of using direct flow-measuring systems, the Station uses dye studies to measure CWS flow volumes. These dye studies are performed at regular intervals (most recently in 1993, 1994, 1995, 1997, and 1998). The flow volume depends on the condition of the pump and the condition of the piping. Thus representative flow volumes, based on historical measurements, are determined for both clean and fouled conditions.

The details of the CWS dye measurement procedure are presented in Exhibit B-1-1. The dye studies are performed in accordance with NJPDES Permit NJ0005622, Part IV-B/C, Section A.10.(b). The test follows a simple procedure. Dye is injected into the pump suction at a measured volumetric rate for several minutes. Dye concentration is normally measured at the inlet to the condensers, where it has become fully diluted with the total flow. The ratio of the injected dye concentration to the fully mixed dye concentration is inversely proportional to the pump flow.

Flow in the SWS is approximated by multiplying the number of pumps operating by the design pump flow of 10,875 gpm.

III.B.4.d. Megawatts Electric

The electricity generated by the turbine that converts steam to electricity is measured in megawatts electric (MWe) using conventional electric power meters. This measurement, as it represents the product from the Station, is made and recorded very precisely.

III.B.4.e. Megawatts Thermal

The heat energy generated by the nuclear reactor system is recorded in megawatts thermal (MWt) using nuclear instrumentation that makes a direct measurement of neutron flux, which is then converted to MWt.

III.B.4.f. Total Residual Chlorine

Total residual chlorine (TRC) is measured in the CWS discharge pipes at least three times per week. The chlorine concentration is determined by amperometric titration. An Orion 1770 chlorine analyzer is an online instrument which will terminate chlorine injection to the SWS before NJPDES limits are exceeded. These analyzers are located in each of the six combined discharge pipes.

III.B.5. Operational Characteristics

When the Station operations result in a steady rate of heat rejection, the heat transferred to the cooling water from the condensers raises the temperature of the cooling water in inverse proportion to the rate of cooling water flow. The relationship between temperature change, cooling water flow rate, and heat input is expressed by the equation (Baumeister, 1979 Eighth Edition, p. 9-63):

$$Q = 500\ G\ c_p\ (T_o - T_i)$$

in which:

Q = heat transferred in Btu/hr

500 = conversion factor from minutes to hours and gallons to pounds

G = volume flow rate, in gallons/min

c_p = specific heat of water in Btu/lb/°F

T_o = discharge water temperature, °F

T_i = intake water temperature, °F

This equation is commonly written as:

$$Q = M\, c_p\, \Delta T$$

in which:

M = mass flow rate of cooling water in pounds mass per hour (lbm/hr)
ΔT = differential temperature between discharge and intake (°F)

These formulae demonstrate that for a constant rate of heat rejection, the change in temperature, or ΔT, is inversely proportional to the cooling water flow rate (i.e., ΔT decreases as cooling water flow rate, M, increases).

III.B.5.a. Circulating Water System Flow Volume

The mass flow rate of the cooling water is not simply the sum of the design ratings of operating pumps. The flow rates are lower for many reasons, including internal friction and gradual fouling inside of the pipes. Although the volume of flow through the CWS is periodically calculated by dye measurement tests, it is also projected theoretically by a systems analysis. The flow rate is defined as the intersection of the Pump Curve with the System Curve. The Pump Curve shows the relationship between design pump flow rate and the total developed head (sum of the suction head and the discharge head). The System Curve is an analogous curve showing the relationship between pump flow rate and system head requirements. Details are described in Exhibit B-1-1 to this submittal. Attachment B-1 presents the details of the calculations of CWS flow volumes. A maximum flow rate occurs when all six pumps for each unit are operating in a clean system; a minimum flow rate occurs when one of the six pumps is out of operation for purposes of cleaning or repair. Pump flows, however, are represented as an average for the six pumps. If one pump is out, and five are operating, the pump flow is still represented as an average for the six pumps.

Analysis of the dye tests and knowledge of the System Curve and the Pump Curve yield the high and low flow rates shown below. Because flow rate is also a function of fouling of the traveling screens, pumps, and pipes, the flow rates shown below assume a measure of fouling.

Nominal	166,000 gpm per pump average
Maximum	175,000 gpm per pump average
Minimum	140,000 gpm per pump average

These parameter values for flow rate are conservative best representations of operations and have a reasonable probability of recurring within design normal operating conditions.

*

The maximum operating value of 175,000 gpm is consistent with the 30-day average cooling water flow limitation in the Station's NJPDES Permit.

III.B.5.b. Heat Output

The heat output, or heat rejected, is a measure of the quantity of heat discharged to the Estuary as a result of Station operations. Station heat rejection rate is measured in British thermal units per hour (Btu/hr). The amount of heat energy rejected cannot exceed the amount of energy generated by the reactor system minus the amount of energy converted to electricity (according to the first law of thermodynamics). It is usually less than this value, because some heat is lost to radiant losses, steam leaks, sampling, etc. Three calculation methodologies having different data sources can be used for this computation: the differential energy method, the flow/differential temperature method, and the plant performance model (ME-141). These calculation methodologies produce comparable results, but their relative accuracy is limited by the data that are available for the calculations.

Attachment B-1 describes in detail these methods used to calculate heat rejection. The differential energy method compares the heat energy generated by the nuclear reactor system, normally reported in MWt; the energy generated by the turbine generator that converts steam to electricity, normally reported in MWe; and the energy transferred to the cooling water, normally reported in millions of Btu/hr (MBtu/hr). This calculation is conservative in that it may overstate the impact on the environment because it does not explicitly address energy losses to other sinks (e.g., steam leaks, samples, etc.). The measurement of nuclear reactor energy is regulated by the USNRC. The electrical energy is generated for sale, and thus requires accurate measurement. Therefore, the differential energy method calculates heat rejection based on data that are quite accurate relative to data for the other methods.

The differential energy method yields a Station parameter value of 15,600 MBtu/hr for the heat rejection rate. This value conservatively best represents Station operations and has a reasonable probability of recurring within the confines of design normal operating conditions.

III.B.5.c. Differential Temperature

Differential temperature (ΔT) is the difference in water temperature between the intake and the discharge of the CWS. The change in temperature results from the addition of heat during flow through the condensers. Nearly two-thirds of the energy generated by the nuclear reactor becomes waste heat, which must be carried away by the CWS water.

In order to derive differential temperatures to be evaluated for permit renewals, several approaches are possible: (1) calculate differential temperature based on intake flow rates and heat rejection as demonstrated above; (2) use a sophisticated computer model (Heat Balance Program or ME-141) to calculate the differential temperature; or (3) use Station operating data.

Attachment B-1 provides a description of these methods. Of the three methods, the calculation of differential temperature based on flow rate and heat rejection rate was selected as the most accurate and representative method.

The minimum and maximum operating values for differential temperature (ΔT) have been calculated to be 14.8° F for high-flow conditions of 175,000 gpm per pump (average), and 18.6° F for low-flow conditions of 140,000 gpm per pump (average).

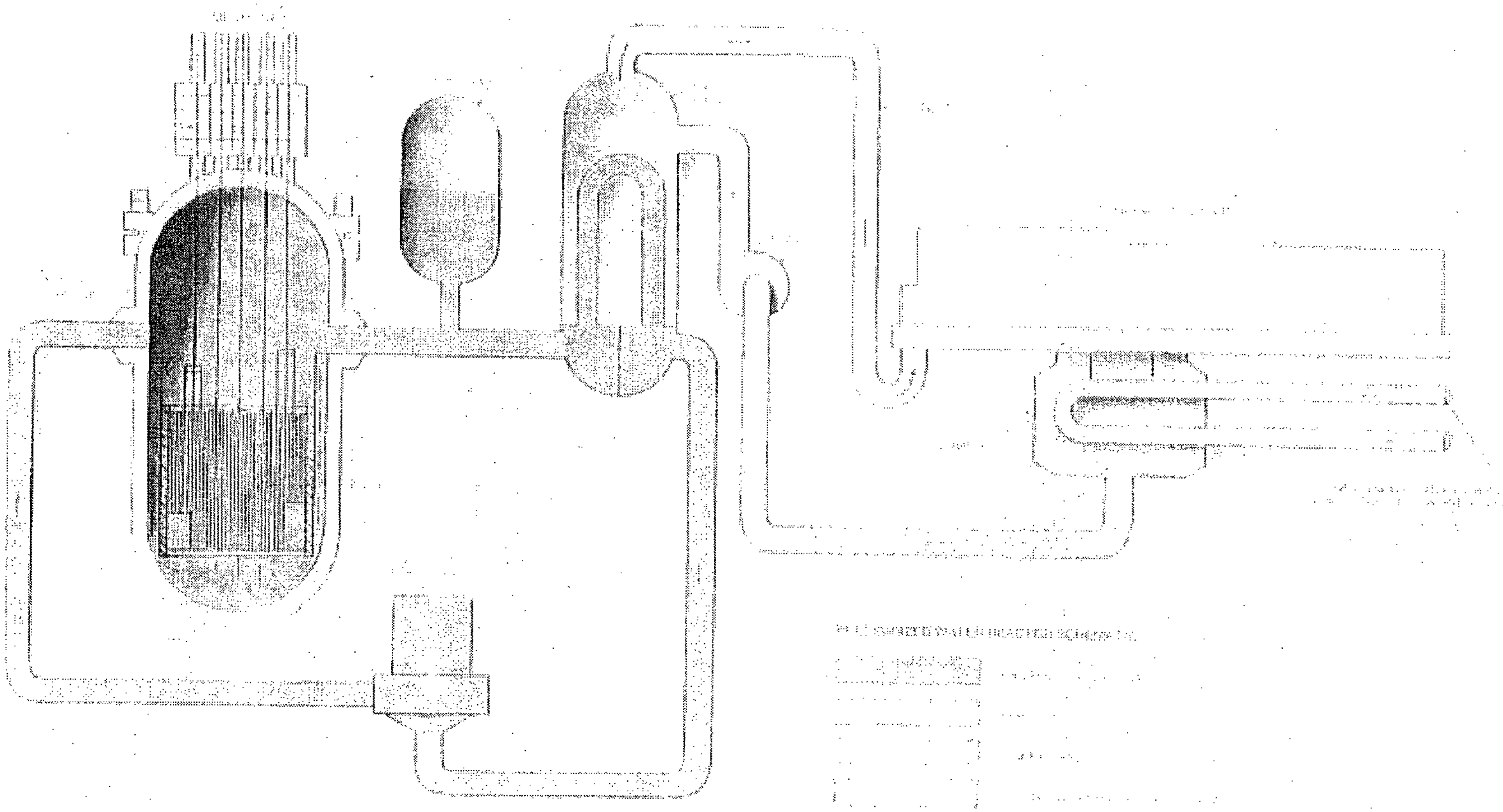
III.B.5.d. Refueling Schedule

The Salem Units are currently on an 18-month refueling cycle with a typical 60-day outage period. Each Unit's outage is scheduled for either spring or fall (not at the same time for both Units). The Station is working toward the goal that future outages will be completed in 39 days (Appendix B).

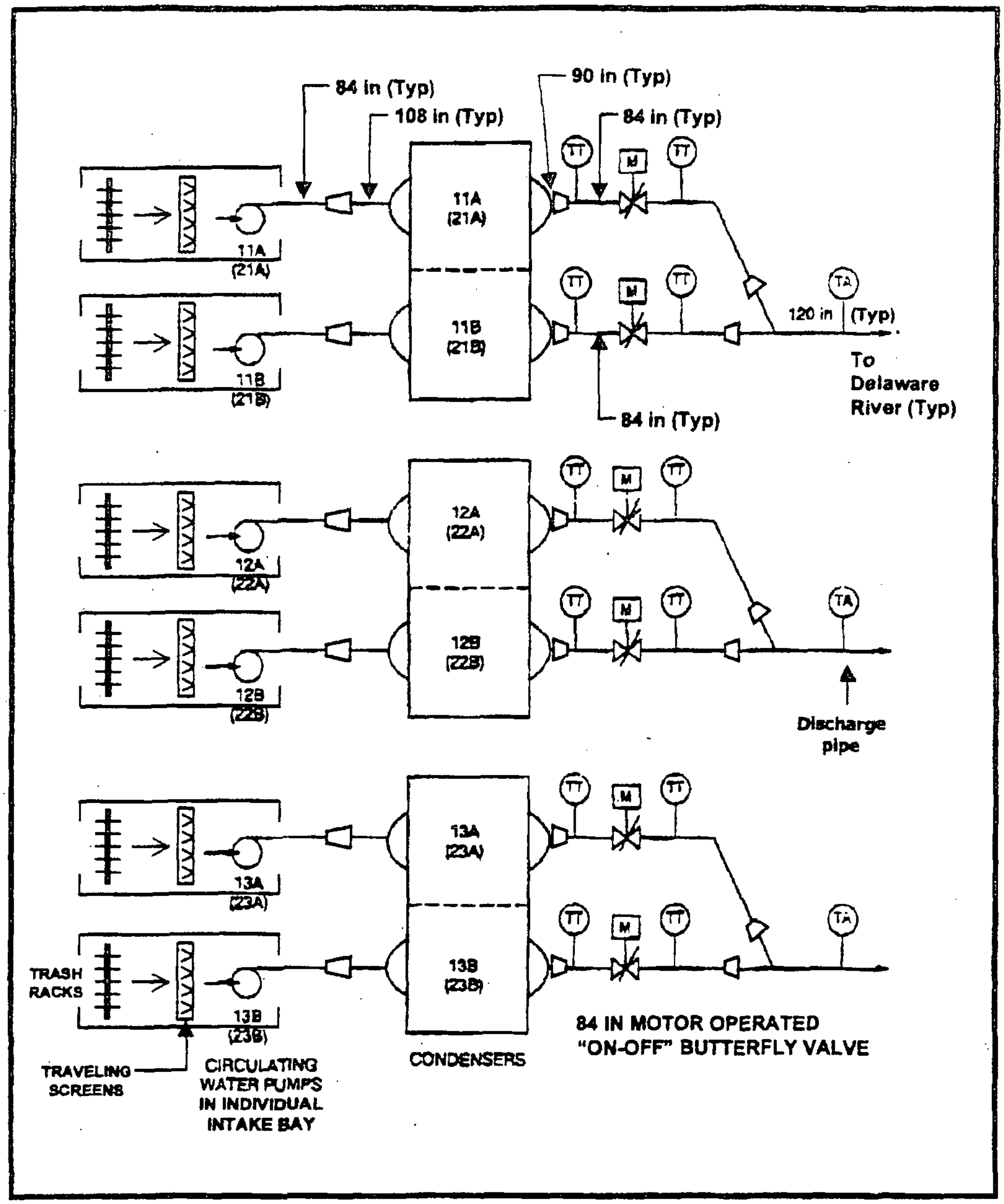
III.B.5.e. Chlorine Injection

There is no chlorine injection in the CWS. The SWS is the only chlorinated cooling water system at Salem. Chlorine minimization and chlorine decay studies of the Station (Burton and Garey 1986) recommended that a minimum total residual chlorine (TRC) concentration of 300 µg/L be maintained at the outlet of the downstream heat exchanger in the nuclear cooling system loop to control biofouling in the SWS. Following this recommendation, a target TRC concentration of 500 µg/L was set. Attachment E-4 describes the assessment of the discharge of chlorine to the Estuary.

HOW SALEM UNITS WORK



E Figure III-1. Simplified steam-electric cycle.



E Figure III-2. Circulating Water System for a single unit at the Station (3 condenser banks per unit).

IV. DELAWARE ESTUARY CHARACTERIZATION OF THE "RECEIVING WATER"

IV.A. Morphology

IV.A.1. Location

The Delaware Estuary's (the Estuary) watershed encompasses portions of Pennsylvania, New Jersey, New York, and Delaware, draining a basin approximately 35,050 square kilometers (approximately 13,533 square miles) in area.

The Estuary possesses many of the same characteristics as other U.S. east coast estuaries, including similar morphology, hydrology, hydrodynamics, and biology. This commonality broadens the basis for understanding processes within the Estuary, allowing instructive parallels to be drawn with similar east coast estuarine systems.

IV.A.2. Shape

One of the major physical features of the Estuary is its variable width (Figure IV-1). It has a classic funnel shape, widening from the ocean entrance (about 11 miles across) to a Bay where the width is greatest (about 27 miles), and then funneling to much narrower widths toward the Transition and freshwater Tidal River Zone (about 0.20 miles at Trenton, NJ). This funnel shape strongly influences the hydrodynamics, and consequently the hydrology of the Bay as a whole. Tidal heights increase from the Bay entrance (4.8 feet) to Trenton (8.1 feet); tidal height reaches 5.5 feet at Reedy Point, three miles upstream of the Station. The tidal amplification enhances mixing and exchange of waters with the other sections of the River.

IV.A.3. Size

The Estuary extends approximately 133 miles from the ocean entrance to the head of the Estuary in Trenton (Figure IV-1). It has a mean depth of 19 feet, with a maximum depth of nearly 148 feet in Delaware Bay. A 30- to 40-foot deep dredged navigation channel extends from Trenton to Philadelphia; a 40-foot deep channel extends to the mouth of the Bay. The surface area of the main stem of the Estuary is about 725 square miles, with tidal creeks adding another 33 square miles. Wetlands bordering the Estuary measure 247 square miles, located primarily in the lower part of the Estuary below the C&D Canal.

The volume of the Estuary is 450 billion cubic feet, and the tidal prism alone is about 140 billion cubic feet. The majority of the Estuary's volume is contained between RM 19 and the ocean entrance (RM 0), which is the widest portion of the Bay and contains some of the deepest waters. Tidal flushing times for the portion of the estuary below Philadelphia vary between about 46 days under high-flow conditions and 228 days under low-flow conditions.

IV.B. Meteorology/Climatology

IV.B.1. Climatological Zone

The climate of the Delaware Estuary is humid subtropical. This zone is characterized by mild winters, perennial moist conditions, and long, hot summers.

IV.B.2. Atmospheric Temperature Conditions

Monthly mean temperatures average 54°F, with a low monthly average of 32°F in January and a high of 76°F in July, based on a data series from Wilmington Airport, Wilmington, DE, for the interval 1948 to 1998 (National Oceanographic and Atmospheric Administration National Climatic Data Center (NCDC), Asheville, NC). Monthly averages are shown in Appendix C to this submittal, C Table 11. Extreme monthly mean temperatures range from a high of 43°F with a low of 22°F in January to a high of 80°F with a low of 73°F in July. Extreme monthly temperatures measured were a high of 74°F with a low of −13°F in January, and a high of 101°F with a low of 50°F in July and a low of 49°F in August. In a climatological sense, and on an annual average basis, the coldest years were 1958 and 1978; the warmest years were 1973 and 1990.

IV.B.3. Solar Radiation/Cloud Cover

Cloud cover is greatest during the winter and spring, and least in summer and fall (Appendix C). Monthly frequencies of overcast conditions vary from a low of 31.9 percent in August to a high of 46.5 percent in January. Frequency of clear sky conditions range from 18.8 percent in May to 31.4 percent in October. The monthly weighted average sky cover varies over a narrow range (from 50 percent in October to 61 percent in May).

Solar radiation in the form of incoming short-wave radiation is generally less in months in which cloud cover is highest, although the clouds can trap the long-wave radiation that reradiates from the earth's surface. These two effects counter each other, but do not balance, as the long-wave back radiation is on the average a small fraction of the incoming short-wave radiation.

IV.B.4. Winds

Wind measurements have been made for decades at the Wilmington Airport (NOAA NCDC). Prevailing winds come from the northwest to the west. Winds from the south and from the north are also common. Northeasterly, easterly, and southeasterly winds are infrequent. Calm conditions were observed for 8 percent of the time. About 65 percent of the time, wind speeds were in the 3- to 10-knot range. Wind speeds exceeding 21 knots occur in less than 0.6 percent of the time. Strong winds are generally from the northwest and northeast quadrants.

IV.B.5. Precipitation

Annual precipitation for the period 1948 to 1998 at the Wilmington Airport averages 41.5 inches, with a range from 25 to 55 inches. Monthly mean precipitation varies seasonally. October is the driest month (with a mean of 2.9 inches of precipitation), correlating with the highest frequency of clear skies. July is the wettest month (with a mean of 4.25 inches of precipitation). July holds the record for both the driest and wettest month on record: 0.2 and 12.6 inches of precipitation, respectively.

IV.B.6. Relative Humidity

Relative humidity is the amount of moisture in the air compared to the maximum amount of moisture at air saturation (the dewpoint). Saturation is a strong function of temperature; warm air can hold more moisture than cold air. However, relative humidity is not a measure of how much moisture is in the air, but is only a measure of its percent saturation.

Relative humidity was also recorded at the Wilmington Airport for the years 1948 through 1998. Relative humidity (at 0700 hours) has an annual mean of 78 percent, with a seasonal variation ranging only from 73 percent to 85 percent. Afternoon readings show considerably lower relative humidity, with the mean ranging from 50 percent to 61 percent. The early morning readings show a maximum monthly mean in September (85 percent), and a minimum in March and April (73 percent). By contrast, the early evening readings show a maximum monthly mean in December (61 percent) and a minimum in April (50 percent).

Dewpoint is the temperature at which the air will reach saturation, causing condensation (fog or dew). As the air temperature increases, the more moisture the air can hold and the higher the dewpoint. The area's annual average dewpoint is 43°F (lower than the annual mean temperature of 54°F), and ranges from a high monthly mean of 65°F in July to a low monthly mean of 22°F in January. The months of June, July, and August are the warmest, and consequently have the highest dewpoints and the most atmospheric moisture.

IV.B.7. Climate-related Phenomena

Storm frequency is often linked to climate. Storms in the Estuary area have several types of origin. Extratropical storms include the damaging northeasters that pepper the coast from time to time. Tropical storms originate farther south over the tropical ocean and include hurricanes which propagate from south to north. The storm frequency varies from year to year and cannot be predicted with accuracy.

Other climate-related events of note include potential climate warming and sea-level rise. Although there is still a lack of consensus among scientists about the magnitude of global warming during the next century, and about the role of human activities on this global warming, continued sea-level rise can be anticipated. During the past century, relative sea level has risen in the Estuary at a rate varying from 1 to 5 mm/yr, depending on location (Emery and Aubrey 1991). Relative sea-level rise is a combined result of human activity (groundwater extraction, oil and gas mining), global change (melting glaciers and thermal expansion of the oceans), tectonics, and other climatic effects.

Relative sea-level rise affects marshes and wetlands of the region by increasing mean water levels. Drowning coastal sites compensate for this increase in water levels by translating the wetlands farther inland; marshes can maintain their relative position by accreting both organic and inorganic matter, thus increasing their bed elevations.

IV.C. Hydrology and Estuarine Dynamics

IV.C.1. Freshwater Hydrology

The annual average freshwater flow to the Estuary is approximately 20,243 cubic feet per second (cfs). Most of this flow comes from the nontidal River (58 percent) and the Schuylkill River (14 percent). Annual mean flows from these two sources are 11,700 cfs and 2,746 cfs, respectively. Only a small portion (10.3 percent) of the annual mean inflow is discharged below RM 59 (the C&D Canal). Of this small portion, 6.8 percent is discharged along the New Jersey shore, and 3.5 percent is discharged along the Delaware shore (Appendix C).

Maximum and minimum flows for the River at Trenton are 19,268 cfs (calendar year 1996) and 5,027 cfs (calendar year 1965), respectively. Highest monthly average flows occur during March and April; lowest monthly average flows, occur in August and September.

The Delaware Basin is a major source of water supply for approximately 15 million people living in New York, New Jersey, Pennsylvania, and Delaware. In 1986, estimated basin-wide consumption of water for domestic, industrial, commercial, and agricultural uses and power generation amounted to 11,900 cfs, roughly equal to the mean annual river flow at Trenton (Phelan and Ayers 1994). Most of this water returns to the basin, with the exception of about 1,100 cfs exported to New York and northern New Jersey.

Groundwater provides water to the Estuary. However, the actual magnitude of this input has not been quantified.

IV.C.2. Estuarine Dynamics

Many physical processes contribute to estuarine dynamics. Freshwater inflow (see above) is one major contributor. However, tidal fluctuations appear to be an equally dominant factor. Appendix C presents an overview of these dynamics. Astronomical tides are predominantly semi-diurnal (two high tides and two low tides in one day), although tidal fluctuations exist on nearly 100 other time scales as well. Tidal propagation in the Estuary is affected by the geography of the system, including its funnel shape. Vertical tides move the tidal zone up and down on the shoreline, whereas horizontal tides (currents) translate the water back and forth. The tidal excursion (distance traveled by a passive particle traveling with the water during one-half a tide) is approximately 8 miles for much of the Estuary. This tidal variation mixes waters more rapidly than pure freshwater advection. The interaction between the tides and the river flow imposes a complex tidal signature which is manifested by differing durations of flood and ebb tides, discordance between slack water and high and low tides, and strong spatial gradients in currents and water-level elevations.

Meteorological tides also impact estuarine dynamics. Strong winds can generate significant surface stresses which can alter the water level. Winds blowing over the Atlantic Ocean can cause water levels to pile up along the coast (set-up, or storm surge); lower atmospheric pressure can have the same effect. Winds blowing over the Estuary can have a similar, though much smaller, effect. Thus, winds and lowered atmospheric pressure can cause a change in water-level elevation that will propagate through the estuarine system in a fashion similar to the tides, altering mixing rates and water velocities.

Wind waves can affect estuarine processes in a variety of ways. Wind waves can alter the bottom friction and hence the propagation of the tide. They stir up and transport sediment, which increases the concentration of suspended sediments and consequently affects water clarity. Wind waves also enhance coastal erosion, providing another mechanism for increasing turbidity in the water column.

Marshes serve as heat sinks or sources, thus contributing to temperature dynamics in the Estuary. Marshes, being shallow, can gain large amounts of heat in the summer, particularly in the daytime, and provide heat sources to the Estuary on the ebb phase of the tide. Conversely, because marshes comprise a large portion of the area of the Estuary from RM 79 down to the mouth of the Estuary, they can serve as heat sinks at night, losing large quantities of heat to the atmosphere.

Other estuarine circulation features exist. Two-layer (or stratified) flow can occur in the Estuary under suitable combinations of tidal and river flow. However, in general the Estuary is only weakly stratified, and is well-mixed vertically. Longitudinal stratification, on the other hand, is much stronger because the salt gradient along the river is strong (see Section IV.C.3 on salinity). Estuarine fronts, areas where water masses of different origin meet, occur. Along these frontal zones, convergent mixing can take place, but dynamically the fronts are much less important than tidal, river flow, and meteorological processes.

Pape and Garvine (1982) mapped the subtidal circulation of the Delaware Bay Zone using seabed and surface drifters. They found surface drifters launched within the zone moved seaward and toward the Delaware shore. In contrast, bottom drifters launched off the bay mouth (as far as 40 km (25 mi) offshore) moved shoreward and often into the bay, though at slower average speeds. For the period studied, their drifter measurements revealed a net surface outflow at about 5 cm/sec (2 in./sec) and a mean bottom flow of about 1.3 cm/sec (0.5 in./sec). These early studies suggested the presence of a relatively weak estuarine gravitational circulation in the Delaware Estuary.

Wong (1994) has proposed a modification of the traditional two-layer gravitational circulation model to explain the subtidal circulation of Delaware Bay. Traditional conceptual models of estuarine circulation assume uniform across-estuary depths. However, Delaware Estuary bathymetry is characterized by a deep, center channel flanked by shoaling areas along the shores. Under the influence of riverine inflows and associated longitudinal density gradients, this characteristic across-estuary bathymetry produces a net outflow along both shores, and a return flow concentrated in the deeper part of the channel. Thus, Wong observed two branches of low salinity along the shores separated by high salinity water in the deep channel and extending to the surface.

Wong's modified gravitational circulation model for the Delaware Bay is supported by recent observations by Keiner and Yan (1997). Using a suite of satellite temperature images and statistical techniques, Keiner and Yan reported net outflows along the sides of the estuary, and the presence of in-flowing waters over the center channel. Wong and Munchow (1995) observed "fronts" in the Delaware Bay Zone-regions in which observed salinity and temperature gradients are steep and, typically involve small-scale circulation. In particular, relatively dense waters were observed in the middle of the Bay Zone, mingling with less dense waters near the shores. On an even smaller scale, Wong (1994) observed lateral temperature variations of 2.1 °C over a 152-m distance (3.7 °F over a 500-ft distance) within the zone.

The along-estuary (axial) flows described by Wong's conceptual model are likely coupled with transverse (across-estuary) circulation patterns (Wong 1994). The characteristic across-estuary bathymetry provides greater frictional resistance in the tidal shoals relative to the deep channel. As a result, a transverse shear develops in the tidal flow, with enhanced flows in the channel. The lateral salinity profile is advected further in the channel than the adjacent shoals (Huzzey 1988). On a flooding tide, this pattern of "differential advection" produces relatively higher salinity over the channel and lower salinity along the shores, as simulated by DiLorenzo et al. (1992*a*). The associated transverse density gradient may produce two transverse circulation cells characterized by converging surface flows (and sinking) at the center of the channel and diverging bottom flows, as observed in other estuaries (e.g., Valle-Levinson and Lwiza 1995). This transverse circulation may aggregate suspended particles, oil slicks and biota along the main axis of the Delaware Estuary.

The modified gravitational circulation model includes two branches of buoyant outflow along the shores separated by a dense inflow centered along the deep channel (Figure IV-2). However, Wong (1994) also reports that local wind may drive two branches of flows along the shores in the direction of local wind stress, and a return flow against the wind that is concentrated in the deep channel. These processes may either reinforce or counteract each other, depending on wind magnitude and direction. A strong wind blowing up the estuary would tend to counteract the modified gravitational circulation and reduce transverse shear. Conversely, a wind blowing down the estuary may reinforce the two effects and enhance transverse variability.

An additional feature of the Estuary subtidal variability is the recent discovery of a buoyancy-driven coastal current—a seaward flow that is driven by density differences between the brackish Estuary waters and salty oceanic waters (Garvine 1991). This current bends southward at the mouth of Delaware Bay to form a broad (19-km-wide; 12-mi-wide), slow-moving (2.5-5 cm.sec; 1-2 in./sec) plume along the inner continental shelf off Delaware (Garvine 1991; Munchow and Garvine 1993). The coastal current is identifiable by a salinity/temperature signature that is coherent over the length of the Delmarva Peninsula. Potentially, this current may distribute river borne nutrients, larvae sediments, sewage, toxic chemicals, and spilled oil dominantly along the shore (Munchow and Garvine 1993).

IV.C.3. Salinity Zones

Salinity in the Estuary varies markedly in response to external factors, including: (1) the salinity distribution of adjacent coastal waters; (2) freshwater inflow variations; (3) tides and tidal exchange processes; (4) estuarine morphology; and (5) local and nonlocal wind-induced circulation. Under typical high river flow conditions, the limit of salt intrusion (defined as the 1 ppt isohaline) is at the C&D Canal (RM 59). Under low river flow conditions, this same isohaline intrudes nearly to Chester, PA (RM 83). During average flow conditions, the salinity intrusion is intermediate to these two extremes (Figure IV-1). Thus, strong spatial and temporal variations of salinity are the rule, not the exception. Superimposed on this river effect are the tidal impacts; the tides oscillate back and forth, over a distance of approximately 8 miles during a tidal cycle (the tidal excursion length).

The longitudinal (axial) mean distribution of salinity decreases nearly linearly with increasing upstream distance (approximately 0.5 ppt/mile Appendix C). Tidal advection, as opposed to river flow, dominates this process.

Spatial gradients in salinity exist in the Bay as well. Wong (1994) and Wong and Munchow (1995) observed lateral salinity variations of up to 6 ppt across the wide lower Bay. Salinity was higher in the main navigation channel, with less saline waters hugging the shorelines of the Bay.

The USEPA's Delaware Estuary Program Scientific and Technical Advisory Committee (STAC) delineated three zones of the Estuary based on patterns of salinity, turbidity, and biological productivity (Figure IV-1): the freshwater Tidal River Zone (or Upper Zone), the Transition Zone and the Delaware Bay Zone (or Lower Zone). The Delaware Bay Zone extends from River Mile (RM) 50 to RM 0. The Delaware Bay Zone is characterized by high salinity, low turbidity, and high biological productivity. The Transition Zone extends from RM 80 to RM 50, and includes the Station, which is located near RM 50. The Transition Zone is one of variable salinity (0 to 18 ppt), high turbidity, and low biological productivity. The freshwater Tidal River Zone extends 53 river miles from the head-of-tide at Trenton, NJ (RM 133: the head of the Estuary) down to Marcus Hook, PA (RM 80). The freshwater Tidal River Zone is the area most impacted by human use; its quality has been improving during the past couple of decades due to improvements in process control, reduced point and non-point discharges to the extensive system, and continued regulatory attention to this water body.

IV.C.4. Sediment Transport

The tidal and subtidal circulation of the Estuary was described previously in Section IV.C.2. This section focuses on Estuary transport processes and their effects on nonliving materials and organisms.

IV.C.4.a. Suspended Sediment and Detrital Transport

IV.C.4.a.i. Riverine Sources

The waters derived from the upland basin of the Delaware system carry a variety of dissolved and suspended substances of natural and anthropogenic origin. Sediment is one of these important substances. Sediment can be stored temporarily in the river floodplains, and its removal from the terrestrial landscape can be dramatically accelerated by human activities. Once transported to the estuary, suspended sediments may alter the environment by: (1) decreasing light penetration, affecting photosynthetic organisms; (2) transporting other materials absorbed to their surface; and (3) modifying the shape and cross-section of the estuary when deposited on the bottom. The distribution of Delaware Estuary sediment types is illustrated in Figure IV-3.

Fitzgerald and Karlinger (1983) estimated that the River at Trenton discharges about 750,000 tons of suspended sediment per year, except in record flood years, when the daily discharge can reach 900,000 tons. They found that over 85 percent of the suspended sediment is discharged during 10 percent of the year, all during periods of highest fresh water flows. The sediment consists of both inorganic and organic components. Mansue and Comings (1974) estimated that 12 percent of Estuary sediments consist of organic matter. The inorganic component consisted of 53 percent silt, 43 percent clay, and 4 percent sand. Biggs et al. (1983) estimated the total suspended load to the Estuary, from gauged and ungauged sources, to be 2 million tons per year.

IV.C.4.a.ii. Transport Mechanisms

Estuarine fluxes of salt and particulate matter are regulated by physical transport processes. This section reviews these processes and their influence on the distribution of both salt and suspended matter in the Estuary.

At a fixed location along the main stem of the Estuary, the concentrations of various water quality constituents vary when flooding and ebbing tides displace a longitudinal concentration gradient (Figure IV-4). This process (tidal "advection" of the mean gradient) may induce significant variability at tidal frequencies. However, such back-and-forth motions may not induce a *net* (tidally averaged) transport of salt, constituent mass or suspended solids.

In most estuaries, the seaward advection of salt and other constituents due to the river outflow is balanced by mean landward fluxes due to the estuarine gravitational circulation and tidal "pumping" (i.e., temporal correlations of velocity and salinity) (Geyer and Nepf 1996). The Estuary is no exception. For example, Wong (1994) observed a modified gravitational circulation in the Bay Zone consisting of a net inflow of saline water that was centered along the main navigation channel, and a net outflow of less saline water along both shores. Steady (time-invariant) velocity and salinity differences across the estuary (steady lateral shears) that are associated with this circulation pattern contribute to the upstream transport of salt in the lower reaches of estuaries (Fischer et al. 1979).

Besides steady shear processes, tidal pumping is an important transport mechanism for salt and suspended sediment. Tidal pumping occurs when the spatial distribution of flood flows across a cross section differs from the distribution of ebb flows, resulting in a net transport of constituent mass (Fischer et al. 1979). Such differences may arise from the interaction of tidal flows with either shoreline irregularities or uneven bottom topography ("tidal trapping"). This process traps low-velocity waters along the sides of an estuary—waters that then move out of phase with the main channel flow. This process tends to disperse constituent plumes and enhance salinity intrusion.

Tidal pumping also arises from time-varying (tidal) shear. It results from correlations (both temporal and spatial) between velocity and salinity variations (vertical and lateral) within a tidal cycle. Tidal shear is important when the time scale of vertical or transverse mixing is comparable to the tidal period (12.42 hr) (Geyer and Nepf 1996).

In terms of these transport components, Garvine et al. (1992) propose two possible mechanisms to explain the buffered salinity response of the Bay Zone to freshwater inflow variations: (1) vertical shear flow dispersion in a tidally stirred regime; and (2) lateral shear coupled to lateral salinity gradients. The former likely contributes to the salt balance primarily through the tidal (oscillatory) shear mechanism; the latter through steady lateral shear. However, both proposed mechanisms include steady and oscillatory components.

Walters (1991) suggests that while vertical shear dispersion is important, it is not a dominant transport mechanism in the Estuary. This observation stems from the fact that time scales associated with vertical mixing in the Estuary are short compared to the period of tidal oscillations. Overall, Walters suggests that the tidally averaged salt transport in the Estuary is dominated by *horizontal* advective processes that lead to shear dispersion, and includes smaller contributions from vertical shear dispersion.

Like salinity, suspended sediment is transported by mechanisms of tidal pumping and steady shear dispersion. However, as noted by Jay and Musiak (1994), a fundamental difference arises because particle settling and deposition/erosion processes introduce additional sources and sinks into the mass balance. Consequently, spatial distributions of salt and suspended sediments differ, as do their associated estuarine transport processes. For example, in the Tamar Estuary—a partially mixed estuary located in the southwest of England—Uncles et al. (1985*a, b*) observed an Up-Estuary transport of suspended sediment due to tidal pumping in tidal shallows–areas where sediment was available for resuspension. Also, he observed down-Estuary pumping in the deeper channel due to the absence of easily erodible bed materials.

Local winds also transport suspended sediments. Local wind patterns described in Section IV.B.4 produce surface waves on the Delaware Estuary. These waves are capable of resuspending and redistributing sediments in shallow waters, creating near-shore currents, and inducing shoreline erosion which can serve as a source of suspended sediment. Winds from the north and west directions are both the most frequent and strongest; winds from the south and east are strong but less frequent. These dominant winds can affect both the Delaware and New Jersey shores of the Bay. The marshy shoreline of the Bay, susceptible to wave attack, is eroding at rates of 0.3-6 m (1-20 ft) per year. Nearshore, wind-induced currents move these fine-grained marsh materials along the shore and frequently into creek and river mouths. Stumpf (1984) showed that surface suspended sediment concentrations, observed from satellite imagery, are dependent on the previous 2- to 3-day wind stress on the Bay Zone. He further described a 0.8-km-wide (0.5-mi-wide) band of turbid water along the shoreline of the Bay Zone (Figure IV-5). Bostater (1988) conducted an analysis of seasonal satellite imagery to measure suspended sediment concentrations within the Bay. He found that suspended sediment concentration can be explained by wind speed, sediment type, and water depth, with high concentrations associated with high wind speeds, fine sediments, and shallow water depths. Thus, there appears to be a persistent near-shore water mass extending around the wider reaches of the Bay. As illustrated by Stumpf (Figure IV-5), this nearshore band merges with and becomes indistinguishable from highly turbid water upstream in the narrower reaches of the system. This near shore water mass around the Bay Zone is consistent with Wong's (1994) model that shows ocean inflow into the bay concentrated in the deep channel with outflow from the rivers concentrated in shallower areas near both shores.

IV.C.4.a.iii. Turbidity Maxima

Estuaries generally contain turbidity maxima somewhere in their upper reaches. The Estuary contains areas of high turbidity and suspended sediment concentrations that have been described in Biggs et al. (1983) (Figure IV-6). These turbidity maxima are not stationary, but move landward and seaward in association with the salinity distribution which, in turn, responds to variations in freshwater inflow and the tidal regime. These turbidity maxima are centered at salinities of 1-3 ppt and 7.5-10 ppt and may generally be found somewhere between RM 35 (RK 56) and RM 80 (RK 129) in the Transition Zone. Generally, the fresher waters upstream of, and the saltier waters below these maxima contain low suspended solids concentrations. The low-salinity turbidity maximum is dominated by individual particles having a mean diameter of 3 μm, though there are aggregated particles up to 100 μm in diameter. These suspended sediments contain about 1-4 percent carbon. Suspended particles in the downstream turbidity maximum consist of aggregated particles held together by an organic matrix having a mean diameter of 12 μm, a maximum diameter of 125 μm, and a carbon content of about 1-4 percent. Seaward of the turbidity maxima, the population of suspended particles is dominated by 10- to 20-μm particles whose carbon content ranges from 4-9 percent.

The phenomena of the turbidity maximum has been attributed by some workers (e.g., Krone 1972) to flocculation. Others (Nelson 1960) have suggested deflocculation as the principal cause. In estuaries having strong tidal currents (like the Transition Zone of the Estuary) sediment resuspension by bottom scour has been advanced as a mechanism for the formation of the turbidity maximum (Schubel 1972). Nichols (1974) advanced the concept of the formation of the turbidity maximum due to subtidal gravitational circulation at the location where the near-bottom downstream river flow is balanced by the upstream estuarine flow (the null zone), and where upward vertical mixing slightly exceeds sediment settling rate. Officer and Nichols (1980) and Nichols and Biggs (1988) have proposed that both gravitational circulation and tidal resuspension are important phenomena, and that either or both may be adequate for the formation of a turbidity maximum. The mechanisms responsible for the turbidity maxima in the Delaware

Estuary are not well understood, though some combination of modified gravitational circulation and tidal resuspension likely dominates.

IV.C.4.a.iv. Suspended Sediment Budget.

Biggs and Howell (1988) have constructed a suspended sediment budget for the Bay Zone. The dominant source of suspended sediment in the Estuary is the watershed, followed by shore erosion and phytoplankton production. The ocean may be a source of suspended sediment, but it is one that has yet to be quantified accurately. The major sinks of suspended sediment appear to be maintenance dredging (with land spoil disposal) and deposition on the surface of salt marshes which is required to maintain them in the face of rising sea level. There is a discrepancy between the total budget sources and sinks which is likely due to the unknown contribution of ocean sources and possible underestimation of riverine sources (Biggs and Church 1984).

IV.C.4.b. Bottom Sediment Transport.

IV.C.4.b.i. Transport Mechanisms

Within the Estuary, sediment is transported either along the bed (bed load transport) or within the water column (suspended load transport). The quantity of material that travels as either bed load or suspended load depends on the following: (1) the characteristics of the sediment materials; (2) the tidal current regime; and (3) the wave climate. For example, fine-grain, non-cohesive sediments are likely to be transported as suspended load in high energy regions of the estuary (e.g., the Transition Zone). Conversely, coarse sediments in the deep channel of the Bay Zone are more likely to be transported as bed load. This section focuses on bed load transport processes throughout the Delaware Estuary.

IV.C.4.b.ii. Bottom Sediment Type and Sources

The sands that have been transported along the bottom of the streams and rivers to the head of the estuary are generally trapped within the Tidal River Zone. Minor bedload transport occurs, principally by tidal currents. Within the Transition Zone, bottom sediments consist primarily of muds, muddy sands, and sandy muds (Figure IV-3). While substantial portions of the estuarine coast consist of marsh muds, small areas of sandy sediments may be found on beaches and shallow areas. The source of these sands is erosion of local outcrops of Coastal Plain sediment that is then moved along the shore by wind waves. The dominant area of sand accretion and transport is in the Bay Zone where strong tidal currents and waves can erode the bottom, resuspend and remove muds, and transport material into the Bay from the ocean (Figure IV-7).

IV.C.4.b.iii. Boundary-layer Processes

Bed friction causes tidal current speeds to decrease rapidly near the bottom. Sand-sized sediment particles are transported either by rolling along the bottom or by saltation (a process in which individual grains are suspended, transported a short distance, and then deposited). Wind waves produce oscillatory currents that can lift individual grains from the bottom and transport them short distances in the direction of wave travel as each wave passes. In both cases, the speed of the current required to move a particle is directly proportional to the mass of the particle.

IV.C.4.b.iv. Modes of Transport: Sand Banks, Sand Waves, Ripples, and Grain Transport

It is possible to determine the direction of transport of sand grains along the bottom through the sedimentary features created by the aggregate of their movement. Ripples and sand waves are two such features. Using sonar techniques, Knebel (1989) has mapped the distribution of sand waves as far north as 40 km (25 mi) above the mouth of Delaware Bay. The distribution of bedforms suggests that bottom sands are transported by vigorous tidal currents along the deep channels in the central portion of the Bay Zone. In those cases when direction of transport could be inferred, Knebel found that the direction was up-bay.

The Bay Zone also is characterized by long, linear sand shoals that are parallel to the deep channel. These banks appear to be composed of materials that have been eroded from the bottom of the major channels, as the tidal energy within the Bay Zone has increased over time due to rising sea levels over the last several thousand years. The crests of these shoals have been modified by local waves and, near the bay mouth, by offshore waves.

The predominant direction of sand transport along the ocean beaches of southern New Jersey is toward the south around Cape May. The transport of sand along the ocean beaches of the northern Delaware ocean coast is toward the north around Cape Henlopen. Thus, both ocean coastlines can contribute coarse materials to the Bay Zone. In addition, the subtidal transport along the bottom is directed into the bay from the shelf and may transport coarse shelf sediments into the mouth of the Estuary.

A conceptual model of sediment transport within the Bay Zone and lower Transition Zone is presented in Figure IV-2. Mud/sandy mud is eroded from watershed soils and transported to Estuary tributaries, while coarse materials are deposited near the head of tide. Fine-grain materials supplied by watershed and littoral sources move seaward along the margins of the bay. The estuary's numerous tidal creeks release suspended sediment to adjacent marshes, partially offsetting the effects of rising sea level. Some unknown, but probably small, amount of suspended sediment escapes to the sea and some unknown amount enters from the sea. Coarse sediment from the rivers is trapped at their headwaters. Local outcrops of sands supply small quantities of material to beaches along the estuary shore. Ocean environs, including its beaches, the continental shelf, and the bay bottom, are a source of coarse materials that may be transported up the Delaware Bay Zone as far as adequate tidal currents persist (certainly up to RM 30; RK 48). These tidal currents may contribute between 200,000 – 350,000 tons/year of sands to the bay from the ocean (Biggs and Church 1984).

IV.D. Human Use of the Delaware Estuary (Appendix C Sections VI.A and VI.B)

The biological resources of the Estuary have been impacted by water pollution, water consumption and diversion, habitat alteration, and commercial and recreational exploitation of fish and shellfish. A §316(a) demonstration requires that the interaction of the thermal component of a discharge with other pollutants be taken into account. This requirement has been more broadly interpreted to include other significant impacts, both positive and negative, on the aquatic biological community related to human activities (Appendix D). A brief summary of these impacts is provided below. More detailed descriptions of these impacts are presented in Appendix C to this submittal.

IV.D.1. Sources and Types of Pollution

The Estuary has a long history of serious water pollution problems primarily attributable to discharges from human population centers, industrial activity, historical and current land use, and consumption and diversion of water from the watershed. Pollution sources include point source discharges, such as municipal and industrial wastewater treatment facilities, and non-point discharges, including urban and agricultural runoff.

IV.D.1.a. Point Source Discharges

Early European immigrants established population centers along the freshwater region of the Estuary, as Native Americans had done before them. These centers were located upstream from significant saltwater intrusion to assure a reliable year-round supply of water for consumptive use. Due to settlement patterns, the majority of point source discharges impacting the Estuary came to be located between Trenton and the C&D Canal (Figure IV-8). As early as 1690, burgeoning populations around Trenton, Philadelphia, and Camden led to water pollution problems. During the 19th century, pollution escalated as a consequence of industrial development. By the 1930s, excessive biochemical oxygen demand (BOD) in the areas of the River flanking Philadelphia-Camden led to dissolved oxygen (DO) levels that were too low to sustain aquatic life. This region of depleted DO blocked the traditional migration of American shad and other anadromous species to upstream spawning grounds.

Presently, there are 1,450 industrial and municipal wastewater discharges in the watershed, 99 of which are major discharges to the Estuary (Sutton et al. 1996). Because lack of DO caused by excessive amounts of organic pollutants has traditionally posed the greatest threat to water quality, regulators have focused their remediation efforts on controlling BOD, total suspended solids (TSS), pH, oil and grease, and bacteria. Based on conservative estimates, the greatest pollutant loadings to the Estuary are from BOD, TSS, and nutrients. Eutrophication, oxygen depletion caused by excessive organic growth fostered by excess nutrients in the water, can have the same deleterious effects as BOD and attenuation of light penetration by TSS.

Aggressive point-source pollution abatement programs during the past 50 years have improved DO concentration to the extent that the worst of the "sag" in dissolved oxygen that was present between RM 100 and RM 70 from 1900 to 1980 has almost completely disappeared (Figure IV-9), restoring substantial low-salinity and freshwater habitat for aquatic life.

As abatement of conventional pollutants has progressed, regulatory focus has shifted to point sources for toxic pollutants, with special emphasis on persistent forms such as heavy metals and chlorinated organic compounds.

Currently, based on sampling results, chemicals of concern listed by regulatory agencies for the Estuary under Section 303(d) or Section 305(b) of the CWA are PCBs, PAHs, DDT, DDD, DDE, PCE, 1,2-DCE, dieldrin, and copper; fecal coliforms are also listed.

IV.D.1.b. Non-Point Source Discharges

Non-point source discharges, including sewer overflows and runoff from urban areas and agricultural lands, contribute significantly to pollutant loadings. As populations increased during the 17th and 18th centuries, vast areas of forest were cleared for farms and towns, and to supply wood for building and fuel. Soil conservation management techniques were not practiced, and large quantities of topsoil washed from the exposed land into the Estuary. This changed the bottom topography dramatically, and contributed significantly to its pollution.

During the first half of the 20th century, reforestation of unproductive farms and land that had been cleared for timber, combined with other soil conservation measures, reduced the rate of soil erosion. However, increased industrial use of environmentally persistent chemicals (e.g., PCBs, PAHs, and heavy metals), as well as the widespread use of chemicals to control mosquitoes and agricultural and urban pests (e.g., DDT, dieldrin) during the same period contributed to a new class of toxic, non-point sources of pollutants to the bottom sediment and aquatic environment in the Estuary.

The trend during the past half of this century toward decentralized population growth and increasing suburban sprawl is consuming forest, agricultural land, and wetlands at a rapid rate. Increased runoff and combined sewer overflows have contributed significantly to the types and quantities of pollutants entering receiving water bodies. Studies indicate that in the freshwater Tidal River Zone, these non-point sources contribute as much as 24 percent of the total maximum daily load of oxygen-demanding materials. These sources are also believed to contribute to levels of fecal bacteria and phenols. Farther upriver, the contribution of pollutants from non-point sources is believed to be even greater. Downstream areas, from Wilmington to Delaware City, are believed to be impacted only slightly by non-point source discharges, according to DRBC (1998).

Controls on non-point source pollutants range from prohibition of their manufacture and use, to collection and treatment of surface runoff, to use of best management practices for reducing pollutants in storm water runoff.

Overall, the water quality of the Estuary has been improving during the past 30 years and now throughout much of its length supports designated water uses. In 1996-97, 95 percent of areas of the Estuary including the vicinity of the Station were at least partially supporting of the aquatic life designated use and 69 percent of the same area was fully supporting of aquatic life (DRBC 1998).

IV.D.2. Consumptive Use and Out-of-Basin Diversion of Water

During the 20th century, 23 reservoirs have been constructed within the Delaware River Basin to store water for human uses. These reservoirs have a combined storage capacity of about 414 billion gallons. Approximately 1,100 cfs of water are exported from the Basin and an additional 465 cfs are consumptively used within the Basin (Appendix C). This total consumptive use can approach the total flow of the Delaware River at Trenton during extreme drought and low flow conditions.

The storage of storm water in reservoirs, out-of-basin diversion, and high levels of consumption have altered the hydrology of the Estuary. Reductions in freshwater discharge to the Estuary result in the intrusion of saltwater upstream and into groundwater aquifers, as well as reduced dilution and flushing of pollutants. These effects can threaten the quality of existing drinking water supplies and cause significant changes in the composition, distribution, and abundance of aquatic life in the Estuary. Basin-wide management of competing water uses is required to minimize these risks. A good faith agreement between the DRBC and New York City seeks to assure a minimum freshwater flow of 3,000 cubic feet per second (cfs) in the River at Trenton.

IV.D.3. Habitat Alteration

Human alteration of biological habitats has significantly affected the biological resources of the Estuary. Alterations include annual dredging of the shipping channel, construction of canals to other basins, construction of dams in the tributaries of the Estuary, land reclamation, and the destruction of wetlands.

The U.S. Army Corps of Engineers dredges the Estuary annually to maintain shipping channels. Large-scale dredging may alter the tidal range, hence the salinity distribution, in the Estuary. Dams are located on many of the tributaries of the Estuary and at the headwaters of the Delaware River above Hancock, New York. These dams can impede the migration and spawning of anadromous fish species, including American shad, blueback herring, and alewife. The conversion of wetlands to agricultural and other uses impacts water quality and removes habitat critical to aquatic organisms. Between 1953 and 1975, New Jersey lost 25 percent (61,675 acres) of its tidal wetlands. The area lost was greatest in southern New Jersey, particularly in the counties bordering the Estuary (Tiner 1985).

IV.D.4. Direct Exploitation of the Biological Resources

Killam and Richkus (1992) provide an historical perspective on the Estuary fisheries. During the late 1800s and early 1900s the majority of finfish landings (pounds harvested) in the Estuary were comprised of anadromous species such as sturgeon, American shad and river herrings (alewives and blueback herring). Landings of many of these species declined rapidly after the turn of the century as a consequence of water quality degradation, waterway obstructions that impeded the ability of these fish to reach historical spawning grounds, and overfishing. During the 20th century, once-dominant upriver finfisheries have been replaced by downbay fisheries targeting species such as weakfish, bluefish, summer flounder, spot and menhaden.

Historical fluctuations in the Estuary finfish populations have been attributed to both natural and anthropogenic causes. The Estuary occupies a unique geographic location in relation to fish stock distribution. Offshore fisheries in the vicinity of Delaware, Maryland, and New Jersey are located at the center of migratory pathways that range from Cape Cod to Cape Hatteras. This central location, visited by both cold and warm temperate species, may explain some of the annual fluctuations in species abundance as migratory patterns are altered in response to climatic variability. Natural climatic factors may contribute to fluctuations in the fisheries of the Estuary; these factors are generally species-specific. Anthropogenic factors such as nutrient inputs, pollution, and overfishing have also impacted the fishery resources.

The human influence on the Estuary has been significant, affecting river flows, water quality, physical structure, and even the biota. The composition, trends in abundance, and distribution of species in the biological community of the Estuary reflect the combined influence of natural conditions and human activities in the basin. A significant positive factor has been improvements in water quality and aquatic life as a result of pollution abatement efforts performed during the past five decades.

IV.E. Water Quality

IV.E.1. Land Use Effects on Water Quality

According to Sutton et al. (1996), "The Delaware Estuary is one of the most heavily used estuary systems in the world. The Estuary supports one of the world's greatest concentrations of heavy industry, the world's largest freshwater port, and the second largest refining petrochemical center in the Nation..." These land uses historically have affected, and continue to affect, the water quality of the entire Estuary. The previous Section discussed human use of the Estuary; this Section focuses on the effects of those uses on water quality.

The urbanization of the regional watershed is illustrated by population trends: from 1880 to 1990, the population in the watershed grew from 2 million to 7 million people (Sutton et al. 1996). Land-use patterns are summarized in Appendix C. Agricultural land use has declined somewhat, but still accounts for substantial land use in the region (31 percent). Various industries in the region (manufacturing, oil refining, coal, chemicals, metals, textiles, and paper, for instance) have contributed to historical water quality degradation. Waste discharge from population centers has also contributed to historical pollutant loads. The Delaware watershed has some 1,450 industrial and municipal wastewater discharges, 162 of which are located along the Estuary itself (Sutton et al. 1996).

Fortunately, water quality trends have been improving during the past two decades. For example, major upgrades of both privately and publicly-owned waste water treatment plants have resulted in reductions in turbidity levels, ammonia concentrations, total phosphorus concentrations, and fecal coliform levels.

IV.E.2. Turbidity/Transparency

The freshwater Tidal River Zone (RM 80 to RM 133) is characterized by relatively low turbidity levels. Between RM 35 and RM 80, which includes the Station, tidal currents are relatively strong and fine sediments are resuspended. Turbidity levels in the lower Estuary are typically low, especially during flood tide (Sutton et al. 1996). Storm-induced waves and currents may cause high turbidity levels in the Lower Bay at times.

Turbidity levels have decreased significantly throughout the Estuary since the 1960s (Marino et al. 1991). Historic reductions in mid-Estuary turbidities (near the Salem Station) were associated with the overall improvement of Estuary water quality during this period, but turbidity is still high there due to both natural and anthropogenic sources.

Turbidity levels impact water transparency (light transmission). In the mid-Estuary region near the Station, high turbidity limits light penetration, and hence algal growth. Even though nutrient levels are sufficiently high to support phytoplankton growth, the light is inadequate because it attenuates rapidly with depth. Consequently, the phytoplankton maximum (represented as the chlorophyll maximum) is located in the lower Bay Zone, not in the upper Bay Zone and lower Tidal River Zone (RM 35 - RM 80).

IV.E.3. Temperature

The §316(a) Demonstration focuses on temperature of the Estuarine waters. During operation, the Station discharges heated water to the Estuary. This discharge affects the natural variability of Estuarine water temperatures. In order to discuss the potential effects of the Station's discharge on the regional temperature field, this Section presents definitions of temperature pertaining to this Demonstration, factors affecting the temperature of the Estuary, and the historical variability in water temperature. Appendix C contains more extensive data and discussion of river and estuarine water temperatures and the factors that influence them.

IV.E.3.a. Definitions

In this Demonstration temperature is generally stated in units of degrees Fahrenheit. Other commonly used measures of temperature are degrees Centigrade (Celsius), and Kelvin, which is an absolute temperature scale. As the primary issue of concern is relative temperature or change in temperature, rather than absolute temperature, the use of degrees Fahrenheit is appropriate. For this Demonstration, various temperatures are referred to for different purposes. The primary temperature definitions follow.

- Natural Temperature

"Natural" temperature is the water temperature that would exist without the addition of heat from any artificial origin.

- Ambient Temperature

"Ambient" temperature is the water temperature that would exist without the localized addition of heat from the Station. This is the base temperature for calculating temperature differences, or ΔT.

- Background Temperature

"Background" temperature is the water temperature that is immediately up-current of the Station's thermal discharge, so that it is the temperature of water not in the immediate plume. This temperature is used for estimating the receiving water temperature for the CORMIX modeling.

- Intake Temperature

"Intake" temperature is the water temperature at the entrance to Salem's CWS intake as affected by heat recirculated from Salem's thermal discharge.

- Acclimation Temperature

"Acclimation" temperature is the water temperature to which an organism is physiologically adjusted.

- Far-field Temperature

"Far-field" temperature is the water temperature beyond the ZIM (i.e., the momentum of the discharge has been dissipated, and the plume moves passively with the ambient water). Temperature in the far-field is still influenced by the discharge. The far-field is the area where diffusion and advection dominate the temperature dispersion, rather than momentum and turbulent mixing induced by the Station's thermal discharge.

- Near-field Temperature

"Near-field" temperature is water temperature within the dynamic influence of Salem's CWS discharge (the ZIM).

- Delta Temperature

"Delta temperature," represented as Delta T or ΔT, is the difference (increase) in water temperature that occurs in the Station's discharge and thermal plume relative to the ambient temperature. Temperature difference (ΔT) is commonly represented as a temperature contour plot, temperature time series, time–ΔT curve, or volume of water at or above a given temperature.

IV.E.3.b. Processes

Temperature of the Delaware Estuary depends on a number of meteorological and physical oceanographic processes, as well as on human influences. Temperature varies strongly in time, as depicted in normal seasonal temperature swings, or even in fluctuations from night to day. Temperature also varies spatially, as water temperature is commonly colder near the bottom of the river than near the surface. Some of the major contributors to water temperature include:

IV.E.3.b.i. Surface Heat Exchange, Air Temperature, Humidity, Wind Speed, and Cloud Cover

Solar radiation, turbulent heat exchange, and various other processes modulate the temperature of the surface waters of the River. Daily heating and cooling have a major effect on this heat exchange, and diurnal (daily) cycles in surface water temperature are common. Surface heat exchange is significantly moderated by cloud cover, which varies daily, monthly, seasonally, and annually. Cloud cover has competing effects. It not only blocks short-wave radiation from reaching the earth from the upper atmosphere but also traps outgoing reradiated long-wave energy and therefore maintains higher near-surface temperatures. This is the basis for the so-called greenhouse effect.

IV.E.3.b.ii. Tidal Effects

Tides move up and down the Estuary, transporting water of various temperatures. A record of water temperature taken at a fixed point in the Estuary would likely show variability on a tidal time scale. Tides may transport cooler water past a point during one phase of the tide, and warmer water during another phase of the tide.

IV.E.3.b.iii. Freshwater Discharge

River and groundwater discharges to the Estuary can modulate the temperature signal as well. Freshwater may be warmer or colder than the Estuary waters, depending on the season. During spring thaw, for instance, fresh surface-water flows may be cooler than the ocean waters, and contribute to cooling of the Estuary.

IV.E.3.b.iv. Marsh Processes

Marshes can influence the temperature of the Estuary waters, as they fill and empty twice daily with the tides. Marshes contribute heat to the Estuary in the summer, when marsh shallows heat rapidly and, upon draining, serve as major heat sources to the Estuary. Because water volumes in the River and over the marshes in the vicinity of the Station are almost equal, marshes can contribute significant amounts of heat, comparable to the Station's thermal discharge to the Estuary (Exhibit E-1-5). At night, marshes can have the opposite effect. The large surface area of the marshes provides for additional cooling of the Estuarine water, and so can serve as a heat sink for the Estuary system. As a result of these factors flows into and from marshes contribute to the temporal and spatial variability of ambient temperatures in open waters of the Estuary. This temporal and spatial variability in ambient temperatures typically ranges from 2 °F to 4 °F daily and may amount to 7 °F or more during bright sunny days.

IV.E.3.b.v. Atlantic Ocean

The Atlantic Ocean serves as both a heat source and sink to the Delaware River Estuary, depending on the tide and on the season. In winter, the Atlantic Ocean is generally warmer than the Estuary, thereby serving as a tidal source of heat to the Estuary. During the summer, the ocean is cooler (heats more slowly) than the Estuary, and serves as a heat sink. This moderating role of the ocean helps maintain the Estuary within a narrower range of temperatures than if it did not exchange water with the Estuary.

IV.E.3.b.vi. Human Influences

Human activities contribute to the heating and cooling of the Estuary. Power plants, including the Station, can serve as a source of heat to the River. Major heat sources to the Delaware Estuary are listed in Appendix C.

IV.E.3.c. Historical Record

The historical record of water temperature in the Estuary is 30 years long (Appendix C). The continuous measurement point closest to the Station is at Reedy Island (RM 54). Instantaneous water temperatures at Reedy Island vary from just under 32°F up to about 86°F. Weekly mean temperatures at the Station vary from about 32°F in the winter to about 79°F in the summer.

The range of temperature variability is smaller in the Atlantic Ocean than those at Trenton, NJ, and the Station. Atlantic Ocean waters have an average minimum temperature of 42.8°F in February and March, and an average maximum of about 75.2°F in August. These temperature differences between Trenton and the Atlantic Ocean at times set up a strong temperature gradient along the Estuary. In winter, the temperatures tend to be highest at the ocean entrance and lowest at Trenton, and vice versa in summer. The difference in temperature between Trenton and the mouth of the Bay may be as much as 7 °F to 10 °F.

IV.E.4. Nutrient Dynamics

Nutrients, primarily nitrogen and phosphorus, determine the potential biological productivity of an estuary. In aquatic systems, these essential elements are usually found in trace quantities. Nitrogen is abundant in the atmosphere and phosphorus is common in the lithosphere. These minerals must be present as dissolved inorganic compounds to support the primary productivity of an estuary.

If nutrients are overabundant in an aquatic system, excessive algal growth may be triggered. Excessive respiratory consumption of dissolved oxygen by algae and consumers of algae relative to input of dissolved oxygen can then lead to a sharp decline in dissolved oxygen (DO) levels. This condition of excessive nutrient enrichment leading to depressed DO levels is termed eutrophication.

The Delaware Estuary receives one of the largest loadings of nutrients of any estuary in the United States. The estimated load of total nitrogen to the Estuary is about 1.1×10^8 lb/yr; the estimated total phosphorous load is about 2.1×10^7 lb/yr (Sutton et al. 1996). Despite high nutrient loads, primary productivity is limited by light penetration in turbid portions of the Estuary (Santoro 1998). The very high nutrient concentrations in the Estuary do not appear to support massive algal blooms or to have caused eutrophication (Sutton et al. 1996). Nutrient levels in the Estuary waters appear to peak near Philadelphia where the highest concentrations of discharges are located. Improved sewage treatment has reduced the levels of ammonia (NH_3) nitrogen during the past three decades (Appendix C). By contrast, the level of nitrate (NO_3), another form of nitrogen, has stayed the same or only slightly decreased in the Tidal River and Transition Zones during the last decade.

IV.E.5. Dissolved Oxygen

IV.E.5.a. Oxygen Dynamics

In all estuarine environments, water-column oxygen content is a key determinant in defining water quality. This important respiratory gas is essential to nearly all aerobic aquatic life. Through its role in various biogeochemical processes, oxygen plays a major part in the maintenance and the health of the abundant resources of estuaries.

Oxygen conditions in estuarine environments at any given moment are the result of complex interactions between both biological and physical processes. Major biological contributions to oxygen cycling are its photosynthetic production by phytoplankton, benthic algae, and attached higher plants; and consumption via respiration by these same algae and plants, by animals, and by microorganisms during decomposition of organic matter within the water column and in the sediments. In a healthy estuary, oxygen production and consumption are appreciably in balance with each other. However, in the upper water column where light effectively penetrates and photosynthesis occurs, there is a net increase in oxygen; at greater depths there is not sufficient light for photosynthesis, and consequently there is a net oxygen loss due to the predominance of respiration. So although the whole system is roughly in oxygen balance, there are local spatial differences in oxygen conditions because of differences in the rates of biological processes that produce and consume oxygen.

Because photosynthetic oxygen production is a light-driven process, there is also a day/night temporal disparity between the biological supply and removal of oxygen. Oxygen is consumed steadily day and night; however, it is produced only during the day. In nearly all coastal embayments, the minimum oxygen conditions occur near dawn, after the maximum period of darkness. From that minimum, oxygen conditions improve throughout the day. Therefore, measurements of oxygen concentrations conducted during daylight hours may overestimate average oxygen concentrations over a day/night cycle. Understanding these processes is very important in any program designed to monitor oxygen conditions for the assessment of water quality.

Physical factors that influence oxygen conditions in estuaries include bathymetry, wind-driven mixing, hydrodynamics, temperature, and salinity. These processes act in concert with biological activities and can have major influences on estuarine oxygen conditions. Under normal circumstances the exchange of water-column oxygen with the atmosphere and with external waters via the tides is a more important regulator of estuarine oxygen concentrations than are biological supply and removal processes. These physical processes alone can account for over half of the flux of oxygen in and out of estuarine systems.

Bathymetry, or bottom depth, can profoundly influence the ability of oxygen to mix in the water column. Isolated deep basins, cut off from light and photosynthetic activity, can affect overlying water-column oxygen concentrations both through the accumulation of organic matter, which results in bottom-water oxygen consumption by decomposition processes taking place in the sediments, and through the inability of wind to physically mix oxygen from surface layers into the deeper basins.

Other physical features of estuaries can influence stratification and distribution of dissolved oxygen. The orientation of an estuary in relation to prevailing winds can have important effects on stratification, either enhancing or inhibiting wind-driven mixing of the water column. Storm events can completely overturn a water column in less than an hour, equalizing oxygen concentrations in the upper and lower halves.

In riverine systems and their associated estuaries, the potential for stratification and subsequent low-oxygen conditions is dependent to a great extent on the velocity of flow and/or velocity of tidal forces, which together with wind-driven mixing will influence oxygenation of these waters and minimize the potential for stratification. These systems can generally be broken down into three categories: (1) estuaries in which circulation is dominated by river flows and tidal influences are less significant; (2) partially mixed estuaries in which both processes are at work; and (3) estuaries in which tidal forces alone are sufficient to vertically mix the water column. In well-mixed estuaries such as the Delaware Estuary, tidal motions are sufficient to mix the water column and the system is primarily vertically homogeneous. Tidally-induced vertical mixing is most dramatic during spring tides (the times when tidal range is maximum; these occur twice each month in phase with the lunar cycle).

Water temperature is another important factor that influences oxygen conditions in estuarine ecosystems. At high temperatures, the solubility, and therefore concentration, of oxygen is low; as water cools, oxygen content increases independent of biological activity (cold water holds more dissolved gas than does warm water). It is frequently observed that a decrease in oxygen concentration is found with increasing temperatures from spring to summer. In many instances, the decrease can be accounted for solely by physical processes influencing the solubility of the gas. Because estuaries are generally shallow with large surface-to-volume ratios relative to oceanic systems, temperature variations are generally large, reflecting changes in atmospheric conditions over time through heat exchange at the air-water interface. As water temperatures increase, biological processes such as photosynthesis and respiration are also affected. Temperature rise causes increases in biological respiration, which in turn potentially lead to oxygen-depleted conditions in the water column.

The above discussion has focused on natural processes that can influence oxygen conditions in all estuaries. However, during the last 100 to 200 years, human activities have played an increasing role in the health of estuarine ecosystems, including oxygen status. Coastal areas have become more heavily populated during this time period, and today are sites of intense domestic, agricultural, and industrial activities. Estuaries have historically been utilized for many of these activities, including the direct discharge of domestic and industrial wastes and fertilizers applied to a variety of agricultural lands. Studies of sediment cores from several estuaries show that oxygen stress has been increasing steadily over the last 200 years and has been particularly acute in the last 50 years (Sutton et al. 1996).

Increased nutrient inputs from human, or anthropogenic, sources stimulate increased rates of primary production of algae and other aquatic plants, through eutrophication. With increased levels of primary production, there is an increase in oxygen demand from respiration, both by the larger populations of algae and plants and by the increased levels of decaying organic matter. This increase in oxygen demand places greater stress on the ability of photosynthesis and physical exchange processes to compensate oxygen loss. When production of organic matter becomes excessive, physical exchange and biological oxygen production cannot keep up with the ecosystem's respiratory demand for oxygen, or Biochemical Oxygen Demand (BOD). BOD is frequently used as an indicator of nutrient imbalance and eutrophication in aquatic ecosystems. In general, the higher the organic matter production, the higher the BOD. An imbalance between oxygen production and consumption results in the degradation of water quality and the disappearance of valuable ecosystem resources. Although this deterioration is ultimately the result of nitrogen loading, it is the depletion of oxygen due to nocturnal respiration of these plants combined with microbial decomposition of organic matter that is the proximate cause.

When an ecosystem is severely eutrophic and on the border of failing in oxygen maintenance, oxygen concentrations in the water can swing repeatedly between completely normal conditions to stressfully low conditions in a matter of a few hours. During periods of heavier organic-matter production, as during summer planktonic algal blooms, coupled with prolonged stratification, the oxygen content of the water column can be reduced to damaging levels for periods of weeks.

Although most of the respiration and nutrient regeneration in estuaries takes place in the water column, sediments can also play an important role in the nutrient and oxygen economy of coastal ecosystems. Marine sediments that receive dead organic matter as it settles out of the water column are sites of active decomposition. As the sediment organic matter decomposes, nutrients are released and BOD increases. The amount of nutrient regeneration and oxygen consumption is directly proportional to the amount of organic matter produced. The re-release of nutrients after algae and phytoplankton (whose growth has been stimulated by the initial availability of nitrogen) die and decompose makes nutrients once again available for production in the water column. The sediments, thus, may act as a "storage battery" for nutrients, continuing to provide a source of nutrients for biological production even though the original nutrient inputs may have diminished or ceased. Nutrients regenerated from the sediments can supply almost half of the total nutrients used in primary production. How many times the nutrients cycle between sediments and the water column before being flushed out to the ocean or buried permanently in the sediments is directly related to the degree of eutrophication and oxygen depletion.

IV.E.5.b. Dissolved Oxygen Time Histories

Prior to the 1980s, the DO concentrations in most of the Estuary did not meet applicable DRBC standards (Sutton et al. 1996). Warm water dissolved oxygen concentrations approached zero in the Philadelphia region (Figure IV-9) of the Estuary, and fish and other aquatic organisms perished. These depletions were due to bacterial respiration during decomposition of the largely untreated sewage entering the Estuary. Since that time, major sewage treatment facility upgrades have improved the DO levels. However, combined sewer overflows (CSOs) still continue to contribute untreated wastewater and stormwater runoff to the Estuary, affecting DO concentrations. Philadelphia, for instance, has 176 CSOs, and Camden County, NJ, has 36 (DRBC 1998).

Historical profiles of DO concentrations along the axis of the Estuary show a sag in oxygen from RM 110 seaward to approximately RM 55 (Figures IV-9 and IV-10). The DO concentration sag was most pronounced between RM 105 and RM 65. In recent years (1995-1997), the DO sag had decreased to approximately 1.5 mg/L compared to earlier sags of about 3.5 mg/L (Appendix C). This increase in DO concentration is a direct result of actions taken to improve the water quality of the Delaware River and Estuary.

Analysis of all historic DO data from Appoquinimink River and Liston Point (Figure IV-10), two sampling sites close to Salem, show no statistically significant long-term trends in DO for the summer season or for the entire year (Appendix C).

IV.E.6. Other Contaminants

Numerous recent studies on the extent of other contamination of the Estuary exist, and are summarized in Appendix C. Contaminants of concern have been identified by regulatory agencies under §303(d) and §305(b) of the Clean Water Act. These contaminants of concern include PCBs, PAHs, DDT, DDD, DDE, perchloroethylene (PCE) or tetrachloroethylene, 1,2-dichloroethane, dieldrin, copper, and fecal coliforms. Appendix C discusses each of these contaminants.

IV.E.7. Water Quality Trends

The Delaware watershed has 1,450 industrial and municipal wastewater discharges, 162 of which are located along the Estuary (Sutton et al. 1996). There has been substantial improvement of waste streams compared to conditions existing prior to the 1970s, when the Clean Water Act and other public initiatives focused attention on improving the condition of the Estuary. As a result of the improvements, such as the upgrades of most sewage treatment plants, water quality trends have also improved.

C Table 19 summarizes improvements in water quality of the Estuary. In the Transition Zone, an increase in the level of DO, and decreases in the levels of ammonia, total phosphorus, turbidity, and fecal coliforms have occurred during the past two decades. The historic DO sag between RM 110 and RM 60 never extended down estuary to the vicinity of the Station and there has been no significant trend up or down during the past 30 years in the vicinity of the Station. Levels of nitrate have increased, the single offset in an otherwise significant improvement in water quality opposite the Station. In particular, DO levels have improved in the Transition Zone.

IV.F. The Biological Community of the Delaware Estuary

The Delaware Estuary biological community consists of all the organisms that utilize the wide variety of habitats within the tidally influenced Delaware Bay and the Delaware River south of the rapids at Trenton, including adjacent wetlands and the tidal portions of all tributaries (Figure IV-11). The physical and water quality attributes that have been described above influence the abundance and distribution of organisms residing in this community. This section describes the major habitat zones, organism movements, and community energy structures in the Delaware Estuary. It provides the biological context for understanding an organism's exposure to the Station's thermal discharge and the relative importance of the area occupied by the Station's thermal plume for the various life cycles of indigenous species.

IV.F.1. Habitat Zonation (Summary from Appendix C)

The Delaware Estuary contains a diverse array of habitats. It is an open-ended system that interacts with both the coastal marine habitat and the freshwater habitat from tributary streams and ponded waters lying above the tide line. Aquatic habitats are customarily classified by zone, on the basis of such characteristics as spatial position in the water body (including depth in the water column) and, in the case of enclosed bays and estuaries, salinity.

As shown in Figure IV-11, the Estuary can be divided into three distinct habitat zones based primarily on salinity, turbidity, and biological productivity (Sutton et al. 1996; and Appendix C to this submittal). These zones, established by consensus at the Delaware Estuary Program's Scientific and Technical Advisory Committee workshops held in the spring of 1990, are as follows:

- The freshwater Tidal River Zone of the Estuary (and associated tidal freshwater wetlands) extends downstream from the head of tide at Trenton, New Jersey (RM 133), typically to about the Delaware-Pennsylvania border (RM 80). Turbidity varies from low at the upstream end of this region to moderate at the downstream end.
- The Transition Zone has highly variable salinity (0 to 15 ppt). It extends from Marcus Hook, PA (RM 80) to the lower end of Artificial Island (RM 50). This habitat zone and the adjacent null zone have high turbidity and relatively low primary biological productivity.
- The Delaware Bay Zone has moderate to high salinity. This essentially marine habitat extends downbay from Artificial Island (RM 50) to the mouth of Delaware Bay (RM 0). Average salinity ranges from about 4 to 18 ppt at the head of the Bay to about 32 ppt at the mouth. Turbidity declines steadily to low levels near the mouth of the Bay and primary productivity is relatively high, particularly in the mid and lower Bay. This zone provides an extension of habitat for many

coastal and marine species and entry to the Estuary for those anadromous species migrating upstream to spawn.

Few species can survive the full range of salinity (0 to 32 ppt) that occurs in the Estuary and in other estuaries. Thus, obligate freshwater organisms that are carried downriver into brackish water regions perish, as do obligate marine organisms that are transported into less saline regions. The freshwater and marine organisms that die as a result of transport into water of unfavorable salinity contribute to the detrital portion of the food supply in brackish areas. The biological community that occupies the Delaware Estuary necessarily can be subdivided on the basis of these habitat types.

As shown in Figure IV-11, the Estuary also consists of horizontal and vertical habitat zones. All of the open water from Trenton southward into the Atlantic Ocean is referred to as the pelagic zone. Vertically, this pelagic zone is subdivided into zones defined by light penetration. The upper, thin euphotic zone (the photosynthetic or primary producer zone) extends to the depth of light penetration where photosynthesis and respiration rates become equal (zero net photosynthetic activity). In the Transition Zone, including the vicinity of Artificial Island, where the river water is highly turbid, the euphotic zone is thin and ranges from about 1 inch to 3 feet deep (Section IV.E.2). The aphotic zone consists of all water deeper than the euphotic zone, in which limited light penetration prohibits net photosynthetic production.

The pelagic zone is bordered on both sides by an extensive complex of shallow near-shore and wetland habitats. These areas, plus adjacent areas lying between the seasonal high and low water levels, constitute the littoral zone. Estuaries commonly have extensive near-shore areas of shallow water with submerged and emergent macrophytes growing on the bottom. The Estuary has almost no submerged macrophytes. However, because the fauna of these areas are more typical of littoral than pelagic zones, the littoral zone in this document is defined as all of the areas lying between the seasonal high water level and water less than 6 feet in depth at low tide even if they lack macrophytes. Vertically, the littoral zone includes the bottom as well as the overlying water column, and also includes any submerged, floating, or emergent vegetation.

The littoral zone occurs largely around the margin of the Estuary, and also around the islands. The organisms that reside in it rely primarily on the extremely productive marsh vegetation for habitat and food. However, during each ebb and flood tide, tidal currents transport a cascade of suspended sediment, nutrients, detritus, and organisms back and forth into and out of this zone. Thus the littoral/wetlands zone and pelagic zone should be considered as interactive subcompartments of the total community.

The bottom portion of the Estuary beneath the open-water pelagic zone is called the benthic zone. The depth of pelagic habitat overlying this benthic habitat is relatively shallow in the freshwater Tidal River and Transition Zones, averaging less than 10 feet except in the shipping channel, where dredging maintains a depth of 40 feet. Water depths increase downstream in the Delaware Bay Zone, with maximum depth about 150 feet in the shipping lane at the mouth of the Estuary.

The varied characteristics of all these spatial dimensions combine to produce a wide variety of aquatic habitats extending from the ocean upstream into each of the tidal freshwater tributaries. In this respect, the Estuary is no different from any other coastal system. This wide variety of habitats supports thousands of species. As a result of evolutionary adaptation, individual species are likely to live in and depend on only a portion of the spectrum of habitats available. Some habitats have suboptimal conditions, and thus do not contribute substantially to the maintenance of the population.

IV.F.2. Organism Movements

Organisms are transported into, out of, and within the Delaware Estuary by a combination of physical transport processes (water movements) and behavioral processes. The relevant physical transport processes are discussed in detail in Appendix C Section III, Section V.A, and Section V.B and will be highlighted here. Also, relevant behavioral processes that have been demonstrated in immature stages of macroinvertebrates and fish will be reviewed here. The key transport mechanisms during successive life stages of particular species will be discussed in connection with the respective taxa in Appendix C Sections VII and VIII.

IV.F.2.a. Physical Transport Processes of Organisms

Vertical and horizontal current shears, and differential advection along streamlines of different velocity, contribute to longitudinal dispersion in the Delaware Estuary. Tidal trapping also contributes to longitudinal dispersion, as tidal currents interact with bottom or shore irregularities (Okubo 1973; Fischer et al. 1979). For example, when a water mass passes a shoreline indentation (e.g., a tributary mouth) during flood tide, part of the mass will move into the indentation and become "trapped" while the rest of the mass migrates upstream. In this way, an initially coherent mass of water becomes separated into fragments which, after only a single tidal cycle, may differ in position by a distance on the order of the tidal excursion .

The significance of these physical transport processes for organism transport is most obvious for microscopic or nearly microscopic organisms suspended in the water-column, such as bacteria, phytoplankton, zooplankton, and the early dispersal stages of many macroinvertebrates and fish. These organisms typically have very limited motility and are nearly neutrally buoyant. Consequently, they tend to be carried along by currents and, to varying degrees, turbulent eddies.

The degree to which such organisms are transported by turbulent eddies appears to be determined mainly by the same factors that apply to fine suspended sediment (McNair et al. 1997). In the vertical direction, the key factor in most situations is the Rouse number (= the fall velocity divided by the product of the shear velocity and Von Kármán's constant, the latter being approximately 0.4 in water not heavily laden with sediment). If the Rouse number for a particular organism or life-stage is sufficiently small, then individuals of that type will be readily transported by turbulence and (in the absence of attachment to the bottom or surface) will tend to become uniformly distributed throughout the water-column; otherwise, the fall velocity will dominate vertical dispersion and individuals will tend to accumulate near the bed (if the Rouse number is "large" and positive) or the surface (if "large" and negative).

Key determinants of an organism's fall velocity include body size, shape (which affects drag), density, and any net vertical component of swimming velocity. Many planktonic organisms (e.g., chironomid larvae and many fish larvae) possess "air sacs" or "swim bladders" that increase their buoyancy and thus decrease their fall velocity. Except for vertical swimming and air sacs, these are the same key factors that determine fall velocities of sediment particles (e.g., Graf 1971).

An important difference between turbulent vertical transport of suspended sediment and of organisms is that the mechanisms whereby particles settle on, or are entrained from, the bottom are often quite different (McNair et al. 1997). For example, active behavioral attachment to, or departure from, the bottom is common among motile organisms. Purely gravitational settlement therefore appears to be much less important for biological organisms than for suspended sediment. Consequently, areas where current speeds and turbulence are sufficient to prevent noticeable accumulation of fine sediment may nevertheless be ideal for colonization by organisms having similar or smaller Rouse numbers than those sediments. In such areas, ambient turbulence may rapidly transport the organism to the bottom, while behavioral attachment prevents scour (e.g., Denny and Shibata 1989; McNair et al. 1997).

IV.F.2.b. Behavioral Processes

Many estuarine organisms, especially zooplankton and higher animals, exhibit behaviors allowing them to play an active role in the transport process. These behaviors range from simple kineses to complex, directed responses to environmental stimuli. The types and complexity of behavior differ markedly among species, and even within a given species often change dramatically during ontogeny, as in many macroinvertebrates and fish. Thus, an adequate discussion of the role of behavioral processes in organism transport requires both a general discussion of the relevant categories of behavior and a series of specialized discussions for key taxa, indicating which behavioral processes are important during the various stages of the life-history. The present section provides a general discussion of behaviors that have been demonstrated in immature macroinvertebrates or fish and that have the potential to alter the transport of these organisms, compared to passively transported particles; taxa-specific information is provided in Appendix C Section VII, Appendix C Section VIII, and Attachments C-1 through C-14, as part of the discussion of the life-history and ecology of each group. Most of the relevant behavioral information comes from a small number of heavily studied species of commercial importance. Some of these species do not occur in the Delaware Estuary, but the behavioral mechanisms are nevertheless of interest since they are likely to be exhibited by other taxa.

Behavioral responses to environmental stimuli may be broadly classified as either kineses or taxes. Kineses are behaviors in which an organism's type or level of activity changes, but where the activity is not directed (spatially) in relation to the stimulus. Taxes are behaviors in which, in addition to any changes in type or level of activity, an organism's activity also becomes directed in relation to the stimulus. In the absence of significant water currents, it is well known that kineses and taxes are capable of producing spatial distributions with high densities of organisms in areas where kinesis is low (implying the mean residence time is high) or where stimuli causing relatively strong positive taxis are present, and with low densities in other areas. Such spatial distributions would differ among species and life-stages with different kinetic and tactic behavioral repertoires and which respond to different environmental cues. The presence of significant currents complicates this picture considerably, particularly given the complex and temporally varying velocity field characteristic of estuaries.

As an example of the different roles that kineses and taxes may play in organism transport, Hughes (1969) found that experimentally increasing salinity caused postlarval pink shrimp (*Penaeus duorarum*) to swim actively, while decreasing salinity reduced or halted swimming activity and caused postlarvae to settle on the bottom. These behavioral responses to salinity are kinetic. On the other hand, juveniles of the same species exhibited tactic responses: they became positively rheotactic in response to increasing salinity and negatively rheotactic in response to decreasing salinity. Hughes (1969) argued that this combination of kinetic and tactic behaviors would interact with tidal flow during flood and ebb tides to move postlarvae into estuarine nursery areas and juveniles outward toward the sea. This is the observed pattern of transport in many estuaries, though it is not known whether this particular combination of physical and behavioral mechanisms is, in fact, the main cause of the pattern.

A wide variety of environmental cues are known to elicit kinetic or tactic behavioral responses in estuarine organisms. These include salinity and other chemical cues, temperature, current velocity (speed and direction), light/dark and other visual cues, hydrostatic pressure, and gravity.

Salinity has been proposed as a potentially important chemical cue for many organisms in and near estuaries (e.g., Miller 1988). Since estuarine salinity tends to increase in the seaward direction (though not uniformly), it contains locational information that organism behaviors may exploit. Moreover, as in the pink shrimp example above, the temporal pattern of change in salinity during ebb and flood tides contains directional information.

Chemical cues other than salinity have also been proposed as potentially important cues in estuaries. For example, evidence suggests that both European and American eel (*Anguilla rostrata*) elvers decrease swimming activity and sink to the bottom when the concentration of inland water is experimentally increased, but increase swimming activity when the concentration of sea water is increased (Creutzberg 1961; Miles 1968). The cue is not simply salinity and appears to be a biodegradable constituent of inland water.

Temperature differences exist between the estuary and sea during most of the year, with the ocean being cooler than the upper estuary during spring and summer, but warmer during autumn and winter. Many organisms are known to exhibit temperature preferences (e.g., fish: Brett 1970). Therefore, the locational information contained in this temperature gradient, in conjunction with physical transport and appropriate kinetic or tactic behavioral responses (e.g., reduced swimming at preferred temperatures), could produce aggregations of organisms in areas near their preferred temperatures. Moreover, seasonal or other temporal changes could induce emigration from areas where temperatures are becoming undesirable (much as in young salmonids, which shift from positive to negative rheotaxis with increasing temperature: Hoar 1951).

Current velocity provides an obvious directional cue associated with the estuary, but one that reverses over each tidal cycle. Many estuarine invertebrates and fish can detect and respond to water currents. For example, fish are able to detect currents at least as slow as 0.01-0.09 m/sec (0.04-0.32 knots; Arnold 1981). Many of these organisms are also able to orient with respect to water currents and may exhibit either positive or negative rheotaxis, as mentioned above in connection with juvenile shrimp. The spatial distribution of maximum tidal current speeds in the Delaware Estuary is illustrated in Figure IV-7 (NOAA 1987). Tidal currents generally decrease from the entrance to the wider portions of Delaware Bay. Here, maximum tidal current speeds within tidal shallows range from about 0.1 to 0.4 m/sec (0.25 to 0.75 knots); maximum current speeds along the bay axis are about 0.5 m/sec (1.0 knot). As the Estuary funnels upstream into the Transition Zone (near Salem and Reedy Point), maximum current speeds increase and approach 0.8 m/sec (1.5 knots). These current speeds are much greater than the sustainable swimming speeds of invertebrates and small fish. For example, swimming speeds of early-stage crab larvae are roughly 0.001 to 0.003 m/sec (0.004 to 0.011 knots; Epifanio 1988); sustainable swimming speeds of fish are roughly 1 to 2 body lengths per second (Miller et al. 1985), which translates to 0.05-0.09 m/sec (0.18-0.32 knots) in a 5-cm-long (2-in.-long) fish. Thus, for invertebrates and small fish, positive rheotaxis is of limited use in opposing near-surface currents in much of the estuary, but could be effective near the bottom and in marginal areas, where current speeds are much lower.

Many types of zooplankton, invertebrate larvae, and fish larvae are negatively phototactic when tested in the laboratory (e.g., Boehlert and Mundy 1988; Epifanio 1988). Solar and lunar light provides both temporal and directional information, though its importance as a directional cue in the more turbid parts of estuaries has been questioned, due to the light-scattering effect of turbidity (Epifanio 1988).

A wide variety of estuarine invertebrates and fish exhibit behavioral responses to gravity, including orientation as well as taxis. For example, early-stage crab larvae typically are negatively geotactic while late-stage larvae and postlarvae often are positively geotactic (Sulkin 1984). This behavioral difference has the potential to place early-stage larvae in near-surface water with a net down-Estuary flow and late-stage larvae and postlarvae in near-bottom water with a net up-Estuary flow, though the degree to which this differential transport mechanism is realized in practice is unknown.

Hydrostatic pressure is another environmental cue to which some estuarine organisms are known to respond. Early-stage brachyuran crab larvae, for example, exhibit a threshold response to increasing hydrostatic pressure: once the threshold is exceeded, swimming speed increases with pressure (e.g., Sulkin and Van Heukelem 1982). This kinetic response would tend to keep these larvae from sinking deep in the water-column.

IV.F.3. Temporal and Spatial Variation in Transport Mechanisms. Superimposed on the physical and behavioral transport mechanisms discussed in the previous section are several potentially important patterns of temporal and spatial variation. Temporal changes in behavioral processes include diel vertical migration, endogenous rhythms, and changes during ontogeny. The main source of temporal variation in physical transport processes is the tide. There are many significant sources of spatial variation in physical transport processes. These include vertical, transverse, and longitudinal differences in current speed and direction within the Estuary, as well as differences between transport processes in the Bay and in nearshore and offshore areas outside the Bay. All of these sources of temporal and spatial variation are potentially important with regard to organism transport, but none is adequately understood at present, even for commercially important macroinvertebrates and fish. (A useful collection of alternative viewpoints can be found in Weinstein 1988.)

The daily pattern of temporal change in light intensity is important in the phenomenon of diel vertical migration, in which many species of invertebrates and fish move upward in the water-column as light levels decrease and downward as light levels increase. It should be noted that reversals in the direction of estuarine currents do not coincide with light-to-dark and dark-to-light transitions, so that vertical migration does not have the effect of preferentially selecting up-Estuary or down-Estuary tidal flows. Nevertheless, depending on how close to the surface a particular organism moves at night and how close to the bottom it moves during the day, its net movement over several tidal cycles can be in either direction, and species with different patterns of vertical distribution will show different patterns of net movement (e.g., Weinstein et al. 1980).

Endogenous activity rhythms provide a possible, though poorly studied, mechanism for selecting up-Estuary or down-Estuary currents, provided such rhythms are entrained to the tidal cycle. Cronin and Forward (1979) provide evidence that vertical migration in blue crab larvae (*Callinectes sapidus*) becomes synchronized to the local tidal cycle and that this synchrony decays several days after larvae are brought into the laboratory from the field. During the first few days in the laboratory, the larvae appear to move upward in the water-column during periods corresponding to flood tides and downward during periods corresponding to ebb tides. In the field, this circatidal behavior potentially would favor up-Estuary movement.

Important temporal changes in behavioral mechanisms affecting organism transport also occur during the ontogeny of individuals. Some examples of this type have already been mentioned in the previous section; e.g., the change in salinity response of immature shrimp between postlarval and juvenile stages of development, and the change in geotaxis between early and late larval stages of brachyuran crabs. Among fish, a variety of important changes occur during metamorphosis which affect behavior in ways that probably alter organism transport. For example, skeletal calcification and full development of fins occur, greatly increasing swimming ability (Blaxter and Staines 1971). Retinal rods develop, permitting vision at low light levels (Blaxter 1974). Flatfish larvae (e.g., flounder) shift from pelagic to benthic habit and largely cease to exhibit either rheotaxis (Arnold 1969) or positive phototaxis (Kawamura and Ishida 1985). During this transition, they alternate between swimming in the water-column and resting on the bottom, potentially providing a trial-and-error mechanism for locating appropriate habitats (Fluchter 1965).

As discussed in Appendix C Section III.B.2.a, the dominant source of temporal variation in physical transport in the Estuary is the tide. Over the course of a tidal cycle, water currents reverse direction even in the upper part of the Delaware Estuary (e.g., Miller 1962). In the Bay, the spatial and temporal pattern of flow is complex and not well understood, but evidence to date supports the view that in much of the Bay, inflow from the ocean is concentrated in the deep, central channel of the Bay and travels mainly but not entirely near the bottom, and that outflow travels mainly along the shallow margins of the Bay (Wong 1994). Consistent with this view, it appears that ocean-derived sand enters the Bay and moves up-Estuary along the bottom, while fine suspended sediment (silt and clay) moves seaward along the margins of the Bay (see Sections V.A and V.B).

These patterns of flow reversal, residual circulation, and net sediment transport, in conjunction with the behavioral mechanisms discussed above, suggest a variety of possible explanations for observed patterns of movement and distribution of immature stages of organisms in the Estuary. The consensus view among researchers studying the various groups of macroinvertebrates and fish is that these patterns cannot be adequately accounted for by assuming simple passive transport by the water in which they are suspended; behavioral mechanisms play an essential role (e.g., Boehlert and Mundy 1988; Miller 1988; Epifanio 1988). Unfortunately, even for relatively well-studied species, the precise nature of this role remains conjectural. A few broad conclusions can, however, be drawn.

First, except in shallow areas along margins of the Estuary, the main direct contribution of behavioral mechanisms with regard to organism transport probably lies in vertical rather than horizontal movements. The dominant water currents run horizontally and travel at speeds that greatly exceed the sustainable swimming speeds of immature macroinvertebrates and fish. Swimming against such currents would therefore be both energetically expensive and futile. But current speed approaches zero near the bottom, and its direction reverses with the tide. Thus, depending on its timing relative to the tide, cyclical vertical migration can preferentially select currents traveling either down-Estuary or up-Estuary, and can result in transport anywhere between the ocean and the upper parts of the Estuary in an energetically efficient manner.

Second, many initially planktonic invertebrates and fish become benthic at some point during ontogeny. Behaviorally driven vertical movement between the water-column and the bottom, coupled with current-driven horizontal transport, is probably a common trial-and-error mechanism allowing immature organisms to locate suitable benthic habitats in which to continue their development.

Finally, current speeds can be greatly reduced in shallow waters along the margins of the Estuary (including marshes). Many organisms have sufficient swimming abilities to successfully oppose currents in such areas, and behaviorally driven horizontal transport will therefore be important.

IV.F.4. Linkage of Ocean and Estuary

IV.F.4.a. Physical Attributes

The hydrography and circulation of the continental shelf influences exchange processes with the Delaware Estuary. Both astronomical and meteorological tides propagate into the Estuary from the adjacent continental shelf. Also, shelf waters provide a vast reservoir of salt water for the Delaware Estuary. The intrusion and mixing of these saline waters regulates estuarine transport patterns and associated chemical, biological and geologic processes (Appendix C Section III.B).

Conversely, the freshwater inflows to the Estuary provide buoyancy fluxes to the adjacent continental shelf. Also, the Estuary contributes vast quantities of nutrients, particulate matter and biota to adjacent coastal waters.

As discussed previously (Appendix C Section III.B), the subtidal circulation of the Delaware Estuary is strongly coupled to the adjacent continental shelf. The mean interaction of Delaware Bay and the adjacent inner shelf results in two principal forms for the mean flow (Garvine 1991). First, low-salinity water exiting the Estuary forms a buoyancy-driven coastal current along the Delmarva Peninsula. This current is initially intense and narrow (12.9 km (8 mi) wide) near the bay mouth and subsequently slower and wider along the Delaware coast (Garvine 1991). The second form of the mean exchange consists of a landward-directed, saline flow over most of the inner shelf (from 40 km (25 mi) offshore) towards the Delaware Estuary (Pape and Garvine 1982). This flow supplies the vigorous mean landward flow (approximately 0.1 m/sec; 0.3 ft/sec) at depth produced by the estuarine gravitational circulation. These near-bottom flows, and the substances that they transport, may extend at least 97 km (60 mi) into the Estuary (the typical limit of salinity intrusion).

Kelley (1980) has reported that Delaware Bay sediment has been identified within the southern New Jersey coastal lagoons, suggesting that the Bay waters can escape around Cape May and transport suspended materials to the north.

IV.F.4.b. Faunal Assemblages and Energy Transfer

The strong currents moving in both directions between the Bay and the contiguous open ocean transport many organisms. As discussed in Appendix C Section V.C, planktonic forms (including early life-stages of many macroinvertebrates and fish) and small pelagic fish are not capable of sustained swimming at speeds that would allow them to oppose these currents, so they are carried with the flow. Certain larger fish and turtles with greater control of their horizontal movement also travel between the Bay and nearshore areas of the ocean.

Most of the important species listed by Sneddon et al. (1995) in marine habitats of the estuary (i.e., habitats with salinity consistently greater than 30 ppt) move between the bay and the contiguous ocean either as immatures or adults, as do several species of marine mammals. Excluding forms that are too rare to contribute significantly to the bay-ocean exchange, this biotic category of species includes the moon jelly (*Arelia aurita*), comb jellyfish (*Phylum Ctenophora*), sea nettle (*Chrysaora* spp.), various copepods, horseshoe crab (*Limulus polyphemus*), mysid shrimp, sand shrimp (*Crangon septemspinosa*), various crabs (including the blue crab), knobbed (*Busycon carica*) and channel (*B. canaliculatum*) whelks, hard-shelled clam (*Mercenaria mercenaria*), sand tiger and sandbar sharks (*Carcharhinus milgerti* and *Odontaspis taurus*), smooth and spiny dogfish (*Mustelus canis* and *Squalus acanthias*), roughtail and bluntnose stingray (*Dasyatis centroura* and *D. say*), bullnose ray (*Myliobatis freminvillei*), clearnose skate (*Raja eglanteria*), little skate (*Raja erinacea*), winter skate (*Raja ocellata*), Atlantic sturgeon, American eel, alewife (*Alosa pseudoharengus*), blueback herring (*A. aestivalis*), Atlantic croaker (*Micropogonias undulatus*), black drum (*Pogonias cromis*), spot, bay anchovy, silversides, striped mullet, Atlantic menhaden (*Brevoortia tyrannus*), weakfish, bluefish, striped bass, American shad, black sea bass, scup (*Stenotomus chrysops*), tautog (*Tautoga onitis*), summer flounder, windowpane (*Scophthalmus aquosus*), Atlantic loggerhead (*Caretta caretta*), green sea turtle (*Chelonia mydas*), leatherback turtle (*Dermochelys coriacea*), hawksbill (*Eretmochelys imbricata*), Atlantic ridley (*Lepidochelys kempi*), humpback whale (*Megaptera novaeangliae*), bottlenose dolphin (*Hyperoodon ampllatus*), harbor porpoise (*Phoecoena phoecoena*), and harbor seal (*Phoca vitulina*). Bay-ocean exchange is particularly significant for the common species with known spawning movements into the ocean (e.g., American eel, menhaden, summer flounder, bluefish, spot) or anadromous species which move into the ocean during summer through spring (e.g., American shad, blueback herring, alewife, striped bass).

IV.F.4.c. Organism Migration

Large seasonal variations in physicochemical conditions, most notably water temperature and salinity, as well as in productivity of lower trophic levels, results in large variability in species, abundance, and distribution of actively swimming fish and macroinvertebrates in the Estuary. During each season, but perhaps to a lesser extent in winter, consistent patterns of immigration and emigration are apparent. This results in a generally stable annual spatial distribution pattern. During spring and fall, major changes in water temperature and salinity prompt shifts in community composition as species adjust their distributions to seek preferred reproductive, nursery, or overwintering conditions. As temperature and salinity become more stable, so does the community, with many species using the warm, highly productive summer period for reproduction and growth. Only a few species are broadly distributed in the Estuary during the cold season.

In March or April, adult bay anchovy, Atlantic silverside, hogchoker, and white perch typically begin to spread out from their overwintering habitat in deeper water downbay, or in the ocean, to other portions of the Estuary to feed in preparation for later spawning. Mummichog, among the few fish to overwinter in tidal creeks and tributaries, become active in the shore zone as they, too, prepare for spawning during spring and summer months. The anadromous striped bass, American shad, blueback herring, and alewife pass through the lower and mid-estuary in the spring en route to spawning grounds upstream or in tributaries.

During late spring, as adult bay anchovy and hogchoker reach spawning condition, they begin to move back downbay to higher salinity spawning grounds. This movement of adults continues through summer as the juveniles mature. Adult weakfish (that entered the Estuary from offshore) and adult naked goby also begin to spawn downbay. By mid-June, some of the progeny of all these species typically have spread throughout the Estuary, and some have been transported back into the low-salinity water near the Station. Their abundance increases and remains high through summer when salinity conditions are favorable. Young spot and Atlantic menhaden prefer even less saline water, and move upstream to the oligohaline portion of the nursery.

Fish abundance declines during late September, October, and November, as decreasing water temperature stimulates emigration to overwintering areas downbay and offshore. The seasonal decline in water temperature also prompts the gradual movement of spot, Atlantic menhaden, and herring through the Transition Zone from upriver nursery grounds to downbay or oceanic overwintering areas. In response to lowering salinity and temperature, white perch also move into the Transition and Delaware Bay Zones from upriver. Conversely, during some years, progeny of the ocean-spawned but estuarine-dependent Atlantic croaker migrate into the same areas and use shallow-water areas and tidal creeks as nursery areas until minimum water temperature (in January or February) prompts their return to warmer water downbay or in the ocean. During winter, only white perch, hogchoker, and silvery minnow are common in the Transition Zone. Low water temperature limits activity as metabolism slows, and this generally restricts the distribution of these fish to the deeper waters.

IV.F.5. Community Composition and Trophic Structure

Partly because of the wide variety of habitats and seasonal utilization described above, the Estuary contains a diverse biological community comprised of thousands of species. All of these species are components of an integrated food web, conceptually illustrated in Figure IV-12, through which energy is cycled. It is customary to categorize biological communities based on habitat occupied, taxonomic association, and hierarchical position in the food web (i.e., trophic level). This organization into trophic levels is useful for understanding the roles that species and biotic categories play in the functioning of the community and for assessing the potential for disturbances from human activity. The trophic levels include primary producers (phytoplankton, macroalgae, and vascular plants), primary consumers (herbivores), secondary consumers (predators on the herbivores), higher level consumers (predators on smaller animals), omnivores (consumers of vegetation, detritus, and animals), and decomposers (bacteria and fungi) of plant and animal remains (detritus).

IV.F.5.a. Primary Producers

The sun's energy is converted by primary producers into the food energy that supports the biological community. Primary producers in the Estuary which utilize sunlight for energy fall into three main categories: phytoplankton, vascular plants, and attached algae. Phytoplankton are plant microorganisms such as certain algae that drift unattached in the water. Several hundred species of phytoplankton have been recorded in the Estuary, with diatoms, chlorophytes, cryptomonads, and cyanobacteria being the dominant taxa (Marshall 1992). Levels of phytoplankton primary production in the Estuary have been reported to be in the middle of the range measured for other East Coast estuaries (Pennock and Sharp 1986). In many aquatic systems, low levels of nitrogen and phosphorous nutrients limit phytoplankton production, while high levels support massive nuisance blooms. Although the Estuary may be characterized as a nutrient-rich system, nuisance blooms have not been observed, suggesting that other variables act to limit phytoplankton abundance. Water turbidity, for example, can limit phytoplankton growth by limiting the depth to which sunlight penetrates. In the Estuary, as a consequence of high suspended sediment concentrations and turbidity (Section IV.E.2), phytoplankton primary production is much lower in the Transition Zone than in the Tidal River or Delaware Bay Zones (Figure IV-13).

Vascular plants in the Estuary are largely restricted to the extensive tidal wetlands (Figure IV-11). The open waters of the Estuary contain few areas with submerged aquatic vegetation and the saline portions do not contain the eelgrass (*Zostera marina*) beds that are common elsewhere. Attached algae, including benthic growths on tidal flats and epiphytic algae which attach to vascular plants, also are found in the littoral/wetland zone. The primary production of the wetland plants is largely consumed as dead plant matter in the form of small organic particles (detritus). Detritus is consumed by omnivores in the marsh, and exported by the tides to feed animals throughout the Estuary. In addition to their role as a major food source, vascular plants are the primary habitat formers in the Estuary, providing food and shelter for a wide variety of organisms. Because of the high and variable water temperatures that result from solar insolation, species comprising the tidal marsh community are characteristically tolerant of fluctuating and high temperatures.

Plant species vary with salinity. In the higher salinity of the Delaware Bay Zone, smooth cordgrass (*Spartina alterniflora*) and salt hay (*S. patens*) predominate. Big cordgrass (*S. cyansouroides*), various sedges (*Scirpus* spp.), cattails (*Typha* spp.), salt marsh fleabane (*Pluchea purpurascens*), and other plants appear with increasing abundance in the brackish water tidal marshes further upbay and into the Transition Zone. Freshwater tidal marshes in the Tidal River Zone occur largely along tributaries. They are dominated by arrowhead (*Sagittaria latifolia*), pickerelweed (*Pontederia cordata*), arrow arum (*Peltandra virginica*), and cattails. During the past 50 years, common reed (*Phragmites australis*) distribution has increased in freshwater and brackish water tidal marshes to nuisance levels (Sutton et al. 1996). The causes of this spread are thought to include introduction of an aggressive European variety, and the physical disturbance of shoreline and marshlands. In addition, purple loosestrife (*Lythrum salicaria*) has become a nuisance in the freshwater marshes in recent times and its distribution is spreading.

IV.F.5.b. Consumers

All aquatic life other than primary producers are consumers. Consumers are totally dependent, directly or indirectly, for their food and nutrition on organic matter produced by these primary producers. Aquatic primary consumers graze on primary producers and resulting detritus. Primary consumers in the pelagic zone include detritus-feeding microbes, small invertebrate zooplankton (e.g., rotifers, cladocerans, and copepods), some larger invertebrates (e.g., opossum shrimp, scud, clams, oysters, and insect larvae), and waterfowl. Primary consumers in the littoral/wetland zone are more varied, consisting of zooplankton, amphipods (scud), opossum shrimp, snails, insects, mussels, crabs, grass shrimp, fish (e.g., mummichog and Atlantic silverside), waterfowl, muskrats, and whitetail deer. Larvae, juveniles, and adults of fish (e.g., American shad, alewife, blueback herring, bay anchovy, white perch, striped bass, weakfish, spot, and Atlantic croaker), macroinvertebrates (e.g., blue crab), waterfowl, wading birds, raptors, reptiles, and a variety of mammal species are among the principal secondary and higher lever consumers in the Estuary.

Of course, many species take advantage of feeding opportunities on multiple trophic levels. Many estuarine species are omnivores, eating particles of suitable size regardless of origin. For example, zooplankton may eat phytoplankton, other zooplankton, or particles of dead organic matter. In addition, a species' preferred food may change over the course of its life cycle. For example, the larvae of predatory fish and macroinvertebrates feed mainly at lower trophic levels (primary/secondary level consumers), but consume larger-sized food at higher trophic levels as they grow (Figure IV-12). This flexible feeding behavior permits individual species to take advantage of available food sources, diluting the effect on the food web of changes in the abundance of any single species.

<u>IV.F.5.b.i. Microbes (Decomposers)</u>

Microbes that grow on detritus are a major source of energy. They are eaten by primary consumers, particularly by suspension-feeding and deposit-feeding animals. The role of detritus in the food web is greatest in the tidal wetlands, in the highly turbid Transition Zone, and in the adjacent waters of the pelagic zone. Sources of detritus in the Estuary include upland vegetation in the watershed, vascular plants in the marshlands, phytoplankton, dead aquatic animals, and wastewater and municipal sewage discharge.

The microbes that feed on this detritus, including bacteria, fungi, and protozoa, link primary producers to the upper trophic levels and constitute an important part of the food web. The detritus-microbe assemblage exists both as fine particles suspended in the pelagic zone and as thick deposits in the marshes and bottom sediments of the mainstream. The microbes are probably the primary energy source for many detritus-feeding organisms (Odum 1971). By decomposing the detritus, they also release many nutrients including various forms of nitrogen, phosphorous, metals and carbon dioxide used by plants to synthesize new organic matter. Generation times for the microbes are measured in minutes to hours.

IV.F.5.b.ii. Zooplankton

Zooplankton are small animals living unattached in water; they have relatively limited powers of locomotion and drift with the currents. Holoplankton are zooplankton species that spend their entire life drifting in the water column, predominantly small crustaceans such as cladocerans and copepods, and single-celled animals such as protozoans. Generation times for the smaller holoplankton (nano- and microplankton) are measured in hours. Meroplankton are zooplankton species that spend only part of their life cycle drifting in the water column, such as the eggs and larvae of fish and shellfish.

The primary consumers of phytoplankton in the Delaware Estuary are mostly holoplankton (Figure IV-12). Holoplankton production in the lower Estuary far exceeds that in the upper Estuary. Copepods of various species comprise 85 percent of the holoplankton biomass (Herman 1988) and may consume 90 percent of the phytoplankton primary production in the lower Bay (Herman and Hargreaves 1988). Copepods are a major food for juvenile fish in the Delaware Estuary. Six species dominate the group: *Halicyclops fosteri*, *Eurytemora affinis*, *Acartia tonsa*, *A. hudsonica*, *Pseudodiaptomus pelagicus*, and *Oithona colcarva*. These species have large geographic ranges and are common in East Coast estuaries (Stearns 1995). Their distribution is salinity-dependent and their abundance is highest during summer months. *Halicyclops fosteri* and *E. affinis* are restricted to the upper portions of the Bay where salinities range from less than 6 to about 10 ppt, while *O. colcarva* is found primarily in high-salinity waters of the lower Bay. *Acartia tonsa*, *A. hudsonica*, and *P. pelagicus* occur throughout the Estuary, but their abundance is greatest at salinities above 5 ppt.

Larger macrozooplankton (retained by a 0.5-mm net) include invertebrates that spend all of their time in the water column such as comb jellies (ctenophores), and those that spend part of the time on or near the bottom as part of the benthos, such as amphipods and mysid shrimp. The latter are most abundant near the bottom (epibenthic), but also migrate vertically to preferred levels of light intensity and/or food supply. Generation times for the macrozooplankton are measured in weeks. Scud (*Gammarus* spp.) and opossum shrimp (*Neomysis americana*) are two important benthic macroinvertebrates (see below) in the Delaware Estuary. They have flexible diets that include plant remains, phytoplankton, and zooplankton and are considered important links to higher level consumers in the food web. The life cycles and distributions of scud and opossum shrimp are discussed in Section IV.G. below.

IV.F.5.b.iii. Macroinvertebrates/Shellfish

The benthic macroinvertebrates include all of the large invertebrates living within the bottom sediment (infauna) and on the surface of the bottom sediment (epibenthos). The distribution of benthic species in the Delaware and other estuaries is strongly influenced by salinity and sediment grain size. Dominant taxa have been reported to be similar to those of other East Coast estuaries (Hargreaves and Kraeuter 1991). Bivalves, including northern dwarf-tellin (*Tellina agilis*), Atlantic nutclam (*Nucula proxima*), and amethyst gemclam (*Gemma gemma*), dominate the benthos in the lower Bay (Sutton et al. 1996). Oligochaete worms and chironomid larvae dominate the benthic community in lower salinity regions of the Transition and Tidal River Zones of the Estuary.

As discussed above, the epibenthos includes mysids and amphipods that spend a portion of their time as part of the zooplankton. Other important epibenthic macroinvertebrate species of the Estuary include the commercially important blue crab, as well as the sand shrimp, horseshoe crab, hermit crab, grass shrimp, and fiddler crab, the latter being generally restricted to saltmarsh habitat. The life-cycle and distribution of blue crab, which utilize the mainstem and marshlands of the Estuary, is described in more detail in Section IV.G.

Benthic macroinvertebrates are an important link between primary producers and higher trophic levels. They recycle nutrients from both plant and animal remains and serve as food for other macroinvertebrates and fish (Figure IV-12). The larger, more motile members of this category (e.g., crabs) are predators on bivalves, crustaceans, and small fish, and are themselves consumed by fish and shore birds. Generation time for the benthic macroinvertebrates is generally measured in months.

IV.F.5.b.iv. Fish

Predatory fish are among the principal upper-level aquatic consumers in the Delaware Estuary. About 200 species occur within the Estuary, mostly on a seasonal basis. Fish species can be divided into two distinct groups: resident fish and migratory fish. Residents can be classified further by salinity preference as either tidal-freshwater, brackish water estuarine, or nearshore coastal marine residents. Migratory fish can further be divided into three groups: diadromous species, predominantly estuarine types, and predominantly marine types. The predominantly estuarine types include hogchoker, white perch, bay anchovy, Atlantic and tidewater silversides, naked goby, and mummichog. Predominantly marine species that use the Estuary include weakfish, spot, Atlantic croaker, bluefish, summer flounder, and Atlantic menhaden. The notable diadromous migratory species are American eel, blueback herring, American shad, striped bass, and alewife. One Delaware Estuary diadromous species, the shortnose sturgeon, is listed as endangered.

Fish larvae and early juveniles in the Estuary are predominantly primary and secondary level consumers, while larger individuals of the predatory species are predominantly third level consumers (Figure IV-12). Because they occupy the highest position in the aquatic food web along with sharks, wading and diving birds, humans, and other predators, fish are highly dependent on successful energy transfer from the lower trophic levels. The abundance of the fish populations therefore should be a sensitive indicator of potential disruptions in the trophic structure of the Estuary community. Generation times generally range from one year to five or six years.

Although estuaries are productive ecosystems, transition zones between the strictly freshwater and higher salinity areas are stressful environments for fish and other organisms (Sutton et al. 1996), due primarily to osmoregulatory stress from tidally induced changes in salinity, as well as to the high concentrations of suspended solids and low primary productivity in this transition area (Sections IV.E and IV.F.3.a). In the Delaware Estuary, fish species that normally inhabit only the Tidal River Zone or Delaware Bay Zone generally cannot tolerate the full range of the saline/freshwater extremes, and are therefore restricted in their longitudinal distribution in the Estuary (Sutton et al. 1996). Relatively few species of fish can tolerate, during part or all of their life cycles, the pelagic, brackish-water Transition Zone. The species that can include some whose population resides in the Estuary for most or all of their life cycle (e.g., white perch); some that migrate seasonally between the ocean and the freshwater Tidal River Zone (e.g., blueback herring, alewife, striped bass, and American shad); and marine species with distribution ranges that extend into the Transition Zone (e.g., weakfish, bay anchovy, spot, and Atlantic croaker). The life cycles and distributions of these selected species are discussed in Section IV.G.

IV.F.5.b.v. Other Vertebrate Wildlife

The Delaware Estuary provides habitat for a number of vertebrate groups other than fish. Over 300 species of birds are found annually throughout the Estuary; among them are numerous species of waterfowl, wading birds, and shorebirds. These aquatic birds are found on the beaches, tidal flats, and tidal marshes.

More than 70 species of amphibians and reptiles live in the Delaware Estuary watershed, most inhabiting upland terrestrial habitats, and freshwater ponds and streams. The only estuarine-dependent members of this group are five species of sea turtles (Atlantic green, Atlantic hawksbill, Atlantic leatherback, Atlantic loggerhead, and Kemp's ridley) and the northern diamondback terrapin. All the sea turtles are marine pelagic species that prefer warm areas of the open ocean, but range into temperate areas and shallow water, including the Delaware Estuary, during the summer months. Three of these species, Atlantic green, Atlantic loggerhead, and Kemp's ridley turtle, are listed as threatened or endangered. The diamondback terrapin inhabits tidal salt marshes along Atlantic coastal waterways and estuaries south of Cape Cod, including those bordering the Delaware Estuary.

IV.G. Species Representing the Biological Community

The Draft 316(a) Guidance provides for the selection of a representative group of species (the RIS) to represent the balanced indigenous community (see Section VI.C.1.c for further detail). A total of 12 macroinvertebrate and fish RIS were selected (Sections VI.D.1 and VI.D.2) using §316(a) guidance criteria following a vulnerability assessment that identified these two biotic categories as the only ones for which more detailed predictive RIS assessment was indicated. These RIS are consistent with prior 316(a) assessments at Salem (Section II.A.).

Life histories for each of the three macroinvertebrate and nine fish species selected as RIS are summarized below. They present information relevant for assessing the potential for Salem's thermal discharge to jeopardize the protection and propagation of a balanced indigenous community in the vicinity of the station. The summaries are based on scientific information available at the time that this Demonstration was prepared. References to specific topics can be found in Appendix C to this submittal and in the species-specific reports (Attachments C-1 through C-12)

IV.G.1. Macroinvertebrates

IV.G.1.a. Scud

Scud (*Gammarus* spp.) in the Delaware Estuary comprise three closely-related gammaridean amphipods (*G. daiberi*, *G. fasciatus*, and *G. tigrinus*) that are common in fresh and brackish waters throughout the eastern United States (Figure IV-14). They are habitat sharers. Most are epibenthic during daylight hours (i.e., they stay near the bottom among detrital materials) and then disperse upward in the water column into the pelagic zone during darkness, especially during warmer months. Although each of the species has a slightly different salinity preference, there is considerable overlap of populations. *Gammarus fasciatus* is found principally in freshwater areas of the Estuary; *G. daiberi* is found in freshwater and low-salinity brackish waters; and *G. tigrinus* is found principally in low- to high-salinity brackish waters.

Scud are year-round residents of the Delaware Estuary and all three species are seasonally abundant in the vicinity of Artificial Island (Figure IV-14). Mating takes place immediately following a female's molt and fertilization is internal. Development of the embryo and subsequent hatching occurs within the marsupium of the female. Incubation time is shorter at higher temperatures. There is no larval stage and newly hatched juveniles are incubated within the marsupium from one to eight days, depending upon water temperature. Scud are released as late juveniles from April through November when water temperatures are higher than 43°F. Juvenile scud reach maturity after approximately one to two months depending on water temperature. Juvenile and adult scud are considered semiplanktonic in that they have the ability to migrate vertically but are transported horizontally by tidal currents once up in the water column.

Owing to their small size (typically half an inch long or less), scud have little if any direct recreational or commercial value to man. However, scud are an important food for many fish, birds, and other macroinvertebrates. As a result of their abundance, scud are often a dominant food item in the diet of many fish species that are important recreational and commercial resources. Scud are described as detritivores, as they feed on the abundant detritus found in the Delaware Estuary. In this role, they provide an important link between the detrital energy base of the ecosystem and higher trophic levels (Figure IV-12).

Additional information regarding the life history of scud can be found in Appendix C to this submittal (Appendix Section VIII.J) and in the species-specific report (Attachment C-10).

IV.G.1.b. Opossum Shrimp

Opossum shrimp (*Neomysis americana*), a member of the mysid shrimp family, is a common inhabitant of bays, estuaries, and near-shore coastal waters from New England to Florida (Figure IV-15). Opossum shrimp are habitat sharers. Like scud, they are epibenthic during daylight hours and move up in the water column during darkness, especially during warmer months of the year. There is no evidence of opossum shrimp subpopulations within the Estuary.

Opossum shrimp are year-round residents of brackish (>1 ppt) areas within the Delaware Estuary and can be seasonally abundant in the vicinity of the Station (Figure IV-15). Highest densities occur at salinities of 15 to 20 ppt. Mating takes place when the females migrate vertically to higher levels in the water column; fertilization is internal. Embryonic and larval development occurs within the female's marsupium, with incubation and larval development time inversely related to temperature. Release of larval opossum shrimp typically occurs three to five weeks after fertilization. Soon after spawning the larvae undergo a second molt to become juveniles with adult characteristics.

Spawning of opossum shrimp can occur from approximately mid-March through December, although production is generally slow at temperatures lower than 59°F. Generally, three generations are produced each year in the Estuary. Juvenile opossum reach maturity when they are approximately two months old, depending upon water temperature. Maximum growth rates occur at approximately 77°F. Juvenile and adult opossum shrimp are considered semiplanktonic in that they have the ability to migrate vertically but are transported horizontally by tidal currents.

Owing to their small size (typically three-quarters of an inch long or less), opossum shrimp have little, if any, direct recreational or commercial value. However, this species is an important food for many fish, birds, and other macroinvertebrates. Because they are abundant, opossum shrimp are often a major food source for many fish species inhabiting the Transition Zone and Delaware Bay Zone waters of the Estuary (Figure IV-12). Many of these fish are important recreational and commercial resources. Opossum shrimp are described as detritivore-herbivores and secondarily as predators. As such, they are an important link between the detrital energy base of the ecosystem and lower trophic levels and the higher trophic levels both in the Estuary and nearby coastal waters.

Additional information regarding the life history of opposum shrimp can be found in Appendix C to this submittal (Appendix C Section VIII.K) and the species specific report (Attachment C-11).

IV.G.1.c. Blue Crab

Blue crab (*Callinectes sapidus*), a member of the swimming crab family, is a common inhabitant of bays, estuaries, and near-shore coastal waters from New England through Central America (Figure IV-16). Adult blue crab overwinter buried in the mud in deeper areas of bays and estuaries and disperse into shallow inshore waters during the warmer months of the year. There is no evidence of blue crab subpopulations within the Estuary.

Adult blue crabs are year-round residents of the Estuary (Figure IV-16). As water temperatures increase in spring, adults migrate up into shallow brackish waters from the deeper overwintering areas. Mating takes place in these shallow, brackish areas and egg fertilization is internal. Following mating, female blue crabs migrate downstream to higher salinity areas near the mouth of the Bay. From two to nine months after fertilization, the eggs are extruded and attached as an egg mass on the underside of the female where they remain until hatching. Successful incubation of eggs occurs at salinities of 18 to 26 ppt and at temperatures of 77° to 86°F.

Hatching occurs approximately one to two weeks after extrusion; the newly hatched larvae are called zoea. These planktonic zoea are transported seaward by near-surface tidal currents. Subsequent development through the seven zoeal stages occurs in the open waters of the continental shelf and requires approximately four weeks. The final zoeal stage molts to produce the postlarval form known as a megalopa. During this stage, the young blue crabs are transported back into bay and estuarine nursery areas by shoreward wind- and tide-induced water movements. In the Delaware, blue crab megalops are most common in high-salinity waters near the mouth of the Bay, although small numbers have occasionally been reported as far upstream as the Transition Zone.

After another one to three weeks, the young crabs molt again to become juvenile crabs with all adult characteristics. During this juvenile stage, the young crabs continue to move upstream into shallow, low-salinity, nursery areas of the Estuary. Juvenile blue crabs occur throughout the Estuary but most commonly in brackish areas of the Tidal River Zone and in tributaries to the Bay. In these areas, juveniles typically molt from 18 to 20 times during a 10- to 20-month period before reaching maturity. This molting requires salinities greater than 3 ppt and temperatures greater than 59°F. An optimal temperature for juvenile growth has been reported as 73°F. Juvenile blue crab remain in these shallow nursery areas during the warmer months but retreat to deeper areas of the Estuary where they burrow into the sediments to overwinter. Blue crabs typically reach sexual maturity when they are one to two years old.

Throughout their geographic range and especially in the Delaware Estuary and adjacent areas, blue crabs are a popular target of recreational and commercial fishermen. In addition, blue crabs are an important prey item providing forage for a variety of piscine and avian predators. In this role, they provide an important trophic link between energy production in shallow-water habitats of the Estuary and higher predators in the waters of the Estuary and nearby coastal areas (Figure IV-12). Many of these larger predators are important recreational and commercial resources.

Additional information regarding the life history of blue crab can be found in Appendix C to this submittal (Appendix C Section VIII.L) and in the species-specific report (Attachment C-12).

IV.G.2. Fish

IV.G.2.a. Bay Anchovy

Bay anchovy (*Anchoa mitchilli*), a member of the anchovy family, is a common inhabitant of bays, estuaries, and near-shore coastal waters from Cape Cod, MA to the Yucatan Peninsula, Mexico (Figure IV-17). In the mid-Atlantic region, which includes the Delaware Estuary, bay anchovies are probably the most abundant and widespread of fish species. Adult anchovies overwinter in deeper waters of bays, estuaries, and in near-shore coastal waters, and some of them disperse into shallow inshore waters, including the Delaware Estuary, during the warmer months of the year. Large numbers also remain in deeper waters of the nearshore coastal zone, sounds, and bays. Genetic studies reveal no distinct subpopulations for this species along the Atlantic Coast.

In the Estuary, adult bay anchovy are common from late spring through mid-fall throughout the Delaware Bay and Tidal River Zones. They occasionally stray as far upstream as Trenton, New Jersey (Figure IV-17). In the Estuary, adult anchovies can be found throughout the water column as well as in tidal tributaries. Female bay anchovy are multiple spawners, releasing many small batches of eggs throughout the spawning season. Spawning occurs from May through mid-August with two peaks, one usually in late May and the other usually in mid-July when water temperatures are higher than 63°F. Spawning occurs primarily in areas with salinities greater than 20 ppt, although some spawning occurs throughout much of the Estuary. Egg hatching success appears to be reduced in lower salinity waters. Anchovy eggs are found throughout the pelagic areas of the Transition and Delaware Bay Zones where water currents transport them. Eggs hatch in approximately one day, and yolk-sac absorption is complete after another two to four days, depending upon water temperature. Active feeding begins after yolk-sac absorption. Larval anchovies are transported by tidal currents throughout saline portions of the Estuary and adjacent ocean waters.

Juvenile bay anchovies reach adult appearance when they are approximately one month old and slightly less than one inch long. Larval, juvenile, and adult anchovies are found throughout the water column in the near-shore ocean, the Bay, and in tidal tributaries. As water temperatures decline in the fall, young anchovies depart the shallow areas of the Estuary and move to deeper areas of the lower Bay and coastal waters to overwinter. Most anchovies have left areas in the mid-estuary by late fall. At this time, young-of-the-year anchovies average from two to three inches long and are active swimmers. During the subsequent spring, the young anchovies disperse again throughout near-shore coastal and estuarine waters following the same migratory patterns as the adults. Bay anchovies typically reach sexual maturity during the summer following their birth although some may also mature within the same year during which they were spawned.

At the present time, there is no directed commercial or recreational use of the bay anchovy population. However, throughout their range, bay anchovies are an important prey species providing forage to a variety of piscine and avian predators. In this role, bay anchovies provide an important trophic link between the Estuary's zooplankton production and higher predators in the waters of the Estuary and nearby coastal areas (Figure IV-12). Many of these larger predators are exploited for recreational and commercial purposes.

Additional information regarding the life history of bay anchovy can be found in Appendix C to this submittal (Appendix C Section VIII.I) and in the species-specific report (Attachment C-9).

IV.G.2.b. Alewife

Alewife (*Alosa pseudoharengus*), one of three anadromous members of the herring family abundant in the Delaware Estuary, is common in coastal waters from Newfoundland to South Carolina (Figure IV-18). Landlocked freshwater populations of alewife also have become established in many ponds and lakes of the eastern United States as well as in the Great Lakes. Alewife use the Delaware Estuary for spawning and nursery habitat; they are believed to return to their natal streams to spawn. Adult alewife live in coastal waters and only enter the Estuary during spring spawning runs. After spawning in freshwater areas, adult alewife return to the sea for the remainder of the year. There is no evidence of subpopulations of alewife within the Estuary.

Adult alewife move from the ocean to shallow freshwater spawning areas in early spring (Figure IV-18). Following spawning, the adults rapidly return to the ocean. Spawning typically occurs from April through June in the mainstem of the Delaware Estuary well upstream of the Station and especially in tributaries to the Estuary when water temperatures range between 54° and 72°F. Optimal hatching success is reported to occur at water temperatures of 64° to 70°F. Hatching time is inversely related to water temperature, ranging from less than three to about seven days. Although initially demersal and adhesive, alewife eggs are gradually dispersed throughout the water column and transported downstream by freshwater flows.

Newly hatched larval alewife remain planktonic and continue to be transported downstream as they grow and develop. During the larval stage, most alewife remain in freshwater areas well upstream of the Station. Optimal temperature for larval growth is reported to be approximately 79°F. As they grow, larval and early juvenile alewife remain within the water column and begin to exhibit strong schooling behavior. Juvenile alewife reach adult appearance when they are approximately two months old and one inch long. These juveniles remain in freshwater nursery areas throughout the summer months. As water temperatures decline in the fall, juvenile alewife leave their nursery areas and pass through the Estuary to oceanic overwintering areas. Some juvenile alewife may also overwinter in deeper areas of the Delaware Bay and Transition Zones. At the time of emigration, juvenile alewife average two to four inches long and are active swimmers. During the subsequent spring, some subadult alewife remain at sea while others migrate to freshwater spawning areas with the adults. Most alewife become sexually mature when they are three to five years old.

Alewife are presently the target of limited recreational and commercial fishing. However, historically this species was the focus of intense commercial fishing pressure, in the Estuary in the 1930s and in offshore areas during the 1960s and 1970s. In addition, juvenile and adult alewife are prey, providing forage to a variety of predators. In this role, alewife provide a trophic link between the Estuary's zooplankton production and higher predators in the waters of the Estuary and nearby coastal areas (Figure IV-12). Many of these larger predators are important recreational and commercial resources.

Additional information regarding the life history of alewife can be found in Appendix C to this submittal (Appendix C Section VIII.G) and in the species-specific report (Attachment C-7).

IV.G.2.c. Blueback Herring

Blueback herring (*Alosa aestivalis*), one of three anadromous members of the herring family abundant in the Delaware Estuary, is common in coastal waters from Nova Scotia to Florida (Figure IV-19). Blueback herring use the Delaware Estuary for spawning and nursery habitat and are among the species believed to return to their natal streams to spawn. Adult bluebacks live in coastal waters and only enter the Estuary during spring spawning runs. After spawning in freshwater areas, adult blueback herring return to the sea for the remainder of the year. There is no evidence of subpopulations of blueback herring within the Delaware Estuary.

In the Estuary, adult blueback herring move from the ocean to shallow freshwater spawning areas in early spring (Figure IV-19). Spawning typically occurs from April through June, principally in the mainstem of the Estuary well upstream of the Station and, to a lesser extent, in tributaries to the Estuary, when water temperatures reach 57°F. Optimal temperatures for spawning are between 70° and 75°F. Following spawning, the adults rapidly return to the ocean. Hatching time is inversely related to water temperature, ranging from less than two to as much as four days. Although initially demersal and adhesive, blueback herring eggs are dispersed gradually throughout the water column and are transported downstream by freshwater flows.

Newly hatched larval blueback herring remain planktonic and continue to be transported downstream as they grow and develop. During the larval stage, most blueback herring remain in freshwater areas well upstream of the Station. Yolk-sac absorption is complete within three to five days, after which larvae begin to feed. As they grow, larval and early juvenile blueback herring remain within the water column and begin to exhibit a strong schooling behavior. Young blueback herring reach adult appearance during the juvenile phase when they are approximately one inch long. These juveniles remain in freshwater nursery areas throughout the summer months. As water temperatures decline, juvenile blueback herring leave their nursery areas and pass through the Tidal River and upper Delaware Bay Zones to oceanic overwintering areas. This emigration begins in September or early October and is essentially complete by late November. Some juvenile blueback herring may also overwinter in deeper areas of the Delaware Bay and Transitions Zones. At the time of emigration, juvenile blueback herring average two to three inches long and are active swimmers. During the subsequent spring, some subadult blueback herring remain at sea while others migrate to freshwater spawning areas along with the adults. Most blueback herring reach sexual maturity when they are three to five years old.

Blueback herring are presently the target of limited recreational and commercial fishing. In the past, however, this species was the focus of intense commercial fishing pressure, both in the Delaware River during the 1930s and in offshore areas during the 1960s and 1970s. In addition, juvenile and adult blueback herring serve as prey for a variety of predators (Figure IV-12). In this role, blueback herring link the Estuary's zooplankton production with higher predators in the waters of the Estuary and nearby coastal areas. Many of these larger predators are important recreational and commercial resources.

Additional information regarding the life history of blueback herring can be found in Appendix C to this submittal (Appendix Section VIII.H) and in the species-specific report (Attachment C-8).

IV.G.2.d. American Shad

American shad (*Alosa sapidissima*), one of three anadromous members of the herring family abundant in the Delaware, is a common inhabitant in larger coastal streams and rivers from Connecticut to North Carolina (Figure IV-20). This species has been successfully transplanted to the Pacific Coast and to one freshwater lake in California. American shad use the Delaware Estuary as spawning and nursery habitat, and are believed to return to their natal streams to spawn. Adult shad live in coastal waters and enter the Estuary only during spring spawning runs. After spawning in freshwater areas, adult American shad return to the sea for the remainder of the year. There is no evidence of subpopulations of American shad within the Estuary.

In the Estuary, adult shad move from the ocean to shallow freshwater spawning areas in early spring (Figure IV-20), returning rapidly to the ocean after spawning. Spawning typically occurs from mid-April through July in the main stem of the non-tidal Delaware River far upstream of the Station when water temperatures are between 54° and 70°F. Time to hatch is inversely related to water temperature, ranging from less than 3 to about 17 days. American shad eggs are dispersed throughout the water column and are gradually transported downstream by freshwater flows.

Newly hatched American shad remain planktonic and continue to be transported downstream as they grow and develop. During the larval stage, shad remain principally in freshwater areas of the non-tidal Delaware River far upstream of the Station. Yolk-sac absorption is complete within four to seven days of hatch at which time larvae begin to feed. As they grow, larval and early juvenile American shad remain within the water column and begin to exhibit strong schooling behavior. Young American shad reach adult appearance during the juvenile phase when they are approximately 1 month old and 1 inch long. These juveniles remain in freshwater nursery areas throughout the summer months. As water temperatures decline, juvenile shad depart the Estuary for oceanic overwintering areas. This emigration begins in September or early October and is essentially complete in December. Juvenile shad apparently remain offshore until maturity. At the time of emigration, juvenile American shad average three to four inches long and are active swimmers. Most American shad reach sexual maturity when they are three to six years old.

American shad is a significant recreational and commercial fishery, especially in the Estuary. Most of this exploitation occurs in freshwater areas during the spring spawning run, as shad roe is highly prized for human consumption. In addition, juvenile and adult American shad provide forage for a variety of piscine and avian predators, trophically linking the Estuary's zooplankton production with higher predators (Figure IV-12). Many of these larger predators are important recreational and commercial resources. The American shad population in the Estuary has increased during the past few decades as a result of water quality improvements and active fisheries management.

Additional information regarding the life history of American shad can be found in Appendix C to this submittal (Appendix C Section VIII.F) and in the species-specific report (Attachment C-6).

IV.G.2.e. Spot

Spot (*Leiostomus xanthurus*), a member of the drum family, is a common inhabitant of bays, estuaries, and near-shore coastal waters from Massachusetts to Mexico, although greatest abundance occurs from Chesapeake Bay through the Carolinas (Figure IV-21). The occurrence of spot in the Estuary varies from year to year. Adult spot spend the winter over the continental shelf south of Virginia, where they spawn 30 to 50 km offshore from late September through March. After spawning, adults move into estuarine and nearshore coastal areas, returning in late fall to winter grounds. Larvae reside in the ocean for several months, during which time they are transported by currents toward estuarine nursery areas. Available size data for age-0+ spot suggest that the juvenile spot recruits entering the Estuary in April are about two to four months old. Recruitment into the Estuary continues into June. These early juveniles disperse quickly, aided by net upstream flow of bottom currents, and typically concentrate in tidal marshes, tributaries, and other areas of reduced salinity. Young remain in these tidal areas throughout the summer, moving around locally until declining water temperatures drive them towards the deeper areas of the Estuary, and ultimately offshore for overwintering. Spot typically reach sexual maturity when they are one to three years old. Adult spot are most commonly found from late spring through mid-fall near the bottom in open areas of the lower Bay (Figure IV-21). During especially cold winters, cold shock can cause significant mortality among spot in northern portions of their geographic range, including the Delaware Estuary.

Spot are a popular target for recreational fishermen; however, most of this harvest occurs south of Delaware Bay. Although there is little direct commercial fishing for spot, large numbers are taken as by-catch of the offshore shrimp industry. Spot is an important prey species, providing food for a variety of piscine and avian predators and acting as an important trophic link between secondary production in shallow-water and marsh habitats and higher predators in the estuarine pelagic and nearby coastal areas (Figure IV-12). Many of these larger predators are important recreational and commercial resources.

Additional information regarding the life history of spot can be found in Appendix C to this submittal (Appendix C Section VIII.D) and in the species-specific report (Attachment C-4).

IV.G.2.f. Atlantic Croaker

Atlantic croaker (*Micropogonias undulatus*), a member of the drum family, inhabits bays, estuaries, and near-shore coastal waters from Cape Cod to Mexico (Figure IV-22). They are most abundant from Chesapeake Bay to the Carolinas. Adult croaker overwinter in deeper waters of bays, estuaries, and in near-shore coastal waters, and disperse into shallow inshore waters during the warmer months. All Atlantic croaker found in the Estuary appear to be from a single population. As the Delaware Estuary is near the northern end of its natural geographic range, the presence of croaker is highly influenced by overall stock abundance and climatological conditions.

In the Delaware Estuary, adult Atlantic croaker are most commonly found from late spring through mid-fall near the bottom in open areas of the lower Bay (Figure IV-22). Spawning occurs over a protracted period from July through April, although most young entering the Estuary appear to have been spawned in late summer or fall. Spawning occurs primarily in offshore areas of the continental shelf, although some spawning may also occur near the mouth of the Estuary. Croaker eggs are found throughout the water column; hatching occurs in one to seven days depending upon prevailing water temperatures.

While still planktonic, larval Atlantic croaker are transported by ocean currents. As they grow, larval croakers move toward shallow-water nursery areas in bays and estuaries. Juvenile croaker reach adult appearance when they are approximately two to four months old and slightly less than one inch long. During warmer months, these juveniles can be found in shallow-water and tidal creek nursery areas in fresh and brackish portions of the Estuary. During cooler periods, juveniles retreat to deeper areas in the Estuary; as water temperatures decline further, young croaker (about 1 year old) move offshore to overwinter. During especially cold winters, cold shock can cause significant mortality among young croaker in this northern portion of their geographic range. By this time, croaker average four to ten inches in length and are active swimmers. Older juveniles and adults remain in higher-salinity inshore waters including lower Delaware Bay. Atlantic croaker typically reach sexual maturity when they are two to four years old.

Atlantic croaker is popular among recreational fishermen and is subject to highly variable commercial fisheries effort. Most of this harvest occurs south of Delaware Bay. Atlantic croaker is a frequent and abundant by-catch of the offshore shrimp fishery. Croaker is an important prey species for piscine and avian predators, and provide an important trophic link between production in shallow-water habitats and higher predators in the Estuary and nearby coastal areas (Figure IV-12). Many of these larger predators are important recreational and commercial resources.

Additional information regarding the life history of Atlantic croaker can be found in Appendix C to this submittal (Appendix C Section VIII.E) and in the species-specific report (Attachment C-5).

IV.G.2.g. White Perch

White perch (*Morone americana*), a member of the temperate bass family, is a common inhabitant of brackish waters from New York to Virginia (Figure IV-23). Landlocked freshwater populations of white perch have also become established in many ponds and lakes of the eastern United States as well as in the Great Lakes. White perch are year-round inhabitants of the Delaware Estuary. Adult white perch overwinter in deeper areas, especially in the upper Bay and lower tidal River. During warmer months, adult white perch can be found throughout the fresh and brackish areas of the Estuary, principally in shallow areas along the shore and in tidal tributaries. There is no evidence of subpopulations of white perch within the Estuary.

During the early spring, adult white perch move upstream from deeper, more saline overwintering areas to shallow, freshwater spawning areas (Figure IV-23). After spawning, the adults disperse throughout the shallow freshwater and brackish areas where they remain until returning to overwintering areas in late fall. Spawning typically occurs from early April through early June in freshwater areas of the Estuary, as far downstream as the Station, and in tidal tributaries. Optimal hatching success occurs at water temperatures of 57° to 61°F; hatching time is inversely related to water temperature, ranging from less than two to about five days. White perch eggs, which are heavier than water and adhesive, sink to the bottom and attach to available substrate.

Newly hatched larval white perch are planktonic and are dispersed throughout the low-salinity areas of the Estuary by currents. Optimal temperatures for early larval growth range from 59° to 68°F. As they grow, larval white perch swim toward the bottom and then toward shallow-water nursery areas. Juvenile white perch reach adult appearance when they are approximately six weeks old and one inch long. Growth of juvenile white perch has been reported to be directly related to water temperature with maximum growth occurring between 81° and 86°F. As water temperatures decline, juvenile white perch leave the shallow nursery areas of the Estuary and move to deeper waters of the upper Bay and lower tidal River to overwinter. At this time, juvenile white perch average from two to four inches long and are active swimmers. During the subsequent spring, subadult white perch return to shallow, low-salinity waters of the Estuary to feed and grow. White perch typically reach sexual maturity when they are two to three years old.

Throughout their coastal range, white perch are popular among recreational fishermen and historically have been an important focus of commercial fisheries. At the present time, advisories against the consumption of white perch from the Delaware Estuary have been issued by the states of Pennsylvania and Delaware owing to contamination by PCBs.

Juvenile and adult white perch are important predators within shallow-water habitats of the Estuary and serve as energy transport mechanisms between shallow areas and deeper estuarine waters (Figure IV-12).

Additional information regarding the life history of white perch can be found in Appendix C to this submittal (Appendix C Section VIII.C) and in the species-specific report (Attachment C-3).

IV.G.2.h. Striped Bass

Striped bass (*Morone saxatilis*), an anadromous member of the temperate bass family, is a common inhabitant of bays, estuaries, and inshore coastal waters from Nova Scotia to Louisiana (Figure IV-24). This species has been transplanted successfully to the Pacific Coast and to numerous freshwater lakes and reservoirs throughout the United States. Striped bass use fresh and brackish areas of the Delaware Estuary as spawning and nursery habitat and higher-salinity areas of the lower Bay as feeding grounds for larger juveniles and adults. This species is believed to return to its natal streams to spawn. Adult striped bass most commonly live in coastal waters, entering the lower-salinity areas of estuaries during spring spawning runs. Striped bass within the Delaware Estuary are treated as a single population for management purposes.

In early spring, adult striped bass move from the ocean toward freshwater spawning areas in the Estuary (Figure IV-24). After spawning, the adults rapidly return to more saline coastal waters. Spawning typically occurs from mid-April through mid-June in the main stem of the Tidal River Zone, usually upstream of Wilmington, Delaware, when water temperatures are in the range of 55° to 68°F. Hatching time is inversely related to water temperature, ranging from less than two days to about four days. The semi-buoyant striped bass eggs are dispersed throughout the water column and gradually transported downstream by freshwater flows.

Newly hatched larval striped bass remain planktonic and continue to be transported downstream as they grow and develop. Optimal temperatures for early larval survival and growth are reported as 64° to 75°F. Older larvae move toward the bottom where they are dispersed both upstream and downstream of the principal spawning areas. During the larval stage, striped bass remain principally in freshwater areas of the Tidal River Zone upstream of the Station. The yolk-sac larval stage typically lasts 3 to 14 days, after which the larvae begin to feed. As they grow, larval and early juvenile striped bass begin to orient toward the bottom and move toward shallow-water nursery areas along the shore.

Juvenile striped bass reach adult appearance when they are approximately one month old and one inch long. These juveniles can be found in shallow, fresh or brackish areas of the Estuary throughout the summer. Juveniles and adults are voracious predators (Figure IV-12), but the larvae and juveniles also serve as prey for avian and other piscine predators. As water temperatures decline in the fall, juvenile striped bass leave the shallow nursery waters and move toward deeper areas of the Transition and upper Delaware Bay Zones to overwinter. This migration begins in September or early October and is essentially complete in December. At the time of emigration, juvenile striped bass average three to five inches long and are active swimmers. During subsequent years, juveniles can be found in higher-salinity areas of the lower Bay Zone as they gradually assume adult behavioral characteristics. Most striped bass reach sexual maturity when they are three to six years old.

Throughout their geographic range, striped bass are the target of intense recreational and commercial fishing. As a result of overharvesting, the Atlantic Coast stock of striped bass was severely depleted during the 1970s and early 1980s. Following implementation of aggressive management strategies, coastal stocks are now on the rebound. The striped bass population in the Delaware Estuary has been on the increase over the past few decades as result of water quality improvements and active fisheries management and as a result the Delaware Estuary population has been declared "restored" (ASMFC 1998).

Additional information regarding the life history of striped bass can be found in Appendix C to this submittal (Appendix C Section VIII.B) and in the species-specific report (Attachment C-2).

IV.G.2.i. Weakfish

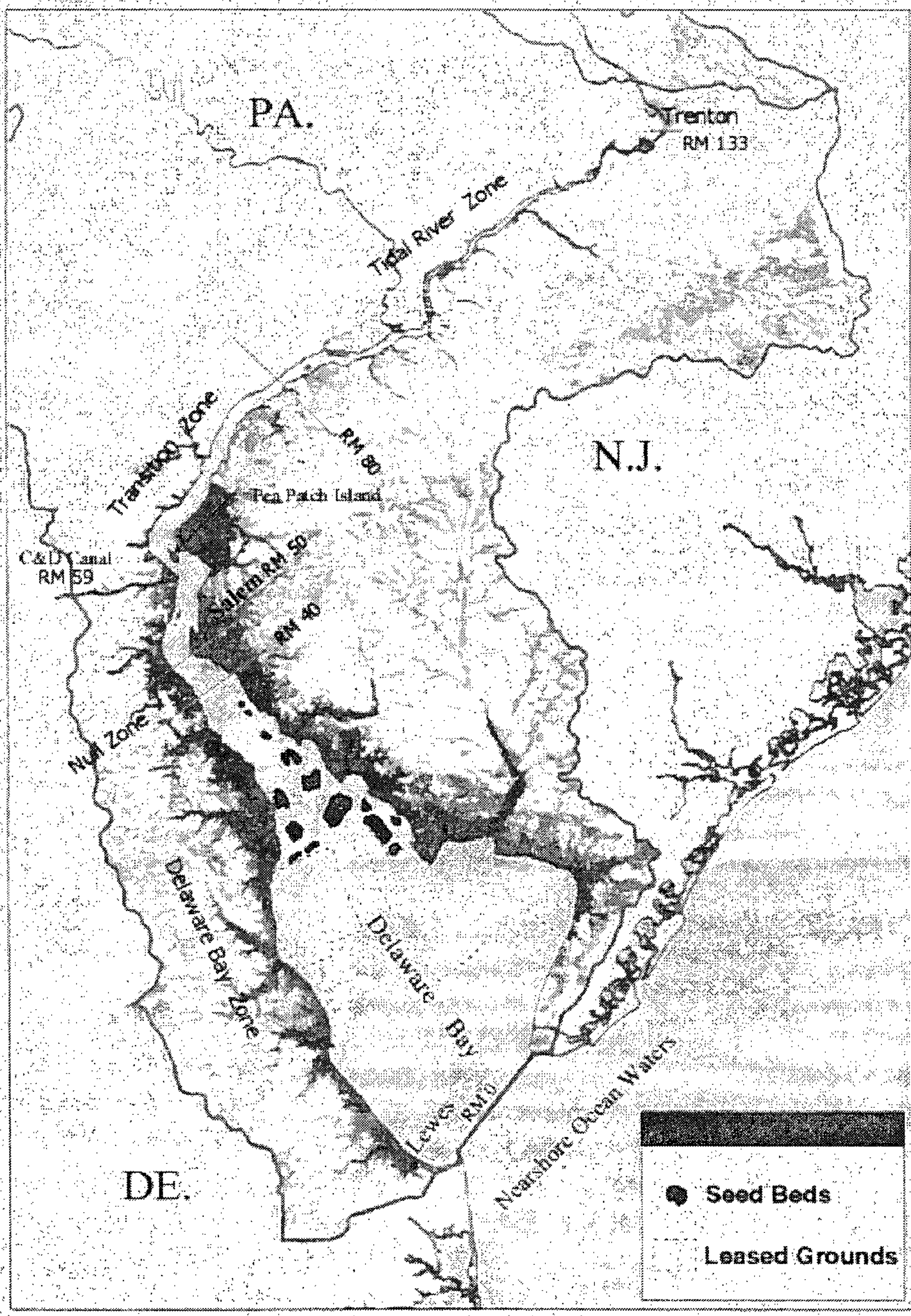
Weakfish (*Cynoscion regalis*), a member of the drum family, is a common inhabitant of bays, estuaries, and nearshore coastal waters from New York to North Carolina (Figure IV-25). Adult weakfish overwinter in deeper waters of the continental shelf from New Jersey to North Carolina and return to shallower, inshore waters, including the Delaware Estuary, during the warmer months of the year. Genetic studies reveal no distinct subpopulations and weakfish are presently managed as a single stock throughout their geographic range.

Adult weakfish are common from late spring through mid-fall in the lower Bay and occasionally stray as far upstream as the Transition Zone (Figure IV-25). Spawning occurs from mid-May to mid-September in the lower Bay from near the mouth to RM 25, where salinities typically range from 12 to 35 ppt. Recent information suggests that spawning may also occur on the inner continental shelf. Optimal reproductive success occurs at water temperatures of 64° to 75°F. After spawning, adults leave the Estuary and remain in coastal areas throughout the summer. Weakfish eggs are found throughout the water column; currents move them about and eggs have been found as far upstream as the Transition Zone. Hatching typically occurs in two to three days and yolk-sac absorption is complete after another two to three days. While still planktonic, larval weakfish tend to move upstream (usually not beyond Wilmington at RM 72) to nursery areas of lower salinity (3 to 15 ppt).

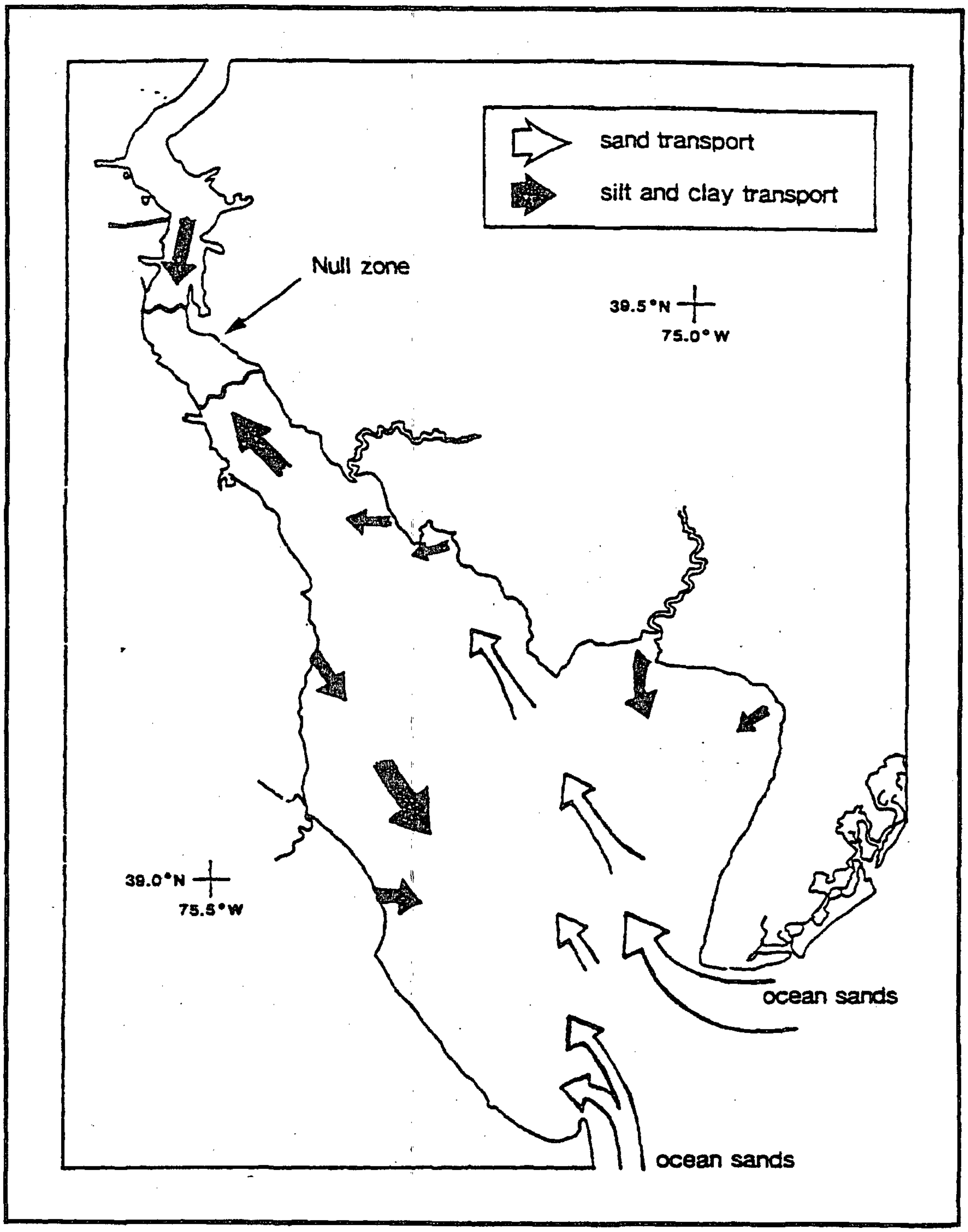
Juvenile weakfish reach adult appearance when they are approximately one month old and one inch long. Before that, older larvae and early juveniles move toward the bottom and into inshore waters of the Estuary until fall. Optimal growth of juvenile weakfish occurs at 20 ppt and at 84°F. As water temperatures decline, juvenile weakfish leave their nursery areas and emigrate offshore to overwinter. Most juvenile weakfish have departed the mid-estuary by late fall. By this time, they average four to five inches in length and are active swimmers. During the subsequent spring, subadult weakfish return to estuarine waters following the same migratory patterns as the adults. Weakfish typically reach sexual maturity when they are one to two years old.

Throughout their geographic range, weakfish are a popular target of commercial and recreational fishermen. In addition, juvenile and adult weakfish are important predators within the Estuary's aquatic ecosystem (Figure IV-12), transporting energy between shallow waters and deeper estuarine and offshore waters. The Atlantic stock of weakfish has historically exhibited wide variability in abundance, most likely a result of natural fluctuations in juvenile recruitment and variations in fishing pressure. Throughout its geographic range, the annual production of young weakfish in nursery areas has been on the increase since the early 1990s.

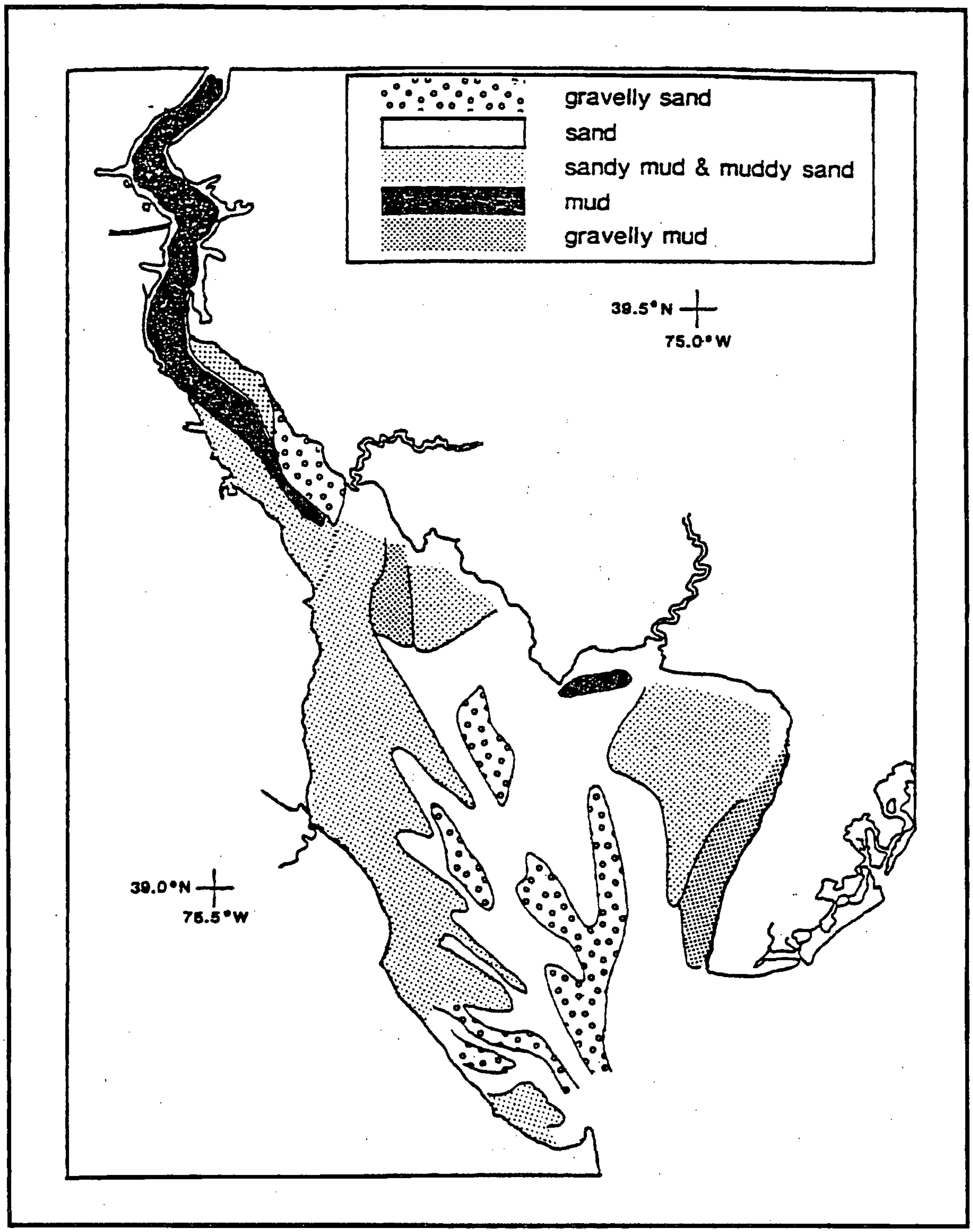
Additional information regarding the life history of weakfish can be found in Appendix C to this submittal (Appendix C Section VIII.A) and in the species-specific report (Attachment C-1).



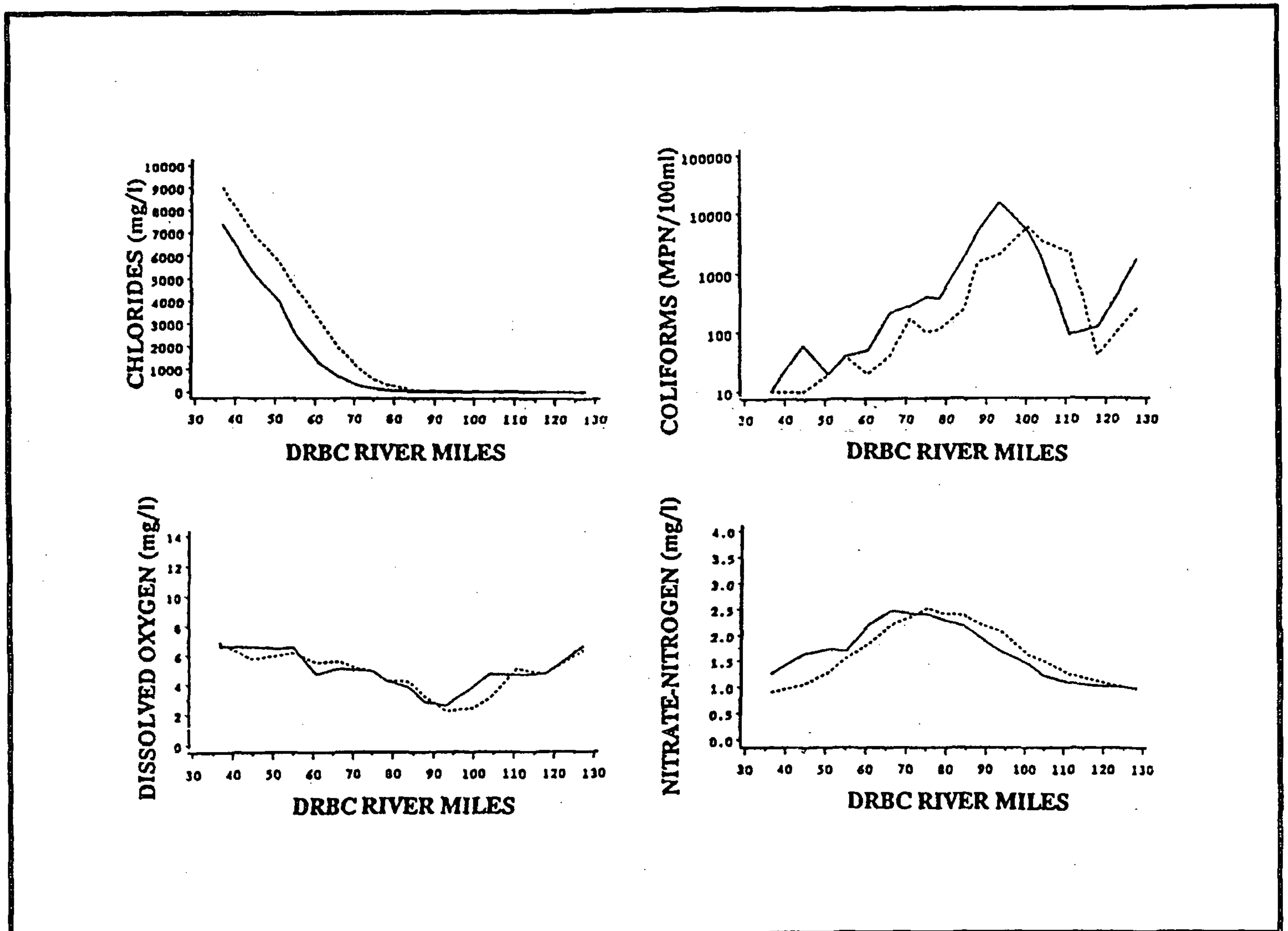
E Figure IV-1. Longitudinal habitat zones of the Delaware Estuary.



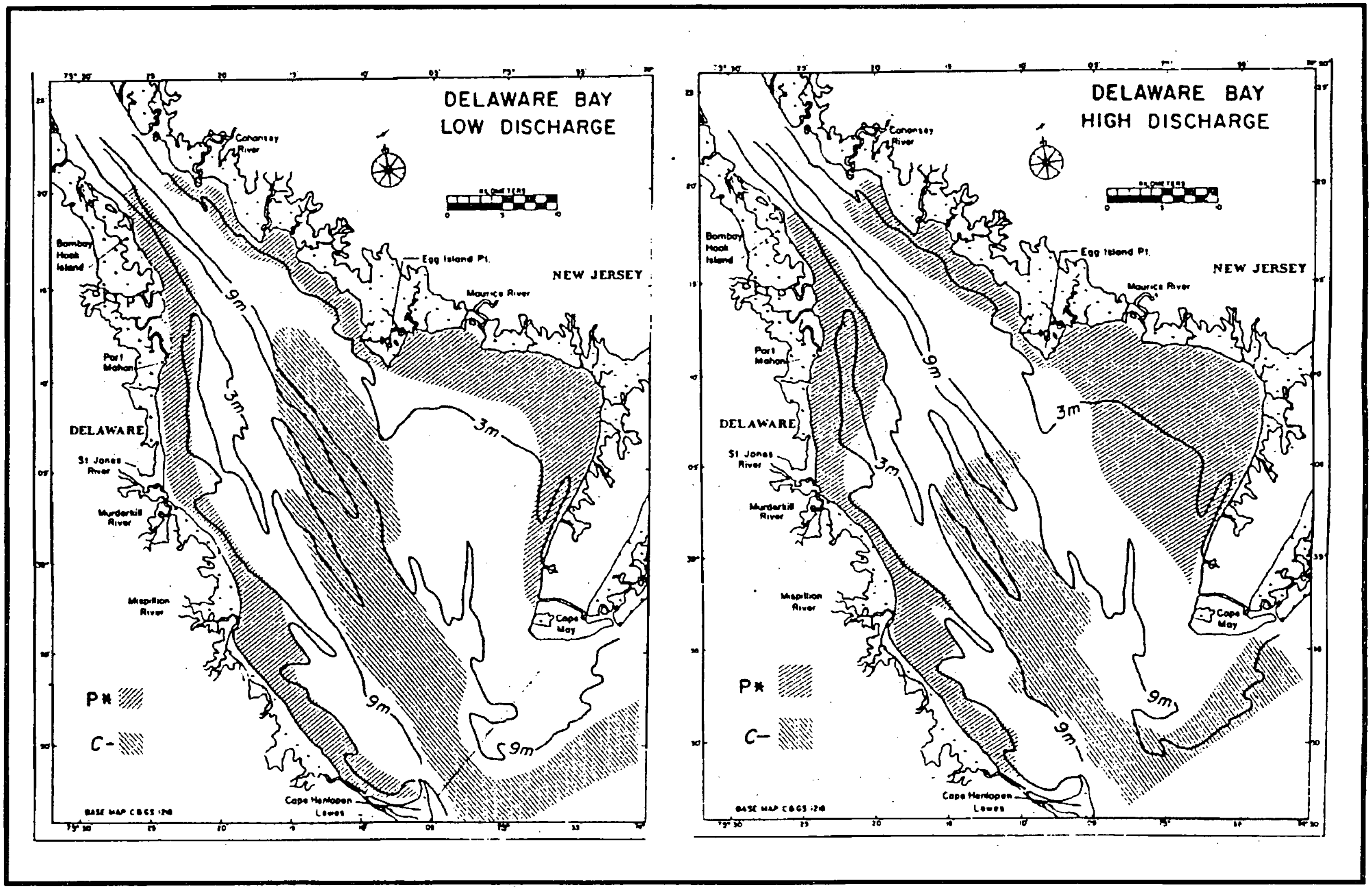
E Figure IV-2. Generalized sediment transport pattern for the Delaware Estuary (from Biggs and Church 1983).



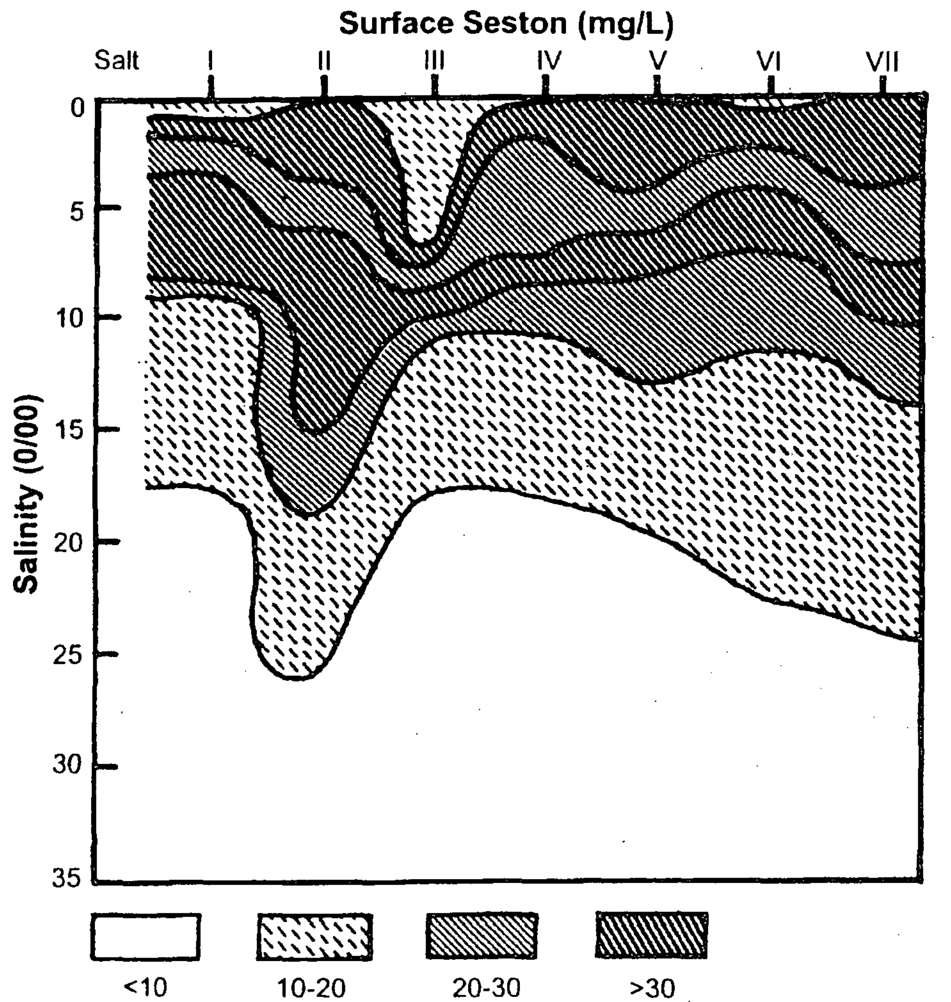
E Figure IV-3. Bottom sediment texture in the Delaware Estuary (from Biggs and Church 1983).



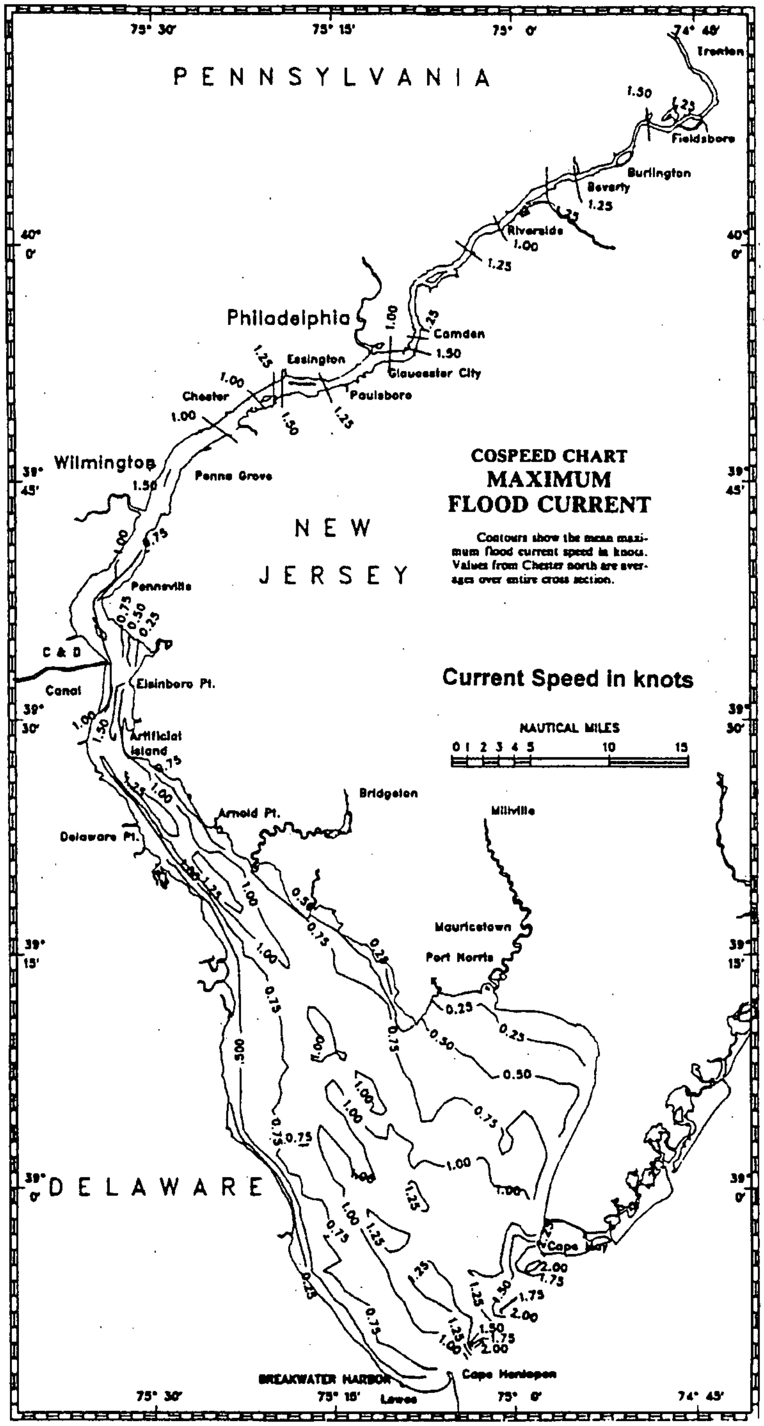
E Figure IV-4. Longitudinal profiles of water quality parameters for the Delaware Estuary. Average concentrations for slack before flood tide (solid curves) and slack before ebb tides (dashed curves) during the summer of 1985 (from DiLorenzo et al. 1992).



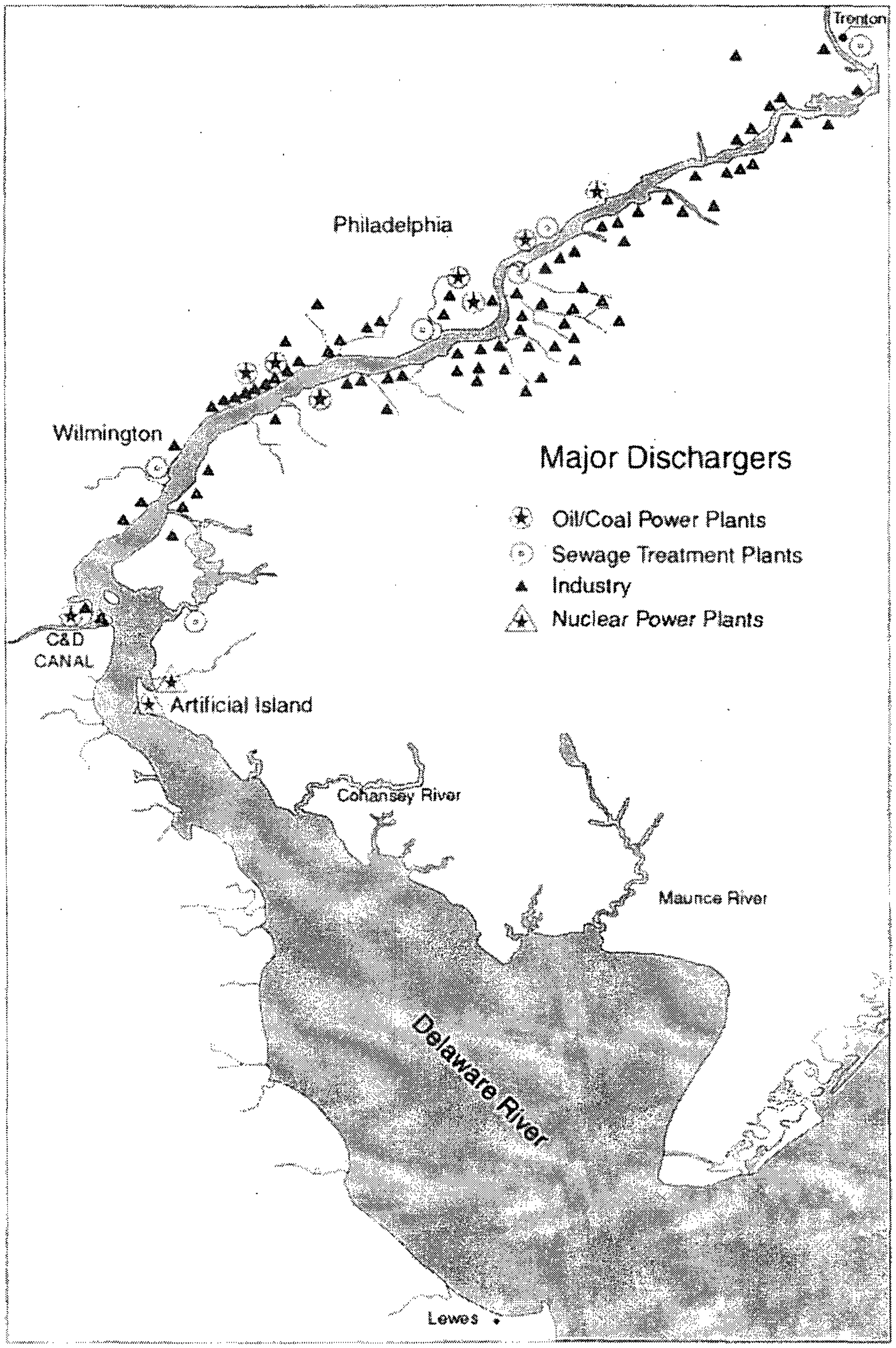
E Figure IV-5. Eigenvector analysis of LANDSAT images of Delaware Estuary during low and high freshwater discharges (Stumpf 1984). P* is platform water, C- is channel water and unshaded area represents a mixture of P* and C- waters. The waters are distinguishable based on their color, principally derived from their sediment, with highest sediment concentrations in the C- water near the shore.



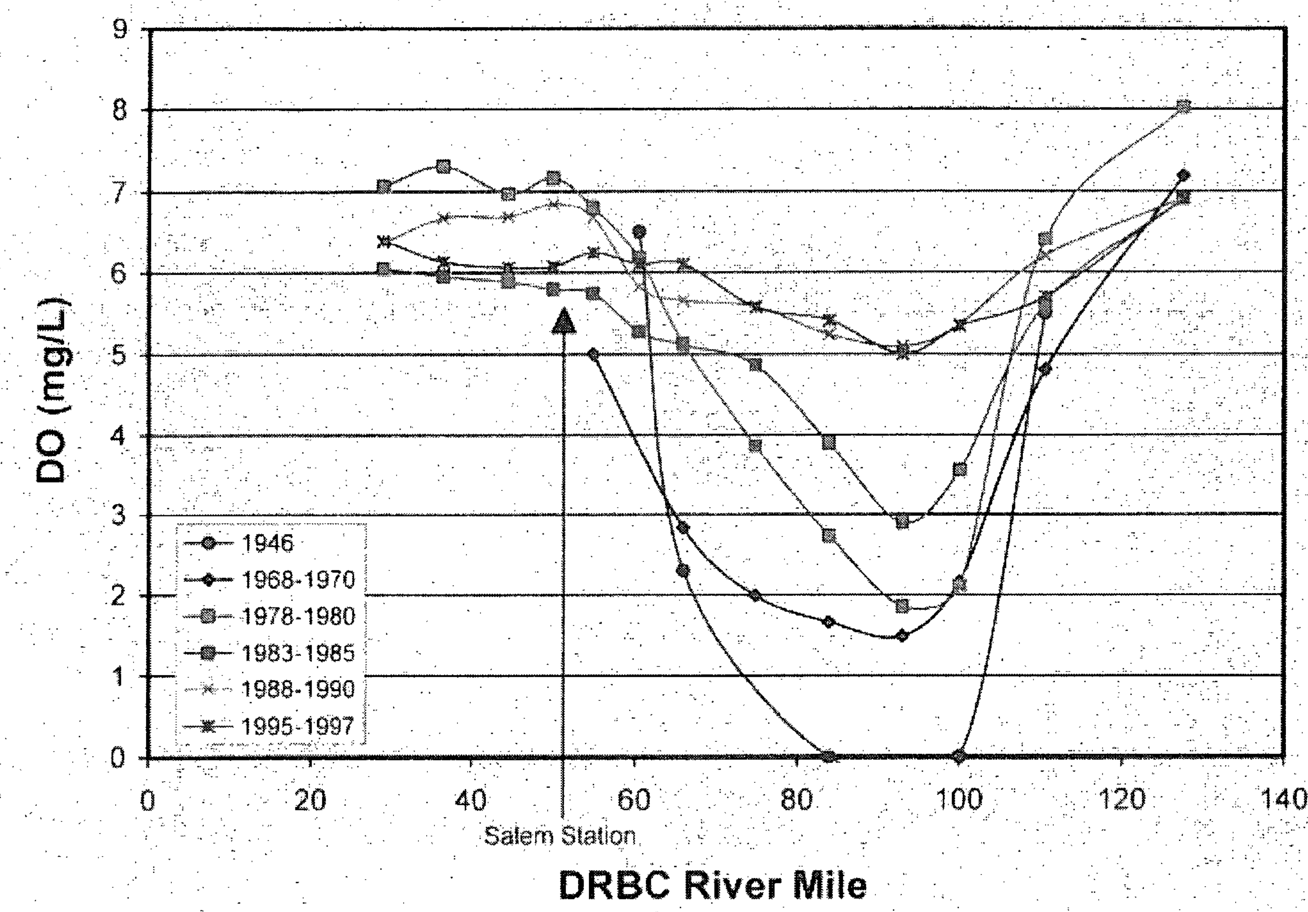
E Figure IV-6. Distribution of suspended sediment concentration (mg/L) in Delaware Estuary as a function of salinity.



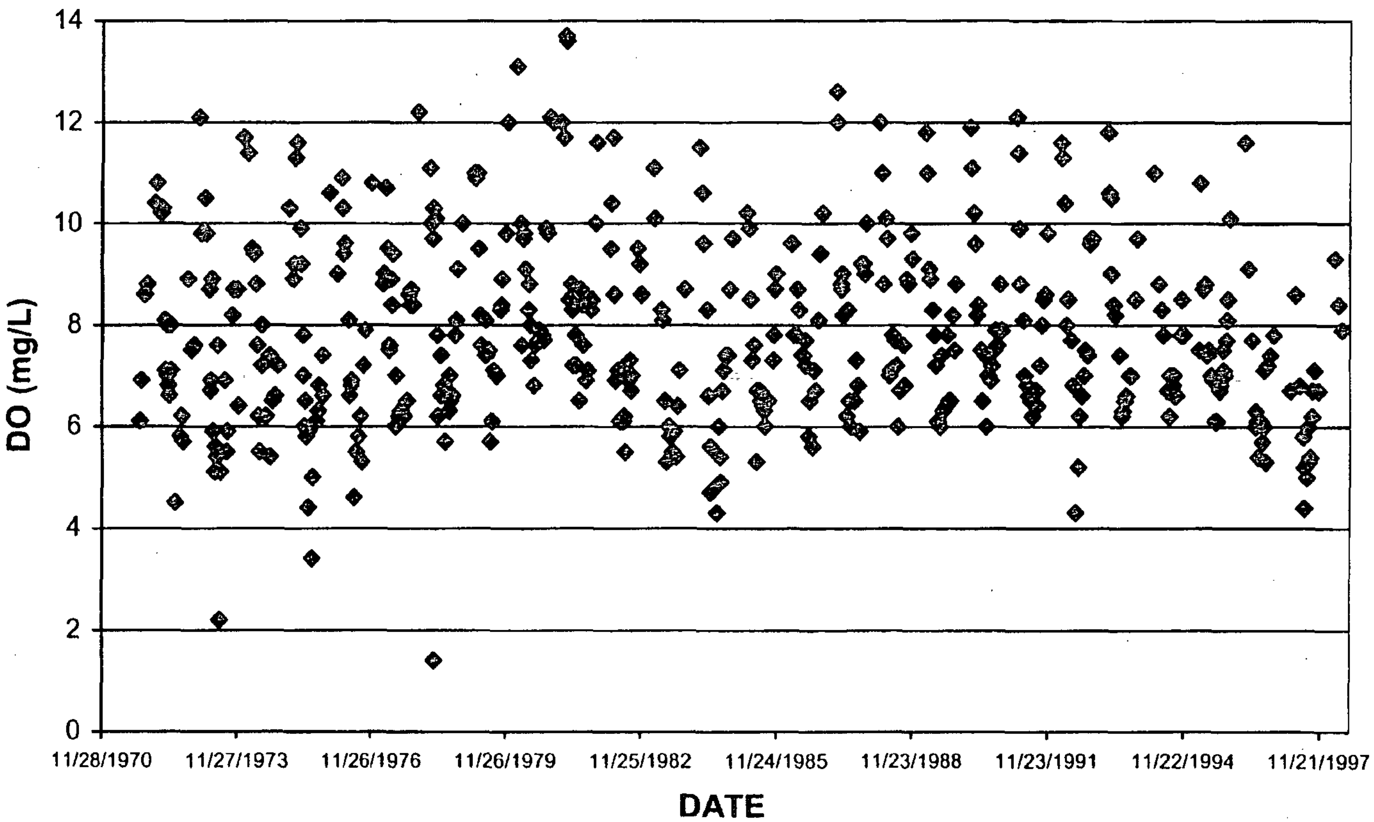
E Figure IV-7. Co-speed chart of maximum flood currents in the Delaware Estuary (NOAA 1987).



E Figure IV-8. Major point source discharges along the Delaware Estuary (from Sutton et al. 1996).

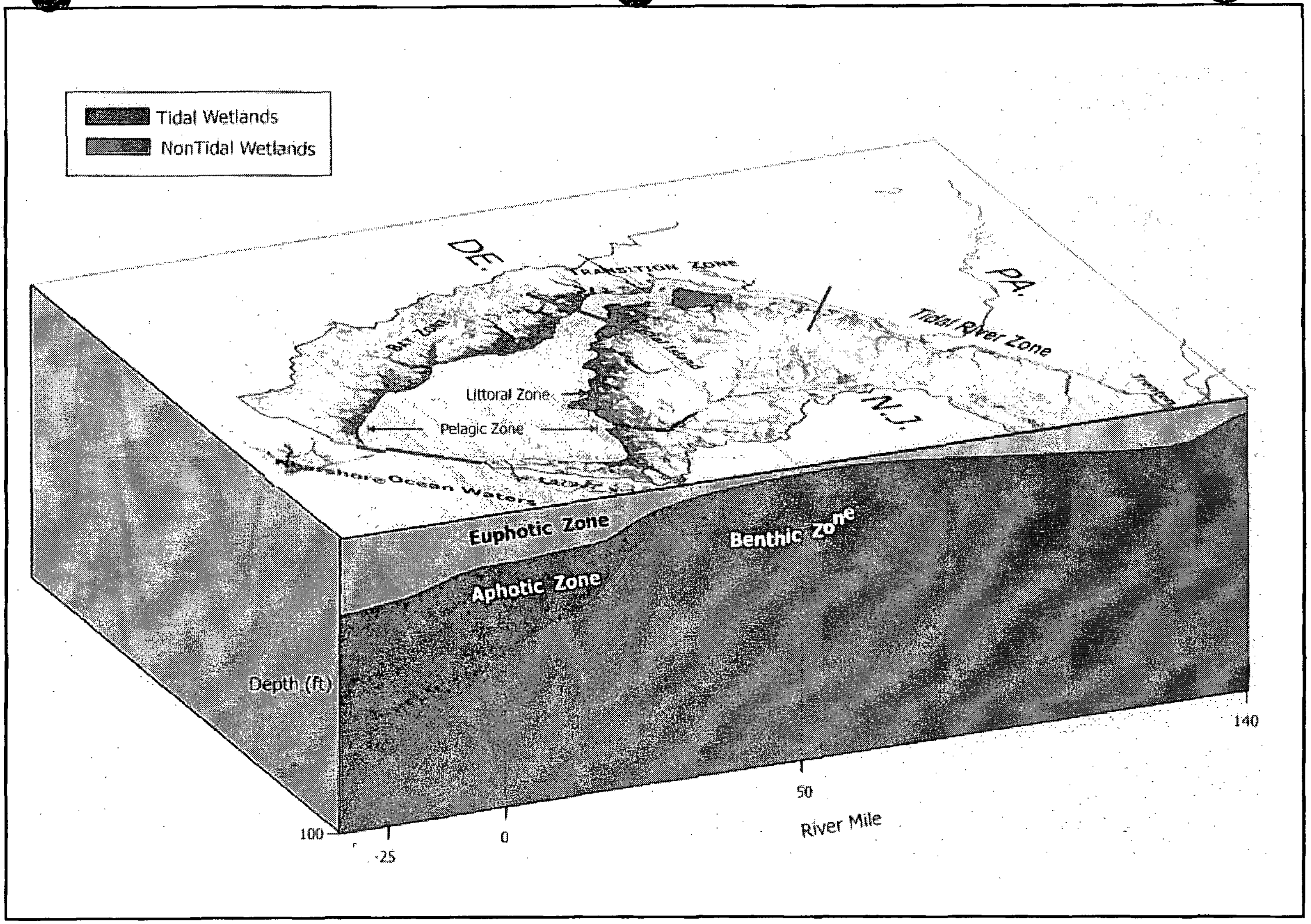


E Figure IV-9. Historical DO profile trends, summer DO for September 1946, 1968-70, 1978-80, 1983-85, 1988-90, 1995-97. The Salem Station is at RM 50. (1946 data from Ellis et al. 1947 as cited in Albert 1988; other data from Attachment C-15.)

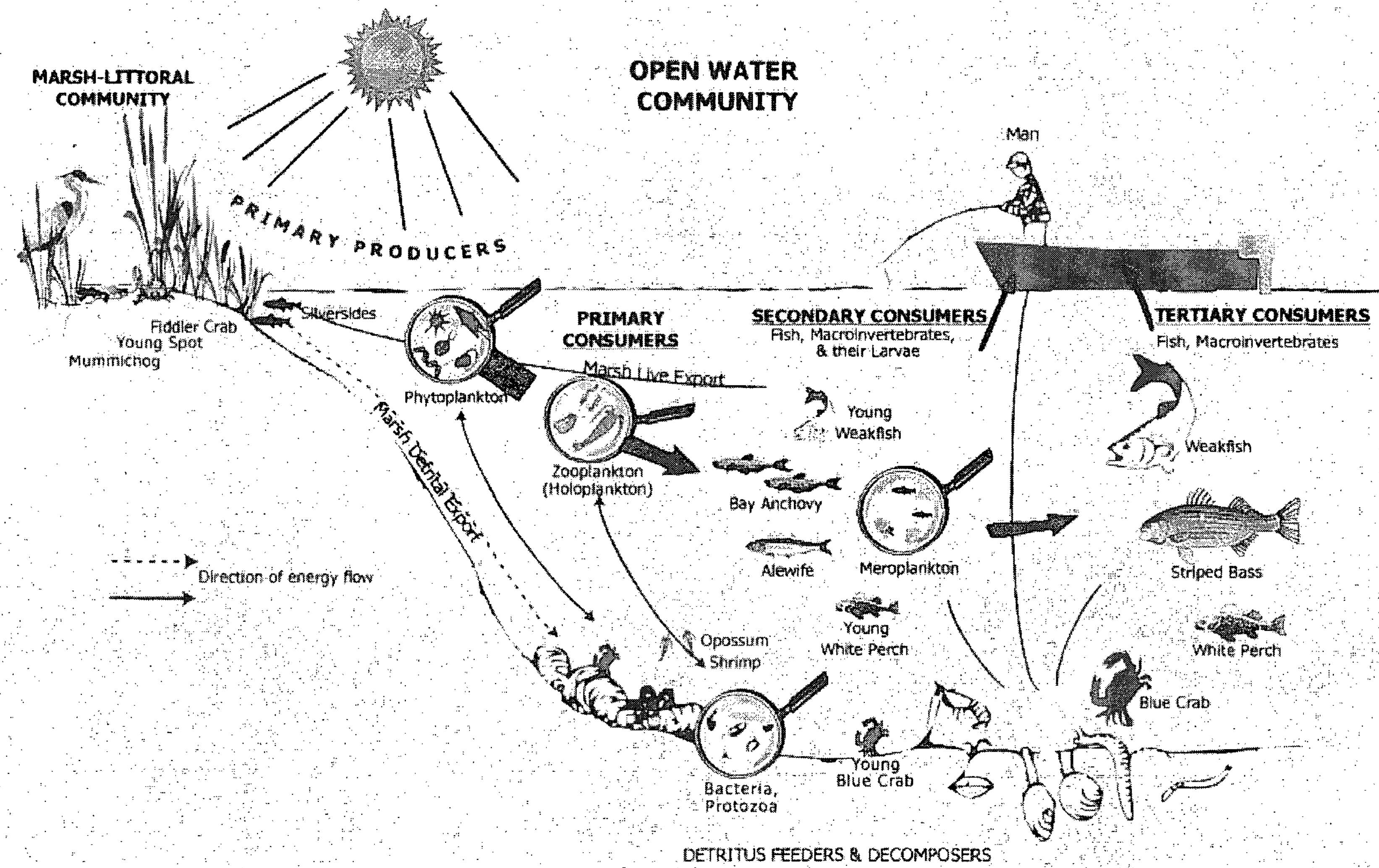


E **Figure IV-10.** Historical dissolved oxygen data near Salem. Combined data for two stations from 1971 to 1998: Appoquinimink River (DRBC RM 51) and Liston Point (DRBC RM 49). (From Attachment C-15)

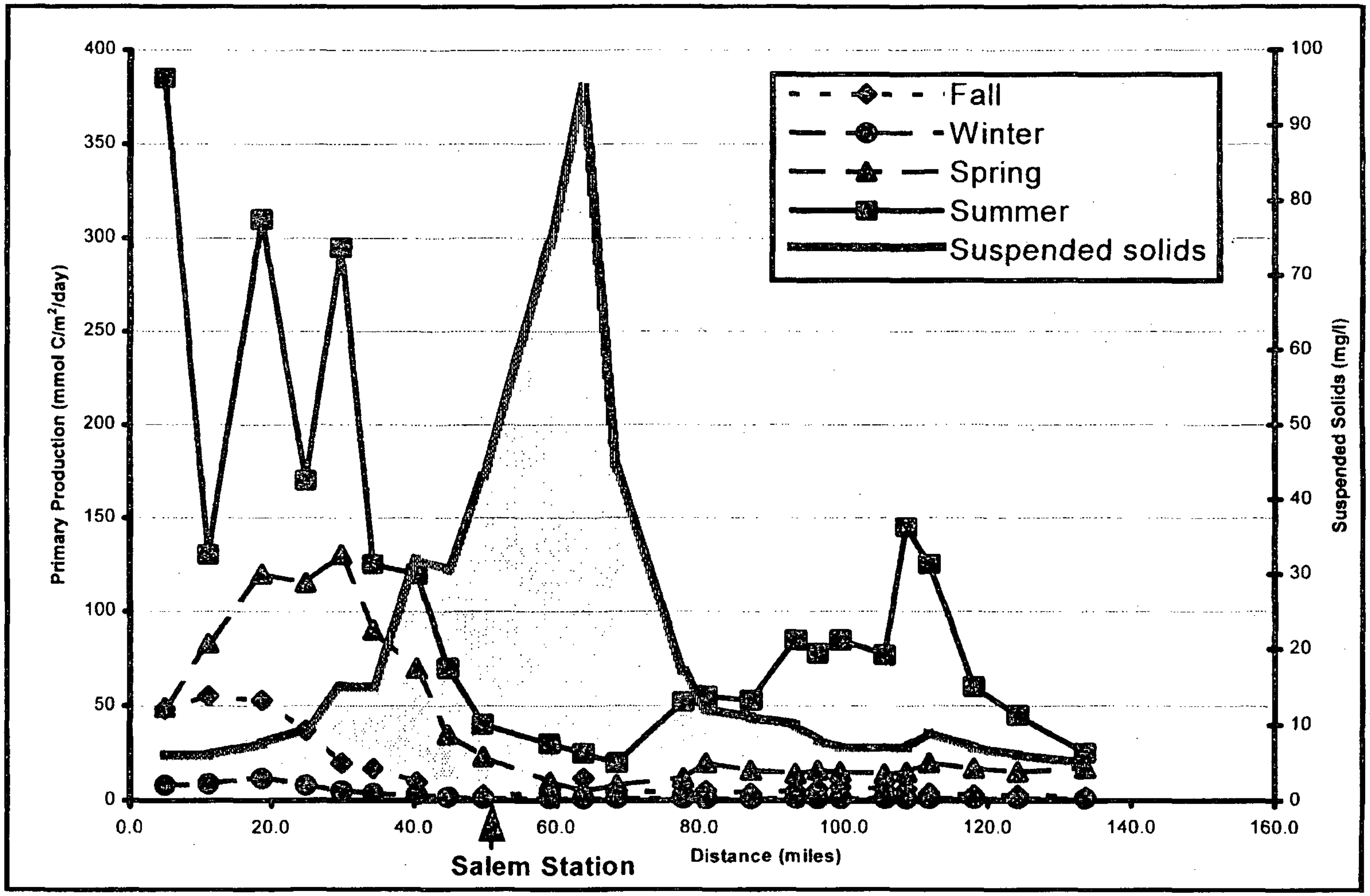
APP E
SEC IV-11



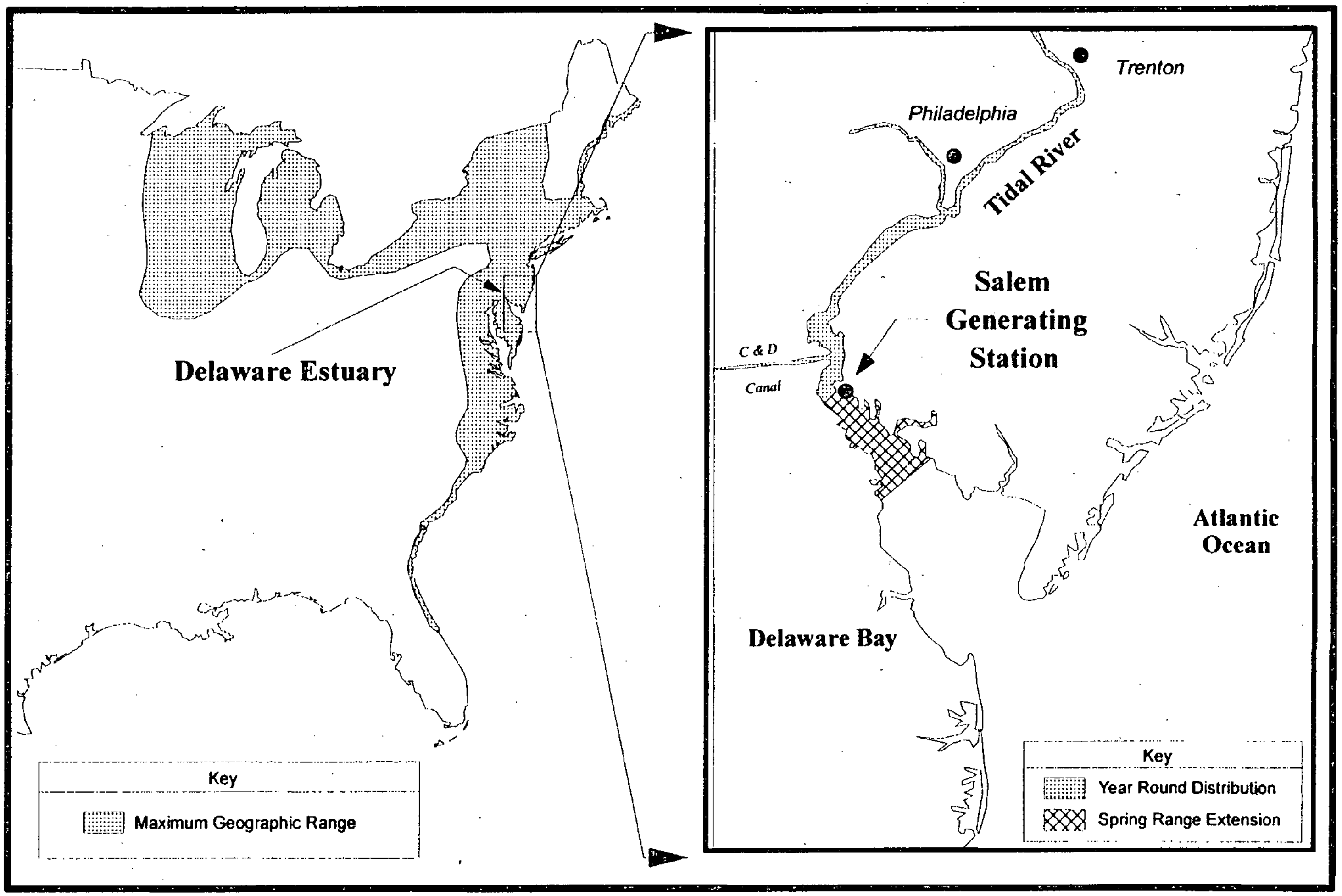
E Figure IV-11. Conceptual diagram of habitat zones of the Delaware Estuary.



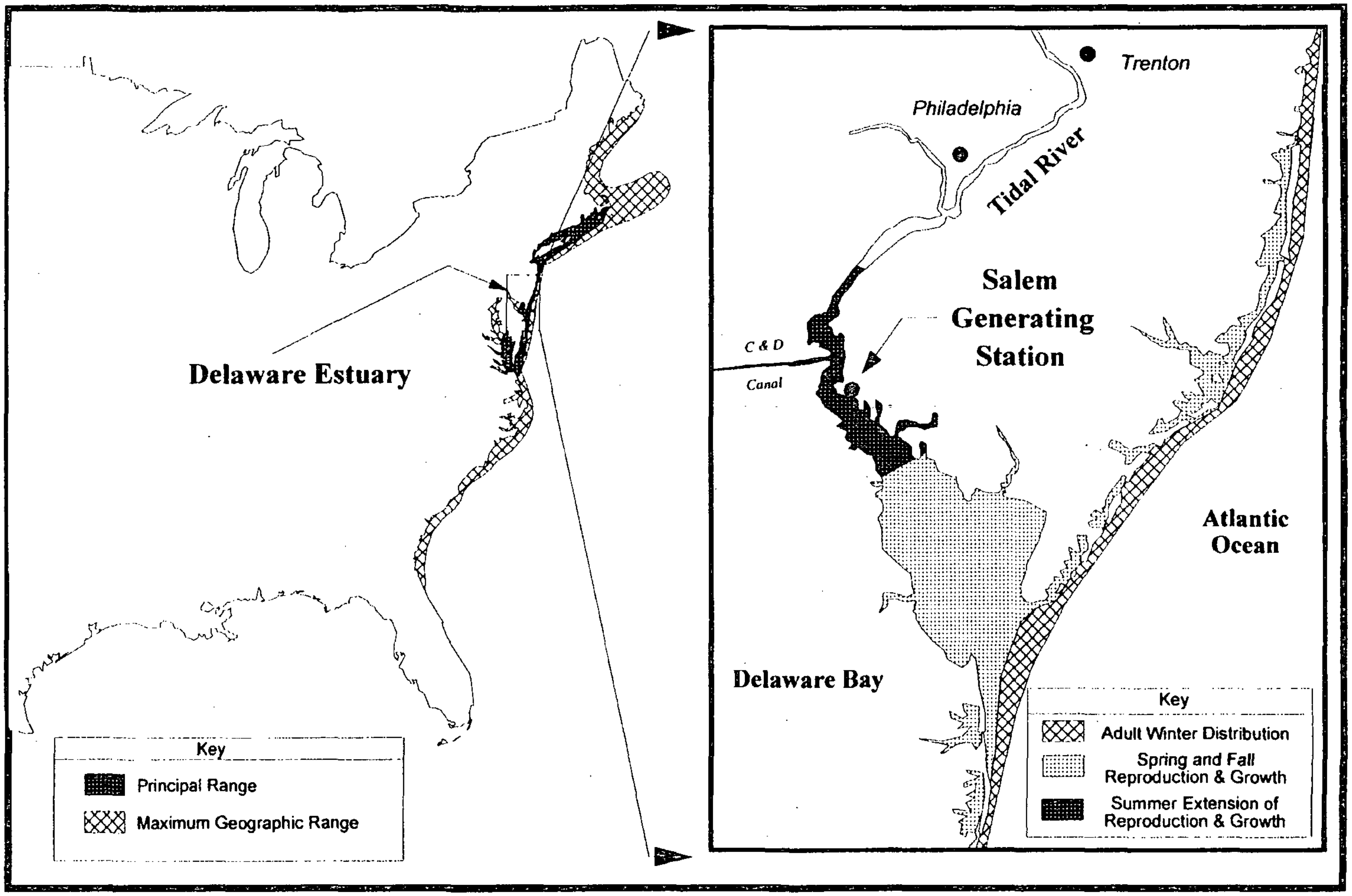
E Figure IV-12. The conceptualized food-energy web for the Delaware Estuary.



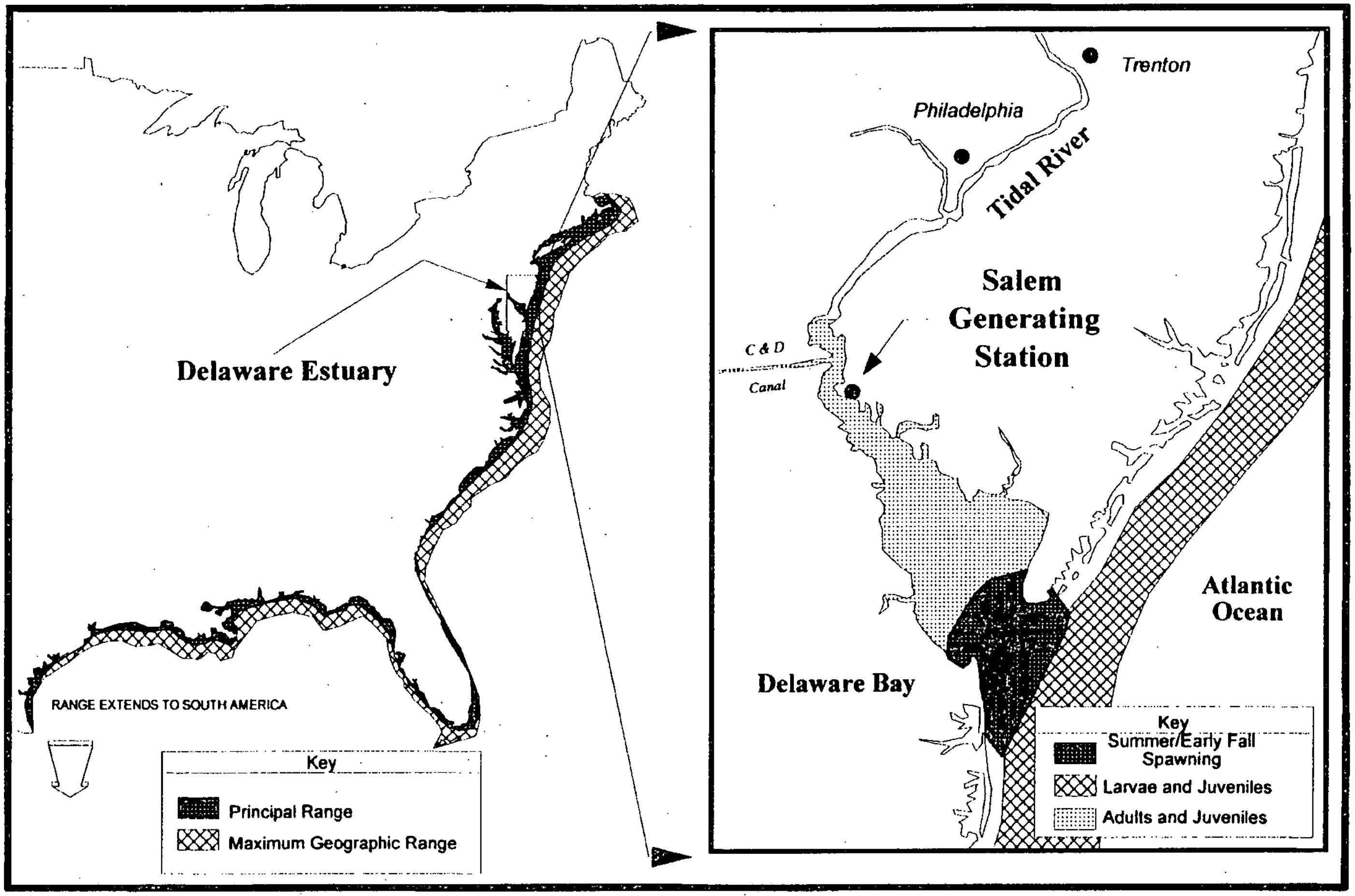
E Figure IV-13. Seasonal primary production and suspended solids concentration along the length of the Delaware Estuary, 1986-87 (adapted from Sutton et al. 1996).



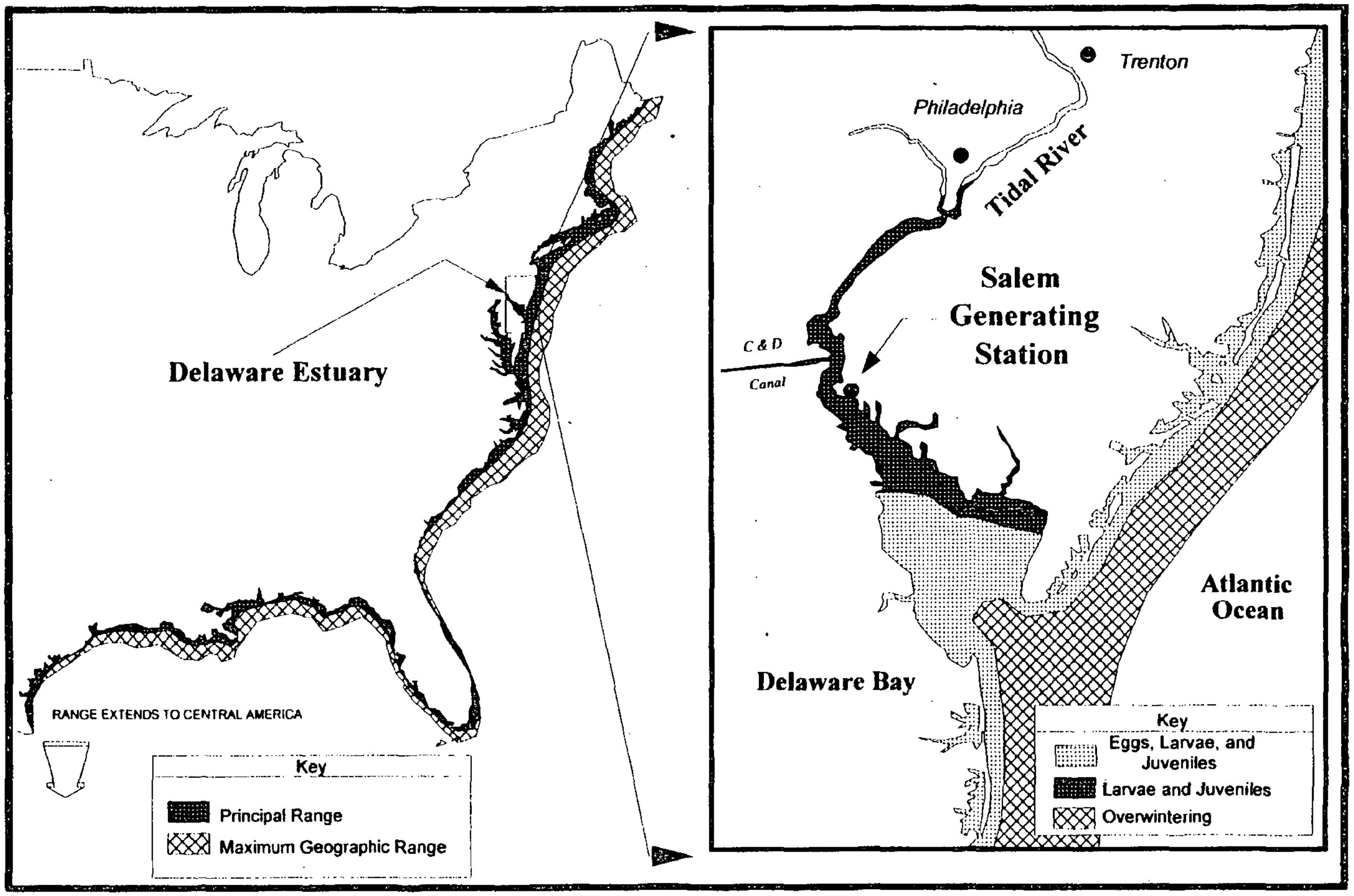
E Figure IV-14. General distribution of scud along the Atlantic and Gulf coasts and areas of principal occurrence within the greater Delaware system.



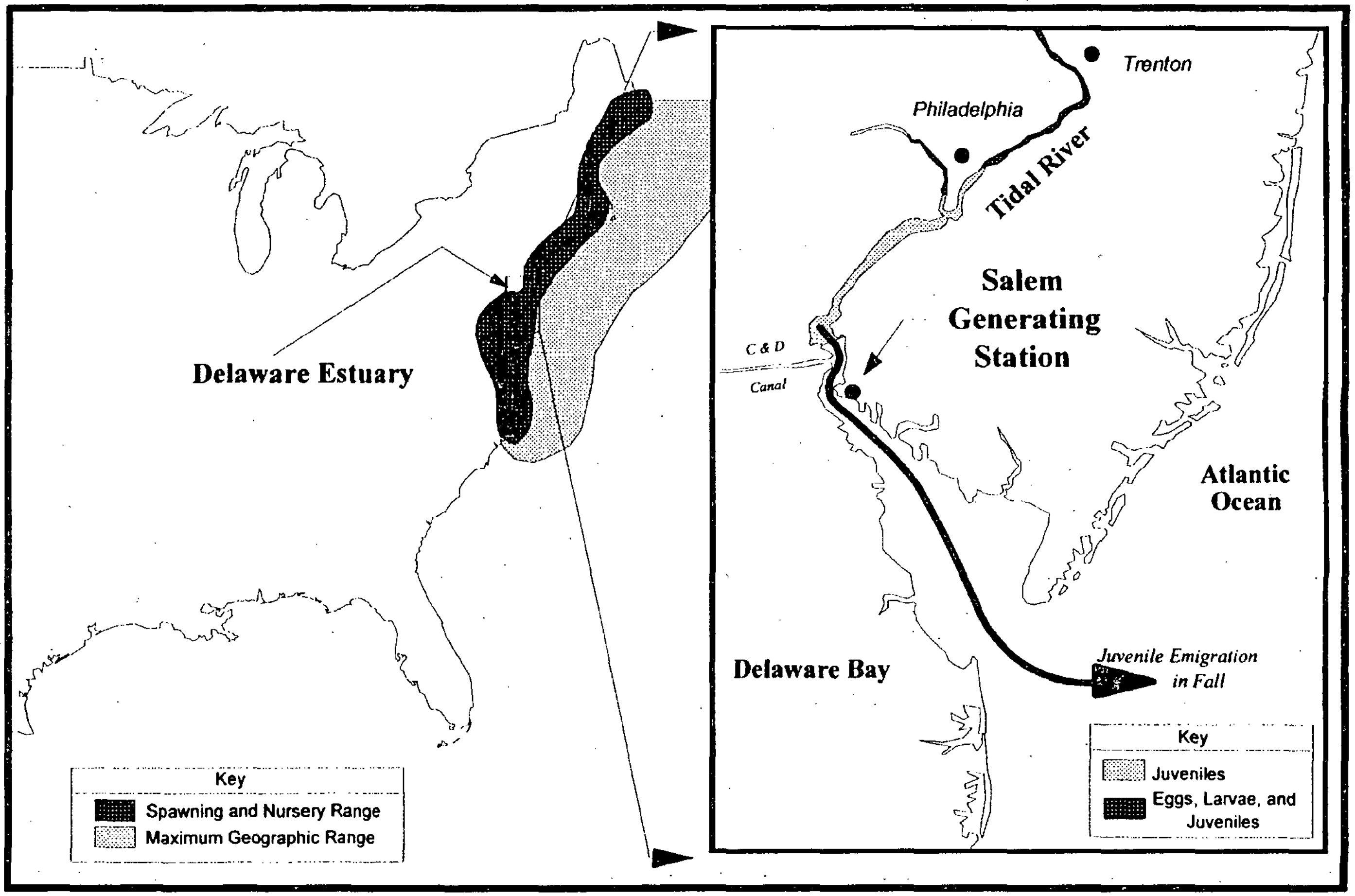
E Figure IV-15. General distribution of opossum shrimp along the Atlantic and Gulf coasts and areas of principal occurrence within the greater Delaware system.



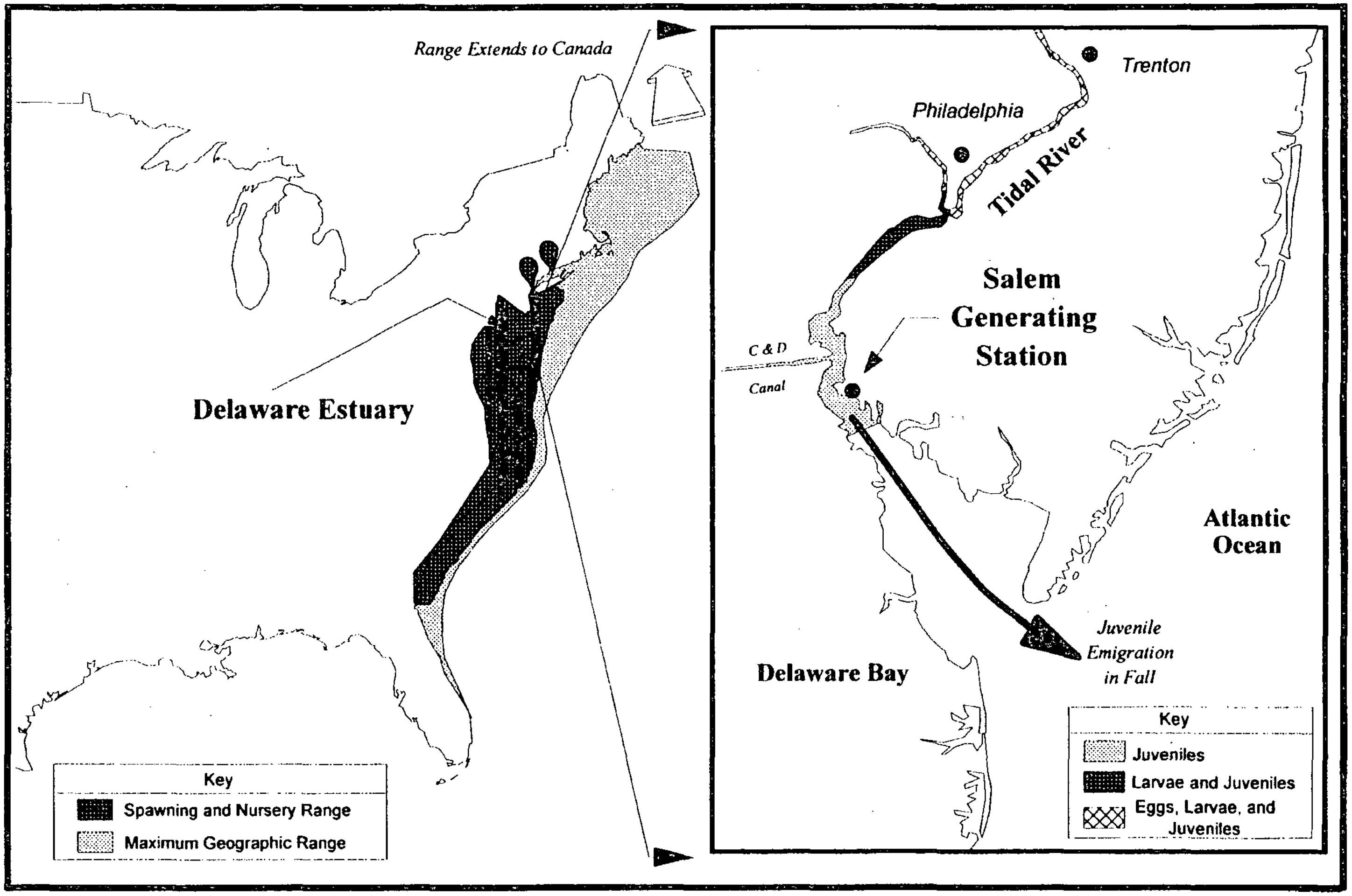
E Figure IV-16. General distribution of blue crab along the Atlantic and Gulf coasts and areas of principal occurrence within the greater Delaware system



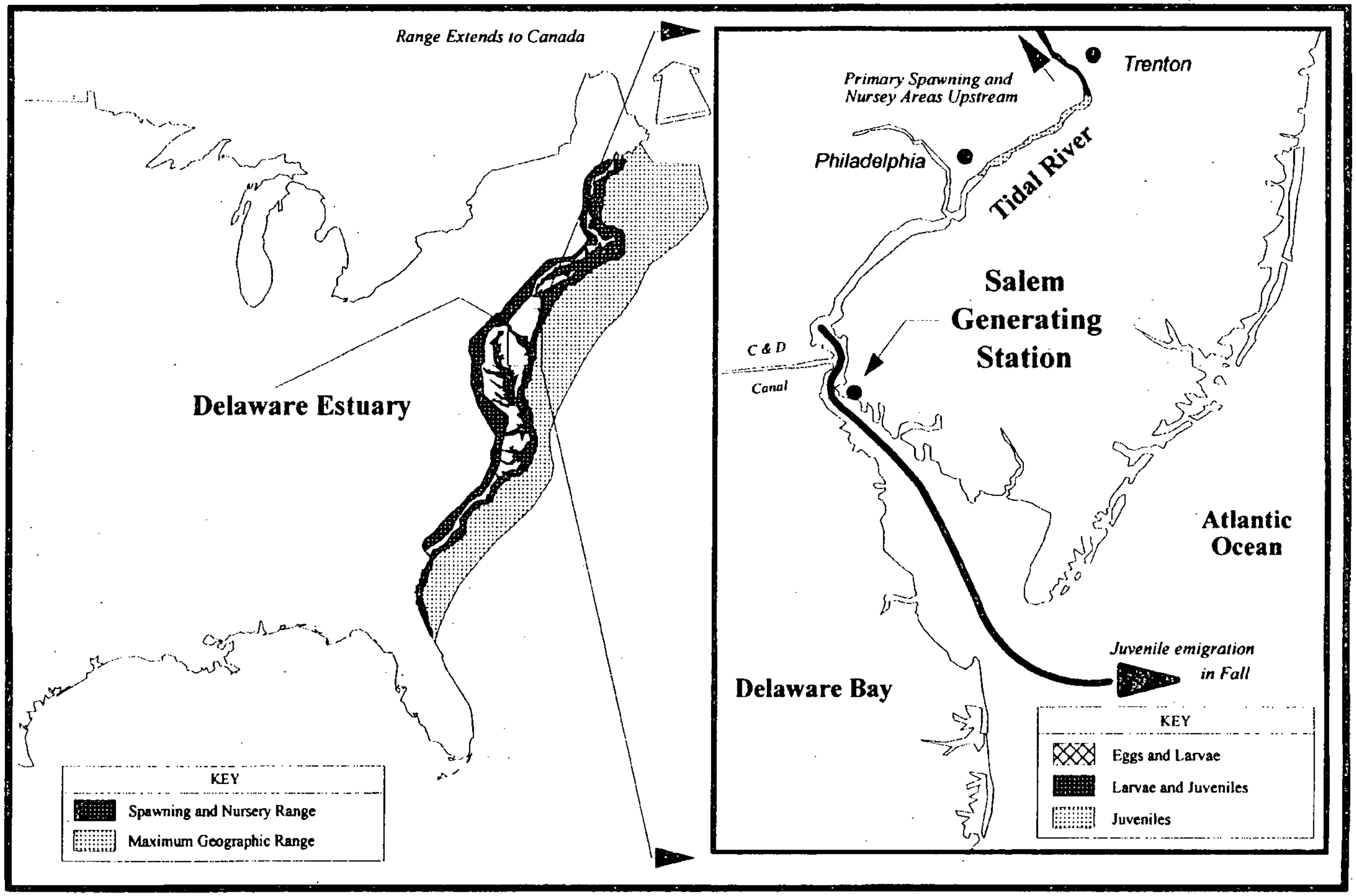
E Figure IV-17. General distribution of bay anchovy along the Atlantic and Gulf coasts and areas of principal occurrence within the greater Delaware system.



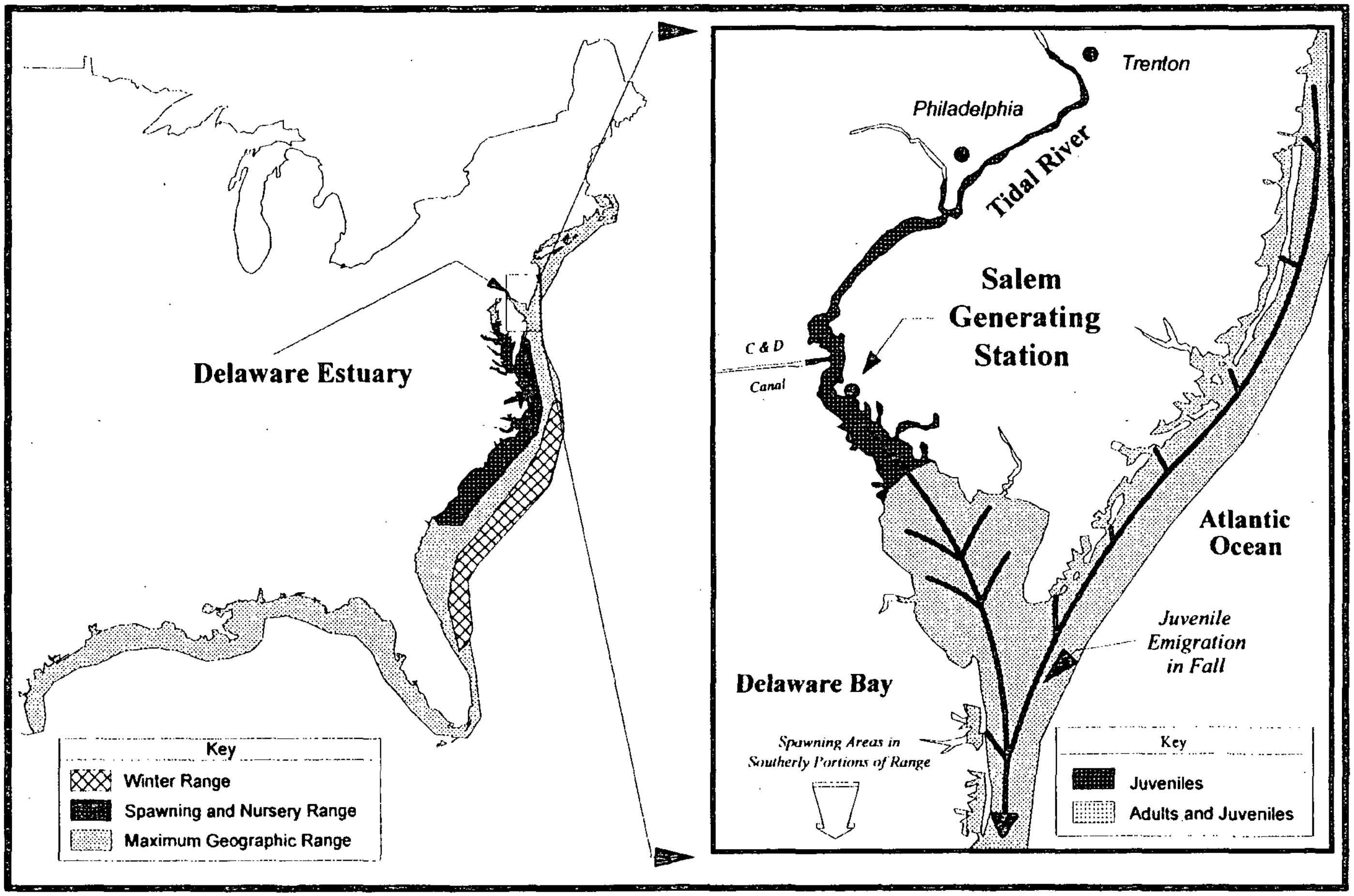
E Figure IV-18. General distribution of alewife along the Atlantic and Gulf coasts and areas of principal occurrence within the greater Delaware system.



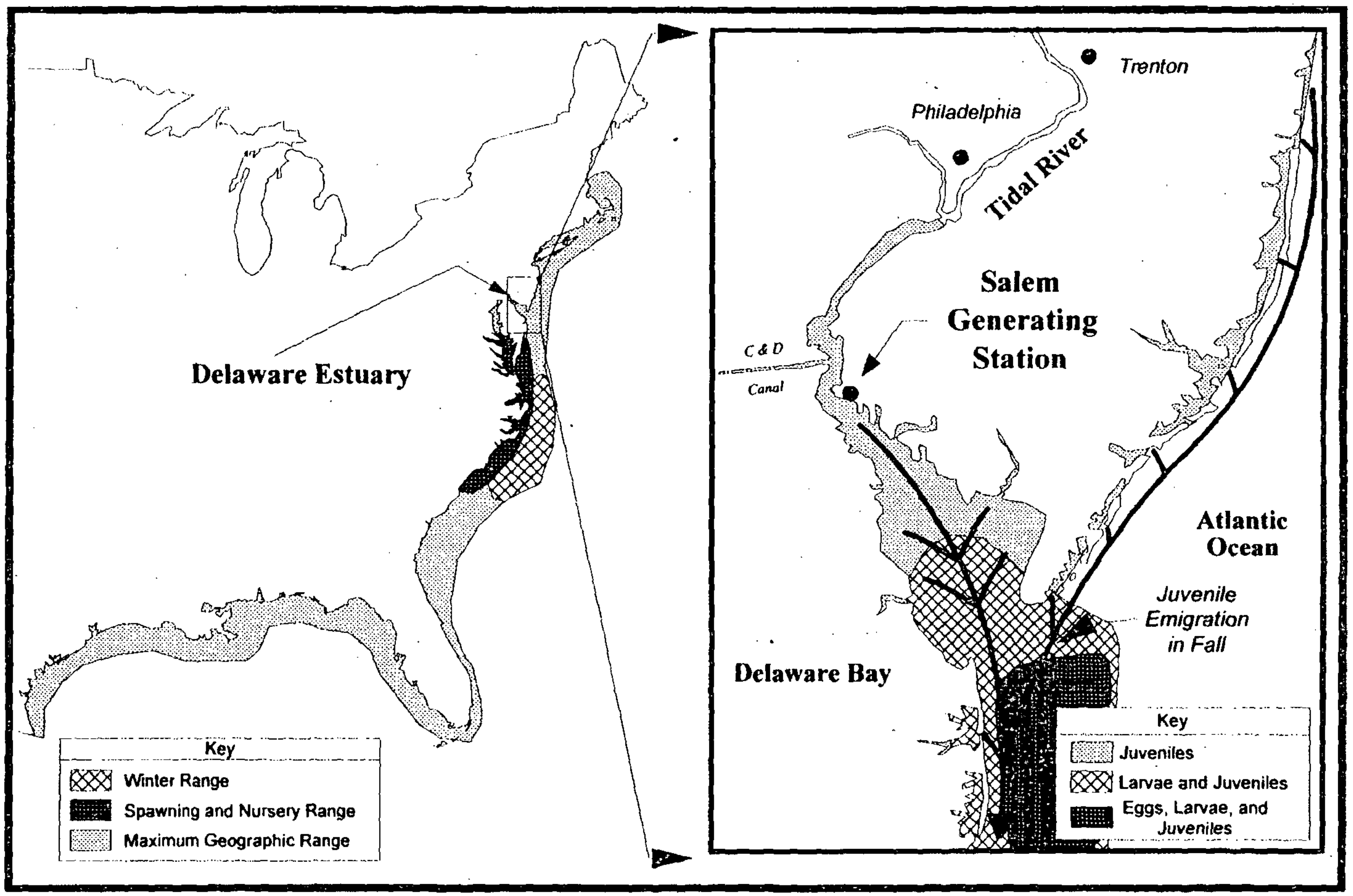
E Figure IV-19. General distribution of blueback herring along the Atlantic and Gulf coasts and areas of principal occurrence within the Delaware system.



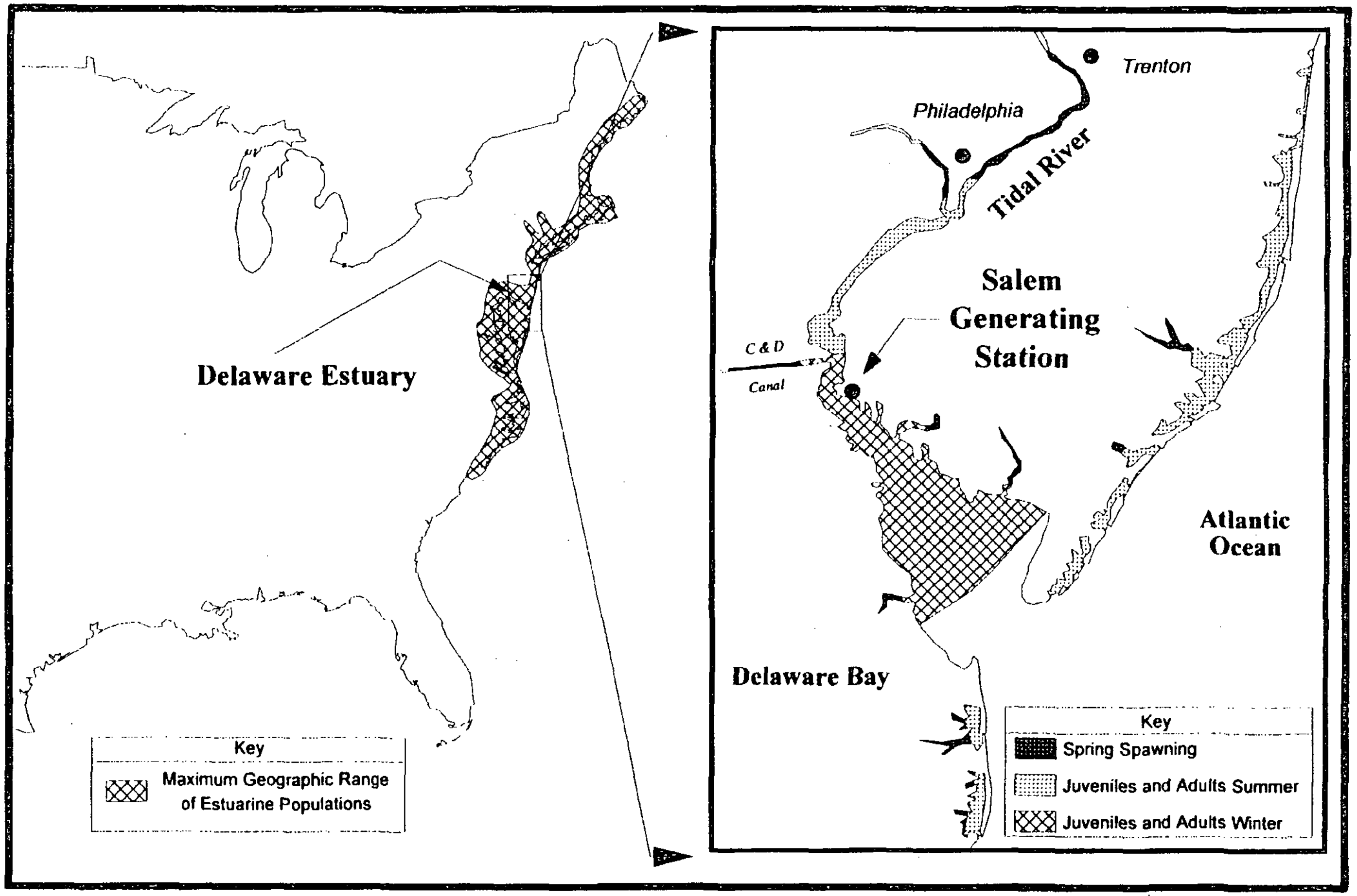
E Figure IV-20. General distribution of American shad along the Atlantic and Gulf coasts and areas of principal occurrence within the greater Delaware system.



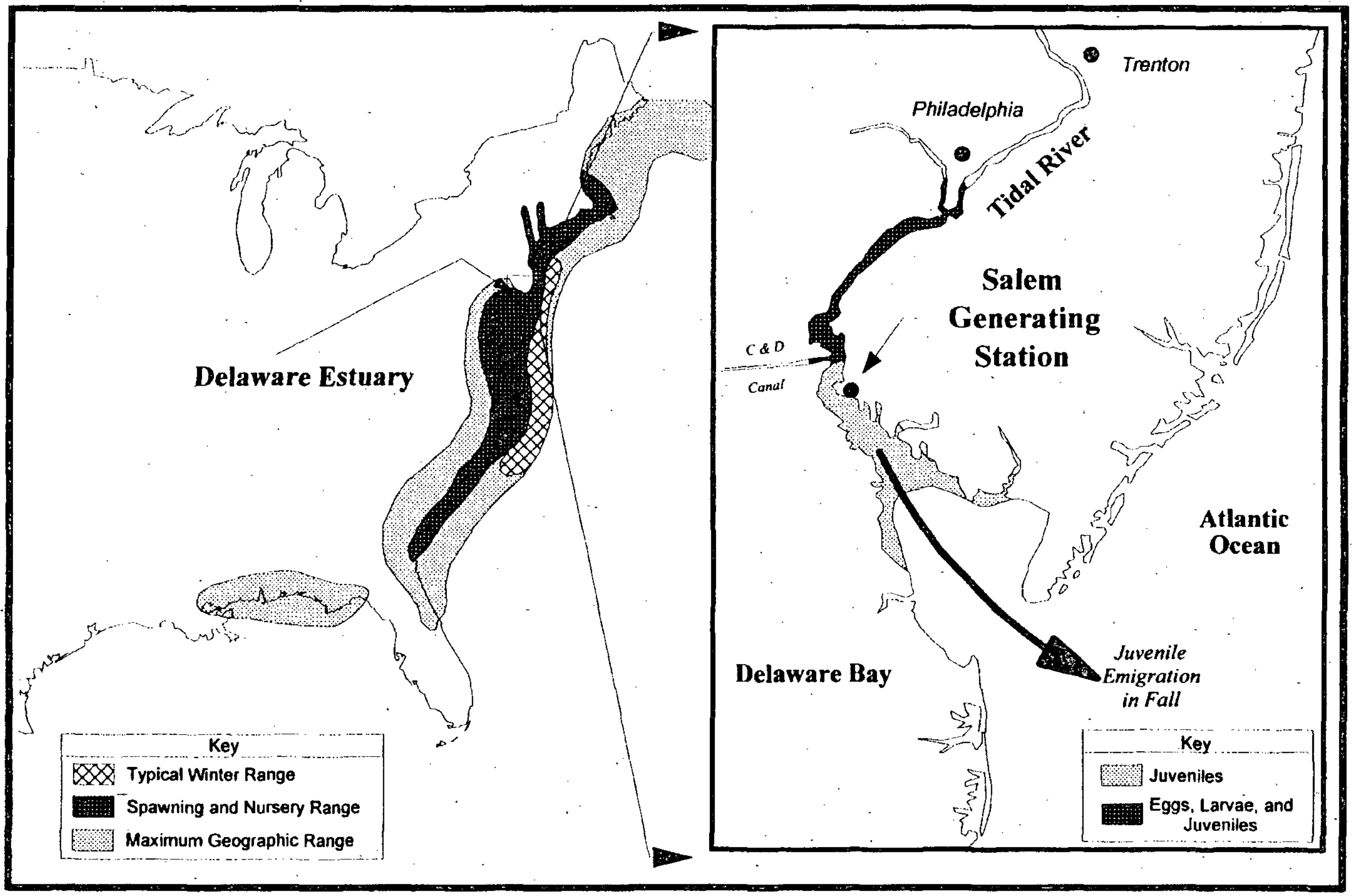
E Figure IV-21. General distribution of spot along the Atlantic and Gulf coasts and areas of principal occurrence within the greater Delaware system.



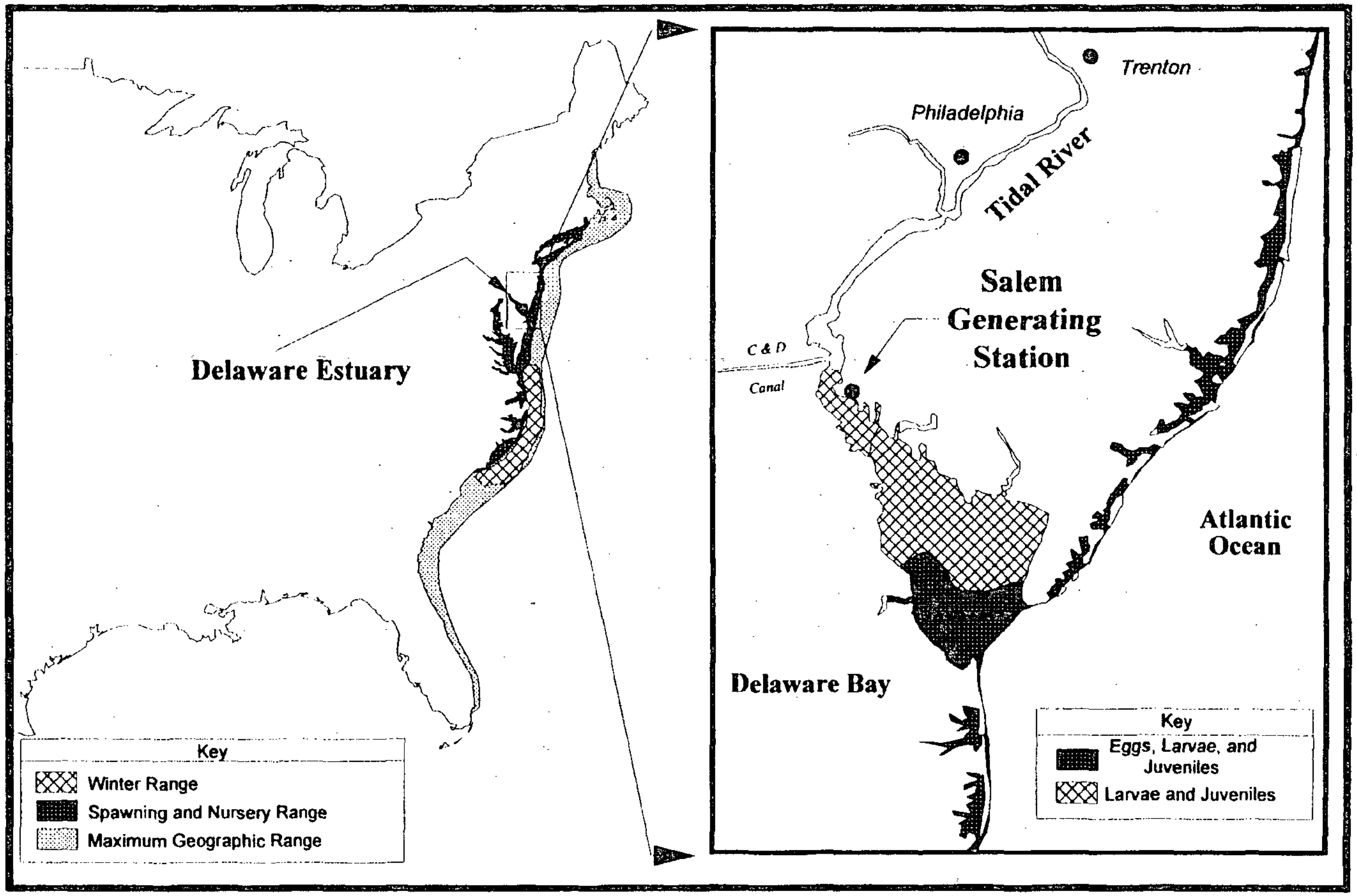
E Figure IV-22. General distribution of Atlantic croaker along the Atlantic and Gulf coasts and areas of principal occurrence within the greater Delaware system.



E Figure IV-23. General distribution of white perch along the Atlantic and Gulf coasts and areas of principal occurrence within the greater Delaware system.



E Figure IV-24. General distribution of striped bass along the Atlantic and Gulf coasts and areas of principal occurrence within the greater Delaware system.



E Figure IV-25. General distribution of weakfish along the Atlantic and Gulf coasts and areas of principal occurrence within the greater Delaware system.

V. CHARACTERIZATION OF THE THERMAL PLUME

V.A. Introduction

Salem Generating Station discharges circulating water at an elevated temperature into the Estuary, generating a plume of heated water (the "thermal plume"). The temperature increase that is attributable to Salem's thermal discharge at any point is referred to as excess temperature (or ΔT). The spatial distribution of ΔT in the Estuary at any time depicts the spatial distribution of Salem's heat and is referred to as a ΔT field.

The thermal plume consists of a near-field region, a transition region (which is different than the Transition Zone discussed in Section IV), and the far-field. The near-field, which is also referred to as the "zone of initial mixing" (ZIM), is a small region within the thermal plume where the mixing of the Salem thermal discharge with the waters of the Estuary is dominated by the momentum of the thermal discharge. In the 1999 Application, the length of the near-field is approximately 300 feet during running tides (flood and ebb), and approximately 1000 feet during the times of slack water for Two-Unit operations. The length is measured along the centerline of the ZIM, which may have a curved shape depending on the magnitude and direction of the local currents in the vicinity of Salem. The transition region extends from the end of the near-field to the beginning of the far-field. In the 1999 Application, the length of the transition region is taken to be approximately 700 feet for the four principal phases of a tide (namely, ebb, end-of-ebb, flood, and end-of-flood). Except for slack tides, the velocity at the end of the transition region is assumed to have a magnitude equal to the ambient current. The far-field comprises the remainder of the thermal plume and is the region where mixing is controlled by the ambient currents. The boundary of the far-field, which is also the boundary of the thermal plume, is often delimited using a line of constant ΔT (or ΔT isopleth). In the regulatory context (NJAC:7:9B-1 et seq.), the thermal plume is delimited by the 1.5°F ΔT isopleth for the summer months (June - August) and the 4.0°F ΔT isopleth for the non-summer months (September - May).

Numerous complex factors govern the ΔT field, and the extent of the thermal plume, including the characteristics of the Station and the Estuary, prevailing meteorological conditions, and hydrothermal plume processes. A brief overview of these factors is presented in Section V.B. below.

In the thirty-year period between 1968 and 1998, a variety of physical and numerical modeling and field data collection programs have been implemented to characterize the Salem thermal plume. The complexity of these studies has increased over the years as science and technology have advanced. As a result, more and more detailed information has been gathered about the thermal plume, particularly in the vicinity of the discharge itself. Section V.C below provides a summary of previous studies.

Studies have shown that the characteristics of the thermal plume are generally similar to what was predicted before the Station was constructed.

In 1997 and 1998, temperature monitoring programs were implemented to further characterize the thermal plume as a component of PSE&G's 1999 316(a) Demonstration. The 1998 Modified Thermal Monitoring Program (Modified TMP) was approved by NJDEP and includes an extensive field measurement program using advanced equipment, as well as the application of state-of-the-art numerical models that would be used to characterize the Salem thermal plume. Section V.D below describes the field data under the Modified TMP. Detailed presentations and interpretations of the field data, including methods and quality control procedures, are provided in Exhibits E-1-2 and E-1-3.

The primary purpose of the 1997 and 1998 field data collection programs was to provide a comprehensive data set that supports the calibration and verification of the numerical models used to characterize the thermal plume. The 1998 hydrothermal modeling components of the MTMP used these data to calibrate and verify a set of computer models. These models were then applied to predict the ΔT fields, size, trajectory, and other characteristics of the thermal plume, and to compute seasonal variations of water temperatures in the thermal plume. The models represent the best tools available for simulating thermal plume dynamics. In some cases, model improvements were implemented for the site-specific Station applications. An overview of the modeling methods is provided in Section V.E below. A more detailed discussion of modeling methods, including a description of the models, case-specific model improvements, and calibration and verification procedures, is provided in Attachment E-2 Section III.

The hydrothermal models were applied to produce characterizations of the thermal plume, and statistics on the annual and interannual variation of ambient water temperature that were needed to complete the Biothermal Assessment component of this 316(a) Demonstration (Section VI). The biological work products from the hydrothermal models are presented in Section V.F.

As methods for measuring and modeling hydrothermal processes have progressed, more detailed descriptions of the thermal plume have been developed. The characterization of the thermal plume in PSE&G's 1999 Application is based on state-of-the-art models and a comprehensive field monitoring program. Overall, the descriptions of the thermal plume provided by this and previous studies have been consistent.

V.B. Description of the Salem Generating Station, the Delaware Estuary, and Hydrothermal Plume Processes

V.B.1. Salem Generating Station

The thermal plume is created as the Station's cooling water is discharged to the Estuary. More detailed information about the Station is presented in Section III. For a complete description of the Station, the reader is referred to Appendix B.

The Station includes two nuclear-powered, pressurized-water reactors, each rated at 1,160 megawatts electric (Mwe) and 3,423 megawatts thermal (MWt). Both Units use a once-through cooling water system, and each is served by six circulating water pumps that draw water from the Estuary (a combined total of twelve pumps serve Units 1 and 2). After the water is withdrawn from the Estuary, it passes through the cooling water system to the condensers where its temperature is raised as the steam is condensed from the turbines. The total rate of heat rejection from Units 1 and 2 is 15,600 million British thermal units per hour (MBTU/hr). At the 30-day average flow rate (Q) of 175,000 gpm per pump, the increase in water temperature across the condensers ($\Delta T_{condensers}$) is 14.8°F. The expected maximum $\Delta T_{condenser}$ is 18.6°F, at the expected minimum flow rate of 140,000 gpm per pump (Attachment B-1). The maximum $\Delta T_{condensers}$ can occur when fouling reduces pump flow rates, or some circulating pumps are not operated.

The heated water is discharged back to the Estuary through six adjacent pipes, each ten feet in diameter. Original construction drawings and a detailed bathymetric survey (Exhibit E-1-4) indicate the discharge location is approximately 500 feet offshore from the Station. The pipes are buried along approximately 450 feet of this distance, and are spaced fifteen feet on center. The water depth at the discharge location is approximately 31 feet below the mean tide level, which was dredged during construction and is deeper than surrounding areas. There are complex bottom features, such as ridges and depressions, surrounding the discharge location. These characteristics of the discharge and surrounding bottom, along with the $\Delta T_{condenser}$ and Q, affect the size, shape and extent of the thermal plume. Consequently, these features of the Station are incorporated into the numerical models used to characterize the thermal plume.

V.B.2. The Delaware Estuary

An overview of the Estuary is provided in Section IV. Appendix C provides a detailed description of the Estuary.

Artificial Island is a peninsula of approximately 700 acres located about 50 miles northwest of the mouth of Delaware Bay and 30 miles south of Philadelphia, PA. In the vicinity of the Station, the Estuary is approximately 2.5 miles wide. Just upriver from the discharge, the Estuary narrows and makes several bends, resulting in complex, spatially-varying flow patterns (Appendix C). South of Artificial Island, the Estuary widens markedly.

The Estuary's changing geometry in the vicinity of the Station causes complex current patterns. The tidal currents are swift, and change direction with the changing orientation of the Estuary's shoreline. In addition to the changing geometry of the Estuary in the vicinity of the Station, the tidal currents are further complicated by the effects of freshwater inflow, the C&D Canal, and wind. All of these natural processes govern the transport and mixing of the thermal plume from the Station. Consequently, the numerical models used to simulate the thermal plume must appropriately simulate these natural estuarine processes.

V.B.3. Hydrothermal Plume Processes

The physics governing the transport and dilution of the thermal plume are complex. The ΔT field is dependent upon the amount of heat discharged by the Station, how rapidly the plume mixes with the receiving water, and heat dissipation to the atmosphere. The degree and mechanism of mixing result from an interplay between discharge characteristics and the conditions in the receiving water. Relevant receiving-water conditions include tides, turbulence, water depth, and bottom roughness that contribute to the velocity field in the Estuary; and the temperature, salinity, and stratification that define the density field. Discharge characteristics include the amount of heat discharged, the geometry of the discharge pipes, and the volume, momentum, and buoyancy fluxes of the discharge. Atmospheric conditions that affect surface heat dissipation include wind speed, dew point, and air temperature.

The processes by which a ΔT field develops are established occur in several steps that can generally be characterized as near-field and far-field processes.

V.B.3.a. Near-field Thermal Plume Processes

The ZIM is a small region of the thermal plume where the Station's heat is rapidly diluted by waters of the Estuary. The dilution is caused by intense mixing that is induced primarily by the momentum of Salem's thermal discharge. The geometry of the discharge pipes, the local bathymetry, and the buoyancy of the thermal discharge also affect this mixing. Based on the results of the 1999 hydrothermal modeling and data from the MTMP, the length of the ZIM is approximately 300 feet during the running tides (flood and ebb) and approximately 1,000 feet during time of slack water for Two-Unit operations.

Initially, the mixing of the Station's discharge with the receiving water is caused by turbulent shear, as the high velocity of the discharge rapidly entrains and is diluted by ambient receiving water. In a multi-pipe discharge, such as the six-pipe diffuser at Salem, the jets from the individual discharge pipes quickly merge to form a plane jet (Figure V-1). The momentum of the jet creates a very turbulent zone of complex flow patterns including eddies which dissipate momentum and increase mixing. A detailed survey of the local bathymetry in front of the discharge site reveals bottom features such as riprapped sides, ridges and holes that may direct some of the discharge toward the surface (Exhibit E-1-4).

The height and width of the ZIM increase with distance from the discharge point as more receiving water is entrained with the effluent. Due to the size of the discharge pipes (10 foot diameter) in relation to their depth of submergence, the ZIM expands over the entire water column and intercepts the water surface (i.e., it surfaces) not far from the point of discharge. Generally, the initial ΔT is reduced by approximately 40 to 50 percent by the time the ZIM reaches the surface (in about 7 seconds). At this point, velocities in the ZIM are considerably less than the discharge velocity.

After the ZIM intercepts the water surface, it continues to expand laterally (or spread out). Mixing and the trajectory of the ZIM are still influenced, to some degree, by the horizontal component of the discharge momentum, but the effect is significantly reduced. As the ZIM expands beyond the surfacing location, the discharge momentum becomes further dispersed and velocities continue to become reduced and to approach the ambient velocity. The far-field begins where mixing is controlled by the ambient current. The region between the end of the ZIM and the beginning of the far-field is a transition region where the rate of change in ΔT is slower than in the ZIM but faster than in the far-field. This is the transition region to the far-field. Dimensions of this near-field, which includes the region where the discharge is dominated by its momentum, and the transition region are presented in Section V.F.

The transition region is a region of buoyant spreading whereby the thermal plume spreads horizontally and stratifies vertically, due to buoyancy, caused by temperature differences. Warm water within the transition region may rise to the surface and promote lateral spreading. Buoyant spreading may induce mixing when there are sharp temperature differences over short distances, but the effects of this process are minimal. Generally, the significance of buoyant spreading decreases with increasing distance from the discharge. Eventually, the velocity of the plume slows to ambient current speeds, and the temperature of the plume is determined primarily by (1) meteorological factors governing surface heat exchange, and (2) dilution from mixing with local currents. The end of the transition region marks the beginning of the far-field.

V.B.3.b. Far-field Thermal Plume Processes

The far-field area begins where the plume is primarily influenced by currents in the receiving water. At the beginning of the far-field, two physical processes dominate: buoyant spreading and passive diffusion.

The characteristics of the thermal plume in the far-field vary with the prevailing meteorological and receiving water conditions. Given the tidal nature of the Estuary, the thermal plume moves alternatively up-Estuary for approximately five hours during incoming flood flow, then down-Estuary for approximately seven hours during ebb flow. Slack tides occur for a period of minutes between flood and ebb. Therefore, the region of the Estuary that is affected by the thermal plume is dynamic and varies over a complete tidal cycle.

V.C. Prior Hydrothermal and Hydrodynamic Modeling Programs

Throughout the past 30 years, various studies have been completed to characterize the thermal plume. The methods utilized for these studies include physical modeling, field observations, and numerical modeling.

There are advantages and disadvantages to each method with regard to the ease of implementation, and the type and accuracy of information produced. Physical and numerical models, when properly developed and implemented, can be used to predict or simulate the impacts of proposed operations and to efficiently analyze a range of operational and environmental conditions. Numerical models are more adaptable than physical models for this purpose because the variations that can be studied with physical models may be limited by scaling factors or physical constraints.

Field observations provide a direct measurement of conditions in the Estuary, but are specific to the circumstances that prevail during the measurement period and often are not comprehensively synoptic. Also, natural background variability makes it difficult to distinguish the thermal plume in regions where ΔT is small. If the observational period is anomalous, the measurements may not be representative of typical conditions. However, field measurements do provide a basis for testing the accuracy of physical and numerical models through model calibration and verification.

Due to advancements in numerical models of thermal plume dynamics and estuarine processes, as well as technological improvements in field measurement equipment, the level of detail achieved in thermal plume studies for Salem has risen significantly since 1968. In particular, the ability to measure and model thermal plume dynamics in the near-field has increased tremendously. Currently, the best methodology for simulating thermal plume dynamics includes a combination of field measurements and numerical modeling.

The advanced techniques for measuring and modeling hydrothermal processes that were implemented for PSE&G's 1999 Application build on the previous characterizations of the thermal plume, and provide more detailed information. In spite of the differences among the various methods, the general description of the thermal plume has not changed materially since the initial physical model of the system was constructed in 1968. Today's predictions of ΔT fields associated with the Salem thermal discharge and the overall extent of the thermal plume are consistent with the predictions presented before the Station was constructed.

A summary of the past studies is provided in this section as the basis for the present characterization of the thermal discharge.

V.C.1. Physical Modeling In Support of PSE&G's Initial Section 316(a) Demonstration

The initial 316(a) Demonstration was submitted to the USEPA on 11 November 1974. The 1974 316(a) Demonstration was submitted before the Station was operational. An important element of that Demonstration was the description of the Station's projected thermal plume. The 1974 316(a) Demonstration showed that the limited effect of the projected thermal plume would assure the protection and propagation of a balanced indigenous community of shellfish, fish, and wildlife in and on the Delaware Estuary.

The description of the thermal plume provided in the 1974 316(a) Demonstration was based on physical modeling performed by Pritchard and Carpenter (1968). Pritchard and

Carpenter used a physical model of the Delaware Estuary constructed at the Army Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi. The Pritchard and Carpenter modeling study originally was undertaken to evaluate alternative discharge configurations in light of, among other factors, the thermal plumes produced by each alternative, and to provide the initial baseline predictions of the thermal plume's characteristics. Pritchard and Carpenter established and adjusted their modeling conditions so that forecasted thermal plumes would correspond to worst-case conditions (conditions under which heat exchange would be minimal, and the potential extent of the thermal plume would reach a reasonable maximum). For modeling purposes, ambient water temperature was maintained at 50°F, a condition that was considered to result in minimum summer loss of plume heat through the water surface. The flow through the C&D Canal was stated to be a net 4,000 cfs non-tidal drift into the Estuary. The Delaware River inflow at Trenton was assumed to be 2,000 cfs, a value lower than the seven-day, 10-year, low flow (2,300 cfs), and significantly lower than the annual mean of 11,700 cfs (Appendix C). Pritchard and Carpenter also assumed that the Station would operate at a net heat rejection rate of 15.25×10^9 Btu/hr to the Delaware Estuary versus the presently assumed value of 15.6×10^9 Btu/hr.

For the discharge structure configuration that was ultimately constructed, the physical model predicted that the greatest increase in temperature would be restricted to the immediate vicinity of the discharge. The extent of the 4°F ΔT isopleth on the surface was approximately 0.5 miles (2,640 feet) long by 0.125 miles (660 feet) wide at the end of the flood tide. The 1.5°F surface ΔT isopleth was predicted to extend northward approximately 31,000 feet during flood tide conditions and southward approximately 41,000 feet during ebb tide conditions. Pritchard and Carpenter concluded that the thermal plume would seldom extend as far to the west as the shipping channel (approximately 6,000 feet offshore of Artificial Island), and that ΔT near the shipping channel would be so small that it would be difficult to observe.

The Delaware River Basin Commission (DRBC) carefully reviewed the Pritchard-Carpenter Report prior to issuing the (original) Docket No. D-68-20 CP for Salem. DRBC understood that Salem's discharge would produce a long plume, as defined by the instantaneous 1.5°F ΔT, but that higher ΔT would be confined to a small area in the immediate vicinity of the discharge. DRBC's understanding was summarized in an internal memorandum as follows:

"[U]nder the worst conditions of tide ...[The] studies indicate that an oblong area, more or less hugging the shore, with a length of approximately one mile, would contain water having a 5° [F] rise. Under these same conditions, there would be a 3°F rise extending over a 1-3/4 mile reach and a 1.5°F rise over a 7 [mile] plus or minus reach (Howlett 1968)."

Following the submittal of the initial 316(a) Demonstration, a number of monitoring surveys and individual studies were conducted from 1977 to 1985 to gather detailed data on Estuary hydrodynamics and Station operations. Field studies were conducted under nonoperational conditions as well as one-and two-Unit operations. These field data collection programs are described briefly below.

V.C.2. ***Thermal Monitoring Program Unit One Operation (1977-1978)***

Monthly or twice-monthly monitoring surveys, as well as a number of special studies, were conducted in 1977 and 1978 to describe the extent of the thermal plume, its effect on the thermal regime of the Estuary, and the dispersion and circulation characteristics of the receiving water body (Weston Environmental Consultants, Inc. 1979). Parameters measured during the monitoring program included the following: temperature, salinity, and current velocity measurements at various depths at 37 monitoring stations over four tide phases during an entire year; close-interval plume mapping using a radio position-finding system coupled with continuous temperature recording; and long-term (17 months) continuous temperature records from moored recording thermographs. Other special studies included: a heat flux study of the role of the extensive salt marshes in the area as heat sources or sinks (results from that previous heat flux study are compared to the present analysis in Exhibit E-1-5); a study of recirculation using a combination of dye tracer and temperature measurements; the use of thermal infrared imagery to define the interaction of the thermal plume with marsh runoff and Estuary water; mobile mapping of the moving thermal plume at four depths during each of the four tidal phases (ebb, end-of-ebb, flood, and end-of-flood); and computer analysis of two and one-half years of pre- and post-operational survey and thermograph temperature data to determine whether any long-term changes had occurred in the temperature regime of the Estuary.

All studies during this period (1977-1978) were performed during the operation of Unit 1 only. A limited attempt was made to anticipate and project the increased effect on the thermal plume from Unit 2, which was to begin commercial operation in 1981. However, the majority of the analyses were treated as empirical measurements of the influence of the then-existing single unit.

The findings of the first year's monitoring program showed that, in the absence of certain meteorological conditions (e.g., strong winds), the thermal plume could be described as a narrow, longitudinal band (usually less than 300 feet in width) during the ebb and flood tides. The longitudinal extent of the thermal plume varied according to the tide and season. The short-lived slack tides exhibited a "puddling" effect, with the major portion of excess heat located within 2,500 feet of the submerged discharge.

Because the thermal plume measured in 1977-1978 was due to the operation of Unit 1 only, and actual field conditions at the time of the surveys were not "worst-case" conditions, the results of the 1977-1978 surveys revealed a thermal plume that was smaller than predicted by the Pritchard and Carpenter physical model. Thus, the conservative estimate of the extent of the thermal plume predicted by Pritchard and Carpenter, and presented in the original 316(a) Demonstration, was retained as the worst-case Two-Unit plume.

In addition to the monitoring program described above, two additional field studies were conducted in 1977. A "Special Recirculation Study" was performed in July to determine if the heat discharged from Unit 1 was being recirculated to the cooling water intakes. A second study, "Special Heat Flux Study, " was conducted in October 1977 to assess heat inputs of Alloway, Hope, and Mad Horse Creeks into the Estuary in the vicinity of the Station (Weston Environmental Consultants, Inc. 1978).

The results of the Special Recirculation Study showed temperatures in the vicinity of the cooling water intakes at Unit 1 to range from 0.0°F to 1.1°F warmer than temperatures at the shipping channel in the middle of the Estuary. Results were inconclusive as to whether solar warming of the tidal shallows or heated effluent was responsible for the slightly higher water temperatures at the intakes on a specific tidal stage.

Results from the Special Heat Flux Study (Weston 1978) provided additional information on the local thermal regime, and served to distinguish temperature changes caused by Salem's thermal discharge from those associated with natural variations in Estuary temperature. The findings of this study indicated that, with respect to any impacts on the Estuary, the thermal discharge from Unit 1 was similar to the daily flux of warm water from the nearby tidal creeks and marshes. Exhibit E-1-5 reviews this conclusion based on new analysis. Weston concluded that on sunny days, the patterns of thermal gradients observed during the monitoring surveys were more often dominated by solar warming than by the Station's thermal discharge.

V.C.3. Thermal Monitoring Program Two-Unit Operation (1982-1985)

To provide data on thermal plume dynamics under two-unit operation, a thermal monitoring program was initiated in 1982, as provided in the Environmental Technical Specifications Appendix B to the AEC/USNRC Operating License issued to Salem Generating Station (AEC/USNRC Dockets 50-272 and 50-311, Units 1 and 2, respectively). The thermal characteristics of the plume were studied as functions of tidal phase, transport velocity and direction, configuration and spatial extent, and other related parameters.

Two major thermal plume field studies were conducted in June and August, 1982. The studies included temperature measurements in the Station's thermal plume using a combination of fixed-station thermographs, continuous-temperature recording mobile mapping, real-time fixed-station water-column temperature measurements, and aircraft-carried sensing imagery. Fixed-station thermographs provided time-varying water temperature at one location, whereas mobile mapping recorded the spatial variation of water temperature over a brief period. The first survey was conducted on 15 and 16 June 1982 during relatively high river flow conditions; the second survey (without infrared imagery) was conducted on 24 August 1982 during low river flow conditions.

The June and August 1982 field surveys of Salem's thermal discharge presented data that showed the following:

- abrupt reduction of temperature in the initial mixing zone;
- a very small region from the discharge point to where the ZIM surfaces;
- further rapid reductions of temperature in the vicinity of the discharge after surfacing;
- more gradual but relatively continuous reductions in temperature in the remaining portion of the study area, which extended two miles upstream and downstream of the Station; and
- changes in temperature attributable to the thermal discharge were not detectable at the two-mile limits of the study areas.

The results of the 1982 field investigations revealed a Salem two-unit thermal plume that was larger than measured in 1977-1978 during one-unit operation; however, it still covered a much smaller area than predicted by the 1968 Pritchard and Carpenter physical model. The differences were due, in part, to the fact that the Pritchard and Carpenter model simulated worst-case meteorological conditions, whereas the 1982 field data represented actual meteorological conditions that prevailed during the measurement periods. The differences also were dependent upon the estimate of the ambient temperature that was subtracted from the measured temperature to compute the ΔT. It is impossible to directly measure the ΔT field attributable to the Salem thermal discharge because it is impossible to simultaneously measure the temperature of the Estuary at a given location both with and without the Station operating. Consequently, the more conservative results presented in the original 316(a) Demonstration were again retained for the purposes of defining the potential worst-case characteristics of the Salem thermal plume.

V.C.4. 1991 Hydrothermal Studies

In 1991, comments were submitted to NJDEP in response to the 1990 Draft Permit for Salem. The 1991 comments included updated thermal plume studies to provide additional documentation to support PSE&G's request of a Section 316(a) Variance.

The updated thermal plume studies submitted by PSE&G included two components. The first component involved use of a mathematical model to characterize the ZIM, which was defined as that portion of the thermal plume from the end of the discharge pipes to where the ZIM surfaces, a distance then estimated to be approximately 325 feet. The second component involved the mapping of the remainder of the near-field portion of the thermal plume, at that time defined as that portion of the plume from 325 to 500 feet from the end of the discharge pipes. The second component also involved the mapping of the far-field portion of the thermal plume, defined at that time as the area extending beyond a point of 500 feet from the end of the discharge pipes. These portions of the thermal plume were mapped using the in-stream temperatures collected in the 1982 field surveys. PSE&G used the average of the temperatures measured at Salem's cooling water intake to establish the ambient temperatures in both components of the analysis. The difference between the estimated ambient temperature at the intake and the in-stream temperatures collected in the field surveys were considered to constitute the temperature increases or

ΔT attributable to Salem's thermal discharge and provided the basis for constructing ΔT fields. Identifying an appropriate source of data to represent ambient temperatures was difficult, due to the number and complexity of natural and man-made sources that contribute heat to the Estuary, and the temporal and spatial variability of in-stream conditions, including temperatures. An accurate measure of ambient temperature is required to locate the isopleths of lower ΔT because these lower ΔT isopleths vary gradually with distance. Thus, a small error in the estimate of ambient temperature can result in a sizeable displacement of the location of a small ΔT isopleth such as the 1.5°F isopleth. A final limitation is the inability to distinguish small temperature variations caused by the Station from those due to natural processes in the thermal plume margins.

The 1991 studies used a mathematical model to characterize the ZIM because it was not feasible during the 1982 field survey to collect in-stream temperatures and velocities for most of this portion of the plume due to high discharge velocities and resulting turbulence. A then state-of-the-art three-dimensional near-field mathematical plume model, UDKHDEN, was used to estimate the ΔT field and velocities in the ZIM, temperature dissipation with time and distance, and the mixing ratio with surrounding waters in the ZIM. Predicted temperature increases at the point where the thermal plume surfaces, using UDKHDEN, were compared to the in-stream temperatures measured during the 1982 field surveys. The UDKHDEN predictions compared reasonably well with those measured in the field survey, typically within 1°F.

The 1991 model analysis of the ZIM using UDKHDEN showed that the thermal plume surfaces within about 325 feet of the discharge pipes, that the $\Delta T_{condenser}$ decreases abruptly by about 50 percent over this distance, and that the high discharge velocities also dissipate abruptly. Also, the results showed that the ZIM, which is the portion of the thermal plume containing more elevated temperatures and higher velocities, represented an extremely small volume of the Estuary.

The 1991 study also mapped the far-field portion of the thermal plume. In addition, the 1991 studies also considered the information gathered in the various field studies and special surveys conducted from 1977 to 1985. By subtracting the estimated ambient temperature (intake) from the in-stream temperature data collected in the 1982 far-field survey, the 1991 analysis developed instantaneous ΔT fields reflecting the meteorological, hydrodynamic, and Station operating conditions for the days in 1982 when the field surveys were conducted.

PSE&G used these ΔT fields to measure thermal plume lengths for the four phases of the tide for the days in the summer of 1982 on which the field studies were conducted. These maps show a relatively continuous decrease in ΔT over the far-field portion of the thermal plume, which was shown to contain mildly elevated temperatures. Based on the locations of the instantaneous 1.5°F ΔT isopleth, the maximum calculated plume lengths were 12,800 feet and 13,200 feet, based on the June maximum ebb data and the June maximum flood data, respectively. The calculated lengths were less than those derived from the results of the Pritchard-Carpenter physical modeling study discussed earlier. This apparent inconsistency reflects the inherent practical limitations of using field surveys to determine maximum plume lengths that were previously discussed.

V.C.5. 1993 Hydrothermal Modeling Program for Salem

The 1993 thermal plume mathematical modeling studies used then state-of-the-art techniques for characterizing the near-field and far-field portions of the thermal plume (as defined by the instantaneous 1.5°F ΔT isopleth), under varying meteorological, hydrodynamic and Station operating conditions. The models were superior to those used earlier, thereby providing a more complete, reliable, and realistic representation of the characteristics of the thermal plume. This characterization was also more comprehensive than that developed from earlier plume studies. The characteristics of the entire thermal plume represented by the 1993 plume studies were, however, consistent with and confirmed the basic plume characteristics presented in all previous thermal plume studies.

V.C.5.a. CORMIX-2 as Applied in 1993

A newly-developed plume model, CORMIX (Version 2), was used in 1993 analyze the near-field portion of the thermal plume. This model was designed to simulate the mixing that is induced by submerged thermal discharges such as Salem's. CORMIX describes the temperatures and velocities in the ZIM and the rest of the near-field portion of the thermal plume based upon assumptions of unidirectional flow, simplified geometry, and negligible surface heat exchange.

The analysis found that temperatures in the near-field portion of thermal plume decrease abruptly from the typical summer instantaneous ΔT of 19°F at the end-of-pipe to about 11°F at the end of the ZIM, and then to about 9°F at the 500-foot radius that then defined the end of the near-field and the beginning of the far-field. The analysis also found that velocities in the near-field abruptly decreased from a maximum of approximately 10 ft/sec at the discharge outfall to much lower velocities approaching in-stream tidal velocities. These findings were very similar to those of the 1991 UDKHDEN studies of the near-field.

V.C.5.b. RMA-10 as Applied in 1993

The far-field was analyzed in 1993 using a three-dimensional hydrodynamic and transport mathematical model, RMA-10, which takes into account the dominant processes, to determine the distributions of water temperatures in the Estuary, such as surface heat exchange, tidal dynamics, inflows, variable geometry, and thermal discharges.

The 1993 thermal plume mathematical modeling used to characterize the far-field was believed to be the first commercial application of a three-dimensional, tidally varying hydrodynamic and transport mathematical model to calculate thermal plume dimensions to verify the results of a physical model study, such as that conducted by Pritchard-Carpenter in 1968.

After being calibrated and verified for application at Salem using the results of the 1982 field surveys, the RMA-10 model was used to characterize the far-field. RMA-10 was run with a range of input conditions and the results were analyzed to calculate the maximum lengths of the thermal plume, defined as an instantaneous 1.5°F ΔT. The computed maximum upstream length at the end of flood was approximately 37,100 feet, and the maximum downstream length at the end of ebb was approximately 36,300 feet.

The conditions that produced the maximum plumes were selected on the basis of a screening analysis of meteorological conditions (surface heat exchange) that would tend to produce the longest thermal plumes. The surface heat exchange on these five days was expected to occur at a frequencies of once in five summers, once in 2.5 summers, once in one summer, twice in one summer, and an average summer condition, respectively.

The ΔT fields that were associated with the thermal plumes having the maximum lengths were used to further characterize the thermal plume for input to the 1993 Biothermal Assessment. These characterizations included volumes, cross-sectioned areas, bottom areas, and surface areas of the Estuary where specific values of ΔT were equaled or exceeded. In addition, these thermal plumes were also analyzed to determine the time dependent exposure to ΔT for particles that drifted along the centerline of the thermal plume. The RMA-10 model results showed that most of the thermal plume consisted of mildly warmed water. The model showed that the region of the thermal plume having a ΔT greater than 5°F occupied less than 7 percent of the surface area of the 1.5°F thermal plume, and that approximately 90 percent of the volume of the thermal plume consisted of ΔT fields of less than 4°F.

The results of the 1993 far-field model represented the first numerical predictions of a worst-case thermal plume for comparison to the original Section 316(a) Demonstration. By way of comparison, Pritchard and Carpenter used a physical model for the 1974 316(a) Demonstration, and predicted that the maximum downstream and upstream extents of the 1.5°F ΔT isopleth would be 41,000 and 31,000 feet, respectively. These plume lengths are remarkably similar to the results predicted by the 1993 computer modeling study, considering the availability of field data and improved numerical modeling techniques that were available in 1993 compared to 1974.

V.C.6 1994-1995 Hydrothermal Modeling Studies, Delaware River Basin Commission

On 20 June 1995, PSE&G submitted an application to the DRBC to revise the heat dissipation area (HDA) specified in Docket No. 68-20 CP. The application requested a revision of the Heat Dissipation Area (HDA) for Salem's thermal discharge in accordance with DRBC's Water Quality Regulations ("WQR"). The request to revise Salem's HDAs was occasioned by renewal by the New Jersey Department of Environmental of Environmental Protection (NJDEP) of Salem's New Jersey Pollutant Discharge Elimination System (NJPDES) Permit No. NJ0005622 (the Permit) and its grant of a variance for Salem's thermal discharge pursuant to section 316(a) of the Clean Water Act (CWA or the Act) in 1994.

The revised HDAs provided that the DRBC's temperature increase standards (calculated as a 24-hour average) for Zone 5 of the Delaware of 1.5°F for June through August ("summer") and 4°F for September through May (non-summer) periods shall not be exceeded at any point beyond specified distances upstream and downstream from the end of the Station's discharge pipes and at a specified distance to the east of the shipping channel of the Estuary. The proposed summer HDA extended 20,000 feet upstream and 25,000 feet downstream, and provided that the thermal plume shall not come closer than 1,000 feet to the eastern boundary of the shipping channel. The proposed non-summer HDA extended 3,300 feet upstream and 6,000 feet downstream and provided that the plume should not come closer than 3,200 feet to the eastern boundary of the shipping channel.

The revised HDAs also include provisos to deal with the infrequent occasions when, because of unusually high, naturally occurring ambient temperatures, Salem might be unable to comply with the maximum 86°F River temperature in the WQR for Zone 5 even though it fully complies with the 1.5°F or 4°F 24-hour average temperature increase standards.

PSE&G based the proposed dimensions of the HDA on predictions of 24-hour average ΔT fields that were computed using a calibrated and verified version of RMA-10. The ΔT fields were constructed for various combinations of tidal range, surface heat exchange, and water temperature at Reedy Island that would likely result in the longest thermal plume. The resulting up-estuary and down-estuary thermal plume lengths and widths were analyzed in combination with long-term records of tidal range, surface heat exchange, and water temperature to determine the appropriate lengths and widths for an HDA. These dimensions were increased by a small margin to allow for uncertainties in the analysis. DRBC approved the proposed HDA and incorporated the provisions for the new HDA into Docket No. D-68-20 CP (Revised) on 29 September 1995.

V.C.7. 1994-1995 Hydrodynamic Field Data Collection and Modeling Program

Although not applied to characterize the thermal plume, an additional extensive field data collection and computer modeling program was completed in 1995 (Exhibit E-1-1). The 1995 modeling program also utilized RMA-10 to identify the physical processes that contribute to the accumulation of detritus in the Estuary near the Station. Hydrodynamic calibration and verification of RMA-10 required an extensive collection of hydrodynamic data, including tide, current, and salinity measurements. As a result, RMA-10 produced a more detailed representation of current patterns than had been known previously, specifically at Sunken Ships Cove and Hope Creek Jetty, which are south of the Station. For this study, the model utilized a numerical grid with a high degree of resolution. The enhanced grid resolution needed to simulate these current patterns was adopted for the 1999 hydrothermal modeling study, to improve the RMA-10 model.

V.D. New Data Sources

V.D.1. Basis/Background for Monitoring Program

Special Condition H.6 in Part IV-B/C of the Permit required PSE&G to submit a Biological Monitoring Program Work Plan (the "BMWP") to the NJDEP and included a requirement to perform a comprehensive thermal monitoring program and a Biothermal Assessment. PSE&G submitted a detailed description of the BMWP, which included a thermal monitoring program designed to support a Biothermal Assessment, to the Monitoring Advisory Committee (MAC) in December, 1994, in a document entitled, "Biological Monitoring Program for Delaware Estuary-Work Plan." This thermal monitoring program is referred to as the Original Thermal Monitoring Program (the "Original TMP"). After being reviewed by the MAC, the BMWP was submitted to the NJDEP for its review and comment on 25 January 1995. Based on comments delivered by the NJDEP, the BMWP was revised on 2 May 1995. The NJDEP approved the BMWP, including the Original TMP by a letter dated 6 April 1996.

The objective of the Original TMP, as specified in the BMWP, was to collect the field data to permit the characterization and extent of the thermal plume in terms of ΔT. This objective was to be achieved using numerical models since ΔT can not be measured directly in the field. Thus, the Original TMP was designed to collect data necessary to calibrate/verify the numerical models that would then be used to calculate ΔT. The calibration/verification process would compare measured water temperatures with those predicted by the models for conditions that existed when the data were collected. Once agreement was established, the models would then be used to calculate the spatial distribution of ΔT at various phases of a tide for tidal and meteorological conditions that would tend to maximize the size of the thermal plume and the regions of warmer water within the thermal plume.

Chapter 5.2.2 of the Original BMWP described the Original TMP which consisted of a near-field component and a far-field component. The near-field component included a series of shipboard surveys of water temperatures, an array of moorings to measure and record water temperature, and the deployment of a current meter to obtain data needed to interpret the effects of tidal action on the near-field temperatures. The far-field component included the deployment of far-field moorings equipped to measure and record water temperature and, possibly, a one-time dye study. The Original TMP was to be conducted over a six month period (May through October) when both of the Station's units were operating at or near full power.

The planned implementation of the Original TMP was delayed due to an unexpected, extended outage of both units beginning in the spring of 1995. This outage was necessitated, in part, by the discovery of microscopic cracks in components of Unit 1's steam generators, and the need to improve the reliability of both unit's performance. Unit

2 returned to steady-state full power in mid-October 1997. Unit 1 returned to steady-state full power operation in May 1998. While certain of the Original TMP's field-work activities were implemented in 1997 with Unit 2's return to service, the absence of a two-unit operation during the Permit Term precluded PSE&G from implementing the Original TMP. PSE&G conducted a field survey in July 1997 to determine the spatial distribution of naturally occurring temperatures (i.e., ambient temperatures) in the River. In addition, after Unit 2 reached and maintained full power operation in October 1997, PSE&G conducted a one unit thermal monitoring program during a two-week period in late October 1997. This program generally included components of the Modified TMP, more specifically described in Section V.D.2.

V.D.2. Modified Thermal Monitoring Program

When both Units returned to full power operation in May 1998, implementation of the Original TMP, involving the collection of six months of field data, would not have provided sufficient time for PSE&G to utilize the collected data to characterize the thermal plume utilizing mathematical models, conduct a Biothermal Assessment, and then present the same in a renewal application on or by March 4, 1999. Accordingly, PSE&G prepared, for NJDEP's review and approval, proposed revisions to the TMP ("Modified TMP") to accommodate this conflict. The Modified TMP was comprehensive and would: (i) provide the requisite data to utilize acceptable modeling techniques for characterizing the near-field and far-field thermal plumes with the detail required to perform an updated Biothermal Assessment; and (ii) permit PSE&G to complete the thermal plume modeling and Biothermal Assessment in accordance with a Section 316(a) variance on or by March 4, 1999, as required by Condition H.11. of the Permit.

On 25 March 1998, PSE&G submitted to the MAC the Modified TMP for technical advice, with a copy to the NJDEP. The Modified TMP included a detailed technical justification for the proposed modifications (PSE&G, 1998). The Modified TMP was designed specifically to meet all the objectives of the Original TMP. It was more detailed than the Original TMP, and included: (1) the technical basis for each component, (2) the relationship of the data to the objectives, and (3) the quality assurance/quality control procedures for handling the data.

Some members of the MAC provided comments and requested additional input on the proposed modifications. PSE&G prepared a response to the comments and questions (PSE&G 1998b). Subsequently, on 28 April 1998, PSE&G submitted a request to the NJDEP, supported by comments and questions , for approval of the Modified TMP. The NJDEP approved the Modified TMP on 5 May 1998.

The Modified TMP was implemented, as designed, in late May 1998 when Units 1 and 2 were operating near full capacity. This implementation, which is termed the Two-Unit Survey, provided a comprehensive data set for understanding the hydrodynamic transport characteristics of the Estuary and calibrating and verifying CORMIX (CORnell MIXing zone program) (Akar and Jirka 1990) and RMA-10 (King 1985). Exhibit E-1-3 describes the Two-Unit Survey in detail, including the dates when data were collected and passed quality assurance, and also identifies the data that were not collected.

As is the case in any complex field observational program, less than 100 percent of the original data planned were collected. Harsh weather conditions, activities by shipping and trawling industries, and other factors led to loss of some small portions of the data. When instrument problems or conditions arose, PSE&G took immediate action to correct those conditions. For instance, redundant instrumentation at each monitoring location was included in much of the six-month mooring study, based on the rate-of-return experienced during the May 1998 intensive survey. Despite the loss of some data, the Two-Unit Survey was comprehensive and provided a high-resolution data set that fulfilled the objectives of the Original and Modified TMPs. In addition, the large amount of data supported an analysis of the physical processes that occur in the Estuary. The results of that analysis are provided in Attachment E-2 Section IV.

The remainder of this section summarizes the results of the Two-Unit survey according to their relationship to the components of the Modified TMP.

V.D.2.a. Intensive Survey

The Intensive Survey was conducted mainly during a two-week period between 21 May 1998 and 4 June 1998. The Intensive Survey had six basic components based on the Modified TMP:

- Fixed Moorings
- Shipboard Surveys
- Dye-tracer Study
- Infrared Surveys of the Near-field
- Hydrodynamic Surveys (including water levels, currents, boundary survey, initial condition survey)
- Marsh Surveys

<u>V.D.2.a.i. Fixed Moorings</u>

A network consisting of 34 moorings (Exhibit-E-1-3 Figure 10-10; 31 in the river, 3 in marsh mouths), with sensors to measure water temperature on all the 34 moorings, conductivity on 14 moorings, and dissolved oxygen (DO) concentration on 5 moorings, were deployed for the two-week intensive survey period. Most moorings had instruments at the surface, mid-depth, and near bottom. Three of these moorings were lost, and no data were recovered. Shipping activity is thought to have caused the loss of these moorings. In spite of the loss of these three moorings, the network succeeded in collecting a comprehensive set of time-series measurements in support of the hydrothermal modeling, and, hence, the Biothermal Assessment. The data were used for the following purposes:

(1) to describe the variations in water temperature, salinity (inferred from conductivity measurements) and dissolved oxygen concentrations, for various time scales;
(2) to resolve spatial temperature gradients with a high spatial density of measurements in the regions of the Estuary where high spatial gradients in temperatures exist (i.e., near-field), and a relatively lower spatial density in regions of the Estuary where the spatial gradients in water temperature are more gradual and controlled by large-scale hydrodynamic processes;
(3) to provide a means to calibrate, verify, and/or validate the various models used in this Demonstration (CORMIX, RMA-10, Ambient Temperature Model (ATM), and Total Temperature Model (TTM)).

The sites for the measurement of water temperature, salinity, and dissolved oxygen were distributed over a segment of the Estuary that extends from twelve miles up-estuary of the Station to twelve miles down-estuary, with sensors deployed near the water surface, at mid-depth, and near the bottom. E-1-3 Table 10-2 provides a tabulated summary including mooring name, sensors used, sensor depths, and station depth. All moorings were deployed for a minimum time period from 21 May 1998 through 4 June 1998.

Temperature gauges, used at mooring locations where temperature was the only measurement made, collected temperature data every five minutes. When other parameters besides temperature were measured, the sampling interval was increased to 10 minutes. Full or partial data sets were recovered from 91% of the moorings. Overall, the data were of high quality, having relatively low noise levels and few extraneous data points (outliers). The Two-Unit Survey is described in detail in Exhibit E-1-3, including data collection, quality control, and percent useable data. The mooring deployment locations and their data return success are summarized in Figure V-2. A data box is drawn in the figure next to each mooring site. The data box is separated into three rows; each row represents the surface (red), mid-depth (blue), or bottom (green) sensors. The shading of the boxes gives an indication of the data that are available for each mooring site during the two-week survey period. If both segments of a row are shaded, a complete data set for the two-week period is available. If only one segment is shaded, then data are available for some portion of the two-week period. If neither segment is shaded, then no data are available for that instrument during the two-week period. Figures V-3a and V-3b show detailed summary boxes for the near-field region. Although there was some loss of data, the quantity and quality of data recorded exceeded typical requirements for hydrothermal models of the type implemented for this demonstration.

V.D.2.a.ii. Shipboard Surveys

Shipboard surveys provide an efficient means of measuring spatial variability of temperature and conductivity over relatively large areas at discrete times in a tidal cycle. It is impractical to cover the entire region with a dense network of moorings because of the need to maintain channel navigability and the time intensiveness of the services required for such a large number of moorings. Therefore shipboard surveys were incorporated to complement mooring data.

Intensive shipboard surveys were conducted to characterize detailed spatial characteristics of the thermal plume six miles up-estuary and six miles down-estuary from the Station at four times during a tidal cycle: maximum ebb, end-of -ebb, maximum flood, and the end-of-flood. Five vessels were deployed to collect these measurements during the second week of the intensive survey (May 29, 1998; Exhibit E-1-3 Figure 10-7). Data collected during the shipboard survey characterized the distribution of water temperature, dye, and salinity across and along the 12 mile segment bounding the Station. Surface measurements and vertical profiles were collected during the shipboard surveys for at least 25 locations during four phases of the tide, except during the maximum ebb tidal phase when three of the 25 locations were missed. The missing data do not pose a difficulty, as the number of vertical profiles exceeded the number originally planned. Data beyond those specified in the Modified TMP were collected by extending transects into adjacent areas such as the marshes and the nearshore regions.

Results from the surveys were compared to assure high data quality. Overlapping transects of adjacent boat surveys were compared to assure calibration was maintained for all instruments on the boats. Combined with pre- and post-survey instrument calibrations, these intercomparisons ensured that high shipboard measurement accuracy was maintained.

An example of the surface temperature contours from one of the shipboard surveys is shown on Exhibit E-1-3-Figure 10-73. The diagram shows the surface temperature isotherms for the end-of-flood tidal phase. Contours are in degrees Celsius.

V.D.2.a.iii. Dye-tracer Study

A dye-tracer study was conducted to track and measure how the Station's thermal discharge mixes in the Estuary over space and time. Dye-tracer studies provide information for understanding mixing processes within the Estuary and indirectly measure the spatial distribution of dilution (hence, spatial temperature gradients) within the thermal plume. Data from the dye-tracer study were used for the model verification process.

A detailed methodology was established for the dye tracer study. Rhodamine WT fluorescent dye was injected into the Station's cooling water system. Dye concentrations also were monitored near the point of injection. Shipboard operations for this study, performed concurrently with the shipboard surveys for temperature and salinity, monitored the concentration of dye in the Estuary using fluorometers. Local background fluorescence was monitored prior to dye injection to correct for fluorescence due to organic processes rather than the injected fluorescence agent (dye).

The dye injection process is described in detail in Exhibit E-1-3, and is illustrated in Exhibit E-1-3 Figure 10-3. Dye is injected into one of the two pumps servicing each condenser. Dye concentration was sampled at the intake, and at the standpipes in the discharge pipes (Appendix B provides details on the Station, and Section II of this Appendix provides a summary). This sampling allowed determination of pump flow rates, "discharge-to-intake" recirculation, and discharge concentrations.

An example of the contour plots generated from the dye sampling is shown in Exhibit E-1-3 Figure 10-75. The ship tracks are overlaid on the contoured dye data results. This figure shows the dye plume extending to the north from the preceding flood tide, and the initial transport of dye towards the south as the tide changes from flood to ebb. This figure can be compared directly with Exhibit E-1-3 Figure 10-73, which shows analogous results for temperature measurements

V.D.2.a.iv. Infrared Surveys of the Near-Field

Much of the near-field area is characterized by turbulent water. There is vigorous upwelling and horizontal spreading. It is not possible to secure moorings in the immediate near-field, and a small vessel experiences difficulty traversing this area. It is difficult, if not impossible, to take vertical profiles within the turbulent near-field using shipboard sensors.

Therefore, infrared aerial photography was used to provide synoptic views of the relative difference in water surface temperature in the vicinity of the Station discharge pipe on May 29, 1998 at four phases within the tide cycle: end-of-ebb, flood, end-of-flood, and ebb. An area of approximately 1000 square meters was imaged from an airplane by single-band photography with a spatial resolution of 3 meters. Infrared aerial images capture the spatial water surface temperature gradients. The results from the CORMIX model and the thermal images were compared to verify that the model was correctly simulating the intensity of the near-field mixing processes and the rates at which mixing occurs.

Exhibit E-1-3 Figure 222 shows one of the infrared images for the end-of-flood tide. The image depicts the thermal plume extending towards the north, a relic of the previous flood tide. The thermal plume shows a bulbous shape in the plume immediately offshore of the discharge, reflecting the momentum of the jet discharge along the line of the discharge at slack tide. Although absolute temperatures cannot be derived from these measurements, the relative temperatures are well represented and document some of the major features of the thermal plume.

V.D.2.a.v. Hydrodynamic Surveys

This survey component provided crucial data sets to characterize the hydrodynamics of the Estuary. While some of the data were used to initialize and force the hydrodynamic model (RMA-10; i.e., initial and boundary conditions), other data were used to evaluate the accuracy of the model output. The hydrodynamic survey consisted of four types of measurements:

V.D.2.a.v. (a) Water Levels

Tide gauges were installed by PSE&G at four locations (Exhibit E-1-3 Figure 10-12) along the study area:

- Lewes, DE
- Woodland Beach (near Ship John Shoal), DE
- Salem Barge Slip, NJ
- Western C&D Canal, MD

These tide gauges were complemented by four NOAA tide gauges located within the study area:

- Cape May, NJ
- Lewes, DE
- Reedy Island Point, DE
- Philadelphia, PA

The USGS tide gauge at Burlington, NJ was used as a ninth gauge for the program. These data were used to provide boundary conditions for the model (Cape May, Lewes, and Western C&D Canal), or for model calibration and verification purposes (remainder of the tide gauges). The gauges installed by PSE&G's contractor (LMS) measured absolute water pressure and were corrected to atmospheric pressure using measurements from the National Weather Service (NWS) station at Wilmington, DE. The water surface elevations measured at the four PSE&G tide gages were converted to the common datum by surveying from a vertical control benchmark.

Results from the tide gauges for the Two-Unit Survey period are shown in Exhibit E-1-3 Figures 10-191 and 10-192. Data from six stations are illustrated. Differences in the amplitude and phases of the tide can be discerned from this graphical depiction of the tide.

V.D.2.a.v. (b) Currents

An Acoustic Doppler Current Profiler (ADCP) was moored approximately 1,000 feet offshore from the discharge to measure vertical profiles of current speed and direction during the two-week intensive survey. Additional current measurements were made using an ADCP mounted on a vessel ("mobile ADCP") during some of the intensive shipboard surveys to provide vertical profiles of the currents over a broad area, for the ebb, end-of-ebb, flood, and end-of-flood tidal phases.

The ADCP is a modern electronic sensor that uses sound waves to measure water velocity (speed and direction) in a number of vertical "bins" extending from near the water surface to near the sediment bed. These "bins" are depth ranges within which the current speed is averaged over a specified interval of time. For instance, the ADCP can be set to measure at three-foot intervals over the entire water depth, at a rate of one sample per bin per second. The results are generally presented as current speed and current direction for various depths. The depth and time averaging intervals were designed so as not to eliminate any detail required for this application. ADCPs provide comprehensive current data sets.

The location of the fixed ADCP is shown in Exhibit E-1-3 Figure 10-13. Time series of currents from this instrument are shown in Exhibit E-1-3 Figure 10-201. The figure illustrates the speed and direction of the current at various depths (0-1 foot, 4-5 feet, 9-10 feet, and 14-15 feet). The current direction (red) reverses; the current flows either towards the WNW during flood or the SSE during ebb tide. For brief periods of time around slack water, the current flows towards the WSW. Most of the time the instrument measures the running tide (either flood or ebb), except at slack water when the thermal discharge flow traverses the ADCP site.

V.D.2.a.v. (c) Temperature and Conductivity - Bay Mouth and C&D Canal

Temperature and salinity of water exchanged with the Atlantic Ocean are required inputs for the RMA-10 model. The spatial distributions of temperature and salinity across the mouth of the Delaware Bay and in the C&D Canal were measured during the two-week intensive survey period. Just as the water level observations at Cape May and C&D Canal were used to define flows in the model at the open boundary in RMA-10, salinity and temperature observations were used to characterize the properties of the water coming into the model at the open boundaries.

V.D.2.a.v. (d) Initial Conditions Survey

The RMA-10 model requires initial estimates of water level, current temperature and salinity (inferred from conductivity measurements) throughout the model domain to begin model simulation. Vertical profiles of water temperature and conductivity were measured at 17 river monitoring stations spaced at 5- to 10- mile intervals (RM 0, 10, 20, 30,40 45, 50, 55, 60, 65, 70, 80, 90, 100, 110, 120, and 130) along the navigational channel from the mouth of the Delaware Bay to Trenton, New Jersey (extending from River Mile 0 to RM133; Exhibit E-1-3-Figure 10-15). Surveys were conducted for model initial conditions (21 May 1998), and for verification purposes on 27 May and 2 June 1998, using either two or three boats. Six of the 17 monitoring stations (RM 40, 50, 70, 90, 100, and 130) also had lateral sampling points on either side of the shipping channel.

An example of results from one of the initial condition surveys on 2 June 1998 is shown in Exhibit E-1-3 Figure 10-36. The longitudinal temperature profile is shown as a function of River Mile for the day. At this time, the Atlantic Ocean was cooler than the Estuary by approximately 7°F, reflecting the more rapid warming of the Estuary under spring conditions, and the delayed ocean response to seasonal thermal warming.

V.D.2.a.vi. Marsh Surveys

The large tidal marshes in the vicinity of the Station store significant volumes of water during the tidal cycle. Natural heating and cooling processes may significantly alter the temperature of the water as it enters and leaves the marshes. The temperatures may approach or exceed the temperatures associated with the Station's thermal plume in the far-field regions.

The Modified TMP provided a special survey to estimate the contribution (either loss or gain) of heat to the Estuary from the marshes. This special survey was intended to provide information to permit the model to simulate the marsh heating and cooling processes, and to evaluate the contribution of these processes to the Estuary heat budget. A previous study for PSE&G (Weston Environmental Consultants, 1978) had also examined the contributions from marshes. They concluded that under One-Unit operations, "the station's thermal discharge is potentially small relative to daily solar radiation effects in the vicinity of the Salem Station on the eastern shore of the Estuary. On sunny days, the larger patterns of thermal gradients are more likely dominated by solar radiation effects, than to the station's present heat output."

For the Marsh Survey, moorings were deployed at the mouth of Alloway, Mad Horse, and Hope Creeks to measure water depth and temperature during the two-week intensive survey period. Moorings at Alloway and Hope Creeks measured conductivity and dissolved oxygen as well. A shipboard survey was conducted at the creek mouths during one tidal cycle within the two-week intensive period. The shipboard survey included vertical profiles of current velocity across the mouth, and discrete vertical profiles of temperature and conductivity at several points across the mouth of the creek. The shipboard survey was repeated for Hope and Alloway Creeks approximately one month following the intensive survey, because the original survey in May 1998 could not include Alloway Creek due to vessel failure.

V.D.2.b. Long-Term Fixed Moorings Program

The Modified TMP also included a two-part, six-month program of Long-Term fixed moorings. The primary purpose of the Long-Term Fixed Moorings program was to collect additional temperature data to validate the Total Temperature Model (TTM), by capturing the seasonal variation in temperature. This part of the field program consisted of nine moorings deployed for approximately six months between 21 May 1998 and 5 November 1998 (Exhibit E-1-3 10-226, E-1-3 Table 10-2—cited earlier in this section). Four of the moorings were deployed in the near-field region of the thermal plume to collect long-term temperature data in the near-field. The near-field temperatures were used to validate the assumption that the total water temperature could be approximated as the sum of the estimated ambient temperature ($T_{ambient}$) and ΔT (i.e., that ΔT is essentially independent of season, particularly in the near-field); six were in the far-field region for the same period. One of the far-field moorings was deployed at the mouth of Mad Horse Creek. In addition to the temperature data collected at three depths (near surface, mid-depth and near bottom) at all nine mooring locations, a single surface temperature measurement was made in Salem River near the city of Salem, NJ.

Although not part of the original Modified TMP, some intensive salinity and dissolved oxygen measurements were added to the long-term program to take advantage of the high water temperatures occurring in summer, 1998. Salinity and dissolved oxygen were measured at three of the nine moorings for the limited time period from 3 September 1998 through 8 October 1998 to characterize the variation of these two water properties during a period when the $T_{ambient}$ was higher than that measured during the two-week intensive study period. These data and the associated quality control procedures are described in detail in Exhibit E-1-3.

An example of the long-term monitoring program, Exhibit E-1-3 Figure 10-228, shows the temperatures measured in the Salem River for the six-month measurement period. The diurnal fluctuations from marsh flows are clear, particularly the high temperature spikes in the summer time. The gradual cooling accompanying fall conditions also is represented.

V.D.3. Other Monitoring Programs

PSE&G has conducted other surveys in addition to the 1998 Two-Unit Survey that support this 316(a) Demonstration. These field programs provided valuable data that were utilized in model calibration, verification, and/or validation.

Section V.D.3.a. describes the Ambient Survey (July 1997), which was designed to measure the spatial and temporal variation in $T_{ambient}$ during periods when the Station was not operating. The Ambient Survey is described in detail in Exhibit E-1-2. Section V.D.3.b. describes the One-Unit Survey, which was conducted in October 1997 when only Unit 2 was operating. The data from the One-Unit Survey were used to verify the RMA-10 and CORMIX models. The One-Unit Survey is described in detail in Exhibit E-1-2. Section V.D.3.c. describes a Survey conducted in 1995, during a period when both the Station's Units were largely operational. These data were used to support the analysis of physical processes in the Estuary. The Survey is described in detail in Exhibit E-1-1.

V.D.3.a. Ambient Survey

Thermal surveys of the Estuary were conducted by LMS for PSE&G. One of the thermal surveys, termed the Ambient Survey, took place from 11 through 16 July 1997, when both the Station's Units were not operational. The objective of the survey was to obtain the spatial distribution of naturally occurring temperatures in the vicinity of the Station without the effects of the Station's discharge.

The survey included five moorings (two in the river and three at creek mouths) deployed for a five-day period from 11 July through 15 July 1997, and shipboard surveys conducted on 14 and 15 July 1997. The five moorings were equipped with sensors to measure and record conductivity, temperature, and dissolved oxygen concentrations at three depths (near surface, mind-depth and near bottom). The shipboard surveys consisted of three boats collecting vertical profile data of salinity (derived from conductivity), temperature, and current speed and direction along five transects in the Estuary on 14 July 1997 and at the mouths of Alloway, Hope and Mad Horse Creeks and Salem River on 15 July 1997. An ADCP was used to measure vertical profiles of current speed and direction. The vertical profile measurements of temperature and conductivity were made by lowering a set of Conductivity, Temperature and Depth sensors (CTD) through the water column. The boats were equipped with Differential Global Positioning Systems (DGPS) receivers to obtain accurate positions of the measurement locations.

Coincident meteorological data were collected at the Station, tidal water surface elevations were measured by NOAA, and river flow was gauged by USGS during the survey period.

V.D.3.b. One-Unit Survey

The One-Unit Survey was conducted between 21 and 30 October 1997, which was a period when only Unit 2 was operating. The One-Unit Survey included fixed moorings and mobile surveys, similar to what was used for the Two-Unit Survey. The primary components of the One-Unit Survey included an initial conditions survey, a tidal boundary survey, tide gauges, moored stations, a fixed-station ADCP, a mobile survey of the River, a mobile survey of marsh mouths, and ancillary data.

Vertical profiles of conductivity (salinity) and temperature were measured at 16 stations spaced at 5- to 10-river-mile-increments between RM 0 and RM 120 using two boats on 21 October 1997 during the Initial Conditions Survey. The tidal boundary survey consisted of vertical profiles of conductivity and temperature at three locations evenly spaced along the mouth of the Estuary during the flood phase on 27 October 1997. There were six tide gauges deployed in the Estuary, in addition to four continuously-maintained NOAA gauges at different locations. Among twenty-four moored stations, five moorings measured temperature, conductivity, and DO; nine moorings measured temperature and conductivity; and ten moorings measured only temperature. An ADCP was used to measure vertical profiles of current speed and direction in the vicinity of the Station's discharge. For the mobile surveys, five boats were deployed with Differential Global Positioning System (DGPS) receivers, and CTDs. Three boats were equipped with ADCPs. Three of the boats operated around the Station's discharge area, and the remaining two boats covered transects from 6 to 12 miles upstream and 6 to 12 miles downstream of the Station. Data from NOAA, USGS, and PSE&G were also collected during the One-Unit Survey.

V.D.3.c. 1995 Survey

Aubrey Consulting, Inc. (ACI) conducted a large-scale hydrodynamic survey of the Estuary on behalf of PSE&G between March and July of 1995 (Exhibit E-1-1). The data provided a basis for comparison with the data set collected by LMS for the 1998 Modified TMP, in addition to providing bathymetric information for the far-field model.

The 1995 survey covered almost the entire Estuary from the mouth of the Bay to Trenton, NJ. The primary region of interest was a five-mile portion of the Estuary surrounding the Station, particularly focused on the area surrounding the Station's intake and discharge structures. The purpose of the survey was to produce a comprehensive data set that could be used to calibrate and verify a hydrodynamic model (RMA-10) of the Estuary. The verified model was applied to understand hydrodynamic circulation in the vicinity of the Station, particularly the Salem intake.

The survey recorded local winds, tidal elevations, currents, temperatures and conductivity (salinity) using mobile measurements, on-site (fixed) measurements at moorings, as well as real-time data acquisition. The mobile surveys included fathometers (for bathymetric measurements), ADCPs, CTDs, and DGPS. Five tide gauges (SeaPac SP2200) and four directional current meters (SeaPac 2000) were deployed. A Real-Time Data Reporting System (RTS) was also used to collect long-term current and salinity data in the Station's intake basin. The RTS allowed for data to be accessed immediately from shore.

The Survey produced a comprehensive and complete data set on the hydrodynamics of the Estuary using a combination of mobile surveys, on-site measurements, and real-time data acquisition. The data from this survey proved to be a valuable reference for comparison to the 1998 Modified TMP Surveys. The 1995 Survey also provided detailed data that were used to improve the RMA-10 model used for the 1999 Application. Additionally, the data provided detailed information about Sunken Core and Hope Creek Jetty that was incorporated in the 1999 model.

V.E. Description of Hydrothermal Modeling Methods

This 316(a) Demonstration requires characterization of the thermal plume associated with the thermal discharge at the Station. This characterization was used to assess the potential effects of the Salem thermal discharge on the balanced indigenous community (BIC) within the Delaware Estuary (Appendix E Section VI.). The characterization incorporated a more comprehensive and technically-advanced suite of field observations and numerical models than had been implemented previously, and produced results that are consistent with and support previous 316(a) Demonstrations for the Station.

The thermal plume has been characterized in past 316(a) Demonstrations and related permit submittals (Section V.C.). These previous characterizations of the thermal plume have been consistent and complementary. The thermal plume itself has not changed during the twenty years since Station operations began except as Station operations vary (outages, maintenance, etc.). Once Unit 2 came on line in 1982, the thermal discharge has remained fundamentally the same, and the thermal plume also has remained the same (Appendix B). Although dredging of the navigation channel has altered the Estuary's circulation, this occurred mainly in the years before the Station was constructed (Appendix C). The fundamental description of the character of the thermal plume, while evolving with time as technology and observational coverage have expanded, has remained essentially the same. The major features of the thermal plume, such as length, width, and differential temperature, have all remained essentially the same with all characterizations. Thus, not only has the thermal plume itself not changed during the past two decades, but also PSE&G's representation of this plume has been supported by increasingly defensible and consistent scientific information.

Past and present characterizations of Salem's thermal plume are based partially on comprehensive field-monitoring programs. However, observations alone are not sufficient to characterize the thermal plume. First, no matter how extensive a survey is, there are practical limitations in spatial and temporal coverage. A model can provide more comprehensive spatial coverage. Second, observations can be made only for conditions that exist at the time of the survey, which may not represent extreme conditions that may produce biologically significant impacts. A model can be used to project extreme conditions. Third, the increase in water temperature caused by the Station's discharge (ΔT) cannot be measured directly. Observations of temperature can indicate only total temperature (ambient plus ΔT from the thermal discharge), not ΔT arising from the Station operations. Coincident ambient temperature cannot be measured while the Station is operating. A model can be used to simulate ΔT.

Lacking the ability to observe all conditions, including those extreme conditions of importance for biological characterizations and assessments, observations must be combined with modeling. Models provide means to simulate actual conditions or scenarios that might exist in the future. Models can simulate, for instance, the temperature fields in the Estuary with and without Station operations, for the same boundary conditions. These simulations are necessary to derive estimates of ΔT contours, which are required for the Biothermal Assessment and for other regulatory analyses. Models can also be used to extend the utility of the observational data base. As described below, the data base for pre-Station ambient temperatures is limited to a seven-year time interval. However, models can be applied to extend this data series to the fifty years for which meteorological data are available, and to derive more meaningful statistics on probability of occurrence of certain temperature exceedences (for instance). In contrast, models in themselves are of limited use without high quality and comprehensive data for calibration and verification. Thus, monitoring data must be acquired to support the modeling directly. In particular, monitoring data are needed to provide: (1) model boundary conditions; (2) model initial conditions; (3) model calibration and verification data; (4) in cases, model validation data; and (5) supporting information to improve our understanding of relevant physical processes.

The Modified TMP, as discussed in Section V.D. and Exhibit E-1-3, presented a comprehensive integrated observational and modeling program in support of the Demonstration. The Technical Basis for the Modified TMP addressed the roles of data and modeling in addressing the Biothermal Assessment needs. The data collection program was designed specifically to support the models.

Figure V-4 illustrates the general approach implemented for the numerical models. Once a model was selected, it was calibrated and verified and/or validated before being applied to generate products that were used to support the Biothermal Assessment. Model calibration was a step that involved modifications to a model to assure it had the capability to simulate an observed process. Model verification was a step implemented after calibration to assure the calibrated model could simulate an observed process independent of the calibration. Model validation was a step implemented to test an already calibrated and verified model for its ability to simulate a site-specific observed process. The calibration, verification, and validation steps all required comprehensive monitoring data.

Section V.D. laid out the extensive observational program undertaken by PSE&G in support of the 316(a) Demonstration. Section V.D. demonstrated that the Modified TMP, and the previous observational programs (1995 Survey (Exhibit E-1-1), Ambient Survey, and One-Unit Survey (Exhibit E-1-2) provide high quality and comprehensive data for the characterization of the thermal discharge. Although previous data sets (Section V.C.) were comprehensive in their own right, the Modified TMP improved upon these previous efforts and created a targeted, focused program to support successful implementation of the models for the 1999 Demonstration.

An essential element of the combined hydrothermal monitoring and modeling program is the proper definition and representation of temperature. Figure V-5 illustrates the dimensions of temperature that were required to characterize the thermal plume. Temperature was described in space, and two time scales. The variation of temperature with space is illustrated by the top left graph on Figure V-5. The horizontal axis represents the distance along the axis of the Estuary in River Miles (RM) from the mouth of Delaware Bay (RM 0) to Trenton, NJ (RM 133). The spatial scale is broken to focus on a four-mile stretch in the vicinity of the Station. Depending upon the proximity to the discharge location, the total water temperature may equal the ambient temperature ($T_{ambient}$), plus a far-field increase in temperature due to the Station's thermal discharge ($\Delta T_{RMA\text{-}10}$), plus a near-field increase in temperature due to the thermal discharge (ΔT_{CORMIX}). A summary of how these components of temperature were estimated follows in this section. Detailed descriptions of the methods are provided in Attachment E-2. For the purposes of this discussion, though, it is important to recognize that the far-field influence of the thermal discharge spans a relatively short stretch relative to the length of the Estuary, and the near-field influence of the thermal discharge is confined within only a small portion of the far-field.

The representation of temperature was considered on two time scales. The thermal exposure of a particle traveling with the discharged cooling water is represented on time scales on the order of minutes (top right graph on Figure V-5). The thermal exposure drops by nearly fifty percent in seconds, and is reduced significantly within one hour or so. The variation of temperature over a longer seasonal time scale is represented by the bottom graph on Figure V-5. Two graphs of temperature on the seasonal time scale are provided. The solid line represents the variation of natural ambient temperature ($T_{ambient}$), and the dashed line adds the increase in water temperature at the end of the zone of initial mixing (ΔT_{ZIM}) to $T_{ambient}$. It is clear that the natural variation in $T_{ambient}$ is the dominant factor controlling water temperature, even in the near vicinity of the discharge (end of ZIM). $T_{ambient}$ varies by nearly 50°F over the course of one year.

Due to the relative importance of ambient temperature for the Biothermal Assessment, it is necessary to have a large term record of ambient temperature at the Station. Some water temperature measurements were collected at Reedy Island by the U.S. Geological Survey. However, these measurements were taken only 7 years prior to the initiation of the Station's operations. After Station operations began, these Reedy Island data were no longer representative of ambient temperature, because they were influenced by Station operations. Since this data series is so limited in time, it is difficult to estimate long-term ambient temperature statistics. Other reasons why a model was preferred instead of the Reedy Island temperature measurements are outlined in Section V.E.1.

One of the goals of the modeling effort, therefore, was to provide a longer time-series of ambient temperature at the Station to provide for estimation of long-term statistics of seasonal variability. The Ambient Temperature Model (ATM), described in Section V.E.1 below, was developed for this purpose. The ATM is discussed in greater technical detail in Attachment E-2 Section III.A.

The ambient temperature provided the base for assessing biological effects. The Modified TMP provided the Technical Basis for the concept that the ambient temperature varies strongly over time on an annual basis, and secondarily in space. Exceptions to this small spatial variability are regions near marshes (Exhibit E-1-5). To characterize spatial variations in water temperature within the influence of the Station's discharge, the differential temperature field (ΔT) associated with the Station operations was added.

Unlike ambient temperature, the ΔT varies strongly in space, but less strongly over time scales beyond those of the semi-diurnal tides (with periods of 12.42 hours). The ΔT cannot be measured directly, because observations of temperature in the Estuary represent the sum of the ambient temperature and ΔT. Only modeling can attempt to separate $T_{ambient}$ from ΔT. For this Demonstration, two models were used to represent ΔT.

In the near-field close to the thermal discharge location, the USEPA-supported CORMIX model was applied. This widely used and accepted model simulates the temperature, velocity, and plume characteristics in the near-field (which includes the Zone of Initial Mixing, ZIM). Because the velocity of the thermal discharge at the end of the pipe is relatively high (10 feet per second), and the discharge is in relatively shallow water (30 ft.), the mixing and behavior of the discharge in the near-field are dominated by the momentum of the discharge jet. CORMIX is specifically designed to address this near-field behavior. The application of CORMIX to the Station's thermal plume is discussed in Section V.E.2. PSE&G worked with staff who maintain CORMIX to apply the model to this specific site (Doneker 1998, 1999). Full technical documentation of this model is provided in Attachment E-2 Section III.B.

Beyond the near-field is the region known as the far-field. The distribution of Salem's heat in the far-field is governed by transport and mixing processes in the Estuary. Therefore, ΔT must be determined using another model (RMA-10) that represents hydrodynamics and transport processes in an estuary accurately. RMA-10 was selected to model the far-field. RMA-10 is a widely accepted, widely used numerical and transport model commonly applied to simulate hydrodynamic and transport. Although RMA-10 simulates a broad array of physical processes in estuaries, including tidal processes, density effects, and surface heat transfer, its primary use in this 316(a) Demonstration is to represent ΔT in the far-field. The contribution of the ambient temperature to the total temperature is estimated using ATM. RMA-10 is described in Section V.E.3 below. A full technical description of RMA-10 and its application to the Demonstration is contained in Attachment E-2 Section III-C.

The results of the near-field model (CORMIX) and the far-field model (RMA-10) were integrated in a transition region. The process of integrating these two models is called Linkage. A Linkage process was developed to integrate these two models for each phase of the tide (ebb, end-of-ebb, flood, end-of-flood). This linkage provided estimates of temperature, velocity, and other thermal plume characteristics in the transition region, which is considered part of the near-field. The Linkage process is discussed in Section V.E.4 below, and in more technical detail in Attachment E-2 Section III-D.

The Biothermal Assessment requires knowledge of the discharge-induced temperature field in time and space as thermal exposures of organisms. Figure V-6 is a schematic showing that the hydrothermal modeling process was designed to support the Biothermal Assessment. After the models were selected and calibrated, verified, and/or validated, the models were applied to represent four types of thermal exposure. The models were applied to characterize the seasonality of exposure, the exposure duration, the spatial extent of thermal exposure, and the frequency of exposure. Graphical output from the hydrothermal models designed to support the Biothermal Assessment is provided in Section V.F.

The models described above were integrated to provide these estimates of temperature. In the near-field, the ATM, CORMIX, and RMA-10 results were integrated to provide the temperature and other thermal plume characteristics for each of four tidal phases (ebb, end-of-ebb, flood, and end-of-flood). In the far-field, results from ATM and RMA-10 were integrated to estimate water temperature. To accomplish this integration, the Total Temperature Model (TTM) was developed. The TTM is described in Section V.E.5 below, and in greater technical detail in Attachment E-2 Section III-E.

V.E.1. Ambient Temperature Model

V.E.1.a. Description of Model

The Ambient Temperature Model (ATM) was developed to calculate the time-varying ambient water temperature in the vicinity of the Station. Ambient temperature is the temperature that would exist within the Estuary in the absence of Station operations. The temporal variations in ambient temperature result from meteorological and solar processes that vary daily, seasonally, and inter-annually. Spatial variations result from non-uniform heating and cooling of the Estuary, tidal mixing, tidal exchange with marshes, and distant anthropogenic sources. The Biothermal Assessment requires estimates of the frequency that certain temperatures are exceeded. In order to provide reliable estimates, a longer record is required than presently exists in observed data sets. A thirty-year record of water temperature at Reedy Island (approximately 3.5 miles northwest of the Station) was available. The Reedy Island data set has limited use, though, for providing information about ambient temperature (i.e., the water temperature that would exist absent the Station). Although Reedy Island is well beyond the region defined as the Salem plume (i.e., the region occupied by the 1.5°F isopleth of ΔT), Reedy Island does experience some thermal influence from the Station. This influence changes depending upon tide conditions, Station operating conditions, and other factors. Consequently, there is no measured estimate of the Station's influence (ΔT) at Reedy Island that can be subtracted from the observed temperature data to produce a time-series of ambient water temperature. Data were recorded at Reedy Island for seven years prior to the Station's operations; however, this data set is not long enough to reliably project ambient water temperatures that occur less often than one year in seven. Also, these earlier data are not necessarily representative of present-day ambient conditions. There also are gaps in the Reedy Island data set.

The Ambient temperature model (ATM), therefore, provides a more meaningful estimate of long-term ambient temperatures in the vicinity of the Station.

The ATM uses calculations of the surface heat exchange, an ocean modulating effect, and a site-specific correction to account for spatial differences in mean temperature throughout the Estuary.

A similar model formed the basis for analysis during the previous permit cycle, under the name Response Temperature Model (RTM). The present analysis is consistent with the previous analysis, and incorporates improvements in the model formulation that build upon previous work.

V.E.1.b. Approach

The ATM solves a set of equations that represent surface heat transfer in the Estuary. The model assumes the water is continually stirred, and therefore the water has uniform temperature. The equations used in the ATM are the same as are used for the surface heat transfer in the RMA-10 model (Section V.E.3 below). Similar input data were used, but the sources differ.

The ATM was formulated and calibrated using temperature data collected at the Station's intake during times when the Station was not operating, and verified against the coincident 26-month data set at Reedy Island. Once calibrated and verified, the ATM was used to create a long-term record of estimated daily average values of $T_{ambient}$ in the vicinity of the Station.

V.E.1.c. ATM Methodology

The ATM model was formulated in a manner consistent with previous filings, but additional terms were added based on experience gained from previous efforts, and an expanded understanding of the physics of the Estuary. The RTM component of the ATM was originally devised for a lake environment. Unlike a lake, the Estuary has a large thermal buffer associated with it: the Atlantic Ocean. The Atlantic Ocean tends to cool the Estuary in the summer, and warm it in the winter. The ATM was formulated specifically to reflect the ocean's moderating influences.

ATM calculates an estimate of daily average $T_{ambient}$ in the vicinity of the Station as the sum of a daily average response temperature (T_r), a daily average adjustment for the Atlantic Ocean's influence ($\alpha \times cos[2\pi(d - \tau)/365]$), and a site-specific adjustment (β) that can be used to account for mean differences such as the variation of $T_{ambient}$ with space in the Estuary:

$$T_{ambient} \approx T_r + (\alpha \times cos[2\pi(d - \tau)/365]) + \beta$$

where:

- α = amplitude (°F) of the daily average adjustment for the buffering effect of the Atlantic Ocean
- τ = phase lag (days) for the daily average buffering effect of the Atlantic Ocean
- d = day of the year (Julian day)

T_r is the daily average temperature that a fully-mixed column of water reaches in response to meteorological and solar conditions. It is computed by solving the following equation:

$$dT_r/dt = H_n/(\rho c_p D)$$

where:

- ρ = density of water
- c_p = specific heat of water
- D = depth of water column
- dT_r/dt = change in response temperature with time
- H_n = net rate of surface heat exchange = $(H_s + H_a - H_{sr} - H_{ar}) - (H_b + H_e + H_c)$
- H_s = short-wave solar radiation
- H_a = long-wave atmospheric radiation
- H_{sr} = reflected short-wave radiation
- H_{ar} = reflected long-wave atmospheric radiation

H_b = back-radiation from the water column
H_e = evaporative heat loss from the water column
H_c = conductive heat exchange with the water column

Model formulations for the various heat transfer terms were produced by EPA (1985). For this 316(a) Demonstration, the equation for T_r is solved at hourly intervals. The hourly values of T_r over a 24-hour period are then averaged to obtain a daily average T_r.

The seasonal buffering effect of the Atlantic Ocean is expressed as a cosinusoidal function that accounts for the differing temperature of the river waters and the ocean. It accounts for the length of time (phase lag) required for the ocean effect on temperature to be realized in the Estuary in the vicinity of the Station.

The site-specific adjustment factor (β) accounts for other contributions to $T_{ambient}$ that are not taken into account either by T_r or the adjustment for the buffering effect of the Atlantic Ocean. Examples include differences in water depth and influence of other heat sources, as well as spatial differences in ambient temperature within the Estuary.

V.E.1.d. Calibration

The calibration process for ATM determines values for α, τ, β and D. Depth is calibrated because a single appropriate depth must be selected to represent the varying water depth in the vicinity of the Station. These coefficients were selected to produce the best correlation between the intake temperature data at the Station (when the Station was not operating) and ATM calculations. The coefficient values yielding the smallest root-mean-square (RMS) difference were selected. Since the site-specific correction (β) was removed before calculating the RMS difference, the RMS difference is essentially a measure of the variance between the measurements and the model predictions.

Figure V-7 compares the time-series of computed and measured $T_{ambient}$ at the Station's intake based on the final calibration of ATM which uses α= 2.0°F, τ = 52 days, β= 0.96°F , and D = 18 ft. The computed time-series of $T_{ambient}$ shows agreement with the time-series of measured intake temperatures at the Station. The RMS difference between the computed and observed temperatures was 1.2°F, during a period when the seasonal temperature varied by nearly 50°F. This RMS difference is only somewhat larger than the accuracy of the measurements.

V.E.1.e. Verification

The verification process compared the results of the ATM with a data set of water temperature observations from a site near Salem outside the thermal plume where ΔT is less than 1.5°F (i.e., the same time period as the calibration when the Station was not operating). The USGS temperature gauging station at Reedy Island provided data during the period 1 July 1995 through 31 August 1997 for verification. The Reedy Island station is approximately 3.5 miles north of Salem, and is expected to exhibit similar variations in ambient temperature (although actual $T_{ambient}$ may differ due to the 3.5 mile spatial difference).

The verification showed a mean difference of 0.62°F (Reedy Island had a slightly higher ambient temperature likely due to spatial variations in $T_{ambient}$) and an RMS difference (after adjustment for the mean difference) of 1.4°F. These values provided acceptable verification when compared with the 1.2°F RMS difference found during the calibration.

Successful verification of the ATM means that it can be relied on to produce acceptable estimates of ambient temperature for the region near the Salem discharge. These estimates of ambient temperature provided the basic building block for estimating water temperature in the thermal plume and for the Biothermal Assessment. The natural variation of $T_{ambient}$ contributes the greatest thermal influence in the Estuary (a 50°F seasonal change).

V.E.2. CORMIX

V.E.2.a. Description of Model

The hydrothermal modeling requires a near-field model to simulate conditions in the vicinity of the discharge, where the distribution of Salem's heat is dominated by the momentum of the discharge. The model used to simulate conditions in the near-field is the CORnell MIXing Zone Expert System (CORMIX) (Akar and Jirka 1990).

CORMIX is not a single model but a synthesis of several existing plume-dilution models. CORMIX's "expert system" is designed to apply an appropriate model to a given situation and location. Because of its versatility, CORMIX is used for the analysis, prediction, and design of aqueous discharges into water-courses. Mathematical emphasis is placed on the geometry and dilution characteristics of the near-field (Akar and Jirka 1990). The model assumes steady-state flow conditions for the thermal discharge and the ambient environmental conditions (flow rate, temperature field, salinity). The application of this steady-state model to simulate the mixing due to the thermal discharge characteristics into the dynamic tidal environment at the Station is described in Attachment E-2 Section III.B.

Since its development in 1985, CORMIX has been continually refined to provide an improved tool capable of simulating dilution for various types of discharges. Version 3.2 of the CORMIX model is the most recent version available, and, thus, was the version applied to simulate the Salem thermal plume. CORMIX is the recommended analytical tool in several key guidance documents regarding the permitting of industrial discharges into receiving waters. The EPA recommends CORMIX in a Technical Support Document for Water Quality-based Toxics Control (EPA 1991).

V.E.2.b. Approach for Salem Permit Renewal

The procedure that was implemented to develop CORMIX so that it simulates the near-field Salem Generating Station plume is outlined in Figure V-8. Data from the One-Unit (Exhibit E-1-2) and Two-Unit (Exhibit E-1-3) surveys were used to validate the performance of CORMIX 3.2 in its original form. Validation is a test to determine that the model reproduces a set of observations (such as temperature, velocity, etc.) from a specific set of conditions.

The results of One-Unit and Two-Unit validations showed that CORMIX version 3.2 did not adequately account for some of the mixing processes that were apparent from the field surveys. Specifically, the observations showed that the mixing zone intercepted the water surface more rapidly than predicted by CORMIX 3.2. Additionally, the effect of tidal action on the mixing process, the interaction of the thermal discharge with the irregular bathymetry offshore of the discharge pipes, and the nonuniform accumulation of heat in the vicinity of the Station were identified as processes not adequately represented by CORMIX. Of utmost importance is the fact that the discharge is in relatively shallow water compared to the dimension of the discharge pipes, which contributes to the rapid surfacing, and is not a condition most typically simulated by CORMIX.

Therefore, modifications were made to improve the ability of the model to represent the site-specific physical processes for Salem. The final modifications were then reviewed and approved by the those responsible for maintaining CORMIX (Doneker 1999).

Once the modifications were made, CORMIX was calibrated using data from the Two-Unit Survey. Following calibration, CORMIX was verified against the One-Unit data and some of the Two-Unit Survey data that were not used previously in the calibration process, as outlined in the Modified TMP.

V.E.2.c. Methodology

CORMIX approximates the near-field plume subject to a number of limiting assumptions. First, is that CORMIX is a steady-state model, whereas the flow in the Delaware Estuary is dynamic and changing. In order to approximate these dynamic conditions, CORMIX was applied at four discrete phases of the tide (ebb, end-of-ebb, flood, end-of-flood) when the conditions were approximately steady. In contrast to RMA-10, CORMIX does not provide hydrodynamic information for every instant of the tide. This assumption of quasi-steady-state is justifiable on the basis that the mixing processes represented by CORMIX have time scales of minutes, whereas tides have time-scales of hours. CORMIX represents running tides (full flood or full ebb flow) better than near-slack conditions. This limitation is not severe since in nature the running tides persist much longer than the brief near-slack tide conditions. Estimates of the ZIM were produced for slack tides as well, though, for the Biothermal Assessment. Field data, currents, velocity, and infrared images were used to ensure slack tide representations of the ZIM were realistic.

A second limitation is that CORMIX cannot approximate the accumulation of heat in the region near the Station that results from continuous thermal discharge. CORMIX represents the development of the ZIM well, but does not account for the heat that has accumulated in the vicinity of Salem over preceding tide cycles. This residual heat increases the temperature of the receiving water that dilutes the Salem thermal discharge. The temperature of this water ($T_{approach}$) equals the ambient temperature plus the residual $\Delta T_{approach}$ in the dilution water. The value for $T_{approach}$ is obtained either from water temperature measurements, when available, or from the far-field model (RMA-10) for times when the measurements are not available.

A third limitation is that the modules used by CORMIX for the Station application depict the plume within the mixing zone as having a constant temperature perpendicular to the thermal plume centerline (width and thickness). Therefore, the near-field is simulated as a completely well-mixed thermal plume in the horizontal and vertical dimensions, with a top-hat shape in horizontal cross-section (i.e., temperature is constant over the plume's width and depth). The plume width increases with distance from the discharge. The vertically well-mixed depiction introduces a measure of conservatism to the near-field representation of the thermal plume, since the near-field mixing zone remains in contact with the Estuary bottom, even though thermally induced buoyancy may cause the edges of the near-field mixing zone to lift off the bottom.

V.E.2.d. Model Refinements

Applied in its original form, CORMIX version 3.2 did not adequately simulate the complex near-field thermal plume processes measured during the One- and Two-Unit Surveys. The lack of agreement arose because the CORMIX application has never been adapted to shallow water situations such as the Station's thermal discharge. Interactions of the thermal discharge with the bottom, shallow water depths, and other factors are important for the Salem application. Consequently, it was necessary to modify CORMIX so that it could be applied appropriately at the Station. Two types of improvements were made to CORMIX: general improvements to correct errors and improve logic in the source code, and site-specific improvements for the Salem application.

Three general improvements were made to CORMIX based on a review of the model's source code and supporting theory. These modifications were made with the concurrence of the scientist responsible for the maintenance of CORMIX for the USEPA.

- Error Correction to the Dilution Equation: A minor error was found in the CORMIX source code. This was corrected and will accompany all CORMIX models in the future.
- Improvement to the Dilution Equation: The CORMIX module that calculates dilution permitted computation of dilution less than one, which is not realistic. This module was improved.
- Improvement to Logic Structure: CORMIX is a system containing numerous solution modules to represent different stages of the plume's evolution.

Corrections were made so the most appropriate module was selected to represent the physics of the Salem plume, rather than allowing the CORMIX logic to select the module based on a generalized condition not appropriate for the Salem discharge conditions. The most appropriate module for Salem accounts for effects on distribution of ambient tidal currents.

Two site-specific improvements were made to CORMIX for the Salem application. The first improvement allowed CORMIX to distinguish the point where the ZIM first intersects the surface from the point at the end of the ZIM. The second site-specific improvement included methods to calculate more detailed distribution of temperature and velocity along the trajectory of the plume. The information provided from the One- and Two-Unit Surveys revealed complex near-field Salem plume processes that had not been observed previously. Due to some of its assumptions, CORMIX version 3.2 did not have the capability to simulate these complex processes. Modifications were made to certain modules of CORMIX version 3.2 to remove these limitations.

These site-specific improvements were implemented through an iterative process. Modifications were made to CORMIX, then model results were compared to field data. Additional improvements were made as needed until the near-field physics were approximated accurately. The improvements to CORMIX are presented in detail in Attachment E-2 Section III.B, and summarized below.

The first site-specific improvement was a more realistic representation of the geometry of the near-field plume (ZIM) as it surfaces. When the ZIM intercepts the water surface, it still retains significant momentum from the thermal discharge compared to the ambient river flow. CORMIX 3.2 assumes that as the ZIM intersects the surface, it begins to lift off the bottom as the discharge momentum is dissipated and buoyancy begins to dominate. The shallow-water discharge at the Station does not follow this behavior. Rather, the point where the ZIM intersects the surface is less distant than the point where the discharge momentum is lost. This different behavior was observed during both the One-Unit and Two-Unit Surveys. The ZIM intercepts the surface within approximately 50-100 feet of the discharge, whereas the discharge momentum does not disappear until a greater distance. Further investigations of the area surrounding the discharge showed significant interaction of the thermal discharge with the Estuary bottom at Salem, a process not represented by CORMIX version 3.2, and one contributing to differences in the observed and simulated mixing zone.

The Salem application of CORMIX is not representative of most locations where it is normally applied. The top of the discharge pipes, which are 10 feet in diameter, lay only 20 feet from the Estuary surface. In general, pipe diameters are submerged many times their depth, not in such shallow water. Attachment E-1 describes the actual physics of shallow water well. CORMIX, therefore, required adaptation to this specific application.

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In order to represent these different behaviors, the thermal discharge was simulated using an actual and a virtual discharge. The actual discharge was used to represent the characteristics of the ZIM between the discharge location and the point of surfacing, as normally represented by CORMIX 3.2. A virtual discharge was used to represent the characteristics of the mixing zone in the remainder of the near-field. This virtual diffuser has characteristic parameter scales that approximate the effects of the bottom interaction and plume trajectory.

The second site-specific improvement to CORMIX was a more accurate method to interpolate plume trajectory, velocity and temperature. In its original form, CORMIX version 3.2 provides output only at the end of each solution module. A non-linear intra-module interpolation scheme was implemented to allow a curvilinear plume trajectory. Additionally, the non-linear interpolation scheme allowed for plume velocity to vary within a module. Heat was conserved based on the non-linear distribution of velocity along the trajectory of the plume and slight adjustments to the plume width. The resulting trajectory, surface temperature, and velocity were representative of conditions measured during the One- and Two-Unit surveys.

V.E.2.e. Calibration of Updated Model

The improved CORMIX model was calibrated using surface temperature and ADCP current velocity data from the Two-Unit Survey. The model was calibrated for three primary characteristics of the plume: plume trajectory and width, plume centerline temperature, and the transverse surface temperature.

V.E.2.e.i. Trajectory and Width

The first characteristic of the plume was the combination of plume trajectory and width. Figure V-9 shows an example of the calibration results for one phase of the tide (ebb tide). This and other figures from the calibration are described in more detail in Attachment E-2 Section III.B. Information representing the field observations is presented by the blue contours and the blue dashed line. The blue contours on these figures represent measured surface temperature. The blue dashed line is an estimate of the observed plume centerline drawn to track the path of the maximum observed surface water temperatures. CORMIX results are presented by the red and green lines. The red line represents the modeled plume centerline, which begins where CORMIX predicted the ZIM surfacing location. The green line represents the margins of the ZIM based on the ZIM width predicted by CORMIX. CORMIX predictions of water temperature are not shown on these plots.

The trajectory of the plume is non-linear, curving toward the southeast direction of the ambient ebb tidal currents. The modeled plume width increases from approximately 50 feet at its surfacing location to nearly 225 feet at the end of discharge momentum. The modeled (red line) and measured (blue dashed line) plume trajectories match, typically differing by less than 10 feet to the end of discharge momentum (second yellow line). The region between the discharge and the end of discharge momentum was the focus of the calibration because the transition to the far-field model began at this point (Attachment E-2 Section III.D).

The model surfacing location also matches the observations. The modeled and measured surfacing locations differ by approximately 25 feet: the surfacing location is approximately 50 feet west-southwest of the discharge, and the measured surfacing location is approximately 75 feet southwest of the discharge mid-point.

The offshore margin of the ZIM, represented by the green line on the left-hand side of the plot, matches the apparent margin of the ZIM based on the data. The landward edge of the plume predicted by CORMIX (green line on right-hand side of plot) does not match the data as well. This difference between the modeled and measured plume width is discussed in more detail in Attachment E-2 Section III.B.9.c.

Overall, the improved CORMIX model matched data within the surface region where the discharge momentum is not fully dissipated. The surfacing location of the ZIM, the trajectory and lateral spreading of the ZIM were simulated well.

V.E.2.e.ii. Centerline Temperature

The second calibration comparison was for the plume centerline temperature. Figure V-10 provides a graphical comparison of the modeled and measured water temperature as a function of distance along the plume centerline, for ebb tide. The red line on this figure is the centerline plume temperature predicted by CORMIX. The first blue circle on the left hand side of the plot represents the measured discharge temperature at the end of the discharge pipes. The remaining blue circles represent measured surface water temperatures along the estimated plume centerline (i.e., the measured surface water temperature along the blue dashed line on Figure V-9). No plume temperature measurements are depicted on these figures between the discharge point and the location where the ZIM surfaced.

The plume temperature decreases substantially within the first 50 feet of the discharge (i.e., the modeled surfacing location). A temperature drop of 9°F (5°C) is experienced at the surfacing location, which represents 48% of $\Delta T_{condenser}$, which is the temperature difference between the discharge temperature and the intake temperature. The plume temperature then reduces less rapidly to the edge of excess discharge momentum at a distance of approximately 300 feet from the discharge. CORMIX results beyond the end of discharge momentum are shown as well. The CORMIX predictions and measured plume temperatures match within the ZIM. The model slightly under-predicts the temperature at the surface for the ebb tide, and slightly over-predicts temperatures at other locations along the plume centerline. CORMIX results are used only out to the start of the transition region (Attachment E-2 Section III.D). CORMIX reproduces the measured plume temperature up to this point.

V.E.2.e.iii. Transverse Surface Temperature

The third type of comparison that received attention during the calibration was the transverse surface temperature, i.e., the water surface temperature plotted along a line perpendicular to the plume centerline trajectory. An example plot of transverse surface water temperature for ebb tide is shown by Figure V-11. The right side of the plot corresponds to the side of the plume closest to the discharge (i.e., looking at the figure is equivalent to facing into the plume). Two transects of the surface of the plume are plotted per tidal phase at the locations indicated by the yellow lines on Figure V-11. One section is at the mid-point of the measured surfacing location; the other section is at the location where CORMIX predicts the end of discharge momentum. CORMIX predictions are shown by the blue lines, and field observations are shown by the red dots.

Although this figure portrays differences between the model and the observations, these differences are characteristic of the limitations of CORMIX. CORMIX predicts the maximum plume temperatures; however, the lateral distribution of plume temperatures at the surface is not reproduced exactly. This limitation is illustrated by the right hand side of Figure V-11, where the CORMIX plume temperature reduces to background temperature approximately 127 feet from the discharge at the surfacing location (top plot), and 320 feet from the discharge at the end of discharge momentum (bottom plot). By contrast, the observations show the plume surface temperature remains elevated farther away from the plume centerline trajectory.

This difference between the model and the observations also is revealed on Figure V-9, where the surface temperatures are elevated beyond the CORMIX predicted extent of the plume (shown by the green line on the right side of the plot). This difference can be attributed to complex mixing processes that CORMIX can not simulate. One Primary mixing process that CORMIX cannot predict is recirculation of heat on the leeward side of the plume. RMA-10 exhibited spatially-varying flow patterns on the ebb tide in the lee of Artificial Island that likely contribute to some recirculation that CORMIX cannot simulate. The difference between CORMIX-predicted surface temperatures and measured surface temperatures also is explained by the absence of far-field heat buildup that is not included in CORMIX (Attachment E-2 Section III.B.4).

V.E.2.f. Verification of Updated CORMIX Model

The updated and calibrated CORMIX model was verified using the One-Unit Survey data, as well as data from the Two-Unit Survey that were independent from the data used for the calibration. Water surface temperature data from the One-Unit Survey were utilized for the verification. Graphical comparisons for the One-Unit Verification are presented in this section for plume trajectory and width, centerline plume temperature, and cross-plume surface temperature. CORMIX was also verified against the infrared photographs and mooring temperature data collected during the Two-Unit Survey. These data sets were not utilized in the calibration process; therefore, they provide independent verification data.

Similar to the calibration, for ebb tide, CORMIX reproduced the surfacing location of the ZIM and the centerline trajectory of the plume up to the location where there is no significant discharge momentum. As with the calibration, CORMIX under-predicted the ZIM width at the surface, due to the uniform lateral and vertical temperature distribution inherent to CORMIX. As for the calibration, CORMIX simulated the rate of temperature decrease along the plume centerline accurately. The model and the observations show that the temperature decreased rapidly from the discharge point to the surface. CORMIX under-predicted the surface temperature by approximately 1.8°F (1°C) at the point where the ZIM intersects the water surface . Beyond the surfacing point, CORMIX was generally conservative, over-predicting centerline temperature by 0° to 1.8 °F (0 to 1°C). Also analogous to the calibration, CORMIX reproduces the maximum measured surface temperature well, but under-predicted the contributions of surface water temperature, for the reasons outlined in Attachment E-2 Section III.4. and Attachment E-2 Section III.8.b.ii.

An additional comparison performed for the verification was with the infrared photographs acquired during the Two-Unit Survey (Exhibit E-1-3). Figure V-12 compares the CORMIX-predicted plume centerline trajectory and width with the infrared data collected during the Two-Unit Survey. The contours on these figures depict relative temperature based on the infrared imagery, rather than actual temperature. The infrared model/data comparisons reveal the ability of CORMIX to reproduce the trajectory and shape of the plume at the surface. There is agreement for all tidal phases. Even the complex end of flood tide, which is a near-slack condition, shows agreement between CORMIX and observations for a distance of approximately 1,000 feet offshore of the discharge (Attachment E-2 Section III.B.).

The last verification of the improved CORMIX model was to compare the model predictions to the temperature data collected at the near-field moorings during the Two-Unit Survey. The near-field mooring locations are illustrated on Figure V-9. As the plume moves with the changing tidal currents, it sweeps through different moorings. Figure V-13 compares the CORMIX results with the near-field mooring temperature data. The lines on this plot are measured near-surface temperatures at the moorings with CORMIX results. The boxes are CORMIX predictions of plume temperature for times corresponding with the four simulated tide phases. In all cases, the model predictions compare with the moored temperature data, to within a tenth of a degree Celsius or less. This is excellent model/data agreement, considering the complex processes governing the near-field.

V.E.2.g. Results

CORMIX was updated and improved so that it could be better applied to the Salem thermal discharge. The updated model was calibrated and verified using data from the One-Unit and Two-Unit Survey. The observed and computed water temperatures along the centerline of the plume agreed, and CORMIX accurately calculated the centerline trajectory of the plume.

Based on the results of the calibration and verification, the modified CORMIX model was used to estimate:

- near-field temperature distributions in time and space,
- near-field velocity distributions in time and space, and
- areas and volumes of water within various ranges of velocity and temperature that comprise the near-field.

These estimates are expected to be conservative. The top-hat temperature distribution provides conservative estimates of water temperature across the entire width of the ZIM. In addition, CORMIX predicts that the ZIM remains in contact with the River bottom up to the point where the discharge momentum is dissipated, thereby overestimating the bottom area in contact with higher water temperature, and current velocities.

V.E.3. RMA-10

V.E.3.a. Description of Model

This is the third in a suite of models used for characterize the Station's thermal plume and thus the thermal exposures for the Biothermal Assessment. The Ambient Temperature Model, described in Section V.E.1, provides the basis for estimating the temperature that would exist absent the plant. Then the model used for calculating ΔT in the near-field, CORMIX, was described in Section V.E.2. RMA-10 is the additional model required to predict the spatial distribution of ΔT in the far-field at any time in a tidal cycle. The far-field model describes the river hydrodynamics and transport of heat from the Station's thermal discharge beyond the near-field.

The objectives of the far-field modeling are:

- to delineate far-field ΔT fields, relative to ambient;
- to provide a model that simulates the dominant estuary-wide processes that govern the transport of the Salem thermal plume;
- to provide a far-field model that can be integrated with the near-field model to provide continuous ΔT fields;
- to estimate $\Delta T_{approach}$ to input to the verification of the Total Temperature Model (TTM), as described in Section V.E.5 and in more detail in Attachment E-2 Attachment III.E; and
- to provide work products (temperature exposures) required for the Biothermal Assessment.

The RMA-10 model was selected to simulate the distribution of the far-field thermal plume because:

- RMA-10 has been applied successfully at Salem for previous applications;
- RMA-10 has been used extensively by consulting firms, universities, and government agencies in the U.S., Canada, Europe, Asia and Australia. In

particular, the model was employed in a hydrodynamic and salinity intrusion study of the Delaware Estuary sponsored by the U.S. EPA (DiLorenzo, 1993). Subsequently, RMA-10 was applied to the Delaware Estuary as a localized, three-dimensional model nested within a large-scale, two-dimensional model (Ramsey et al., 1995). Also, the model was adapted to the Chambers Point region of the Delaware Estuary (Lawler, Matusky and Skelly Engineers (LMS), 1990);

- RMA-10 has a re-circulation module that was developed specifically for the Station. The module simulates the withdrawal of water through the intake, adds a Station-specific heat load, and discharges the added heat and the same volume of water through the discharge structure. In this manner, both water mass and heat are conserved;
- RMA-10 has the ability to simulate surface heat exchange based on a heat budget method;
- RMA-10's finite element structure is flexible, allowing the specification of varying element sizes, shapes, and dimensions (one-, two-, and three-dimensional). This flexibility helps characterize the system of interest, because relatively coarse grid spacing can be used to fit the Estuary's irregular shoreline configuration and bathymetry;
- RMA-10 has an advanced marsh module. It has the capability to simulate alternately wet and dry marsh areas (King and Roig, 1988; MacArthur et al., 1990); and
- RMA-10's implicit solution scheme allows for the use of relatively long time steps (e.g., tens of minutes).

V.E.3.b. Model improvements since the last submittal

Version 4.3 RMA-10 was used as the far-field model for the Salem permit renewal submitted in 1993. Since 1993, several improvements have been incorporated into RMA-10. These improvements are listed below, and are supported by more detail in Attachment E-2 Section III.C.

- Simplifying the input of boundary condition information.
- Improved debugging capabilities.
- Open boundary condition improvement.
- Surface heat exchange formulation improvement.

In addition, the RMA-10 developers distributed several improvements within RMA-10 version 6.4:

- improved calculation of surface density gradients (version 4.4),
- revised input data structure to ease data input (versions 5.0, 6.0, 6.2, and 6.3),
- inclusion of an alternative surface heat exchange computation (version 6.1), and
- inclusion of the Smagorinsky turbulence closure model (version 6.3).

A related but slightly different Version 6.6 RMA-10 was used for this 1999 permit renewal request.

V.E.3.c. RMA-10 Methodology

The RMA-10 model is a numerical hydrodynamic and transport model used to simulate the hydrodynamic and transport processes in the Estuary from the mouth of the Estuary to the head of tide at Trenton, New Jersey (the model domain). The primary use of RMA-10 in this 316(a) Demonstration was to provide ΔT contours in the far-field outside of the ZIM ($\Delta T_{far\text{-}field}$). Although RMA-10 is capable of simulating the ambient temperature ($T_{ambient}$), this capability was not the focus of the present application. The Ambient Temperature Model (ATM) was used instead for this purpose.

This section presents a discussion of the steps undertaken to apply RMA-10 to simulate the Salem thermal discharge. A more complete description of the methodology of this application is provided in Attachment E-2 Section III.C.

V.E.3.d. RMA-10 Set-Up

A number of steps were completed, including the assembly of data sets, to set-up RMA-10 for this application. These steps built on the 1993 hydrothermal studies (TRA et al. 1993), which provided the starting point for this 1999 improved far-field modeling effort. The set-up included:

- grid generation;
- definition of model input parameters;
- specification of boundary conditions; and
- specification of initial conditions.

V.E.3.d.i. Grid Generation

The physical features of the Estuary are represented in RMA-10 as a computational grid that extends over the entire model domain. The computational grid is a network of discrete points ("nodes") that are joined to form "elements."

Figure V-15 is a plan view of the computational grid following calibration. The finite element grid in the vicinity of the Station is three-dimensional. Between RMs 34 and 57, the grid is comprised of two layers of three-dimensional elements, which provides five points (nodes) over depth at which calculations are made. The purpose of the three-dimensional grid is to give the model the capability to simulate plume stratification. Two-dimensional elements were used for the lower portion of Delaware Bay from RM 34 to the Atlantic Ocean, and north of Artificial Island from RM 57 to RM 80. Any vertical salinity or temperature stratification in the lower Delaware Bay does not significantly affect the transport of the Salem plume; therefore, it was not necessary to model these processes. Two-dimensional elements also were used between RMs 57 and 80. North of RM 80, one-dimensional elements were used. Two- and one-dimensional elements were used north of RM 57 because there is no vertical stratification there.

Figure V-15 shows an enlargement of the grid in the immediate vicinity of the Station where smaller elements were used. The numbers and sizes of these small elements were based on design drawings of the Salem outfall, the joint calibration of RMA-10 and CORMIX, and numerical properties of RMA-10 that affect the conservation of Salem's discharge heat. This enhanced horizontal resolution was provided so that RMA-10 could resolve changes in water temperature over small distances in the vicinity of the Salem discharge. This computational grid includes specific elements that withdraw and discharge the cooling water. The elements that withdraw the cooling water are located on the grid adjacent to the Station's intake. The inclusion of these elements allows RMA-10 to calculate the recirculation of heat resulting from the operation of Salem's once-through cooling operations. RMA-10's power plant boundary condition was designed specifically for the Salem application. The discharge elements surround the Salem discharge. Although RMA-10 was not set-up to simulate the momentum of the discharge, an attempt was made to incorporate this effect. The momentum of the discharge transports the plume farther offshore during the brief slack tides. This effect was incorporated into RMA-10 by using different elements during slack tides as opposed to running tides as shown in Figure V-15.

<u>V.E.3.d.ii. Model Input Parameters</u>

Specific data on the physical features and hydrodynamic characteristics of an element are provided at the element's nodes. This information includes the local elevation of the river bottom relative to a reference datum and the spatial coordinates relative to a defined reference. Each type of element is assigned empirical coefficients that are used to represent certain processes in the model, such as energy dissipation (turbulent exchange coefficients), hydrodynamic dispersion (diffusion coefficients), and surface heat exchange (shading factors, wind factors). The depths are taken from NOAA charts published for the region (Attachment E-2 Section III.C). The empirical coefficients are approximated from published literature, but may be modified through the calibration and verification processes. The element types and coefficients are provided in Attachment E-2 Section III.C.5.d.

<u>V.E.3.d.iii. Boundary Conditions</u>

Information about the model boundaries was input to the model. The major boundaries for the model domain associated with the Salem thermal plume are the ocean boundary (between Cape May, NJ and Lewes, DE), the eastern end of the Chesapeake and Delaware (C&D) Canal, the river boundary at Trenton, NJ and the freshwater tributaries, the river shoreline excluding marsh channels, the Station and major point sources of heat, and the water surface. At each of these boundaries, specific information is required, as described briefly below, and in more detail in Attachment E-2 Section III.C.

- Ocean boundary: At the ocean boundary, information was provided on the tidal height, water temperature, and water salinity. Tidal height was represented by a linear interpolation of tides measured at Lewes, DE and Cape May, NJ across the mouth of the Bay. This important boundary condition is described in Attachment E-2 Section III.C.

- C&D Canal: The C&D Canal provides exchange of water between the Chesapeake Bay and the Estuary. Exchange through the C&D canal affects the Estuary's hydrodynamics. The C&D Canal may flow either into or out of the Estuary. For the calibration and verification periods, water level elevation, salinity, and temperature were measured at the C&D Canal. For other periods lacking direct measurements of flow comparable to that available for river flow at Trenton, the boundary information for the C&D Canal was calculated using a transfer-function approach, based on dates from NOAA tide gauge Station in upper Chesapeake Bay; as described in Attachment E-2 Section III.C.
- River flow at Trenton, NJ and other tributaries: The Delaware River flow has a significant influence on Estuary hydrodynamics. The U.S. Geological Survey (USGS) maintains a station for measuring river flow at Trenton. These river flow and temperature data were applied as boundary conditions at Trenton. Other Tributaries distributed along the Delaware River provide freshwater to the Estuary. The largest tributary is the Schuylkill River, and numerous others are distributed along the River. Of these others, eight (Assunpink Creek, Crosswicks Creek, Neshaming Creek, Rancocas Creek, Chritina River, Salem River, Cohansey River, and Maurice River) were used as model boundaries. Freshwater flow and temperature were provided as boundary conditions for each of these tributaries. Of these tributaries, only the Schuylkill River has a flow measuring gauge. The other tributary flows were represented as fractions of the Schuylkill River flow, the fraction determined by a ratio of the respective drainage basin areas. Attachment E-2 Section III.C. describes the treatment of tributaries in greater detail.
- The Estuary's shoreline: The Estuary's shoreline is another boundary of the model domain. Two kinds of boundary conditions were applied. First, there was no flow from the River into the shoreline (the no-flow condition).
- The Station and other point sources: The Station discharges heat to the Estuary, as described in Appendix B. During the calibration and verification runs, the Station conditions were represented by actual measurements at the Station. For the biological worst-case runs, the Station conditions were represented by low flow, high ΔT conditions (Appendix B, Attachment 1). Other point heat sources to the River that are located on the shoreline (power plants) were implemented in the model, to reproduce the heat input to the River accurately. Six point sources other than the Station were identified and their heat discharge included in the model (Attachment E-2 Section III.C).
- Water surface: At the water surface, solar insolation and meteorological data were applied as boundary conditions. For the periods of calibration and verification, most of these data were available from the Station. For other periods, the long-term NOAA records at Wilmington, DE were used as boundary conditions. The specific derivation of these boundary conditions, and corrections

made to certain parts of the data series, are described in Attachment E-2 Section III.C.

V.E.3.d.iv. Initial Conditions

In order to start the model, the dependent variables at all the nodes in the model domain must be assigned an initial value. These are known as the initial conditions. Generally, RMA-10 will converge faster with detailed initial conditions. The time for the numerical solutions to become practically independent of the "initial values" is referred to as the "spin-up time," which decreases as the accuracy of the initial conditions increase. After the spin-up time, the solutions may be used for the particular application. Model spin-up is discussed in Attachment E-2 Section III.C.5.a.iv.

The initial conditions prescribed included salinity, temperature, velocity, and water surface elevation at each mode. The initial conditions were defined from an initial condition field survey and RMA-10 hot-start simulation (Attachment E-2, Section III.C.5.a.ii).

V.E.3.e. RMA-10 Calibration

As with any numerical model, RMA-10 had to be calibrated to assure the model represented the observed processes. This calibration procedure is complex and multi-faceted. It requires multiple types of data, and multiple perspectives. RMA-10 was calibrated for the period between May 21 and June 4, 1998. The primary calibration data set was the Two-Unit Survey performed according to the Modified TMP (Exhibit E-1-3).

Calibration is an iterative and systematic process of modifying the inputs to RMA-10 until: (1) the model reproduces the observed Estuary-wide hydrodynamic and transport processes (Estuary-wide calibration); and (2) reproduces the observed heat transport processes associated with Salem's discharge (plume calibration). The modifications to RMA-10 included reconfiguration of the computational grid, and the assignment of new values to some of the empirical coefficients at the computational nodes. The detailed calibration process is described in Attachment E-2 Section III.C.5.

V.E.3.e.i. RMA-10 Calibration Data Sets

The Modified TMP produced most of the data that were needed to evaluate the performance of RMA-10. The Modified TMP was comprehensive, and was designed specifically to support the numerical models. Additional data obtained from NOAA and the USGS were tidal elevations at the City of Burlington, New Jersey; Philadelphia, Pennsylvania; and Reedy Island, Delaware. Exhibit E-2 Table III-7 lists an inventory of the types and sources of data and summarizes how the data were used to calibrate RMA-10, the periods for which data were available, and the frequencies of data collection.

The Two-Unit Survey is described in Section V.D., and in greater detail in Exhibit E-1-3. It consisted of two time spans of data acquisition. First, an intensive two-week long survey characterized of the Station's thermal plume and the Estuarine dynamics. Second, a six-month mooring program characterized seasonal changes in estuarine behavior, measuring temperature, salinity, and oxygen at nine moorings both within and external to the Station's thermal plume.

The mooring data and shipboard surveys were intended to complement each other. The moorings provided data that primarily captured temporal variability, whereas the shipboard surveys provided data that captured spatial variability. The moorings measured time-series of water temperatures, conductivity (salinity), and dissolved oxygen concentrations within the near- and far-fields of the Salem thermal plume and beyond (where ΔT is less than 1.5°F). The shipboard surveys measured the surface distribution of water temperatures; vertical profiles of temperature and conductivity (salinity); and dissolved oxygen concentrations. The shipboard measurements were taken at four phases of a tidal cycle (approximately at maximum flood, end-of-flood, maximum ebb and end-of-ebb).

A dye-tracer study was performed in tandem with the shipboard surveys. Dye is a conservative surrogate for heat. Since no dye exists naturally in the Estuary, dye concentrations measured throughout the Estuary mimic some aspects of dilution of ΔT. Therefore, maps of dye concentrations are representative of the shape of the Station's thermal plume, and characterize dilution rates independently of temperature measurements.

Infrared photographs provided synoptic views of surface water temperatures within the thermal discharge region at the four phases of the tide. These photographs show where rapid changes in the spatial distribution of surface temperature are greatest, where the momentum of the Salem has a significant effect on the near-field mixing processes, and how the warmest regions of the Salem thermal plume change shape over a tidal cycle. The results of these surveys were used to guide refinements to the configuration of computational elements that are used to approximate the near-field; and to refine the diffusion coefficients in the immediate vicinity of Salem.

An Acoustic Doppler Current Profiler (ADCP) measured the vertical profile of current speed and direction at a point in the near-field for the two-week intensive survey. In addition, vertical profiles of the current speeds across several transects in the Estuary at the four phases of a tidal cycle were measured using mobile ADCPs during the shipboard surveys. The current measurements, plus the observations of tidal elevations, were used to adjust the friction and energy loss coefficients to ensure RMA-10 accurately simulated the tidal hydrodynamics of the Estuary, and correctly calculated the flux of water over cross-sections of the Estuary.

The marsh surveys were designed to estimate the potential contribution of heat to the Estuary from the marshes. Exhibit E-1-5 discusses the heat fluxes to and from marshes near the Station. The marsh temperature alterations may approach or exceed ΔT associated with the Station in much of the Estuary.

These observational data were used in various combinations for the model calibration.

V.E.3.e.ii. Calibration Procedure and Results

The model was calibrated in an iterative fashion. There is no unique calibration. Calibration can be achieved by a number of different combinations of coefficients and model changes. Verification is required to assure that the calibration process leads to reasonable predictions against an independent data set. The calibration is discussed in detail in Attachment E-2 Section III.C.5.

RMA-10 was calibrated to simulate two scales of processes: the tidal hydrodynamics of the Estuary (the estuary-wide calibration) and the transport and mixing of the Salem thermal discharge in the Estuary (the plume calibration). The estuary-wide calibration was completed first since the transport and mixing calculations for the Salem thermal plume require accurate estimates of ambient currents, which are available only from the estuary-wide calibration. This section summarizes the processes used to complete both phases of the calibration, and elaborates on those components of the plume calibration that are unique to the Salem discharge.

V.E.3.e.ii.(a). RMA-10 Estuary-wide Calibration

The procedure for the estuary-wide calibration was standard for tidal hydrodynamic models, such as RMA-10. The sizes and arrangements of elements over sub-regions of the entire model domain or for specific features of the Estuary were modified, and friction and energy loss coefficients were adjusted until RMA-10 simulated the tidal hydrodynamics of the Estuary. The accuracy of the simulations was evaluated based on model/data comparisons that included:

- time-series of tide elevation, current speed, and current direction at the tide gauge and fixed-station ADCP locations;
- variation of salinity, temperature, tide height, and tide phase along the axis of the Estuary;
- flux of water mass across transects of the Estuary for different phases of the tide;
- time-series of salinity and temperature from the mooring locations;
- vertical distributions of salinity and temperature at locations established for the shipboard surveys.

The calibration results from the examination of tidal processes showed that tides are well represented by the model. Figures V-16a and 16b are sample comparisons of the modeled and measured tides at various locations. The following conclusions were drawn regarding RMA-10's ability to simulate tides.

- Tidal range: The modeled water surface elevation reproduces the observed semi-diurnal (twice-daily) tidal oscillations reasonably well, along with the spring/neap tidal cycle. The spring/neap cycle causes the tide range, i.e., distance between successive low and high tides, to vary over a fourteen day period. The highest tides corresponding to the near-spring tides occurred between May 25 and 28.

- Tidal amplification: The modeled tide range was amplified from the mouth of the Bay up to Burlington in similar fashion as the observations. The tidal amplification occurs primarily due to the funnel shape of the Estuary.
- Tidal asymmetry: The modeled tide curves reproduced the characteristics of the observed tidal curves, namely short, steep flood tides and longer, more shallow ebb tides. This distortion of the tide curve strengthened as the tide propagates up-Estuary, and is a nonlinear process that occurs as the tide responds to the friction and the changing geometry of the Estuary.
- Tidal phase: The modeled times of high and low tides were nearly coincident with observations, particularly from the mouth of Delaware Bay up to Salem Barge and Reedy Point, which best represented the tide in the vicinity of the Station. At Philadelphia and Burlington (48 and 61 miles, respectively, above Salem), the modeled and measured times of high and low tide differed by approximately one hour. The calibration process showed this difference could be reduced by increasing bottom friction, i.e., slowing the tide down; however, increasing friction also reduced the tide height, which was not preferred. A high priority was placed on modeling the observed tide height.

Overall, the graphical comparisons demonstrated the tides predicted by RMA-10 compared reasonably well with observations.

Calibration results for the measured versus modeled currents in the vicinity of the Station showed:

- The modeled and measured current velocities exhibited similar tidal oscillations. Maximum modeled and measured current velocities were approximately 2.5 to 3 feet per second.
- There was almost no difference between modeled and measured current direction for the running ebb and flood tides.
- During slack tides, the observations revealed velocities oriented in-line with the discharge. These are discharge-induced velocities that were not included in the present RMA-10 applications, and, therefore, were not represented by the model results. The near-field Model, CORMIX, was implemented to simulate the momentum of the discharge.
- Observed short-duration motions were not reproduced by the model. These high frequency motions, which may represent turbulent fluctuations, were not expected to be simulated by the model, and are not expected to significantly affect plume transport.
- There was little depth-variation of current speed and direction.

In addition to the fixed-station ADCP data, the mobile ADCP cross-section data were compared with model predictions. The ADCP data were post-processed to estimate total flow through the measured cross-section of the Estuary. Figure V.17 compares the observed flow (dots) through each of the three transects with the modeled flow (line). The observed data were available for the four phases of the tide during which the vessels traversed each Estuary transect. There was excellent agreement between the model results and the observations.

Overall, the modeled currents matched observations reasonably well. The modeled current patterns at the location of the fixed-Station ADCP matched observations extremely well. Additionally, the modeled and measured volumetric flow through cross-sections of the Estuary matched extremely well. Although there are some detailed observed cross-Estuary and depth-varying current patterns that are not reproduced by the model, the modeled currents match observed currents most closely on the east side of the Estuary in the vicinity of the Station. Thus, the model accurately simulated the advective transport of the plume.

Overall, the modeled salinity distribution was also similar to the observations. The observed along-channel variation in salinity from the mouth of the Bay up to RM 130 was well represented by the model. The distribution of salinity produced by the model in the vicinity of the Station also compared well with data. Although there are observed depth-variations of salinity that the model did not represent, particular near the shipping channel, these variations do not influence significantly the transport processes governing the plume.

Water temperatures were also compared. Overall, the model simulated the balance of water temperature throughout the Estuary quite well. There are some observed depth-variations in water temperature in the channel that the model did not simulate. Additionally, there are observed depth-varying temperatures in the Bay Zone that the model cannot reproduce since the model is two-dimensional (depth-averaged) in these locations. These limitations are typical of models of this sort, and are not expected to impact transport processes governing the Salem thermal plume.

The "estuary-wide" calibration was completed when the simulated tidal hydrodynamics on-balance showed good agreement with the observations in the sense that further adjustment of model parameter produced no significant improvement. A graphical presentation of the model/data comparisons (Section III.C.5.c.i.) shows that RMA-10 is well calibrated on an estuary-wide basis with the May-June 1998 Two-Unit Survey. A detailed assessment of the model's ability to simulate Estuary-wide temperature gradients is presented in Attachment E-2, Section IV.

V.E.3.e.ii.(b) RMA-10 Plume Calibration

The procedure for the "plume" calibration included two components: the first is a basic component that is common to most transport calculations; the second component addressed unique aspects of RMA-10's application to the Salem discharge and the Estuary. The basic component of the "plume" calibration involved making refinements to the computational grid to improve spatial resolution where sharp gradients in temperature or salinity existed, and adjusting vertical and horizontal eddy diffusivities to reproduce the vertical and horizontal distributions of salinity and water temperature. The more complex components of the "plume" calibration dealt with the RMA-10 schematization of the near-field, the recirculation of heat in the vicinity of the Salem, RMA-10's ability to budget the mass of a dye tracer, and the effect of tidal marshes on water temperatures in the vicinity of the Station.

Although RMA-10 was not expected to produce accurate calculations of the plume distribution in the near-field, it was necessary to calibrate the model to achieve a match with the near-field model, CORMIX (Section V.E.2.). To achieve this match (or linkage), modifications were made to RMA-10 in the near-field region. First, the near-field was approximated as a "volume heat source" with a discharge flow rate and $\Delta T_{condenser}$ that combined to equal the heat flux of the Salem thermal discharge. Because the size of the elements of the discharge and their distribution of heat affect the recirculation of water into the intake structure of the Station, part of the calibration procedure involved assuring that the intake temperatures did not exceed measured temperatures. Temperature data were used for this part of the calibration.

A dye balance (analogous to heat balance) was evaluated to determine how the model represented the transport of a conservative tracer. The dye balance study documented the change in mass (dye) in the system over the interval of simulation. The results showed that during a period of 10 days, the calibration run conserved dye to within 16%, and this resulted in a small, conservative result in that RMA-10 over-estimates $\Delta T_{far\text{-}field}$ by approximately 0.1-0.2°F.

Extensive tidal marshes surrounding the Station can affect water temperatures in the vicinity. Natural cooling and heating processes can affect dissipation of heat from the Station (Exhibit E-1-5). Several modifications were made to the computational grid to include specific tidal marshes that could affect the dissipation of Salem's heat: Alloway Creek, Hope Creek, and Mad Horse Creek. One computational grid was constructed that allowed RMA-10 to accurately simulate the flow rates and temperatures into and out of the tidal marshes. This grid included many of the tidal marshes tributaries and accurately depicted many of the finer topographic details of tidal marsh. When RMA-10 was tested for mass conservation (via the dye balance), however, this grid was found to artificially increase the total of amount of dye relative to what was discharged. Consequently, a simpler representation of the tidal marshes was adopted for the final calibration.

The simplified marsh scheme conserved marsh surface area and volume to ensure surface heat exchange processes were represented. Simulations based on the detailed computational grid for the tidal marshes provided useful information for understanding the extent to which the dissipation of heat from Salem within the tidal marshes was affected by using a simplified representation of the tidal marshes.

Model results were compared to data using graphics throughout the calibration process. The types of graphs that were presented are listed below, along with a brief qualitative summary of how well the model compared with the observations. Details related to these comparisons are provided in Attachment E-2 Section III.C.5.f.

- Comparisons of surface water temperature isotherms (Attachment E-2 Section III.C.5.f.iii): Water surface temperature (isotherm) contour maps were developed from the observed data and modeled water surface temperatures. These comparisons were intended to determine how well RMA-10 simulated the pattern and extent of the observed isotherms. It was concluded that the model reproduced the measured data reasonably well. The shape and extent of the isotherms compared well, as did the movement of the isotherms patterns with the changing tides in the Estuary.
- Comparisons of water temperature at the Station's intake (Attachment E-2 Section III.C.5.f.iv): Time series of intake water temperature were compared to determine whether RMA-10 simulated the recirculation of discharge heat accurately. The ability of RMA-10 to simulate recirculation was important, because it directly affects the temperature of the discharged water (RMA-10 adds $\Delta T_{condenser}$ to the temperature of the intake water). Too much recirculation would have overestimated the temperature of the discharge water, and vice-versa. Graphical comparisons revealed only minor differences between observed and modeled intake water temperature; hence, RMA-10 simulated the recirculation correctly.
- Comparisons of $\Delta T_{far\text{-}field}$ (Attachment E-2 Section III.C.5.f.v): These comparisons were developed to evaluate graphically the primary capability of RMA-10 for this application, namely the simulation of $\Delta T_{far\text{-}field}$. The results from a RMA-10 simulation without the Station operating were subtracted from the results from a RMA-10 simulation with the Station operating to compute a value for $\Delta T_{far\text{-}field}$ at each node within the model domain. Although $\Delta T_{far\text{-}field}$ cannot be measured directly in the field, it was estimated by subtracting the temperature recorded at the moorings during the shipboard surveys from the water surface temperature data. Contour maps of modeled and estimated $\Delta T_{far\text{-}field}$ (isopleths of $\Delta T_{far\text{-}field}$) were generated. Visual comparisons of these maps revealed the model simulated the shape and extent of the plume well. Figures V-18 through V-21 illustrate the modeled plume for four tide phases during the calibration period.

Based on the model/data comparisons, the model was determined to be calibrated in terms of its ability to simulate the temperature and extent of the far-field thermal plume (i.e., $\Delta T_{far\text{-}field}$) associated with the Station's discharge of once-through cooling water. An additional assessment of RMA-10's ability to simulate the physical processes governing the transport and mixing of the thermal plume is provided in Attachment E-2 Section IV.

V.E.3.f. RMA-10 Verification

RMA-10 was verified by ensuring that the calibrated model could properly simulate the hydrodynamics and transport processes using independent data sets not used for the calibration. For the verification simulations, the finite element grid and model parameters -- such as friction, turbulent exchange, and turbulent diffusion -- remained the same as those used for the calibration simulation. The verification of RMA-10 was performed using two independent data sets. First, RMA-10 was verified using the One-Unit Survey data along with coincident data that were provided by the Station and various state and federal agencies. The One-Unit Verification is particularly robust because it spanned a time period characterized by completely different surface heat exchange processes than the calibration time period. October was a period of cooling and May was a period of warming. The verification period also was unique from the calibration period in that only one of the two Units was operational; therefore, Station operating conditions, including flow rate and $\Delta T_{condenser}$, were significantly different.

To be consistent with the calibration process, the verification included an Estuary-wide verification and a plume verification. The plume verification also was based in part on the measured dye concentrations from the Two-Unit Survey.

Input data for the RMA-10 verification simulations was derived in similar fashion as the calibration. The One-Unit verification simulation required input data for the period spanning 21 October 1997 through 1 November 1997. As for the calibration simulation, data were compiled for the boundary conditions, including tides, freshwater inflow, and surface heat exchange; initial conditions; and other point sources of heat. One modification was made to the input of wind speed for the One-Unit Verification simulation to account for the increased importance of evaporation and conduction during the late October cooling period. Details on the input data used for the verification simulations is provided in Attachment E-2 Section III.C.6.a.

Input data for the Two-Unit dye verification run were the same as the data used for the Two-Unit Calibration period with one exception. Dye was input to the Station's discharge at concentrations measured during the field survey. RMA-10 was used to simulate the distribution of dye for comparison to the field data.

Data available for comparison to RMA-10 predictions for the purposes of evaluating the results of the verification simulation were comprehensive. The One-Unit Survey included mooring, shipboard, hydrodynamic, and marsh survey components similar to the Two-Unit Survey. The additional data set for the Two-Unit Survey that was used for the verification is the results of the dye tracer survey. These data were used to generate graphs that could be compared to similar graphs of the model results.

V.E.3.f.i. RMA-10 Estuary-wide Verification Results

The Estuary-wide verification was based on comparisons of observed and modeled tidal elevations, currents, salinity concentrations, and water temperature for the period of the One-Unit Survey (21 October 1997 through 1 November 1997). These comparisons revealed a similar level of agreement between RMA-10 results and observed data as was obtained for the calibration simulation. Tide and current processes were well-represented by the model. Additionally, the Estuary-wide distributions of salinity and temperature were reasonable consistent with the field data. Modeled changes in salinity and temperature along the shipping channel from the Bay Zone to Trenton matched observations. As with the calibration, there were measured vertical and some cross-channel variations in these parameters that were not represented by the model. However, considering that these variations do not affect the distribution of the Salem plume, and that the model was not calibrated to simulate detailed salinity and temperature gradients, the level of model/data agreement fulfilled the purpose of this RMA-10 application. RMA-10 was, therefore, verified for its ability to simulate the Estuary-wide processes that govern the Salem thermal plume.

V.E.3.f.ii. RMA-10 Plume Verification Results

The plume verification was based on direct comparisons of model results with observed water temperature during the One-Unit Survey. Similar comparisons were made for the One-Unit Verification as were made for the Two-Unit Calibration, namely comparisons of water surface temperature distributions, comparisons of intake temperature, and comparisons of $\Delta T_{far\text{-}field}$. The additional comparison made for the plume verification was based on the Two-Unit dye tracer survey data.

Comparisons of modeled and observed isotherms compared favorably. The shape and extent of isotherms compared well for the four tide phases (ebb, end of ebb, flood, and end of flood). Additionally, the temperature gradients, evaluated by the relative distances between adjacent isotherms, compared well. There also was little difference between modeled and observed intake temperatures for the verification period, which indicated the model accurately simulated recirculation for the One-Unit operation. Finally, comparisons of modeled and observed $\Delta T_{far\text{-}field}$ compared well. Although the model could not represent all the detailed observed temperature variations, the gradients and extent of modeled $\Delta T_{far\text{-}field}$ were consistent with the estimates developed based on the field data. The differences are not of a magnitude or duration that negatively impacted the reliability of RMA-10's simulations. Based on the One-Unit verification, RMA-10 was verified for its ability to simulate the Salem thermal plume ($\Delta T_{far\text{-}field}$).

In addition to the One-Unit verification, RMA-10 was verified using the Two-Unit dye tracer survey data. The dye comparison is particularly informative because it is not present naturally in the Estuary, which eliminates the bias associated with natural heat sources, such as marshes (Exhibit E-1-5), experienced with model/data comparisons for temperature. Similar to the temperature comparisons, isopleths of constant dye concentration were developed for the model results and the field observations. These maps were compared to evaluate the model's performance. RMA-10's simulation of dye concentration compared well with the field observations. The overall shape, extent, and gradient of dye concentrations were similar between the observations and the model results. Also, the movement of the dye with the changing tides in the Estuary was simulated with reasonable accuracy by the model.

Another comparison that was made using the Two-Unit dye tracer survey data was at the intake structure. Time series of modeled and observed dye concentrations at the intake compared well, and further verified RMA-10's ability to simulate recirculation, which is the basis for RMA-10's ability to simulate the thermal plume.

V.E.3.g. Marsh Investigation

RMA-10 Version 6.6 incorporated improvements compared with previous versions (Section V.E.3). One of these improvements was the representation of marshes and marsh processes. The observational program carried out as part of the Modified TMP included components that addressed the influence of marshes on the Estuary as a whole, and or the Station's thermal plume.

Exhibit E-1-5 addresses the effects of marshes on the Estuarine heat balance. Marshes contribute large amounts of heat on ebbing tides, which dwarfs the Station's thermal discharge during certain portions of the year, including the summer. Station effects on the protection of the balanced indigenous community must be assessed in the context of the marsh effects on the Estuary surrounding the Station.

Attachment E-3 addresses the dissolved oxygen dynamics of the Estuary, in the context of interactive effects of the Station's thermal discharge on pollutants. One finding from this study was that the marshes can provide a large oxygen contribution to the River surrounding the Station. During certain portions of the year, marshes can exert a large oxygen demand on the River, with deficits of up to 4.5 mg/L in dissolved oxygen.

These observations helped achieve the Modified TMP goal to investigate marsh interactions with the Estuary near the Station. Experimental simulations of marsh hydrodynamics showed the marshes could be represented by RMA-10. However, for the purposes of characterizing the Station's thermal plume and thermal exposures, the simulations and observations showed proper marsh area representation was important to characterize thermal exchange between the Estuary and marshes. Consequently, the marsh areas were incorporated in all subsequent simulations.

V.E.4. Linkage Model

V.E.4.a. Objectives and Approach

The results from CORMIX and RMA-10 are integrated to produce a continuous field of ΔT, spanning the near-and far-field. This process of integration is called Linkage.

V.E.4.b. Definitions

The near-field is the zone of complex turbulent flow, where mixing processes are dominated by momentum effects. This region is known also as the Zone of Initial Mixing (ZIM). The ZIM area changes with tide. On the flood tide, the ZIM extends upstream from the discharge. On ebb tide, the ZIM reverses direction. Thus, the ZIM is not a fixed boundary, but one defined by momentum processes, and one that varies with tidal stage.

External to the ZIM is the far-field. In the far-field, mixing processes are dependent on factors other than discharge momentum, such as tidal mixing, wind-induced mixing, shear-induced mixing, and so on. Just as the ZIM boundaries change with tide, so the far-field boundaries change to reflect the changes in ZIM.

Since the hydrodynamic description of the near-field as described by CORMIX and the far-field as described by RMA-10 differ, a transition region has been modeled to effect the linkage between the two models. Plume shapes, variation with depth, and other plume characteristics must be matched across this zone. This is the chore of the Linkage model.

V.E.4.c. Linkage Procedure

It was necessary to develop a procedure for combining the results from CORMIX and RMA-10 to produce continuous ΔT field. This procedure ensures there were no discontinuities in the model predictions of ΔT, and was termed Linkage. The relatively small region over which the models were linked was termed the transition region, and is considered part of the near-field. The transition region is an area where neither CORMIX nor RMA-10 demonstrates a clear advantage in matching observed data. CORMIX employs a dilution equation that calculates ΔT up to the beginning of the transition region, and RMA-10 calculates ΔT beyond the transition region (i.e., the far-field). The procedure used to calculate ΔT at a point, "x", within the transition region relies on a linear interpolation from the point where CORMIX results are no longer used to a point where RMA-10 begins to produce results that are used. Figure V-22 illustrates the transition region using a curve of time versus ΔT which represents the decreasing excess temperature with time as the flow is advected from the thermal discharge. The curve consist of three segments (namely, the ZIM, the transition region, and the far-field). The actual locations of the transition region, which is different for running and slack tides, are presented in Attachment E-2 Section III.D.2. An interpolation scheme also is required to compute cross-sectional plume dimensions (width and depth) in the transition region. The description of the intermediate field also includes approximations of its cross-sectional dimensions (namely, width and depth). Different methods were used to make these approximations for the times of flood and ebb, and for the times of slack water.

The detailed procedure for modeling this transition region is presented in Attachment E-2 Section III.D. The procedures are different segments of for time-ΔT curves and for estimates of hydrodynamic properties.

The end of ZIM and the beginning of the far-field were selected based on comparisons to measurements. In the intermediate area between these two points, a straight line interpolation in temperature was used. For example, Figure V-23 shows an example of the time-ΔT curve for ebb flow. The ZIM is contained within the region of plume travel from discharge to about 2 minutes from discharge; within this zone, CORMIX results are applied. The far-field begins at about 10 minutes from discharge, after which the RMA-

10 far-field results apply. In between, the temperature is interpolated in a simple linear fashion.
The procedure for calculating heat and velocity distribution, as well as plume dimensions, is slightly more complicated. The selected procedure conserves heat and momentum, and results in a top-hat shaped distribution that linearly expands with distance out to the point where RMA-10 results first apply (the beginning of the far-field). Because of the assumption of the top-hat distribution, slices of temperature, velocity, or other plume properties across the transition region will show abrupt discontinuities. Although a smoothing procedure could have been applied to remove the discontinuity, the top-hat was preserved and the discontinuities remained. There is no significance to this approximation, other than that the model was not unduly complicated by forcing an arbitrary smoothing procedure.

The ZIM for running tides has different configurations than for slack tides (Figure V-24). Running tides have a shorter zone of initial mixing, and the thermal discharge interacts more strongly with ambient flow early in its trajectory. By contrast, at slack water, the momentum from the thermal discharge overwhelms the low ambient momentum, so the ZIM maintains its momentum identity farther offshore. Figure V-24 shows the relative dimensions of the ZIM for different tidal conditions. For flood and ebb running tide, the ZIM has a dimension of 300 feet or so. For slack waters, the ZIM is longer, and extends a distance of about 1000 feet. The transition region is about 700 feet for all tidal phases for the calibration period. The transition region length is dependent upon discharge and receiving water characteristics. For instance, the transition is approximately 900 feet for running tides and One-Unit Station operating conditions.

The slackwater ZIM is still a small portion of the Estuary cross-section. Generally, it has small length, area, and volume scales since slack waters do not persist for long (typically less than one hour). Bottom contact excess momentum associated with the thermal discharge is limited to within the ZIM. High velocity exclusion areas are confined to the ZIM. Therefore, the scale of the ZIM provides some measure of biological effect scales.

V.E.5. Total Temperature Model (TTM)

V.E.5.a. Approach

The purpose of the TTM is to provide estimates of total water temperatures expected to occur due to the continuing operations of Salem. The TTM merges the results from the various models described above are combined by superimposing fields of ΔT on to an ambient temperature with ΔT fields. The ambient temperature would exist in the absence of Station operations, and are subject to daily, seasonal, and interannual fluctuations. The ΔT describes the spatial and intertidal effects of the Station's thermal plume on the temperature within the Estuary; this ΔT field varies much less on a daily, seasonal, or inter-annual basis. The ΔT field variability is primarily spatial.

The ΔT associated with the Station operations is made up of two parts. First is the heat build-up associated with continued Station operations, CORMIX computes a local near-field increment to ΔT that accounts for the heat as it is being discharged from the Station.

The TTM solution for each the near-field and the far-field contain two parts. The near-field solution must incorporate the combination of the ambient temperature, the "approach temperature" that represents the heat build-up, and the incremental increase in ΔT due to the heat as it is being discharged (ΔT_{CORMIX}). The far-field solution is external to the ZIM, and is external to the region described by CORMIX. In this region, the solution is represented by a superposition of ΔT calculated by RMA-10 on to the ambient temperature.

The TTM can be used to estimate water temperatures in the immediate vicinity of the Station's thermal discharge for times of maximum flood and ebb, and of slack water. It can also be used to estimate far-field temperatures during any moment of a tidal cycle, and to estimate the seasonal and annual variations in water temperature. These characteristics make the TTM a valuable tool for producing biological work products (thermal exposures) to support the Biothermal Assessment.

Before it was used to generate temperature predictions, TTM was validated using observed water temperatures. No calibration and verification procedure was required, because the TTM is built upon three models that were themselves each calibrated and verified. The validation assures that the sum of the results from the models themselves are correct, compared to observations.

Once validated, TTM is applied using hypothetical combinations of natural conditions and Station operations selected to simulate reasonable worst case water temperatures in the Salem thermal plume at any time of year. The selected combinations are based on assessment of the sensitivities of key plume characteristics (such as magnitude and duration) to potential tidal range, surface heat exchange, freshwater inflows, discharge flow rate, and Station $\Delta T_{condenser}$.

V.E.5.b. Validation

TTM was validated using coincident time-series of measured water temperatures, estimated $T_{ambient}$, and actual Station operations, and specific estimates of the near-field temperature and current speeds for four tidal cycles (maximum flood and ebb, and end-of-flood and end-of-ebb slack). The time-series of measured water temperatures were recorded at four near-field moorings (moorings 21, 22, 23 and 24) and two far-field moorings (moorings M9 and 9M) from 17 May 1998 through 05 November 1998, as part of the Modified Thermal Monitoring Program (Figure V-24). The time-series of $T_{ambient}$ was calculated by ATM based on the solar and meteorological conditions that existed during the same six-month period (Section V.E.1). Coincident time-series of discharge flow rates and temperature increases across the Station's once-through cooling water system ($\Delta T_{condenser}$) were used to identify those inputs to CORMIX that would result in estimates of the near-field component of ΔT consistent with actual measurements of near-field plume temperatures.

The four near-field moorings were distributed around the immediately area where Salem's thermal discharge initially mixes with the Estuary and where the ZIM intercepts to the water surface. Moorings 21 and 22 were located in the typical trajectory of the plume during times of slack water, a southwesterly or southwestward direction from the Station's discharge. Mooring 23 was located up-estuary from the Station's discharge in the path of the plume during times of flood. Mooring 24 was located down-estuary from the Station's discharge in the path of the plume during times of ebb. Each mooring was equipped to measure water temperatures at three levels: near the water surface, at mid-depth, and near the bottom. The relative positioning of the four moorings typically resulted in at least one mooring in the path of the thermal plume.

Representative estimates of $\Delta T_{approach}$ were derived from RMA-10 outputs for two simulations using the hydrodynamic, meteorological and solar conditions. The simulations were identical except that one simulation included the Station's thermal discharge, and the other did not. Estimates of $\Delta T_{approach}$ for locations immediately up- and down-Estuary of the four near-field moorings were obtained by subtracting the results of the simulation run without the Salem thermal discharge from the results of the simulation run with the Salem thermal discharge.

The results from the TTM validation were positive. Figure V-25 provides one time-series from the validation. On this figure, the upper graph displays the measured water temperatures (plotted as a continuous curve), and the daily estimated maximum and minimum water temperatures (plotted as "stepped" curves). The time-series of measured water temperature is labeled as the Observed Water Temperatures (°F). The lower stepped curve is the estimated minimum water temperature that would occur when the plume does not intercept a mooring, which is identified as the Estimated Minimum Water Temperature (°F) and is the sum of $T_{ambient}$ and $\Delta T_{approach}$. The upper stepped curve, identified as the Estimated Maximum Water Temperature (°F), is the sum of $T_{ambient}$, the near-field component ΔT_{CORMIX}, and the impinged $\Delta T_{approach}$. The close correspondence between the observations and the modeled minimum and maximum temperatures demonstrates the ability of TTM to simulate natural and Station-related temperature effects. Attachment E-2 Section III.E shows other examples of the validation, demonstrating the range of fit between the model and the observations.

During the six-month verification period, TTM correctly tracked the daily range of observed water temperatures from a high of approximately 90°F in August 1998 to a low of 55°F in November of that year. With few exceptions, TTM correctly estimates the near-field component of ΔT during changing Station operations, and can, thus, be used to estimate water temperatures in the plume for a range of conditions and operations. The effect of annual variations in $T_{ambient}$ on water temperatures in the thermal plume are addressed by varying $T_{ambient}$ as a function of return period.

The RMS differences between the six-month time-series of observed daily average water temperatures at far-field Moorings M9 and 9M, and the results of the TTM were compared with the RMS differences computed in the ATM calibration and verification. Because the principal source of variability in the far-field TTM is $T_{ambient}$ and the far-field daily average $\Delta T_{approach}$ is seasonally constant, comparison of the RMS differences provides a valid measure of the performance of the TTM in the far-field.

The RMS differences between the adjusted TTM time-series and the time-series of daily water column-averaged observed temperatures was computed for the six-month period. The RMS difference at Mooring 9M is 1.46°F, and at Mooring M9 it is 1.53°F. These values are close to the RMS differences achieved in the ATM calibration and verification, indicating that the TTM predictions for the far-field are reliable.

The demonstrated ability of TTM to estimate reliably the actual daily minima and maxima of water temperature during a six-month period (during which Station operations varied, as did solar inputs and meteorological conditions) also confirms that the two-day intensive field survey as provided by the Modified TMP yielded an adequate data set for characterizing both near-field and far-field mixing processes. Thus, the ability of a calibrated and verified version of CORMIX to characterize the near-field mixing processes was established using a short-term, well-defined field study.

V.F. CHARACTERIZATION OF THE THERMAL PLUME AND BIOTHERMAL EXPOSURE

V.F.1. Approaches for Describing Thermal Exposures of Organisms

This section describes how the hydrothermal models were applied to produce graphical products and statistics that characterize thermal exposures to organisms required for the Biothermal Assessment. The rationale for the selection of different models for particular work products is presented as well.

Extensive hydrothermal monitoring and modeling, described in Appendix E Sections V.D and V.E and Attachments E-1 and E-2, were conducted to support the estimation of biological effects in the Biothermal Assessment (which follows in Section VI). Characteristics of thermal plumes from the modeling perspective (heat transfer, advection, diffusion, etc.) need to be translated to describe the temperatures experienced by organisms. Collaboration between the hydrothermal and biothermal analyses throughout the development of the 316(a) Demonstration ensured the hydrothermal models were designed to characterize appropriate thermal exposures to organisms.

The pathway to developing thermal exposures of organisms can be visualized in Figure V-26. The character of the Estuary, as described in Appendix C, and the Station operations, as described in Appendix B, define the setting of the analysis. The tools available for developing thermal exposure estimates are monitoring data from the Delaware Estuary both when the Station is operating and when it is not, and a suite of computer models. The models assimilate the monitoring data and basic physical principles in ways that allow estimation of exposures under many different scenarios of environmental and Station operating conditions. It is not possible to measure temperatures and other relevant environmental features under all possible conditions, so the conditions of special interest must be simulated (e.g., the reasonable worst-case conditions for biological effects). These simulations require that the models have the capability to represent the processes involved in determining plume temperatures under a variety of conditions. Thus, the models undergo rigorous calibration, verification, and/or validation processes, as described in Attachment E-2.

From a biological perspective, four types of important temperature exposures have been identified (shown at the bottom of Figure V-26). These are (1) seasonality of exposure, i.e., the type of seasonal cycle and how it may be affected by the thermal discharge, (2) the duration for which an organism is exposed to temperatures above ambient, (3) the spatial extent of the elevated temperatures, and (4) the frequency of exposures when they are not constant, but recurring at some interval. Each of these features may vary as a thermal discharge and its plume fluctuate in a body of water such as the Delaware Estuary.

To progress from monitoring data and theoretical models to the four types of thermal exposures of organisms required several analytical stages. These are represented in the middle of Figure V-26. The stages fall into two general categories: one that concentrates on understanding and simulating the ambient conditions that determine the seasonal cycle, and another that concentrates on the characterization of the thermal plume ΔT. The ambient environment (that is, the environment that would exist without the Station) determines both typical seasonal temperatures and interannual variability. Variability is important because the analysis must consider what happens to organisms in both typical and exceptionally warm or cold years. The Station's thermal plume exists not only as a feature in space (spatial variability of temperatures across length, width, and depth) but also in time (temporal variability in the plume's shape and temperatures) as the heated discharge water rapidly mixes with the surrounding water, and as the tides move the plume upstream and downstream.

Four models were used to conduct the hydrothermal modeling of thermal exposures (Figure V-27). The principal three are an Ambient Temperature Model (ATM) describing temperatures in the absence of a Station discharge, a near-field model, CORMIX, for simulating $\Delta T_{near\text{-}field}$ and water velocities in the zone close to the discharge, and a far-field model, RMA-10, for simulating $\Delta T_{far\text{-}field}$ farther from the discharge, where the momentum of water jetting from the discharge pipes no longer dominates the shape and direction of the plume. The two models are linked in a transition region between the near- and far-fields. The RMA-10 and CORMIX models are also linked with the ATM in certain instances to produce a Total Temperature Model (TTM) for the plume. The method of model deployment to provide thermal exposure information is described further below.

Characterization of the ambient temperature regime over an annual cycle is important for establishing the normal baseline of temperatures that organisms experience. The thermal discharge from the Station is a relatively small incremental addition to the normal cycle that is established regionally by climatic factors. Long-term trends in climate also establish interannual variability, so that over decades there are warm and cold years, often in a recurring cycle. Organisms typically become physiologically acclimated to ambient temperatures, and their responses are keyed to that baseline. Understanding interannual variability is critical because in warm years, for example, organisms are closer to their upper tolerance limits due to natural temperature variations than in cold years. The ATM model was used to characterize the likely ambient temperature cycles of the Estuary during the past 50 years, on the basis of on meteorological records. From this simulated history, ambient water temperatures for the average year (one to two years), and the warmest and coolest (one in ten years), were determined for use in the Biothermal Assessments. The frequency of exceeding specific temperatures (such as critical temperatures for the lifecycle of a species), because of variability in the baseline ambient temperature, was also estimated for the Biothermal Assessment.

Several types of organisms and their habitats must be considered when estimating thermal exposures in the plume for conducting a Biothermal Assessment. Each type of exposure requires application of a different mix of models and a different characterization of the plume.

First, planktonic organisms can be drawn into the discharged cooling water as it is mixed with the surrounding water, in a process called "plume entrainment." The most extreme thermal exposure would be to an organism drifting in the Estuary, and mixing with the near-field discharge to form the plume. This planktonic organism would be exposed momentarily to the temperature of the discharge andwould then experience a rapid decline in water temperature as the discharge experienced its first phase of rapid mixing (simulated by CORMIX). In an ideal sense, this organism might traverse the warmest portion of the near-field plume as heated and surrounding water are mixed. In reality though, the organism would experience a sequence of thermal highs and lows, as warmer upwellings merge with cooler vortices from the plume edges. Examples of measured transit temperatures and the modeled case are shown in Figure V-28. Here it is seen that CORMIX simulates that the organism transits nearly the highest centerline temperatures as the water in the ZIM plus the transition region moves to about 1,000 feet from the discharge point. Fields of $\Delta T_{far\text{-}field}$ beyond the first thousand feet are simulated by RMA-10, which is a more appropriate model for simulating the different mixing processes resulting in more gradual temperature declines that occur in the far-field plume, more distant from the discharge. The biothermal analysis is conducted using temperature elevations (ΔT) in the plume in relation to baseline ambient temperatures computed by the ATM, so that reasonable worst-case ambient conditions are represented.

CORMIX and RMA-10 were combined to provide a continuous field of ΔT, spanning the near- and far-field. For the Biothermal Assessment, the distances are converted to travel times, because the effects were determined by the combination of exposure temperatures and exposure duration at each incremental temperature. Just as the near-field discharge ΔT fields can be modeled using CORMIX, the physiological responses of the entrained organisms are modeled mathematically in a time-temperature exposure model that establishes, based on laboratory test data, whether an organism would be killed by its transit through the rapidly declining temperatures of the plume (Appendix E, VI.C.2.a.ii). For the Biothermal Assessment, the ambient temperature is considered to be the organism's acclimation temperature. It is appropriate to use the maximum temperatures experienced along the centerline of the plume (as estimated by CORMIX), and to assume that each organism begins its transit at the point of discharge (whereas most would enter the plume later in the mixing process) in order to establish whether it is at all possible that organisms would be killed. If not, then any organism receiving a lesser exposure would be assured of survival.

Second, mobile organisms might, in principle, reside in the plume and receive harmful thermal exposures or actively avoid temperatures above an avoidance temperature. Residence is precluded in the zone nearest the discharge by high velocities, as estimated by CORMIX. Only beyond a zone of initial mixing (ZIM) could organisms possibly resist the flow. Even there, their ability to remain is determined by sustained swimming speeds. Water velocities estimated by CORMIX are compared to the swimming speeds of organisms such as fish to indicate the potential for residence in the plume. In the far-field plume, modeled by RMA-10, the ambient tidal velocities dominate. Although fish and other mobile organisms could reside in the plume in these locations, they would have to consciously move about with the changing tides to remain in heated water for any extended period. The RMA-10 model includes these transient conditions, and (when combined with CORMIX as the TTM) calculates the surface areas and volumes of the Estuary that would be enclosed by various isotherms. From this area and volume, the percentage of the Estuary so affected can be calculated. The volumes can be used for considering either attraction or avoidance in the Biothermal Assessment, and whether the temperatures experienced there would affect growth, reproduction, cold shock (if the temperatures dropped quickly to ambient), or other effects. The biothermal analysis must consider whether the particular species and life stage is likely to reside in the plume, how much volume of warmed water is available, the likely frequency of exposure if the organism moves in and out of the plume (or the plume fluctuates around a preferred location of the organism), and the likely length of time the organism would be exposed.

Third, organisms attached to the bottom would be resistant to the currents of both the near-field and far-field plume, and would be exposed to the temperatures in the water above them. CORMIX defines a zone close to the discharge where water velocities are high enough to scour the bottom sediment and prevent organisms from attaching. Beyond this zone, the temperatures experienced at the bottom are calculated by RMA-10. The model calculates areas of the bottom that experience various isotherms, so that the

Biothermal Assessment can consider the relationship of these areas to the physiological responses of organisms and the proportion of the Estuary affected. Because of tidal changes, an attached organism in the pathway of the plume would receive a pattern of alternating warmed and ambient temperatures during a 24-hour period. This cycling was monitored at fixed stations and incorporated in the plume models. As for mobile organisms, the Biothermal Assessment of bottom-dwellers must consider the frequency, duration, and spatial extent of the exposures to particular temperatures.

Fourth, there is a need to consider organisms that reside in the littoral, or shoreline, zone of the Estuary, including marshes at the edge of the main Estuary. The RMA-10 model locates the isotherms that would contact the shoreline and estimates the length of shoreline affected by particular temperatures. This distance is used by the Biothermal Assessment to evaluate effects on the shoreline biological community.

Fifth, migratory species must pass the Station undeterred by high temperatures in the plume. They must also be able to enter and leave the mouths of creeks that flow from marshes. The combined RMA-10, CORMIX, and ATM models (TTM) estimate the cross-sectional area of the Estuary between the Station and the opposite shore that would be occupied by various isotherms. The RMA-10 model also estimates temperatures at the mouths of nearby Alloway and Hope creeks. The Biothermal Assessment can then compare these areas to avoidance temperatures of the migratory species to establish whether and by what percentage of the Estuary cross-section migrations could be blocked.

Reasonable worst cases were selected for modeled conditions (as further described in Section V.F.4) in an attempt to establish whether detrimental effects for organisms could occur in the Station's thermal plume. If these modeled conditions are shown by the biothermal analysis methods to be non-detrimental to organisms, then lack of harm is assured for the more likely conditions. When potential for harm is suggested by these reasonable worst case conditions, then the biothermal analysis evaluates the likelihood of harm by assessing the levels of conservatism applied in estimating plume temperatures and in applying biological knowledge.

In conclusion, this rationale and the descriptions below should provide a guide to the logic for determining thermal exposures to organisms in the Station's thermal plume. This analysis of the Station's plume and its biological effects is the most extensive, intensive, and well-integrated of those conducted for the Station over the 30 years of study. Yet the conclusions remain the same: the Station's operations are protective of the BIC.

This Section is organized as follows. Section V.F.2 describes the methods used for characterizing the thermal plume and the thermal exposure. Section V.F.3 summarizes the results from the hydrothermal numerical models (Section V.E), and shows that the characterization of the thermal plume and thermal exposure have been consistent and similar for all Salem thermal plume studies performed during the past 30 years. V.F.4

describes the methods used to define the biological reasonable worst case for quantifying thermal exposure. Finally, V.F.5 describes the thermal and scour exposures.

V.F.2. Methodology

This section discusses the models that were applied to characterize the thermal plume, the methods of their integration, and the quantification of thermal exposure of organisms. Figure V-27 shows a schematic of the way the different models described in Section V.E and Attachment E-2 Section III were synthesized to estimate thermal exposure. The three models used (Ambient Temperature Model, RMA-10 and CORMIX) have been described in Section V.E and Attachment E-2 Section III. The models have all been calibrated, verified, and/or validated based on the extensive results from the Modified TMP.

RMA-10 was used to simulate far-field processes. CORMIX simulated near-field processes. In order to characterize the entire plume, CORMIX and RMA-10 had to be linked. This linkage process (Figure V-27) is described in Section V.E. Together, RMA-10 and CORMIX provided estimates of the ΔT fields within the Estuary.

The Ambient Temperature Model (ATM) is described in Section V. and Attachment E-2 Section III. It is used to extend the observed water temperature record to greater spans of time so that more detailed calculation of long-term statistics of interannual water temperatures can be made. When the ATM is combined with RMA-10 and CORMIX, the Total Temperature Model (TTM) results. The TTM predicts water temperature in the Estuary by adding the appropriate ΔT, provided by CORMIX and/or RMA-10, to the ambient temperature predicted by ATM. Validation of the TTM (Attachment E-2 Section III) also validated the assumption that ΔT fields vary primarily in space, particularly in the near-field, which was a key element of the Modified TMP. That the TTM accurately represented an independent three-month data set at different locations in the Estuary attests to the accuracy of the time-varying $T_{ambient}$ versus spatially-varying ΔT temperature paradigm.

These combined models are used to characterize thermal exposures, as indicated on Figure V-27. The TTM produces representations of thermal exposure on seasonal scales (Seasonality of Exposure) and interannual scales (Frequency of Exposure).

The linkage between RMA-10 and CORMIX produces alternate representations of thermal exposure required for the Biothermal Assessment. These include descriptions of thermal exposures entrained in the plume centerline, areas and volumes associated with isopleths of ΔT, areas and volumes of scour, and related spatial and short-time exposures. These thermal exposure characterizations are described in greater detail in Section V.F.5.

CORMIX is used to characterize the distribution of ΔT in the ZIM (Attachment E-2 Section III.B). Although it is a steady-state model that was not developed specifically for tidal flows, CORMIX can be used to represent those times in the tidal cycle when the flow is nearly steady. CORMIX provides characterization of the areas and volumes of temperatures and velocities in the ZIM, which, on running tides, extend from the point of the Station's thermal discharge to the point where momentum alone ceases to control mixing processes. At slack water, the ZIM extends to 1,000 feet from the discharge.

RMA-10 is a hydrodynamic transport model that simulates the water levels, sea surface elevation, salinities, temperatures, and other features of the Estuary. RMA-10 is used to characterize these variables in the area referred to as the far-field (E-2-III.C).

The simulations provided by CORMIX and RMA-10 overlap in an area called the transition region. For each of the four tidal phases simulated by CORMIX, a region between CORMIX and RMA-10 must be specified in order to link the two models. This transition region is specified by selecting the model that best approximates time–ΔT behavior therein, on the basis of detailed observational data. For the running tides, CORMIX terminates between approximately 150 and 300 feet from the thermal discharge, and RMA-10 begins 700 feet beyond. For the simulated near-slack tides, the end of the ZIM is 1,000 feet and RMA-10 is applied at 1,700. Between the points not modeled exclusively by either CORMIX or RMA-10, the CORMIX output was extended to transition smoothly with the RMA-10 output (Attachment E-2 Section III.D). Temperatures and velocities within this transition region were estimated using a telescoping top-hat temperature distribution. The telescoping top-hat refers to the rectangular cross-section of the transition region. As the rectangular cross-section expands in time, it creates a visual effect similar to a telescope opening.

The ATM provided daily estimates of the ambient temperature in the Estuary near the Station that would exist in the absence of the Station (Attachment E-2 Section III.A). This model permits extrapolation of daily River water temperatures near the Station even for those times when observational data are not available. In particular, because the observational record of River temperature without Station operation is limited, the ATM permits extension of these observations. ATM estimates generally surpass the quality and quantity of observations that exist close to the Station. The ATM is merged with output from CORMIX and RMA-10 to create the TTM, which estimates the temperature for any time in the far-field by superimposing results from RMA-10 and ATM, and for the four tidal phases in the near-field, by superimposing the results from CORMIX, RMA-10, and ATM (Attachment E-2 Section III.E).

The velocity and thermal exposure in the ZIM were characterized by using outputs from CORMIX and RMA-10. Thermal exposure by plume entrainment was characterized by using output from CORMIX and RMA-10. Plume exposure outside the ZIM is characterized using RMA-10 in conjunction with CORMIX and ATM. Finally, seasonal temperature distribution is characterized by summing all three models into the TTM. Output from the ATM allows for assessment of temperature conditions in all seasons.

V.F.3. Consistency in the Characterization of the Thermal Plume

The regulatory thermal plume is defined by the 1.5°F isopleth of ΔT for the regulatory summer period (June, July and August), and by the 4°F isopleth during non-summer months (September through May) (NJAC:7:9B-1 et seq.). The intention of this Section is to assess the direct effects of the Station's thermal plume and any indirect interactive effects on the protection and propagation of a BIC within the Estuary. Therefore, it is important to understand the complex set of characteristics that make up the thermal plume.

The thermal plume is a volume of water at a temperature that is elevated compared to ambient. It has a characteristic thermal signature, a characteristic shape (morphology), and a characteristic behavior. The thermal plume comprises a near-field region where intense mixing (and hence rapid dilution) is dominated by the momentum (and, to a much lesser extent, the buoyancy of the discharged water) of the discharge, and a far-field where the mixing is controlled by ambient tidal currents and where dilution occurs at a slower rate. The temperature of the plume decreases rapidly in the near-field as the turbulent discharge mixes with receiving water, and continues to decline to ambient temperatures in the far-field due to mixing and surface heat exchange processes.

The size, shape, and dynamics of the Salem thermal plume are dependent on the design of the cooling water discharge, the local bathymetry around the discharge, the characteristics (volume flow rate and enhanced temperature) of the thermal discharge, the hydrodynamic conditions occurring in the Estuary, and the prevailing climatology. The interaction of these factors can be evaluated using mathematical or physical models to accurately simulate the transport, mixing, and heat exchange processes that take place in the vicinity of Salem and throughout the Estuary. .

The Salem thermal plume results from once-through cooling water discharged through six ten-foot diameter pipes extending approximately 500 feet from shore into the Estuary, at a water depth of about 30 feet. These large-diameter discharge pipes occupy about one-third of the water depth at the point where they terminate at the River bed.

Since the original application to the United States Atomic Energy Commission (USAEC) for permitting of the Station (approved on 25 September 1968), the thermal plume and the related thermal exposures to organisms have been characterized numerous times (DRBC 1970; USAEC 1973; 316(a) Demonstration 1974 with sequiturs; NJDEP 1982; NJDEP 1991; NJDEP 1993, DRBC 1995). These characterizations have been made using a variety of methods, models, and data. The methods employed have varied with time, ranging from physical model simulations in a tidal basin to reliance on observational data and to complex numerical simulations using computers. Simulation models have improved, culminating in the present use of sophisticated models capable of representing the physics of the Estuary in three dimensions. The data have improved continually with time, as each submittal has brought new information and hence new insight into the processes controlling the Station's thermal plume in the Estuary.

This repeated sequence of data collection, modeling, and analysis during the last thirty years has not changed the interpretation of the characteristics of the thermal plume or the thermal exposures. The representation of the plume characteristics and exposure of organisms has evolved with time, as data and improved models became available. However, the thermal plumes described in all these efforts are consistent, and the thermal exposure is similar. All thermal plume characterizations support the repeated conclusion, backed by thirty years of increasingly sophisticated data and analysis, that the Salem thermal discharge is supportive of the protection and propagation of a BIC.

Since Unit 2 began operating in 1981, Station operations have remained essentially the same (Appendix B). The Station's two Units are essentially identical, each with a thermal power rating of 3,423 megawatts thermal. They are designed to operate continuously at their licensed thermal power rating as base-loaded electrical generating units. The Station generates electricity in the same manner today as it was licensed to do in 1977 and 1980.

The early physical model developed by Pritchard and Carpenter in 1968 to characterize the Station's predicted thermal plume for design and permitting showed a thermal plume extending to a maximum distance of about 31,000 feet downstream at the end-of-ebb, and 41,000 feet upstream at end-of-flood, under reasonable worst-case Station operating conditions and summer receiving-water conditions. The thermal plume was defined by the 1.5°F ΔT isopleth. Plume width ranged up to 6,000 feet. The area expected to be covered by the 4°F ΔT isopleth was about 40 acres.

Thermal studies were conducted in 1977-1978 to characterize the thermal plume under One-Unit operating conditions. Vessel observations and infrared studies were used without complementary numerical modeling. No comparisons with prior or subsequent results can be made because the heat load in 1977 was not characteristic of Two-Unit operations..

The next major plume characterization studies were undertaken between 1982 and 1985, when thermal infrared mapping, dye studies, and vessel surveys were conducted to characterize the plume under Two-Unit operating conditions. The studies indicated a instantaneous flood tidal phase plume length of about 30,000 feet and a width of about 3,500 feet, based on the 1°C (1.8°F) ΔT isopleth. For the slack water following ebb tide, instantaneous plume length was estimated to be about 36,000 feet and width was about 6,000 feet. Because this characterization relied on field data and remote thermal imagery, only an empirical characterization of the extant plume was done. The empirical characterization was for conditions that prevail during the surveys, and did not prepresent worst-case conditions. In addition, as described in V.A, it is difficult if not impossible to measure differential temperatures in the field. These field observations, therefore, were approximations of the thermal plume dimensions relying solely on observations, but still were consistent with the findings of Pritchard and Carpenter.

The 1982 studies also helped to define some characteristics of the plume. The plume was characterized as well mixed throughout the water column near the discharge (near-field), gradually becoming more stratified away from the discharge. Field data, however, show a generally well mixed water column at all locations, with only a slight temperature increase (about 1°F) near the surface in the plume far-field.

The 1991 Section 316(a) Demonstration for Salem included the first application of a numerical model, UDKHDEN, to characterize the near-field region of the Salem thermal plume. UDKHDEN is a three-dimensional steady-state mathematical plume model that was used to estimate ΔT fields in the near-field only. In 1991, UDKHDEN was state-of-the-art with respect to three-dimensional near-field models. The far-field thermal plume was characterized using the data from the 1982-1985 field studies. Projections of thermal plume widths under different conditions than those prevailing during the 1982-1985 measurement program, such as worst-case, were still limited to the 1968 physical model results of Pritchard and Carpenter.

In 1993, numerical models were again used to characterize the Station's plume, and to estimate the seasonal and interannual variation of ambient water temperatures. The numerical model selected to simulate the far-field for the first time was RMA-10. The thermal plume lengths resulting from this modeling study were comparable to those of the 1968 study: about 37,000 feet upstream to 35,000 downstream of the discharge, based on the regulatory 1.5°F ΔT isopleth. Maximum widths ranged up to about 7,000 feet on ebb tide, and to less than 5,000 feet on flood tide. The near-field was characterized by the Cornell Mixing Zone Expert System, Version 2 (CORMIX-2) which estimated near-field temperatures, velocities, and time of exposure. CORMIX-2 represented a modeling technique improvement over the UDKHDEN model applied in 1991.

In 1995, PSE&G commissioned additional studies of the thermal plume to support the DRBC filing. Instantaneous thermal plume lengths were not characterized in this study, because the focus was on the 24-hour average regulatory temperature field. The near-field model used was CORMIX (Section V.E), and the far-field model was RMA-10.

Finally, the present submittal provides an extensive analysis of the Salem thermal plume. It has used the same basic suite of models (CORMIX, RMA-10, and ATM) as in 1995, with updates incorporated as appropriate to reflect improvements in the detailed observational descriptions of the thermal plume, as well as theoretical improvements in numerical modeling techniques. These improvements to the models are discussed in Section V.E.

The present submittal has extensively characterized both the near-field and far-field thermal plumes. For the present Demonstration, an unprecedented data collection and analysis, and modeling effort, was completed (Sections V-D and V-E). The results from this extensive data collection and modeling effort were synthesized in the form of graphics and tables that characterize the Station's thermal plume and the thermal exposure to organisms. The data collection effort was guided by the 1998 Modified Thermal Monitoring Program (Modified TMP), described in Section V.D. This Modified TMP outlined an ambitious and comprehensive effort to collect data to characterize the Station's thermal plume, and to provide a source for development and application of sophisticated numerical models. This observational program successfully achieved its objectives.

The numerical modeling effort (Section V.E) was unique in its level of effort and accomplishments. A suite of numerical and statistical models was selected to represent different aspects of the physics of the Estuary. From a broad scale, models were developed to characterize seasonal and interannual water temperature variability in the Estuary near the Station. These models were used to identify average temperatures, extreme cold (one in ten years), and extreme warm (one in ten years) conditions to address the range of potential conditions for thermal exposure. The spatial characteristics of the plume were addressed, including the near-field dynamic portion of the plume, and its linkage with the far-field description. Finally, the models simulated the short-time history behavior of organisms exposed to thermal stress. The observations show that the ZIM surfaces much closer to the discharge than previously characterized (less than 100 feet as opposed to about 300 feet in the 1993-1995 calculations). The dilution factor at the point of surfacing is about two, the same as in the previous filings. The present submittal has substantially refined the characterization of geometry, temperatures, and velocities in the near-field.

The far-field thermal plume characterization has also been improved in the present submittal by enhancements to the RMA-10 model. The plume morphology is substantially similar to previous characterizations. It is narrow, with a 1.5°F isopleth that does not veer markedly from the New Jersey shore. The widest plumes occur on the ebb phase in areas where the shoreline curves sharply to widen the Estuary; the western edge of the plume retains its orientation, as the eastern edge of the plume tends to follow the widening shoreline. Because of greater shoreline curvature south of the Station, the plume tends to be wider there than to the north, in accordance with previous characterizations.

Maximum plume lengths extend to about 43,000 feet maximum upstream, and about 36,000 feet downstream. Widths on flood are about 4000 feet, and on ebb about 10,000 feet. Width, as discussed, is controlled by shoreline curvature, not by thermal plume mixing processes alone.

The 4°F ΔT isopleth is a useful representation of the region of potential biological effect. Comparison of the 1993 submittal with the present submittal shows that the area enclosed by a ΔT above 4°F is smaller in the present submittal than in the 1993 characterizations for all tidal phases except end-of-flood. (Table E-V-7 of PSE&G 1993; Table V-2 of PSE&G 1999). Similarly, volumes of water having ΔT of 4°F or above are approximately equal for flood and end-of-flood, but smaller in the present submittal for the ebb and end-of-ebb tidal phases.

Time histories of potential organism exposure to elevated plume temperature from the point of discharge to 180 minutes later show roughly similar thermal exposures in the 1995 and present submittals. Although the temperatures drop more rapidly in the near-field using the present improved near-field model, compared to 1993 and 1995, the far-field decline in temperature remains similar.

Based on review of all previous information, the conclusion is that the characterization of the Station's thermal plume has remained consistent since 1968 when the original physical model studies of the proposed Station were conducted. Station operations have not changed substantively since that time. The River dynamics have not changed during that time. Consequently, the thermal plume has remained the same, and PSE&G's characterization of the thermal plume has been similar.

Minor differences in thermal plume characterization, whether in morphology or thermal exposure, have resulted from improvements in observational data with which to constrain the modeling; improved model techniques, including grid improvements and a more refined shoreline and River bathymetry to represent plume morphology more accurately; and improvements to the near-field model to represent the shallow discharge dynamics more accurately. These incremental improvements have led to improved understanding of the Station's thermal plume, but have not altered its overall characterization.

Even with these improvements, the previous 30 years of characterization of the Station's thermal plume show a consistent morphology, a consistent rapid decline in temperature from the discharge through the near-field and into the far-field, and a consistent quantification of low-level thermal exposure of organisms to the elevated plume temperatures.

V.F.4. Identification of Hypothetical Biological Worst Case Scenarios

Draft technical guidance for the §316(a) Demonstration (USEPA 1974, 1977) suggests that the applicant "provide a detailed narrative with appropriate tables and figures to show why impacts, or potential impacts, of the heated discharge are so insignificant that the protection and propagation of indigenous species of fish, shell fish, and wildlife populations will be assured."

To ascertain potential impacts, a predictive Biothermal Assessment was performed as part of this 316(a) Demonstration to compare predicted temperature exposure to the temperatures known from the scientific literature to cause biological effects. Information regarding the temperature exposure in the plume was derived from the sophisticated suite of numerical models and combined with an extensive set of observational data, to perform the predictive Biothermal Assessment. As a basis for determining maximum temperature exposure, a biological "reasonable worst case" condition was identified.

Reasonable worst case was defined from a biological perspective. There are many possible definitions of reasonable worst case, depending on the biological resource in question and the effect being examined. Based on previous submittals, and in-depth knowledge of the Delaware Estuary biology and plume dynamics, one definition was selected as most appropriate for this Demonstration. Reasonable worst-case conditions are defined here as prolonged or sustained exposure of organisms to elevated temperatures in the near-field portion of the thermal plume.

The reasonable worst case for the Biothermal Assessment is defined as that combination of plant operating, meteorological, and estuarine hydrologic conditions that could be expected to occur, and that result in the highest sustained time-temperature exposure for organisms transported through the centerline of Salem's thermal plume. This predicted worst-case temperature is defined as the superposition of the ambient temperature, the heat build-up around the Station, and the near-field differential temperature (ΔT).

A ten-year record of meteorological, hydrologic, and hydrographic information was used to evaluate biological reasonable worst case conditions. The record from 1988 to 1998 was used because this interval represented a time when river conditions were relatively constant (no new industrial heat sources, both Units on line).

One approach to screen for the biological worst case would be to run the hydrodynamic models for the ten-year record, and then to derive ΔT maps from these continuous runs. The CORMIX/RMA-10 linkage then could produce time–ΔT results for each tidal cycle. The worst-case conditions (highest temperatures, longest exposure times) would be selected as the "worst case." This procedure is clearly unrealistic, though, due to computational constraints and that no hydrodynamic model can be run for 10 years without periodic updates with data (data assimilation).

A more realistic alternative method for the selection of biological worst case conditions used information gained from the plume characterization simulations during previous and current permit renewal submittals. This procedure is outlined below.

Five time periods selected from the 10-year record reveal the external factors that dominate the plume morphology (plume intensity, width, and length). The five time periods were based on a screening analysis to rank each day of the 10 years by thermal plume lengths. The ranking considered the major factors that control plume morphology, including surface heat transfer, tidal range, freshwater flow, and meteorology. After the ranking was completed, conditions expected to represent the 50, 75, 80, 90, and 99 percentile plume morphologies were identified.

Hydrodynamic models were run for these five periods, and the character of the numerical plume was compared for each run. Time–ΔT diagrams were calculated for each model run using both CORMIX and RMA-10. The time–ΔT curves were compared, and their dependence on the driving factors (tidal range, surface heat exchange, river flow) was determined. Analysis of these five pre-screened plume projections showed that, of all the external factors, tidal range has the strongest correlation with time–ΔT behavior. For example, a neap tide (the smallest tidal range) minimizes tidal mixing, retains heat closest to the discharge, and therefore contributes to the highest sustained temperatures for the Biothermal Assessment.

With tidal range identified as the dominant external influence on plume characteristics, a time interval within the 10-year screening period was selected to characterize the variability in behavior of the time-ΔT curves. The late May-early June 1998 time interval was selected to define the biological reasonable worst case ΔT based on the preliminary screening described above. This time interval has the best available data for model calibration (from the Modified Thermal Monitoring Program of 1998). Also, the model simulation spanned the spring/neap tidal cycle in order to characterize a wide range of tidal conditions. The spring tides of May 26 exceed the tidal range experienced for 97.1 percent of the entire year, and the neap tides of 2 June are smaller than 91.8 percent of the tides during the entire year . This worst-case ΔT then can be added to the seasonally "worst case" actual temperatures of mid-summer to characterize worst-case thermal exposures.

For each of the four phases of each of 13 tidal cycles during this interval, individual time–ΔT curves were produced (Figure V-28). The combined CORMIX and RMA-10 runs were performed assuming the worst-case Station operating conditions of low volume discharge and high ΔT (Appendix B-1). These are worst-case conditions in the sense that low volume discharge produces a higher initial temperature, and the warmest discharge. Sustained elevated temperatures contribute to enhanced thermal exposures.

In addition to these Station conditions, the model runs all relied on actual measured boundary and forcing conditions. Use of these measured conditions increases the accuracy of the model simulations.

Among these 52 time–ΔT curves (13 tidal cycles for each of four phases of the tide), the biological worst case phases were determined by calculating the area underneath each curve (Figure V-28). Figure V-28 shows the time–ΔT curves from these extensive simulations. The maximum sustained elevated temperature criterion corresponds to the curve having the largest area under it. For each tidal phase, the curve identified as that having maximum sustained and elevated temperature is shown in bold. In the thermal exposure characterization presented in Section V.F.5., both this maximum and the corresponding minimum curves are shown to represent the envelope of variability associated with these characterizations.

V.F.5. Methods for Characterization of Temperature Exposures for Organisms

Figure V-26 describes schematically how the hydrothermal models were combined to produce representations of thermal exposure required for the Biothermal Assessment.

Section V.F.1 provides a description of the approach used to derive thermal exposure characterizations for the Biothermal Assessment. Figure V-27 describes how the numerical models were combined in various ways to present different analyses of thermal exposure. The melding of the models used to generate these many and varied perspectives of thermal exposure is described in Section V.F.2. The model results are compared to previous submittals in Section V.F.3. The combination of models used in this submittal has produced plume characteristics that not only compare with the extensive data from the Modified TMP, but also with past descriptions of the Salem thermal plume dating back 30 years. The concepts behind and the processes for selection of a biological reasonable worst case were described in V.F.4. The reasonable worst case is simply described as that combination of plant operating, meteorological, and estuarine hydrodynamic conditions expected to occur and resulting in prolonged or sustained exposure of organisms to elevated temperatures in the near-field portion of the plume.

The present section describes the various characterizations of the thermal exposure of organisms, derived for purposes of supporting the Biothermal Assessment. Four types of important temperature exposures have been identified (Figure V-26): (1) duration of exposure, (2) spatial extent of exposure, (3) seasonality of exposure, and (4) frequency of exposure. Each of these types of characterizations is presented by a series of graphics and summary tables.

The size of the thermal plume can be placed in context of the overall estuary. Figure V-29 shows the geographic region surrounding the Station (approximately 15 miles up- and down-stream). The inset depicts the region directly offshore from the Station. Also shown are mooring locations that have been used to describe the behavior of the plume in the near-field where elevated temperatures are expected. First, the depiction of the ebb tide 4°F ΔT isopleth shows the area covered by this isopleth is small compared to both the Estuary and its cross-section. The areas and volumes are discussed later in this Section. Figure V-30 shows time-series of temperature acquired at the moorings located in Figure V-29, for 29 May 1998. The different panels refer to three moorings, one located upriver, one downriver, and one cross-river, approximately, from the discharge. The diagram shows that the plume flows primarily in one direction or another for most of the tidal cycle: either to the north-northwest or south-southeast. During periods of slack water, which lasts less than one-half hour every six hours, the plume swings to the west and changes direction with the tide. Mooring 21 is located in the slack water discharge area; mooring 23 is on the flood flow side of the discharge, and mooring 24 is in the ebb flow side of the discharge.

This description of temperature exposure led to the depiction of the near-field flow according to tidal phase. During flood flow, the near-field (Zone of Initial Mixing or ZIM) is extended towards the north. During ebb flow, the ZIM is oriented towards the south from the discharge. During slack waters, the ZIM transitions from one running tide direction to the next, exposing briefly the areas west of the discharge to higher temperatures and velocities. Thermal exposures are presented according to this tidal phase separation.

The duration of exposure can be represented as a time–ΔT curve (Figures V-23, 31, 32, and 33). Two curves are depicted on each graph. These two curves represent the variability in time–ΔT behavior based on the modeling described in Section V.F.4. The time–ΔT relationship varies with tidal phase by about 1-2°F.

The upper curve represents the worst-case condition, practically unattainable, of an organism entrained in the center of the thermal discharge at the point of discharge, and entrained in the centerline of the plume for a duration of 180 minutes. Since the end-of-pipe is an exclusion zone for most organisms due to high velocities, this situation is not expected to occur in nature. However, for purposes of characterization of reasonable worst case, this depiction is presented for biological screening.

Figure V-31, for instance, shows the discharge of about 23°F, and its rapid decline to about 12.5°F within seven seconds of discharge. This rapid temperature decline mirrors the rapid mixing associated with the discharge as it surfaces within 100 feet of the discharge. This portion of the curve, from zero to about 10 minutes, is described using the linkage model, primarily relying on output from CORMIX.

The discharge ΔT of 23°F is relative to the ambient temperature, which is assumed in a conservative sense to be the acclimation temperature for the organisms. In other words, for the sake of conservatism, the organisms are assumed not to be acclimated to the elevated temperatures in the general vicinity of the Station.

The discharge temperature is comprised of two parts: first is the temperature build-up in the vicinity of the Station, which represents the broader plume generated from continuous operations of the Station. The second part is the heat added to the discharge by the cooling process, as the CWS removes water from the condensers. The temperature build-up varies with tide (ranging from about 2.5 to 4°F). The heat contribution from the CWS due to condenser cooling is assumed constant and high in these models: 18.6°F.

The ΔT curves drop further until the end of the ZIM, at a time of about 10 minutes. During running tides, this represents a distance of 150 to 300 feet, depending on discharge flow rate. At this point, the excess momentum from the discharge is lost relative to the ambient current, and the ambient tidal flow, as described by RMA-10, simulates the journey through the plume centerline. The RMA-10 simulation begins approximately 700 feet beyond the end-of-ZIM. In the intermediate zone, the transition region, a linear transition is made between the two model outputs (Section V.E).

From the end-of-ZIM to the 180 minute duration of these plots, the temperature of the thermal discharge continues to decay, to a value of 4°F or less.

Another characterization of the duration of thermal exposure is required for the littoral zone. The Station's thermal plume contacts portions of the shoreline along the New Jersey side. However, since the discharge was designed such as to minimize shoreline contact, this contact does not present continuous, elevated temperatures.

Two depictions of shoreline temperature elevation are provided. Figure V-34 shows the ΔT representative of the entire shoreline of Artificial Island, which is the only portion of the shoreline where the plume contacts with temperatures exceeding a few °F. This figure shows a time-series of temperatures, including a mean value ranging from near zero up to a tidal peak of about 2°F. The maximum shore contact temperatures are about 4°F, but vary strongly with tide.

The second depiction (Figure V-35) is for that portion of the shoreline where shoreline protection (bulkheads, revetments) is absent. These results are similar to the previous figure, although the temperatures are a little smaller. The core of the thermal plume is located away from the shoreline, limiting temperatures at the shore.

Another type of characterization of the thermal plume is spatial variability. A series of graphs and tables represents the extent of the thermal exposure within the ZIM. These representations take the form of surface contours of ΔT in the ZIM (Figures V-36 to V-39), and plume centerline cross-sections of ΔT (Figures V-40 to 43). Each of these characterizations is presented for four phases of the tide.

The representations of ZIM temperatures can be described using Figure V-36. The main graph shows the surface map of temperatures, in this case during the ebb tidal phase. The discharge location is shown in the upper right hand corner, and the plume shape is depicted along the plume trajectory. The origin of the plume depiction is the point where the thermal discharge surfaces (the point where the ZIM intersects the water surface). The centerline water temperatures are annotated, as is the width of the plume. The inset depicts a slice through the thermal plume centerline, showing the temperature decay with distance from the surfacing location to the end-of-ZIM. The ambient current at this time is 1.85 feet per second, and the ZIM orients itself with the ambient current. These representations of time–ΔT behavior form the basis for later cross-sectional area depictions.

The centerline cross-sections (Figures V-40 through V-43), depict the temperatures throughout the water column along a line following the thermal discharge centerline. The rapid decay of temperature following discharge is shown in the inset to each figure, where the most rapid decay occurs from point of discharge to the surfacing location. Beyond the surfacing location to the end-of-ZIM, the temperature decays less rapidly. At the end-of-ZIM, the ΔT is about 12.8°F for the ebb tide example. The graphs for slack waters (Figures V-41 and V-43) show the ZIM extends to 1,000 feet on these tides. This is a conservative prediction, because the slack water is so short, changes at different times along the path of the ZIM centerline, and therefore no steady-state condition would be reached. However, for purposes of characterization, the slack waters are represented by the elongated ZIM. For running tides, the ZIM extends to about 150 to 300 feet, depending on Station discharge rates.

The differences in ZIM shape and elongation are illustrated in the inset to Figure V-29. The inset shows the ZIM to scale with the Estuary and the Station. At this scale, the running tide ZIMs are indistinguishable. The slack water ZIMs are larger, but of much shorter duration.

The areas of the end-of-ZIM and the volumes of the ZIM are listed in Table V-1b. The slack water ZIMs are the largest (ranging up to nearly 75 acre-ft), whereas the ZIM is small during running tides (about 8 acre-ft) which occupy most of the tidal cycle.

Another characterization within the ZIM required to complete the Biothermal Assessment is the velocity field. The velocity affects exclusion of organisms and the area of bottom scour. Figures V-44 through V-52 represent two different aspects of the velocity field. Figures V-44 through V-47 show the bottom contours of velocity, from the point-of-discharge to the end-of-ZIM, for each of four phases of the tide. A summary of the bottom scour area is presented in Figure V-48. Figures V-49 through V-52 depict the velocity along a cross-section below the centerline of the plume, in a fashion analogous to the ΔT contours described earlier.

The bottom contact velocity is represented for ebb tide in Figure V-44. These velocities were derived from CORMIX and the linkage model. The bottom velocities are shown from the discharge (upper right hand side of each bottom contact area) to the end-of-ZIM. Velocities are highest at the point-of-discharge, and decline rapidly. Centerline velocities are depicted and values given at intervals along the thermal discharge centerline. The inset shows how the speed of the discharge declines rapidly from point-of-discharge out to the surfacing location (about 55 feet in this example), declining more gradually from that point to the end-of-ZIM. The inset shows a discontinuity in the bottom contact velocity, where the CORMIX solution modules change to reflect the different physical processes controlling the thermal discharge.

This representation is conservative in several respects. The velocity interpolation from CORMIX assumes a constant velocity throughout the plume cross-section. As the thermal plume surfaces, this approximation is an overestimate of the bottom contact velocity (Figure V-49, for instance).

These bottom contact velocities are summarized in Figure V-48. The shaped region shows the area expected to be occupied by the ZIM on various tides. As depicted in Figure V-29, the ZIM is larger on slack waters than on running tides. The outer dark line (to 1000 feet from discharge) depicts the total extent of the ZIM. Velocities at the outer portion of the ZIM are 1.7 to 1.9 feet per second. This velocity is less than the mean ambient tidal velocities, and doesn't represent areas where increased scour may be expected due to thermal discharge processes alone. The inner line (labeled 500') encompasses the region where the bottom contact velocity is approximately 3 feet per second or greater. This area is the zone where the thermal discharge may contribute to enhanced scour. The total area of the ZIM region is about 11.2 acres. The enhanced scour area is about 3.7 acres.

The next sequence of graphs depicts the velocities along the ZIM centerline. Velocities range from 10 feet per second at the discharge, to less than 2 feet per second at the end-of-ZIM. The velocity decreases rapidly in the zone where the plume expands rapidly (to the surfacing location), and decreases less rapidly from there to the end-of-ZIM. The insets of the plume centerline speed show the rapid drop-off in velocity, followed by the more gradual decay.

Table V-1a summarizes the areas where ZIM velocities exceed specified values (2 and 3 feet per second). Velocities exceeding 2 feet per second (approximately equal to the mean ambient tidal velocity) cover volumes ranging from 3.8 to 67 acre-feet, depending on tidal phase. Velocities exceeding 3 feet per second (approximately equal to the maximum daily tidal velocity) cover volumes ranging from 1.3 to 17 acre-feet. Thus, the volume of enhanced bottom velocities is small compared to pertinent spatial scales of the Estuary.

Another way to show the thermal plume in the context of the Estuary is by contour maps of ΔT at the water surface. Whereas the previous depictions of the near-field (ZIM) relied heavily on CORMIX output, this next sequence of products relies most on RMA-10 output. Figures V-53 and V-54 show the surface ΔT isopleths for end-of-flood. The main diagram shows the extent of the 1.5°F ΔT isopleth, extending from the Station to the north. The inset shows the contours of ΔT values greater than 1.5°F. The plume, as discussed in Section V.F.3, remains adjacent to the New Jersey shore. Figure V-54 shows the analogous diagram for end-of-ebb.

Another characterization of thermal stress for benthos is the bottom contact ΔT. These are represented by isotherms of ΔT, in an analogous fashion as the surface ΔT contours. Figures V-55 and V-56 show these bottom ΔT contours.

Most representations of the thermal exposure are presented on a large scale to depict the details of the extent of thermal exposure. It is useful to put these areas and volumes into an Estuary-wide perspective. Figure V-57 does this. On this map of the Estuary, the surface area covered by temperatures at or above the 4°F ΔT isotherm is depicted for end-of-ebb tide. This area varies with tidal cycle, but these variations are small compared to the perspective provided by this figure: the area of potential thermal exposure at or above a ΔT of 4°F is nearly indistinguishable in an Estuary-wide context.

Section V.F.1 introduced other aspects of the Biothermal Assessment related to the spatial context of the plume, including blockage of migration and exclusion areas. These are represented by a series of diagrams showing Estuary-wide cross-sections of temperature. Two sets of figures are provided. Figures V-58 through V-61 provide cross-sections through the ZIM and across the Estuary adjacent to the Station. Figures V-62 through V-67 provide cross-sections up- and down-Estuary from the Station.

Cross-sections of water ΔT through the ZIM on the four tidal phases are depicted to an observer looking down-Estuary from the Station. The Estuary's approximate bottom contour shows the region near the Station to the left, the shipping channel near mid-graph, and the Delaware shoreline on the right. The locations of the cross-sections are shown in V-24. The sections extend across the Estuary from the Station, through the end-of-ZIM for the respective tidal phase. No contours are shown for ΔT of less than 1.5°F. The thermal plume is confined to the eastern shore, and does not encroach on the shipping channel.

Cross-sections of ΔT away from the Station are presented for the locations shown on Figure V-62. Sections are across the mouths of the Creeks bounding the Station. These sections show the Station's thermal plume and the shipping channel intersect on portions of the tide. However, ΔT values in the thermal plume at this location are less than 4°F.

Figures V-63 through V-67 show the cross-sections to the Creek mouths for different phases of the tide. Representative cross-sections are plotted. For all tidal phases not shown in these cross-sections, the ΔT values in the cross-sections never exceed 1.5°F. At none of the four tidal phases does the ΔT at a marsh creek mouth adjacent to the Station exceed 1.5°F.

Based on the characterizations of thermal exposure discussed above, the surface areas, cross-sectional areas, and volumes associated with different ΔT isopleths were computed. Table V-2 shows the cumulative surface area within each ΔT isopleth for ΔT values ranging from 1.5°F up to 13°F. Table V-3 summarizes the cumulative volumes associated with the thermal plume ΔT values. Table V-4 summarizes the cross-sectional areas within each ΔT isopleth, for the four tidal cycles and the cross-sections shown in Figure V-24.

The volumes and areas have been compared to previous filings (Section V.F.3). In general, the ΔT areas and volumes are smaller than in previous filings, due to improved characterization both of the distribution of temperatures and velocities in the ZIM, and the far-field thermal plume.

Finally, the seasonal and interannual thermal exposures were calculated. These calculations relied on the ATM and the CORMIX/RMA-10 linkage to form the TTM (Figure V-27; Section V.F.2). The depictions are based on the 50-year ATM temperature representation for the Station region, and the hydrothermal model outputs.

Figure V-68 shows the ambient temperature for three different conditions. The upper panel shows the ambient temperature curve (solid) for a typical seasonal cycle expected to occur once every two years. The middle panel shows the conditions expected to occur only during warm years, with a recurrence interval of about 1-in-10 years. That is, this seasonal curve is expected to represent the warmest year of every decade. The bottom panel represents the ambient seasonal temperature expected for a cool year that will occur once every 10 years. These statistics represent an improvement over previous submittals, and are possible due to the extended 50-year temperature series provided by the ATM modeling.

Superimposed on each of these panels is a curve that depicts the end-of-ZIM temperature added to the ambient temperature. The end-of-ZIM temperature is a conservative (higher ΔT) estimate of thermal exposure in the region near the Station, because there are no physical mechanisms that could possibly retain an organism within the ZIM for extended periods.

INCORRECT. No table 5?

Interannual variations in temperature can also be represented in terms of the persistence of temperatures. Ambient temperatures for the 50-year ATM model output were examined and catalogued in terms of persistence of extreme temperatures (Table V-5). This table shows a threshold temperature, defined as the maximum temperature during a thermal "event." A thermal event is a warming interval of one to forty days, and the threshold temperature represents the maximum water temperature for that event. The duration of the warming event is provided along the horizontal axis.

To illustrate the utility of the table, a query can be made about how many thermal events reached a temperature of 84.5°F. The far right hand column indicated that during the fifty-year period, two events reached that temperature. The durations (persistence) associated with the events at that temperature were two and five days. To obtain an estimate of the total thermal exposure during the 50-year time period for a particular temperature, a calculation is shown for 84.5°F. The right-hand column shows that 84.5°F water temperature events were modeled twice within 50 years. The persistence was two days for one event, and five days for the other. To obtain an estimate of how many days in 50 years the temperature exceeded this value, the durations of each event are added together. For the 84.5°F example, the exceedence occurred for seven days. This calculation indicates that water temperatures exceeding 84.5°F are rare, and don't persist longer than a few days. As the temperature increases, the persistence (duration) is shorter, and the number of "events" is smaller. This table is a useful to examine exceedence of temperature thresholds. It represents a significant improvement over previous submittals.

In summary, characterization of biothermal exposure relies on a number of different perspectives, including spatial, short-term duration, seasonal, and interannual scales. The biothermal exposure characterization provided in this submittal is extensive, complete, and accurate, relying on the extensive data acquired during the Modified TMP as described in V.D, and relying on the comprehensive modeling presented in Section V.E. These graphs and tables, characterizing the thermal exposure based on the numerical models, were used for the Biothermal Assessment (Section VI).

E Table V-1. a) Plume Volumes within ZIM Velocities Greater than ambient velocity, 2 fps, 3 fps

Ebb: 6/2/1998 at 08:30 hrs		End of Ebb: 6/2/1998 at 00:00 hrs		Flood: 6/4/1988 at 16:30 hrs		Flood: 6/2/1988 at 16:00 hrs	
Velocity (fps)	Cumulative Volume (acre-f)	Velocity (fps)	Cumulative Volume (acre-ft)	Velocity (fps)	Cumulative Volume (acre-ft)	Velocity (fps)	Cumulative Volume (acre-ft)
>3	1.3	>3	17.0	>3	1.3	>3	13.8
>2	4.0	>2	56.0	>2	3.8	>2	67.0
>1.85	8.1	>1.72	73.0	>1.80	8.5	>1.91	73.8

Note: 1. The extent of the estimate for running tides (ebb, flood) is the end of discharge momentum.
2. The end point for the slack tides (EOE, EOF) is 1,000 ft.

b) Summary of End-of ZIM Parameters

	Delta T (degree F)	Cross- sectional Area)sq. ft)	Percent of Estuary Cross-section	Volume (acre-ft)	Percent of Total Estuary Volume
Ebb	12.83	2820	1.1	8.14	0.0008
End of Ebb	11.32	5167	1.4	73.31	0.00068
Flood	12.02	3962	1.1	8.58	0.0008
End of Flood	9.64	4849	1.1	73.77	0.00069

E Table V-2. Cumulative Surface Area within each ΔT Isopleth

	Ebb: 6/2/1998 at 0830 hrs		End of Ebb: 6/2/1998 at 0000 hrs		Flood: 6/4/1998 at 1630 hrs		End of Flood: 5/31/1998 at 1600 hrs	
ΔT (°F)	Surface Area (acres)	Percent of Estuary Area	Surface Area (acres)	Percent of Estuary Area	Surface Area (acres)	Percent of Estuary Area	Surface Area (acres)	Percent of Estuary Area
>13	0.08	0.00002	0.00	0.00000	0.00	0.00000	0.00	0.00000
>12	0.46	0.00010	0.47	0.00010	0.21	0.00004	0.00	0.00000
>11	0.98	0.00020	2.15	0.00045	0.61	0.00013	0.00	0.00000
>10	1.66	0.00034	2.15	0.00045	1.15	0.00024	0.85	0.00018
>9	2.22	0.00046	2.15	0.00045	1.82	0.00038	1.93	0.00040
>8	3.19	0.00066	2.15	0.00045	2.64	0.00055	1.93	0.00040
>7	4.32	0.00090	5.10	0.00106	3.59	0.00075	1.93	0.00040
>6	5.61	0.00116	11.32	0.00235	4.68	0.00097	1.93	0.00040
>5	36.60	0.00760	21.43	0.00445	56.58	0.01174	2.14	0.00044
>4	150.08	0.03115	45.11	0.00936	245.94	0.05105	205.37	0.04263
>3	631.42	0.13106	739.88	0.15357	585.78	0.12158	920.75	0.19111
>2	1947.91	0.40430	2519.94	0.52303	2212.75	0.45927	2093.04	0.43442
>1.5	3156.56	0.65517	3725.19	0.77319	3703.61	0.76871	3596.95	0.74657

Notes:

1. Plant Conditions: Low flow (140,000 gpm/pump), high ΔT (18.6°F)
2. Total surface area of the estuary = 481,796 acres.
3. Reasonable worst-case tide phases selected based on analysis of time-temperature curves.
4. Running tides (e.g. ebb and flood) include area approximation of the intermediate field.

E Table V-3. Cumulative Volume Area within each ΔT Isopleth

	Ebb: 6/2/1998 at 0830 hrs		End of Ebb: 6/2/1998 at 0000 hrs		Flood: 6/4/1998 at 1630 hrs		End of Flood: 5/31/1998 at 1600 hrs	
ΔT (°F)	Volume (acres-ft)	Percent of Estuary Volume	Volume (acres-ft)	Percent of Estuary Volume	Volume (acres-ft)	Percent of Estuary Volume	Volume (acres-ft)	Percent of Estuary Volume
>20	0.02	0.0000002	0.02	0.0000002	0.00	0.0000000	0.00	0.0000000
>19	0.04	0.0000004	0.04	0.0000004	0.00	0.0000000	0.00	0.0000000
>18	0.11	0.0000011	0.09	0.0000008	0.04	0.0000004	0.02	0.0000002
>17	0.19	0.0000018	0.16	0.0000015	0.09	0.0000008	0.04	0.0000004
>16	0.32	0.0000030	0.26	0.0000025	0.16	0.0000015	0.09	0.0000009
>15	0.52	0.0000048	0.40	0.0000038	0.32	0.0000030	0.17	0.0000016
>14	0.83	0.0000077	0.68	0.0000063	0.53	0.0000049	0.28	0.0000026
>13	4.03	0.0000375	1.08	0.0000100	0.87	0.0000081	0.50	0.0000046
>12	15.89	0.0001480	17.04	0.0001588	8.58	0.0000800	0.76	0.0000071
>11	28.71	0.0002676	73.31	0.0006832	21.01	0.0001957	1.24	0.0000115
>10	43.03	0.0004010	73.31	0.0006832	34.85	0.0003248	33.26	0.0003100
>9	53.84	0.0005018	73.31	0.0006832	50.50	0.0004706	73.77	0.0006875
>8	71.94	0.0006704	73.31	0.0006823	68.48	0.0006382	73.77	0.0006875
>7	93.17	0.0008683	167.00	0.0015563	89.63	0.0008353	73.77	0.0006875
>6	118.86	0.0011077	350.19	0.0032635	115.30	0.0010745	73.77	0.0006875
>5	955.51	0.0089044	640.54	0.0059692	1967.64	0.0183366	152.99	0.0014258
>4	3654.06	0.0340525	1247.49	0.0116254	5402.81	0.0503493	4122.04	0.0384136
>3	13705.19	0.1277199	13659.48	0.1272939	12019.14	0.1120074	17216.55	0.1604427
>2	43849.62	0.4086387	45609.81	0.4250420	41390.39	0.3857209	37171.93	0.3464086
>1.5	76806.34	0.7157654	73624.92	0.6861175	68836.81	0.6414966	63733.82	0.5939414

Notes:

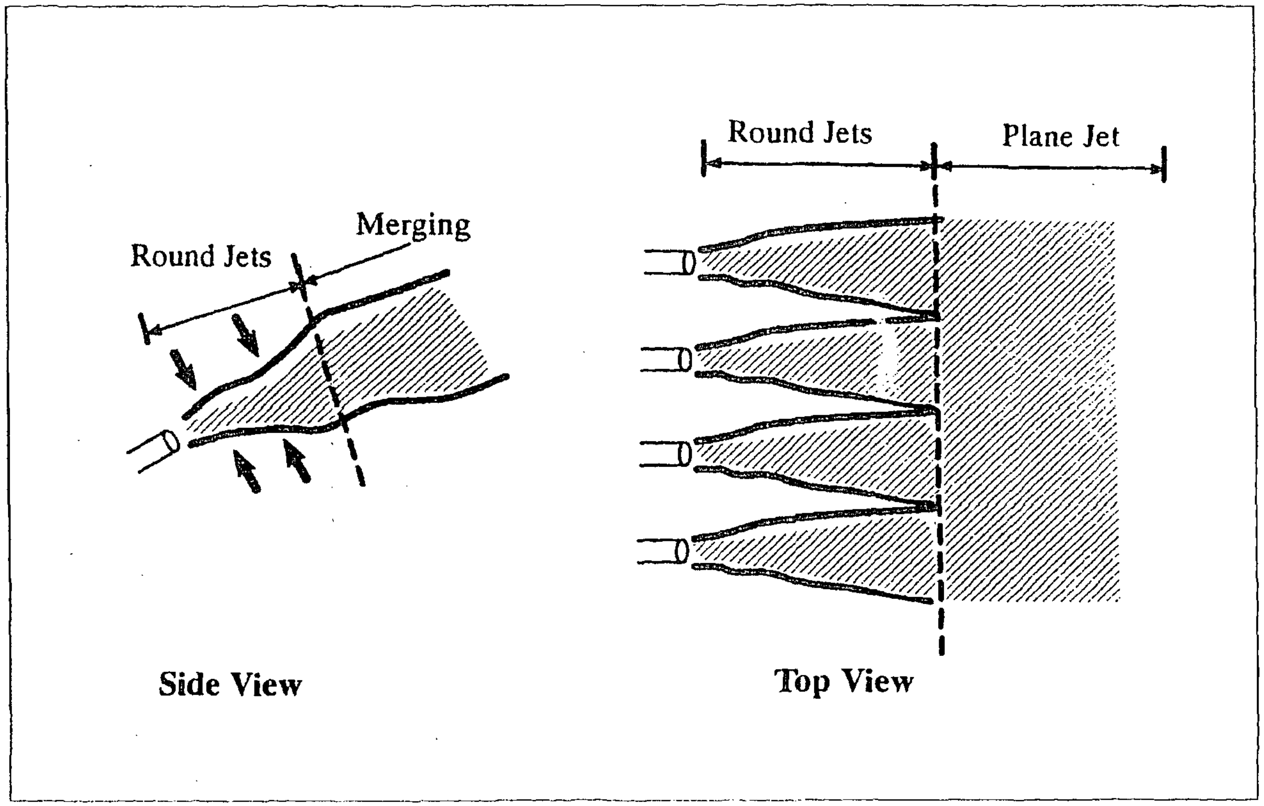
1. Plant Conditions: Low flow (140,000 gpm/pump), high ΔT (18.6°F)
2. Total estuary volume = 10,730,658 acres-ft
3. Reasonable worst-case tide phases selected based on analysis of time-temperature curves.
4. Running tides (e.g. ebb and flood) include volume approximation of the intermediate field.

E Table V-4. Cumulative Cross Sectional Area Within each ΔT Isopleth

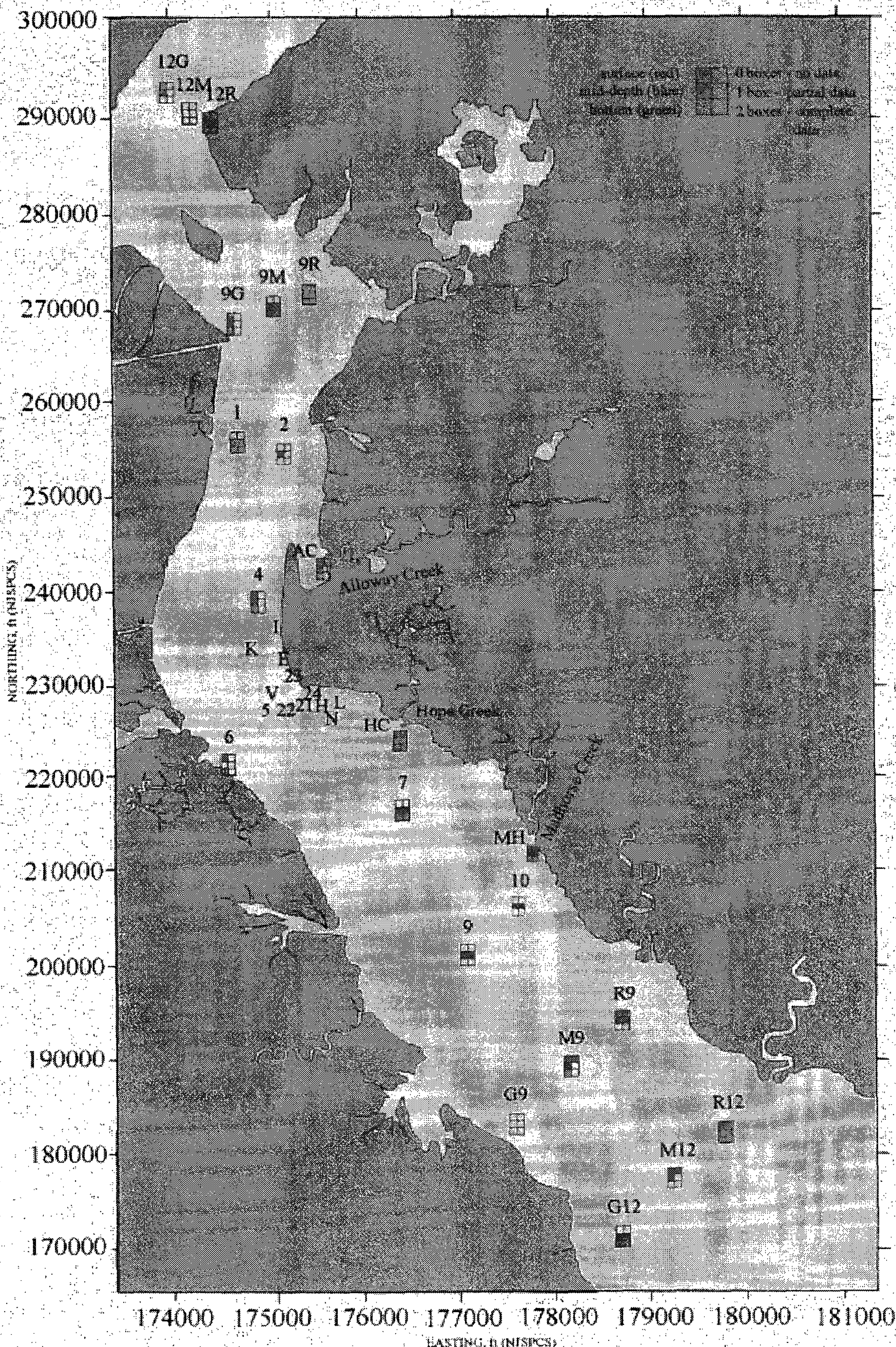
ΔT (°F)	Ebb: 6/2/1998 at 0830 hrs		End of Ebb: 6/2/1998 at 000 hrs		Flood: 6/4/1998 at 1630 hrs		End of Flood: 5/31/1998 at 16 hrs	
	Area ft^2	Percent of Cross Sect. Area	Area ft^2	Percent of Cross Sect. Area	Area ft^2	Percent of Cross Sect. Area	Area ft^2	Percent of Cross Sect. Area
>12	3,819	1.1	11,059	3.0	3,963	1.1	0	0.0
>11	3,819	1.1	32,046	8.7	3,963	1.1	0	0.0
>10	3,819	1.1	32,046	8.7	3,963	1.1	20,873	4.9
>9	3,819	1.1	32,046	8.7	3,963	1.1	35,911	8.5
>8	3,819	1.1	32,046	8.7	3,963	1.1	35,911	8.5
>7	3,819	1.1	46,439	12.6	3,963	1.1	35,911	8.5
>6	7,790	2.2	54,723	14.8	3,963	1.1	35,911	8.5
>5	16,599	4.6	65,039	17.6	15,398	4.1	35,911	8.5
>4	22,848	6.4	74,400	20.1	21,494	5.8	53,571	12.6
>3	33,264	9.3	83,133	22.5	33,188	8.9	75,956	17.9
>2	60,180	16.8	117,880	31.9	59,394	16.0	90,301	21.3
>1.5	84,701	23.6	156,737	42.4	121,094	32.6	107,170	25.2

Notes:
1. Station Conditions: Low flow (140,000 gpm/pump), high delta-T (18.6°F)
2. Reasonable worst-case tide phases based on analysis of time temperature curves

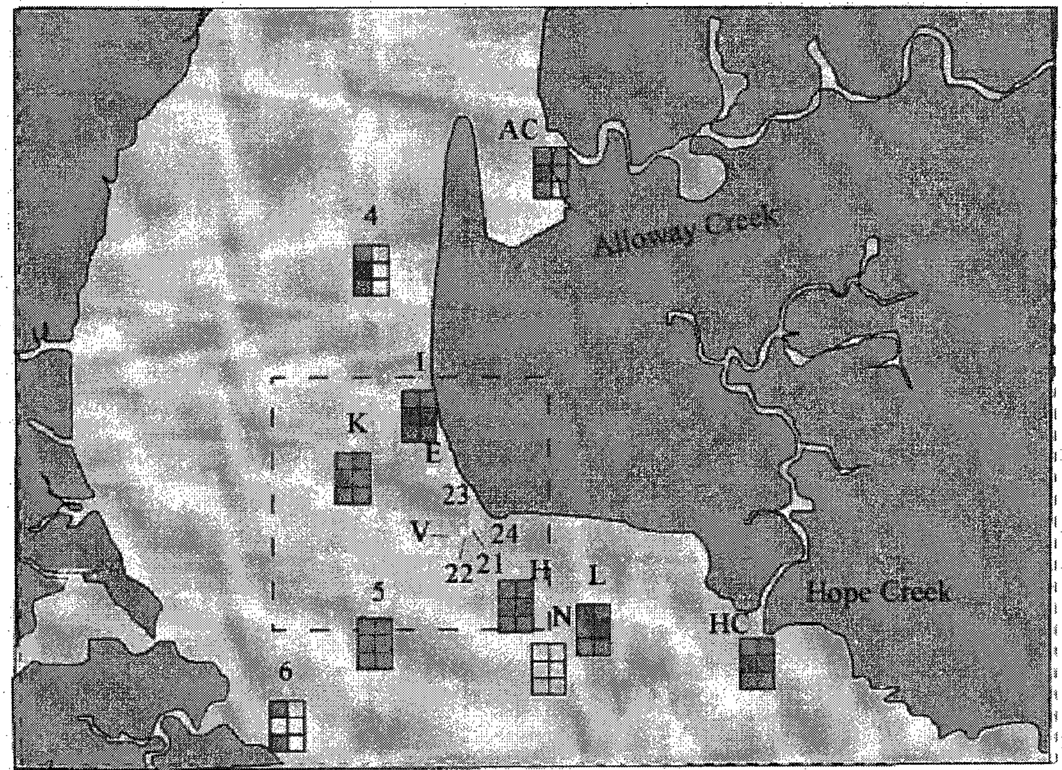
Table V-5
referenced
on pg. 176—
no table
V-5!



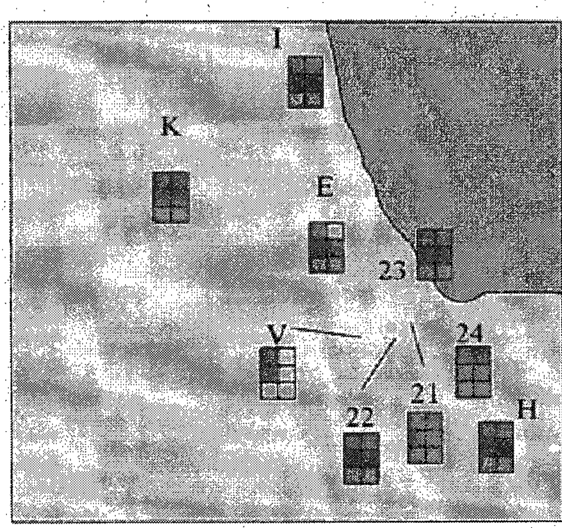
E Figure V-1. Schematic depicting the process of jet merging at a unidirectional multiport diffuser forming a plane bouyant plume.



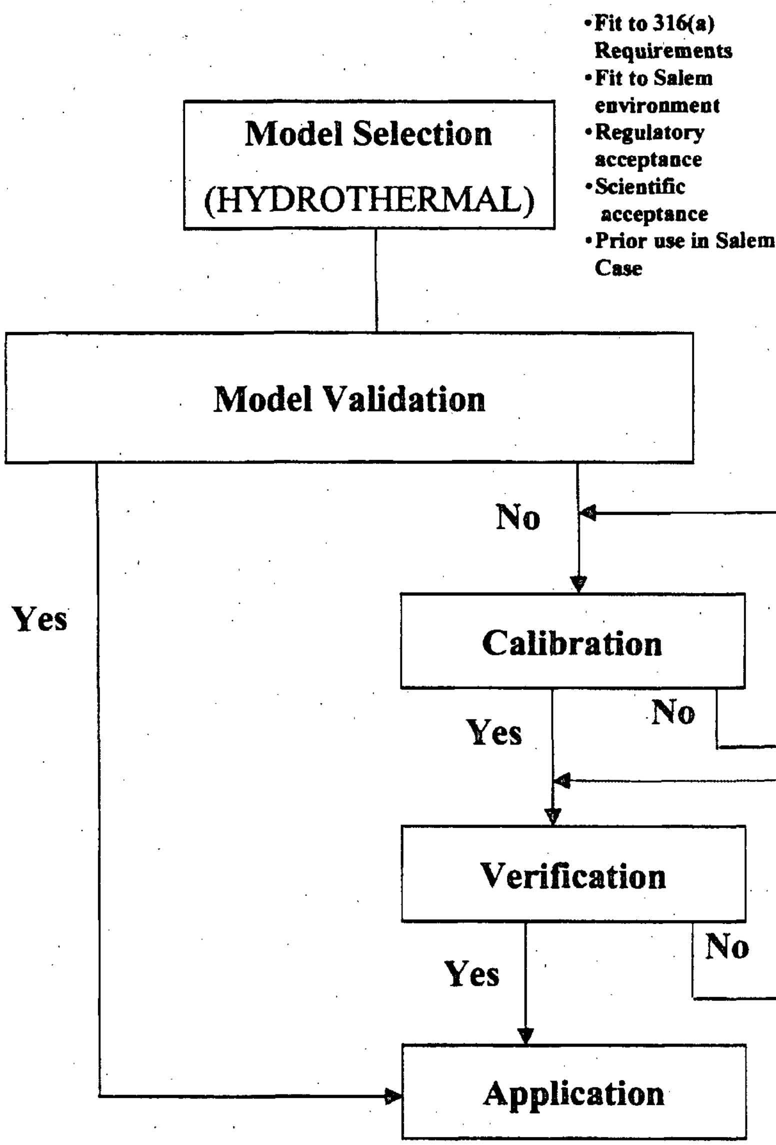
E Figure V-2. Map comparing instrument deployment locations with actual data recorded during the Two-Unit Survey.



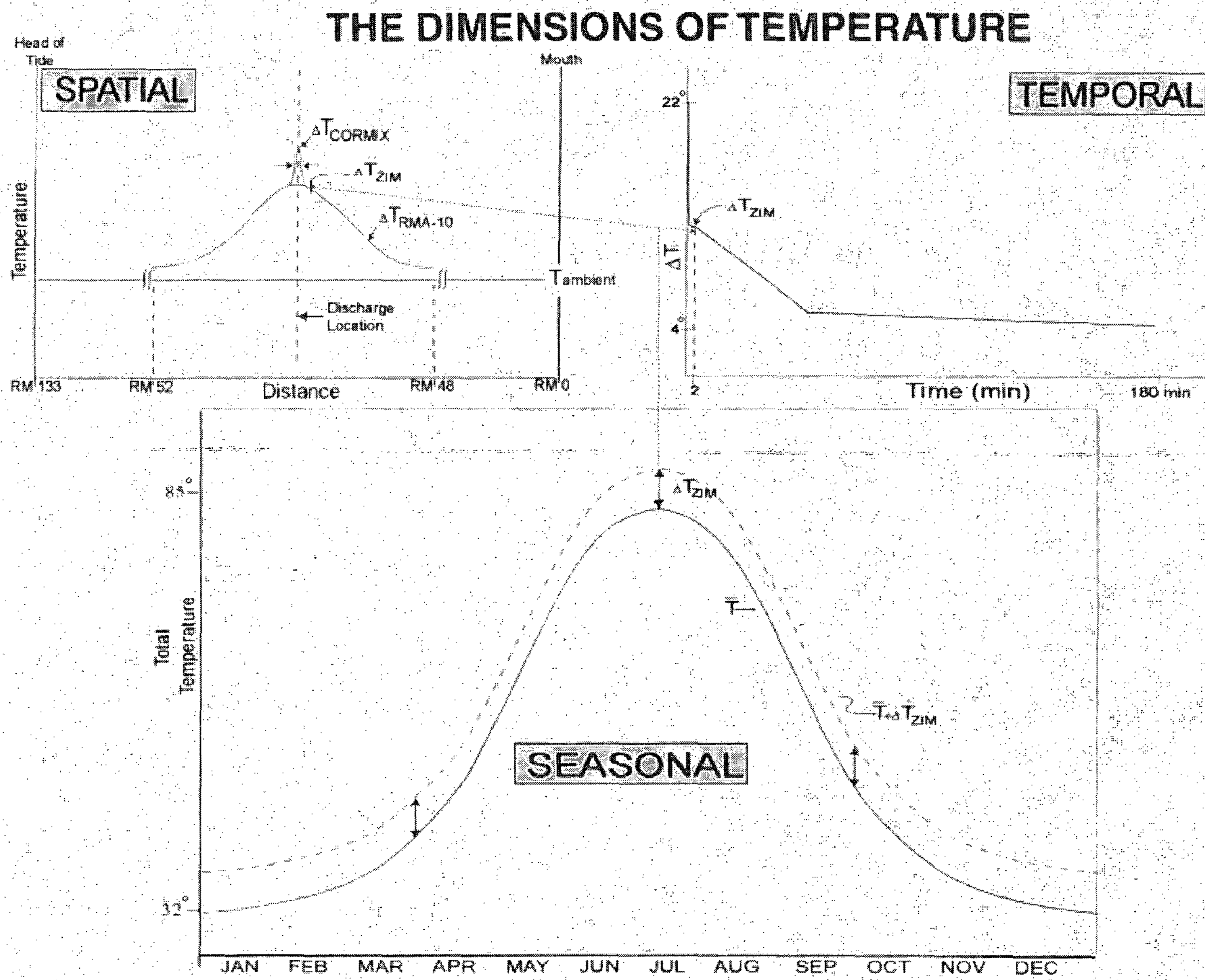
E Figure V-3a. Map comparing instrument deployment locations with actual data recorded during the Two-Unit Survey for the central region.



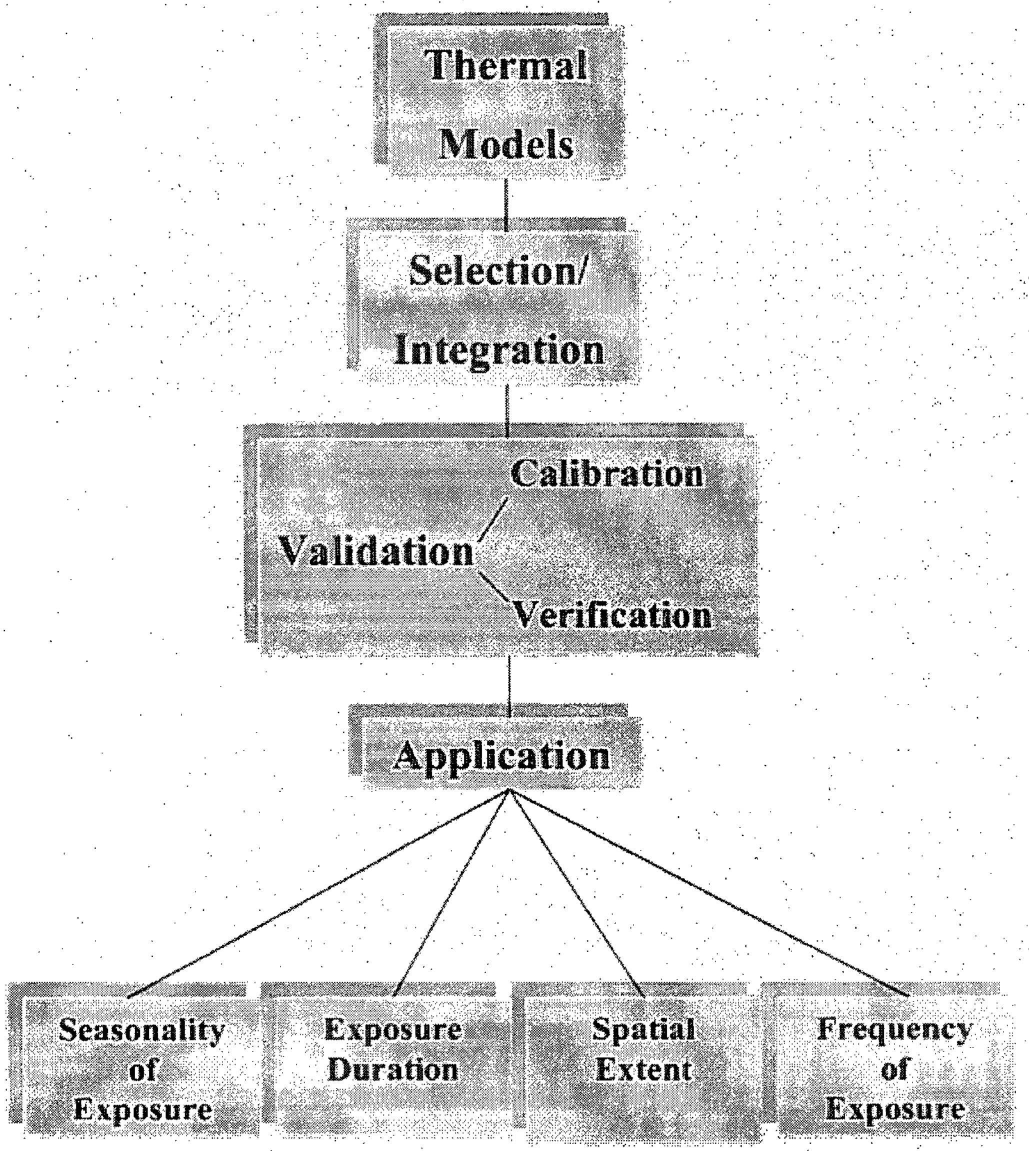
E Figure V-3b. Map comparing instrument deployment locations with actual data recorded during the Two-Unit Survey for the vicinity of the Station.



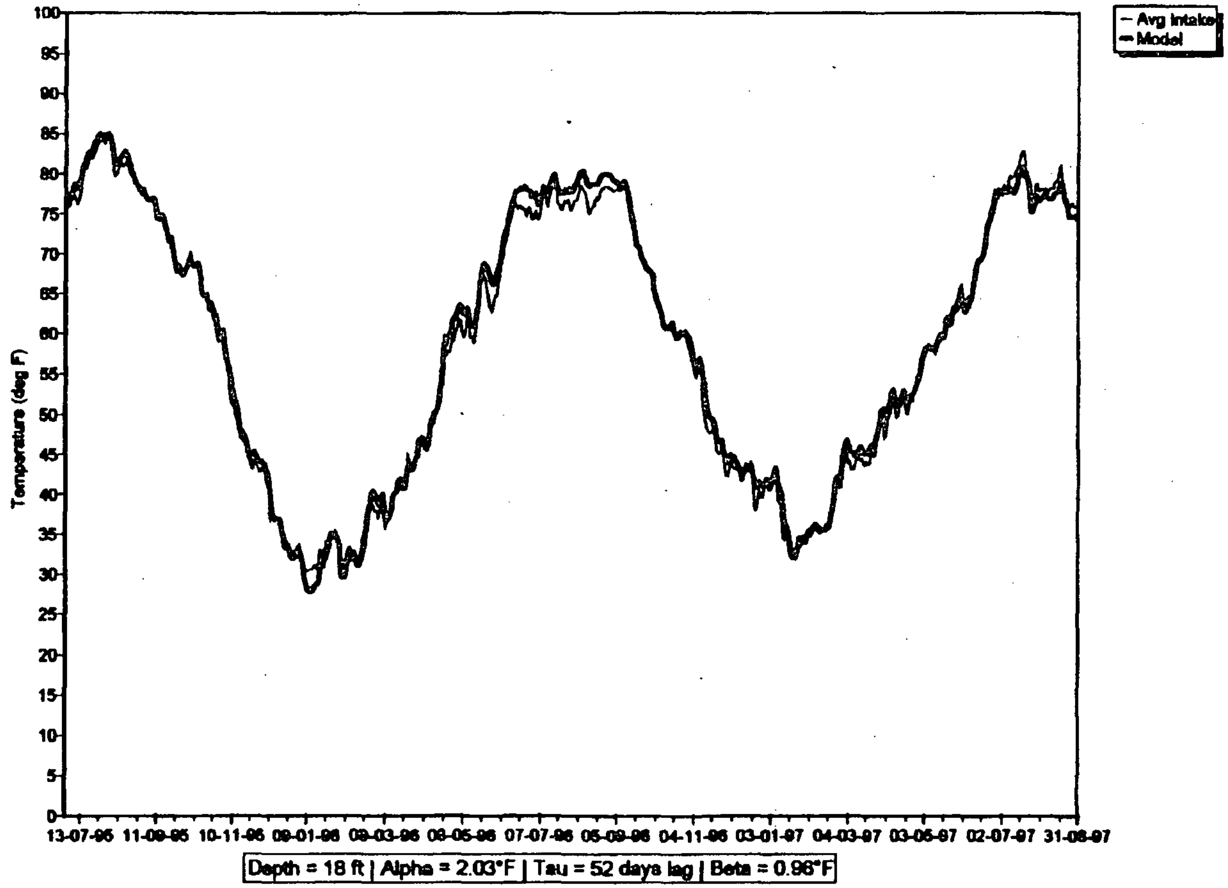
E Figure V-4. General numerical modeling procedure.



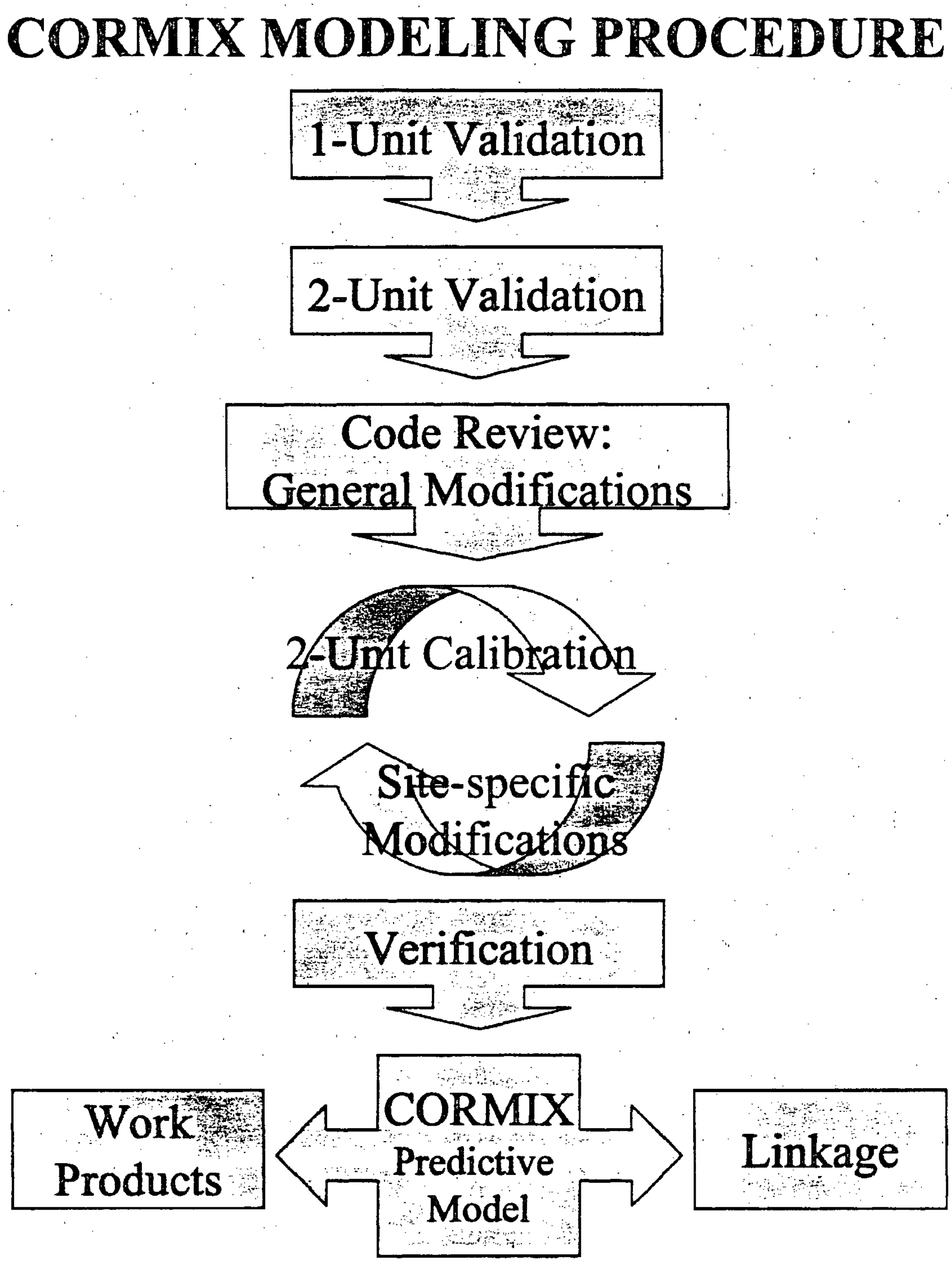
E Figure V-5. Components of the Total Temperature Model where $\bar{T}$ represents $T_{ambient}$.



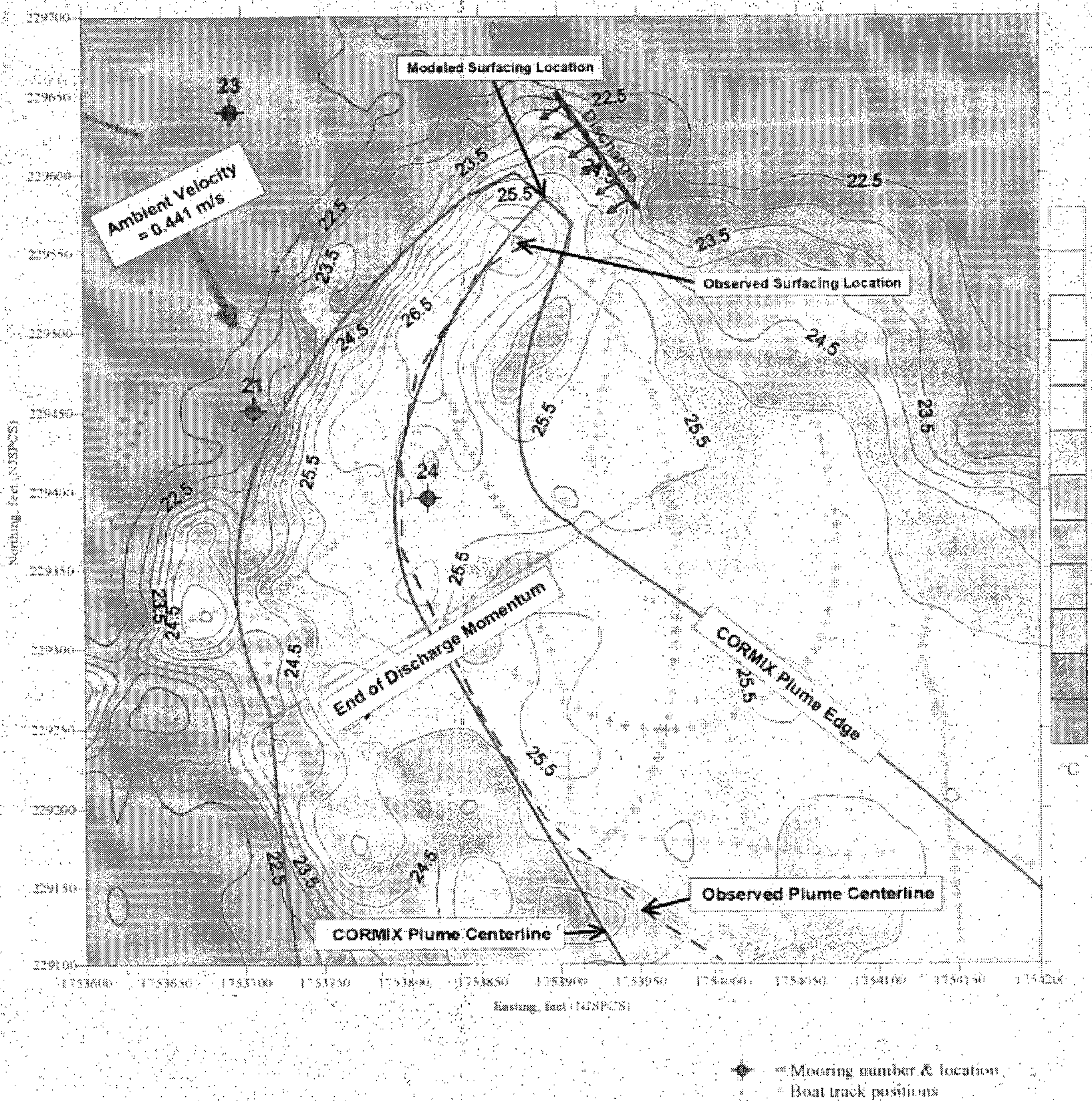
E Figure V-6. Schematic of thermal modeling procedure to evaluate thermal exposure.



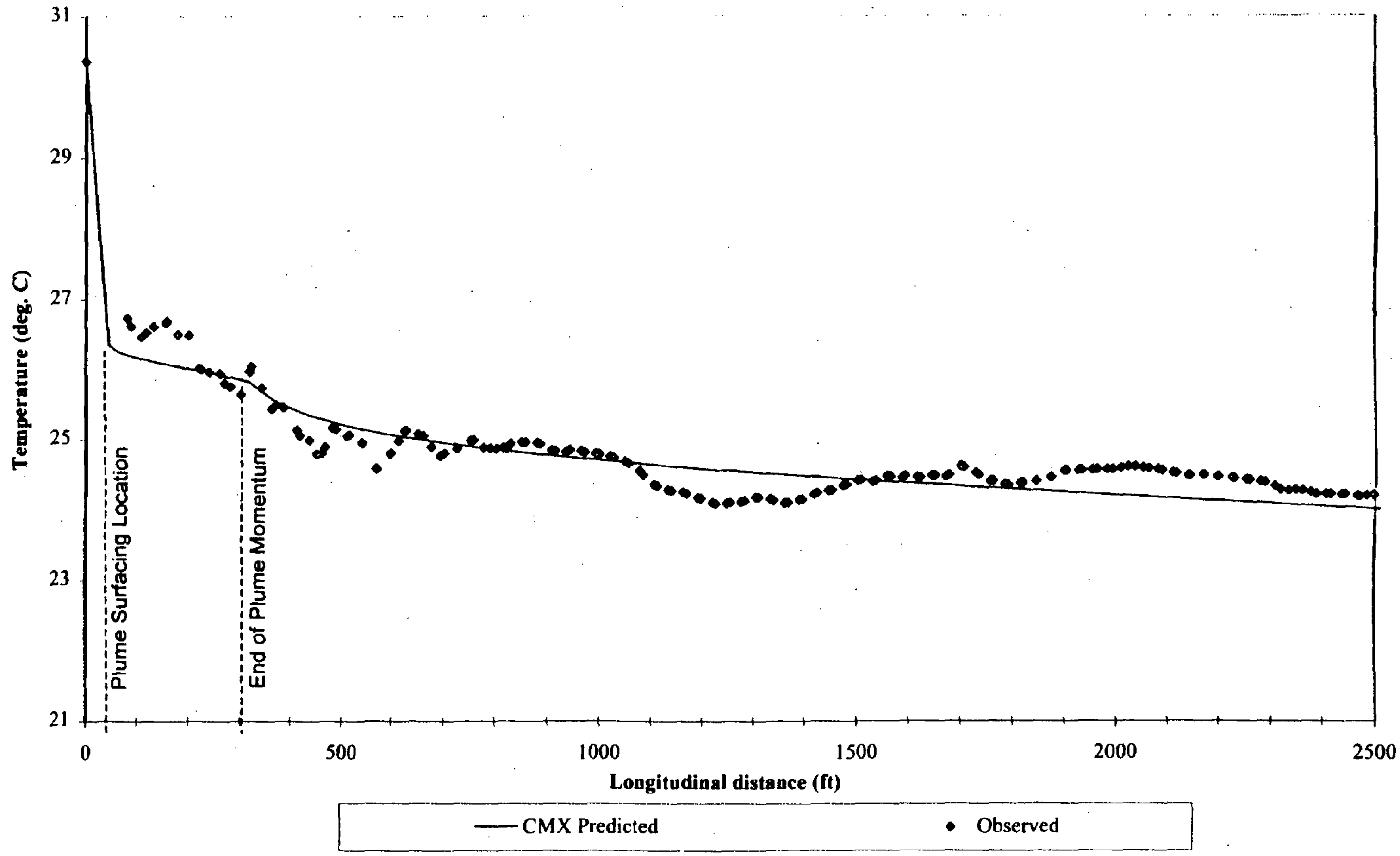
E Figure V-7. Ambient Temperature Model (ATM) calibration comparison.



E Figure V-8. Near-field modeling procedure.

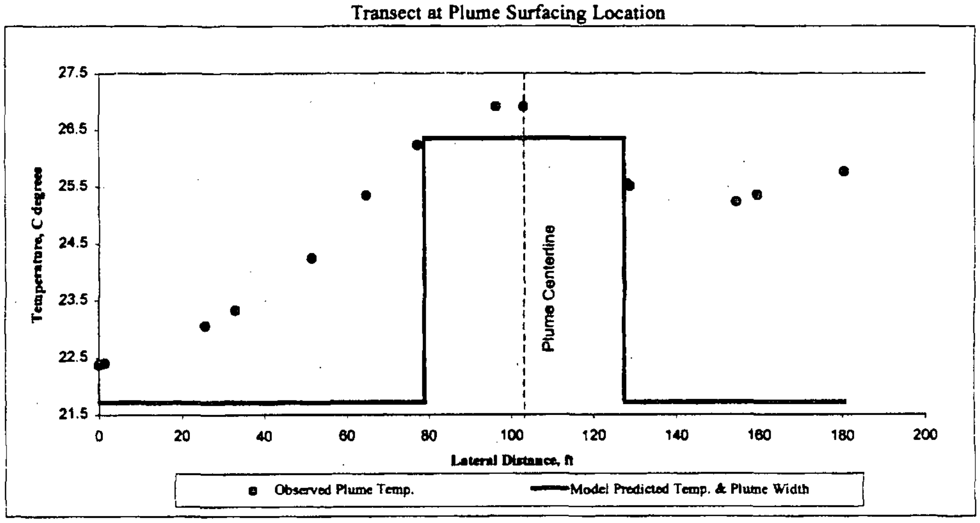


E Figure V-9. CORMIX Two-Unit Calibration; 29 May 1998
Temperature Contours & CORMIX Predicted Plume Dimensions at the Surface
Ebb Phase (06:40 - 08:40)



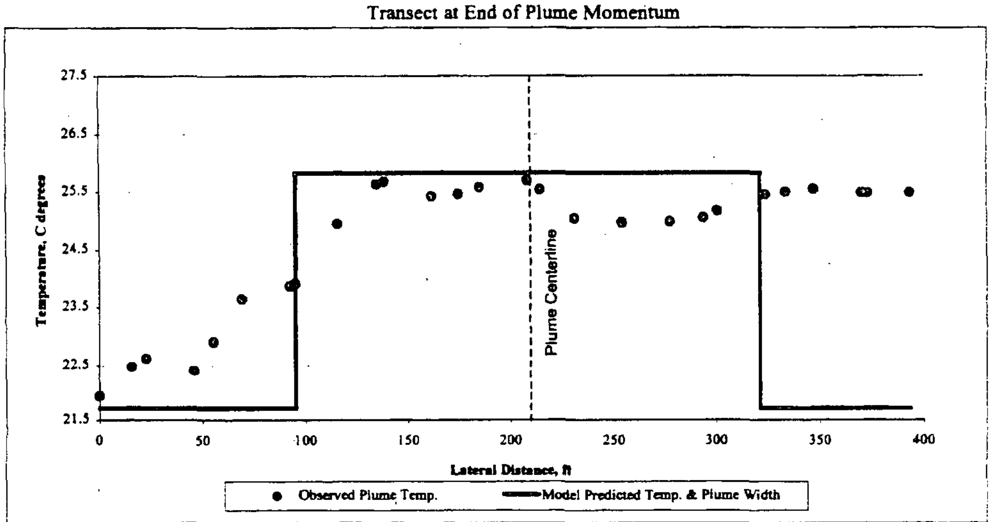
E Figure V-10. CORMIX Two -Unit Calibration; 29 May 1998,
Observed Surface Temperature vs. CORMIX Predicted Temperature
Ebb Phase [Approach Temperature = 21.72 deg. C]

Transect at Plume Surfacing Location

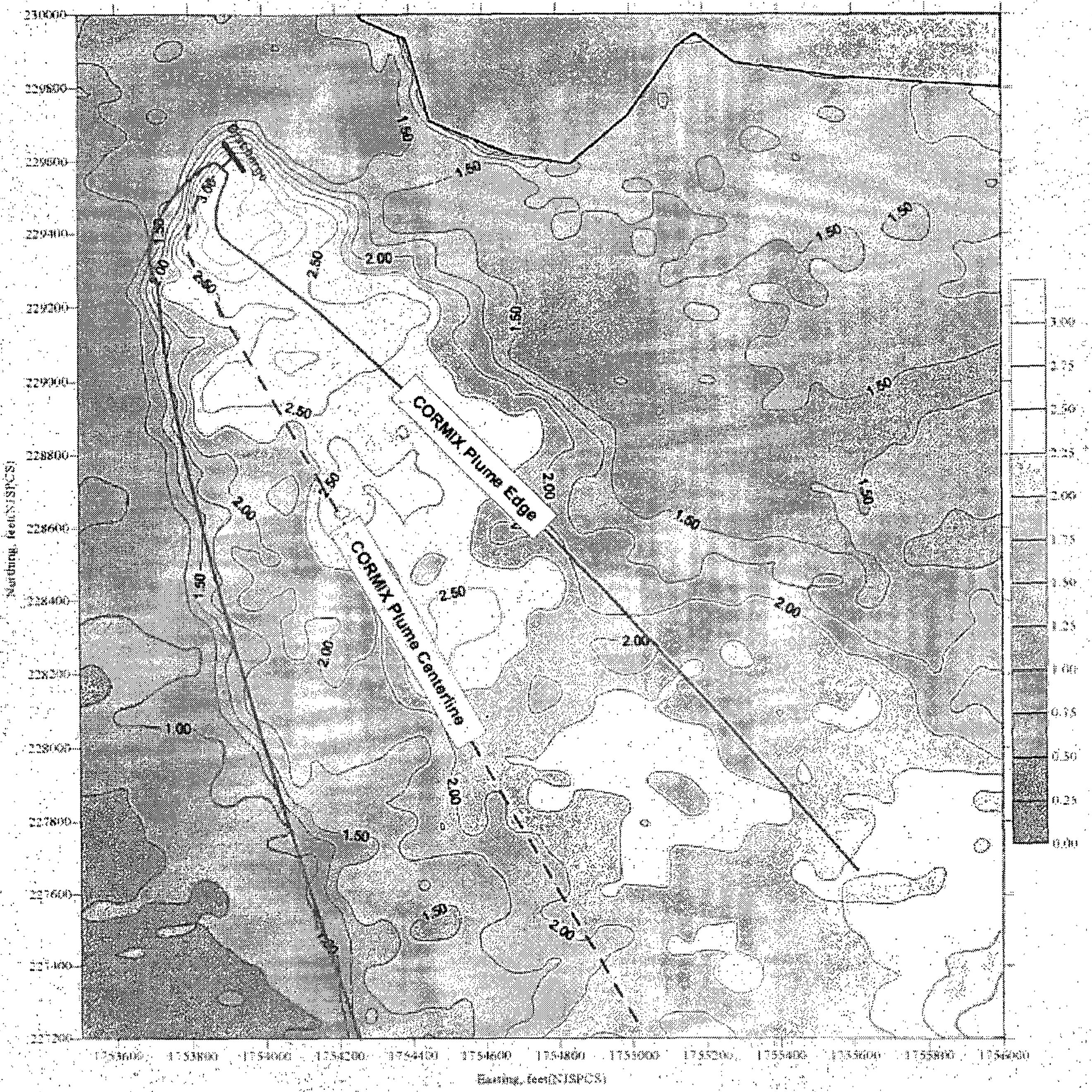


Note : Vantage point is facing the oncoming plume.

Transect at End of Plume Momentum

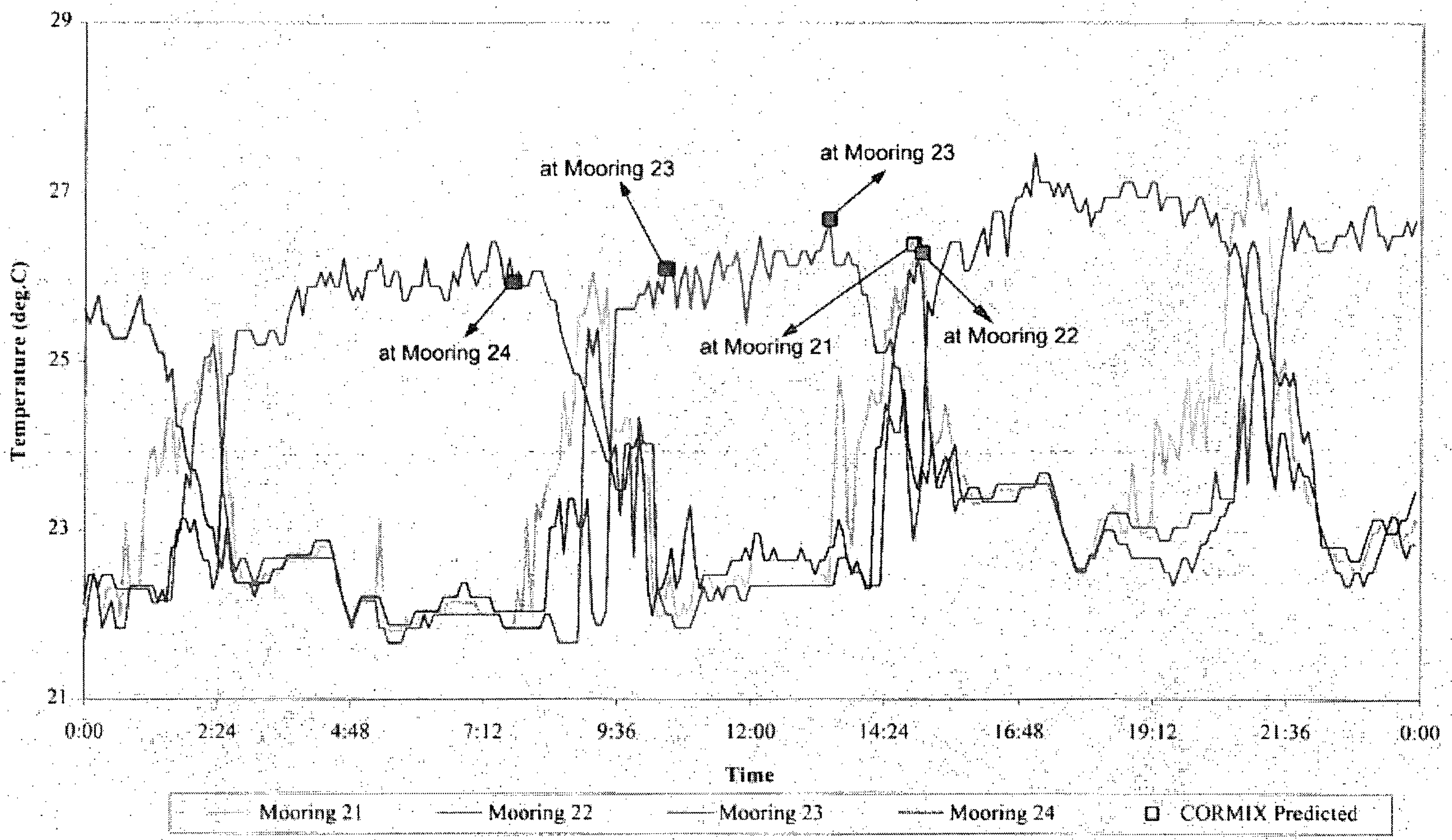


E Figure V-11. CORMIX Two-Unit Calibration; 29 May 1998
Comparison of Model Predicted vs. Observed Lateral Temperature Distributions
Ebb Phase

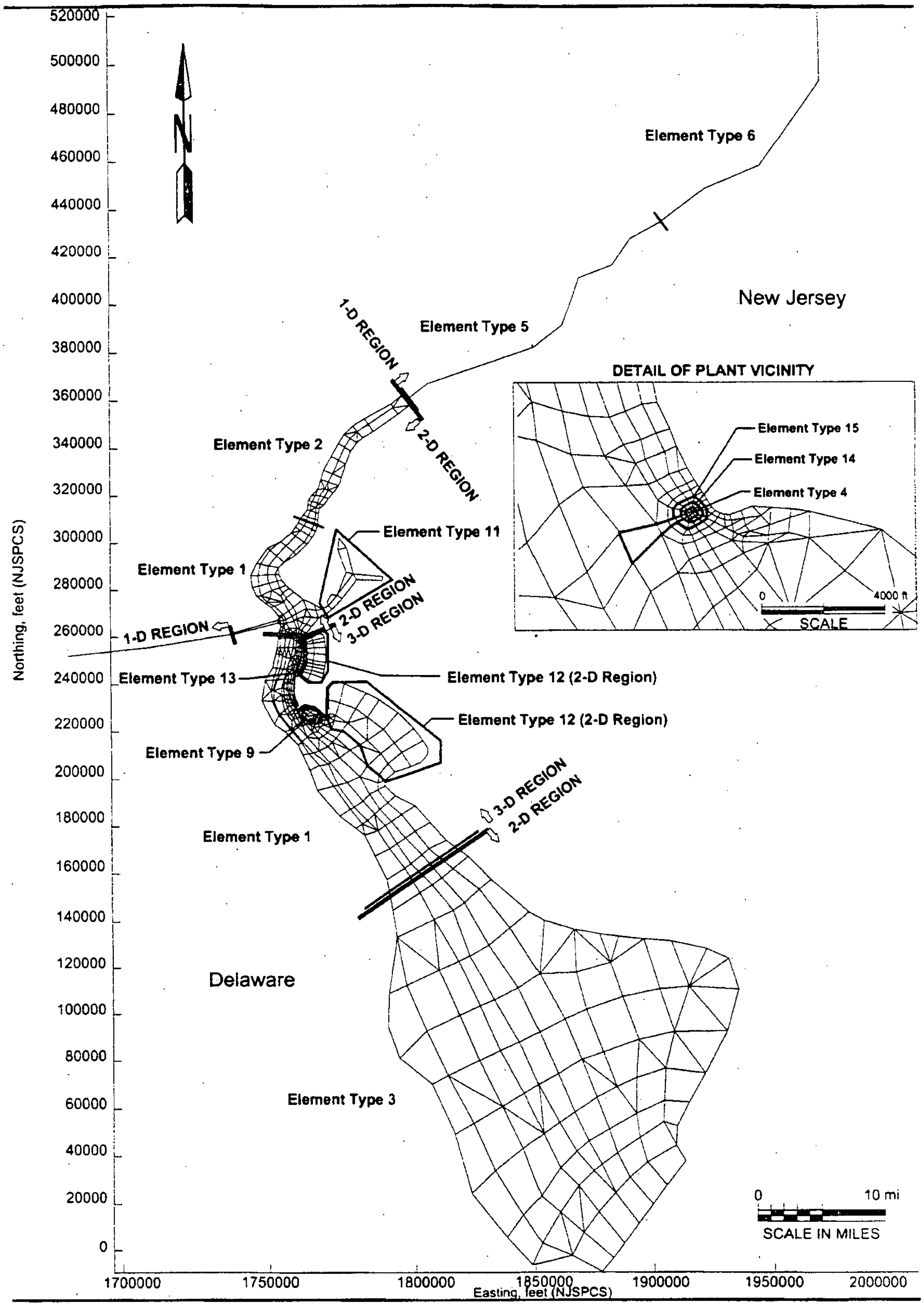


Note : Isotherms represent relative temperature gradients.
The values do not represent actual delta-Ts.

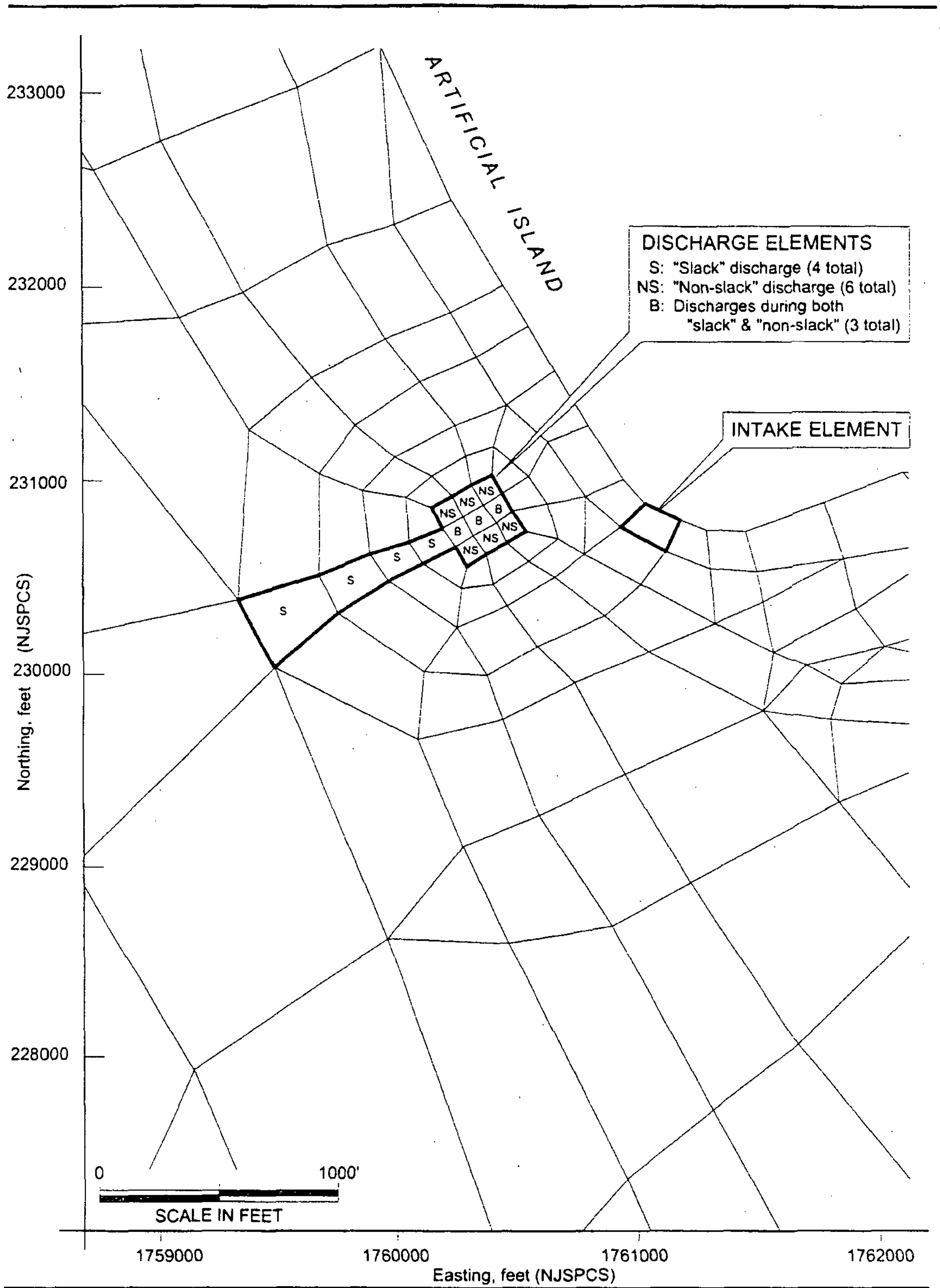
E Figure V-12. Infrared Imaging Contours, 29 May 1998
Ebb Phase (18:07 - 18:10)



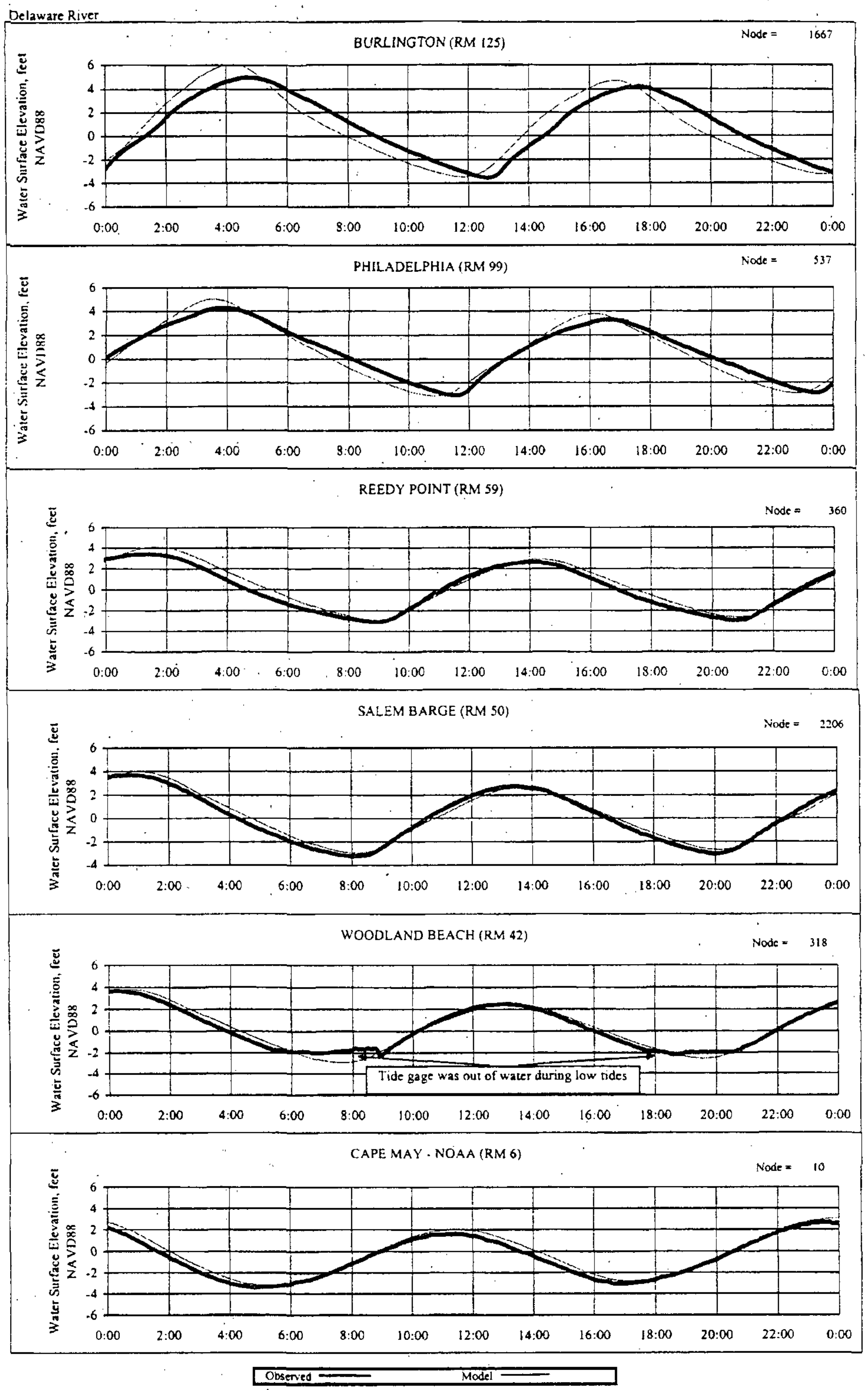
E Figure V-13. Observed Near-field Surface Mooring Temperature vs. Model Predicted Plume Surface Temperature, 29 May 1998 .



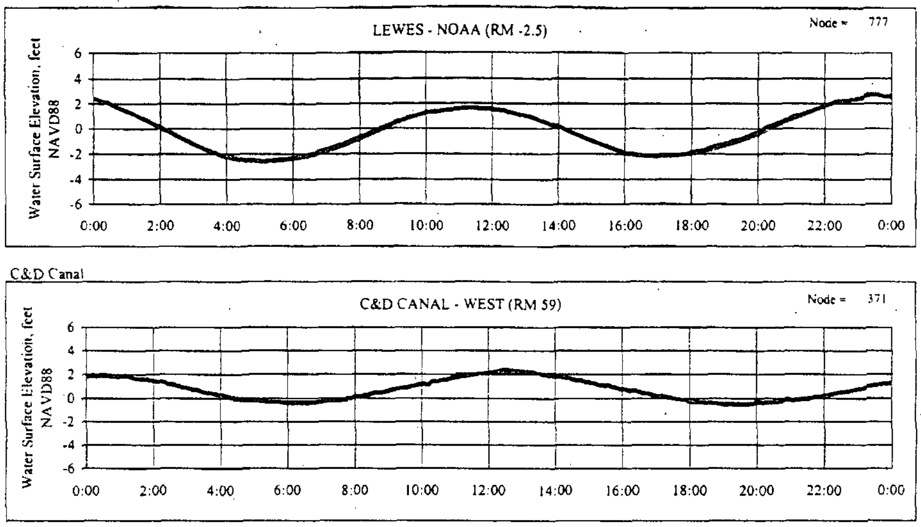
E Figure V-14. Model grid showing element types and dimensional classifications (i.e., 1-D, 2-D, and 3-D regions).



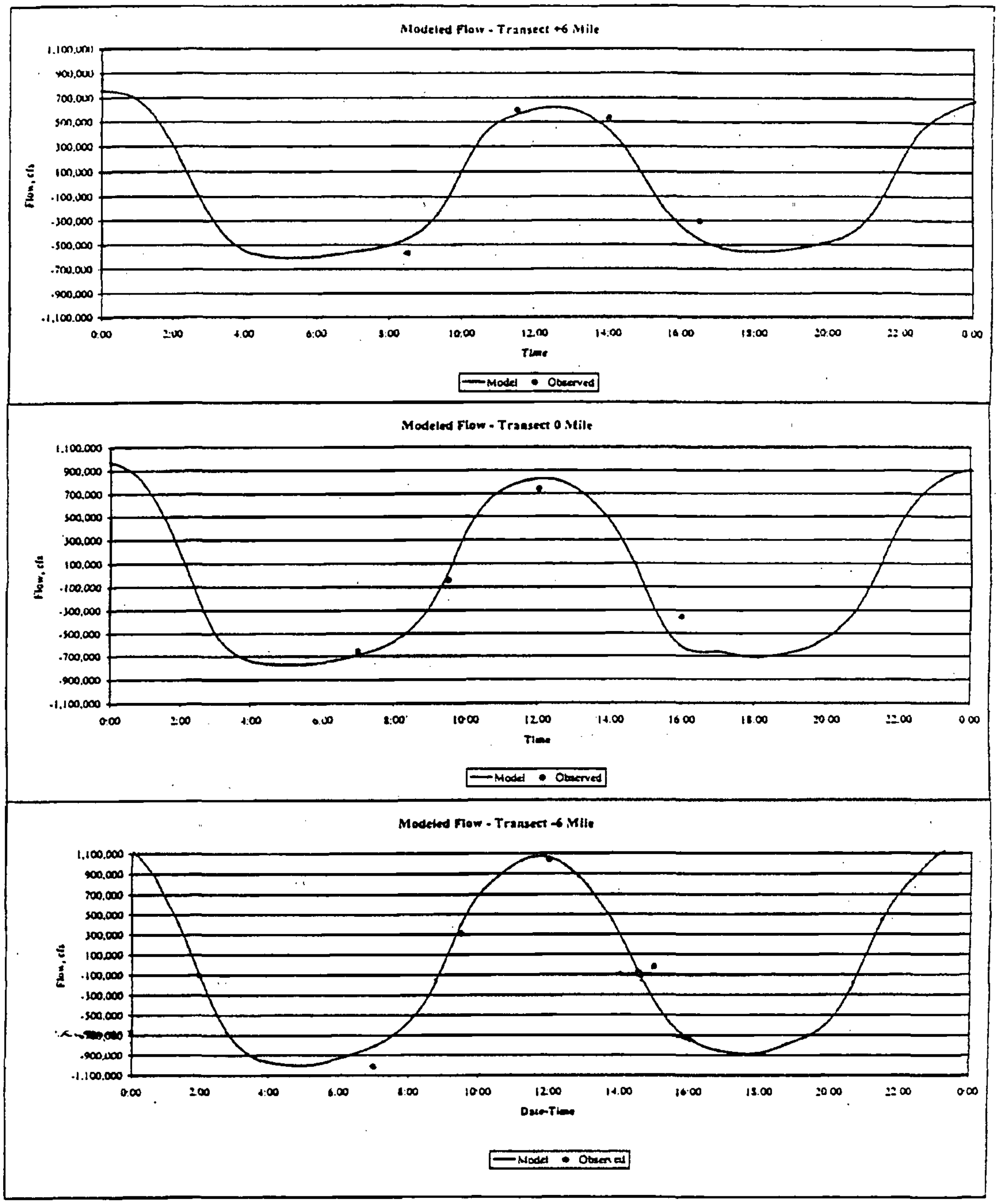
E Figure V-15. Model grid in the vicinity of the Station showing intake and discharge elements.



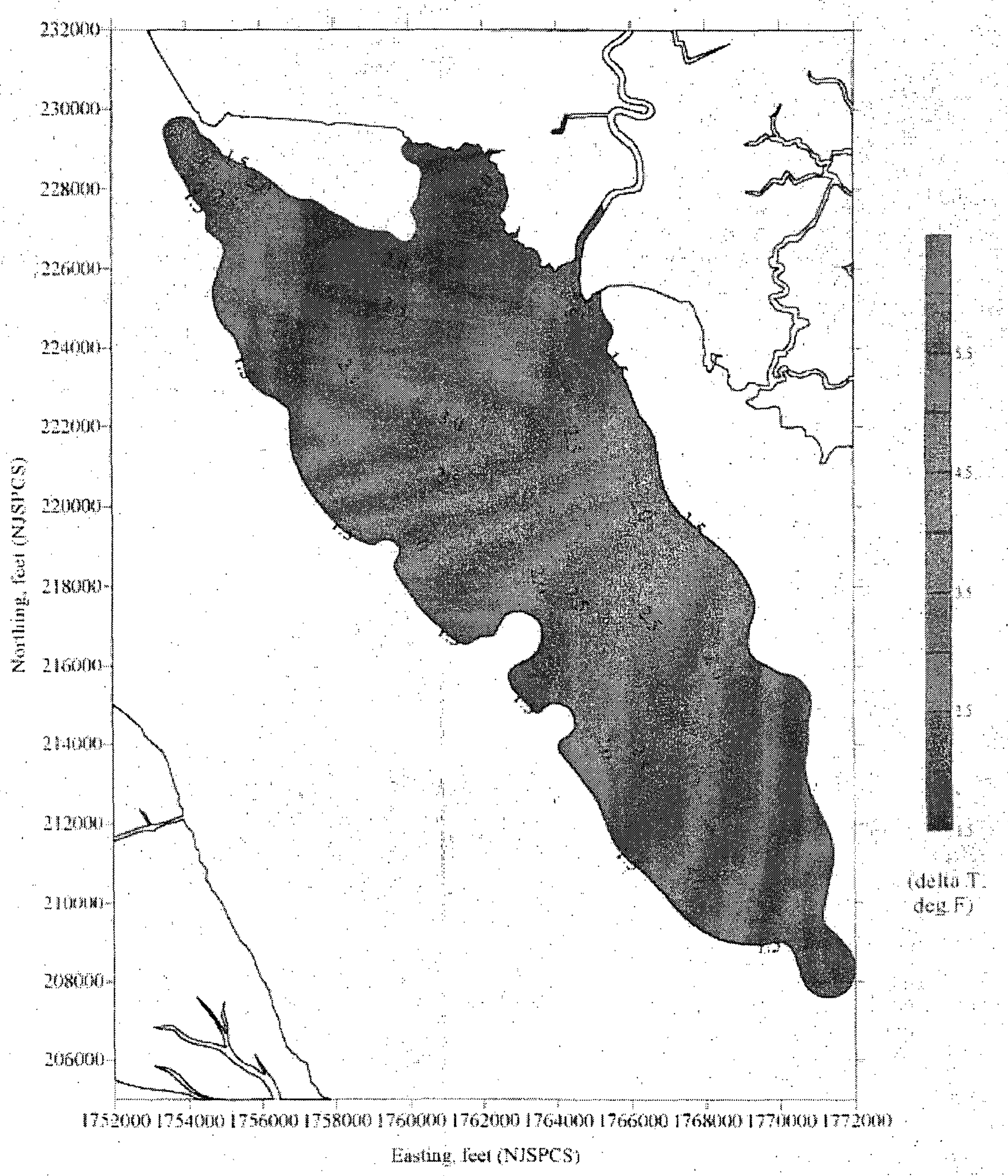
E Figure V-16a. Comparison of modeled and measured tides in the Estuary for 29 May 1998.



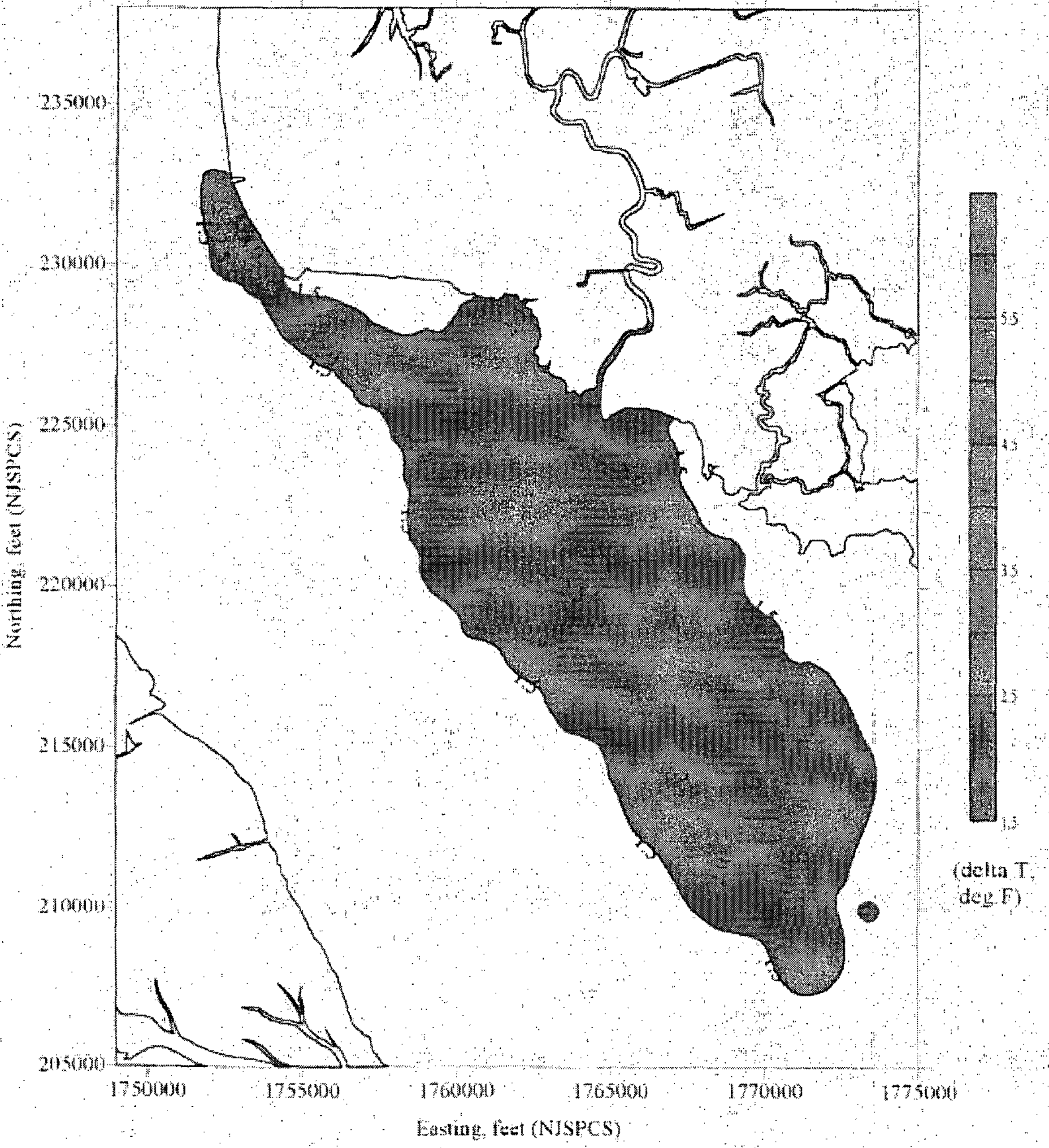
E Figure V-16b. Comparison of modeled and measured tides at the west side of the Bay mouth (Lewes, DE) and the western end of the C&D Canal for 29 May 1998.



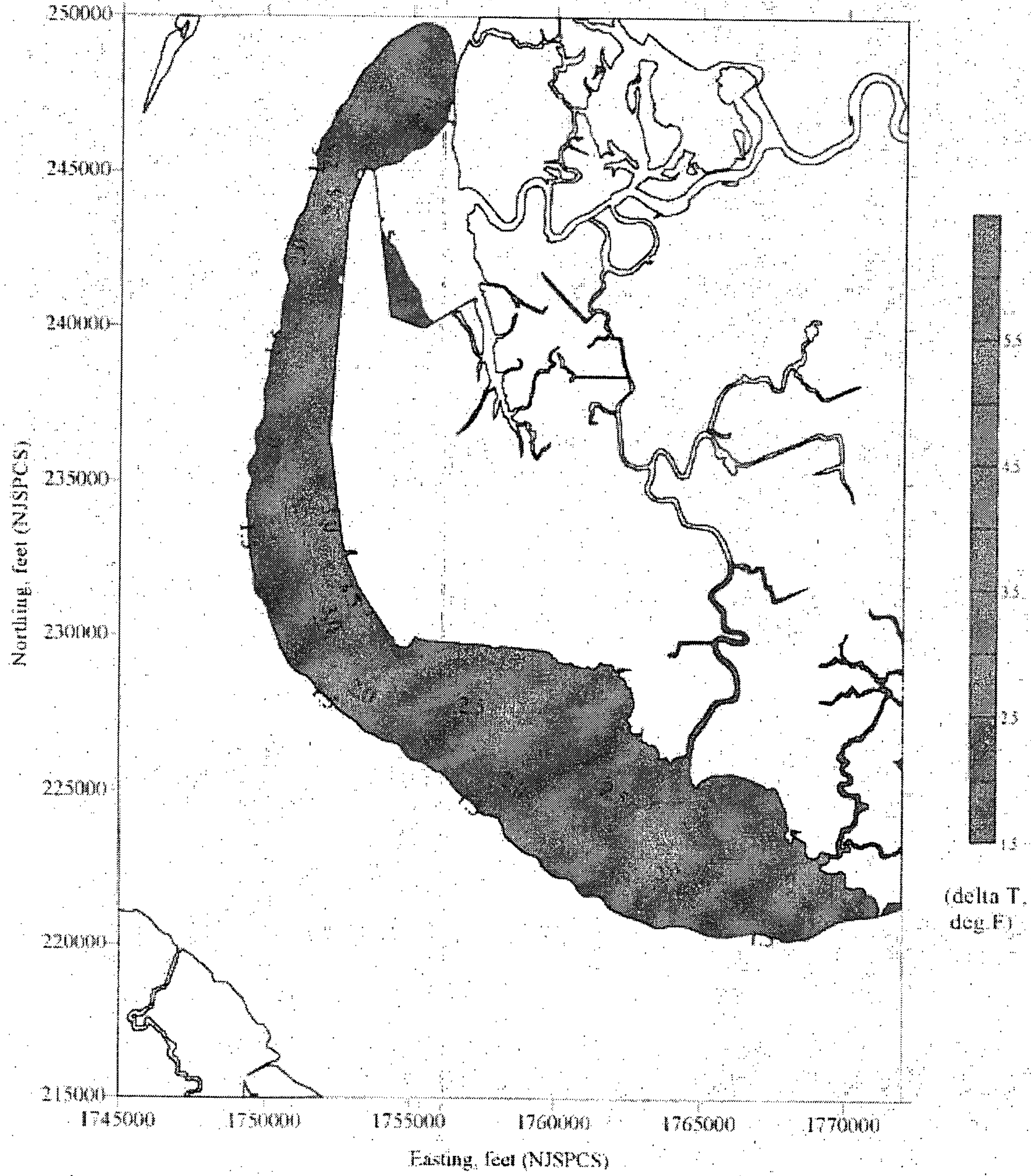
E Figure V-17. RMA-10 calibration of Estuary flow through transects.



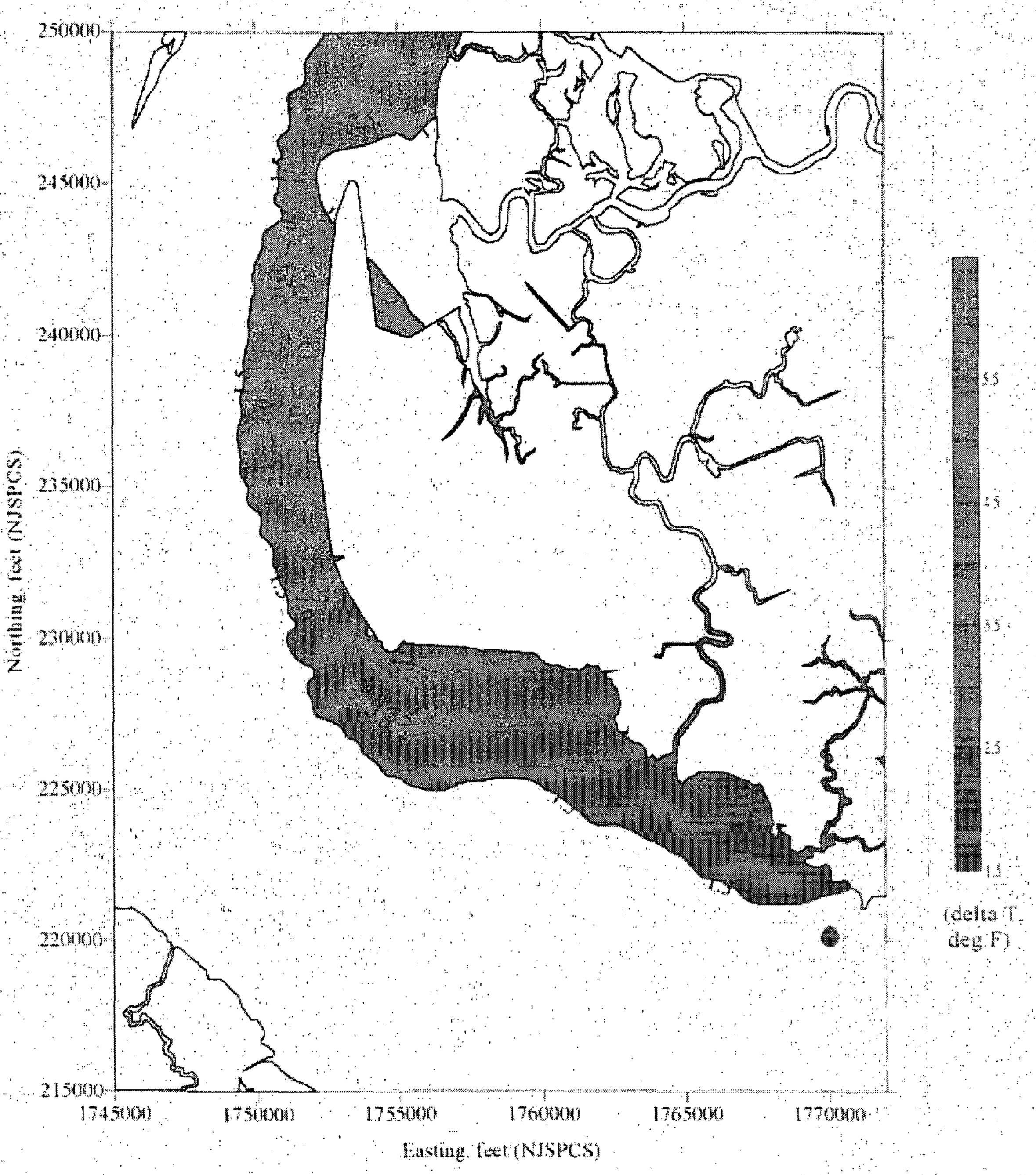
E Figure V-18. Contours of modeled surface delta temperatures for an ebb phase on 29 May 1998.



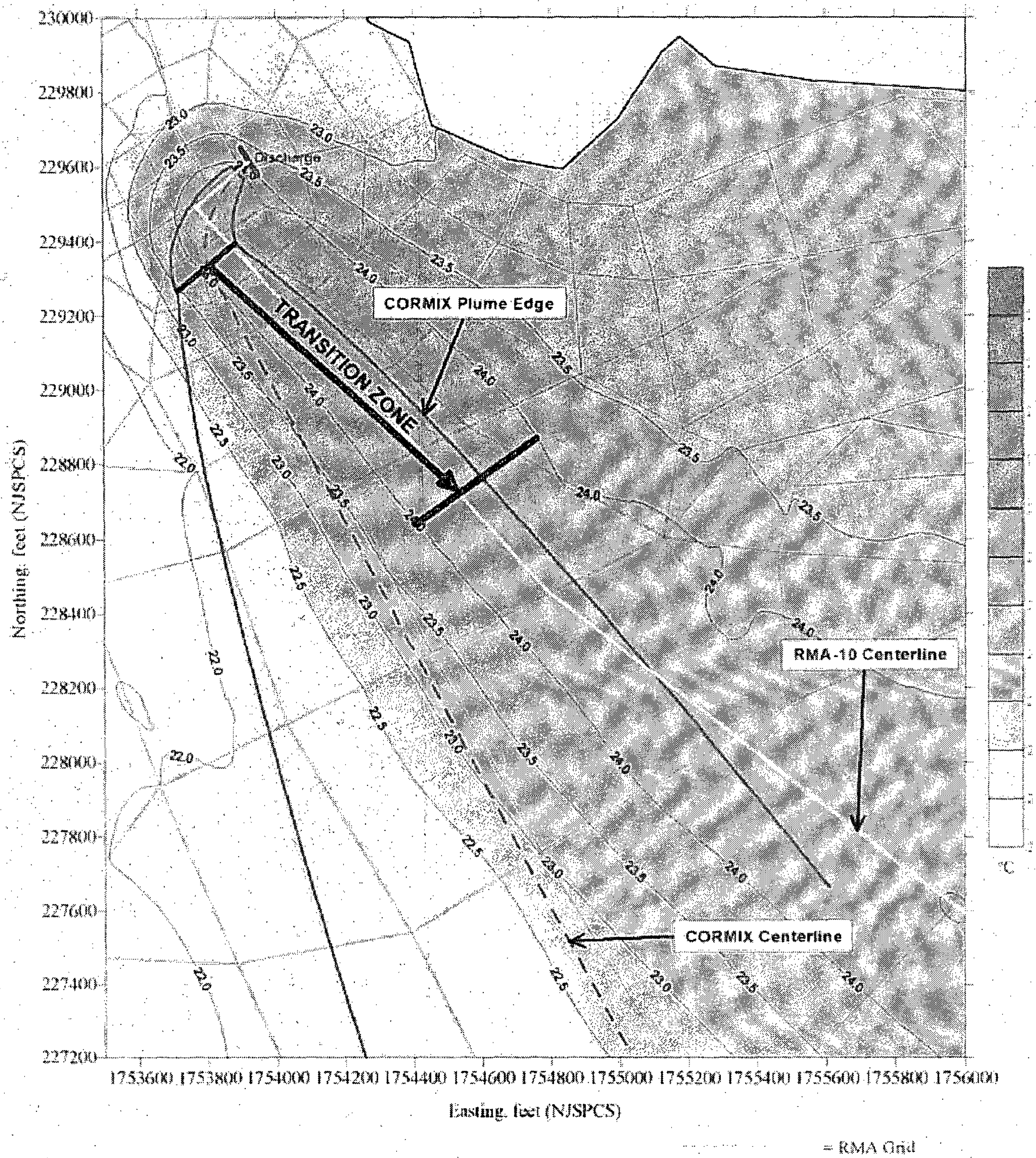
E Figure V-19. Contours of modeled surface delta temperatures for a slack phase (end-of-ebb) on 29 May 1998.



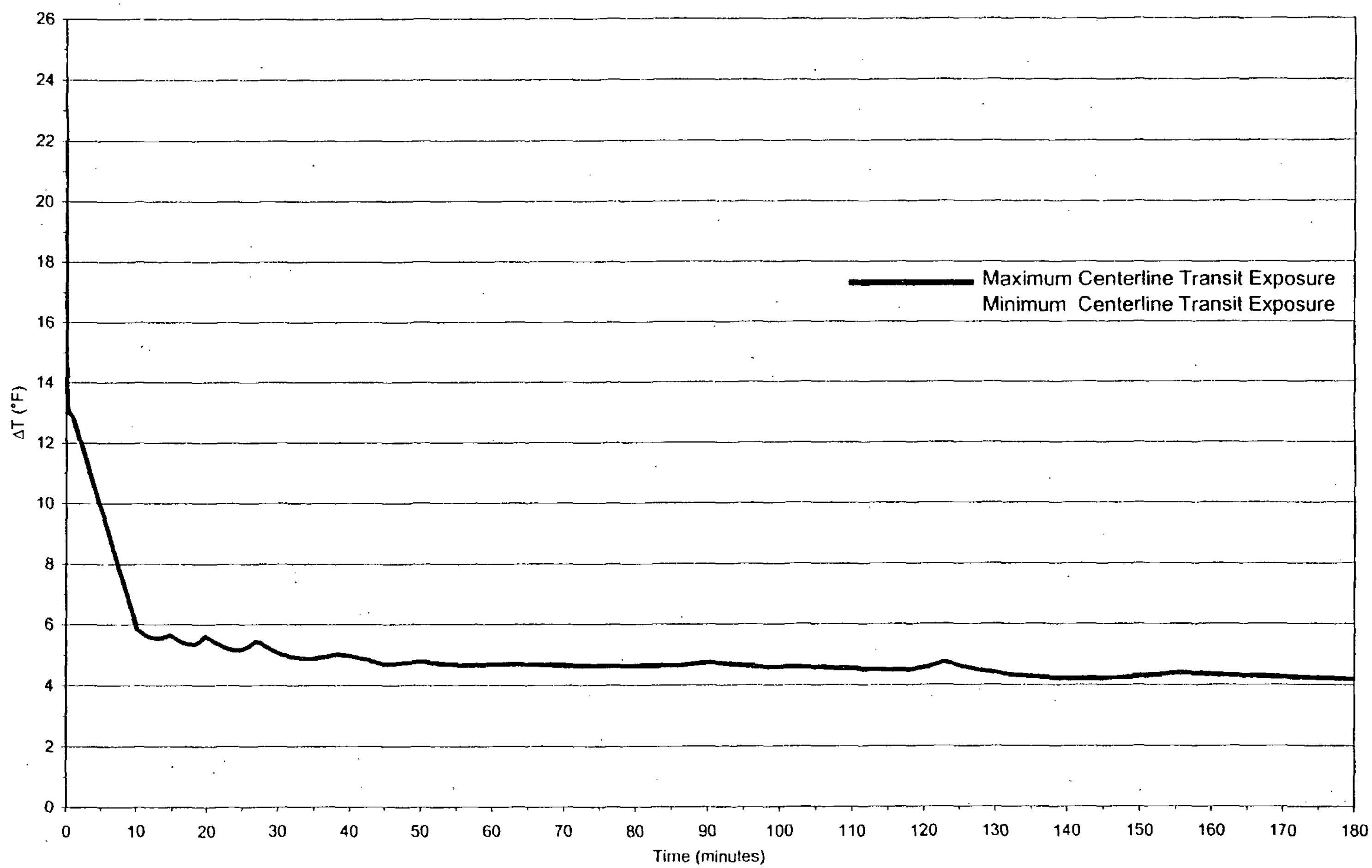
E Figure V-20. Contours of modeled surface delta temperatures for a flood phase on 29 May 1998.



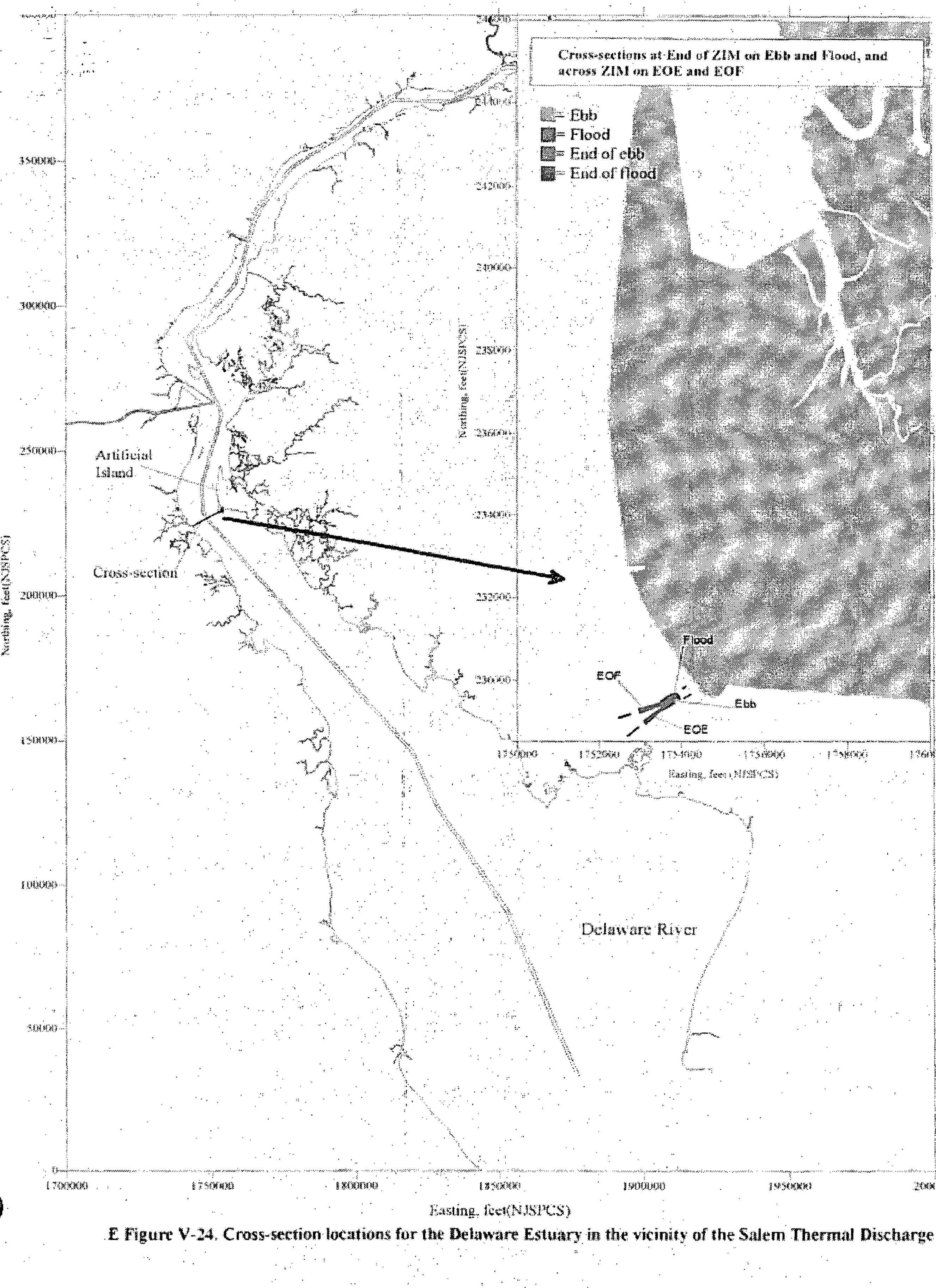
E Figure V-21. Contours of modeled surface delta temperatures for a slack phase (end-of-flood) on 29 May 1998.



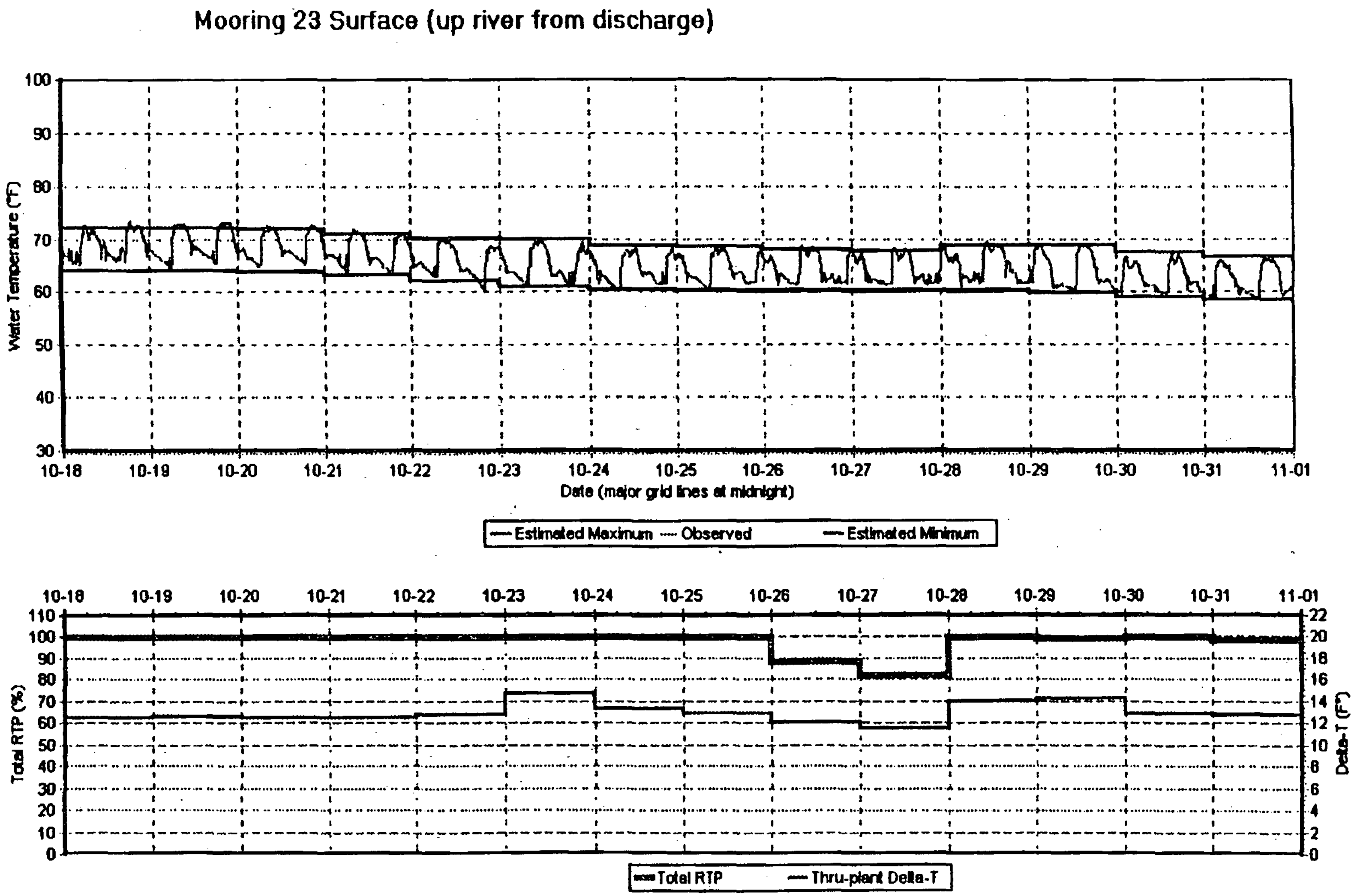
E Figure V-22. Schematic of linkage procedure and transition zone.



E Figure V-23. Time-ΔT history for ebb phase, 2 June 1998, 0830 hrs.

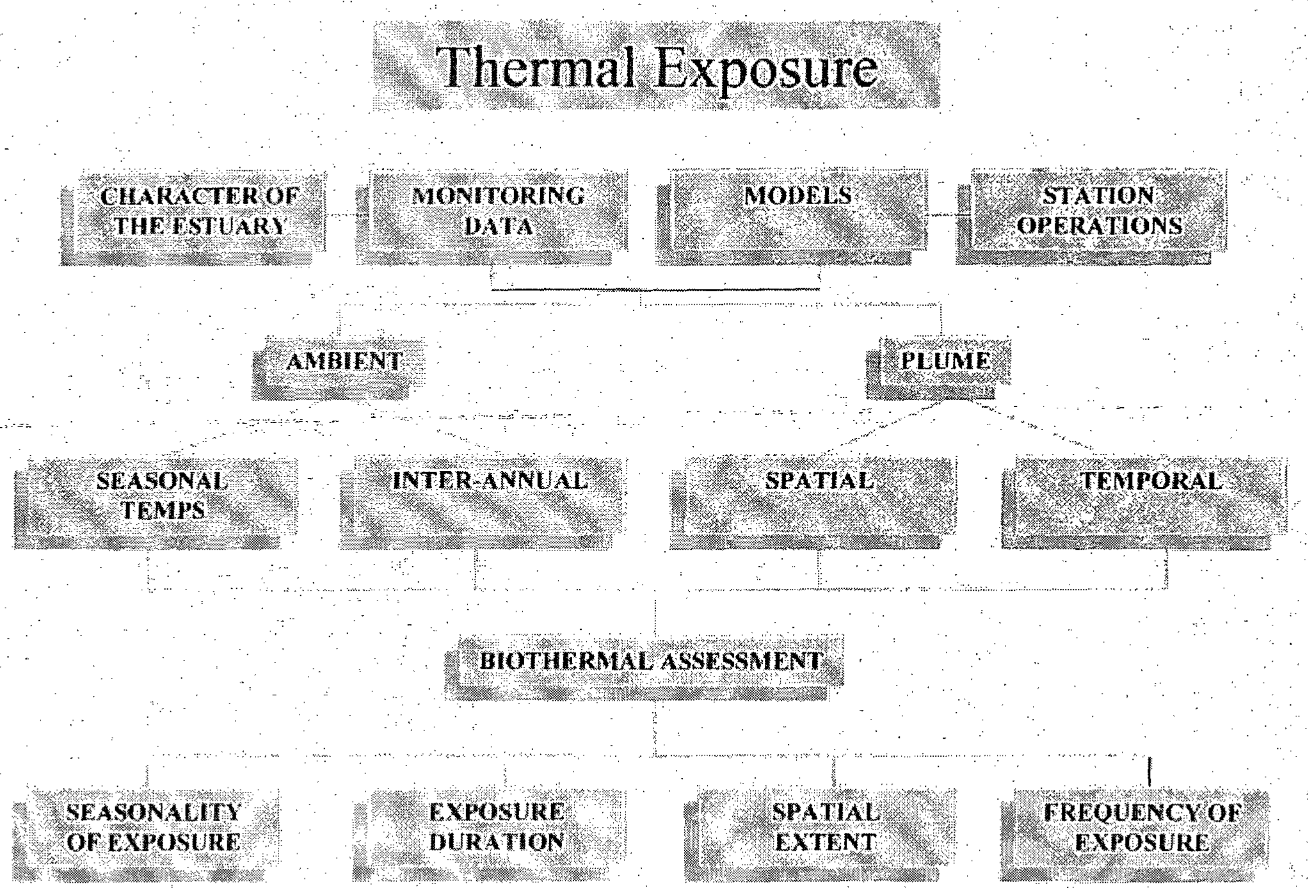


E Figure V-24. Cross-section locations for the Delaware Estuary in the vicinity of the Salem Thermal Discharge

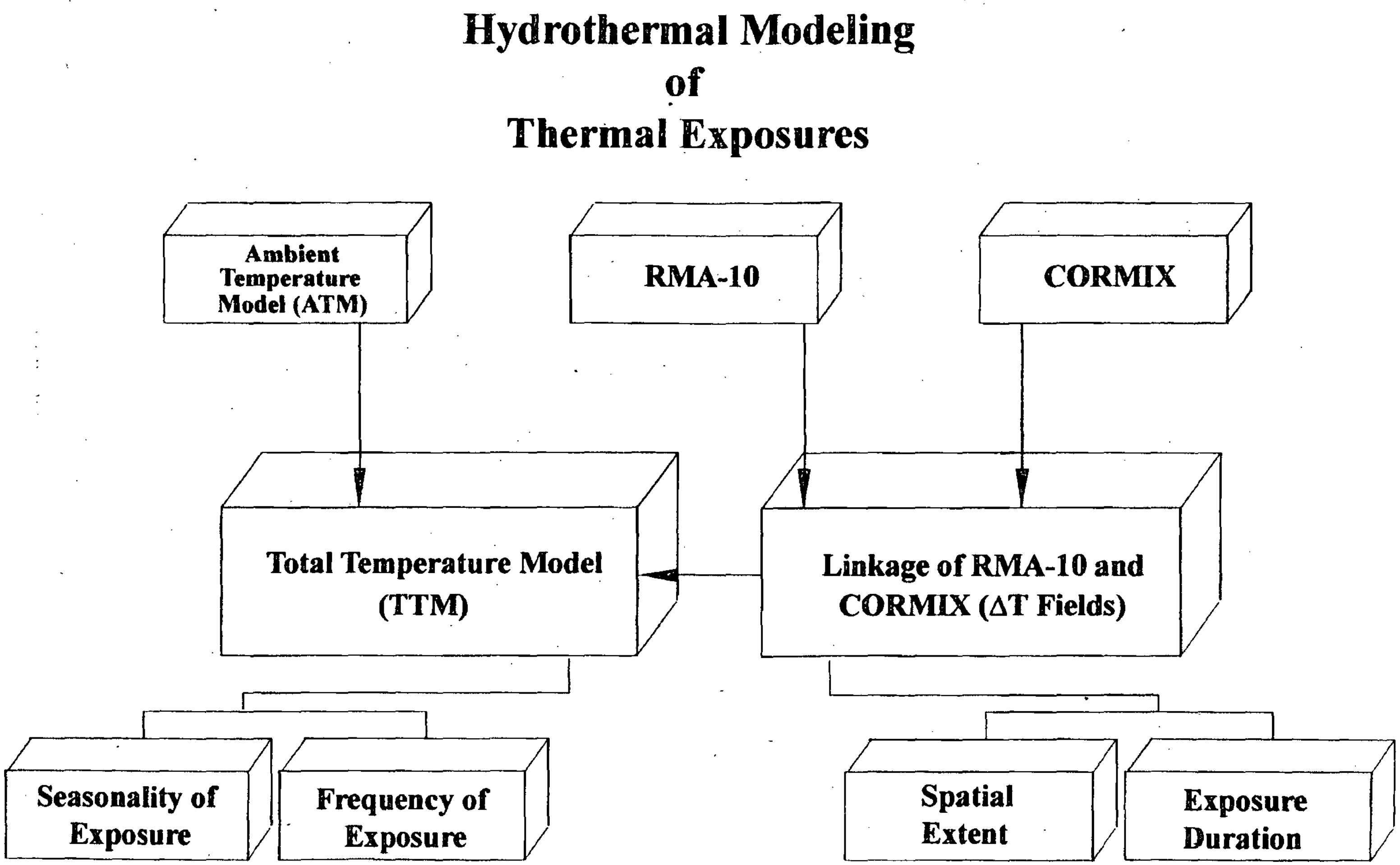


04-Feb-99

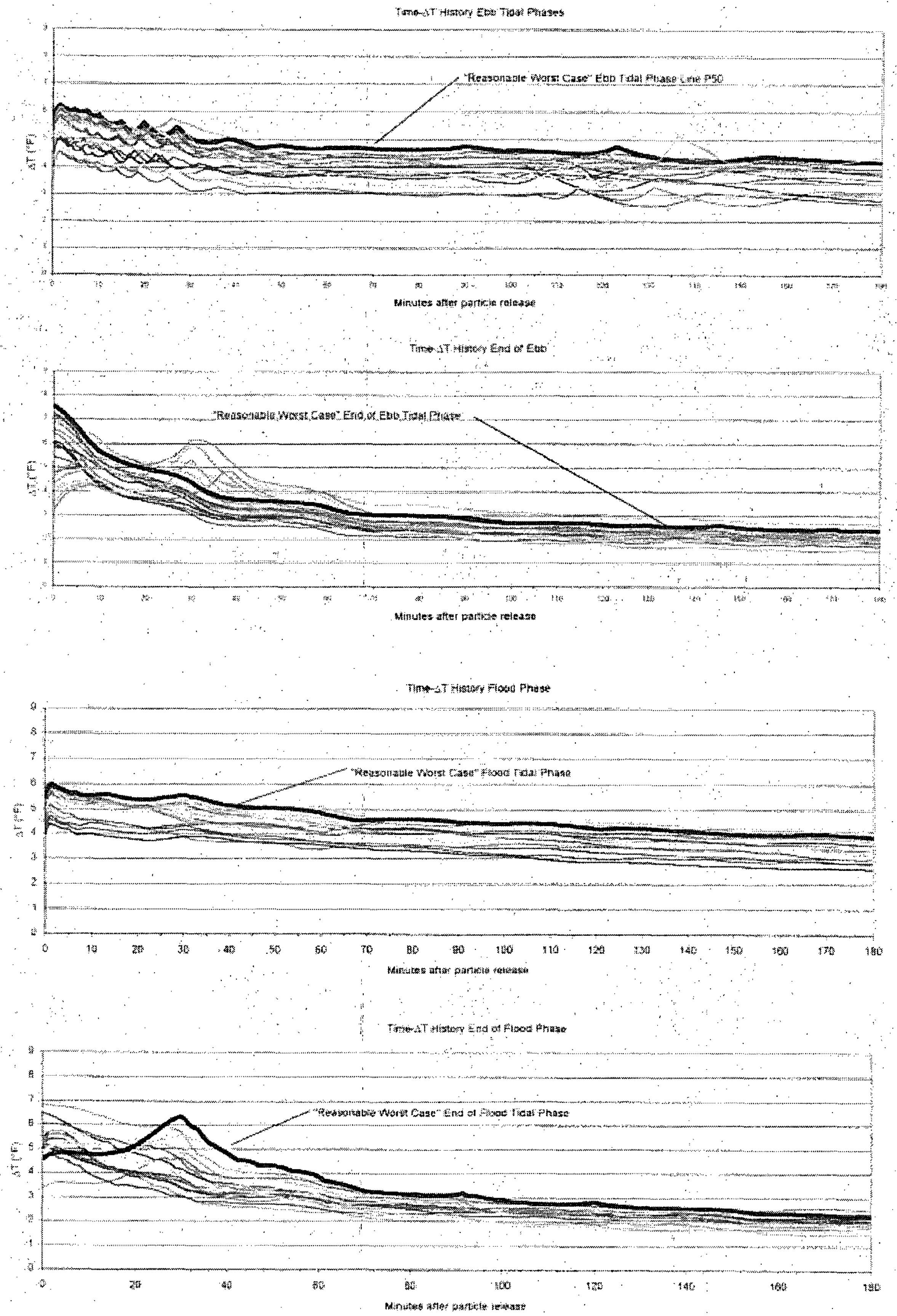
E Figure V-25. Validation of Total Temperature Model (TTM) against Near-Field Mooring 23.



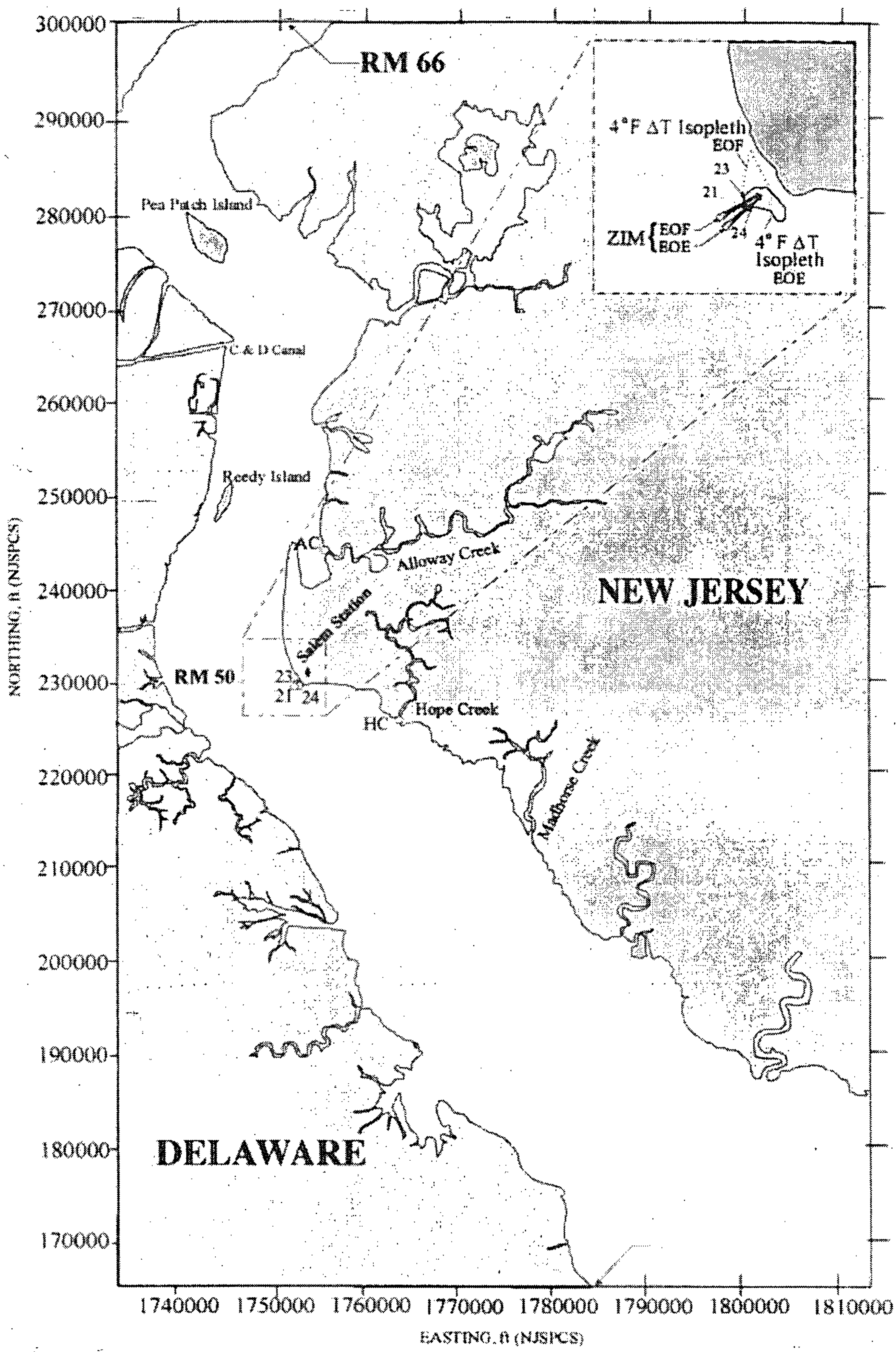
E Figure V-26. Process by which information about the Estuary and Station is incorporated into models to produce characterizations of thermal exposure.



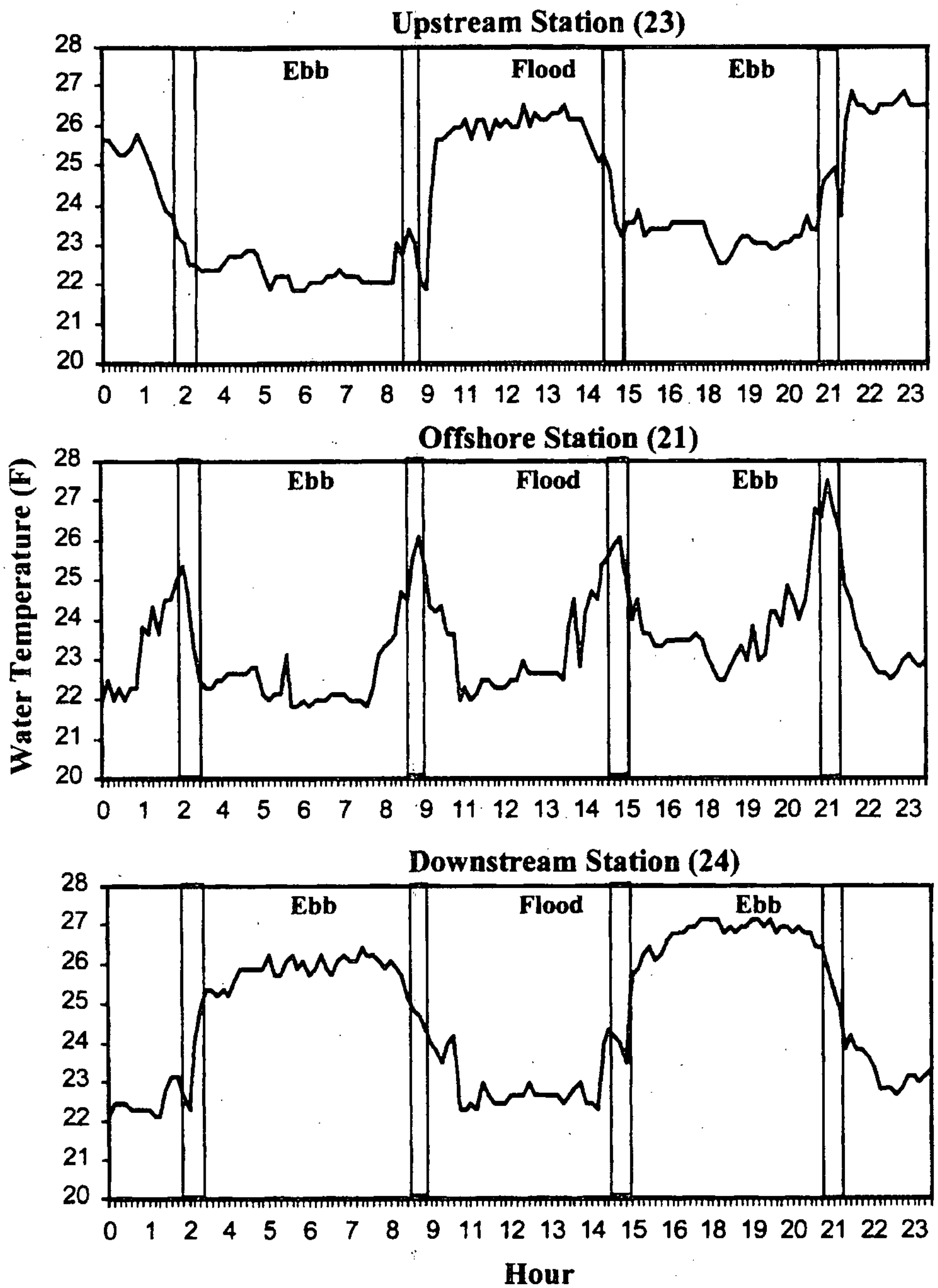
E Figure V-27. Schematic showing how the hydrothermal models are used to define the thermal exposure.



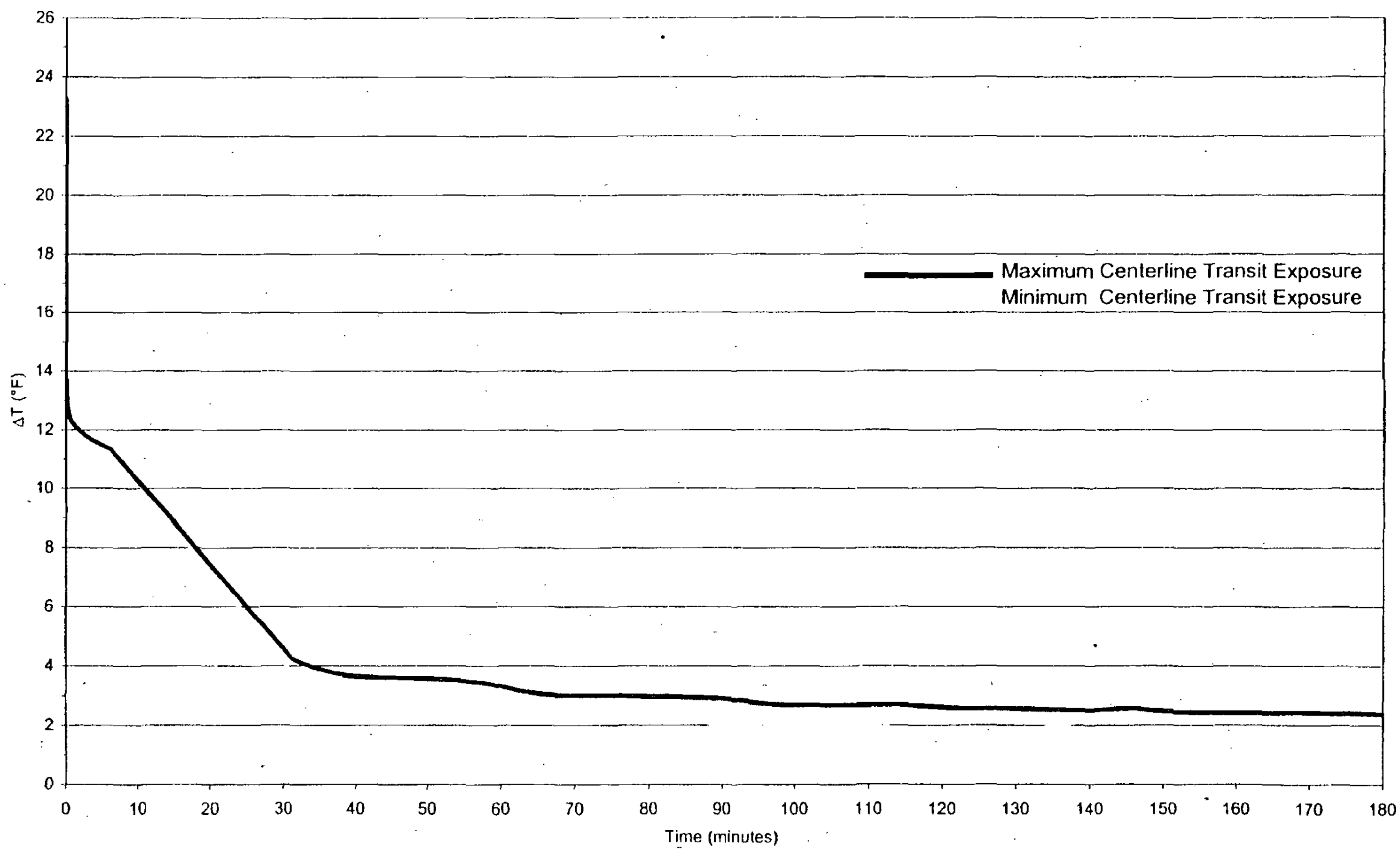
E Figure V-28. Time ΔT Curves for Four Tidal Phases, for 26 May - 4 June 1998 interval, based on RMA-10 output only.



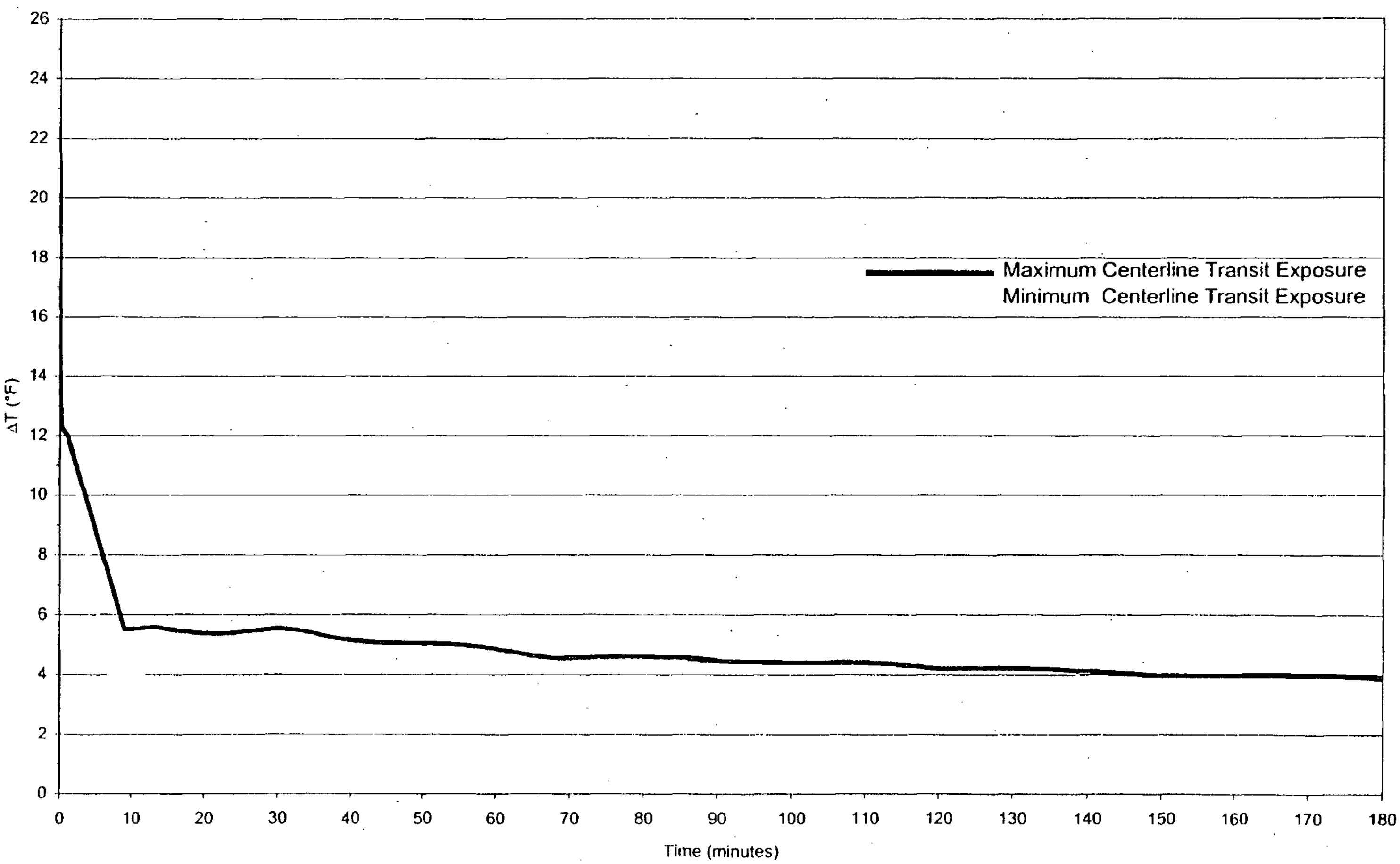
E Figure V-29. Map showing size of Salem's ZIM and 4° ΔT Isopleth relative to a section of the Delaware Estuary (from RM 38 to RM 66).



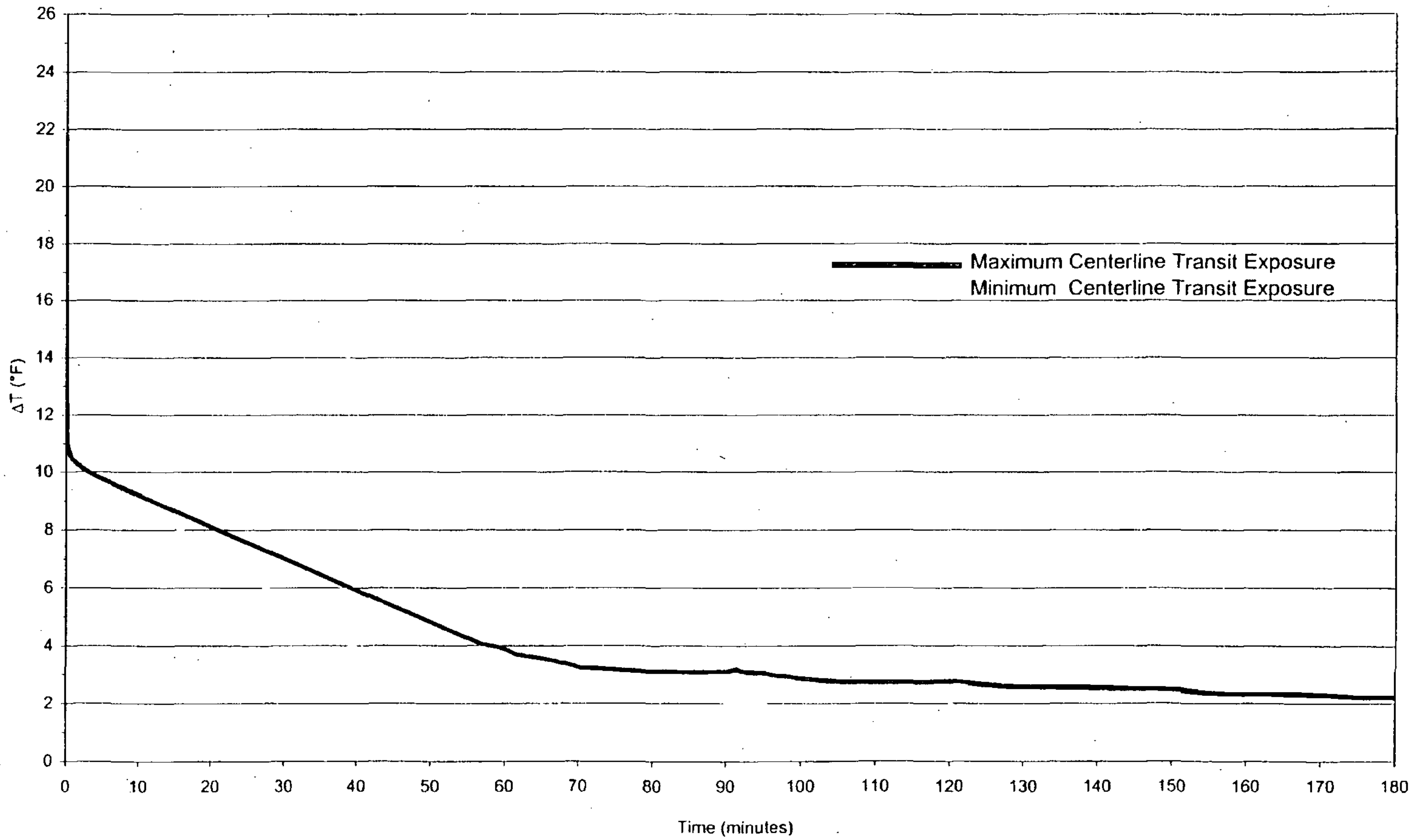
E Figure V-30. The variation of temperature at the near-field moorings over one tide cycle 29 May 1998. Slack tide periods are indicated by the vertical bands, based on the fixed station ADCP data.



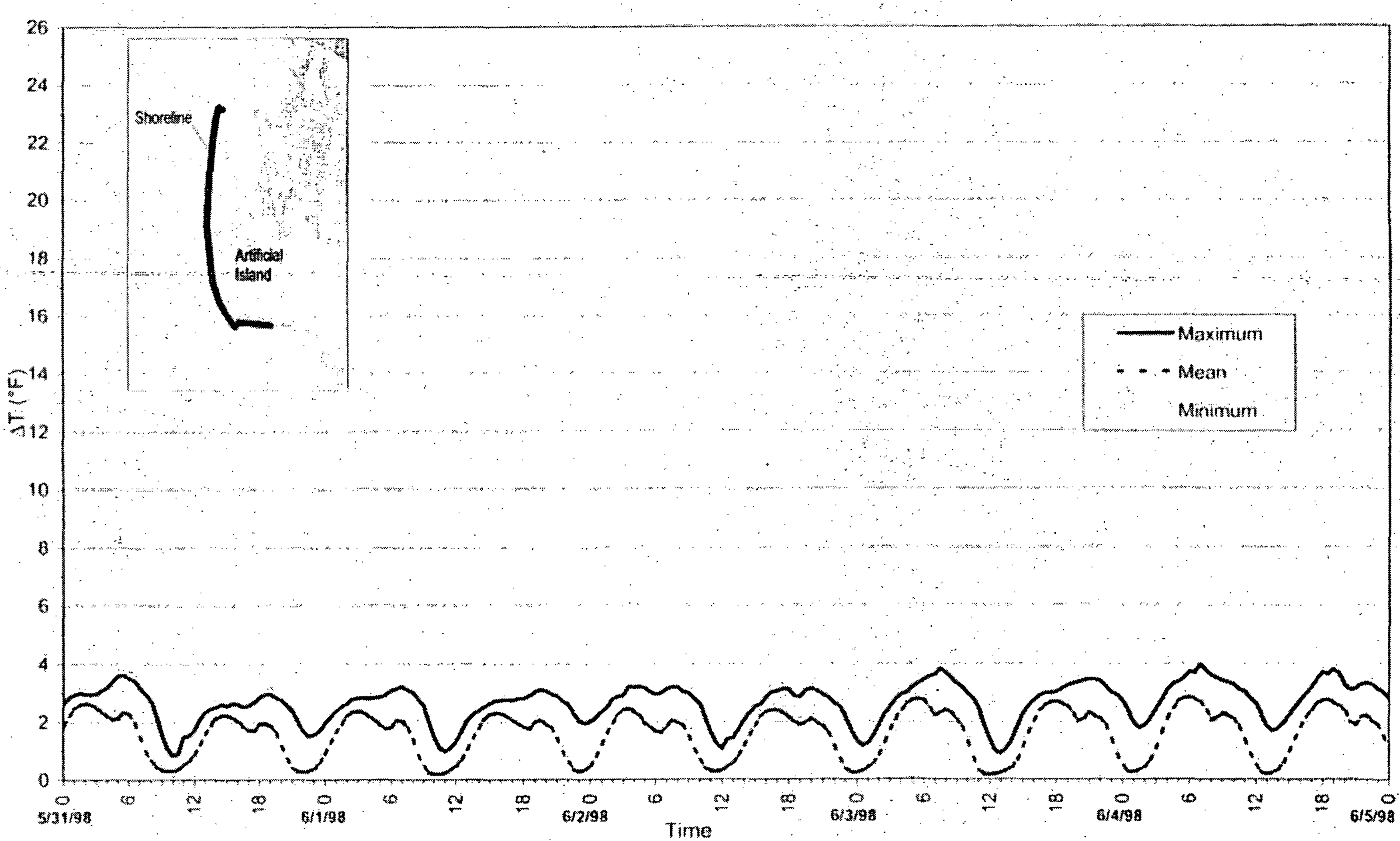
E Figure V-31. Time-ΔT history for end-of-ebb phase, 2 June 1998, 0000 hrs.



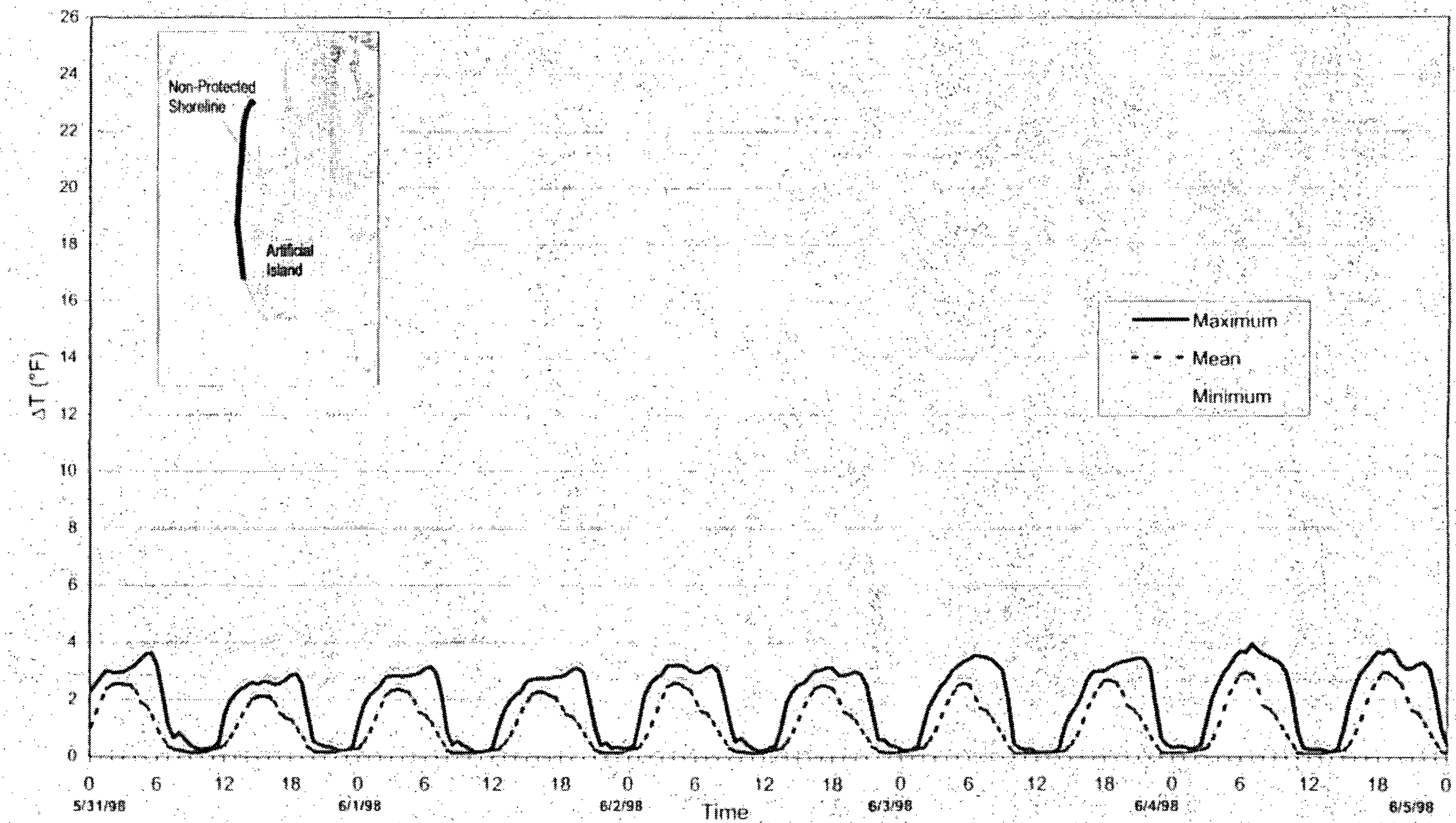
E Figure V-32. Time-ΔT history for flood phase, 4 June 1998, 1630 hrs.



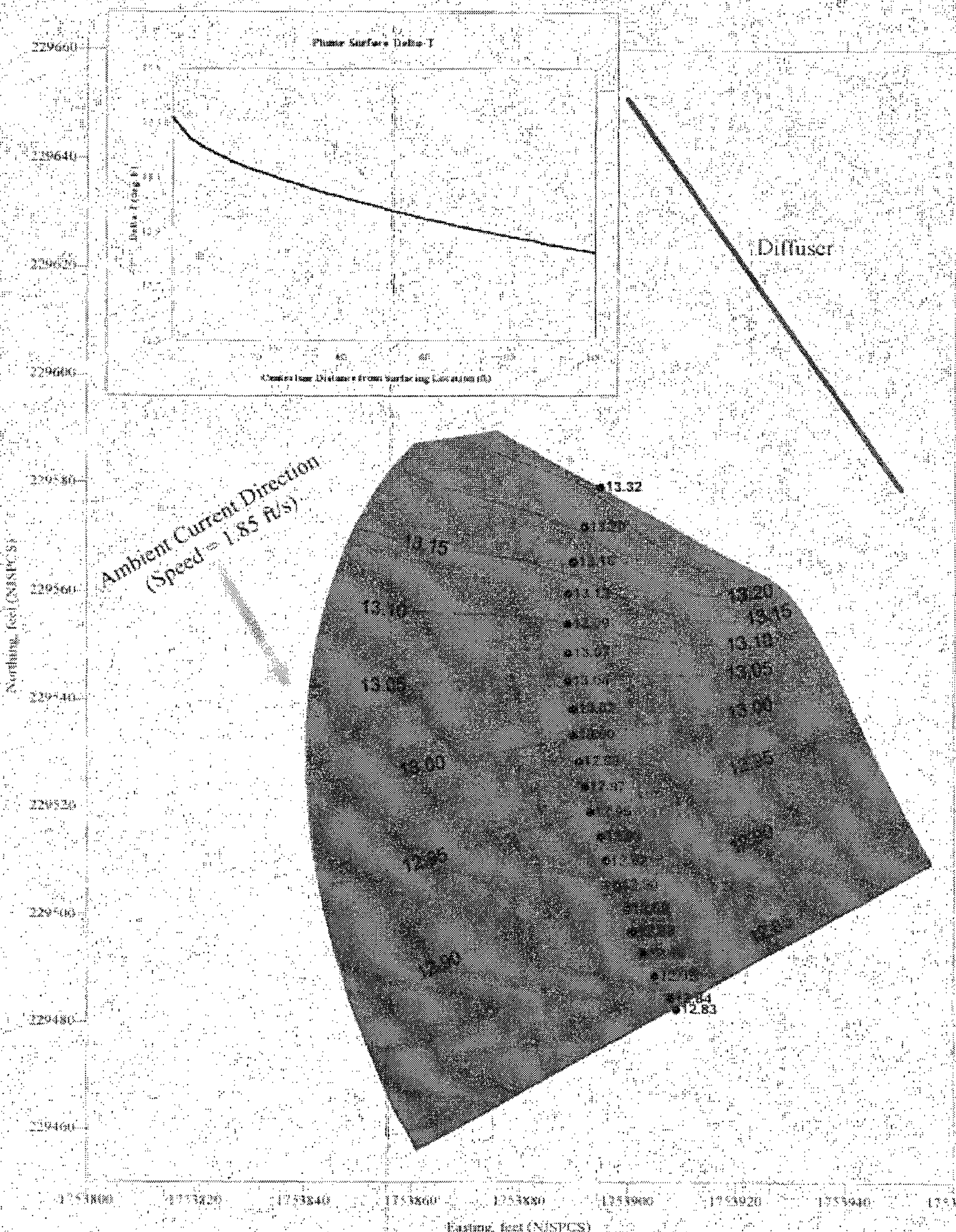
E Figure V-33. Time-ΔT history for end-of-flood phase, 31 May 1998, 1600 hrs.



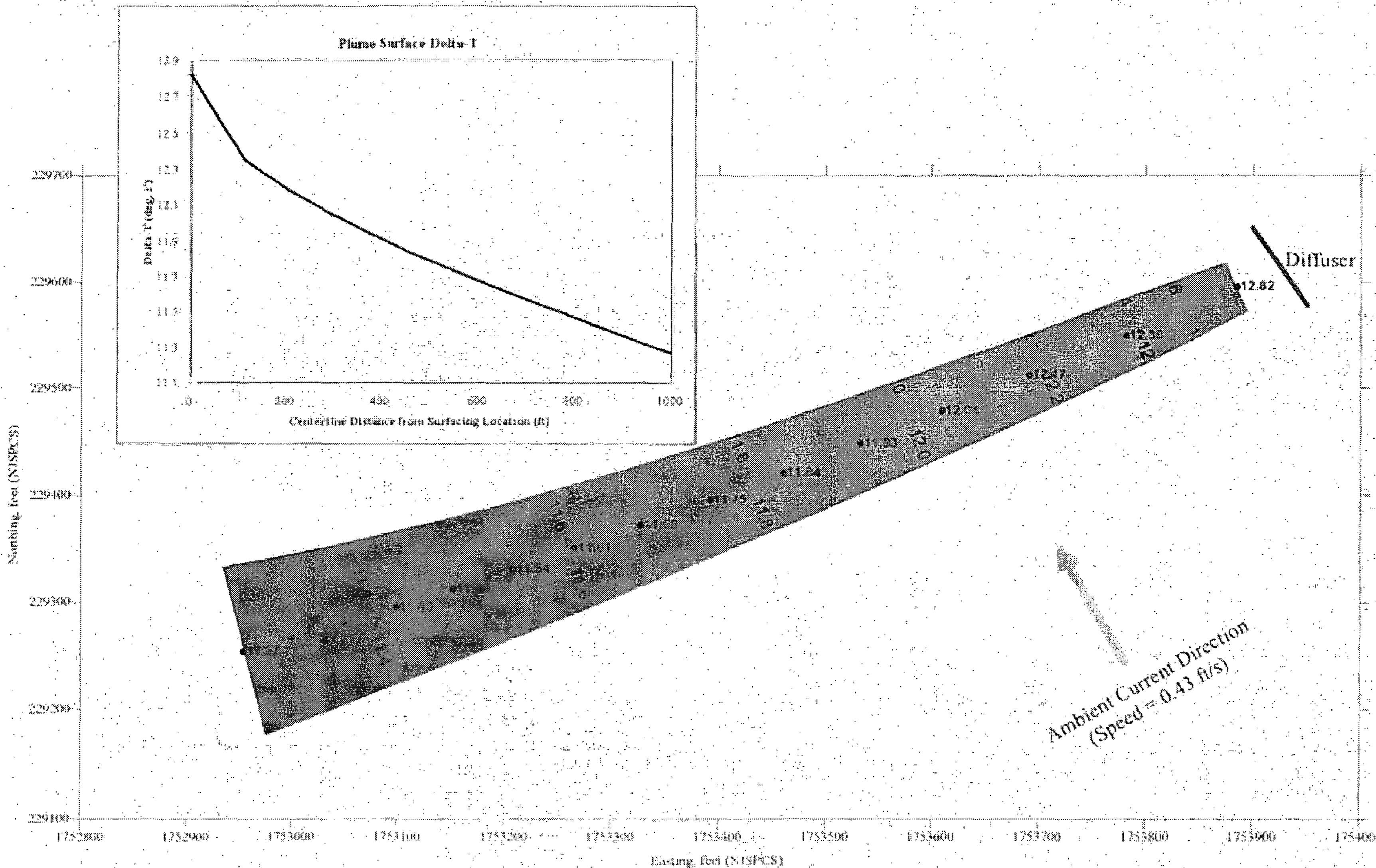
E Figure V-34. Time series of shoreline ΔT along Artificial Island (31 May - 4 June 1998).



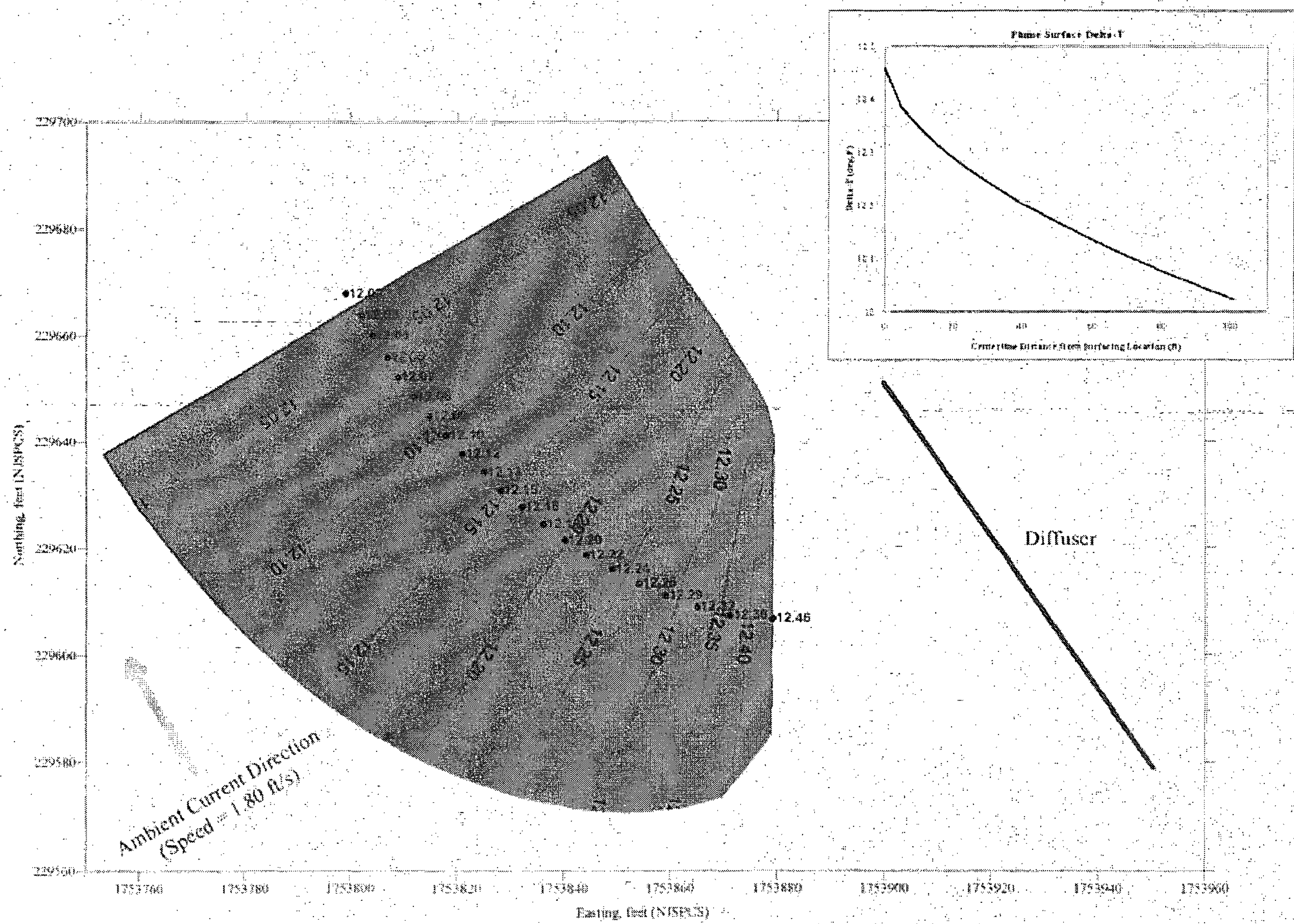
E Figure V-35. Time series of shoreline ΔT along the Non-Protected Shoreline of Artificial Island (31 May - 4 June 1998).



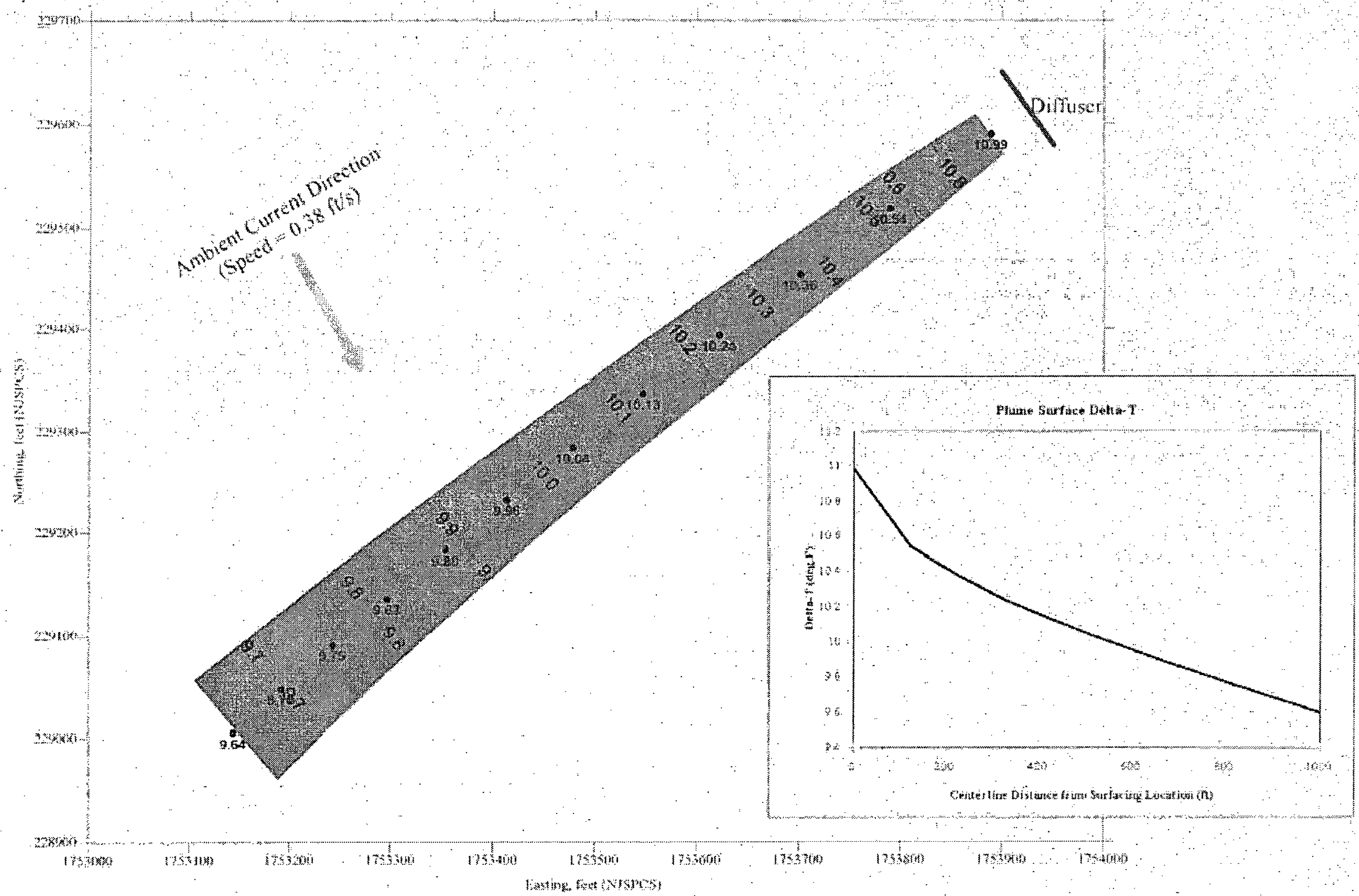
E Figure V-36. Plume Surface Delta-T Contours Ebb Tidal Phase, 6/2/98 0830 hrs Discharge Delta-T = 22.7 deg.F (Relative to Ambient Temperature).



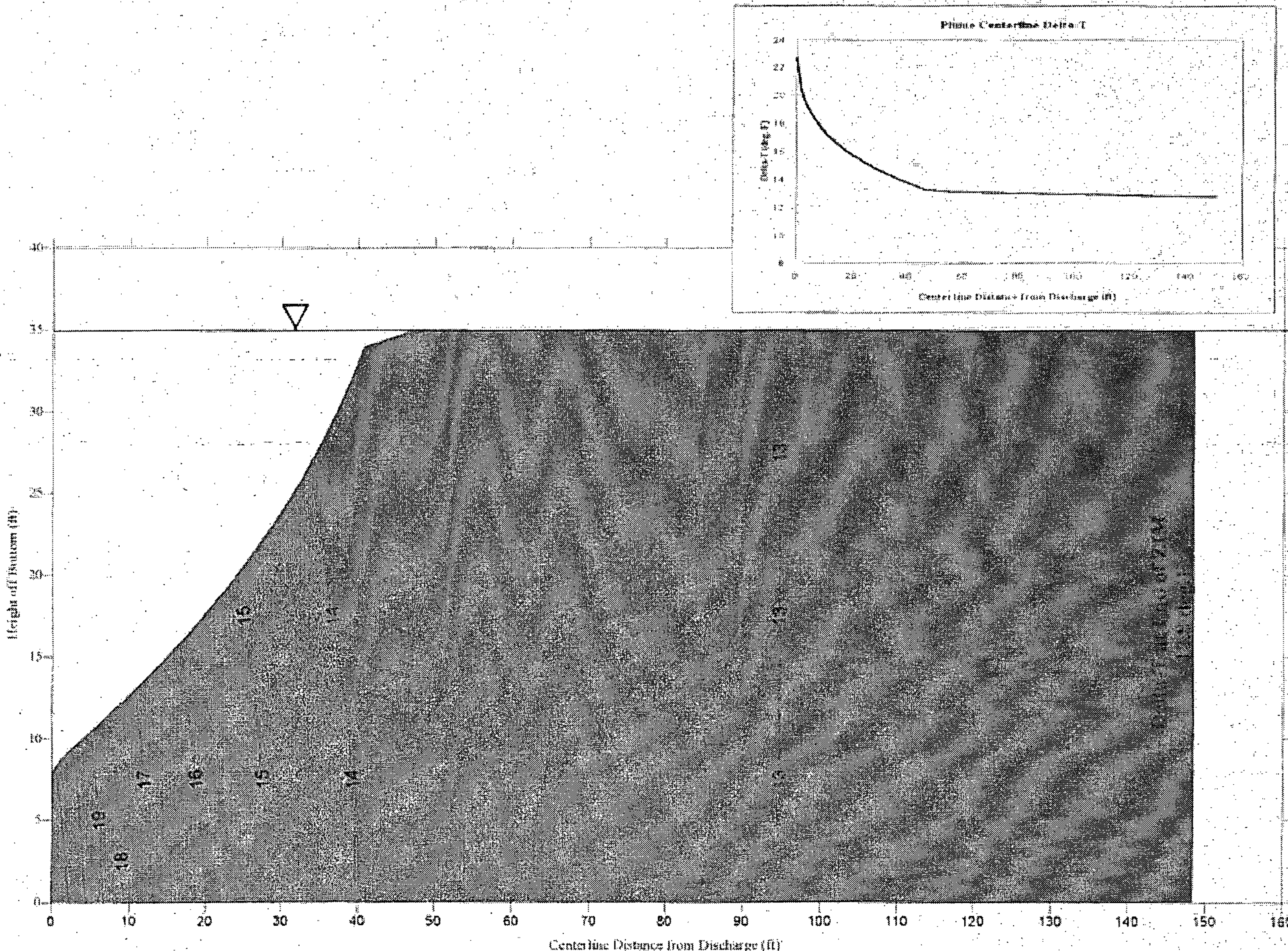
E Figure V-37. Plume Surface Delta-T Contours End-of-Ebb Tidal Phase, 6/2/98 0000 hrs
Discharge Delta-T = 23.2 deg.F (Relative to Ambient Temperature).



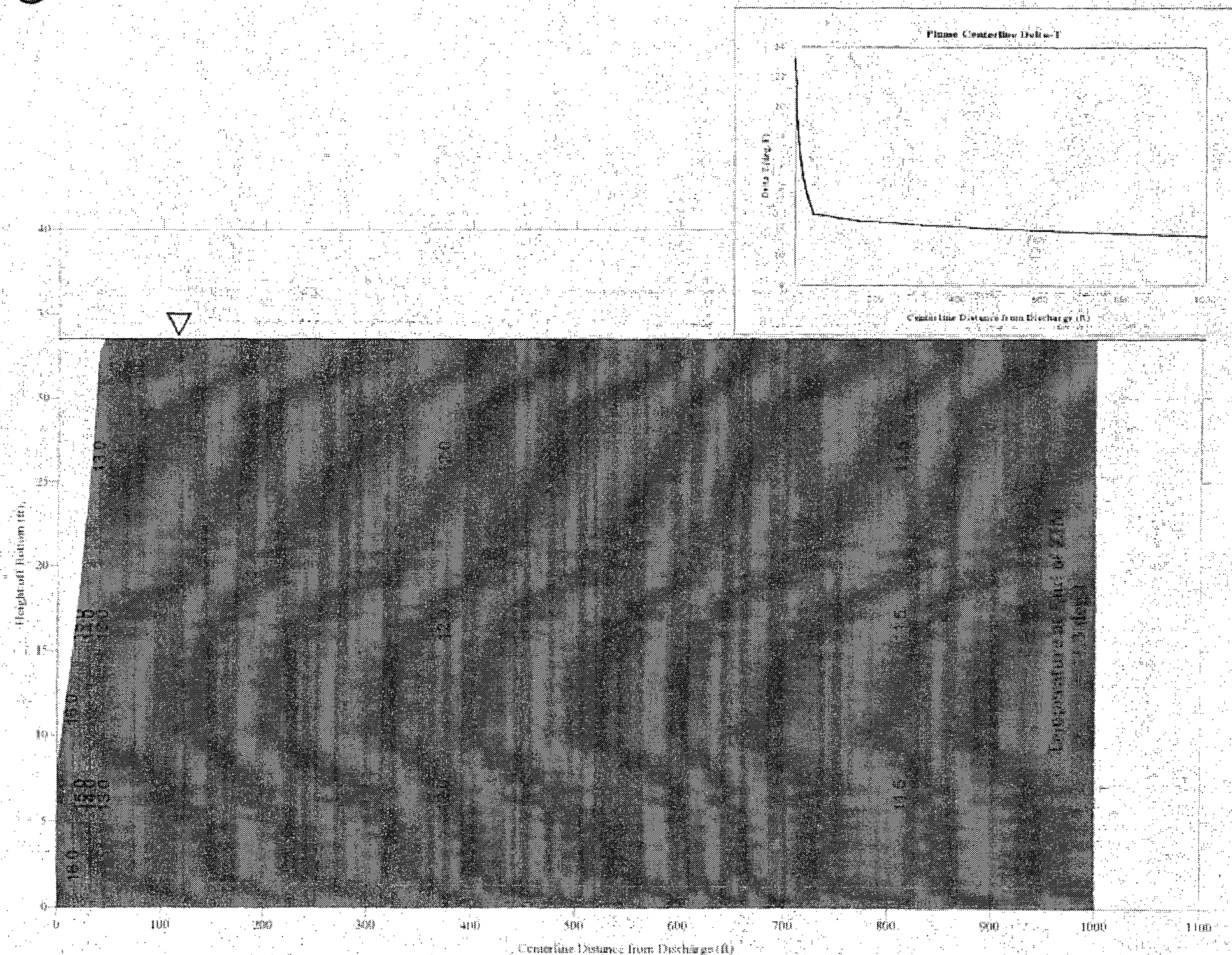
E Figure V-38. Plume Surface Delta-T Contours Flood Tidal Phase, 6/4/98 1630 hrs Discharge Delta-T = 21.2 deg.F (Relative to Ambient Temperature).



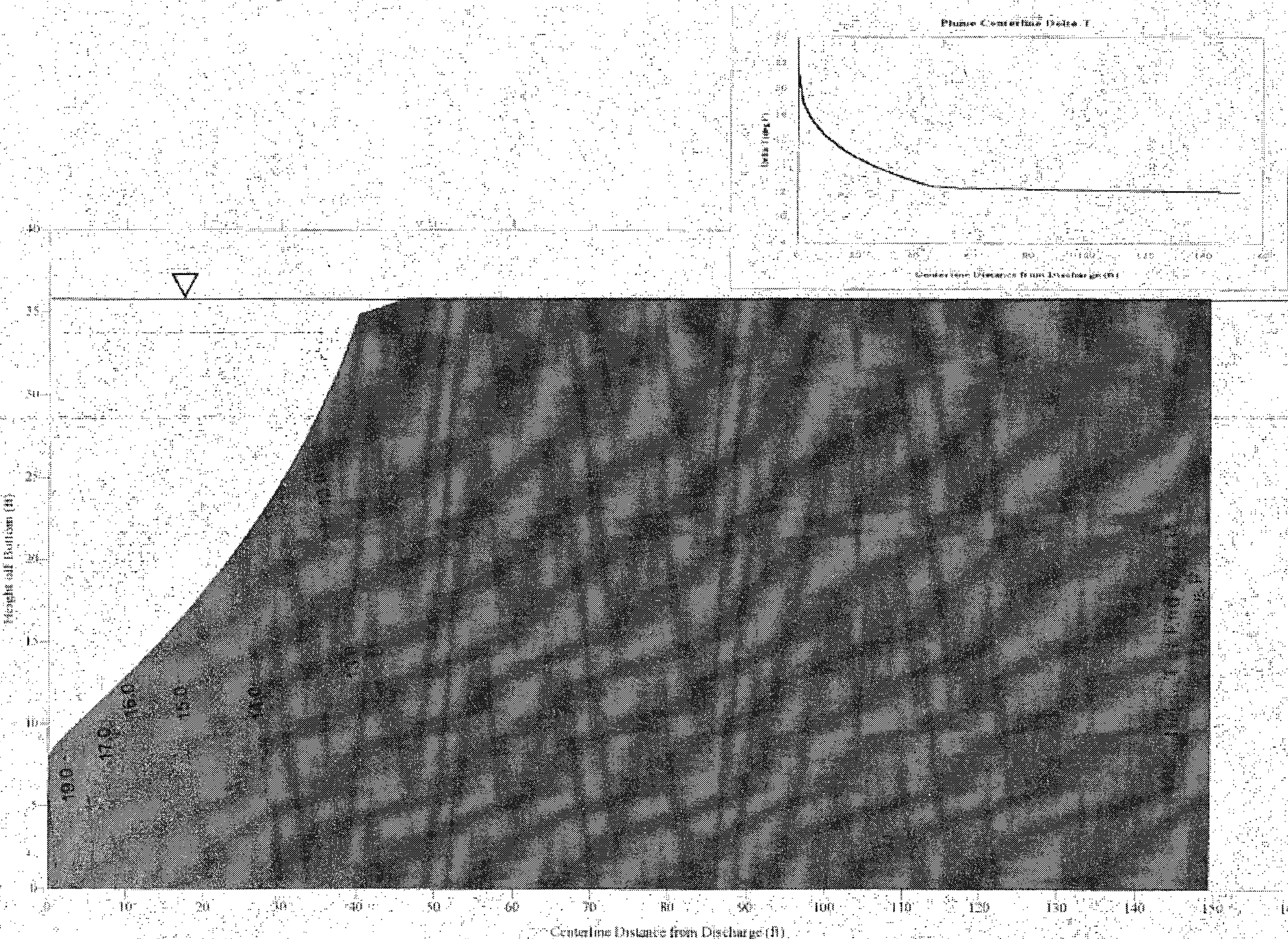
E Figure V-39. Plume Surface Delta-T Contours End-of-Flood Tidal Phase, 5/31/98 1600 hrs Discharge Delta T = 21.8 deg.F (Relative to Ambient Temperature).



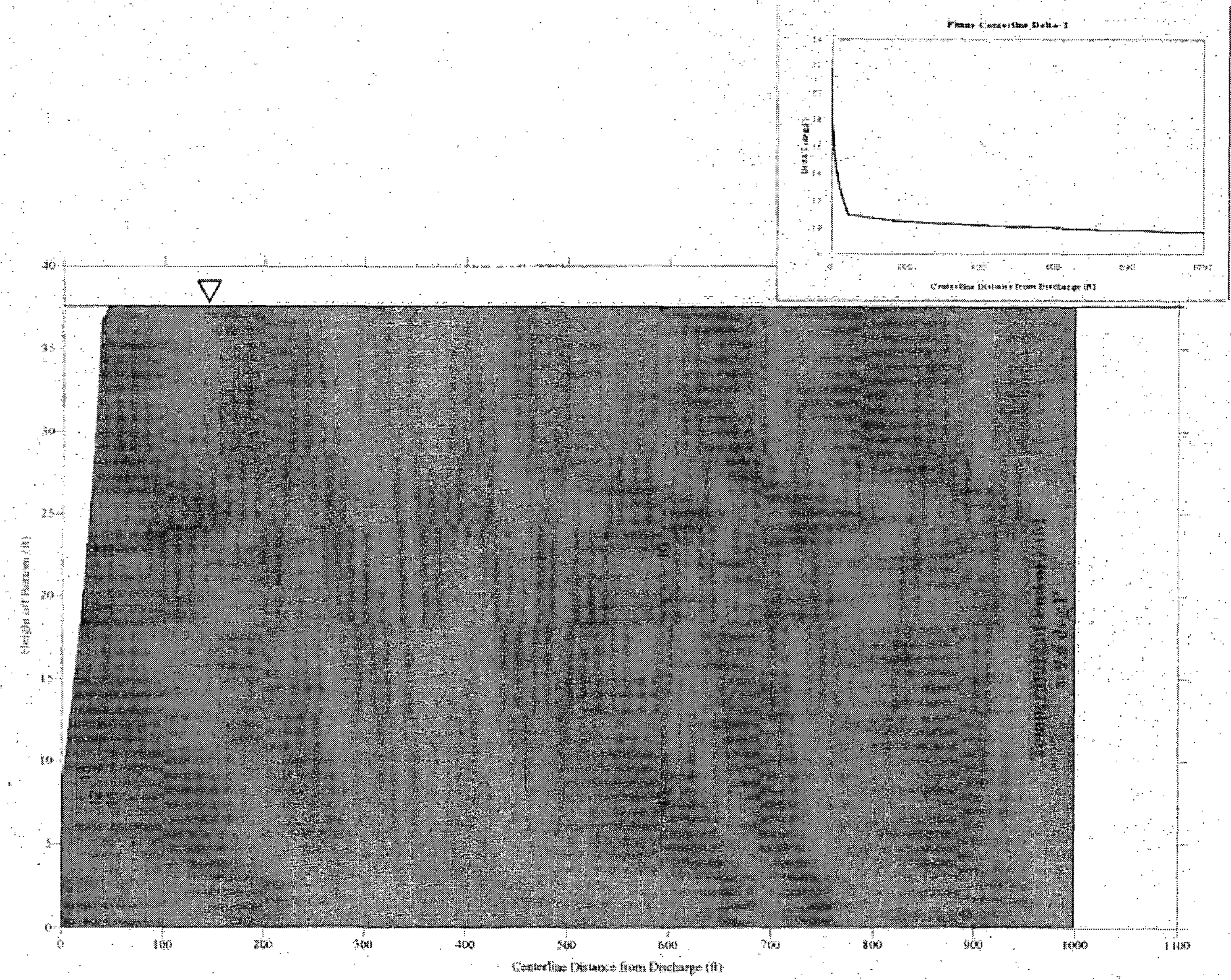
E Figure V-40. Plume Centerline Delta-T (degrees F) Ebb Tidal Phase, 6/2/98 0830 hrs Discharge Delta-T = 22.7 deg.F (Relative to Ambient Temperature).



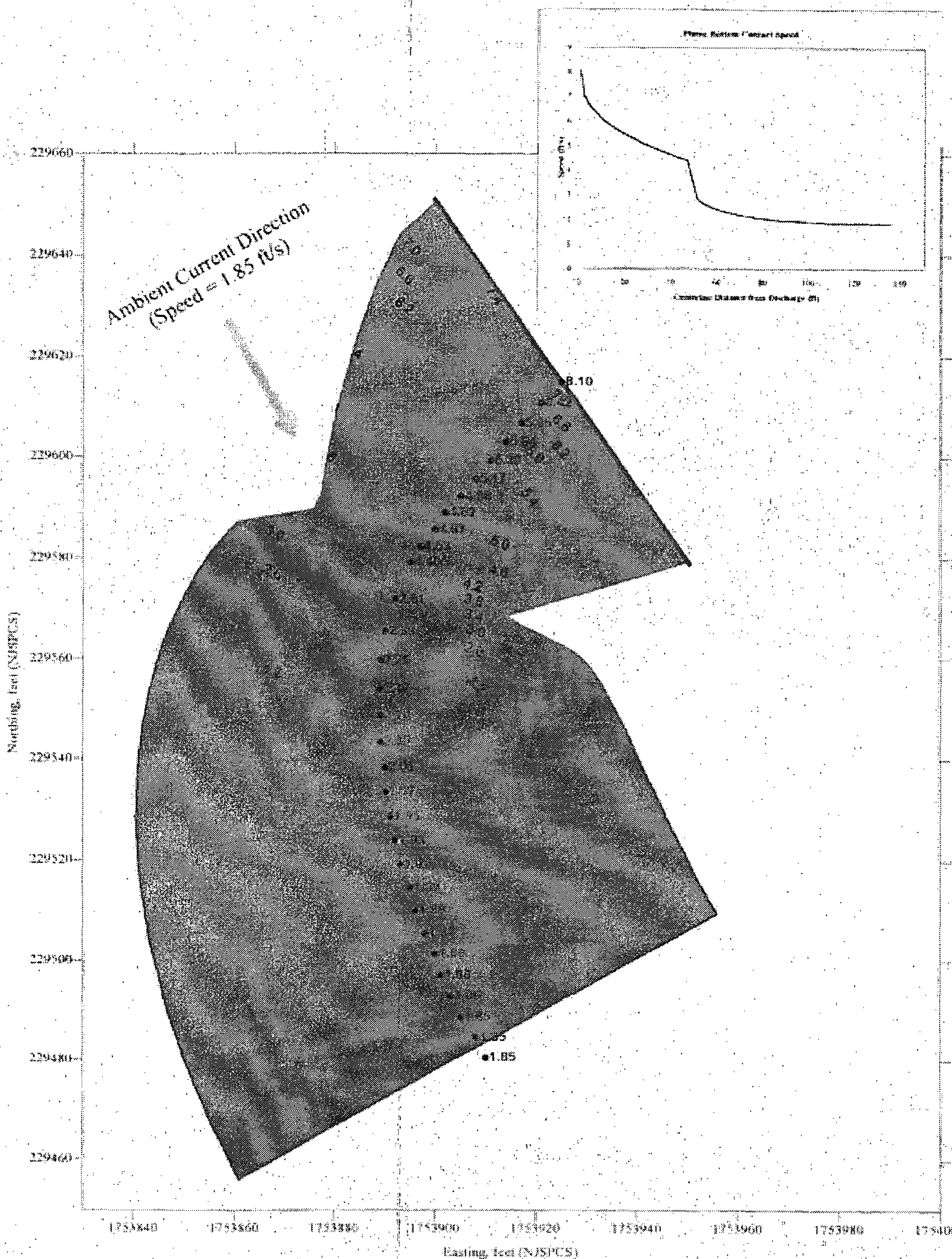
E Figure V-41. Plume Centerline Delta-T (degrees F) End-of-Ebb Tidal Phase, 6/2/98 0000 hrs Discharge Delta-T = 23.2 deg.F (Relative to Ambient Temperature).



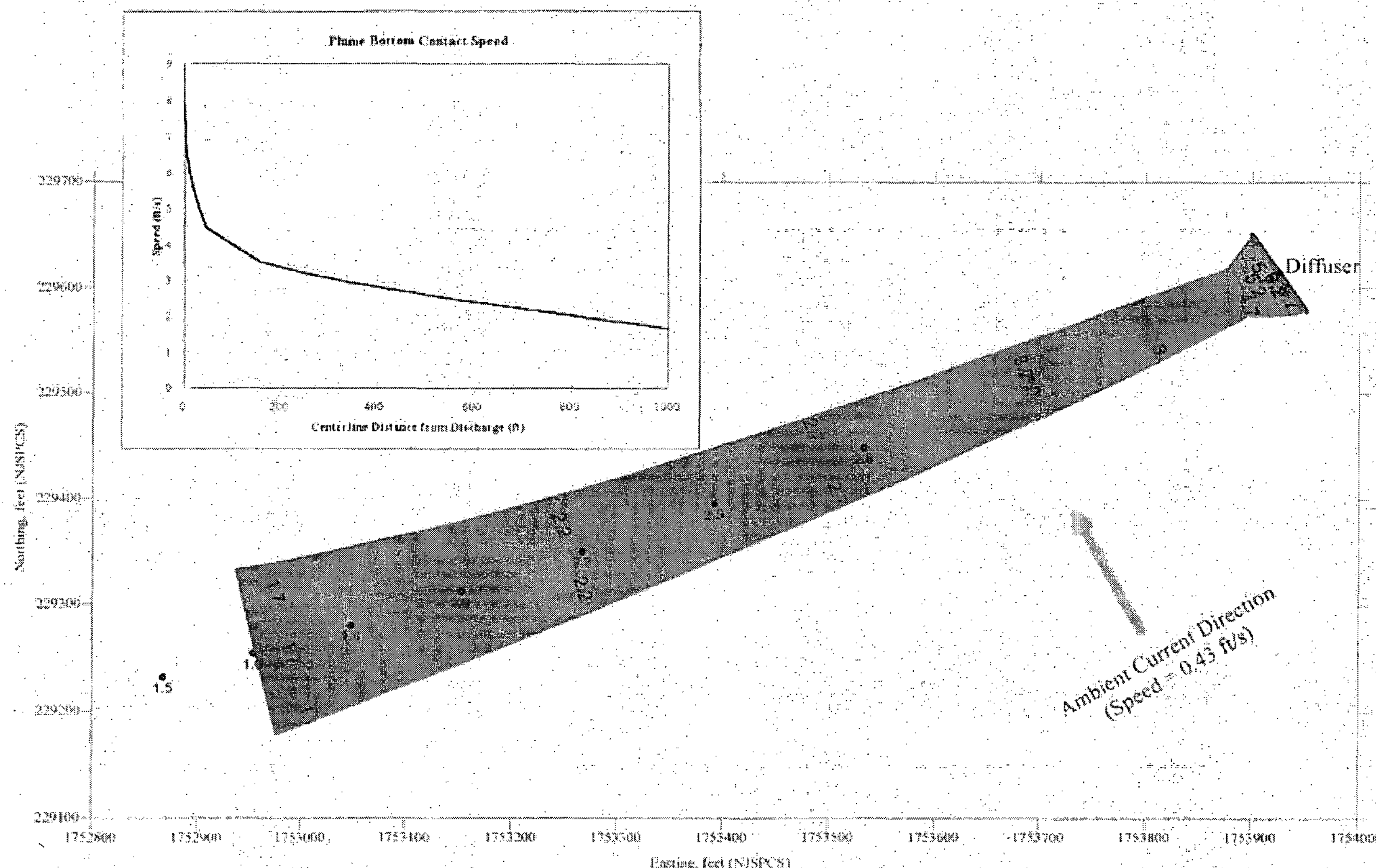
E Figure V-42. Plume Centerline Delta-T (degrees F) Flood Tidal Phase, 6/4/98 1630 hrs Discharge Delta-T = 21.2 deg.F (Relative to Ambient Temperature).



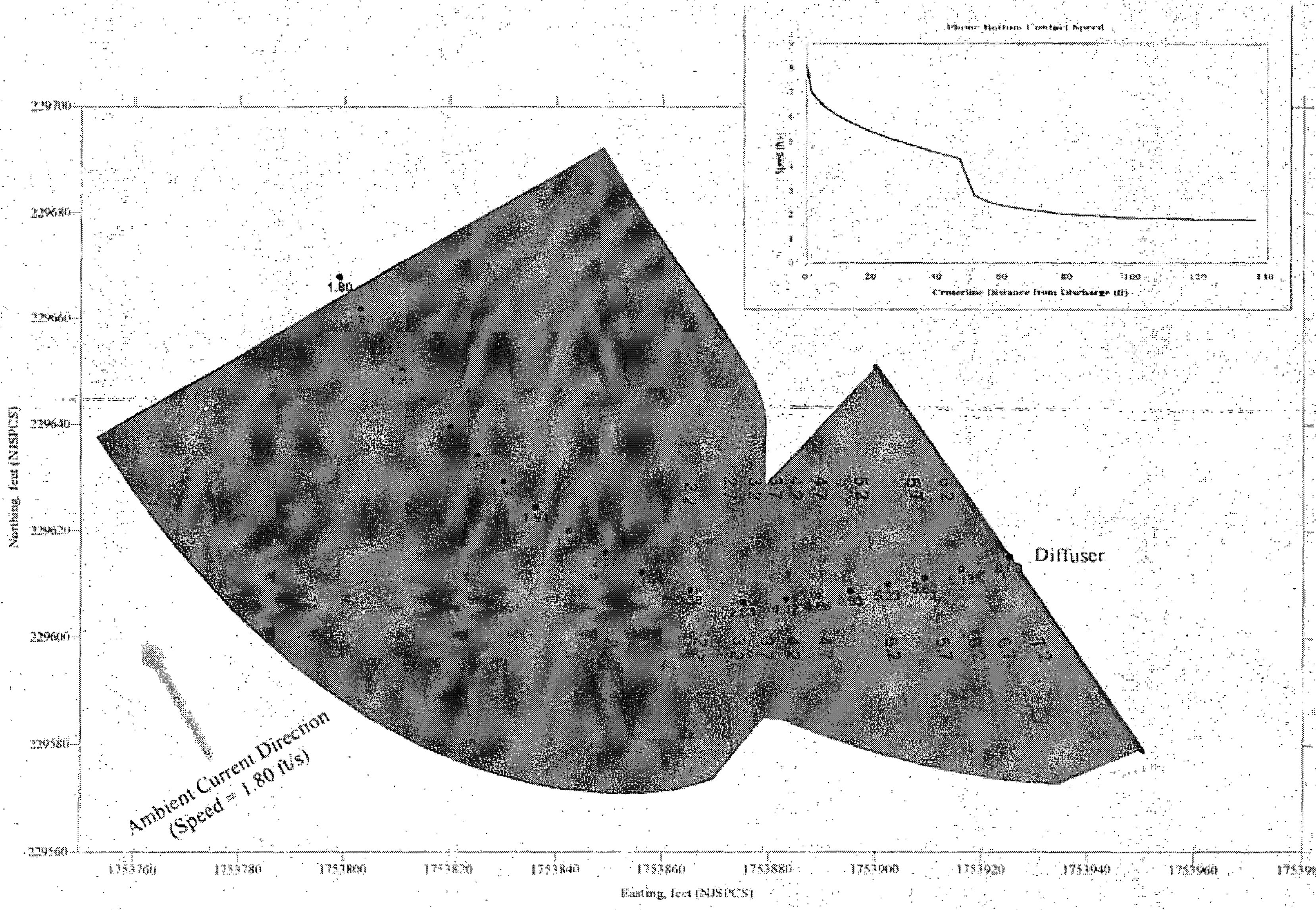
E Figure V-43. Plume Centerline Delta-T (degrees F) End-of-Flood Tidal Phase, 5/31/98 1600 hrs Discharge Delta-T = 21.8 deg.F (Relative to Ambient Temperature).



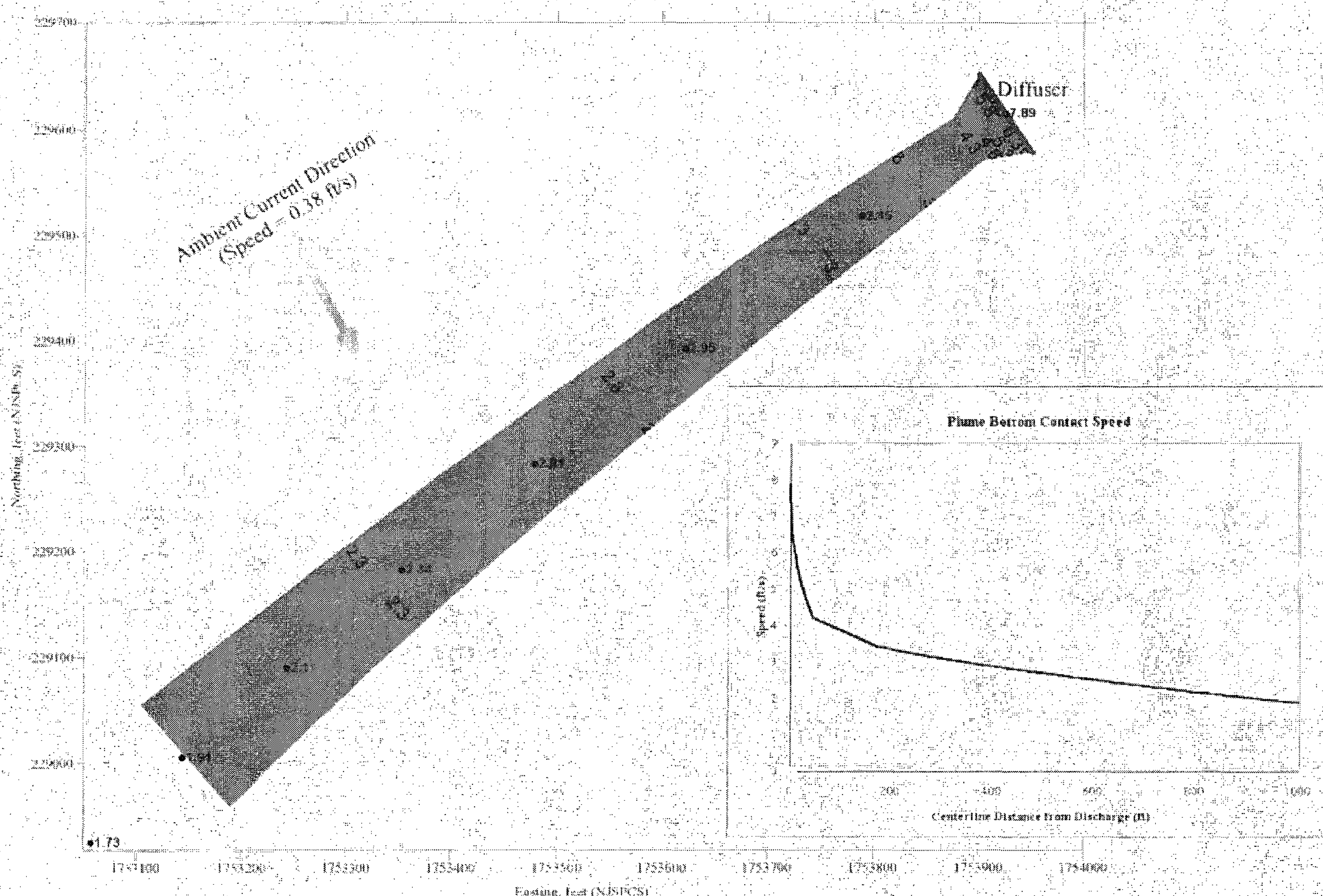
E Figure V-44. Plume Bottom Contact Velocity (feet per second) Ebb Tidal Phase, 6/2/98 0830 hrs.



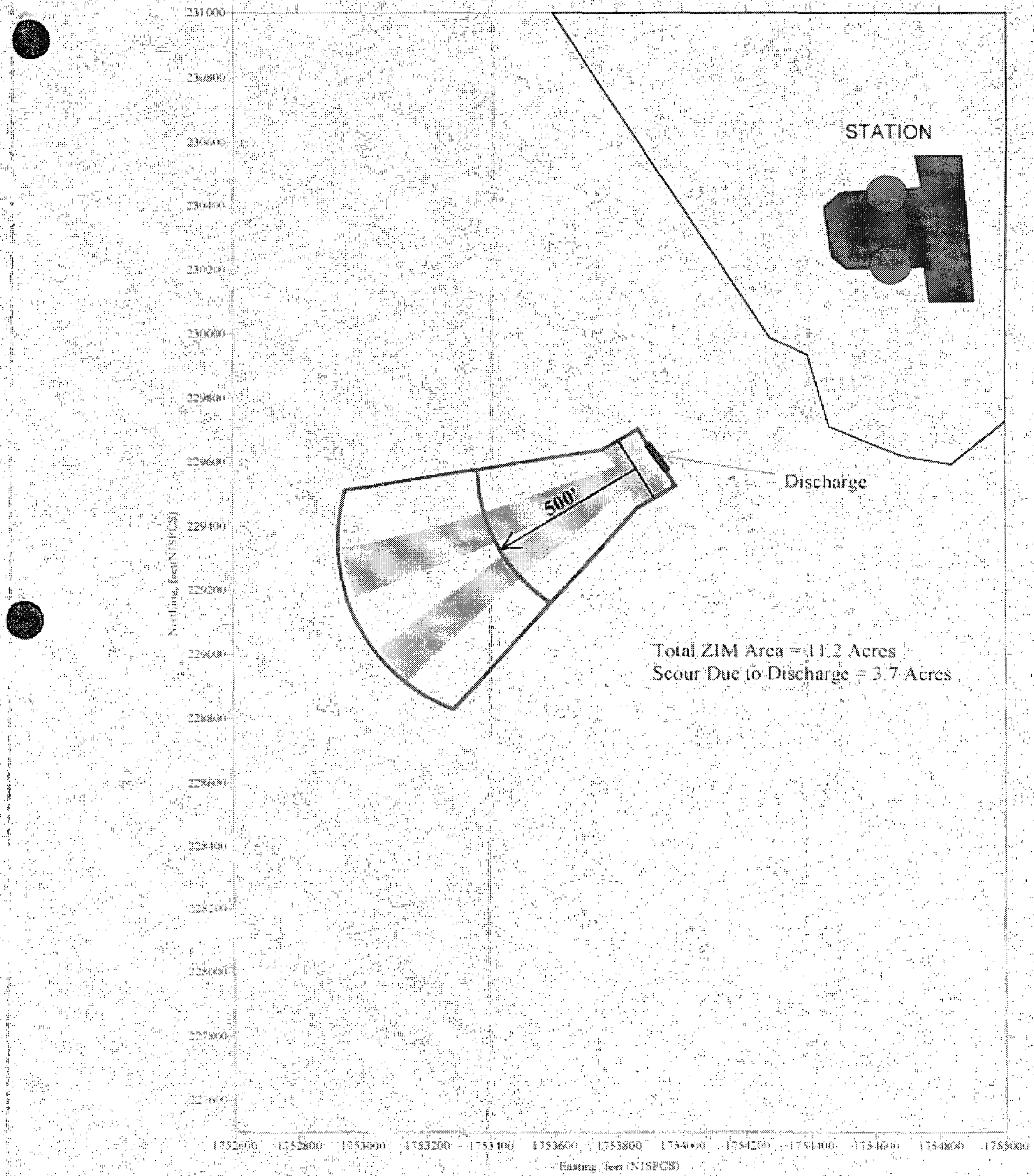
E Figure V-45. Plume Bottom Contact Velocity (feet per second) End-of-Ebb Tidal Phase, 6/2/98 0000 hrs.



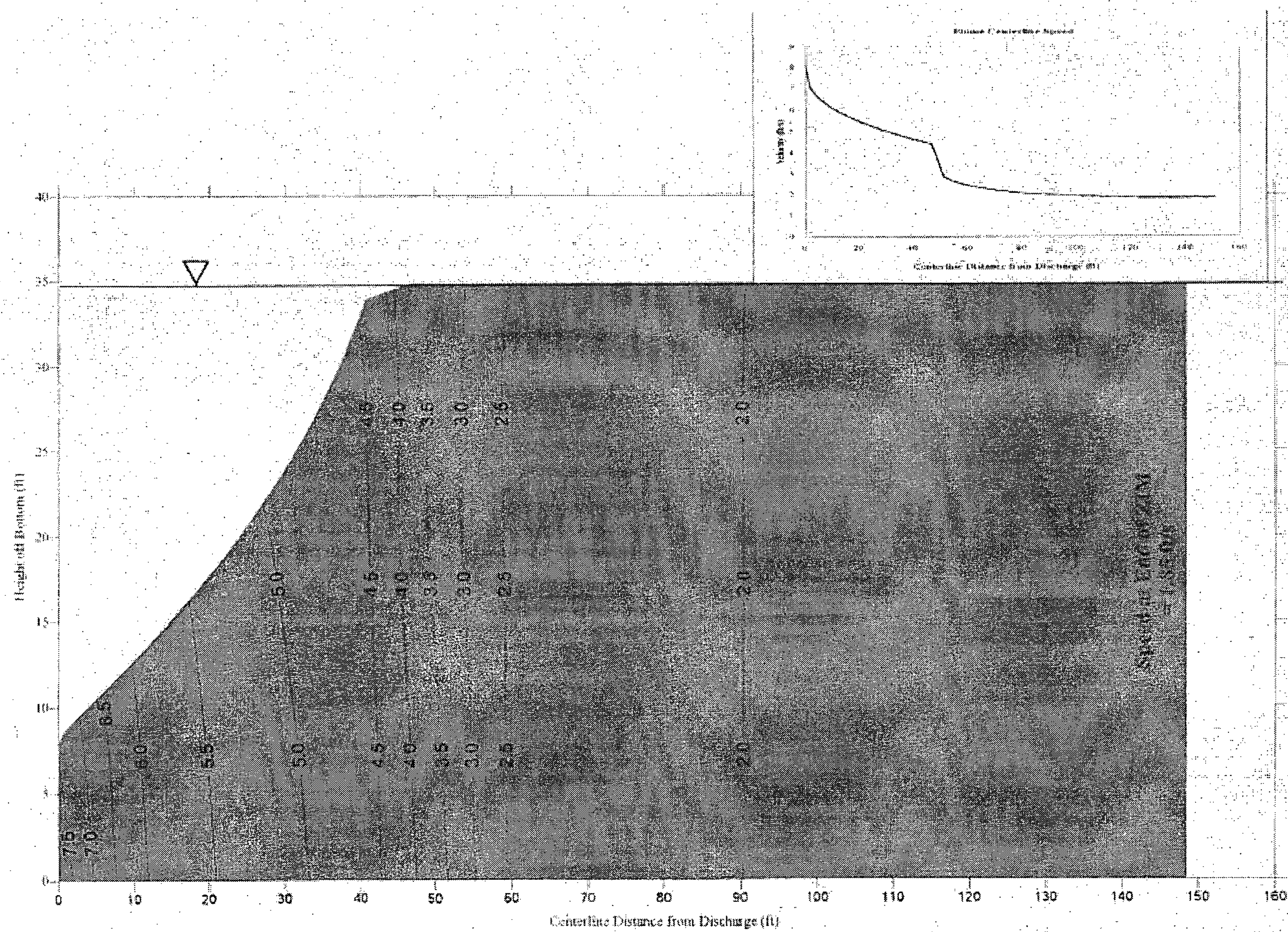
E Figure V-46. Plume Bottom Contact Velocity (feet per second) Flood Tidal Phase, 6/4/98 1630 hrs.



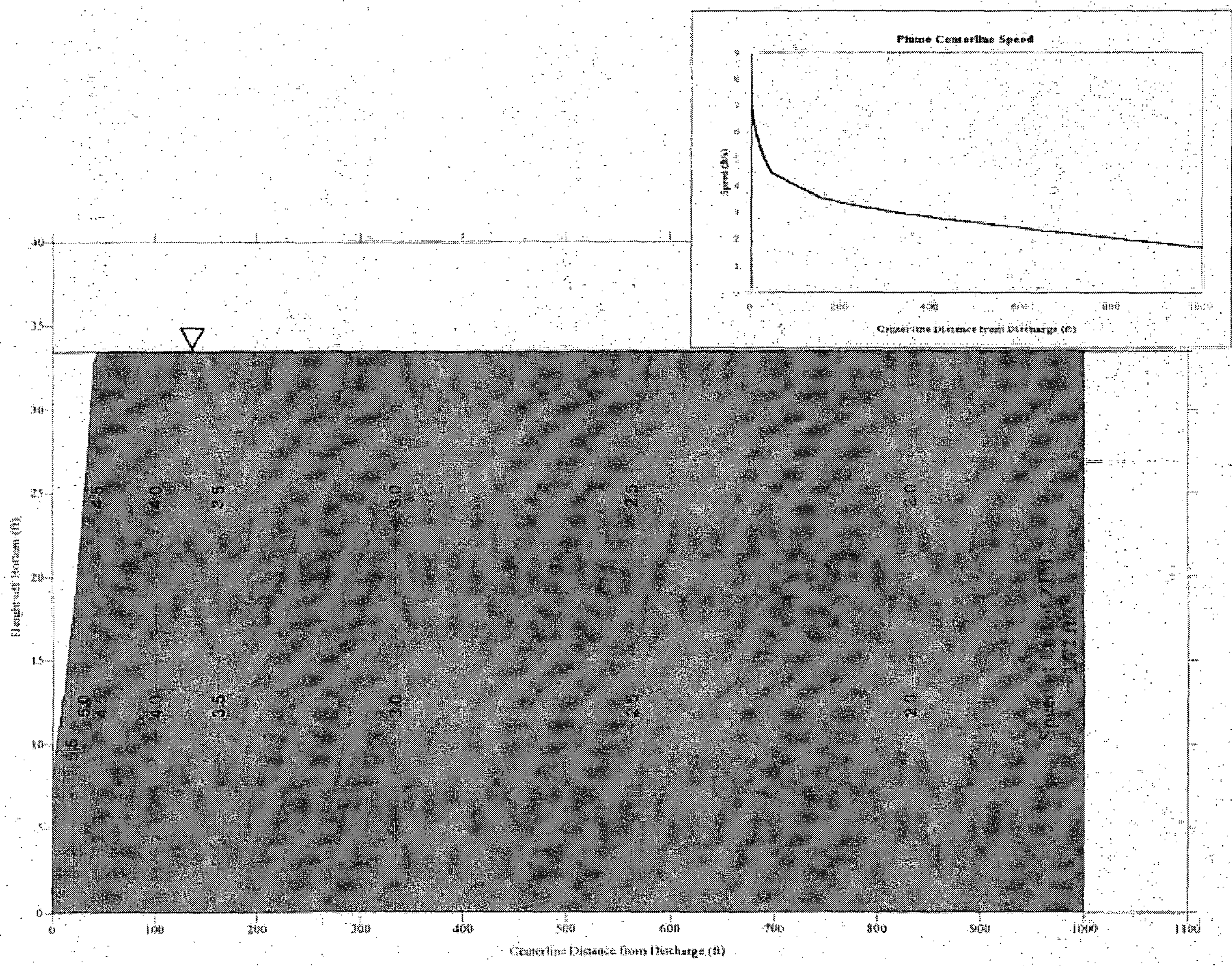
E Figure V-47. Plume Bottom Contact Velocity (feet per second) End-of-Flood Tidal Phase, 5/31/98 1600 hrs.



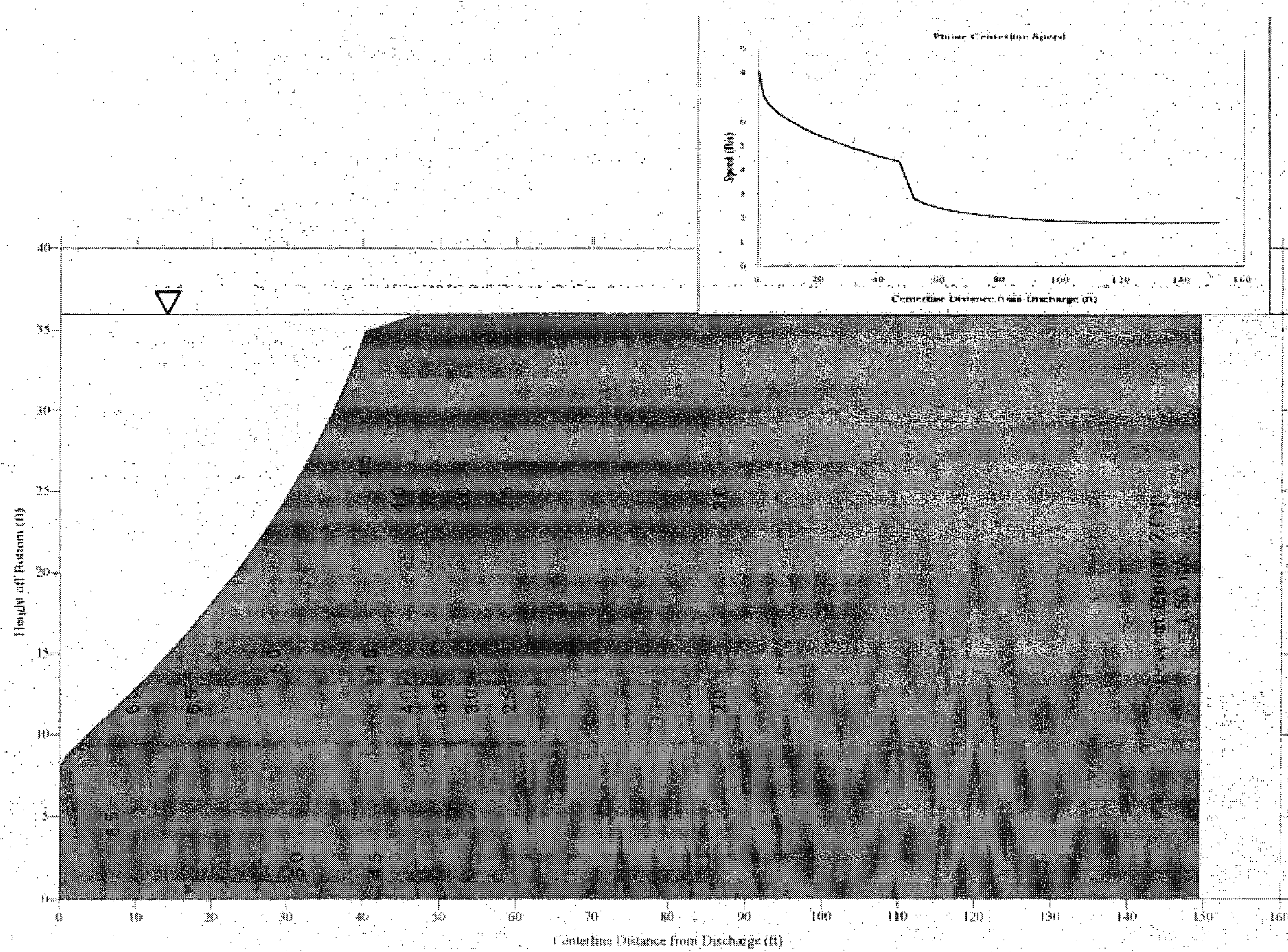
E Figure V-48. Scour area within momentum-dominated near-field region. Shaded area represents ZIMs for four tidal phases. Refer to E-1-4 Figure IV-2 for bathymetric indication of scour.



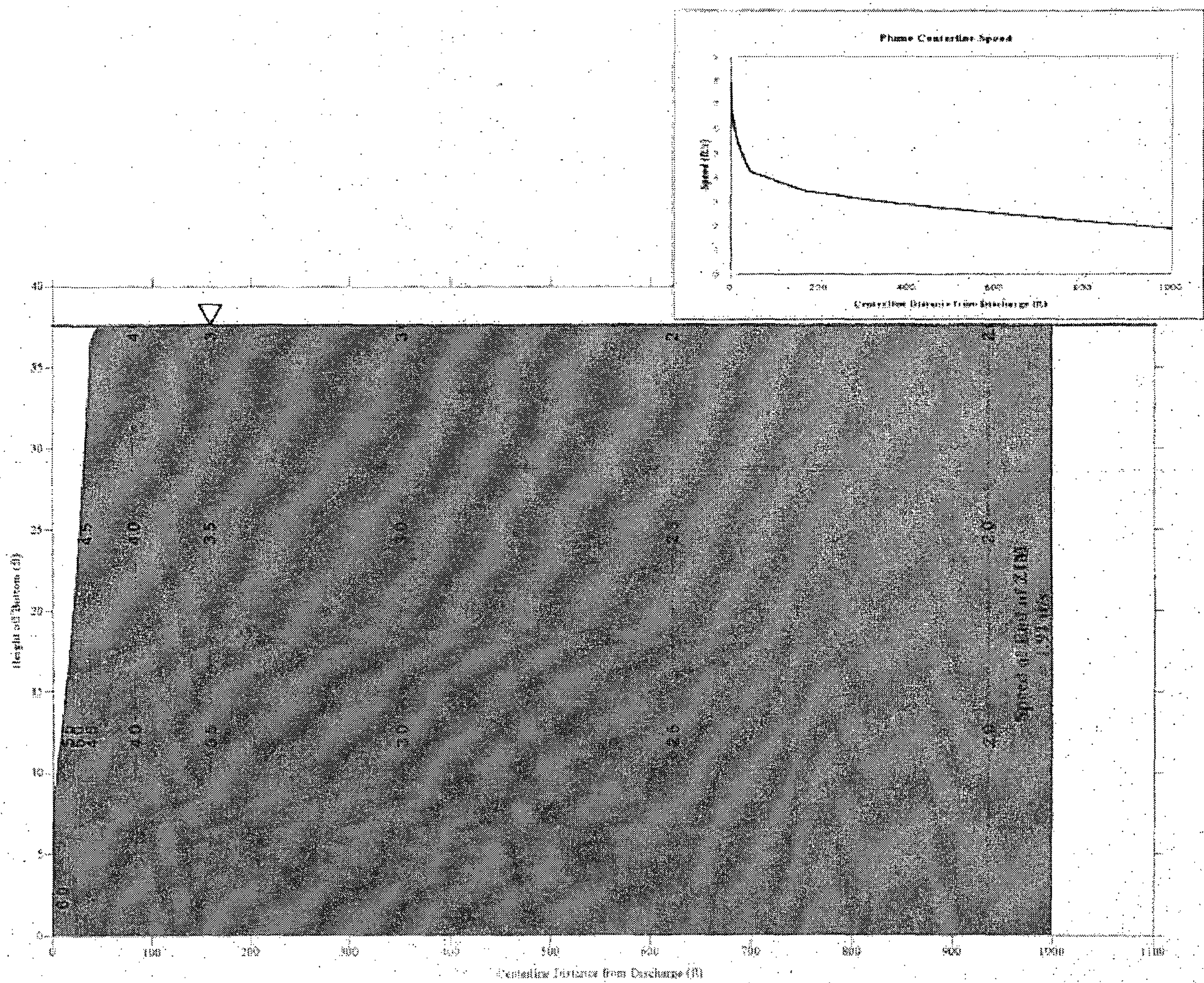
E Figure V-49. Plume Centerline Velocity (feet per second) Ebb Tidal Phase, 6/2/98 0830 hrs Ambient Velocity = 1.85 ft/s.



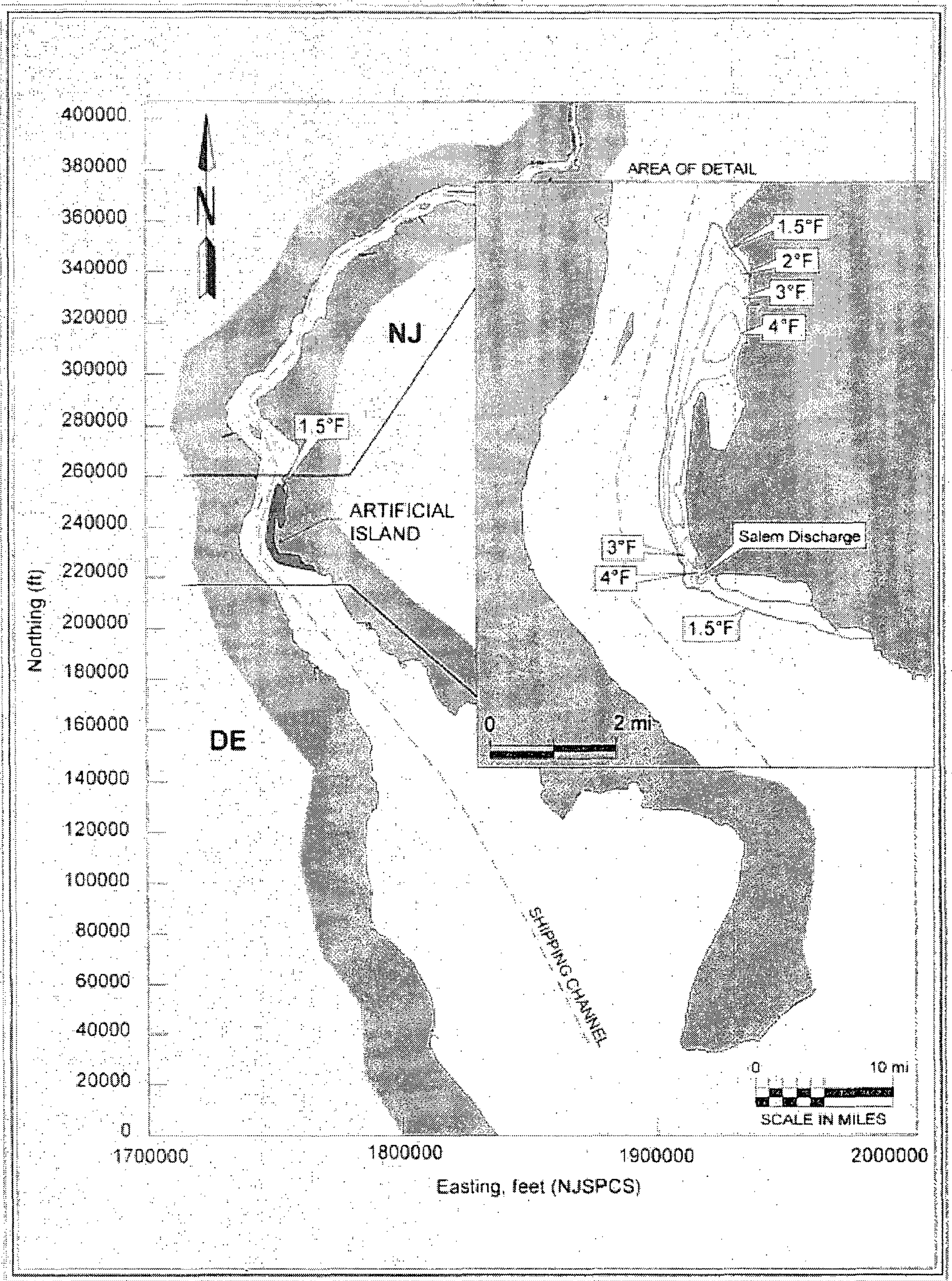
E Figure V-50. Plume Centerline Velocity (feet per second) End-of-Ebb Tidal Phase, 6/2/98 0000 hrs Ambient Velocity = 0.43 ft/s.



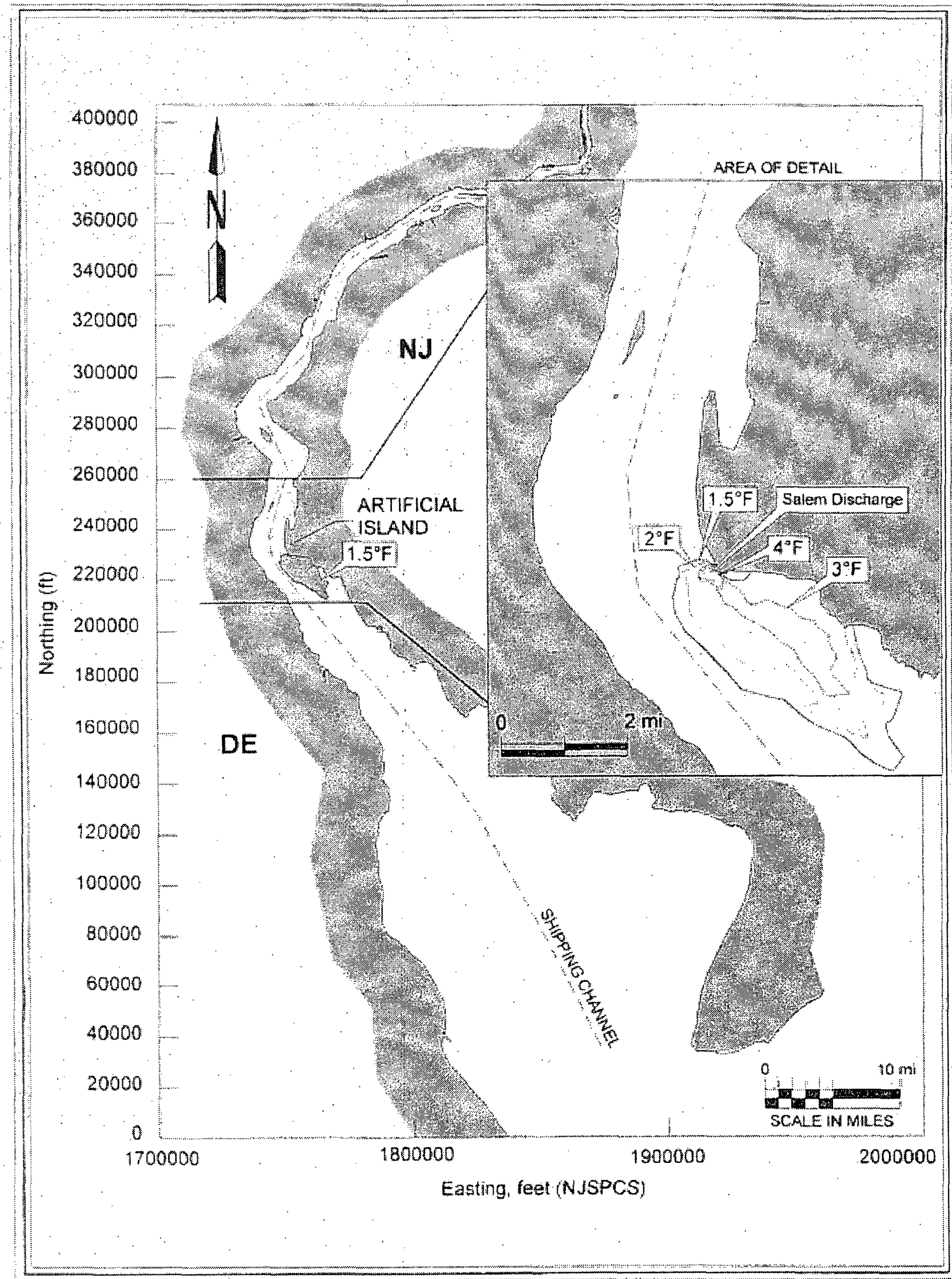
E Figure V-51. Plume Centerline Velocity (feet per second) Flood Tidal Phase, 6/4/98 1630 hrs Ambient Velocity = 1.80 ft/s.



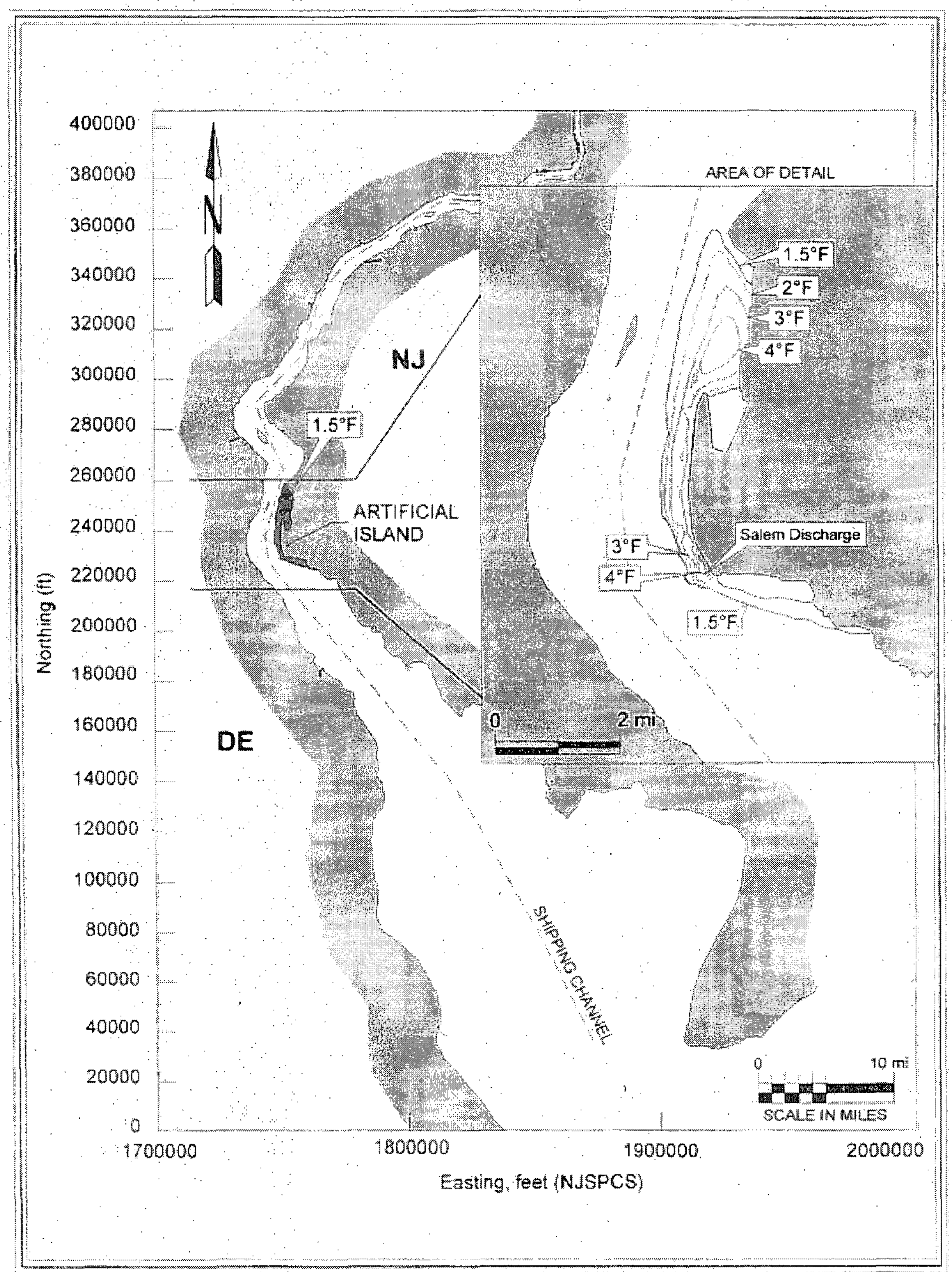
E Figure V-52. Plume Centerline Velocity (feet per second) End-of-Flood Tidal Phase, 5/31/98 1600 hrs Ambient Velocity = 0.38 ft/s.



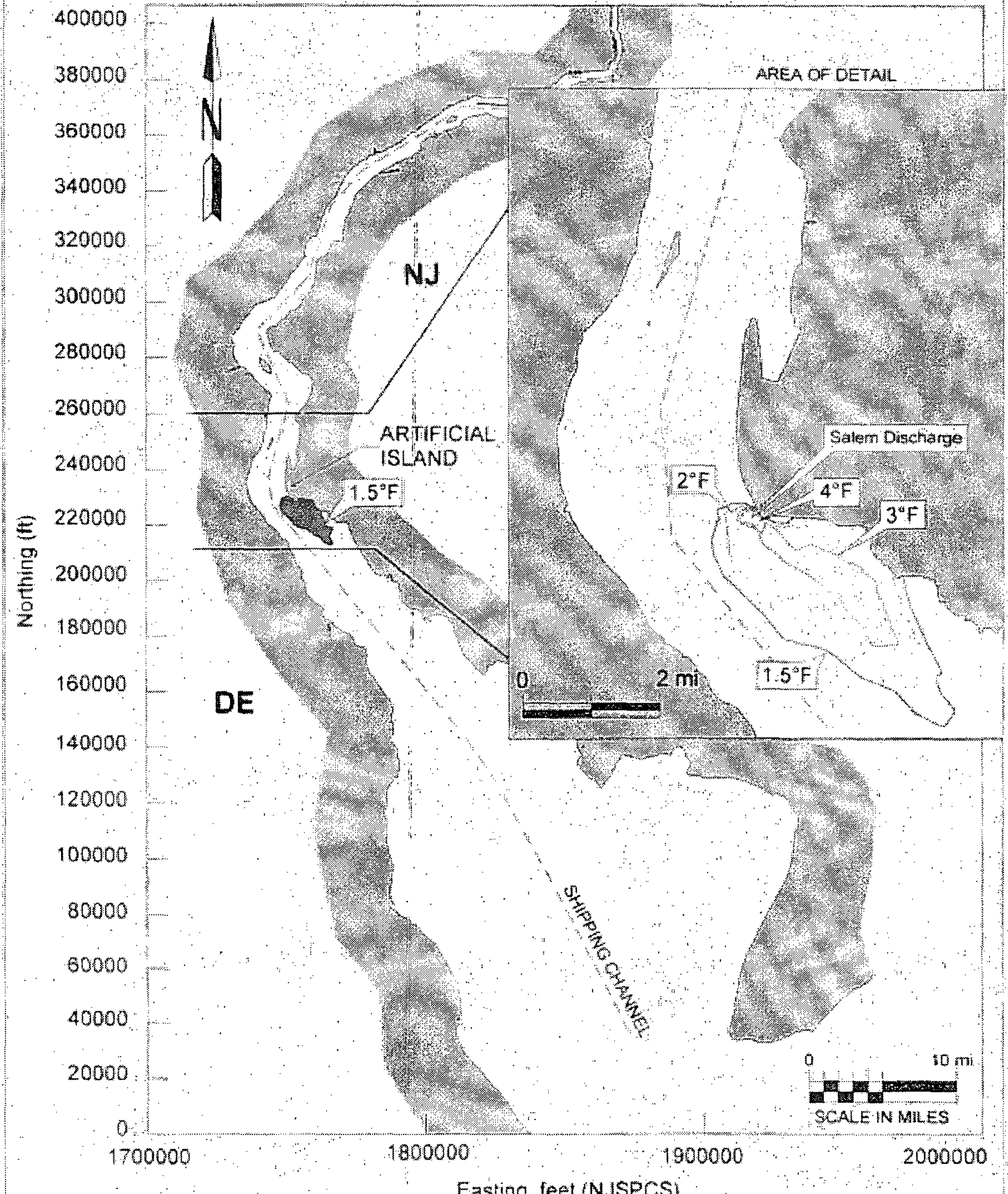
E-2 Figure V-53. Surface ΔT isotherms for Salem's longest plume at end-of-flood on 31 May 1998



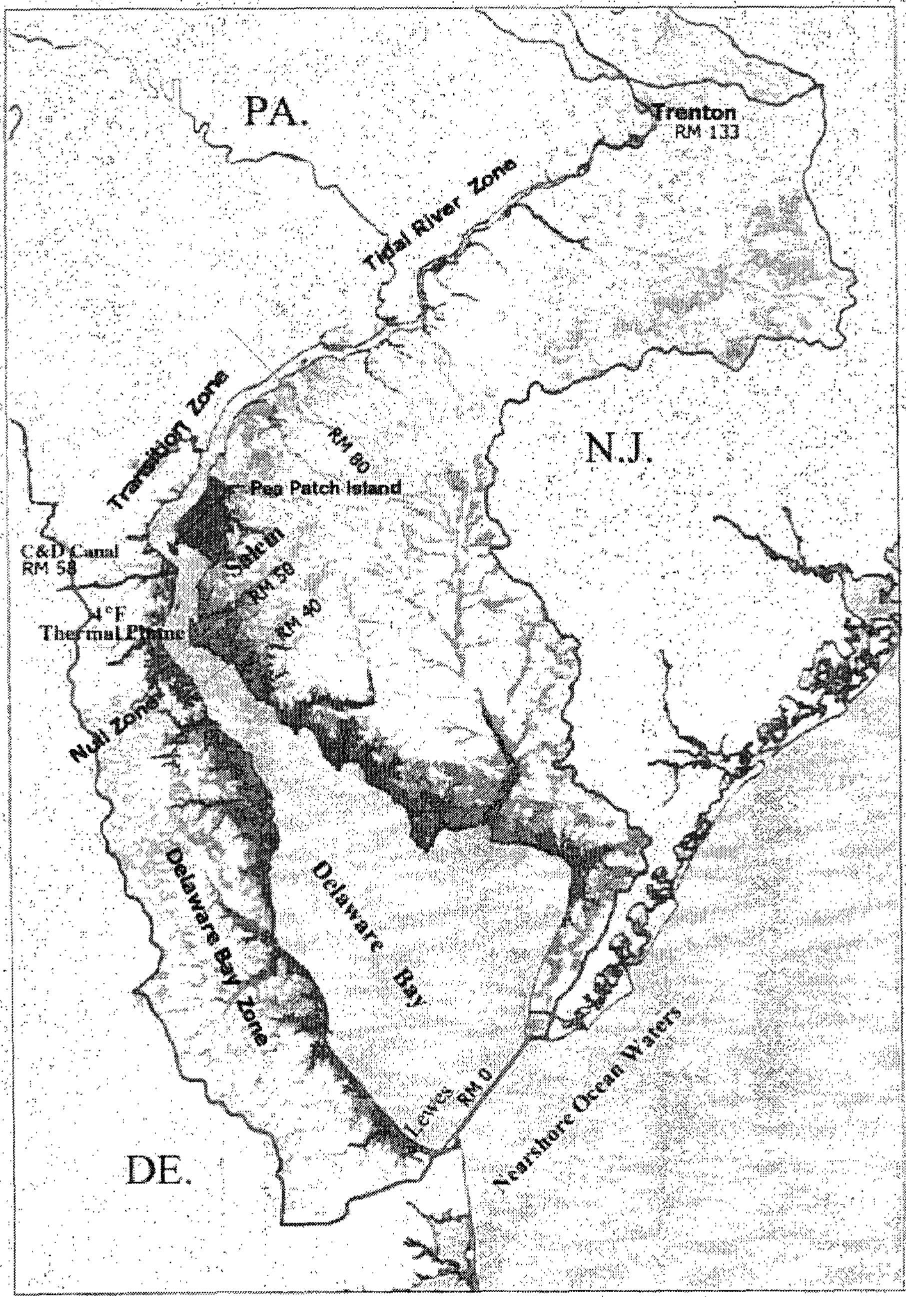
E Figure V-54. Surface ΔT isotherms for Salem at end-of-ebb on 2 June 1998.



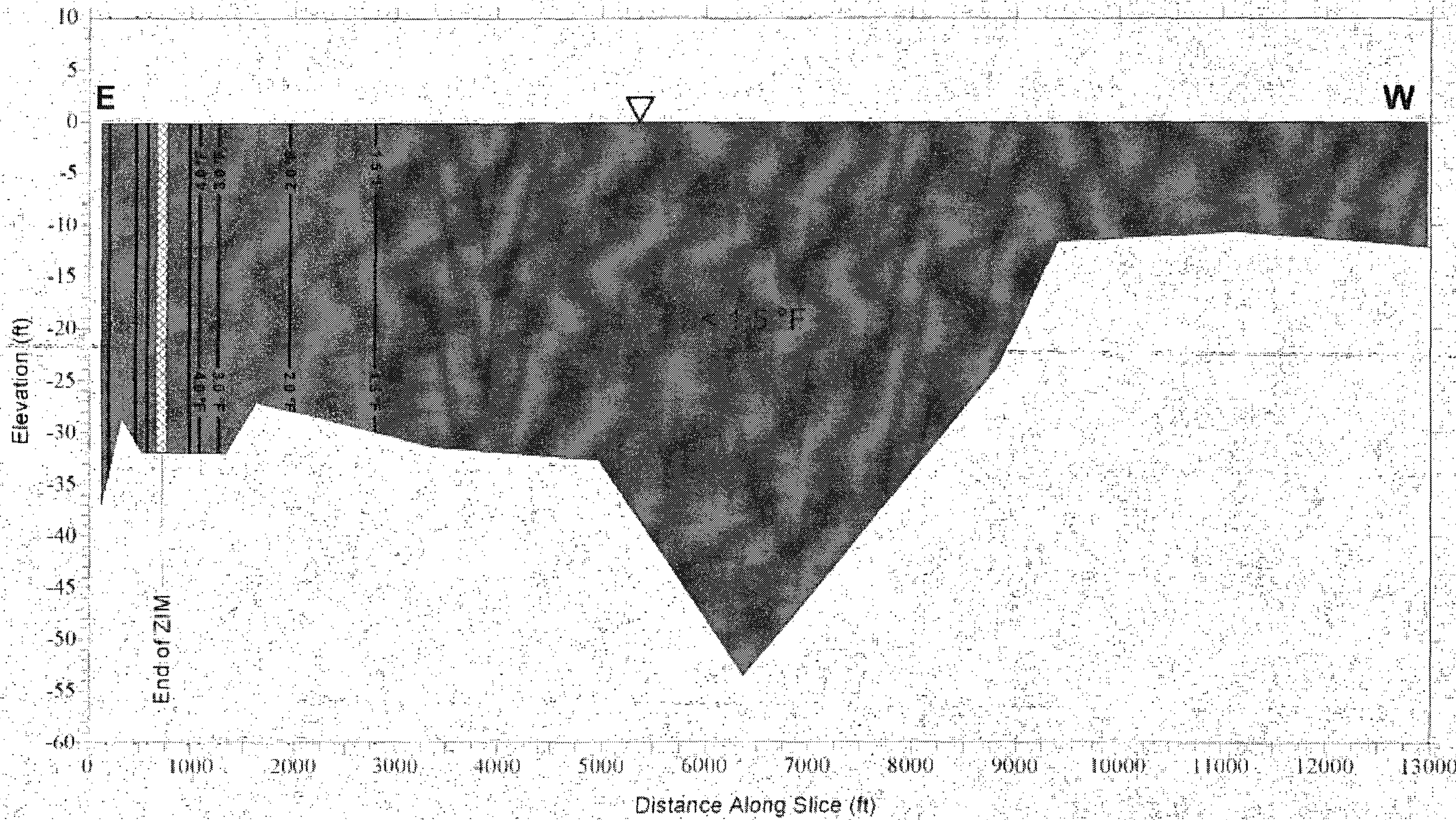
E-2 Figure V-55. Bottom ΔT isotherms for Salem's longest plume at end-of-flood on 31 May 1998



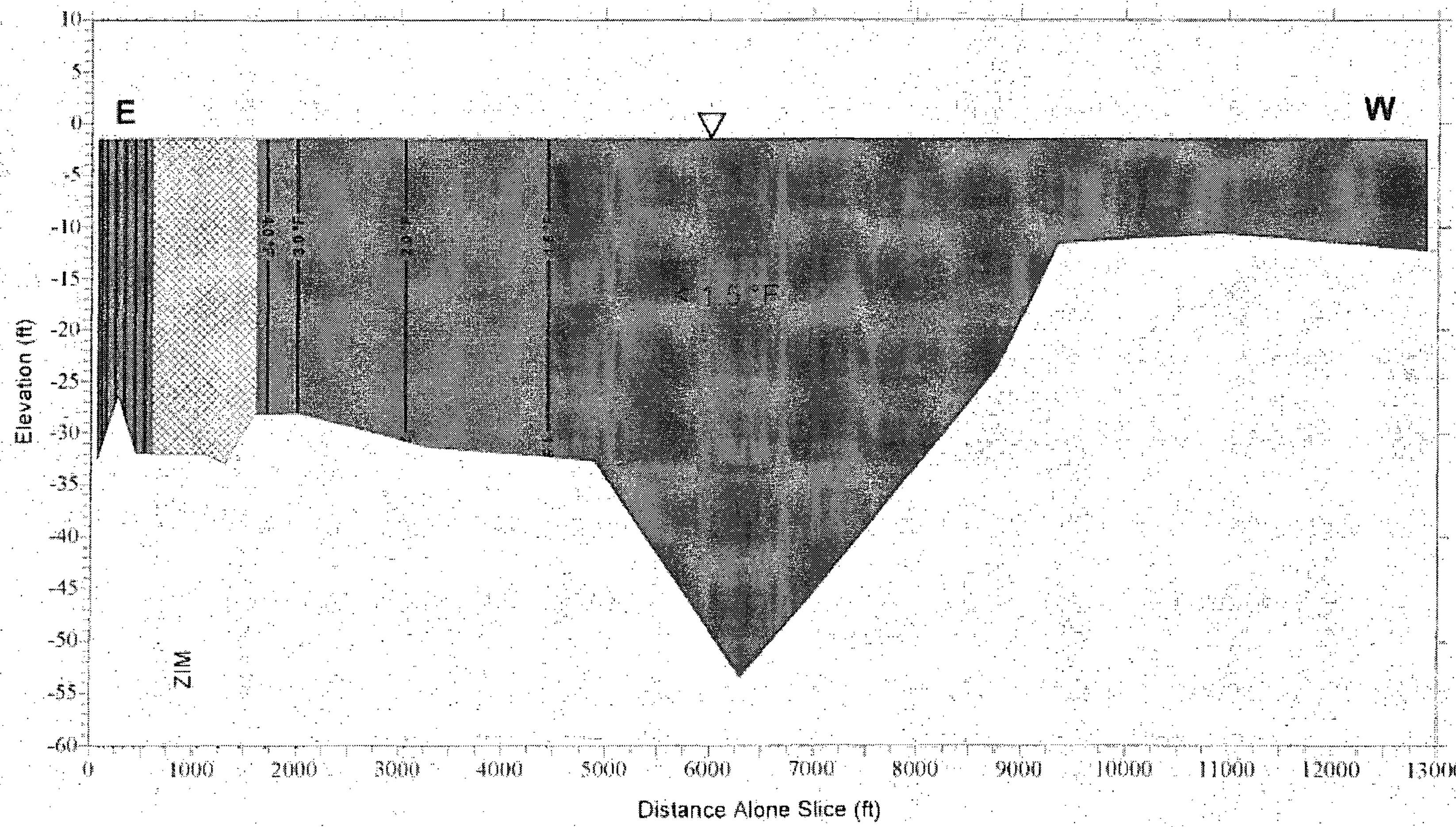
E Figure V-56. Bottom ΔT isotherms for Salem at end-of-ebb on 2 June 1998.



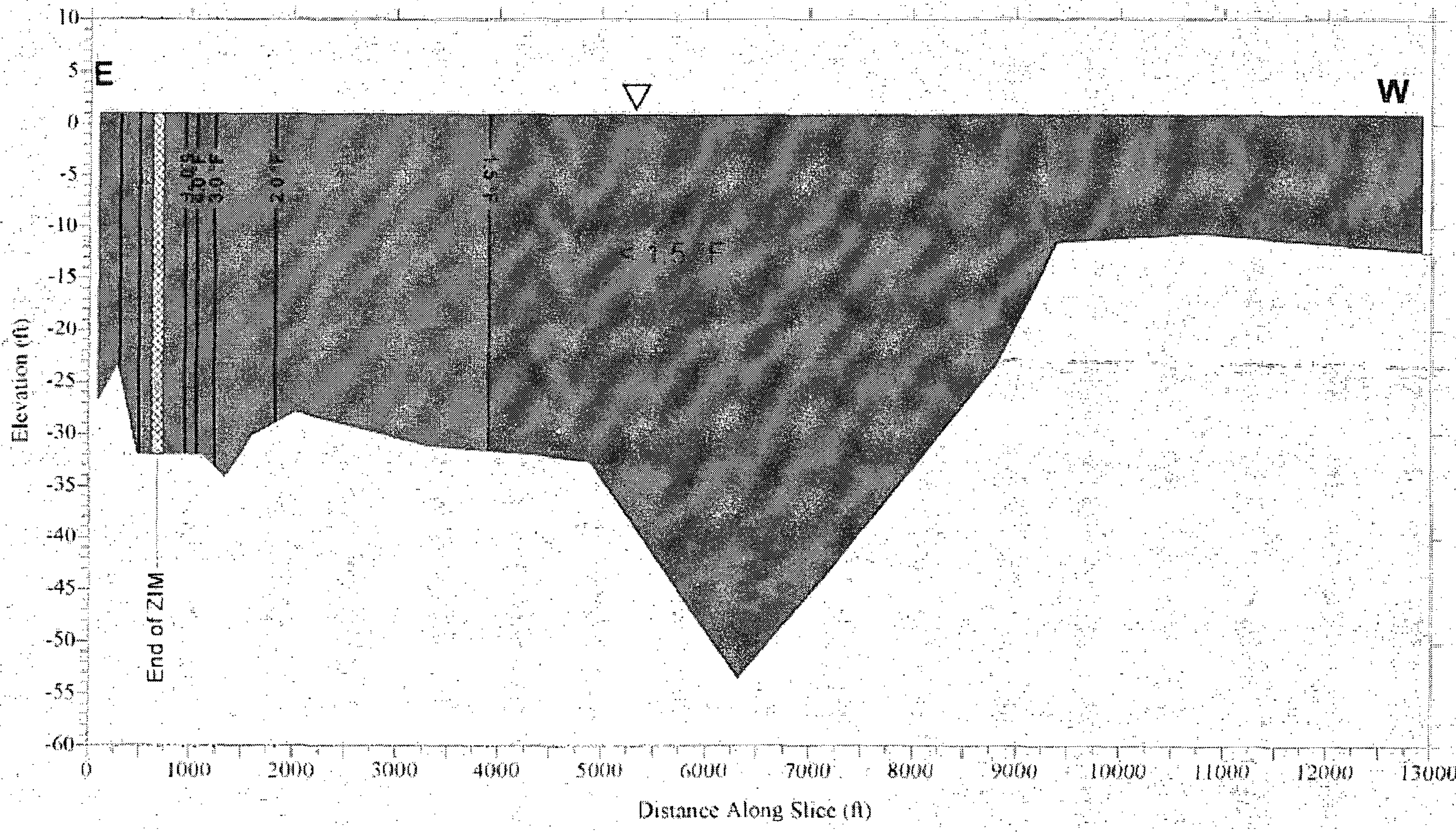
E Figure V-57. Plume isopleth of 4° F in relation to the Delaware Estuary.



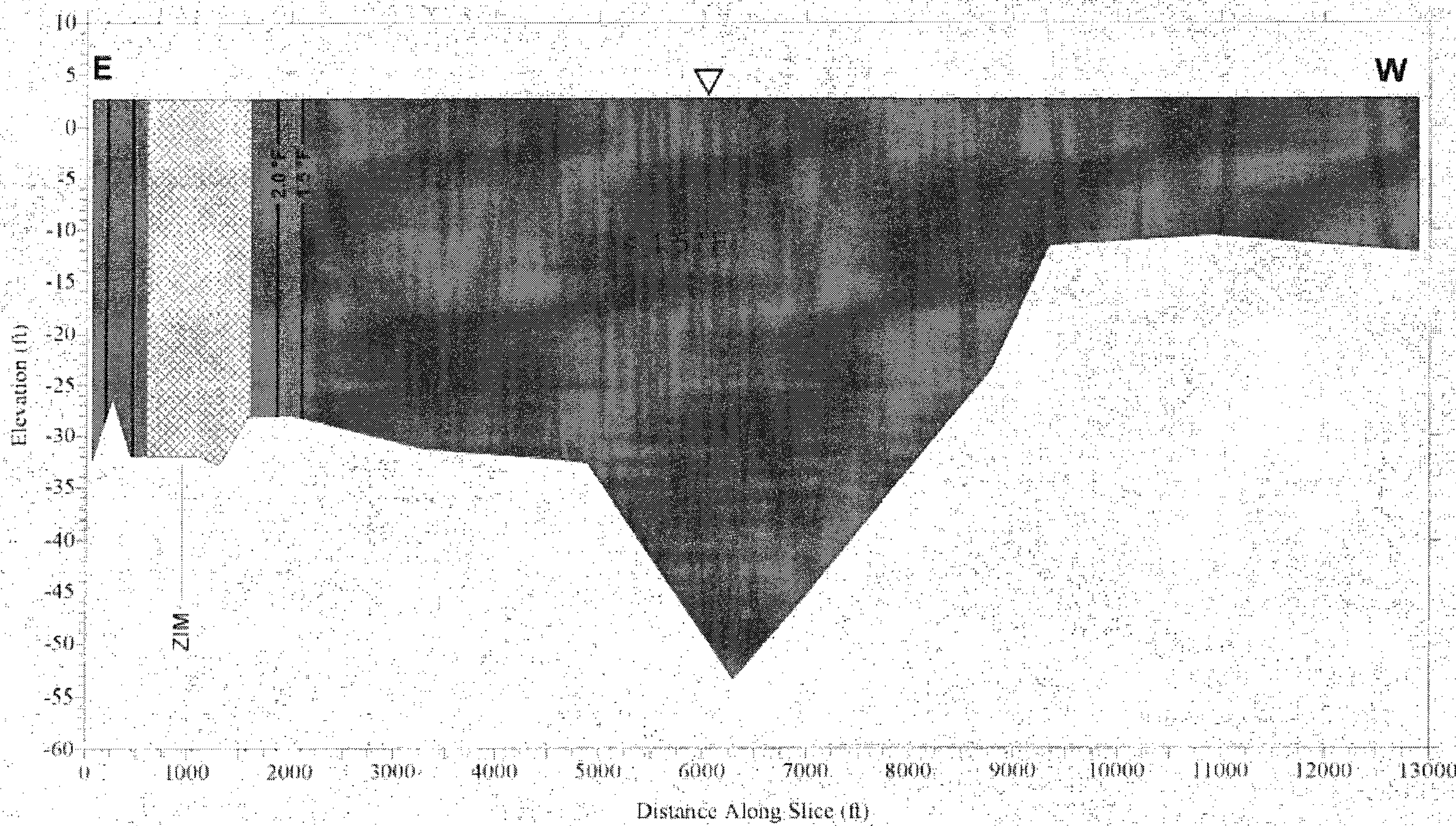
E Figure V-58. Delaware River delta-T cross-section looking down-river at end of ZIM on ebb tide, 2 June 1998, 0830 hrs.



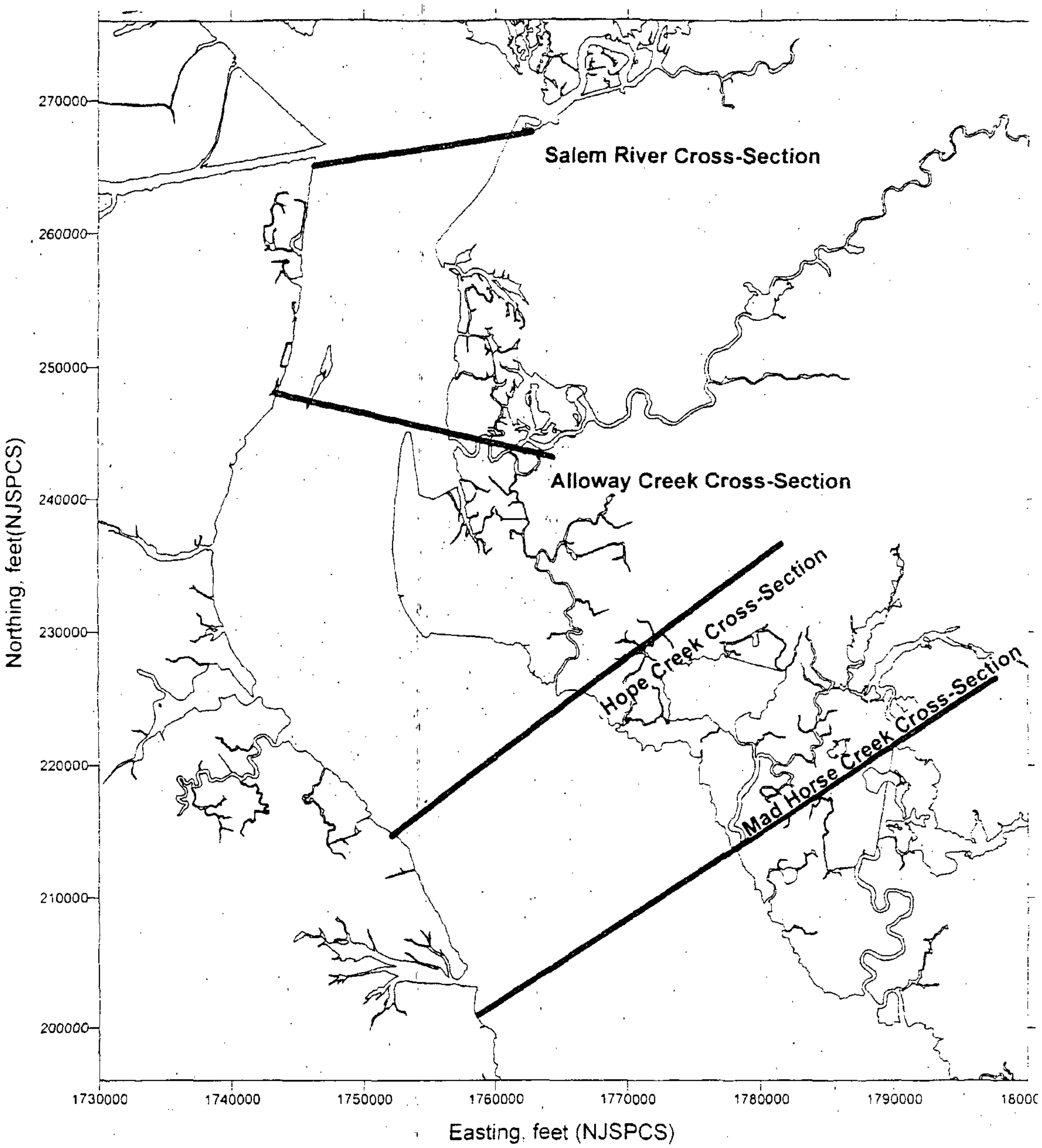
E Figure V-59: Delaware River delta-T cross-section looking down-river across ZIM on end-of-ebb tide.



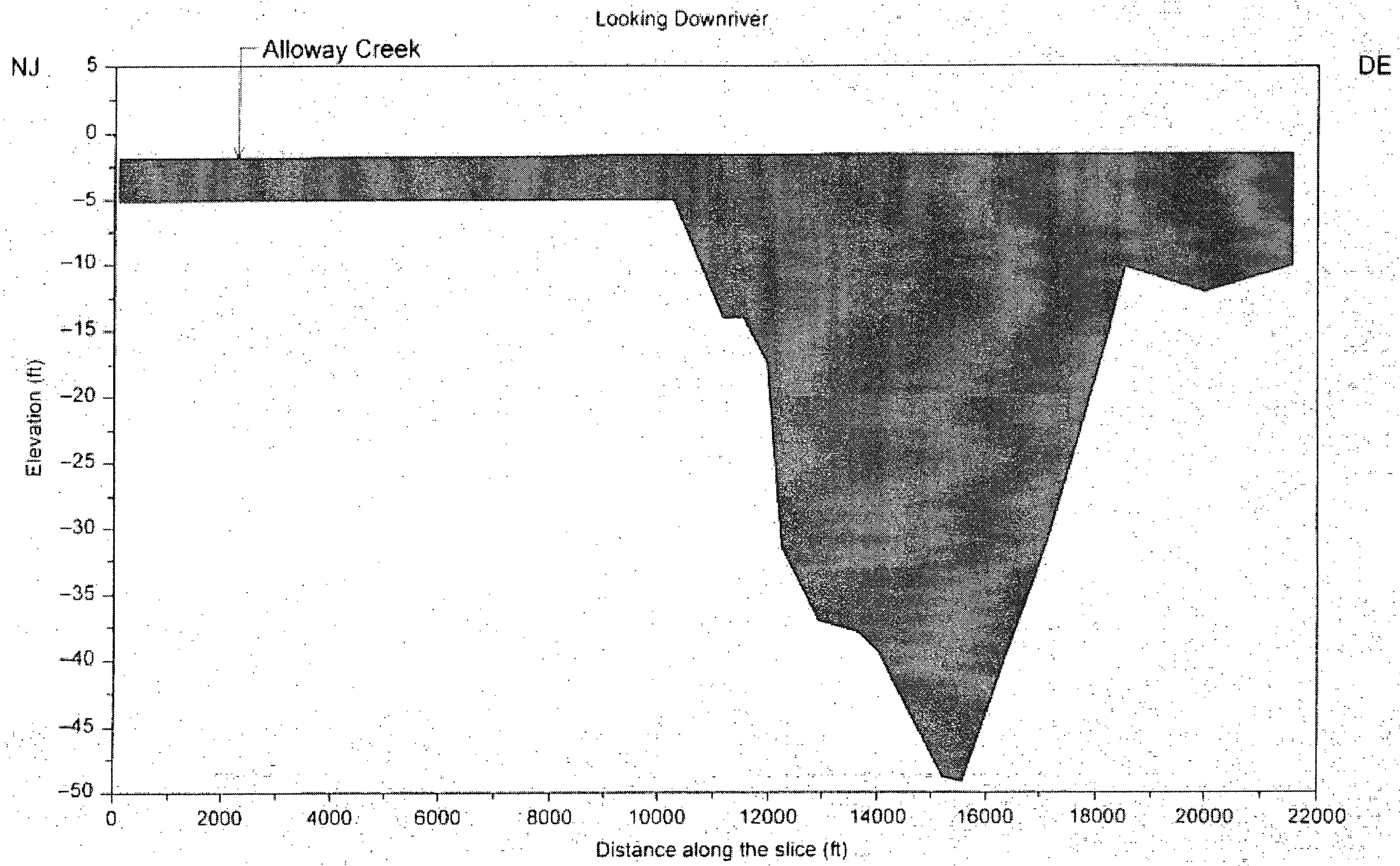
E Figure V-60. Delaware River delta-T cross-section looking down-river at end of ZIM on flood tide.



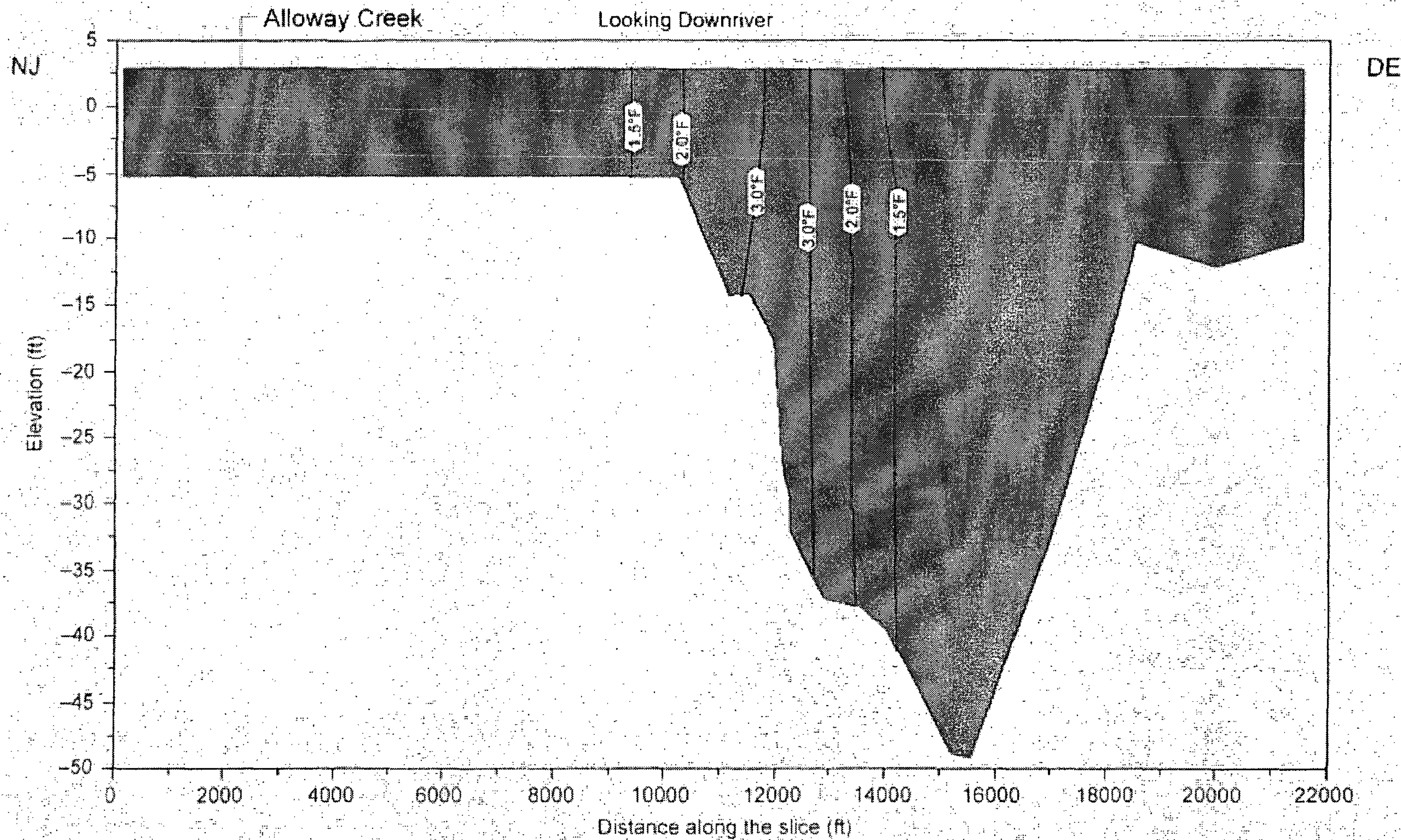
E Figure V-61. Delaware River delta-T cross-section looking down-river across ZIM on end-of-flood tide.



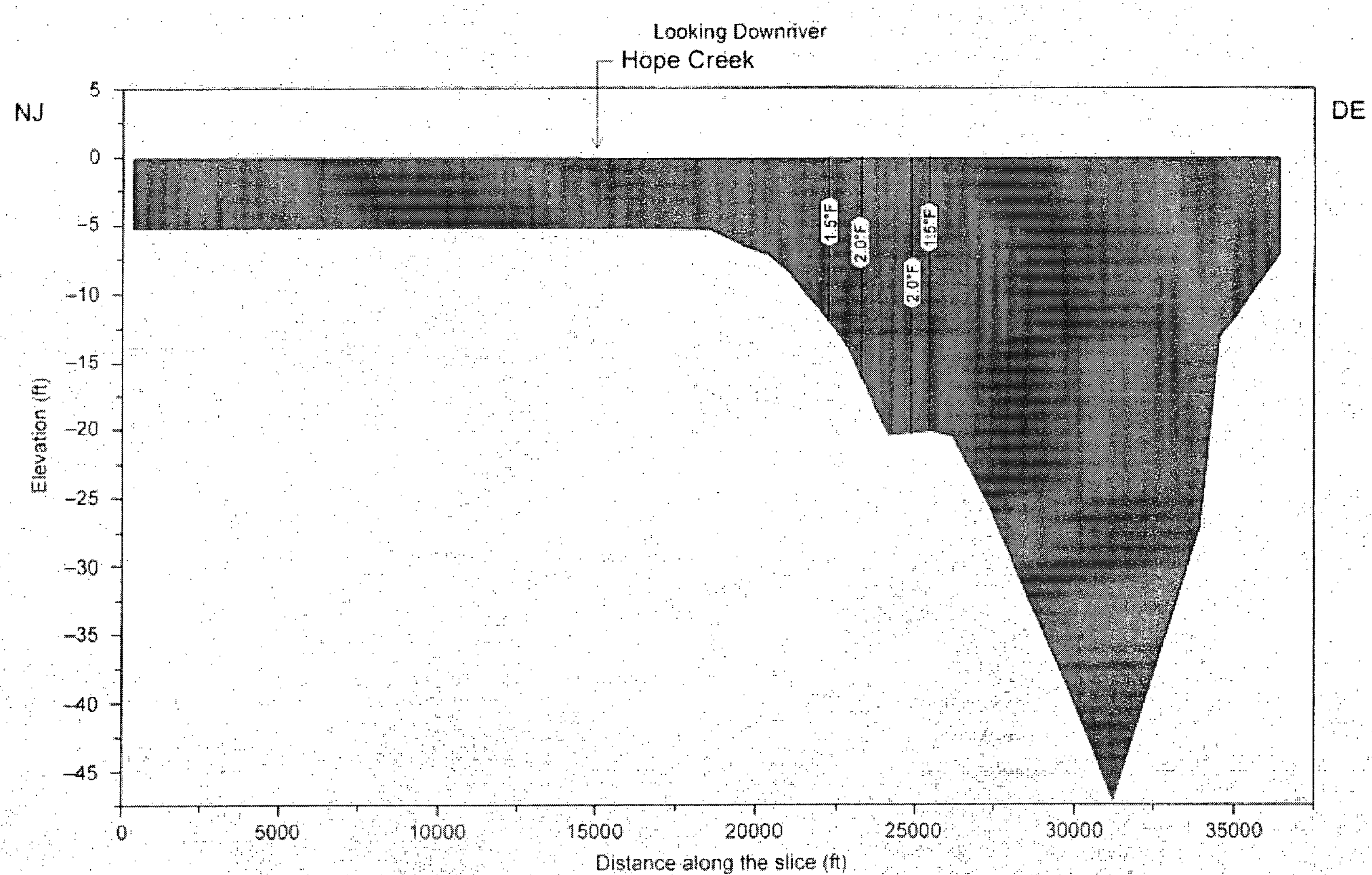
E Figure V-62. Locations of Delaware River cross-sections at mouths of tributaries.



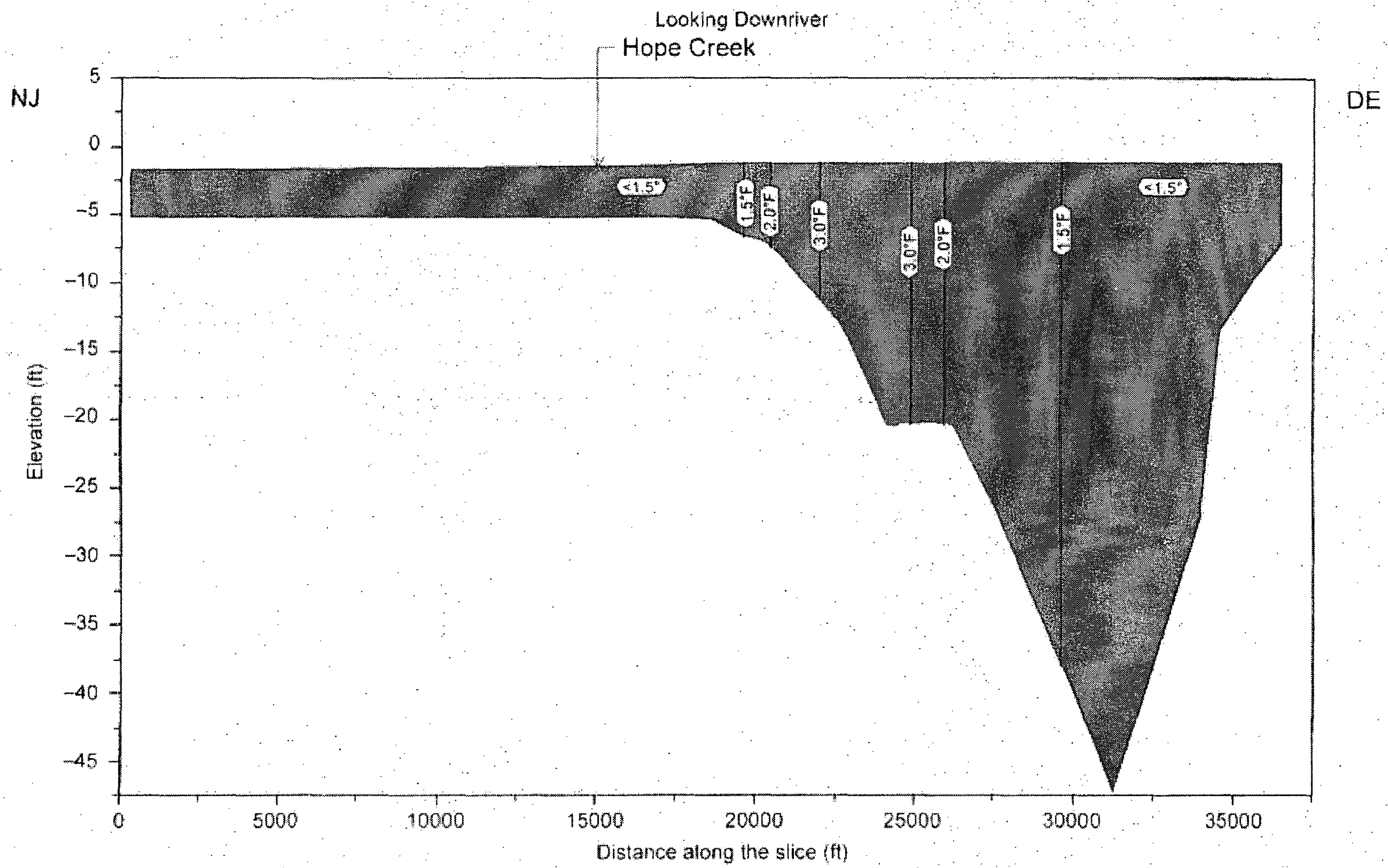
E Figure V-63. Cross section of ΔT: Delaware River at Alloway Creek on end-of-ebb tide, 6/2/98, 08:30.



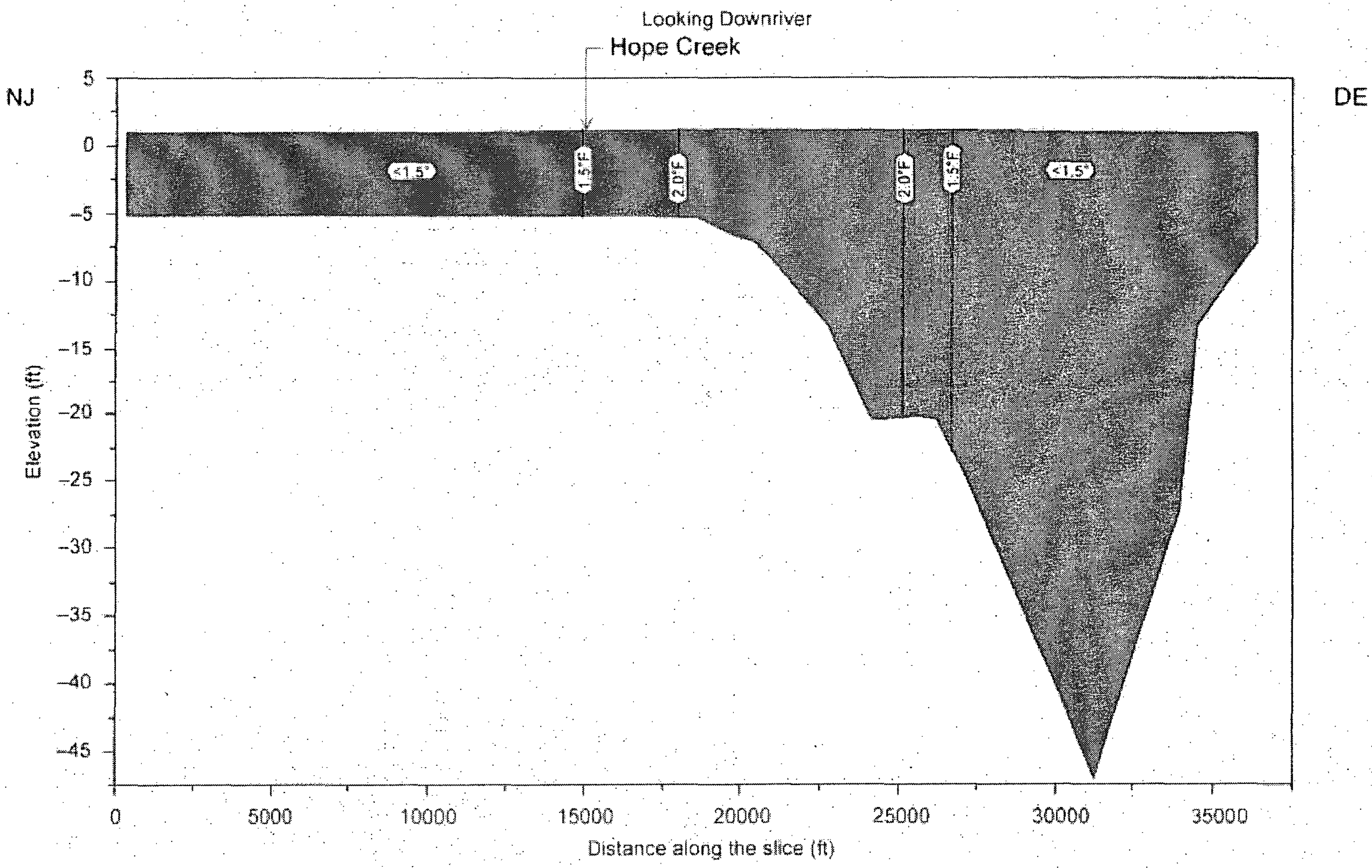
E Figure V-64. Cross-section of ΔT: Delaware River at Alloway Creek on end-of-flood tide, 3 June 1998, 1600 hrs.



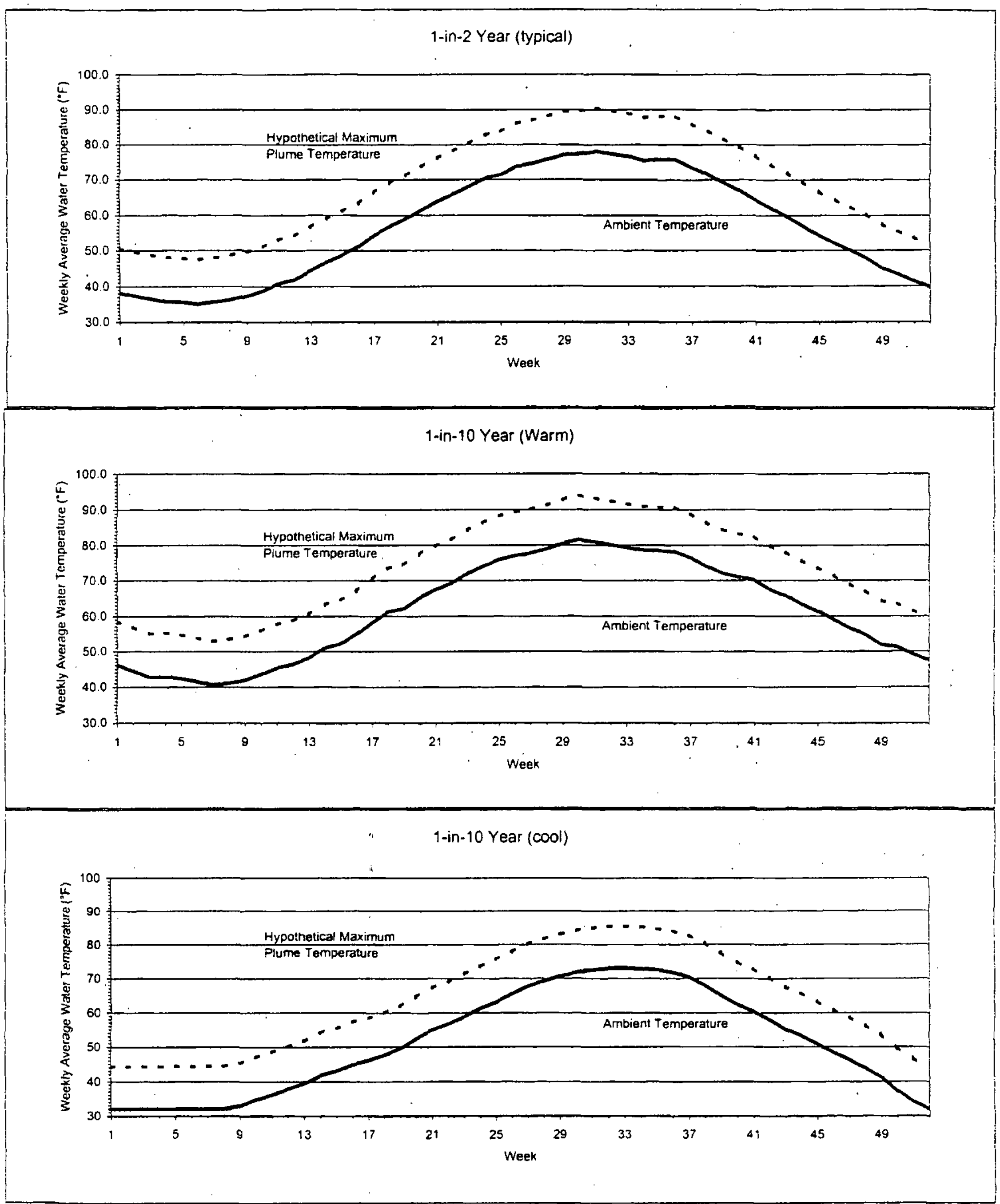
E Figure V-65. Cross-section of ΔT: Delaware River at Hope Creek on ebb tide, 2 June 1998, 0830 hrs.



E Figure V-66. Cross-section of ΔT: Delaware River at Hope Creek on end-of-ebb tide, 2 June 1998, 0000 hrs.



E Figure V-67. Cross-section of ΔT: Delaware River at Hope Creek on flood tide, 4 June 1998, 1630 hrs.



E Figure V-68. Ranked weekly average temperatures.

VI. BIOTHERMAL ASSESSMENT

VI.A. Introduction

VI.A.1. Purpose of this Submittal

The primary objective of this biothermal assessment is to demonstrate in satisfaction of the requirements for obtaining a variance from certain discharge limitations under Section 316(a) of the CWA that the thermal discharge from the Salem station assures the protection and propagation of a balanced indigenous community of shellfish, fish, and wildlife in and on the receiving water body.

VI.A.2. History of Biothermal Assessments

Extensive studies of the characteristics of the Station's thermal plume, and its potential biological effects, have been conducted during the 30 years of regulatory proceedings relating to the Station's cooling water system. This section summarizes the results of these studies, which have been consistent and mutually reinforcing. The principal studies and key findings are presented in Table VI-1 and discussed below in more detail.

VI.A.3. Assessments Supporting Salem Generating Station's Initial Licensing

PSE&G began to conduct biothermal studies for the Salem Station in 1968, even before the commencement of facility construction. The purpose of these studies was to select a location and a design configuration for the Station's thermal discharge that would minimize the potential for adverse environmental effects and thereby facilitate the project's approval by the DRBC. The passage of the National Environmental Protection Act (NEPA) in 1969 resulted in a contemporaneous need for the U.S. Atomic Energy Commission (AEC) to evaluate and approve the nonradiological environmental impact of the Station's construction and operation, including its thermal discharge, in connection with AEC's licensing of the Station.

PSE&G retained a hydrodynamic expert, Dr. James Carpenter of Johns Hopkins University, and his firm, Pritchard-Carpenter Consultants, to perform studies of the projected thermal discharge. Pritchard-Carpenter used a physical model of the Delaware Estuary developed by the U.S. Army Corps of Engineers and Pritchard and Carpenter's own mathematical model to characterize the thermal plume that could be expected from the Station's operation (Section V.C.1).

PSE&G also retained Dr. Edward Raney of Cornell University, an expert in aquatic biology, and his firm, Ichthyological Associates, Inc. (IA), to assist in the selection of a discharge design configuration and the performance of a biothermal evaluation of the proposed design. Under the direction of Dr. Raney, IA conducted field studies of the water quality and aquatic life in the Delaware Estuary. In addition, IA performed laboratory studies to determine, for key species, their ranges of water-temperature tolerance, and their patterns of temperature preference and avoidance, and conducted a search of the scientific literature for relevant information.

VI.A.3.a. Delaware River Basin Commission 1970 Docket

Reports on the studies by Pritchard-Carpenter and Dr. Raney were submitted to the DRBC in 1968 and 1969, in connection with PSE&G's concurrent application to the DRBC for approval of the Salem project. The DRBC retained its own experts to review the study methods and findings, and then held a public hearing on PSE&G's application. Dr. Raney testified in support of PSE&G's application and responded to questions posed by Commission members and technical staff.

For his evaluation of the potential biological effects associated with the thermal discharge (the expected characteristics of which had been analyzed by Pritchard-Carpenter), Dr. Raney relied on field studies conducted in the vicinity of the Station and on his extensive knowledge of the natural history and temperature requirements of the relevant aquatic populations. He concluded that:

- the design configuration selected was the best of the 36 alternatives evaluated for the site (IA 1969);
- the proposed submerged offshore location of the Station's discharge would induce rapid mixing and thereby minimize the zone of elevated plume temperatures (DRBC 1969);
- the water temperature at the proposed discharge site had occasionally exceeded 86°F under normal conditions and would continue to do so, but only for short periods (Raney 1970);
- the proposed offshore site of the Station's discharge would be in an area of dynamic tidal currents and salinity; where relatively few fish are found compared with the littoral zone (DRBC 1969);
- few oysters or other shellfish inhabit the area within four to five miles of the proposed discharge location (DRBC 1969);
- neither shad nor striped bass spawn in the area (DRBC 1969);
- motile organisms, such as fish and blue crabs, would avoid the higher temperatures in the plume during warm summer conditions, but the area of offshore habitat avoided would be too small to have an adverse impact on populations in the Estuary (Raney 1970);
- the thermal plume would not block the migration of shad, striped bass, or other fish in the main stem of the Delaware, the Estuary, or in creeks in the vicinity of the Station because of the plume's offshore location and the relatively small size of the warmer-temperature portion of the plume (DRBC 1969); and
- the water temperature rise attributable to the thermal plume would have no measurable effect on the populations of planktonic organisms floating through the plume (DRBC 1969).

The DRBC in turn concluded in its approval of PSE&G's application and issuance of the Salem Docket (Docket No. D-68-20-P) in 1970 that: the Station's thermal discharge would have no adverse effect on the water resources of the Delaware Basin and would not impair or conflict with the DRBC's Comprehensive Plan for the region. It found that the effect of the project on biomass in the vicinity of Artificial Island would be minimal; that the effect of the Station's operation on anadromous and catadromous fish would be negligible; and that the project would not interfere in any way with the recreational use of the Estuary near Artificial Island. The DRBC further found that the Station's cooling water system "provides beneficial use of the water resources . . . conforms to accepted public policy, and does not adversely influence the present or future use and development of the water resources of the Basin (Section II.A)."

VI.A.3.b. The Atomic Energy Commission's Environmental Impact Statement Pursuant to the National Environmental Policy Act

The enactment of NEPA in 1969 required the AEC, in connection with its licensing of the Salem Station, to evaluate the nonradiological environmental effects of the plant's construction and operation, including its thermal discharge. At the request of the AEC, PSE&G prepared and submitted an Environmental Report in June 1971 addressing the potential environmental effects of the Station's operations. This document included the 1968 Pritchard-Carpenter report and the biothermal assessment of the thermal plume prepared by Dr. Raney in 1969, as well as additional information assembled after the DRBC proceeding ended (PSE&G 1971),[i] which further characterized the physical, chemical, and biological environment in the vicinity of the Station. These data were collected as part of the ongoing ecological monitoring programs initiated in 1968.

The staff of the AEC also conducted an independent predictive evaluation of the characteristics of the Station's thermal plume, as well as an assessment of the plume's potential effects on local biological resources and on other beneficial uses of the Estuary. The AEC issued a draft Environmental Impact Statement (EIS) in October 1972 (publicly issued in the Federal Register on 31 October 1972), which was transmitted for review and comment to numerous federal, state, and local regulatory authorities, including the DRBC, USFWS, NMFS, and USEPA.

The AEC issued its Final EIS for the Salem project in April 1973. The Final EIS considered PSE&G's submittals, along with information from other cited sources including site visits and calculations and appraisals made by the AEC's technical staff. The Final EIS concluded that the proposed configuration of the Station's thermal discharge would minimize the potential for adverse thermal effects on aquatic life and would not pose a barrier to the migration of fish. It also found that the thermal plume would not interfere with recreational uses of the Estuary (USAEC 1973). Thus, the AEC's independent review of the Station's thermal discharge and its potential biological effects, which considered additional data available after the issuance of the DRBC 1970 Salem Docket, confirmed the DRBC's determination that the Salem Station's thermal discharge would not harm the uses and resources of the Delaware Estuary. The AEC also requested additional field studies as a license requirement.

VI.A.4. Assessments Supporting Clean Water Act NPDES Permitting

Since the initial licensing period, PSE&G has regularly conducted studies and gathered information to characterize the thermal discharge and assess its biological effects. A series of biothermal assessments, discussed below, were conducted to support requests for a variance from thermal discharge limitations pursuant to Section 316(a) of the CWA as well as for establishing a heat dissipation area (HDA) pursuant to DRBC water quality regulation.

VI.A.4.a. 1974-1979 Section 316(a) Demonstration

On 11 November 1974, PSE&G submitted a predictive (Type 2) Section 316(a) Demonstration (the 1974 Demonstration), prepared in accordance with USEPA 1974 draft guidance, in support of its request for a variance from the then existing thermal effluent limitations and surface water quality standards proposed in the 1974 Draft NPDES permit for the Salem Station (PSE&G 1974). The 1974 Demonstration included a predictive study, which described the area extent and characteristics of the Salem Station's plume on the basis of the Pritchard-Carpenter report. It also included a study, performed by Dr. A. B. Rudavsky of Hydro-Research Science, of flow patterns in the vicinity of the Station's discharge outfall, which used a physical model of the Station's cooling water system (Rudavsky 1972).[3] The Rudavsky study confirmed Pritchard-Carpenter's finding that vigorous mixing of the discharge would occur in the near-field portion of the plume.

The biothermal assessment portion of the 1974 Demonstration presented information on the biology of fish, benthos, and plankton in the Estuary, as well as on the environment of the Estuary near the Station. It described the environment in the vicinity of the Station as a transition zone characterized by low but fluctuating salinity (0 to 18 ppt), high turbidity, and high tidal velocity.

The 1974 Demonstration therefore found that the area in the vicinity of the Station was not a preferred spawning or nursery area for any fish or shellfish Representative Important Species (RIS) (i.e., opossum shrimp, scud, blue crab, bay anchovy, white perch, striped bass, American shad, blueback herring, alewife, spot, Atlantic croaker, weakfish). The 1974 Demonstration also determined that most of the hundreds of species inhabiting the estuarine system either are not found in this salinity transition zone at all or are found there only seasonally. The 1974 Demonstration presented information on the life history and temperature requirements for RIS, including information on species' thermal tolerance, avoidance, and preference. The data on the geographical distribution of RIS and their life history and temperature requirements were evaluated together with the characteristics of the projected plume to predict the plume's potential effects on aquatic life. In summary, the 1974 Demonstration found that:

- neither the immediate area of the proposed thermal discharge, nor the area projected to be affected by the plume, is a unique or preferred spawning or nursery area for RIS (nor do these areas contain oyster beds or other unique habitats);
- the thermal plume would potentially preclude from use as habitat only a small area in the immediate vicinity of the discharge;
- the plume would not harm any spawning area or form a thermal barrier to migrating fish;
- few fish or macroinvertebrates would be affected by cold shock even if both of the Station's units shut down simultaneously; and

- the thermal discharge would not cause a proliferation of undesirable or nuisance species.

On the basis of these findings, the 1974 Demonstration concluded that the Station's thermal plume would be protective of the balanced, indigenous community of aquatic life in the Estuary. The USEPA deferred its decision on PSE&G's 1974 Section 316(a) variance request, finding that additional biothermal information was needed to make a final determination. In response to USEPA's request for additional information, PSE&G submitted three supplements to its 1974 Section 316(a) Demonstration. The supplements provided responses to questions posed by USEPA and other environmental resource agencies concerning thermal plume characteristics and the potential biological effects of the Station's thermal discharge.

The first supplement (1975) responded to questions concerning the following issues: undesirable organisms; cold shock; low thermal responsiveness; use of the area as a nursery; juveniles of commercially important species; spawning; the movements of anadromous fishes; the occurrence of juvenile fishes; effects of the thermal plume on macroinvertebrates, such as blue crab, oysters and shipworms; and the impact of the thermal discharge on benthos (PSE&G 1975). The second supplement (1978) responded to additional questions posed by the regulatory agencies concerning: attraction of fish to the thermal plume and the potential for cold shock: the effect of thermal plume entrainment on ichthyoplankton and zooplankton; impact of the thermal plume on use of the area near the Station as a nursery by juvenile fishes: and the effect of the thermal plume on the migration of anadromous fishes (PSE&G 1978*a*). The third supplement (1979) provided information unavailable at the time the second supplement was submitted. It responded to questions about cold shock and secondary plume entrainment and provided the results of laboratory studies of cold shock sponsored by PSE&G in 1978 and 1979 (PSE&G 1979).

In summary, PSE&G's 1974-1979 Section 316(a) Demonstration, as supplemented extensively, expanded the information and data previously presented to the DRBC and to the AEC. It also substantiated the findings consistently made by these agencies in issuing licenses or permits for the Station, that the Station's discharge would be protective of aquatic life in the Estuary.

The USEPA issued its Final Permit for Salem in 1975. That Final Permit incorporated New Jersey Surface Water Quality Standards with thermal effluent limitations consistent with open-cycle cooling. The 1975 Final Permit also required achievement of a set of closed-cycle effluent limitations by July 1981 unless PSE&G's 316(a) variance request was granted. PSE&G challenged those thermal effluent limitations.

In resolving PSE&G's challenge to the 1975 Final Permit, the U.S. EPA deferred its decision on the 316(a) variance pending PSE&G's submittal of entrainment and impingement studies to facilitate a Section 316 (a) Determination. In addition, compliance with the USEPA thermal effluent limitations and the state thermal water quality standards was stayed, and the interim thermal limitations in the 1975 permit remained the operative limits through USEPA's issuance of a second NPDES permit for Salem in 1981.

In 1982, responsibility for administering the NPDES program in New Jersey was assumed by NJDEP as the NJPDES program (Section II.B). In 1984, PSE&G submitted its Section 316(b) Demonstration for Salem. NJDEP issued a NJPDES permit for the Station in 1985 that removed the earlier USEPA closed-cycle thermal effluent limitations.

VI.A.4.b. The 1986-1989 Technical Review and Evaluation by New Jersey Department of Environmental Protection's Consultants

In April 1986, NJDEP contracted with Martin Marietta Environmental Systems (which later became Versar, Inc.) to conduct a technical review of PSE&G's 1974-1979 Section 316(a) and 1984 Section 316(b) Demonstrations. Versar issued an initial report in September 1986 and a revision in 1989. In those reports Versar concluded that the effects of Salem's thermal discharge "were small and localized and not a major source of impact" and therefore "do not need to be reduced to protect the balanced indigenous populations."

VI.A.4.c. The 1991 Biothermal Assessment

NJDEP issued a draft NJPDES permit for the Station in 1990 that proposed denying the pending Section 316(a) variance and retrofitting of the Station for closed-cycle cooling. The proposed denial of the Section 316(a) variance was based on NJDEP's concerns regarding the potential environmental effects of the Station's intake on the RIS identified by Versar, rather than any potential adverse effects of thermal discharge. PSE&G's comments on the 1990 draft NJPDES permit presented updated thermal plume studies, along with an updated biothermal assessment based on these studies (PSE&G 1991).

Using the alternative Type 3 Demonstration assessment methods recommended by USEPA (USEPA 1974, 1975, and 1977), the 1991 biothermal assessment provided both predictive and retrospective evaluations of the potential biological effects of the Station's thermal discharge on the balanced indigenous community of aquatic life in the Delaware Estuary. The retrospective assessment included additional documentation to support PSE&G's application for a Section 316(a) variance (PSE&G 1991), including data on the abundance of RIS fish in the Delaware Estuary that were collected from 1966 to 1990 by environmental and resource management agencies, the University of Delaware, and PSE&G (PSE&G 1991). Data from long-term studies of fish abundance in the Delaware Estuary for the period after the Station began operation were compared with the findings of studies conducted before operation, and were examined for trends over time.

Information on the thermal plume's characteristics developed from the 1991 updated studies was integrated with life-history information and with the temperature requirements of the RIS. The integrated information was used to predict the potential of the thermal plume to cause appreciable harm to indigenous populations. The assessment also included an evaluation of the potential interactive effects of heat and other parameters (e.g., dissolved oxygen, chlorine, and toxic substances). The predictive assessment concluded that Salem's thermal discharge does not threaten the protection and propagation of a balanced indigenous community of aquatic life because:

- only very small portions of the populations were being exposed to the higher-temperature regions of the plume for more than short (one to two minutes) periods of time;
- differential temperatures within the far-field portion of the plume are small; the volume encompassed by the instantaneous 1.5°F ΔT isopleth is small, relative to the extensive RIS habitat within the Estuary, and organisms are exposed to the far-field portion of the plume for relatively short periods of time;
- the potential for fish mortality due to cold shock is low, primarily because of the design and location of the discharge; and
- the plume has little potential for adverse population effects due to its mixing with other pollutants, and it does not significantly affect characteristics of the receiving waters such as the level of dissolved oxygen.

These predictive conclusions were supported by retrospective analysis of long-term data on fish abundance, which revealed no decline in the abundance of any fish RIS potentially affected by the Station's thermal plume.

VI.A.4.d. The 1993 Biothermal Assessment

In 1993, NJDEP issued a Draft Permit (1993 NJPDES Draft Permit) in which it proposed granting Salem a Section 316(a) variance and imposing special conditions proposed by PSE&G (with certain NJDEP modifications). PSE&G commissioned state-of-the-art mathematical studies to characterize Salem's thermal plume, and presented the results in its comments on the 1993 NJPDES Draft Permit. The characterization of the thermal plume was similar to that originally predicted by Pritchard-Carpenter (1968). The 1993 biothermal assessment updated the predictive impact evaluation on the basis of additional available biothermal information. The retrospective evaluation was also updated based on additional long-term information on fish abundance[4] and a statistical analysis of long-term abundance trends. The predictive findings of this reassessment were consistent with the predictions of Dr. Raney in 1970 and with the findings of all other previous biothermal assessments:

- the volume of the near-field portion of the thermal plume, which contains the more elevated temperatures and higher velocities, is extremely small (less than 0.0001 percent) in relation to the available habitat for the RIS in the Delaware Estuary;
- due to the high velocities and the rapid reduction in plume temperature in the Zone of Initial Mixing (ZIM) or near-field, the exposure of nonmotile organisms to elevated temperature is brief, and does not typically exceed the thermal tolerance levels of the RIS;
- the ZIM, or near-field portion of the plume occupies less than two percent of the cross-sectional area of the Estuary in the vicinity of the thermal discharge. Migration is therefore not blocked because 98 percent or more of the cross-section remains available for passage during the spring and fall migration seasons;

- the increased temperatures in the regions of the plume outside the ZIM, when considered with the typical background temperatures of the Estuary, will not adversely affect the survival, growth, reproduction, or abundance of any RIS populations;
- because of the high velocities in the ZIM, the potential for cold shock is low;
- the thermal plume does not have an impact on wildlife or on threatened or endangered species, including sea turtles and shortnose sturgeon;
- the interaction of the thermal discharge with other pollutants does not harm aquatic populations; and
- the thermal plume does not cause a proliferation of nuisance species.

These predictive conclusions were again supported by updated retrospective analysis of actual long-term fish abundance trends, which indicated no decline in the abundance of any species of fish potentially affected by the Station's thermal discharge.

In 1994, NJDEP issued the Final Permit (the Permit) for Salem and granted PSE&G's request for a Section 316(a) variance, with modified Special Conditions, NJDEP concluded that the continued operation of Salem in accordance with the terms of the Permit "would ensure the continued protection and propagation of the balanced indigenous population of aquatic life" in the Estuary (NJDEP 1994). The Permit contained the same thermal limitations for the Station's discharge as had been imposed in the earlier Salem NJPDES permit. EPA subsequently favorably reviewed the 1994 Permit.

VI.A.4.e. 1995 Revision of DRBC Salem Docket

Having received a 316(a) variance from NJDEP, on 30 June 1995, PSE&G applied to the DRBC for revision of the Salem Docket to provide summer and non-summer Heat Dissipation Areas (HDAs) to conform with the 316(a) analysis. The proposed HDAs were defined to assure protection of the resources and uses of the Estuary consistent with DRBC's water quality regulations. Mathematical modeling and statistical analyses were performed in 1994 and 1995 to characterize the maximum size of the summer thermal plume (June through August) and 'non-summer thermal plume' (September through May) in terms of 24-hour average ΔTs. The 1994 and 1995 hydrothermal studies used the same basic mathematical modeling techniques and statistical analyses as were used for the 1993 biothermal assessment. Although not submitted in connection with a NJDEP Section 316(a) Demonstration, these hydrothermal studies and the updated biothermal assessment are nonetheless instructive as additional evidence of the characteristics of the Station's thermal plume and the potential for effects on the aquatic biota in the Estuary. .

An updated biothermal assessment was also conducted in 1995 for submission to the DRBC, based on the characteristics of the Station's 24-hour average plumes as reported in the 1994 and 1995 plume studies. A thorough literature search was conducted to update PSE&G's historical data base on temperature tolerance, preference, and avoidance for the RIS and to gather information on long-term abundance trends for the RIS in the Estuary. This search was performed to assure that the best reasonably available information was used in the assessments. The accumulated information was used to perform an assessment for DRBC of the Station's thermal discharge, which consisted of both a predictive biothermal evaluation and a retrospective evaluation based on long-term trends in the abundance of RIS populations.

The 1995 predictive biothermal assessment indicated that the Station's thermal discharge and associated HDA do not have the potential to cause appreciable harm to aquatic life or to relevant beneficial uses of the area. The assessment also found that Salem's thermal discharge has negligible potential to interfere directly or indirectly with the maintenance, propagation, migration, habitat use, or trophic function of important species (including commercial, recreational, and threatened or endangered species). Retrospective analyses of abundance data indicated that the populations of RIS had remained stable or increased from 1980 through 1994, a period during which both of the Station's units were operating.

On the basis of these assessments and after a public hearing in 1995, the DRBC issued a revised Salem Docket granting the requested HDA.

VI.B. Biothermal Responses of Aquatic Organisms

The balance of aquatic communities indigenous to a particular region can be influenced strongly by water temperature (USEPA 1976). Temperature is a normal part of the habitat structure experienced by all aquatic organisms, and spatial and temporal variations in water temperature are a natural feature to which the indigenous species have adapted. In order to evaluate the likelihood and magnitude of potential impact from Salem's thermal discharge, it is important to understand the temperature requirements of aquatic organisms and the nature of their responses to variations in water temperature. This section provides a general discussion of temperature requirements and responses of aquatic organisms, including the concepts of temperature tolerance, preference, and avoidance, and temperature requirements for growth and reproduction. These concepts form the basis for the approach and assumptions used in this biothermal assessment, and are discussed further in that context in section VI.C below.

VI.B.1. Adaptation to Temperature Changes

Temperature affects metabolic processes of organisms by influencing the kinetics of chemical reactions and the effectiveness of enzymes. Among organisms lacking the physiological mechanisms to control tissue temperature, such as aquatic plants, invertebrates, and fish, the rate of metabolism at rest rises nearly exponentially with temperature increase. Over long periods, fish and other aquatic organisms adapt genetically and physiologically to a range of seasonal and daily temperatures that are characteristic of the climate of their geographical distribution. Thus, these organisms can survive within a range of temperatures specific to each species, called the "zone of thermal tolerance." For example, species residing in surface waters of arctic and Antarctic regions, and at high altitudes in temperate zones, are adapted to a relatively narrow annual range of seasonal cold to cool water temperature changes (NAS/NAE 1973). Similarly, species occupying tropical and sub-tropical waters adapt to a relatively narrow range of very warm water temperatures. Aquatic populations resident year-round in temperate zone waters, such as the Delaware Estuary, have had to adapt to the full range of seasonal temperature changes, from 32°F winter temperatures to summer temperatures up to 95-100°F, or higher in some locations (NAS/NAE 1973).

Organisms also adapt physiologically to short-term daily changes in water temperature, thereby expanding their total temperature tolerance range. Laboratory studies show that thermal tolerance is enhanced when animals are maintained under a diurnally fluctuating temperature regime typical of temperate estuaries rather than at a constant temperature (Costlow and Bookhout 1971; Furch 1972; Hoss et al. 1975).

As discussed in Section IV of this appendix, the Station's location on the Delaware Estuary is in the southern portion of the cold temperate zone of the Atlantic Coast (USEPA 1976). The typical range of ambient estuarine temperatures at Salem is from about 32°-40°F in the winter to 73°-82°F in the summer (Figure V-68), with daily maximum temperatures in especially hot, dry years up to 84.6°F (Section V). Daily cycles of temperature, and temperatures at different locations, vary by 2°F to 5°F or more (Section V; Raney 1969; PSE&G 1991, Appendix E; Ketchum 1952; Weston 1978; Aubrey 1996). In order to maintain year-round residence in a temperate zone location such as the Delaware Estuary in the vicinity of Salem, a species must be able to accommodate the full range of seasonal and daily temperature fluctuations, or undertake localized migration associated with spatial and temporal variation in temperature. Those species that cannot adapt are necessarily limited to seasonal expansion of their geographical distribution in the Estuary. Species adapted genetically and physiologically to a relatively narrow range of annual cold temperatures can extend their geographical range into the Delaware Estuary only during the fall, winter, and early spring (e.g., winter flounder). By contrast, species adapted to warm sub-tropical temperatures extend their range into the Delaware Estuary during warmer months (e.g., weakfish, croaker and spot), and generally leave the Estuary in the fall or perish due to cold winter temperatures. Thus, seasonal and daily temperature changes influence the geographical distribution of species and the seasonal community structure at any given coastal estuary location, including the Delaware Estuary.

VI.B.2. Temperature Tolerance

As noted above, aquatic organisms can adjust to the thermal environment physiologically, thereby shifting their tolerance range, but this acclimation has limits and ultimately a water temperature may be reached that would be lethal (Figure VI-1). The upper and lower lethal limits of thermal tolerance are typically determined by laboratory experiments and are defined as the temperature resulting in death of 5, 50, or 95 percent of the test organisms (TL5, TL50, TL95). Immobilization or death resulting from sudden increases or decreases in water temperature beyond an organism's upper or lower tolerance limit is often referred to as "heat shock" or "cold shock," respectively.

The tolerance of organisms to extremes of temperature change is influenced by three factors: (1) their genetic ability to adapt to thermal changes within their characteristic temperature range; (2) the acclimation temperature prior to exposure to a change; and (3) the duration of exposure to the elevated or lowered temperature (Coutant 1972).

The first factor, genetic ability to adapt to temperature changes, differs among species and among developmental stages within a particular species (Hochachka and Somero 1971). For example, striped bass tolerate higher temperatures than salmon, and juvenile striped bass have higher tolerances than adult striped bass (EA 1978*a*; Coutant 1970).

The second factor, the temperature to which an organism has become physiologically adapted (acclimation temperature), affects aquatic organisms' upper and lower temperature tolerance to long- and short-term periods of exposure (Brett 1956; Coutant 1972; Lauer et al. 1974). True acclimation to changed temperature requires several days to more than a week (Brett 1941; Fry 1971; Hochachka and Somero 1971). For long-term exposure, the ultimate upper incipient lethal temperature, which is the highest temperature at which 50 percent (TL50) of a sample of organisms can survive long-term exposure (96 hours to one week) is determined for each organism at the highest sustainable acclimation temperature.[5] The lowest temperature at which 50 percent (TL50) of the warm acclimated organisms can survive long-term exposure is the ultimate lower incipient temperature.

Tolerance to short-term (seconds to hours) exposures to temperature changes also depends on the organism's acclimation temperature (Lauer et al. 1974; EA 1978*b*; IA 1978*a,b,c,d*; IA 1979; Greges and Schubel 1979). A sample of organisms acclimated to temperatures at the low end of their range of tolerance typically can tolerate larger increases in temperature than a sample of the same organisms acclimated to temperatures near the high end of their range of tolerance (Lauer et al. 1974). For example, striped bass post yolk-sac larvae acclimated to 68°F tolerated a 23.4°F temperature rise (equal to an exposure temperature of 91.4°F) for 5 minutes, whereas the same species life stage acclimated to 78.8°F tolerated only a 19.1°F rise (equal to an exposure temperature of 97.9°F) for the same exposure time (EA 1978*a*). Nonetheless, organisms acclimated to warmer temperatures generally can tolerate higher maximum temperatures than if they were acclimated to lower temperatures. For example, the 5-minute TL50 for striped bass post yolk-sac larvae acclimated to 68°F is 91.4°F, while the 5-minute TL50 for the same species life stage acclimated to 78.8°F is 97.9°F.

The third factor crucial to tolerance of temperature change is duration of exposure (Coutant 1972). The tolerance of an organism to temperature changes is a direct function of exposure time. Organisms tolerate exposure to greater changes in temperature if the exposure is for a short period (Brett 1952). For example, striped bass acclimated to approximately 77°F survive an increase in temperature of 29°F (equal to an exposure temperature of 106°F) for only 10 seconds, but tolerate an increase in temperature of 18°F (equal to an exposure temperature of 95°F) for 60 minutes (EA 1979). This time-temperature aspect of tolerance of temperature change is crucial to an accurate and scientifically valid assessment of the potential for organisms to tolerate heat shock from potential exposure to the Station's thermal plume.

VI.B.3. Temperature Avoidance

In the case of mobile species, organisms may adjust to their thermal environment behaviorally by movement along existing temperature gradients. When exposed to a temperature gradient, unconfined, free-swimming juvenile and adult fish and other mobile organisms avoid stressful high temperature by moving through the gradient to water having lower temperatures (Meldrim et al. 1974; Neill and Magnuson 1974; TI 1976*a*; EA 1978*a*). This is known as "temperature avoidance": Avoidance will occur as water temperature exceeds the species' preferred temperature by more than 2-5°F. This response precludes problems of heat stress from thermal discharge for juvenile and adult fishes and other mobile organisms in open water systems such as the Delaware Estuary (USEPA 1976). The effect of localized elevations in temperature that approach thermal tolerance limits for such species is therefore generally limited to exclusion from otherwise usable habitat.

VI.B.4. Temperature Preference

By the same token, when exposed to a temperature gradient, juvenile and adult fish and other mobile organisms will tend to move to, and stay within, a preferred temperature range. The preferred temperature first selected by an organism depends on the initial acclimation temperature. Organisms continue to select progressively higher or lower temperatures until they reach their ultimate preferred temperature. This behavior provides a thermal environment, which approximates the optimal available temperatures for many physiological functions, including growth (Neill and Magnuson 1974). A species' ultimate preferred temperature is usually near the upper end of its optimum range for growth (Brett 1971; Coutant 1975).

A consequence of thermal preference behavior is that fish in temperate and colder climates usually are attracted to heated water, such as may be caused by industrial discharges, during the fall, winter, and spring. When they are able to stay long enough to become acclimated to the warmer temperatures of the plume, there is potential for cold shock (i.e., a sudden decrease in temperature sufficient to cause severe thermal stress to aquatic organisms).

VI.B.5. Optimum Temperature Range for Growth

Within the range of thermal tolerance there are temperature optima for metabolism controlling essential functions like growth and reproduction. Species are adapted to a range of temperatures in their environment over which they function at close to maximum physiological performance. As water temperatures increase above or below this range physiological performance rapidly degrades. The optimum temperature range for growth is different for cold, cool, and warm water species, and also varies among developmental life stages of particular species. For example, the optimum temperature range for growth of most salmonids is between 54.5 °F and 61°F (NAS/NAE 1973); for American shad it is between 64°F and 75°F (Leggett and Whitney 1972; EA 1978*a*; IA 1978*a*), whereas the optimum temperature for growth of small juvenile striped bass and blue crabs is approximately 80-86.5°F (Kellogg and Gift 1983; Meldrim et al. 1974; Holland et al.

1971). The maximum value in a species' temperature range for optimal growth typically coincides with the organism's final temperature preference (Brett 1971; Coutant 1975) and is within 3-5°F of its maximum temperature tolerance for survival.

Thus, there is a potential for thermal discharges to either increase or decrease an exposed organism's physiological performance and growth by shifting water temperatures toward or away from its optimum temperature range. Changes in physiological performance in turn have the potential to directly affect growth and reproduction, and indirectly alter the competitive ability of species and change community composition.

VI.B.6. Temperature Requirements for Reproduction

Spawning can be influenced by an array of factors varying among species, including lunar cycles, tidal elevation, photoperiod (i.e., duration of daylight), salinity, and water currents in addition to water temperature (Hoar 1969; Hardy 1978; Middaugh 1981; Conover and Ross 1982; Conover and Kynard 1984; Tewksbury and Conover 1987). Thus, field observations of typical spawning temperatures in some instances may be merely coincidental, while spawning may be controlled by other factors not necessarily accounted for by qualitative observation.

The act of spawning may be relatively instantaneous for an individual organism and may coincide with a relatively narrow range of water temperatures. However, the conditioning that precedes the event and assures that mature individuals are at the appropriate stage of reproductive development when spawning temperatures occur can be a period of weeks or months (Hoar 1969; Hokanson 1977; Jones et al. 1976). Thus, reproductive condition in fish may represent a biological response to the range and average of environmental factors experienced during an extended period. Temperature is only one factor in a complex interrelationship of conditions conducive to spawning. These factors interact to assure that the time of spawning usually coincides with conditions (e.g., temperatures, food availability, salinity) conducive to development and survival of embryo and larval stages.

VI.B.7. Dynamics of Thermal Response

Organisms in temperate estuaries such as the Delaware Estuary typically experience natural temporal fluctuations and spatial variability in ambient water temperature on a daily and seasonal basis. The likelihood and magnitude of effects from a changing thermal environment may be most closely related to either the short-term or long-term temperature regime, depending on the biological response in question.

Optimum temperatures for a particular life history function typically represent a temperature interval of only 5°-10°F within the total range of natural temperature and may occur for only a brief period during the seasonal ambient temperature pattern. During the rest of the year ambient temperatures will be greater or less than optimum, but the organism will continue to function at some rate less than at optimum. For example, maximum net growth may occur over a few weeks in early and late summer each year with slower rates outside of this period. However, the overall annual growth increment for an individual organism reflects the integration of the varying thermal experience of that organism over its entire growing season. Other limiting factors such as food availability, competition, and an array of physical and chemical water quality conditions also effect growth (NAS/NAE 1973). Of the bio-thermal responses discussed above, growth, reproduction, and shifts in community composition depend on the match between long-term thermal structure of the environment and the organism's optimum temperature range for physiological performance. These responses reflect long-term thermal conditioning and exhibit net temperature-related effects that are typically measured on time scales of days to months.

In contrast, thermal tolerance depends on the relationship between environmental temperature and the organism's temperature threshold, beyond which basic biochemical and physiological functions are disrupted. The threshold temperature depends on exposure time, but morbidity and mortality occur rapidly once this threshold is exceeded. Heat shock and cold shock, in particular, reflect the influence of the recently experienced temperature regime and are typically measured on time scales of minutes to hours. Behavioral avoidance and preference also are relatively rapid responses triggered by the organism's sensation of gradients in its immediate thermal environment. Although the movement associated with these responses may be gradual, it is continually redirected based on the recent history of temperatures experienced.

VI.C. Biothermal Assessment Approach

This section describes the approach that was used to identify the likelihood and magnitude of biothermal responses elicited by Salem's thermal discharge and to assess their significance, in the context of the regulatory standards and requirements identified in the legal requirements applicable to a Section 316(a) Demonstration. The approach was based on several sources of guidance, including:

- USEPA draft guidance manuals (Draft 316(a) Guidance) issued for the implementation of Section 316(a) of the CWA in 1974, 1975, and 1977 (USEPA 1974, 1975, 1977);
- professional practice in prior Section 316(a) assessments at Salem and other generating stations; and
- Guidelines for Ecological Risk Assessment (ERA Guidance) recommending approaches and criteria for assessing impacts from chemical, physical, or biological stressors (USEPA 1998*a*).

The latter guidance is not specific to biothermal impact assessments, but was used to verify that the design of this assessment and the criteria used for assessing the potential adversity of effects are consistent with current regulatory advice and scientific practice.

The biothermal assessment process, the approach and types of information and assumptions used for the assessment, and the criteria used to assess the significance of effects predicted from Salem's plume are discussed below.

VI.C.1. Overview of the Biothermal Assessment Process for the Salem 316(a) Demonstration

The biothermal assessment process for the Salem 316(a) Demonstration consisted of five sequential steps (Figure VI-2):

1. Review of regulatory standards and criteria;
2. Evaluation of Biotic Category vulnerability;
3. Selection of Representative Important Species (RIS);
4. Detailed predictive and retrospective evaluations of biothermal impact; and
5. Evaluation of BIC protection and propagation.

The output and conclusions from each step provided the foundation for the analyses and interpretations performed in the subsequent step of the assessment. The overall framework provided by these steps and associated inputs, considerations, outputs and conclusions used for the Salem 316(a) Demonstration are illustrated in Figures VI-2 and VI-3 (a-c). Each of these five steps is described in more detail below.

VI.C.1.a. Review of Section 316(a) Regulatory Standards and Criteria

The first step in the process was the review of regulatory standards and criteria for the Section 316(a) Determination. The review, which is summarized above in Section II, defined the management goal (compliance standard) and identified requirements and guidelines for determining the demonstration type, assessment scale, and assessment endpoints (i.e., impact criteria). Each of these are defined below:

VI.C.1.a.i. Compliance Standard

The management goal and overall endpoint for this assessment was the protection and propagation of the balanced indigenous community of the Delaware River Estuary, consistent with the compliance standard defined by statute and legal precedent. The meaning of the terms used in this standard was researched in the regulatory guidance and precedent case history of Section 316(a) and is explained in Section II above, and in Appendix D.

VI.C.1.a.ii. Demonstration Type

The 1977 Draft 316(a) Guidance provides for three types of demonstrations:

- Type I, ("No Prior Appreciable Harm" or "Retrospective Assessment"): This type of demonstration is based almost entirely on empirical results from field studies to show that no appreciable harm to the balanced indigenous community has resulted from the thermal discharge. A Type I demonstration involves hydrothermal studies to determine the characteristics of the thermal plume and biological studies to determine the actual post-operational effects of an existing plume.
- Type II, ("RIS" or "Predictive Assessment"): This type of demonstration predicts thermal impacts based on field characterization or mathematical modeling of the thermal plume (at either a pre-operational or operating facility). The predicted plume characteristics are then integrated with results from laboratory studies of thermal effects of species selected as representative important species (RIS) of the BIC and with field studies of organism abundance and distribution; and

- Type III, ("Biological, Engineering and Other Data" or "Alternative Assessment"): Typically the characterization of the thermal plume is based on both empirical data and predictive mathematical modeling. The biological assessment preferably also includes both predictive and retrospective evaluations.

The framework used for this assessment corresponds to that of a Type III Demonstration. This Demonstration provides two main lines of evidence about the potential for impacts from Salem's thermal plume, a predictive line and retrospective line. The predictive line was first used to assess the potential biological impacts of the projected "reasonable worst case"[6] thermal plume. The reasonable worst case plume is one that could result in the most prolonged exposure of organisms to the highest, and potentially most stressful temperatures. Then, available empirical data from field studies were used to retrospectively evaluate whether there were any observable impacts on the Delaware River Estuary community attributable to Salem's thermal plume.

Four methods of evaluation were used for this biothermal assessment, consistent with draft technical guidance for preparation of Section 316(a) demonstrations (USEPA 1977). These include two screening methods (Critical Function Zone (CFZ) and Biotic Category (BC) assessments), and two detailed methods (Predictive/Representative Important Species (RIS) and Retrospective/No Prior Appreciable Harm (NPAH) assessments).

VI.C.1.a.iii. Assessment Scale

Generally accepted scientific practice, Draft 316(a) Guidance and precedent indicate that aquatic biological communities (and the water body segments they occupy) are defined in terms of one or more of the following:

- natural geographic boundaries;
- common hydrologic, chemical, and biological characteristics;
- regions defined by human use patterns;
- regions in which life cycle functions of component populations are completed; and
- regions in which critical ecological functions are performed.

Based on the above considerations and the accepted precedents from prior biothermal assessments and variance proceedings for Salem, the tidally influenced area of the Delaware Estuary from the fall-line at Trenton to the mouth of Delaware Bay will be used as the relevant receiving water body for this 316(a) Demonstration. The receiving water body description, which is summarized above in Section IV, characterizes the balanced indigenous community (BIC) contained in this geographic region.

For the predictive portion of this Demonstration, Draft 316(a) Guidance recommended that the community of organisms that become involved with the thermal plume be divided into several biotic categories for purposes of assessment. The predictive and retrospective assessments of protection of the balanced indigenous community addressed each of the USEPA-recommended biotic categories, which are:

- phytoplankton;

- habitat formers;
- zooplankton and meroplankton;
- shellfish/macroinvertebrates;
- fish; and
- other vertebrate wildlife.

For some individual biotic components of the balanced indigenous community, the area evaluated is smaller or larger than the receiving water body defined above. This is appropriate since the species and biotic categories comprising the overall balanced indigenous community are not uniformly distributed in space and time. The area selected for analysis of biothermal effects therefore also depended on the life history and distribution of the species and community components involved.

VI.C.1.b. Evaluation of Potential Vulnerability of the BIC to Salem's Thermal Plume

The second step in the biothermal assessment process was to evaluate the potential vulnerability of the BIC and its component biotic categories to Salem's thermal plume (Figure VI-3a). For purposes of this Demonstration, "vulnerability" means either the potential for exposure to the plume and/or level of resistance to impacts from exposure. This screening step identifies the attributes of Salem's discharge design and location that reduce the potential for thermal impacts on the BIC. It also evaluates the relative potential for thermal discharge impacts on the biotic categories, based on the habitat zones they occupy, the importance of their role in ecosystem energy dynamics, or their life-history characteristics. Two screening methods were used in this step of the assessment to evaluate the potential for impact, referred to herein as the Critical Function Zone (CFZ) and Biotic Category (BC) methods (Figure VI-3a). Assessment criteria used for both methods were those suggested by the Draft 316(a) Guidance (Section VI.3.b.(1)). The vulnerability evaluation screens out those biotic categories that have low potential for impacts from Salem's thermal plume (LPI categories), and focuses the detailed predictive RIS assessment and retrospective NPAH assessment on the remaining biotic categories.

VI.C.1.c. Selection of Representative Important Species (RIS)

Step three in the biothermal assessment process for the Salem 316(a) Demonstration was to select species to represent the balanced indigenous community for impact assessment purposes (Figure VI-3a). The Draft 316(a) Guidance recognizes that it is impractical to study and assess in great detail every species at a site, and it is therefore necessary to select a smaller group to be representative of the balanced indigenous community. These selected species are designated as representative important species (RIS). Generally 5 - 15 RIS are chosen to represent biotic categories that are not classified as Low Potential Impact (LPI). According to the USEPA Draft 316(a) Guidance, RIS are to include species that are:

- Commercially and recreationally valuable;
- Threatened or endangered;
- Critical to the structure and function of the ecosystem (e.g. habitat formers);
- Potentially capable of becoming localized nuisance species; and

- Necessary in the food chain for the well being of species determined above.

Other considerations for RIS selection include the extent of the species involvement with the thermal plume, the species thermal sensitivity, and the quantity and quality of information available for the assessment.

Using the above criteria, RIS were selected for this biothermal assessment as detailed in Section VI.D.2. Together, Steps 2 and 3 of the biothermal assessment process address the three criteria suggested in EPA Ecological Risk Assessment Guidance (USEPA 1998*a*) for selecting appropriate assessment endpoints: susceptibility to the stressor (in this case the thermal plume); ecological relevance; and relevance to management goals and societal values. Assessment endpoints, which are explicit expressions of the actual environmental value that is to be protected, are discussed further in Sections VI.C.2 and VI.C.3.

VI.C.1.d. Detailed Evaluations of Potential for Impact

The potential for Salem's thermal plume to impact the selected RIS and the biotic categories that they represent was evaluated by predictive and retrospective methods in Step 4 of the assessment process (Figure VI-2).

VI.C.1.d.i. Predictive Evaluation

The potential for impact was evaluated by first predicting the nature and likelihood of potential thermal effects on individual organisms, and then assessing the significance of those effects on the RIS populations. In the language of USEPA Draft Section 316(a) Guidance, the significance of effects equates to their potential for causing "Appreciable Harm" (Figure VI-3*b*). The nature and likelihood of thermal effects was characterized by comparing the habitat preferences, seasonal occurrence, and temperature requirements or limits of each species to reasonable worst-case thermal plume conditions that could potentially occur as a result of the Salem's operation.

An important consideration is that the detailed predictive RIS Biothermal assessment is performed at three levels of protective conservatism. First, excess temperatures (ΔTs) used to characterize exposure of the RIS were based on a "reasonable worst-case" thermal plume (Section V.F.3). This plume was modeled based on full generating load and low CWS flow conditions, which result in a maximum ΔT of 22.7°F above ambient estuary temperature at the point of discharge in the Estuary (Section V.F). In addition, the plume was modeled based on hydrological and meteorological conditions that result in higher near-field plume temperatures than would occur during most times of the year.

Second, the total plume temperatures to which the RIS may be exposed at various times of year were characterized based on both "warm" or "cool" (1-in-10-year recurrence) and "average" (1-in-2-year recurrence) ambient water temperatures in the vicinity of the Salem Station. For the assessment of potential effects from exposure to temperature elevation, the warm year was represented by the highest mean weekly temperatures recurring 1 in 10 years, and for cold shock assessment the cool year was represented by the lowest mean weekly temperature recurring 1 in 10 years (Section V.F).

Third, the likelihood of thermal effects on individuals of the RIS exposed to the plume was assessed using highly conservative assumptions about the location and duration of their residence in the thermal plume. Effects on organisms drifting through the plume were initially evaluated based on the highest (centerline) ΔT that could be experienced, beginning from the point of discharge (Section V.F). Chronic effects on more mobile life stages of RIS were initially evaluated based on the highly unlikely case that they could and would choose to maintain position in the highest ΔT fields near the edge of the zone of initial mixing (ZIM). Effects, if any, that were evident from these highly conservative initial evaluations were then examined in more detail to determine their potential for causing appreciable harm.

Water temperatures at a given location in the Delaware River in the vicinity of Salem vary daily by about 2°F to 5°F and seasonally by about 45°F to 50°F (Appendix C Sections IV and V). The dimensions and location of the Station's thermal plume, which are overlaid on these daily and seasonal fluctuations in ambient temperature, change dynamically in response to tidal and meteorological conditions (Section V.F). Except for that very small area referred to as the zone of initial mixing ("ZIM") in the immediate vicinity of the discharge, a given temperature substantially above ambient is unlikely to occupy any specific location for more than a brief and intermittent period during the daily tide cycles. Field measurements and instantaneous model simulations represent momentary, ephemeral snapshots of the physical configuration of this dynamic plume. Since fish and other organisms exhibit a seasonal range of temperatures that they prefer and utilize if available, it is unlikely that organisms would actively follow portions of the plume with temperatures outside their preferred range as the plume shifts with the tide and wind.

In addition, the likelihood of all of these three conservative conditions occurring at the same time is extremely low.

The potential effects of the thermal discharge were evaluated for the following five biothermal response categories as recommended in the Draft 316(a) Guidance:

1. thermal shock tolerance (heat and cold) of juveniles and adults;
2. upper temperature tolerance for short-term exposure of planktonic forms of the RIS
3. upper avoidance temperature;
4. temperature requirements for performance and growth; and
5. temperature requirements for spawning and early development.

The potential for Salem's plume to elicit these biothermal responses was analyzed graphically by comparing seasonal occurrence of the RIS in the Salem vicinity and biothermal response data for these species obtained in laboratory studies to the predicted seasonal ambient and maximum plume temperatures to which the organisms may be exposed (Figure VI-3b). The types of biothermal response data used in the predictive RIS evaluation and their application in the graphical analyses are discussed in detail in Section VI.C.2 below.

The graphical analyses screen for potential effects by relating the occurrence of each life stage in the Station vicinity to potential thermal effects produced by contact of that life stage with the highest accessible plume temperatures. They were used to identify the nature and seasonal timing of the thermal effects expected for each RIS. They clearly identify the conditions that would be unable to elicit particular biological responses (e.g., mortality). For each condition under which a thermal effect is predicted, estimates were made of maximum cross-sectional areas, surface areas, and volumes of the thermal plume in which important biological activities would potentially be limited by increased temperatures. Thus the thermal effects evaluation yielded predictions of the likelihood of thermal effects being caused by Salem's thermal plume, and the nature, spatial extent, and temporal pattern of such effects (Figure VI-3b).

The potential for Salem's thermal plume to have an appreciable impact on the populations of the Delaware Estuary RIS was assessed by evaluating the likelihood, nature, and spatial scale of thermal effects predictions in the context of:

- species life-cycle requirements and characteristics;
- species ranges and distributions;
- dimensions of available habitat in the Delaware Estuary and population resilience; and
- potential for reversal of effects.

These evaluations specifically addressed the criteria presented in the Draft 316(a) Guidance dealing with issues of survival, growth, reproduction, and habitat exclusion (see Section VI.C.3.b.(2)). The evaluations relied on detailed descriptions of RIS life cycles and biology presented in Appendix C and its Attachments C-1 through C-12.

Also included in this predictive analysis is an evaluation of the effects of Salem's thermal discharge on the biological communities of the Estuary that would result through the potential interaction of Station-related temperature increases and other pollutant-related stresses in the Estuary (Figure VI-3b). The focus of this evaluation is on two classes of pollutant-related stresses: dissolved oxygen and toxic chemicals. The potential for interactive effects involving dissolved oxygen began with an estimation of the likely effects of Salem's thermal discharge on the concentrations of oxygen in the vicinity of Salem. These predicted effects were compared with monitoring data in the vicinity of the plant using these estimates of effect, the likely biological consequences of these effects for dissolved oxygen concentration were evaluated.

The Section 316(a) draft guidelines indicate that the effects of the thermal plume be evaluated in conjunction with contaminants in the system (interactive effects). The potential for interactive effects between Salem's thermal discharge and toxic chemicals considered two groups of toxic chemicals: chlorine, which is used as a biocide in Salem's service water system, and the nine contaminants designated by regulatory agencies as being of concern in the Delaware Estuary. For each of these chemicals, this evaluation began with estimation of the concentration of each chemical occurring in the Estuary in the vicinity of Salem. Concentrations of chlorine were predicted using information on chlorine decay and dilution within Salem's cooling and service water systems. Concentrations of the contaminants of concern were based on data available from ongoing monitoring studies of the Estuary. The biological effects of any potential for interaction were then determined based on expected concentrations of these toxic chemicals and the duration of the potential coincident exposure between these concentrations and elevated temperatures resulting from Salem's thermal plume.

VI.C.1.d.ii. Retrospective Evaluation

Under this evaluation, existing empirical information was carefully analyzed to determine whether there is any evidence that Salem's thermal plume has caused appreciable harm to the biological communities over the 20-year period of Station operations (Figure VI-3c).

This evaluation was conducted in two parts. First, there was consideration of each biotic category, other than those considered LPI, because of low or no exposure to the thermal plume, i.e. habitat formers and other vertebrate wildlife. This part considered community-level factors such as species composition, structure and overall abundance to reach conclusions about current conditions for each biotic category as a whole compared to that expected had Salem not operated.

The second part of this evaluation considered the condition of the population of each RIS in the Delaware Estuary. This part focused on long-term trends in abundance of RIS within the Estuary. For most species, these abundance estimates are for the juvenile stages that can be used as an index of annual production of young from spawning and nursery habitats within the Estuary. One of the first signs of a continuing decline in population abundance is a downward trend in recruitment (i.e. young fish produced each year). Therefore, examination of this stage should provide both a reliable measure of potential thermal effects on the early life stages of each species as well as an indicator of potential effects on the adult stock.

The results of both the biotic category and RIS population level retrospective evaluations were then compared to phenomena identified by USEPA as evidence of appreciable harm to biological communities (USEPA 1977). The intensity and magnitude of effects observed through this retrospective evaluation was then assessed in light of the potential for Salem's thermal plume to induce such effects.

VI.C.1.e. Overall Evaluation of BIC Protection and Propagation ("Master Rationale")

Step 5 of the biothermal assessment process evaluated the potential for Salem's thermal discharge to impact the protection and propagation of the balanced indigenous community in the Delaware Estuary (Figure VI-2). This evaluation addressed the potential for impact on structural and functional attributes of the biotic community as a whole, and compared the findings of the predictive and retrospective evaluations with Draft 316(a) Guidance criteria for a successful Section 316(a) demonstration (i.e., "Master Rationale") (Section VI.C.3)

In effect, Step 5 provides a synthesis of the individual predictive and retrospective lines of evidence from the prior evaluations of community components performed in steps 2 to 4 of the biothermal assessment. Those prior steps evaluated the potential for impact from the direct and interactive effects of the plume's elevated temperatures on individual RIS species and biotic categories. This final step summarizes the conclusions of those assessments in the context of community-level decision criteria and the Section 316(a) Demonstration standard, protection and propagation of a balanced indigenous community.

VI.C.2. Data and Methods Used in the RIS Evaluations

This section discusses the source and types of biological data and their use in evaluating the potential for thermal impacts on the RIS.

VI.C.2.a. Biothermal Response Parameters and Thermal Effect Diagrams

Thorough review and evaluation of all reasonably available information from the literature provided thermal response information for each of the RIS (Attachments C-1 to C-12). Sources of the biothermal response data used in the predictive RIS biothermal assessment are identified in the graphical analyses (thermal effect diagrams) by the numerical reference codes shown in Table VI-2. Application of this information for thermal impact assessment required professional judgment and assumptions, which are discussed below.

VI.C.2.a.i. Thermal Shock Tolerance (Plume Entrainment)

Two methods were used to assess potential for mortality from exposure to elevated temperature during plume entrainment. The potential for mortality resulting from plume entrainment (heat shock) was predicted for planktonic organisms and life-stages based on TL50s for exposure durations ranging from 10 seconds to 3 hours. Safe temperature limits were calculated from TL50 data by subtracting 3.6°F (2.0°C). Although the 50% mortality endpoint is most valid statistically, the use of safe-temperature estimates provides a higher level of protection for assessing the potential for acute effects. It has been shown that a 3.6°F safety factor is sufficient to adjust TL50 temperatures to temperatures at which essentially no mortality would occur (NAS/NAE 1973). These safe temperature limits were expressed as ΔT and compared graphically to the maximum ΔT exposure that could be experienced by an organism drifting along the centerline of Salem's thermal plume, beginning at the point of discharge.

Second, the potential for mortality of organisms entrained in the Salem thermal plume was assessed using methods derived from the National Academy of Sciences/National Academy of Engineering report *Water Quality Criteria 1972* (NAS/NAE 1973). The methods have been described in other reports, also (e.g., Coutant 1972, 1977). The following text describes the rationale and methodology for assessing potential mortality from plume entrainment..

At temperatures above the upper incipient lethal temperature (the threshold for safe temperature limits of a sample of animals), survival depends not only on the exposure temperature but on the duration of exposure, with mortality occurring more rapidly the farther the temperature is from the safe temperature threshold. A semi-logarithmic relationship is generally seen between a high test temperature and the logarithm of time to 50% mortality for species and life stages of aquatic organisms.

$$\log \text{time} = a + b \text{ temperature} \qquad \text{Equation 1}$$

The lethal effects of high temperature thus follow the typical dose-response pattern seen for toxicants and pharmaceuticals (Bliss 1937), and has a strong basis in scientific principles.

Because fish become physiologically acclimated to a particular holding temperature over time, there is a separate semi-logarithmic line for each distinct acclimation temperature. The lines differ in their intercept with the temperature axis and the minimum temperature at which mortality no longer occurs. Although the effect of acclimation temperature could be included in the initial equation, it is usually not included because calculations of the relationship between temperature and time to death are generally carried out for a single prior holding (acclimation) temperature.

Equation (1) can be rearranged so that it will determine whether an organism will survive a certain duration of exposure. The equation looks like this, and survival is ensured if the left side of the equation is less than unity:

$$1 = \frac{time}{10^{(a+b(temperature))}} \qquad \text{Equation 2}$$

In the case of an actual power station thermal discharge, organisms are rarely exposed to a constant elevated temperature, as they are in laboratory tests. The exposure temperature generally changes over time, as in the exposure of a planktonic organism that drifts into the initial thermal discharge and progresses through the mixing and cooling of the plume. In a worst case exposure for the drifting organism, it would enter potentially lethal temperatures (if exposed long enough) at the discharge and follow along the warmest temperatures of the centerline of the plume until it reached temperatures it could normally survive (Figure V-23). It would continue to experience changing (gradually cooling) temperatures, but these would be below potentially lethal levels. Most entrained organisms would experience temperatures less severe than that extreme case because they would enter the plume at some location beyond the discharge point or follow through the plume in areas cooler than the highest-temperature at its center line. Nonetheless, the worst centerline exposure is useful for establishing on a conservative basis if the thermal plume is capable of causing mortality.

The cumulative effects of these changing temperatures on survival can be calculated from the basic time-temperature information given in equation (1). The comparison of time and temperature with unity (as in Equation 2) is made for a series of times of exposures to specific temperatures, and the increments in the series are added until below-lethal temperatures are reached. The series represents the changing temperatures of the plume broken into discrete time-temperature segments. The plume is thus assumed to consist of a stepwise change in temperatures over time. For example, an organism entrained into a thermal plume may be estimated to be exposed sequentially to 95°F for 10 seconds, 94°F for 15 seconds, 93°F for 30 seconds, 92°F for one minute, 91°F for 2 minutes, and 90°F for 5 minutes, after which it is below its incipient lethal temperature (minus 3.6 °F). The time and temperature increments can be selected to give a reasonably good estimation of the continuous exposure. The equation would look like this:

$$1 = \frac{time1}{10^{(a+b(temperature1))}} + \frac{time2}{10^{(a+b(temperature2))}} + etc. \qquad \text{Equation 3}$$

For the biothermal analyses of possible mortalities of entrained organisms in the Salem thermal plume, the plume temperature decay curve CORMIX and RMA-10 models were used to calculate the plume temperature decay curve. For purposes of the biothermal assessment this temperature decay curve was broken into time and temperature segments, as above, in a computer spreadsheet. Equations specific to species and life stages of organisms were used. The calculations at the right-hand of Equation 2 for individual segments were summed until the incipient lethal temperature of that species/life stage minus 3.6°F was reached. The final summation was compared with unity to estimate if mortality would have occurred during that time-temperature exposure. The process was repeated for each species and life stage for which the basic time-temperature equations could be developed from literature data.

VI.C.2.a.ii. Survival of Juveniles and Adults

The upper limit of the temperature range permitting survival of juveniles and adults was used to identify areas of the plume that are potentially uninhabitable by these life stages for extended periods of time because of excessive temperature. The principal thermal effects parameters used to estimate this upper limit were 24-hr to 96-hr TL50s, the UILT and the UUILT.

While plume areas at temperatures greater than the incipient-lethal temperatures may be excluded for indefinite habitation, some of these areas could still he utilized for shorter periods (e.g., foraging for food, escape from predation, or migration). In addition, the combination of avoidance behavior and the natural acclimation prevents actual mortality from occurring in the vicinity of a thermal discharge. The UILT is measured under conditions that do not permit the organism to acclimate to higher temperatures (as pointed out in the previous section) or to move out of potentially lethal temperatures. In the natural setting, juvenile and adult fishes would be expected initially to avoid the warmer temperatures but might eventually acclimate to them (depending on their temperature preference). Consequently, an exclusion area based on UILT represents only a temporary exclusion.

Because of the ongoing acclimation process, the UUILT, which is free of acclimation temperature constraints, was taken as the best estimate of the boundary between the zone of thermal tolerance and the zone of thermal resistance. Therefore the UUILT is the preferred parameter for identifying areas of a thermal discharge that are potentially excluded for long-term habitation and was used instead of other tolerance data whenever available. Even areas at temperatures greater than UUILT would not produce mortality because of the ability of mobile organisms to actively avoid temperatures that cause stress. In addition, organisms can temporarily utilize portions of the exclusion areas at temperatures greater than UUILT but within the zone of thermal resistance.

VI.C.2.a.iii. Mortality from Cold Shock

Thermal mortality can occur by cold shock, where aquatic organisms residing in elevated temperatures within the thermal plume are subject to temperatures below their thermal tolerance limits in the event of a plant shutdown. Cold shocks have the potential to cause mortality if the change in temperature exceeds the tolerance of the species.

The extent of the thermal impact due to cold shock depends on the magnitude and rate of the decrease in the discharge temperature as well as the actual discharge temperature at the time of the outage. The potential for cold shock was addressed using cold-shock data (lower incipient-lethal temperatures [LILT]) on each species as available (Figure VI-1).

VI.C.2.a.iv. Upper Avoidance Temperature

Avoidance temperatures were used to define areas of a thermal discharge that potentially are excluded as available habitat or as a zone of passage because of elevated temperatures. In most cases, mobile aquatic organisms would avoid temperatures equal to or slightly lower than UILT (Figure VI-1, EA 1978*a*).

Avoidance temperatures are typically derived in a laboratory where observations are made on fish behavior in a thermal gradient. Most of the avoidance temperature data reported in the literature are measured during a relatively short exposure interval (e.g., 1-4 hours) and consequently are dependent upon acclimation temperature in the same manner as the UILT. Exclusion areas or restricted zones of passage based on these acute avoidance temperatures are best interpreted as temporary conditions since fish in a natural setting eventually would be able to acclimate to higher temperatures and thus be able to utilize portions of the "excluded" area. A more relevant avoidance parameter would be a chronic, or long-term upper avoidance temperature, but data on this parameter are rarely available. As a substitute for a chronic upper avoidance temperature, avoidance temperatures determined at high acclimation temperatures are often used. This chronic avoidance temperature generally would be expected to be slightly lower than the UUILT for a species (Figure VI-1).

The temperature elevation that elicits an avoidance response (i.e., avoidance temperature) depends on the temperature to which the organism is physiologically acclimated as it encounters a temperature gradient. For the fish RIS, the avoidance temperature was estimated as a function of acclimation temperature by linear regression of laboratory determined avoidance temperatures on the acclimation temperatures at which the tests were conducted. The resulting regression coefficients were used to predict the avoidance response temperature of each fish RIS during their primary seasons of occurrence at Salem using the equation:

$$\textit{avoidance temperature} = a + b\ (\textit{ambient temperature}) \qquad \text{Equation 4}$$

where fish were conservatively assumed to be acclimated to the prevailing mean weekly ambient temperature in the vicinity of Salem during the average (1 in 2 year recurrence) and warm (1 in 10 year recurrence) years (Figure V-68).

Estimation of exclusion areas based on avoidance temperatures might suggest that the actual presence or absence of fish could be predicted. However, the actual presence or absence of organisms in a thermally altered area also is influenced by non-thermal factors, such as availability of food, cover, velocities, and substrate type. These non-thermal factors can override the temperature-avoidance response, thereby optimizing the overall survival of the organism (Brett 1971; Coutant 1970, 1975; Reynolds 1977).

VI.C.2.a.v. Optimum Temperatures for Performance and Growth

This biothermal response parameter identifies the temperatures producing an optimum, or maximum, level of metabolic activity and physiological performance affecting such functions as growth, food conversion, and digestion rate. The most integrative function is growth rate (Coutant 1972) and most of the thermal effects data on physiological functions reported in the literature are for growth. The optimum range for growth is defined as the range of temperature at which growth is not significantly different from the temperature supporting maximum growth. For example, the growth response curve of Figure VI-4 shows the instantaneous rate of growth for striped bass post yolk-sac larvae and juveniles (EA 1978*a*). Maximum growth took place at 27.3 °C (81.1 °F), while growth at 25.1 °C (77.2 °F) and 29.6 °C (85.3 °F) was not significantly less than at 27.3 °C (81.1 °F). Thus, the range of temperatures for optimal growth is determined to be 25.1-29.6 °C (77.2-85.3 °F), and the optimum temperature for performance and growth is 29.6 °C (85.3 °F). It is also apparent from the figure (Figure VI-4) that growth continues at a high rate to a temperature of about 32.2 °C (90 °F).

Thus, the upper limit of the temperature range optimal for growth was used whenever possible to estimate the maximum temperature permitting optimum or near-optimum performance. Extended exposure to temperatures above this limit (but below UUILT) do not necessarily contribute to thermal mortality or prohibit growth, but are higher than documented for optimal performance and growth (Figure VI-4). Comparable estimates of this limiting growth temperature are the maximum weekly average temperatures (MWAT) for growth derived by Brungs and Jones (1977) (one-third of the range between a species' optimum growth temperature and its UUILT) and the average of optimum and zero-growth temperatures suggested by Coutant (1972). Depending on the availability of thermal response data for a given species, any of the above estimates of the limiting temperature were used to define the maximum plume temperature allowing optimum growth and performance.

For some species, only information on optimum temperature was available, and thus, estimates of the upper limit of the optimum temperature range could not be made. In these cases, optimum temperature was used instead of the upper limit of the range and the extent of the predicted area affected consequently was overestimated to some degree. When data on optimum temperatures were not available, final thermal preferenda (preferred temperatures) were used as an estimate of the optimum temperature. The final preferendum is generally accepted as an estimator of the optimum temperature for growth (Brett 1971; Coutant 1975). However, use of the final preferendum to estimate the limiting temperature for optimum growth also will overestimate plume areas affecting growth in the same manner as use of the optimum temperature.

This thermal response parameter is applicable for prolonged exposures (e.g., several days or weeks), and thus, is not relevant for estimating effects from short-term plume exposures. Furthermore, temperatures in excess of the upper limits of the optimum temperature range for growth would not necessarily exclude fish from an area, but merely indicates that growth and other physiological functions may not be functioning optimally. As noted by the National Academy of Sciences and National Academy of Engineering (1972), "optimum temperatures (such as those producing fastest growth rates) are not generally necessary at all times to maintain thriving populations and are often exceeded in nature during summer months." Although laboratory evidence indicates that fish tend to respond predictably to temperature, factors such as habitat type, food availability, and others can influence the thermal distribution of a fish species in the field (Reynolds 1977).

VI.C.2.a.vi. Spawning and Early Development

Temperature requirements for early development were used to define zones of the thermal plume that may have been suitable habitat for spawning and early development, but may not be available for these activities because of the change in temperatures. The life stages addressed (when appropriate thermal effect data are available) are eggs, larvae, and early juveniles. The principal thermal response parameters are:

- successful spawning temperature range;
- upper end of the optimum temperature range for normal hatch; and
- thermal tolerance limits for larvae and early juveniles.

The upper limit of the optimum temperature range for hatch was used, whenever available, to identify areas of the thermal plume that may be unfavorable for egg incubation because of temperature. The maximum temperature for embryo survival also was used for this purpose when available. These thermal response parameters usually are determined from laboratory studies on hatching success. When this type of data was not available for a species, the upper limit of the temperature range for successful spawning was used to identify areas of the plume that may be unfavorable for spawning.

Tolerance limits, determined in the laboratory for larvae and early juveniles, were used to identify areas of the thermal plume that are potentially unsuitable as nursery areas. TL50s (24-hr to 96-hr), the ultimate upper incipient-lethal temperatures (UUILT) and upper incipient-lethal temperatures (UILT) were used.

Laboratory determined incipient-lethal temperatures are based on fairly rapid (sometimes instantaneous) temperature increases and are conditional on the acclimation state of the fish (i.e., the temperature at which the fish's physiological and biochemical functions are equilibrated). If given the opportunity to acclimate slowly to higher temperatures (a condition that usually exists in the natural setting), young fish would be able to utilize warmer zones of the discharge than would be predicted on the basis of incipient-lethal temperatures alone. The ultimate incipient-lethal temperature is not constrained by acclimation temperature, and, although rarely available for early life stages, was used instead of incipient-lethal temperature data whenever available.

VI.C.2.a.vii. Thermal Effect Diagrams

A hypothetical example of the basic elements of a thermal effect diagram is shown in Figure VI-5. Thermal effect diagrams were constructed for each of the RIS by plotting thermal response data in relation to ambient temperatures according to the seasonal occurrence of each life stage. The temperature profile for plume temperatures was then superimposed over those data to reveal relationships between the temperature requirements of each species or life stage and the plume temperature to which they might be exposed at various times (temperatures) during the year. However, for predicted effects to be meaningful, they must be considered in light of the occurrence and distribution of each selected species or life stage within the vicinity of the plume. For example, if a life stage is not in the vicinity of Salem when plume temperatures exceed its thermal requirements, then in reality no effect is possible.

The thermal effect diagrams were used primarily to identify the likelihood of each specific type of thermal effect on each of the RIS, as well as the periods of time when the potential effect might occur. The temperature profile, thermal response, and seasonal occurrence elements included in the thermal effect diagrams are illustrated in the hypothetical example shown in Figure VI-5.

VI.C.2.b. Retrospective/NPAH Evaluations

The retrospective analysis was conducted in two parts; a biotic category evaluation and an RIS trends evaluation. Biotic category analysis focused on four components of the biological community in the Estuary which were identified as having the greatest potential for exposure to Salem's thermal plume. Information used for the biotic category analysis for the phytoplankton, zooplankton, and macroinvertebrates/shellfish categories were derived from existing scientific studies in the Estuary including IA (1980) for all categories; Marshall (1992), Pennock (1988), Pennock and Sharp (1986), and Sutton et al.

(1996) for phytoplankton; Herman (1988), Herman and Hargreaves (1988) and Stearns (1995) for zooplankton; and ECSI (1993), Epifanio and Tweed (1988), Hargreaves and Kraeuter (1991), USEPA (1995) and Walker (1989) for shellfish/macroinvertebrates. For the fish biotic category, the biotic category assessment was based on a graphical and statistical analysis of bottom trawl sampling conducted in the vicinity of Salem which has been conducted since 1970 (Appendix F).

Trends analysis were conducted based on the following three fishery independent surveys conducted in various sections of the Estuary:

- Delaware Department of Natural Resources and Environmental Conservation (DNREC) Small Trawl Survey - 1980 through 1998.
- New Jersey Beach Seine Survey - 1980 through 1998.
- PSE&G Near-field Bottom Trawl Survey - 1979 through 1994 (except 1983 to 1987).

Catches from these surveys were used as an estimate of the abundance of each of the RIS species within the area sampled. Graphical and statistical analysis of these data are detailed in Appendix J and summarized herein.

VI.C.3. Criteria for Assessing Impact

The overall protection objective described in the case history of thermal discharge regulation shows a clear recognition that "every thermal discharge will have some impact on the biological community of the receiving water."[7] Therefore, in determining compliance with Section 316(a), "the issue is the magnitude of the impact and its significance in terms of the short-term and long-term stability and productivity of the biological community affected."[8] The overall regulatory standard (that is, the management goal) for determining the significance of thermal discharge effects on marine ecosystems has been established in both regulatory guidance and practice. The discharge temperature and plume size must assure the protection and propagation of a balanced indigenous community (BIC) inhabiting the water body.[9] Thermal effects guidance further characterizes that "protection" means prevention of appreciable harm, and that "it is not intended that every change in flora and fauna should be considered appreciable harm, unless it impacts an endangered species or a potential critical habitat for an endangered species".[10] Therefore, the objective of this impact assessment was not only to identify potential changes, or effects, caused by Salem's thermal plume, but also to characterize their significance so as to identify whether sustainability of the BIC is threatened (USEPA 1995).

This section describes the factors used in this assessment to judge the significance, or adversity, of Salem's thermal discharge effects. That is, what is their potential for causing appreciable harm to the biological community of the Estuary?

Factors applicable for evaluating the potential for appreciable harm from Salem's thermal discharge have been drawn from Draft 316(a) Guidance. In addition, the recent USEPA Ecological Risk Assessment (ERA) Guidance was reviewed and compared with Draft

316(a) Guidance to assure that the decision criteria used in this assessment were congruent with current practice in impact assessment. Draft 316(a) Guidance provides "decision criteria" for use in assessing compliance with the requirement for protection and propagation of the BIC. These decision criteria identify the "assessment endpoints", which ERA Guidance recommends be established to clarify interpretation of the management goal and form a basis for measurement of impact.

ERA Guidance identifies the following factors for evaluating the adversity of changes in assessment endpoints: the nature and intensity of effects; the spatial and temporal scale of effects; and the potential for recovery from effects (USEPA 1998*a*, p. 103). The following considerations were made for each of these factors, as applicable, in evaluating the potential for Salem's thermal plume to cause appreciable harm:

<u>Nature and intensity of effects</u>

- The relative magnitude of change.
  - How broad are the effects relative to the spectrum of potential effects from the stress? For example, for potential ecological effects involving survival, growth, and reproduction of a species, do predicted or observed effects involve survival and reproduction, or only growth?
  - How pervasive is each effect among the biological species or components of the ecosystem?
  - Is the percent change in the effects that do occur (e.g. survival, local abundance) large or small?
- The severity of change.
  - Are the changes severe enough to produce acute/direct effects or are the changes restricted to sublethal/indirect effects?
  - Are there net effects, or are the effects limited to changes in rates of biological processes and timing of events? For example, is a net change in reproductive success expected or only a shift in the seasonal onset of reproduction?
- The functionality of change.
  - Does the change affect the functioning of the community in a fundamental way, such as by disrupting the energy base, diversity, trophic or habitat structure of the community? Is ecological redundancy present in the community, in which some unaffected species can perform functions similar to affected species?

<u>Temporal scale of effects and potential for recovery</u>
The temporal dimension of ecological change is important to understanding the magnitude and duration of effects, as well as the potential for recovery of the affected zone of aquatic habitat. Recovery is the rate and extent that an ecosystem reverses the ecological effects caused by the stress. This recovery response of the community may be the result of its ability to adapt to an ongoing local stress, or the termination of effects following removal of the stress.

The potential for recovery is an important consideration for the decision-maker because it affects the viability of future management action to curtail effects. Provided the allowable changes do not represent an irreversible and irretrievable commitment of the resource, an adaptive management approach that holds open the future use of alternative strategies for stress reduction is feasible. Factors that are important to consider include:

- Implications of the characteristics of the stress on recovery potential.
  - Is the stress a component of the natural environmental variation to which the community is adapted or is it a unique occurrence? Are the changes likely to be quickly reversed, slowly eversed, or essentially irreversible.
- Mechanisms of resiliency in the ecological system.
  - Is the compensatory reserve of the populations likely large enough to sustain populations? What level of redundancy is available in the community to compensate for stress induced change, such that no functional changes occur in the community? What is the reproductive potential of the species indigenous to the community? How far reaching and rapid are the mechanisms for transport of colonizers and their propagules?
- Spatial extent of disturbance.
  - What is the extent of the affected area in relation to the availability of colonizers and their propagules from unaffected areas? For example, what percentage of total water body occupied by indigenous species populations does the affected area represent?

<u>Spatial and biotic scale of effects</u>

Ecological significance increases with the proportion of the water body populations or communities affected by the human activity. The size of the area affected in relation to the relevant water body zone and the proportion of species populations lost influence both the societal acceptability of change and the ecological potential for adaptation to and recovery from disturbance. The spatial and biotic scale places the effects in the context of the water body as a whole. Significance increases with the size of the area affected because a larger area is likely to be subject to a greater number of other stresses, and is more likely to include other specific components of concern, such as critical habitat for endangered species. Also, the larger the affected area the greater the commitment of natural resources to the human activity causing the stress and the more difficult the recovery. Significance increases with the proportion of species populations lost because the compensatory reserve of the populations (i.e. the natural ability to offset losses by density-dependent changes in rates of birth and death) has upper bounds beyond which further losses threaten persistence of the populations. Factors that are important to consider with regard to the spatial criterion are:

- Proportional scale of effect.
  - Is the percent of the area in which effects are predicted or observed small or large in relation to like habitat, range of involved species, or critical spawning or nursery habitat needed by members of the community?
- Pattern of effect.

- Does the pattern of effect fragment the community/habitat in a way that interferes with corridors or transport mechanisms required for successful migration of members of the community?

VI.C.3.a. Decision Factors from USEPA Draft 316(a) Guidance

The decision criteria used in this biothermal assessment are those suggested in USEPA Draft 316(a) Guidance. However, as shown in Figure VI-6, Draft 316(a) Guidance criteria are congruent with criteria derived from ERA Guidance, discussed above. The following sections describe the Draft 316(a) Guidance criteria in more detail.

<u>VI.C.3.a.i. Biotic Vulnerability Factors</u>

As discussed above in Section VI.C.1.b, Step 2 of the assessment was to evaluate the potential vulnerability of the BIC and its component biotic categories to Salem's thermal plume. First, the Salem discharge was evaluated using the 1977 316(a) guidance concept of Critical Function Zones (CFZ) and the potential for the discharge design and location to impact such zones. The guidance provides that a discharge may be determined to be a low potential impact discharge, on a case-by-case basis, for either of the following situations:

- The thermal plume comprises a relatively small percentage of the shore to shore distance and cross-sectional area of the fresh water body segment or stream flow and is not an area of high biological value; or
- The discharge is an offshore marine discharge, which results or would result in a plume which does not or would not impact benthic or shoreline organisms, offshore migratory paths, spawning areas of fishes, or areas of upwelling.

As discussed in detail in Section VI.D.1.a, the 1977 316(a) draft guidance intended that marine LPI design and location criteria apply to estuarine waters. Therefore, the marine criterion was used to assess the extent to which Salem's discharge minimizes the potential for impacting Critical Function Zones.

The 1977 draft 316(a) guidance suggests that resource zones and "critical functions"[11] be considered to determine whether the location of thermal mixing zones minimizes impact on aquatic resources. In considering resource zones, the draft guidance indicates that the acceptable area of biothermal "damage" is a function of the total amount of equivalent area available in the water body segment, and that for a given location the smaller the area "damaged" the better. Areas supporting "critical functions" should be avoided.

Next, the Salem discharge was evaluated using the Draft Section 316(a) Guidance on biotic category features contributing to low potential for impact, which defines LPI sites as having the following characteristics relative to specified biotic categories:

- Phytoplankton: Areas in which the food web is based on detrital material and phytoplankton contributes only a small amount of the primary photosynthetic activity supporting the community.

- Zooplankton and Meroplankton: Areas characterized by low concentrations of commercially important species, rare and endangered species, species that are important components of the food web, or areas where the thermal discharge will be a relatively small portion of the receiving water body.
- Habitat Formers: Discharge areas devoid of habitat formers because of low levels of nutrients, inadequate light penetration, sedimentation, scouring and stream velocities, substrate character or toxic materials.
- Shellfish/macroinvertebrates: The occurrence of species of existing or potential commercial value is marginal. Threatened or endangered species of shellfish/macroinvertebrates do not occur at the site. The site does not serve as the primary spawning or nursery area for shellfish/macroinvertebrates species.
- Fish: The occurrence of sport and commercial species of fish is marginal. The discharge site is not a spawning or nursery area. The plume configuration will not cause fish to become vulnerable to cold shock or have an adverse impact on threatened or endangered species.
- Other vertebrate wildlife: The plume does not impact large or unique populations of wildlife or important (or threatened or endangered) wildlife.
- Nuisance species: The plume does not cause a shift toward nuisance species of phytoplankton, invertebrates, fish, or wildlife.

<u>VI.C.3.a.ii. Biotic Category/RIS Appreciable Harm Factors</u>

Those categories that have substantial involvement with the thermal plume and that were not judged by the above criteria to have low potential for impact, were assessed in Step 4 based on the detailed Draft 316(a) Guidance criteria for a successful demonstration for each biotic category. These criteria, presented in Table VI-3, focus on the prevention of "appreciable harm". Assessment of appreciable harm for these biotic categories also included detailed RIS predictive evaluations based on Draft 316(a) Guidance Criteria for Survival, Growth, Reproduction, and Exclusion (SGRE criteria); specifically, PSE&G assessed the risk that the RIS may suffer appreciable harm due to:

- direct or indirect mortality from excess heat;
- direct or indirect mortality from cold shock;
- exclusion from unacceptable large areas;
- blockage of migration;
- reduced growth; or
- reduced reproductive success.

According to the Draft 316(a) Guidance, appreciable harm consists of effects severe enough to result in the following phenomena that would be evident at the population-level:

- substantial decrease of formerly indigenous species, other than nuisance species;
- reduction of the successful completion of life-cycles of indigenous species, including those of migratory species; or
- elimination of an established or potential economic or recreational use of the waters.

Existence of prior appreciable harm caused by Salem's discharge was retrospectively assessed by the analysis of long-term trends in population abundance of RIS with respect to these criteria.

VI.C.3.a.iii. Community Appreciable Harm Factors – 316(a) "Master Rationale"

All of the predictive and retrospective lines of evidence were compared and synthesized to increase confidence in the conclusions about the potential for Salem's thermal plume to threaten the protection and propagation of a BIC in the Delaware River estuary. Because there are few numeric thresholds for determining the significance of effects, the assessment of impact potential was based on professional scientific judgments that collectively consider the influence of all of the lines of evidence on the overall resource protection objective. This "lines of evidence" approach using the best information reasonably available has been advocated for assessing ecological risks (USEPA 1998*a*). Both regulatory guidance and the administrative record on regulation of thermal effects provide that certitude is seldom if ever possible, and that regulatory decisions must therefore be made using the best information reasonably available, including statistical analysis, estimation techniques, and professional judgment (USEPA 316(a) technical guidance 1974).

The technical criteria for this evaluation were those presented in Draft 316(a) Guidance for the "Master Rationale", on which the Regional Administrator/Director would find the 316(a) Demonstration, as a whole, to be successful. As specified by the Draft 316(a) Guidance, the following are the decision criteria upon which the regulator would base a decision that the existing thermal discharge protects the balanced indigenous community:

- There is no convincing evidence that there will be damage to the balanced indigenous community, or community components, resulting in such phenomena as those identified in the definition of appreciable harm. One definition of appreciable harm put forth by USEPA is that "appreciable harm" may occur if a thermal discharge causes "such phenomena as the following:"
  - Substantial increase in abundance or distribution of any nuisance species or heat-tolerant community not representative of the highest community development achievable in receiving waters of comparable quality;
  - Substantial decrease of formerly indigenous species, other than nuisance species;
  - Changes in community structure to resemble a simpler successional stage than is natural for the locality and season in question;
  - Unaesthetic appearance, odor, or taste of the waters;
  - Elimination of an established or potential economic or recreational use of the waters;
  - Reduction of the successful completion of life cycles of indigenous species, including those of migratory species; and
  - Substantial reduction of community heterogeneity or trophic structure (USEPA 1977).

- Receiving water temperatures outside of State established mixing zones would not be in excess of temperature limits for survival, growth, and reproduction as applicable, of any RIS occurring in the receiving water.
- Receiving waters are not of such quality that in the absence of proposed thermal discharge excessive growths of nuisance organisms would take place.
- A zone of passage will not be impaired to the extent that it will not provide for the normal movement of populations of RIS, dominant species of fish, and economically (commercial or recreational) important species of fish, shellfish, and wildlife.
- There will be no adverse impact on threatened or endangered species.
- There will be no destruction of unique or rare habitat without a detailed and convincing justification of why the destruction should not constitute a basis for denial.
- The Applicant's rationales present convincing summaries explaining why the planned use of biocides such as chlorine will not result in appreciable harm to the Balanced Indigenous Community.

VI.D. Biothermal Evaluations

VI.D.1. Balanced Indigenous Community Vulnerability Evaluation

The vulnerability of the Delaware Estuary biota to the Station's thermal discharge was evaluated using two measures of vulnerability: potential for exposure to the thermal plume and biological resistance of the biota to impacts from such exposure. Factors affecting potential for thermal exposure of the Estuary's biological community are influenced by the general design characteristics of the Station's CWS discharge and by its specific location relative to the habitat zonation of the biological community. As suggested by USEPA Draft 316(a) Guidance, the evaluation considers whether the Estuary segment biothermally influenced by Salem's thermal discharge constitutes a "critical function zone" (CFZ) for the community's biotic categories or its RIS. Factors affecting biological resistance to impacts from exposure include the abundance, distribution, and reproductive capacities of the community's populations. In the Draft Section 316(a) Guidance, USEPA recognizes the importance of these factors in assessing the potential impact of thermal discharges and provides criteria for defining low potential impact (LPI) sites and biotic categories, which are addressed below (USEPA 1974 and USEPA 1977).

VI.D.1.a. Discharge Design and Location

The Draft 316(a) Guidance (USEPA 1974) provides that an existing or proposed thermal discharge may be determined to be a low potential impact (LPI) discharge if either (1) the thermal plume is a relatively small percentage of the shore-to-shore distance and cross-sectional area of the freshwater-body segment or stream flow, and is not an area of high biological value, or (2) an offshore marine discharge results, or would result, in a thermal plume that does not, or would not, substantially affect benthic or shoreline organisms, offshore migratory paths, spawning areas of fish, or areas of upwelling. In 1974, USEPA defined marine waters as typically having salinity greater than 0.5 ppt and predictable tidal cycles. USEPA recommended that estuarine and coastal sites should be selected to optimize the dissipation of heat and minimize the surface area affected by excessive temperature (USEPA 1974). USEPA further emphasized that thermal discharges into estuarine and coastal waters should be located in areas with good flushing characteristics, a bottom community of minimal ecological importance, and low thermal addition to the intertidal zone. Therefore, it is clear that USEPA considered estuarine and marine waters as one category, and intended that the marine LPI design and location criteria apply to estuarine waters.

This assessment evaluated the Station's discharge area in accordance with these criteria and recommendations for marine discharges. Because it exits from pipes on the bottom of the Delaware Estuary as a horizontal momentum jet about 500 feet offshore (Section III.B), the Station's discharge is considered to be offshore. The high exit velocity (up to approximately 10 ft/sec) of the discharge results in relatively rapid dilution. The temperature is reduced to less than about 58 percent of the initial discharge temperature within 7 seconds. The short potential exposure time and rapidly declining temperature within the zone of initial mixing ("ZIM") reduce the potential for mortality and sub-lethal effects on the reproduction and growth of organisms that drift through the plume. The potential for lethal effects of winter cold shock, in the event of a sudden Station shutdown, are also reduced because the high exit velocity and turbulence prevent fish from staying in the warmest temperatures of the plume long enough to become acclimated to those temperatures.

As predicted by the CORMIX modeling analyses, the highest velocity portions of the thermal plume in the ZIM that have velocities exceeding typical tidal current velocities contact the bottom of the Estuary within approximately 150 feet of the Station discharge pipes. On slack tides, this high velocity zone may extend to about 1,000 feet from the discharge structure, but this condition persists only briefly. The plume produces an area (less than about 4 acres) of potential bottom scour as it sweeps alternately up and downstream with the changing tide (Section V.F). However, the potential for affecting the benthic community of the Delaware Estuary is low because the area of scour is extremely small in relation to the total bottom habitat of the Estuary (more than 480,000 acres). Because of the rapid dilution achieved by Salem's discharge design, values of ΔT which contact the bottom of the Estuary beyond the ZIM approach levels comparable to natural variations in temperature within an area measuring up to approximately 250 acres, exposed to ΔT greater than approximately 4°F (Section V.F).

The Transition Zone of the Estuary where the Station is located is characterized by high tidal energy, with maximum tidal speeds approaching 2.3 ft/sec. The geology and geomorphology of the Estuary near the Station, combined with subtidal gravitational circulation in the Transition Zone, produce spatially complex and dynamic flow fields (Appendix C Sections III and V). A high degree of deposition, resuspension, and movement of sediments is characteristic of areas near Salem. As a result, benthic infauna in the vicinity of Salem tend to be limited to species that can rapidly recolonize in the face of repeated scouring and redeposition of bottom sediments. No commercially important benthic infauna inhabit this region of the Estuary; and the infauna are dominated by polychaete and oligochaete worms (IA 1980). The offshore location of the discharge in this area of variable and shifting bottom substrate in the Transition Zone also minimizes plume exposure of attached benthic forms that require hard substrates, such as oysters (Bay Zone inhabitants) and mussels (Littoral Zone inhabitants). For these reasons, Salem's discharge design and location have low potential impact on the benthic communities of the Delaware Estuary.

Salem's far-field thermal plume has minimal impact on shoreline organisms because the discharge is submerged and located about 500 feet offshore. By the time the rapidly mixing buoyant plume reaches the surface, the warmest (less than about 13°F above ambient) centerline portion of the plume is 550 to 600 feet offshore. As a result, changes in temperature of only 1°F to 4°F make intermittent contact with the shoreline along Artificial Island, during the various phases of the tidal cycle (Figures V-34, V-35). The far-field ΔT isopleths that contact the bottom are typically 4°F or less, a temperature change too small to affect benthic populations. This change in temperature is well within the range of naturally occurring channel-to-shore, diel, and day-to-day temperature variations within the Delaware Estuary (Attachment E-1; Ketchum 1952; Weston 1978; Section V; Section VI.B.1). These far-field plume ΔT isopleths are indistinguishable from the fluctuating temperatures of water that flows out of marshes and tidal creeks each summer day during ebb tides (Exhibit E-1-5; Ketchum 1952; Weston 1978) and is too small to adversely affect shoreline or benthic organisms. Long-term benthic monitoring studies in the vicinity of other estuarine sited power plants support this conclusion. Effects were found to be highly localized to the discharge location and consisted primarily of increased abundance and secondary productivity of the macrobenthos (Holland et al. 1989).

The design and location of Salem Station's thermal discharge ensure that it has a low potential impact on migratory pathways. Strong tidal currents and the rapid decrease in discharge temperature reduce the cross-sectional area occupied by the highest-temperature portions of the plume. At the Station's location along the upper end of the Delaware Bay, the Estuary is relatively wide (about 2.5 mi.). The biothermal analyses presented in Section VI.D.3 indicate that more than 95 percent of the cross-sectional area of the Estuary at Salem's location remains available as a pathway for migrating representative important species (RIS) during the majority of each day.

The warmer portions of the thermal plume (more than 4°F above ambient) are confined to a relatively small area of open water in the low-salinity Transition Zone of the Delaware Estuary (Figure V-57 and V-53 to V-56), where the water fluctuates between fresh and saline depending upon the seasonal cycles of freshwater flow into the Estuary (Appendix C Section III). The salinity in the vicinity of the Station ranges from less than 1 ppt to approximately 20 ppt. Although hundreds of species occur in the Estuary, this salinity Transition Zone provides suitable year-round habitat only for the relatively few species that can tolerate this large salinity range.

Thus, the Station's discharge design characteristics and its specific location within the Estuary minimize the potential for its thermal plume to threaten the maintenance of a BIC. However, because estuaries contain highly productive and diverse biological communities and serve as the principal spawning grounds, nursery areas, or migratory pathways for some species, a comprehensive assessment of the potential for biothermal impacts from the Station's operation was conducted at both the biotic category and RIS levels, as presented in Subsections D.2 to D.5 and Section VII of this Appendix.

VI.D.1.b. Biotic Category/Threatened and Endangered Species Evaluations

The 316(a) Draft Guidance (USEPA 1977) provides the characteristics of LPI sites applicable to each of the biotic categories defined for the biothermal assessment (Table VI-3; Section VI.C). These characteristics were used to identify those biotic categories which qualify as LPI categories in the vicinity of Salem and to focus the more detailed RIS assessment on the remaining biotic categories. Each biotic category is assessed below with regard to its vulnerability to potential impacts from Salem's thermal plume and compliance with the USEPA LPI criteria.

VI.D.1.b.i. Phytoplankton

Phytoplankton are photosynthetic microorganisms, such as algae, that drift unattached (are planktonic) in the water (USEPA 1977); they are primary producers, meaning they use energy from sunlight to grow. The 316(a) Draft Guidance (USEPA 1977) defines LPI sites for phytoplankton as areas in which the food web is based on detrital material, phytoplankton contribute only a small amount of the primary photosynthetic activity supporting the community, and the discharge will not encourage a shift toward nuisance blooms of algae.

The Estuary in the vicinity of Salem is the zone of highest transport of suspended solids (seston) (Figure IV-13) with very high sedimentation and turbidity and very limited light penetration (Biggs and Church 1983; Pennock 1988). Therefore, the Estuary in the vicinity of the Station supports very low levels of phytoplanktonic photosynthesis; 90 percent of the phytoplankton photosynthetic production in the Estuary normally occurs in the less turbid areas downstream of Ship John Light (RM 36) (Pennock and Sharp 1986).

The contribution of phytoplankton to photosynthesis in the vicinity of the Station, and to food production in the Estuary is small (Pennock 1988). The major contributions to the food base are detritus from marsh plant production on the Estuary's approximately 200,000 acres of wetlands, material washed in from the tributaries, and phytoplankton production in the middle and lower bay (Daiber et al. 1976; Pennock 1988).

The potential for the Station's thermal plume to cause shifts toward nuisance species is very low because of the small size of the plume relative to the Estuary, and because high turbidity and low light penetration, not temperature, are the primary factors that affect the growth of phytoplankton in the portion of the Estuary that includes the Station (Appendix C; PSE&G 1974; Pennock 1988). Due to high turbidity and low light penetration, phytoplankton photosynthesis in the Transition Zone of the Estuary, where the Station is located, is very limited. Recent scientific characterizations of the Delaware Estuary indicate that, despite high nutrient levels in the Estuary, no massive algae blooms have occurred (Sutton et al. 1996).

Therefore, the phytoplankton biotic category clearly qualifies as an LPI category under EPA criteria in the area of Salem's thermal discharge. Further, even if the community energetics in the vicinity of the Station were phytoplankton-based, there would be little potential for appreciable harm to a Delaware Estuary balanced indigenous community (BIC). Phytoplankton generally are broadly distributed and abundant, with high reproductive and growth rates and short generation times. They are rapidly transported and dispersed by water currents and recover rapidly from localized stresses within the environment.

Numerous studies of power plant thermal discharges into estuaries and coastal marine waters during the 1960s and 1970s showed that adverse effects on phytoplankton populations are rare and generally occurred, if at all, in a small area in the immediate vicinity of the discharge. Such effects were limited to periods of maximum discharge temperatures during the summer and during those hours when the circulating water was chlorinated to control biofouling of the condensers (Jensen 1974, 1978; EA 1978*c*; UWAG 1978*a*, 1978*b*). Thermal effects measures used in these studies included maximum temperature tolerance of resident assemblages of phytoplankton species, as determined in laboratory studies, changes in community structure, abundance of nuisance species, standing crop (biomass), and photosynthetic rate. Power plant sites studied include freshwater systems, estuaries, and ocean sites (UWAG 1982). Study findings supported the expectations that there were not likely to be any detectable differences in community structure in the vicinity of the Station's discharge, nor any shift toward dominance by nuisance species. In fact, post-operational studies near Salem confirm that the production within the Estuary remains at healthy levels (Pennock 1988), and the food web continues to be based primarily on the detritus rather than phytoplankton. More recent studies by Marshall (1992) confirm that the abundance and taxonomic composition of the phytoplankton assemblage in the Delaware Estuary has remained relatively constant (Section VI.D.5) and that no phytoplankton species are present at nuisance levels. USEPA (1995) concluded that the phytoplankton assemblage in the Estuary is relatively healthy.

VI.D.1.b.ii. Zooplankton (excluding Meroplankton)

Zooplankton are animal microorganisms living unattached in the water column. Zooplankton have relatively limited powers of locomotion and drift with the currents. Zooplankton may eat phytoplankton, other zooplankton, or particles of suspended organic matter; in fact, many are omnivores and eat particles of suitable size regardless of origin. Zooplankton include three subgroups: holoplankton, meroplankton, and tychoplankton. Holoplankton spend their entire lives as plankton; small crustaceans such as cladocerans and copepods, and single-celled animals such as protozoans, predominate. Meroplankton are plankton only during part of their life cycles. Examples include the eggs and larvae of fish and shellfish. Meroplankton are addressed as part of the shellfish and fish biotic categories in Subsections VI.D.1.b.iv and VI.D.1.b.v below. Tychoplankton are epibenthic organisms that periodically enter the water column either as part of their normal diel cycle of activity or as a consequence of hydraulic suspension such as during storm surges. Mysids and amphipods are typical of this group, which is addressed in Subsection VI.D.1.b.iv as macroinvertebrates. This categorization is consistent with Section 316(a) Guidance (USEPA 1977), which defines aquatic macroinvertebrates as those invertebrates large enough to be retained by a 0.595-mm mesh and that can generally be seen by the unaided eye.

The 316(a) Draft Guidance (USEPA 1977) defines LPI sites for zooplankton as areas characterized by low concentrations of commercially important species, rare or endangered species, and species that are important components of the food web; or areas where the thermal discharge will be a relatively small portion of the receiving water body.

The results of the pre-operational field studies conducted consistent with the Section 316(a) Draft Guidance (USEPA 1977), indicate that the zooplankton category is a LPI category in the vicinity of the Station. Seasonal cycles of species composition and abundance are typical for such salinity transition zones in mid-Atlantic estuaries, and no zooplankton represent a nuisance species threat (Pennock and Herman 1988; IA 1980) (see Subsection VI.D.5). The Estuary in the vicinity of the Station has low concentrations of immature planktonic stages of commercially important shellfish, no commercially important species of zooplankton, and no threatened or endangered species of this biotic category (IA 1980). The potential for the Station's thermal plume to cause shifts toward nuisance species is very low because of the small size of the plume relative to the Estuary. The Station's thermal plume containing values of ΔT in excess of natural spatial (and short-term temporal) variation in temperature (4-5°F) involves no more than about 0.05 percent of the total volume of the Estuary (Table V-3). In addition, low salinity prevents invertebrate marine wood borers from invading the discharge area (PSE&G 1975). No increase in fish parasites has been observed in the area; they are most likely prevented by the inability of fish to reside, due to the high flow velocities, in the highest-temperature portions of the plume.

Several other lines of evidence also indicate that the possible effects of the Station's thermal discharge on zooplankton have little potential for appreciable harm to the Delaware Estuary BIC. The invertebrate RIS and several other indigenous species of zooplankton can tolerate the full range of rapid temperature increase and decrease in the thermal plume, even in the highly unlikely event that a given organism is transported along the full length of the centerline of the plume (Figure VII-5). Further, zooplankton have short generation times and high reproductive capacities, allowing populations to readily offset the loss of individuals. With optimum temperature (78° to 86°F) and food supply, protozoan populations can double their numbers up to three times per day. Under such conditions, small crustaceans such as rotifers and cladocerans can double their numbers up to five times per day (Edmondson et al. 1962; Hall 1964).

Numerous studies during the 1970s and early 1980s of power plant thermal discharges into open systems, such as estuaries and coastal marine waters, support the conclusion that zooplankton are in an LPI category. Effects on zooplankton populations were limited to a small area in the immediate vicinity of the discharge, occurring with maximum discharge temperatures in the summer and during those hours when the circulating water was chlorinated to control fouling of the condensers (EA 1978*c*; Tetra Tech 1978; UWAG 1982). Chlorination is not currently used in the circulating water system at Salem Station.

Post-operational study confirms that the species diversity and abundance of zooplankton in the Station vicinity and the Estuary are typical for mid-Atlantic estuaries (Herman 1988). No species of zooplankton are present at nuisance levels.

VI.D.1.b.iii. Habitat Formers

Habitat formers are any assemblage of plants and animals characterized by a relatively sessile life stage with aggregated distribution on which other organisms attach or with which they associate. In the Delaware Estuary, the primary habitat formers are rooted vascular plants in the tidal wetlands (Figure IV-11). These plants also are major food producers for the Estuary. Oyster beds are habitat formers but they occur only downstream of the Station in the Bay. Submerged aquatic vegetation (SAV) is another typical habitat former in estuaries, but SAV has typically been absent in the Delaware Estuary (Appendix C). The area within the ZIM of the Station's submerged, high-rate discharge is devoid of rooted aquatic plants, which, for the most part, are located in tidal marshes far removed from the warmest temperatures in Salem's thermal plume. Submerged aquatic vegetation (SAV) is also absent in the vicinity. As noted in a recent assessment of the condition of mid-Atlantic estuaries, the "Delaware Estuary probably never had extensive SAV beds because the water in this shallow bay is kept naturally murky by tides and storms" (USEPA 1998*b*).

The 316(a) Draft Guidance (USEPA 1977) defines LPI sites for this biotic category as areas devoid of habitat formers as a result of low levels of nutrients, inadequate light penetration, sedimentation, scouring and stream velocities, substrate character, or toxic materials. Therefore, the habitat formers biotic category qualifies as a LPI category under EPA criteria in the area of Salem's thermal discharge. ΔT values in the range of 1°F to 4°F reach the shore zone along and near Artificial Island over the tidal cycle (Figure V-34 and V-35). This segment is less than four percent of the more than 280 miles of shore zone habitat along the two sides of the Estuary (Figure IV-1). More importantly, temperatures in this range are well below temperatures that are stressful to marsh plants (MMES 1985), and well within the range of natural short-term temporal and spatial variations in Delaware Estuary water temperature (Appendix C Section VI). Temperature varies daily by about 4° to 5°F in the open water portion of the Delaware Estuary, and by up to about 4°F to 7°F in tidal creeks, marshes, and mud flats. The most likely effect is a positive one, i.e., a slight increase in the duration of temperatures conducive to growth of marsh plants (MMES 1985).

In sum, protection of habitat formers is assured by the offshore location and design of the Station's discharge, the small portion of shoreline touched by the Station's plume, and the small incremental temperature resulting from that shoreline contact.

VI.D.1.b.iv. Shellfish/Macroinvertebrates

As an assessment category, shellfish include all mollusks and crustaceans, such as oysters, clams, shrimp, crayfish, and crabs, that are important components of the benthic, planktonic (meroplanktonic), or nektonic fauna in freshwater and saltwater (USEPA 1977). Aquatic macroinvertebrates are those invertebrates, including shellfish, large enough to be retained by a U.S. Standard No. 30 sieve (which has 0.595-mm openings); they generally can be seen by the unaided eye (USEPA 1977).

Aquatic organisms are categorized on the basis of where they occur and are sampled in the water body. Thus, macroinvertebrate organisms that live within or on the bottom, and are captured in dredges or other bottom sampling devices, are categorized as benthos or epibenthos, respectively. Macroinvertebrates that occur in the open water and are captured in plankton nets are categorized as macrozooplankton. The more actively swimming vertebrates, such as fishes, and invertebrates, such as swimming crabs, are categorized as nekton.

In reality, many animals, such as insect larvae, amphipods, mysids, shrimp, and crabs may be categorized as habitat sharers. At any given time, some individuals of a species may be resting in or on the bottom and so are counted among the benthos. Others may be swimming in the water and so are counted among the macrozooplankton or nekton; still others may be attached to aquatic macrophytes or other submerged objects, such as fallen tree limbs and debris, and so are counted among the epifauna.

The 316(a) Draft Guidance (USEPA 1977) defines LPI sites for this biotic category as areas where there are no shellfish/macroinvertebrate species of current or potential commercial value, or where their occurrence is marginal; where shellfish/ macroinvertebrates do not serve as important components of the aquatic community; where there are threatened or endangered species of shellfish/ macroinvertebrates; and where the site does not serve as the primary spawning or nursery area for shellfish/ macroinvertebrate species.

Most of the Estuary acreage of habitat formers (vascular plants, oysters), the habitat for macroinvertebrate epifauna, is located outside the influence of the Station's thermal plume. Therefore, macroinvertebrate epifauna is an LPI biotic subcategory, and does not warrant further assessment. The Station's thermal discharge is in the Transition Zone of the Estuary, which is not the primary habitat of most marine and freshwater benthic macroinvertebrates and macrozooplankton (Section IV; Appendix C). No threatened or endangered shellfish/macroinvertebrate species occur in the area.

The eastern oyster is a dominant attached epifaunal macroinvertebrate in the brackish and saline areas of Delaware Bay (Ford et al. 1995). The early life stages of oysters are planktonic while juvenile and adult oysters are largely confined to areas well south of Artificial Island (Appendix C). Historically, survival of oysters has been highest in lower salinity areas where predator abundance is low whereas oyster growth rates were higher further downstream owing to greater phytoplankton production. The closest oyster bed to Salem was the small Hope Creek Bed, located approximately 2 miles downstream of the Station. This bed, located at the upbay edge of oyster habitat, is now considered extirpated as a result of prolonged drought in the 1960s. The last reported harvest from this bed was in 1967, well before the start of Salem's operations.

The oysters of Delaware Bay have historically supported one the East Coast's major commercial oyster fishery. Annual harvest was estimated to be as high as 2.4 million bushels when record keeping began in 1880 and stabilized in the 1-2 million bushel per year range into the 1950s. In 1957, a parasitic protozoan disease (MSX) was first identified in oysters from the Delaware Estuary. Within 2 years, MSX killed 50 to 95 percent of the Bay's oysters. This disease is largely limited to higher salinity waters (>15 ppt). In 1970s and 1980s there was a slight recovery in oyster populations and harvest increased. In the 1990s, a second parasitic protozoan disease (Dermo) was discovered in Delaware Bay. Since its introduction, Dermo has spread throughout much of Delaware Bay oyster grounds resulting in heavy losses.

At present, the oyster population in Delaware Bay is severely depleted as a result of the two diseases. As a result of the destruction of historic oyster reefs, many areas of the Bay have been converted to unstable, coarse sand habitat (Kinner et al. 1974; Maurer et al. 1979). These unstable areas no longer support the set of oyster spat even in years of relatively high reproduction. Consequently, it is unlikely that the Delaware's oyster populations will return to historic levels until the effects of both MSX and Dermo are overcome (e.g., through hatchery production of disease resistant oysters) and hard bottom habitat (e.g., oyster shell) is reestablished.

Several macroinvertebrate/shellfish species of ecological and economic importance occupying benthic and open water habitats, including opossum shrimp, scud, and blue crab, are seasonally abundant in the vicinity of Salem's thermal plume. Therefore, the potential for the Station's thermal discharge to affect benthic macroinvertebrates and macrozooplankton was examined in more detail at the RIS level (Section VI.D.3), in order to complete the assessment of this biotic category with a reasonable level of assurance.

VI.D.1.b.v. Fish

Fish are vertebrates and individual species feed at all levels of the food web; many are opportunists and eat whatever is most available. The large adults of some fish species are the principal top-level predators in the Delaware Estuary.

The 316(a) Draft Guidance (USEPA 1977) defines LPI sites for fish as areas where the occurrence of sport and commercial fish species is marginal; where the discharge site is not a spawning or nursery area; where the thermal plume will not occupy a large portion of the zone of passage, thus blocking or hindering fish migration; where the plume configuration will not cause fish to become vulnerable to cold shock, and where the plume will not have an adverse impact on threatened or endangered species.

The Station's thermal discharge is at the outer margin of the distribution of most marine and freshwater fish species that inhabit the Delaware Estuary (Appendix C Section IV). The primary spawning and nursery areas for most species in the Delaware Estuary are remote from the Station's thermal discharge. Primary spawning and nursery areas are generally located either downstream in the more saline water of the lower Bay and the Atlantic Ocean, or upstream in freshwater reaches of the River. At most, the thermal plume reaches the margin of the extensive spawning and nursery areas of euryhaline species such as bay anchovy and weakfish. As discussed above in Subsection VI.D.1.a, the design and location of Salem's discharge minimize the potential for blocking fish migration or causing cold shock.

One endangered fish species, the shortnose sturgeon *Acipenser brevirostrum*, occurs in the Delaware Estuary. However, a review of its distribution and life history indicates little likelihood of interaction of this species with the Salem thermal plume. The shortnose sturgeon's range extends from New Brunswick, Canada to Florida. The species is anadromous, spawning in the freshwater segments of tidal rivers. In much of its range, the shortnose sturgeon remains within larger tidal rivers or very near its natal river for most of its life. There is no evidence of schooling behavior in this species, thus minimizing the likelihood of fish congregating in the vicinity of the Station's discharge.

Adult sturgeon overwinter in deeper areas of the lower Bay. Individuals spawn at intervals of two to four years. Spawning adults begin to migrate upstream when water temperatures reach 48° to 54°F. The surface-oriented plume occupies a small cross-section of the Estuary and does not present a barrier to the migration of this species (Subsection VII.D.3.d).

In the Delaware River, shortnose sturgeon spawning is concentrated far upriver from Salem in the area between Trenton Falls (RM 132) and Scudders Falls (RM 137); spawning sturgeon may occasionally stray as far north as Lambertville (RM 148) (Masnick and Wilson 1980; Hastings and O'Herron 1987). Spawning takes place primarily from April to June over rocky rubble, sand, and gravel substrate. The adhesive eggs and larvae remain on or near the bottom with minimal downstream drift. Eggs and larvae are not likely to be transported the 80 to 100 miles downstream from the spawning grounds into the vicinity of the Station and indeed have not been collected in this area. Thus, the Station does not interfere with early development of shortnose sturgeon.

Sturgeon young-of-the-year appear to remain above the tidal front for at least the first year, and possibly for several years or even until maturity. During their first year, sturgeon grow rapidly, reaching 6 to 12 inches in length. After the first year, sturgeon grow more slowly and may not mature until 8 to 9 years of age (Smith 1985). Juveniles and mature sturgeon are demersal; they feed on organisms in and on the bottom. Sturgeon appear to move into shoal areas to feed actively at night.

Shortnose sturgeon are rare in the vicinity of the Station. Juvenile and adult sturgeon inhabit areas well upstream of Salem, and they prefer deeper water or channel habitat (Hastings and O'Herron 1987). The few occasionally found in the vicinity of the Station would be able to avoid any stressful temperatures that might occur in the highest temperature portions of the plume. Since 1978, only 13 juvenile or adult shortnose sturgeon have been collected from the Station's bar racks. Therefore, the plume does not affect migration, reproduction, growth, or survival of the shortnose sturgeon.

The fish assemblage cannot be considered to have low potential for impact because some fish species occupy the Salem Station discharge vicinity seasonally, including those of sport and commercial importance. The design and specific location of the Station's discharge within the Estuary, combined with ecosystem characteristics, generally minimizes effects. To complete the assessment of impact for this biotic category with a reasonable level of assurance, the potential impact of the Station's thermal discharge on fish was examined in more detail at the RIS level (Section VI.D.3.).

VI.D.1.b.vi. Other Vertebrate Wildlife

Vertebrate wildlife other than fish includes waterfowl, turtles, and mammals. The 316(a) Draft Guidance (USEPA 1977) defines LPI sites for vertebrate wildlife as areas where the plume does not impact large or unique populations of wildlife or important, threatened, or endangered wildlife. The Section 316(a) Guidance acknowledges that most sites in the United States will be considered LPI sites for this category.

The preferred habitat of vertebrate wildlife such as ducks, geese, muskrats, and raccoons is the shore zone and its wetlands (Daiber et al. 1976; Daiber and Roman 1988; Stein et al. 1988). The open-water location of the Station's plume is used only incidentally by waterfowl for temporary resting and feeding. The plume has not attracted large concentrations of waterfowl to over winter there rather than to migrate farther south. Furthermore, the Station's thermal plume does not adversely affect any other vertebrate wildlife, nor does not affect large numbers of individuals of any population. No population of vertebrate wildlife is unique to the vicinity of the Estuary in which Salem is located. No threatened or endangered vertebrates are affected by the thermal discharge, nor does it adversely affect habitats (e.g., wetlands) that are supportive of vertebrate wildlife other than fish.

The most important wildlife in this category occurring intermittently in the region of the Station are three species of sea turtles: Kemp's ridley turtle (*Lepidochelys kempii*), the loggerhead turtle (*Caretta caretta*), and the green turtle (*Chelonia mydas*). The Kemp's ridley is federally listed as endangered, and loggerhead and green turtles are listed as threatened.

The Kemp's ridley is categorized as an endangered species of sea turtle. There is only a single known colony of this species near Rancho Nuevo, Tamaulipas, Mexico, but young juveniles are widespread in the North Atlantic and Caribbean. The total population for this species has been estimated at 2,200 turtles, based on observed numbers of nesting females and other life history parameters (Marquez 1989). Females lay clutches of about 100 eggs and can deposit from one to ten clutches per season (National Research Council 1990). Coastal development and shrimp trawling may have an important influence on the Kemp's ridley population; an estimated 767 turtles are killed annually by trawlers alone (NMFS 1987). The nesting population was possibly decreasing at a rate of three percent per year (Ross et al. 1989). However, the population of Kemp's ridley is now reported to be increasing (USEPA 1998).

The loggerhead is the most common sea turtle in the coastal waters of the United States and occurs in many other locations throughout the world. Its population along the south Atlantic coast (North Carolina to Florida) was estimated by NMFS in 1987 at over 387,000 turtles. This loggerhead population is considered by most investigators to be stable, but threatened by reductions in nesting and foraging habitat caused by the continued development of coastal areas, and by losses from incidental capture in shrimp trawls. An estimated 9,800 turtles are killed annually from trawlers not using turtle exclusion devices (NMFS 1987).

Sonic and satellite tracking studies have shown that loggerhead turtles use a wide variety of habitat types in the Delaware Estuary, including shallow shoreline areas, the shipping channel, and tributary streams and marshes. Tracking of seven loggerhead turtles over several periods ranging from 2 to 22 days between 1992 and 1996 provide no indication that these turtles are attracted to Salem's thermal plume (PSE&G 1997).

Green sea turtles are found in tropical and subtropical waters throughout the world. In the U.S. this species occurs in the United States Virgin Islands, Puerto Rico, and from Texas to Massachusetts. The green turtle is likely to use shallow habitat in summer, feeding on aquatic vegetation and invertebrates (Schoelkoph and Stetzar 1995). Regionally, green turtles occur primarily in the coastal areas of New Jersey and Delaware around the mouth of the Delaware Estuary. They are rarely retrieved from the bar racks at the Station.

An assessment of the impacts of the Salem and Hope Creek Generating Stations on Kemp's ridley and loggerhead sea turtles was prepared by PSE&G (1989) for submittal to the NRC and NMFS in compliance with Section 7 of the Endangered Species Act. PSE&G (1989) concluded that the continued operation of the Salem and Hope Creek Generating Stations would not jeopardize the turtles. The NRC and NMFS agreed with this conclusion and issued a "no jeopardy" opinion for the stations on 2 January 1991 (USNRC 1991). On 14 May 1993, NMFS and NRC issued a second "no jeopardy" opinion, finding that the stations are not likely to jeopardize the continued existence of any listed threatened or endangered species (NMFS 1993). Recently, NMFS reviewed PSE&G's turtle tracking study discussed above and concluded that the Salem Station region "is not preferred habitat for the turtle and that there is no evidence that the operation of the SGS attracts sea turtles to the intake trash bar region" (NMFS 1999). NMFS issued an amended incidental take permit which contained a third "no jeopardy" opinion stating that the anticipated take level for Salem Station was unlikely to result in jeopardy to Kemp's ridley, green or loggerhead turtles or shortnose sturgeon.

Potential acute and chronic thermal impacts from the Station's operation are inconsequential to these turtle populations because the Station is at the margin of their geographical distribution ranges and, as strong swimmers, the turtles are able to avoid the areas of the plume where temperatures may be warmer than they prefer. Thus the Station's plume qualifies as an LPI area for vertebrate wildlife other than fish, and no further evaluation is needed for this biotic category.

VI.D.1.c. Biotic Category Vulnerability Conclusions

Phytoplankton, zooplankton (excluding meroplankton), habitat formers, and vertebrate wildlife (other than fish) meet the 316(a) Draft Guidance criteria established by USEPA for LPI categories based on evaluations of biotic category vulnerability to the Station's thermal discharge (Figure VI-7). Further evaluation at the RIS level is not warranted for these biotic categories in view of their low potential for exposure and low susceptibility to impact.

The vulnerability evaluation indicates that the Station's thermal discharge would likely expose only a very small portion of the populations of shellfish/macroinvertebrates and fish of the Delaware Estuary during their seasonal occurrence near the Station. These two categories were further evaluated using the RIS approach to assess the likelihood of thermal effects and the extent of population exposure. Focusing on shellfish/macroinvertebrates and fish is warranted because they include species that are recreationally and commercially important or serve important trophic roles in the community. These two groups include the principal top-level consumers, and should therefore be indicative of any ecologically significant effects at lower trophic levels.

VI.D.2. Representative Important Species Selection

Representative important species were selected to represent the shellfish/ macroinvertebrate and fish biotic categories of the BIC, as recommended by 316(a) Draft Guidance. The species listed below were selected by applying the 316(a) Draft Guidance criteria for RIS selection (Section VI.C.1.c) to the results obtained from the evaluation of biotic category vulnerability. Table VI-4 shows how the selected species relate to both the Draft 316(a) Guidance selection criteria and the biotic category analyses.

Fish species selected as RIS for biothermal vulnerability evaluation are alewife (*Alosa pseudoharengus*), American shad (*Alosa sapidissima*), Atlantic croaker (*Micropogonias undulatus*), bay anchovy (*Anchoa mitchilli*), blueback herring (*Alosa aestivalis*), spot (*Leiostomus xanthurus*), striped bass (*Morone saxatilis*), weakfish (*Cynoscion regalis*), and white perch (*Morone americana*). The macroinvertebrate RIS chosen are blue crab (*Callinectes sapidus*), opossum shrimp (*Neomysis americana*), and scud (*Gammarus* daiberi, G. fasciatus, G. tigrinus). Detailed reviews of the life cycles and biology of these twelve species are presented in Appendix C (Appendix C Section VIII; Attachments C-1 to C-12) and summarized in Section IV.G. The twelve RIS species selected for this assessment are the same species evaluated as RIS in the 1993 Biothermal Assessment, which was the basis on which NJDEP granted a Section 316(a) variance for Salem in 1994.

VI.D.3. Predictive RIS Evaluation of Potential for Direct Thermal Impacts

This section assesses the potential for appreciable harm to the selected RIS from the Station's thermal discharge by predicting the nature and likelihood of thermal effects on individual organisms, and then evaluating the significance of those effects on the RIS populations. The nature and likelihood of thermal effects is predicted by comparing temperature exposures that the RIS may receive in areas contacted by Salem's thermal plume with the temperature requirements or limits of each species. The total temperature to which an organism is likely to be exposed was determined from an analysis of ambient water temperatures in the Delaware Estuary (Section V.F.4.d), reasonable worst-case excess temperature distributions in the plume (Section V.F.4), and the seasonal occurrence of the RIS in the vicinity of Salem's discharge (Figure VI-8). The likelihood and magnitude of direct thermal effects from temperature elevation was assessed for both "average" and "warm" conditions using the highest mean weekly ambient temperatures predicted to occur at Salem with a frequency of one year in two, and one year in ten, respectively (Section V.F.4.d). To assess the potential for cold shock under extreme ambient conditions, the "warm" condition was replaced by a "cool" condition, using the lowest mean weekly temperature occurring one year in ten. Thermal response information obtained from the literature (Attachments C-1 to C-12) was used to identify temperature requirements and limits of each RIS, as described in Section VI.C. The reader is referred to Sections VI.B and VI.C.2 for explanation of biothermal relationships and definitions of the response temperature parameters used in this assessment.

The potential for Salem's thermal discharge to cause appreciable harm (Section VI.C) to the populations of the RIS is assessed based on the nature and magnitude of the predicted effects and on the biology of the species (Appendix C Section IV.G). Consistent with USEPA Draft 316(a) Guidance (USEPA 1977), this evaluation considers the potential for appreciable harm due to: (1) mortality from excess heat, (2) mortality from cold shock, (3) habitat exclusion, (4) blockage of migration, (5) reduced growth, and (6) reduced reproductive success. Each of these decision criteria is discussed below on a species-by-species basis, first for the macroinvertebrates/shellfish biotic category, then for the fish biotic category. The fish are discussed in the following groups based on similarities in their biological characteristics and in their seasonal occurrence in the Delaware Estuary near Salem:

- Anadromous herring: alewife, blueback herring, and American shad are anadromous herring species that primarily utilize the freshwater portions of the Estuary as spawning and nursery habitat. Their seasonal occurrence near the Station is associated with brief periods during upriver migration of sub-adults and adults in the spring and emigration of young-of-the-year from their nurseries in the freshwater portions of the Estuary to the ocean in the fall.

- Temperate bass: white perch and striped bass both spawn primarily in freshwater portions of the Estuary, but utilize the Estuary over a wider range of salinity as juveniles and yearlings. White perch continue to reside within the Estuary through the adult stage, while striped bass adults are oceanic residents. The seasonal occurrence of these two species near the Station is very similar. Young-of-the-year and yearlings are most abundant from fall through spring and reside primarily in low salinity areas upstream of Salem during summer. Striped bass eggs historically have not occurred at the Station in most years, but when they do they are present in April and May. White perch eggs are adhesive and therefore generally do not drift to the vicinity of the Station. Larvae of both species are present near the Station in spring and early summer, although most occur upstream in freshwater zones of the Estuary.
- Oceanic-estuarine residents: bay anchovy, Atlantic croaker, spot, and weakfish are primarily coastal marine species that utilize the Estuary in a variety of ways. Bay anchovy extend their distribution from coastal and lower Bay habitat into the Estuary during warmer months where they primarily utilize the pelagic zone as habitat for all life stages. Spot and Atlantic croaker spawn in the offshore ocean; their young move into the Estuary mainly at the juvenile stage, where they use tidal creeks and marshes as nursery habitat. Weakfish spawn in the nearshore ocean and lower Bay with all life stages extending distribution into the Estuary during warmer months. Although eggs and larvae are distributed throughout the water column, juveniles move into the littoral zone, which they utilize as nursery habitat until early fall. With the exception of Atlantic croaker, one or more life stages of the oceanic-estuarine species occur near the Station, primarily during the summer including the midsummer period of peak ambient temperature.

VI.D.3.a. Potential for Appreciable Harm Due to Mortality from Excess Temperature

The Station's thermal discharge would cause mortality if the temperature and duration of exposure exceeded the upper tolerance limits of the species. To assess the potential for mortality, two cases were considered:

1. Exposure of planktonic/weakly mobile forms that may be entrained into the thermal plume with dilution water as the discharge mixes with the receiving water. These organisms may be entrained at any point along the mixing plume and drift with the plume as it moves away from the discharge and mixes with ambient water. The specific path that the organisms follow would determine their time-temperature exposure through the plume (Section V.F). The potential for mortality from excess temperature exposure was very conservatively assessed by considering the extreme worst case in which organisms are entrained at the point of discharge and drift continuously along the centerline of the plume. The range of time and temperature exposures thus received during centerline transit through the worst-case plume (Section V.F) was used for graphical comparisons with

short-term thermal tolerance of the RIS. However, considering the turbulence and dynamic tidal mixing characteristics of the Estuary and plume, it is hardly conceivable that any individual or group of organisms would likely be transported along the entire centerline of the plume. The more likely circumstance is that passively transported organisms would enter the plume throughout its length and only a portion of those would be exposed, and for much shorter times, to the maximum temperature in the centerline of the plume near the Station discharge pipes. Even those organisms entrained into the plume at the point of discharge would follow non-centerline paths through the plume, leading to lower average time-temperature exposures than would be reflected by the centerline plume temperatures.

2. Exposure of larger, more mobile species/life stages that are better able to move against water currents and therefore could conceivably occupy a location in the plume for an extended period of time. However, the swimming speeds that the RIS are able to sustain (Table VI-5) greatly limit their ability to occupy positions in the highest temperature portions of the plume, which occur in the Zone of Initial Mixing (ZIM), where discharge velocities and turbulence are at their maximum (Section V.F). Therefore the potential for thermal mortality, as well as other effects resulting from long-term thermal plume exposure, were assessed based on maximum temperatures that might be experienced at the edge of the ZIM and on far-field temperature distributions beyond the ZIM (Section V.F). This analysis was conducted conservatively by assessing potential effects of the Station's reasonable worst-case plume and by assuming that organisms are acclimated to ambient water temperatures (i.e., estimated temperature in the absence of Station operation as described in Section V) at the time of their exposure to the plume. In reality, organisms in the vicinity of the thermal discharge may be acclimated to temperatures 1° to 2°F higher than ambient as a result of regular exposure to the slightly higher background temperatures created by residual heat from the plume.

VI.D.3.a.i. Short-Term Exposure from Plume Entrainment

Those RIS that may be readily entrained into the plume are scud, opossum shrimp and the eggs and larvae of other RIS that may be seasonally present in the vicinity (Figure VI-8). Temperature elevations that can be safely tolerated by RIS susceptible to plume entrainment for brief time periods (10 seconds to 180 minutes) are compared to predicted maximum and minimum centerline time-temperature ΔT exposure in Figures VI-9 to VI-12. In addition, Table VI-6 presents the potential cumulative mortality effects from plume entrainment, estimated for several RIS[1] using methodology derived from Water Quality Criteria 1972 (NAS/NAE 1973), as described in Section VI.C.

VI.D.3.a.i. (a) Macroinvertebrates

Time-temperature tolerance data indicate that scud, opossum shrimp and the blue crab megalops and early juveniles that occur in the vicinity of the Station's thermal plume can tolerate the time-temperature exposure that they would experience during an average year, even in the extremely unlikely event that they were to drift along the centerline through the entire length of Salem's thermal plume. During unusually warm years (i.e., one year in ten), maximum centerline plume time-temperature exposure may exceed the tolerance limits of opossum shrimp during peak summer temperatures. Even in those years, the potential for plume entrainment mortality to impact populations would be negligible because the number of organisms exposed to such temperatures would be extremely small relative to the overall Estuary-wide and coastal populations.

VI.D.3.a.i. (a) (i) Scud

Thermal tolerance test data indicate that scud are able to tolerate all of the reasonable worst-case time-temperature conditions in the Station's thermal plume (Figure VI-9a). Safe ΔT limits for scud calculated from TL_{50} test results reported for 10-second to 60-minute exposures are well above the centerline plume ΔT values for those exposure times. Scud can easily tolerate the highest temperatures that they might experience in the thermal plume. Scud acclimated to 66°F to 72°F tolerate temperatures of 105°F to 108°F for 10-second exposures with no mortality (EA 1978*a*). That tolerance temperature is higher than the maximum plume temperature at the point of discharge (104°F), even in warm weather years (i.e., one-in-ten-year case). Considering that dilution reduces the Station's plume ΔT to less than 58 percent of the maximum discharge ΔT within seven seconds (Section V.F), there is no potential for mortality of scud from transit through the highest plume temperatures.

Analysis of the potential cumulative effect of exposure to decreasing temperatures experienced during transit through the plume indicates that scud can survive the potentially lethal temperatures initially encountered for the first few seconds during which the momentum of the plume carries them to areas with temperature levels at which they can normally survive indefinitely. The cumulative ratio of exposure time to resistance time (i.e., length of time the organisms can survive at a given temperature) for scud transit through the centerline of the plume during summer is less than the lethal threshold (unity) for both the average year (Ratio = 0.01) and warm year (Ratio = 0.10) ambient temperature conditions (Table VI-6). Therefore, entrainment of scud into Salem's thermal plume would not be expected to cause acute mortality from exposure to excess temperatures, even during reasonable worst-case centerline exposure in warm years.

VI.D.3.a.i. (a) (ii) Opossum Shrimp

Results of laboratory and field thermal tolerance data indicate that opossum shrimp would survive exposure to excess temperature during transit along the plume centerline in all but, perhaps, the warmest years. Safe ΔT limits for opossum shrimp calculated from TL50 test results reported for 5-minute, 10-minute, and 60-minute exposures at acclimation temperatures of 57°F to 78°F are above the centerline plume ΔT values for those exposure times (Figure VI-9b). Test data for shorter exposure times commensurate with the rapid initial temperature reduction in the Station's plume, such as 10 seconds and one minute, are not available; however, test data for such short exposure times are available for scud. Those data show that scud tolerance at a given acclimation temperature is about 8°F to 14°F higher for a 10-second exposure than for a 10-minute exposure.

Assuming that the relationship of temperature tolerance to exposure time for opossum shrimp is similar to that observed for scud, opossum shrimp are likely to tolerate temperatures of 98°F to 104°F for 10 seconds. That tolerance temperature range bounds the maximum weekly average plume temperature at the point of discharge during the average year (about 101°F). Considering that dilution reduces the plume ΔT to less than 58 percent of the maximum discharge ΔT within seven seconds, opossum shrimp entrained at the first instant of mixing with the thermal discharge are likely to tolerate transit through the highest temperature portion of the reasonable worst-case centerline plume in an average year.

Under the conservative assumption that thermal tolerance does not increase when ambient temperatures rise above 78°F, safe ΔT values can be estimated by adjusting the tolerance values downward by the amount the ambient temperature rises above 78°F. In the warm year, safe ΔT values adjusted in this manner lie near or below the maximum centerline plume exposures, suggesting that some mortality of larvae entrained into the highest temperature portions of the plume may be expected during especially warm summers when ambient water temperature reaches about 81.5°F.

Although the tolerance data suggest that some mortality of opossum shrimp entrained into the highest temperature portions of the plume may potentially occur during especially warm summers, only a very small fraction of the population would actually incur mortality for the following reasons:

- Because opossum shrimp are broadly distributed in the Estuary, with the vast majority of the population downriver of the Station, relatively few would ever contact the small portion of the plume containing potentially lethal temperatures.
- Based on an analysis of the estimated ambient temperatures in the vicinity of Salem (Section V.F), temperatures exceeding 81.5°F occur on about 105 days over a 50-year period, or about one percent of the time during the primary seasonal occurrence of opossum shrimp at Salem.
- The safe temperature limits used in the analyses represent the threshold, above which mortality may be incurred by a percentage of exposed organisms. Percent mortality increases linearly with exposure temperature above this threshold, reaching 50 percent at a temperature 3.6°F higher than the safe limits used in the analysis. Therefore, mortality would only be expected in a small percentage of organisms exposed to temperatures exceeding the safe temperature limits, even during periods of extremely warm ambient temperatures.
- Only a small percentage of those opossum shrimp entrained into Salem's plume would be exposed to the conservative maximum centerline plume temperatures used in the analysis.

VI.D.3.a.i. (a) (iii) Blue Crab

During their planktonic stage, blue crab have negligible involvement with Salem's thermal plume. This is because eggs remain attached to the adult females during incubation, which occurs in higher salinity waters near the mouth of the Delaware Estuary. Following hatch, larval blue crab are transported seaward where they develop in open waters of the continental shelf (Section IV.G.1.c.; Appendix C Section VIII). Blue crabs reenter the Estuary as post-larval megalops, with the vast majority found in the lower Bay. Although megalops may appear in low densities as far upstream as Artificial Island, survival and metamorphosis into juvenile crabs is greatly reduced at the salinities typical of this location (Costlow 1967). Therefore, the potential effect of plume entrainment on the blue crab population is negligible, because those life-stages that drift with the currents are not present in abundance and do not survive well in that area of the Delaware Estuary near Salem regardless of Station operation.

The thermal tolerance data indicate that early juvenile blue crab would survive maximum centerline time-temperature exposure even in the unlikely event that they were entrained through the full length of Salem's plume. Upper tolerance limits for long-term exposure (≥24-hr) of juvenile blue crab are at least 4°F greater than for scud (Figure VI-13a), which as discussed above, are able to tolerate the full exposure to temperatures along the plume centerline. Measured and estimated safe ΔT-tolerance limits for short-term exposure of juvenile blue crab are well above the ΔT exposures in the plume centerline for comparable periods of time (Figure VI-9.c).

VI.D.3.a.i. (b) Fish

Time-temperature tolerance data indicate that eggs, larvae and early juveniles of those fish RIS occurring in the vicinity of the Station can tolerate the maximum time-temperature exposure that they would experience during an average year, even in the extremely unlikely event that they were to drift through the entire length of Salem's thermal plume. During unusually warm years, maximum centerline plume time-temperature exposure may exceed the tolerance limits of early life-stages of some of the RIS (bay anchovy, weakfish) that are present during peak summer temperatures. Even in those years, the potential for plume entrainment mortality to impact populations would be negligible because the number of organisms exposed to such temperatures would be extremely small relative to their Estuary-wide and coastal populations. In addition the low frequency that maximum centerline plume temperatures may exceed the tolerance threshold of these species further indicates that the potential for mortalities at levels sufficient to harm the populations of these RIS is negligible.

VI.D.3.a.i. (b) (i) Anadromous Herring

American shad spawn far upstream in freshwater portions of the Delaware River, primarily above RM 236 and as far as RM 329 in the mainstem, and as far as RM 342 in the East Branch. As a result, no eggs or larvae occur at Salem. Alewife and blueback herring also spawn in upstream freshwater regions of the mainstem as far as RM 195–298 and in freshwater tributaries to which they can gain access throughout the Estuary. No eggs of these two species occur at Salem, but some larvae do drift into the vicinity. These two life stages occur at Salem primarily in May at ambient water temperatures of about 59°F to 67°F (Figure VI-8).

Thermal tolerance test data indicate that alewife larvae are able to tolerate all of the time-temperature conditions in the Station's thermal plume (Figure VI-10). Safe ΔT limits for alewife larvae calculated from TL50 test results, reported for 5-minute to 60-minute exposures at acclimation temperatures below about 67°F, are well above the maximum centerline plume ΔT values for those exposure times. Plume ΔT values are reduced below safe temperature limits for long-term (≥24hr) exposure within the first few seconds following discharge (Figure VI-10). Analysis of the potential cumulative effect of exposure to decreasing temperatures experienced during transit through the plume indicates that alewife can readily survive the temperatures initially encountered for the first few seconds during which plume temperature returns to levels at which they can normally survive indefinitely. The cumulative ratio of exposure time to resistance time (i.e., length of time the organisms can survive at a given temperature) for alewife transit through the centerline of the plume during summer is less than the lethal threshold (unity) for both the average year (Ratio=0.00006) and warm year (Ratio = 0.0008) ambient temperature conditions (Table VI-6). Therefore, entrainment of alewife into Salem's thermal plume would not be expected to cause acute mortality from exposure to excess temperature, even under maximum centerline exposure in warm years.

No relevant data are available on the short-term thermal tolerance of blueback herring larvae. However, the single tolerance estimate for 60-minute exposure of blueback herring juveniles (Figure VI-10), and the TL50 data available for blueback herring yearlings (Figure VI-15), indicates a thermal sensitivity comparable to that of alewife. Therefore, entrainment of alewife or blueback herring larvae into Salem's thermal plume would not be expected to cause acute mortality from exposure to excess temperatures, even under reasonable worst-case centerline exposure in warm years.

VI.D.3.a.i. (b) (ii) Temperate Bass

White perch and striped bass primarily spawn upstream of Salem in freshwater areas above Wilmington, DE (RM 75) (Section IV.G, Appendix C Section VIII). Some of the eggs, larvae, and early juveniles of white perch and striped bass drift into the vicinity of Salem during spring (Figure VI-8). Ambient water temperatures range from about 50° to 64°F during the primary season for egg occurrence and between 52° and 77°F during the peak season for larvae and early juveniles.

Thermal tolerance test data indicate that the early life stages of white perch and striped bass are able to tolerate all of the reasonable worst-case time-temperature conditions in the Station's thermal plume (Figure VI-11). Safe ΔT limits for white perch larvae, calculated from TL50 test results reported for 5-minute to 60-minute exposures at acclimation temperatures below about 77°F, are well above the centerline plume ΔT values for those exposure times (Figure VI-11a). White perch and striped bass can easily tolerate the highest temperatures that they might experience in Salem's thermal plume.

Safe ΔT limits for striped bass eggs, larvae, and early juveniles, calculated from TL50 test results reported for 10-second to 60-minute exposures at acclimation temperatures below about 77°F, are well above the reasonable worst-case centerline plume ΔT values for those exposure times (Figure VI-11b). Plume ΔT values are reduced below safe temperature limits for long-term (≥24hr) exposure of larvae within about seven seconds following discharge. Striped bass early juveniles can readily tolerate the highest temperatures that they might experience in Salem's thermal plume. Striped bass early juveniles acclimated to 64°F to 77°F tolerate temperatures of 103°F to 105°F for 10-second exposures with no mortality (Figure VI-11b; Figure VI-16). That tolerance temperature is higher than the maximum plume temperature at the point of discharge during the primary period of occurrence of larvae and early juvenile striped bass, even in relatively warm weather years (78° to 100°F). Although no appropriate short-term thermal tolerance data are available for white perch eggs, the data for striped bass, a congeneric species with similar temperature tolerance (Figures VI-11a and VI-11b; and Figure VI-16), indicates that white perch eggs would also tolerate the highest temperatures in Salem's thermal plume.

Analysis of the potential cumulative effect of exposure to decreasing temperatures experienced during transit through the plume indicates that white perch and striped bass can readily survive the potentially lethal temperatures initially encountered for the first few seconds during which plume temperature returns to levels at which they can normally survive indefinitely. The cumulative ratio of potential exposure time to resistance time for transit of white perch and striped bass larvae and early juveniles through the centerline of the plume during summer is less than the lethal threshold (unity) for both average and warm years (Table VI-6). Therefore, entrainment of white perch or striped bass during early life stages into Salem's thermal plume would not be expected to cause acute mortality, even under worst-case centerline exposure during warm years.

VI.D.3.a.i. (b) (iii) Oceanic-Estuarine Residents

Spot and Atlantic croaker are offshore ocean spawners whose young move into the Estuary mainly at the juvenile stage, where they use tidal creeks and marshes as nursery habitat (Section IV.G; Appendix C Section VIII). No eggs of these two species occur at Salem, and the few late larvae that occur in the vicinity of the Station are well up-Estuary from their primary range (Figures IV-21 and 22). Spot larvae are present at Salem during late May and June at ambient water temperatures of about 60° to 73°F, while Atlantic croaker larvae occur in September, at temperatures of about 66° to 75°F (Figure VI-8).

Thermal tolerance test data indicate that spot are able to tolerate all of the reasonable worst-case time-temperature conditions in the Station's thermal plume (Figure VI-12a). Safe ΔT limits for spot larvae and juveniles, calculated from TL50 test results reported for 10-minute to 40-minute exposures at acclimation temperatures below about 73°F, are well above the centerline plume ΔT values for those exposure times. Plume ΔT values are reduced below safe temperature limits for long-term (≥24hr) exposure within the first few seconds following discharge (Figure VI-12a). No short-term TL50 values were available from the literature for Atlantic croaker larvae. However, critical thermal maxima determined by Horton and Bridges (1973) for 19-60 mm Spot and 20-60 mm Atlantic croaker indicate nearly identical thermal tolerance of the two species (Figure VI-13b). Therefore, entrainment of Atlantic croaker larvae into Salem's thermal plume would also not be expected to cause acute mortality from exposure to excess temperatures, even under reasonable worst-case centerline exposure in warm years. However, mortality among larvae experiencing the highest plume temperatures would not appreciably harm the croaker population. Copeland et al. (1974) have reported an optimum temperature for Atlantic croaker juveniles of 91.5°F. The volume of the thermal plume exceeding this temperature, during the period that Atlantic croaker are near the Station, lies within the ZIM, which itself is extremely small in relation to the volume of the Estuary (0.0001 percent). Further, the majority of Atlantic croaker larvae are not found near Salem, but rather in the Lower Bay, along the coast, and offshore in the ocean.

Weakfish spawn in the nearshore ocean and lower Bay and a portion of the eggs and larvae are transported into upstream portions of the Estuary during warmer months. Weakfish eggs and larvae occur at Salem during late spring and summer (Figure VI-8). During the average year, eggs are present in this area at ambient water temperatures of about 69° to 77°F; larvae are present at temperatures ranging from about 67°F to peak summer temperature of about 78°F. In a warm year, maximum weekly average ambient water temperatures could reach 79°F and 81.5°F for eggs and larvae, respectively.

Thermal tolerance test data indicate that weakfish are able to tolerate all of the reasonable worst-case time-temperature conditions in the Station's thermal plume during the average year (Figure VI-12b). Safe ΔT limits for weakfish eggs and larvae, calculated from TL50 test results reported for 3-minute to 90-minute exposures at acclimation temperatures below about 73°F, are well above the centerline plume ΔT values for those exposure times. Within the first few seconds following discharge, plume ΔT values are reduced to levels below those that are unsafe for long-term ($\geq$24hr) exposure at this ambient temperature (Figure VI-12b). Under the conservative assumption that thermal tolerance does not increase when ambient temperatures rise above 73°F, safe ΔT values can be estimated by adjusting the values at 73°F acclimation downward by the amount the ambient temperature rises above 73°F. The data adjusted in this manner also suggest that in the average year, eggs and larvae will tolerate the maximum plume temperatures when ambient temperature rises above 73°F in summer. In the warm year, safe ΔT values adjusted in this manner occur at or near the maximum reasonable worst-case centerline plume exposures, suggesting that some mortality may occur if weakfish larvae are entrained into the highest temperature portions, during periods when ambient water temperature reaches about 81.5°F.

The cumulative effect of exposure to decreasing temperatures experienced during reasonable worst-case transit through the centerline plume in an average year was conservatively analyzed using tolerance data for acclimation temperatures below 73°F, to further explore the relationship between maximum summer ambient water temperature and the potential for weakfish mortality. Cumulative mortality was not calculated for a warm year, because the tolerance data available for estimating the resistance time equation (Section VI.C) for weakfish larvae are for acclimation temperatures about 9°F lower than peak (summer mean weekly ambient temperature during the warm year). Because thermal tolerance would be expected to increase with increasing acclimation temperature, cumulative mortality calculations based on available data would grossly overestimate the potential for mortality in the warm year.

The cumulative ratio of exposure time to resistance time for transit of weakfish larvae through the centerline of the plume at maximum mean weekly temperature in the average year is less than the lethal threshold (unity), indicating that weakfish can survive exposure to maximum plume temperatures under these conditions (Table VI-6). Although the tolerance data suggest that some mortality of larvae may occur if they were to be entrained into the highest temperature portions of the plume during especially warm summers, only a very small fraction of the populations would incur mortality because:

- Weakfish larvae are broadly distributed in the Estuary, with the vast majority of the population found in the lower Bay. Very few would ever come into contact with this small portion of the plume.
- Based on an analysis of the estimated ambient temperatures in the vicinity of Salem (Section V.F), temperatures exceeding 81.5°F occur with a frequency of about 105 days over a 50 year period, or about 3 percent of the time that weakfish larvae occur at Salem.
- The safe temperature limits used in the analyses represent the threshold above which mortality may be incurred by a percentage of exposed organisms. Percent mortality increases linearly with exposure temperature above this threshold, reaching 50 percent at a temperature 3.6°F higher than the safe limits used in the analysis. Therefore, mortality would only be expected in a small percentage of organisms exposed to temperatures exceeding the safe temperature limits, even during periods of extreme warm ambient temperatures.
- Only a small percentage of those larvae entrained into Salem's plume would be exposed to the conservative maximum centerline plume temperatures used in the analysis.

Bay anchovy move from coastal and lower Bay habitat into the Estuary during warmer months where they primarily utilize the pelagic zone as habitat for all life stages. Eggs and larvae/early juveniles of bay anchovy are present at Salem during late spring and summer, when mean weekly ambient water temperatures in the average year range from about 66° to 78°F (Figure VI-8).

Thermal tolerance test data indicate that bay anchovy are able to tolerate time-temperature conditions in the Station's thermal plume during the average year (Figure VI-12c). Safe ΔT limits for bay anchovy eggs, larvae and juveniles, calculated from TL50 test results reported for 30-minute to 180-minute exposures at acclimation temperatures below about 78°F, are well above the reasonable worst-case centerline plume ΔT values for those exposure times. Based on the observed relationship between thermal tolerance and exposure time for bay anchovy juveniles (Figure VI-12), the safe temperature limit for 10-second exposures of juveniles acclimated to 78°F is estimated to be 100°F. This tolerance limit is about equal to the maximum plume temperature at the point of discharge during the average year (100.7°F). Since dilution reduces Salem's plume ΔT to less than 58 percent of the maximum discharge ΔT within seven seconds, bay anchovy drifting in estuary water involved at the first instant of mixing with the thermal discharge should be able to tolerate transit through the highest temperature portion of the plume in the average year.

In the warm year, when weekly mean temperature reaches a maximum of 81.5°F, maximum centerline plume temperatures approach safe ΔT values for bay anchovy, indicating that some mortality of larvae entrained into the highest temperature portions of the plume may potentially occur. The cumulative effect of exposure to decreasing temperatures experienced during reasonable worst-case transit through the centerline plume was analyzed to further explore the relationship between maximum summer ambient water temperature and the potential for bay anchovy mortality. The analysis indicates that bay anchovy can survive exposure to maximum plume temperatures when ambient water temperatures are below about 81.3°F (Table VI-6). Ambient temperatures exceeding 81.3°F can be expected to occur during approximately 115 days during a 50 year period, or less than about 3 percent of the time during the seasonal occurrence of bay anchovy eggs and larvae at Salem. Mortality of those bay anchovy eggs and larvae entrained at the point of discharge and exposed to the maximum plume temperatures at the centerline of the plume may potentially occur during these infrequent warm periods. However, the potential cumulative exposure experienced by larvae entering the plume 10-seconds or more from the discharge point at ΔT values below about 13°F would not exceed lethal levels, even in the warm year. The estimated volume of the plume with isopleths exceeding that temperature is about 0.00004 percent of the volume of the Estuary (Table V-3).

VI.D.3.a.i. (c) Conclusions

Salem's thermal discharge is not expected to cause appreciable harm to any of the RIS due to mortality from exposure to excess temperatures during plume entrainment for the following reasons:

- Eggs and larvae of American shad are not susceptible to plume entrainment since they are not present near Salem.
- Scud, blue crab and the early life stages of alewife, blueback herring, white perch, striped bass, spot, and Atlantic croaker are able to tolerate the maximum temperatures that would be experienced during transit through the entire plume even in especially warm ambient temperature conditions.
- Opossum shrimp, weakfish, and bay anchovy are generally able to tolerate the maximum temperatures that would be experienced during transit through the entire plume. During periods of peak summer ambient water temperature in extreme warm years, exposure to maximum plume temperatures could potentially cause limited mortality of these RIS. This mortality is unlikely to occur to more than a very small fraction of the organisms present near Salem because of the infrequency and short duration of potentially lethal conditions; the infrequency of

low flow (high ΔT) operation in summer months; the low probability of larvae experiencing the maximum temperatures throughout their transit through the plume; and the small volume of the plume with potentially lethal temperatures.

- The effect of this potential mortality on populations of opossum shrimp, weakfish, and bay anchovy would be inconsequential considering the small portion of their populations that could potentially be exposed. Further, the distribution of the vast majority of opossum shrimp and the eggs and larvae of weakfish and bay anchovy is extensive and well down-Estuary of Salem's discharge.

VI.D.3.a.ii. Long-Term Exposure Beyond the ZIM

The potential for elevated plume temperatures to reduce survival of RIS depends in part on the period of the year in which various species occur in the vicinity of the Station (Figure VI-8). However, even when RIS are in the vicinity of Salem, mortality from chronic exposure to excess temperatures is, in reality, negligible for several reasons. First, exposure of individuals to higher plume temperatures for more than a few minutes to a few hours is highly unlikely. This is because the location and orientation of the plume is highly dynamic. It sweeps back and forth with the tides, occupying any one position for a maximum of about six hours (Figure V-29). Also, velocities within the ZIM are too high for the RIS to occupy that portion of the plume more than momentarily. Even beyond the ZIM, organisms are unlikely to maintain one position for long due to the high tidal flow velocities that occur in this region of the Estuary (Table VI-5; C Figures 26-28). Finally, thermal mortality has rarely been documented for mobile life stages in the vicinity of any thermal plume because fish avoid potentially lethal temperatures. This would be especially true at Salem, because of the Station's high velocity offshore discharge. The rapid dilution of temperatures and open water location of this design minimizes the potential for thermal attraction to the plume and allows free movement of organisms. No instances of thermal mortality of juvenile and adult fish have been observed over the 20+ years of Station operation.

Reported temperature limits (24hr - 48hr TL50s, UILT, UUILT) for survival of macroinvertebrate RIS and young-of-the-year and older fish RIS from chronic exposure to elevated temperature are compared to maximum temperatures at the edge of the ZIM when each species is present at Salem (Figures VI-14 to VI-17). The comparison was made for both average and warm ambient temperature conditions based on the mean weekly ambient temperatures recurring once in two years and once in ten years, respectively. Although temperatures near the ZIM may exceed the laboratory-predicted tolerance limits for juveniles and adults of some species, no mortality would be expected for the reasons cited above. Rather, the analysis below provides an indication of the potential for seasonal avoidance of portions of the plume by mobile life stages of the RIS, an effect which is examined in more detail in Sections VI.D.3.c and VI.D.3.d below. Those macroinvertebrate RIS that are planktonic, scud and opossum shrimp, would drift with the plume and tidal current flows, and therefore would also not be exposed for long to the higher plume temperatures. The relevant analysis of the potential for mortality from plume exposure of these RIS is presented above in Section VI.D.3. TL50s for long-term exposure of scud and opossum shrimp are presented below primarily to examine the relative thermal sensitivity of the species and provide data to aid the interpretation of the plume entrainment analysis presented above.

VI.D.3.a.ii. (a) Macroinvertebrates

The macroinvertebrate RIS are most abundant at Salem during spring, summer, and fall. Temperature tolerance tests indicate that thermal sensitivity varies substantially among the three macroinvertebrate RIS, blue crab being the most tolerant of high temperatures, and opossum shrimp the least tolerant (Figure VI-14). Upper tolerance limits for chronic (≥24hr) exposure of scud generally are higher than maximum temperatures at the edge of the ZIM, except for brief periods in warm years when ambient temperature peaks in mid-summer. Lethal temperatures for opossum shrimp also exceed maximum plume temperatures during spring and fall, but are lower than maximum plume temperatures occurring during summer in average as well as warm years. However, exposure to the highest plume temperatures for 24 to 96 hours could not conceivably occur for scud or opossum shrimp drifting through the Station's thermal plume. As discussed above in Section VI.D.3.a., scud are able to tolerate the full time-temperature exposure that they could potentially receive in drifting through Salem's thermal plume. Opossum shrimp are also generally able to tolerate the maximum temperatures that could be experienced during transit through the entire plume, except potentially during periods of peak summer ambient water temperature in warm years. Exposure to plume temperatures exceeding safe tolerance limits would be infrequent and would involve only a small percentage of the opossum shrimp contacting the plume (see Section VII.D.3.a.i (a) (ii)).

Blue crabs likely would be excluded from more than momentary exposure to the warmest portion of the plume because of the associated high velocities. In any case, temperature tolerance data indicate that blue crab could tolerate the warmest temperatures in the plume if exposed to such temperatures (Figure VI-14).

VI.D.3.a.ii. (b) Fish

VI.D.3.a.ii. (b) (i) Anadromous Herring

From mid-May through September, few American shad, alewife, or blueback herring occur in the vicinity of the Station (Figure VI-8). Adults and subadults of all of these species pass Salem to freshwater habitat upriver from the Station for spawning during late winter and spring, and juveniles use similar areas for nursery habitat during the summer. After spawning, adult American shad, alewife, and blueback herring may again pass the Station as they move back to coastal marine habitat, as may young-of-the-year when they exit the Estuary in fall (Section IV.G; Appendix C Section VIII).

Tolerance limits determined from laboratory tests on alewife are above maximum plume temperature at the edge of the ZIM for both average (Figure VI-15a) and warm (Figure VI-15b) ambient conditions when the anadromous herring are present at Salem. This indicates that there would be no thermal mortality of alewife from extended exposure to Salem's plume even in the improbable event that they were to be continuously exposed to maximum plume temperature at the edge of the high velocity zone. Since tolerance of the three congeneric species of herring to extremes of temperature is very similar (Figure VI-

15, summer period, and Figure VI-19), there would also be no risk of mortality for American shad or blueback herring. As discussed above, fish avoid potentially lethal temperatures. The potential for Salem's thermal plume to cause avoidance behavior in the anadromous herring is assessed in more detail in Section VI.D.3.c.

VI.D.3.a.ii. (b) (ii) Temperate Bass

From mid-May through late September, few white perch or striped bass occur in the vicinity of the Station (Figure VI-8). Adults of both of these species pass through the Salem vicinity to use freshwater habitat upriver from the Station for spawning during the spring. Juveniles primarily use freshwater to slightly brackish water areas upriver from the Station for nursery habitat during the summer. After spawning, adult striped bass move back to coastal marine habitat; white perch subadults and adults remain primarily in brackish or freshwater areas of the Estuary. Young-of-the-year move into deeper, higher salinity parts of the Estuary in Delaware Bay to over winter (Section IV.G; Appendix C Section VIII).

Tolerance limits determined from laboratory tests on each species are well above maximum plume temperature at the edge of the ZIM for both average (Figure VI-16a) and warm (Figure VI-16b) ambient conditions when the white perch and striped bass are present at Salem. This indicates that there would be no thermal mortality of either species from extended exposure to Salem's plume, even in the improbable event that they were to be continuously exposed to maximum plume temperature at the edge of the high velocity zone. Since fish avoid temperatures only a few degrees (F) below lethal temperatures, these results also suggest that the potential for the temperate bass RIS to avoid plume temperatures at the edge of the ZIM and beyond is low. The potential for Salem's thermal plume to cause avoidance behavior in the white perch and striped bass is assessed in more detail in Section VI.D.3.c.

VI.D.3.a.ii. (b) (iii) Oceanic-Estuarine Residents

From February through September, few Atlantic croaker occur in the vicinity of the Station (Figure VI-8). Croaker juveniles normally do not enter the Delaware Estuary until late summer and primarily utilize tidal marshes and tributaries as nursery areas, before moving downriver in fall to overwintering areas in the lower Bay and offshore in the ocean (Section IV.G; Appendix C Section VIII.).

Spot, weakfish, and bay anchovy primarily occur in the vicinity of Salem during the summer. Spot are primarily present at the Station from late spring to late summer and again throughout the fall. Weakfish are only present throughout the summer months, while bay anchovy occur at Salem during spring, summer, and early fall.

Tolerance limits determined from laboratory tests are well above maximum plume temperature at the edge of the ZIM for both average (Figure VI-17a) and warm (Figure VI-17b) ambient conditions when spot are present at Salem. This indicates that there would be no thermal mortality of spot from extended exposure to Salem's plume even in the improbable event that they were to be continuously exposed to maximum plume temperature at the edge of the high velocity zone. Since fish avoid temperatures only a few degrees (F) below lethal temperatures, these results also suggest that the potential for spot to avoid plume temperatures outside the ZIM is low. The potential for Salem's thermal plume to cause avoidance behavior in the spot is assessed in more detail in Section VI.D.3.c.

No long-term TL50 values were available from the literature for Atlantic croaker larvae. However, Miglarese et al. (1982) reported that juvenile and adult croaker were found in South Caroline estuaries at water temperatures up to 88.5°F, and Copeland et al. (1974) have reported optimum temperature for Atlantic croaker juveniles of 91.5°F. Critical thermal maxima determined by Horton and Bridges (1973) for 19-60 mm spot and 20-60 mm Atlantic croaker indicate nearly identical thermal tolerance of the two species (Figure VI-13b). Therefore, Atlantic croaker would also be expected to survive continuous exposure to maximum plume temperature at the edge of the ZIM for both average (Figure VI-17a) and warm (Figure VI-17b) ambient conditions during their primary periods of occurrence at Salem.

Tolerance limits reported for bay anchovy at acclimation temperatures occurring during peak summer temperatures are near or below maximum plume temperatures at the edge of the ZIM and beyond for both average and warm conditions (Figures VI-17a and VI-17b). Furthermore, mobile bay anchovy may avoid the high temperature portions of Salem's plume near the ZIM and the likelihood and extent of such avoidance is assessed in more detail in Section VI.D.3.c.

No long-term upper temperature tolerance estimates were available for weakfish. As discussed in detail above, long-term exposure to the higher plume temperatures at Salem is highly improbable. In any case, weakfish would avoid exposure to potentially lethal plume temperatures (Section VI.D.3.c).

VI.D.3.a.ii.(c) Conclusions

In summary, the elevated temperatures in the Station's thermal discharge should not cause any mortality of juvenile or adult fish RIS. The behavior of fish and the physical characteristics of the plume and Estuary minimize the probability of any mortality. Provided with a range of temperatures, fish typically avoid temperatures just below their upper tolerance limit, thus avoiding potentially lethal temperatures should they occur in the plume. The RIS have negligible potential for adverse impact due to mortality from long-term exposure to excess temperature in Salem's plume because:

- Except for migration, the vicinity of Salem's offshore thermal discharge is not a critical habitat zone for any of the RIS.
- The RIS cannot maintain their position in the immediate discharge area for more than a few minutes to a few hours because the velocity of the discharge and of the peak tidal flows exceeds their swimming capacity.
- The location and orientation of the plume, which is highly dynamic and sweeps back and forth with the tides, further reduces the potential for the RIS to be exposed to the higher plume temperatures for more than brief periods.

- Alewife, blueback herring, American shad, striped bass, white perch, and Atlantic croaker are most common in the vicinity of the Station during fall, winter or spring. At those times their tolerance of elevated temperatures, ranging from about 13°F to 17°F ΔT, is well above the highest isopleths occurring at the edge of the ZIM.
- Spot are commonly found in the vicinity of the Station during summer, but are very tolerant of high temperatures, so that their tolerance of elevated temperatures, ranging from about 16°F to 26°F ΔT, is well above the highest isopleths occurring at the edge of the ZIM.
- While bay anchovy and weakfish can be abundant in the vicinity of the Station during summer, when they may be exposed to plume temperatures exceeding their upper tolerance limits, they have demonstrated the ability to avoid lethal temperatures.

VI.D.3.b. Potential for Appreciable Harm Due to Mortality from Cold Shock

When prevailing background water temperatures are cool during the late fall, winter, and early spring, plume temperatures generally would be preferred by RIS species. Cold shock may occur if fish acclimated to elevated temperatures of the plume experience a rapid decrease in temperature, as in the event of a sudden Station shutdown. Whether mortality actually occurs depends upon whether the organism is acclimated to elevated plume temperatures and whether it can tolerate the rate and magnitude of the temperature decrease. The lethal threshold for sudden temperature drops, as measured in the laboratory, is called the lower incipient lethal temperature (LILT) (Figure VI-1).

Reported tolerance limits (24-96 hr TL50's, LILT, ULILT) of macroinvertebrate RIS and young-of-the-year and older fish RIS to sudden drops in temperature were compared to the maximum drop in temperature that could potentially occur at the edge of the ZIM when each species is present at Salem (Figures VI-18 to VI-21). The comparison was made for both average and cool ambient temperature conditions based on the mean weekly ambient temperatures recurring once in two years and once in ten years, respectively. However even when RIS are in the vicinity of Salem, mortality from temperature drops is, in reality, negligible for several reasons. First, acclimation of organisms to the higher plume temperatures is highly unlikely. This is because the location and orientation of the plume is highly dynamic, sweeping back and forth with the tides, and therefore occupying any one position for a maximum of about six hours (Figure V-29). Also, velocities within the ZIM are too high for the RIS to occupy that portion of the plume more than momentarily. Even beyond the ZIM, organisms are unlikely to maintain one position for long due to the high tidal flow velocities up to about 2.4 feet per second that occur in this region of the Estuary (Table VI-5; C Figures 26-28). Finally, mortality attributable to cold shock has usually been associated with shoreline discharges, where low discharge velocity and confined areas (e.g. canals) of high discharge temperatures cause fish to congregate in winter. This does not occur at Salem, because of its high velocity, offshore discharge and the high tidal energy of the Delaware Estuary at the Station. The high velocity of Salem's discharge, rapid dilution of temperatures, tidally shifting plume, and open water location of this design minimizes the potential for thermal attraction to the plume. No instances of mortality from cold shock have been observed over the 20+ years of Station operation.

VI.D.3.b.i. Macroinvertebrates

The macroinvertebrate RIS do not occur in abundance in the vicinity of Salem when the water temperature is 40°F or less and the potential for cold shock is greatest (Figure VI-8). It is inconceivable that scud or opossum shrimp would remain in contact with the warmest portions of the plume for a sufficient period of time to become acclimated to those elevated temperatures. Drift with the discharge flow, tidal flow, and wind-driven currents would limit their residence in or near the ZIM. Lower lethal temperatures determined from laboratory tests on scud and opossum shrimp are below ambient temperature at the edge of the ZIM for both average (Figure VI-18a) and cool (Figure VI-18b) ambient conditions when these RIS are present at Salem. This indicates that there would be no mortality of scud and opossum shrimp due to cold shock even in the highly improbable event that they were to acclimate to maximum plume temperature at the edge of the high velocity zone.

It is conceivable, but unlikely for the reasons discussed above, that adult blue crab could become acclimated to the plume temperatures near the ZIM. However, lower lethal temperatures determined from laboratory tests on blue crab are below ambient temperature at the edge of the ZIM for both average (Figure VI-18a) and cool (Figure VI-18b) ambient conditions for the primary period in which they occur at Salem.

VI.D.3.b.ii. Fish

VI.D.3.b.ii. (a) Anadromous Herring

American shad, blueback herring, and alewife that enter the Estuary during the spawning run primarily occur near Salem from February to May, when water temperatures are still relatively cold (Figure VI-8). Abundance of these two species and of alewife generally peaks after mid-March. Lower tolerance temperatures for the anadromous herring RIS are below ambient temperatures for both average (Figure VI-19a) and cool (Figure VI-19b) ambient conditions during this period of peak abundance at Salem, indicating that the anadromous herring would be able to tolerate temperatures drops associated with sudden plant shutdown.

During virtually all of the fall migration of young-of-the-year past Salem, anadromous herring would tolerate the maximum temperature drop that could occur at the edge of the ZIM in the event of sudden Station shutdown (Figure VI-19). During February and early March, lower tolerance temperatures for these species are at or above ambient temperature for that time of year. This indicates that mortality from cold shock could be possible if fish were acclimated to the maximum temperature at the edge of the ZIM, and the thermal discharge were to suddenly cease. The implausible aspects of physiological adaptation to the plume temperatures were discussed above. The fact that Salem consists of two separate Units with the same discharge location further reduces the potential for the warm plume to disappear suddenly and create conditions conducive to cold shock. If one Unit shuts down suddenly, the heated water from the other is usually available to prevent rapid and extreme temperature decreases in the vicinity of the discharge. Given this combination of circumstances the potential for mortality from cold shock is negligible, even during the period of coldest winter temperatures.

VI.D.3.b.ii. (b) Temperate Bass

White perch and striped bass primarily occur at Salem during fall, winter, and spring. Lower tolerance temperatures for white perch and striped bass are below ambient temperatures for both average (Figure VI-20a) and cool (Figure VI-20b) conditions during these periods. Tolerance data were available for a narrower range of acclimation temperatures for white perch than for striped bass. However, thermal tolerance of the two species is similar, and the available data indicate that white perch may be somewhat more tolerant of temperature drops than striped bass (Figure VI-20). Therefore, the potential for Salem's thermal plume to cause mortality of white perch and striped bass due to cold shock is negligible.

VI.D.3.b.ii. (c) Oceanic-Estuarine Residents

The tolerance data for spot indicate that they are able to tolerate the maximum drop in temperature that could occur outside the ZIM during their primary occurrence at Salem, which is in summer and fall. Lower lethal temperature values are well below ambient temperatures in the vicinity of the Station for both average (Figure VI-21a) and cool (Figure VI-21b) conditions. By the beginning of winter, when ambient water temperature approaches the lowest temperature tolerated by spot, most have moved downriver of Salem toward wintering grounds in the lower Bay and ocean (Section IV.G; Appendix C Section VIII).

Only one value for the lower temperature tolerance of Atlantic croaker was found in the literature. However, given the availability of tolerance data for spot, and the similarities of the two species, Atlantic croaker likely could survive the maximum possible temperature drop outside Salem's ZIM during the fall (Figure VI-21). In January, ambient temperature approaches the ultimate lower incipient lethal temperature for Atlantic croaker. Lankford (1997) has shown that Atlantic croaker are generally highly susceptible to winter mortality when water temperature declines below about 37°F. Atlantic croaker that remain in the Transition Zone of the Estuary in winter would be susceptible to cold shock, regardless of Salem's operation. Therefore sudden drops in temperature in Salem's thermal plume during January and February would not increase the inherent risk of winter mortality for Atlantic croaker that remain near Salem in mid-winter.

Based on the available tolerance data, weakfish would tolerate the maximum temperature drops that could occur in Salem's plume outside the ZIM (Figures VI-21a and VI-21b). Bay anchovy would also be able to tolerate the maximum temperature drops outside the ZIM, except in early spring (Figure VI-21).

VI.D.3.b.iii. Conclusions

Salem's thermal discharge is not expected to cause appreciable harm to any of the RIS due to mortality from cold-shock for the following reasons:

- Except for migration, the vicinity of Salem's offshore thermal discharge is not a critical habitat zone for any of the RIS and is not their primary winter habitat.
- The high velocity of Salem's discharge precludes the RIS from being able to stay in the portion of the reasonable worst-case plume that is warmer than the tidally averaged temperature at the edge of the ZIM (ΔT=12.2°F) long enough to become acclimated to those temperatures.
- The location of Salem's thermal plume in the Estuary reverses direction with each change of the tide. This dynamic change in plume location and the relatively high ambient tidal flow velocities near Salem during ebb and flood tides further reduce the potential for RIS to remain and become acclimated to temperatures in the plume.
- Lower temperature tolerance test data indicate that all of the RIS are generally able to tolerate the highest drops in temperature to which they could conceivably be exposed in the event of sudden Station shutdown during their peak periods of occurrence at Salem.
- Salem consists of two separate Units with the same discharge location, which greatly reduces the potential for the warm plume to disappear suddenly and create conditions conducive to cold shock.

VI.D.3.c. Potential for Appreciable Harm from Habitat Exclusion

Free-swimming juvenile and adult RIS would avoid stressful high temperature in the plume by moving along temperature gradients to water having lower temperatures (Section VI.B.3). As discussed above in Section VI.D.3.a., this response precludes mortality of juvenile and adult RIS from exposure to excess temperatures in Salem's plume. However the avoidance response also may preclude organisms from occupying otherwise usable habitat, an effect that could potentially harm RIS populations by excluding them from habitat needed for life-cycle functions. The potential for harm is a function of the spatial dimension of the habitat excluded and the extent to which the affected zone is critical to the reproduction and survival of the population.

Minimum temperatures that blue crab and young-of-the-year and older fish RIS would likely avoid during their primary period of occurrence were compared to maximum temperatures at the edge of the ZIM when each species is present at Salem (Figures VI-22 to VI-30). The comparison was made for both average and warm ambient temperature conditions based on the mean weekly ambient temperatures recurring once in two years and once in ten years, respectively. For fish, avoidance temperatures were predicted as a function of seasonal ambient temperature using the regression equations developed from laboratory-determined avoidance temperatures for a range of acclimation temperatures (Section VI.C.2.a.; Figures VI-22 to VI-30).

Although temperatures near the ZIM may exceed the predicted avoidance temperature for juveniles and adults of some species, complete exclusion from these areas of the plume would be unlikely. While plume areas at temperatures greater than the avoidance temperature may be excluded for long-term habitation, some of these areas could still be utilized for shorter periods of time (e.g., foraging for food, escape from predation, or migration). This is because fish can tolerate even those temperatures exceeding their upper incipient lethal temperatures for brief periods (Section VI.C.2.a.). Further, since Salem's thermal plume is highly dynamic and shifts location every few hours, no area beyond about 50 to 100 ft from the discharge would ever be continuously excluded from habitation (Section V.F; Figure V-52).

Within the small area of the ZIM, exclusion would also result from the high velocities and turbulence during initial mixing of the discharge with Estuary waters. The volume occupied by the ZIM is less than about nine acre-ft during ebb and flood tides, or less than 0.0001 percent of the volume of the Delaware Estuary (Table V-1). During slack tide conditions, the ZIM volume is less than about 74 acre-ft, or about 0.0007 percent of the volume of the Estuary. However, the slack-tide plume condition lasts for less than 60 minutes of each full tidal cycle (about 8 percent of the time) (Section V.F.).

VI.D.3.c.i. Macroinvertebrates

Of the macroinvertebrate RIS, blue crab has sufficient mobility to avoid areas of high temperature in Salem's plume. Blue crab also have very high tolerance to extremes in temperature (Figure VI-14). Upper avoidance temperatures, determined in laboratory studies for blue crab acclimated to 77° to 78.8°F, ranged from 91.4° to 98.6°F, with a mean of 94.6°F (PSE&G 1974). Tidally averaged peak summer temperature at the edge of the ZIM for the worst-case condition is about 90.2°F for an average year, during which peak summer ambient temperature is comparable to the acclimation temperature used in the laboratory studies. Therefore, there is no potential for Salem's plume to exclude blue crab from habitat beyond the ZIM in an average year. The reported UUILT for blue crab of 98° to 99°F (Tagatz 1969) indicates that even for a warm year, when maximum temperature at the edge of the ZIM is about 93.7°F, the potential for Salem's plume to exclude blue crab from habitat beyond the ZIM is negligible.

VI.D.3.c.ii. Fish

VI.D.3.c.ii. (a) Anadromous herring

During the spring and fall, when migrating adult and juvenile American shad, alewife, and blueback herring use the Delaware Estuary in the vicinity of the Station, predicted avoidance temperatures are above the plume temperatures at the edge of the ZIM during both average (one year in two) and warm conditions (one year in ten) (Figure VI-22 to VI-24). Avoidance temperatures for the anadromous herring range from about 4°F to 18°F higher than temperatures at the edge of the reasonable worst-case ZIM during the spring migration. Avoidance temperatures for young-of-the-year range from approximately 2°F to 13°F higher than edge of ZIM temperature during their fall migration. Therefore, none of the anadromous herring RIS would avoid plume isopleths below about 14°F. Plume ΔT values of 14°F and higher are only found within the ZIM, and the ZIM occupies less than 0.0001 percent of the volume of the Estuary on running tides.

VI.D.3.c.ii. (b) Temperate Bass

White perch adults and juveniles primarily use the area of the Estuary near the Station as habitat from October to May (Figure VI-8). Predicted avoidance temperatures for white perch are higher than temperatures at the edge of the ZIM in both average and warm years (Figures VI-25*a* and VI-25*b*). Predicted avoidance temperatures for adult and yearling white perch in the winter and spring of the warm year range from approximately 9°F to 20°F higher than reasonable worst-case temperatures at edge of Salem's ZIM (Figure VI-25*b*). Avoidance temperatures for young-of-the-year range from approximately 3°F to 9°F higher than edge of ZIM temperature during their fall migration in warm years.

Predicted avoidance temperatures for striped bass are higher than maximum plume temperatures at the edge of the ZIM in both average and warm years (Figures VI-26*a* and VI-26*b*). Yearling and older striped bass present at Salem in winter and early spring would not avoid the temperatures existing in Salem's plume beyond the ZIM. Predicted avoidance temperatures are about 7°F higher than plume temperatures that would exist at the edge of the ZIM in the warm year (Figure VI-26*b*). Striped bass juveniles capable of avoiding high temperatures in the plume primarily use the area of the Estuary near the Station as habitat from October through December (Figure VI-8). Predicted avoidance temperatures for young-of-the-year striped bass during this period range from approximately 4°F to 19°F higher than temperatures at the edge of the ZIM (Figure VI-26*b*).

Therefore, predicted avoidance temperatures for white perch and striped bass indicate that they would not avoid plume ΔT isopleths below about 15°F to 21°F. Plume ΔT fields of 15°F and higher are only found within the ZIM, and the ZIM occupies less than 0.0001 percent of the volume of the Estuary on running tides.

VI.D.3.c.ii. (c) Oceanic-Estuarine residents

Spot is a marine species that in its juvenile stage uses bays and estuaries, including the Delaware Estuary, for nursery habitat (Figure IV-21). Juveniles enter the Delaware Estuary in the spring, disperse quickly throughout the Estuary including all tributaries and adjacent marsh areas, and are particularly abundant in shallows with mud bottoms and reduced salinity. Such areas are subject to significant diel fluctuations in temperature up to 7°F as a result of solar heating (Ketchum 1952; Weston 1978). In the vicinity of the Station, spot occur primarily from May through August and again from October through December (Figures VI-8).

In fall, spot would not avoid plume temperatures beyond the ZIM, in either the average or the warm year (Figures VI-27*a* and VI-27*b*). Predicted avoidance temperatures for spot during fall of the warm year are about 1°F to 13°F higher than the edge of ZIM temperature (Figure VI-27b), representing avoidance ΔT fields of approximately 13°F to 25°F. During peak summer temperatures in July and August of both the average and the warm year, maximum temperatures near the ZIM exceed the avoidance temperatures predicted for spot. Spot may avoid plume isopleths beyond the ZIM that exceed about 8°F ΔT during this period. However, temperature elevations greater than 8°F that might be avoided by juvenile spot in warm years do not encroach on the shallow inshore and tidal marsh areas, which constitute their preferred nursery habitat. Thus, spot access to nursery habitat in the vicinity of the Station is unobstructed by Salem's thermal plume.

Atlantic croaker, a marine species which spawns offshore, uses bays and estuaries including the Delaware Estuary for juvenile nursery habitat (Figure IV-22). During summer months, juveniles primarily utilize shallow habitat, including tidal creeks in brackish water portions of the Estuary. Young Atlantic croaker are found in the vicinity of the Station primarily between October and January (Figure VI-8) with peak abundance in December and January. Predicted avoidance temperatures indicate that young-of-the-year croaker may potentially avoid plume temperatures that exist beyond the ZIM during October in both average and warm years, but not during their peak occurrence in December and January (Figure 28*a* and 28*b*). Atlantic croaker access to nursery habitat in the vicinity of the Station during their peak period of occurrence in December and January would be unobstructed by Salem's thermal plume. The potential for avoidance during October in the warm year would be limited to the plume volume within a ΔT of about 5°F, or less than 0.02 percent of the volume of the Estuary (Table V-3) on running tides.

Weakfish, a coastal marine species, spawn from late spring through summer in bays and estuaries, including the lower Delaware Estuary, and the young spread throughout the Bay and bordering tidal creeks (Figure IV-25). In the vicinity of the Station, juvenile weakfish primarily occur from June through September with the peak from late June through August (Figure VI-8). Predicted avoidance temperatures indicate that young-of-the-year weakfish would avoid ΔT fields above about 8°F during summer in average years (Figure VI-29a) and above about 6.5°F during warm years (Figure VI-29b). Based on the predicted avoidance temperatures, weakfish may potentially avoid plume temperatures occupying less than about 0.0009 percent of the volume of the Delaware Estuary during an average year, and less than about 0.003 percent during a warm year (Table V-3). Consequently, Salem's thermal plume would potentially exclude juvenile weakfish from only a very small portion of the extensive nursery habitat available in the Delaware Estuary and its tidal tributaries.

Bay anchovy is a ubiquitous marine species that spawns in coastal waters, bays, and estuaries. The Delaware Estuary is a small portion of the extensive coastal habitat of this species (Figure IV-17). Juveniles and adults occur throughout the year, but are abundant in the vicinity of the Station only from late April through October (Figure VI-8). Predicted avoidance temperatures for bay anchovy are higher than plume temperature at the edge of the ZIM during spring and fall in both average and warm year (Figures VI-30*a* and VI-30*b*). In an average year, avoidance may occur at ΔT fields that are slightly beyond the ZIM (above about 10°F) during peak summer temperatures (Figure VI-30*a*). During summer in the warm year, bay anchovy may avoid plume temperatures beyond the ZIM to ΔT isopleths as low as about 7.5°F (Figure VI-30*b*). Based on the predicted avoidance temperatures, bay anchovy may potentially avoid plume temperatures occupying less than about 0.0008 percent of the volume of the Delaware Estuary during an average year, and less than about 0.002 percent of the volume of the Estuary during a warm year (Table V-3). Therefore the spatial dimension of the plume isopleths that bay anchovy may avoid represents a negligible portion of the nursery and spawning habitat that extends throughout much of the Delaware Estuary.

VI.D.3.c.iii. Conclusions

Salem's thermal discharge is not expected to cause appreciable harm to any of the RIS due to habitat exclusion for the following reasons:

- Although high velocity and turbulence in the ZIM may exclude organisms from permanently occupying a volume of less than 25 acre-ft in the immediate vicinity of the Station's discharge, this is a negligible portion (less than 0.0002 percent) of the habitat available to RIS in the Estuary.
- Extremely high temperature tolerance and laboratory-determined avoidance temperatures indicate that blue crab would not be excluded from additional habitat due to avoidance of reasonable worst-case plume temperatures beyond the ZIM.
- Avoidance temperatures predicted from laboratory data indicate that American shad, alewife, blueback herring, white perch, and striped bass would not be excluded from habitat due to avoidance of reasonable worst-case plume temperatures occurring beyond the ZIM in either average or warm years.
- Avoidance temperatures predicted from laboratory data indicate that Atlantic croaker would not be excluded from habitat due to avoidance of reasonable worst-case plume temperatures occurring beyond the ZIM during their peak period of occurrence at Salem in November and December. Although they may potentially avoid ΔT values above about 5°F in early October, their abundance is relatively low at that time and the volume of potential habitat exclusion is too small a portion (0.02 percent) of their available habitat in the Estuary to harm the population.
- Avoidance temperatures predicted from laboratory data indicate that spot and bay anchovy would not be excluded from habitat due to avoidance of reasonable worst-case plume temperatures occurring beyond the ZIM during the average year. Although they may potentially avoid ΔT values above about 7.5° to 8°F in summer during warm years, the volume of potential habitat exclusion is too small a portion (0.0009 percent on running tides) of their available habitat in the Estuary to harm the population.
- Avoidance temperatures predicted from laboratory data indicate that weakfish may be excluded from habitat due to avoidance of reasonable worst-case plume temperatures occurring beyond the ZIM during its summer period of occurrence in both warm and average years. However, the volume of potential habitat exclusion is less than 0.0009 to 0.003 percent of the volume of the Estuary in running tides, too small to adversely affect the broadly distributed weakfish population;
- Since Salem's thermal plume is highly dynamic and shifts location every few hours, no area beyond about 50 to 100 ft from the discharge would ever be continuously excluded from habitation.

- Even when plume temperatures exceed the predicted avoidance temperature for juveniles and adults of some species, these areas could still be utilized for shorter periods of time for foraging and other activities by those same species.
- Other than its function as a corridor for migrating species (Section VI.D.3.d), the vicinity of Salem is not a critical habitat zone for any of the RIS (Section IV.F and IV.G; Appendix C Section VIII). The anadromous herring and temperate bass RIS primarily use freshwater habitat upriver from Salem for spawning and nursery functions. Spot and Atlantic croaker primarily use the ocean for spawning and the marshes, shallow bays and tributaries of the Estuary as nursery. Weakfish spawn in the lower Bay and ocean and, although young extend into the vicinity of Salem, the primary nursery habitat is downstream in the Bay. Although bay anchovy use the vicinity of Salem for spawning and nursery, the area is not critical for these functions, which occur over extensive areas well downstream of the Station in the Bay and throughout the coastal marine environment.

VI.D.3.d. Potential for Appreciable Harm from Blockage of Migration

This section addresses the likelihood and extent to which the avoidance responses discussed in Section VI.D.3.c may interfere with major migratory movements of the RIS. Five fish RIS are anadromous or semi-anadromous, undertaking annual adult migrations upriver to freshwater tidal and/or non-tidal portions of the River to spawn. Juveniles emigrate downriver to overwinter in the lower Estuary or coastal waters. These species are American shad, alewife, blueback herring, striped bass, and white perch. The vicinity of Salem is a critical habitat zone for these species with regard to migration, since they pass through the vicinity of the Station to their spawning or overwintering habitats.

Based on laboratory data, avoidance temperatures were predicted for the seasons when these migratory RIS are present at Salem, using both average year and warm year ambient temperature conditions (Section VI.D.3.c). The potential of the plume to block RIS migratory paths was evaluated by first calculating the cross-sectional area of plume isopleths that exceed the avoidance temperature predicted for each week the species is present in Salem's vicinity. These avoidance cross-sections were then compared to the total Estuary cross-sectional area available at Salem's location for migrating fish passing through the area. Unobstructed passage is assured if substantial portions of the cross-section do not exceed avoidance temperatures. For example, recommendations in the Section 316(a) Draft Guidance and in various state and federal water quality regulations issued since 1968, provide that migratory function will be protected when at least one-third to three-quarters of the cross-section is available for passage (USEPA 1974; NAS/NAE 1973; NJDEP 1998).

<u>VI.D.3.d.i. Anadromous Herring</u>

Minimum avoidance ΔT values predicted for American shad, alewife, and blueback herring during their primary periods of occurrence at Salem range from 13.4 to 18.1°F. These ΔT isopleths all lie within Salem's ZIM. Therefore, the entire cross-section beyond the ZIM is free from any thermal blockage. High velocities within the ZIM may be sufficient to deter fish from swimming through that portion of the Salem's plume, which amounts to 1 to 3 percent of the total Estuary cross-section. Anadromous herring that may prefer to avoid the discharge flows in the ZIM have the remaining 97 to 99 percent of the Estuary cross-section available for passage.

Because the vicinity of Salem is a critical habitat zone for the migratory RIS, avoidance cross-sections were analyzed conservatively using the 95% confidence bound for the predicted avoidance temperatures (Section VI.C.; Figures VI-22 to VI-30). On this basis, minimum avoidance ΔT fields for the anadromous herring RIS range from 5.0° to 10.6°F, and these RIS may avoid plume isopleths beyond the ZIM during a portion of seasons that they are present at Salem. These avoidance ΔT fields occupy less than 1.1 to 4.6 percent of the Estuary cross-section on running tides during the warm year (Table VI-7). On slack tides, plume temperatures exceeding the conservatively estimated avoidance ΔT fields occupy less than 14.8 percent of the Estuary cross-section available. However, the slack condition persists for only about 60 minutes of each full tidal cycle, or less than 8 percent of the time.

VI.D.3.d.ii. Temperate Bass

Minimum avoidance ΔT values predicted for white perch and striped bass during their primary periods of occurrence at Salem range from 15.5° to 21.9°F. These ΔT isopleths all lie within Salem's ZIM. Therefore, the entire cross-section beyond the ZIM is free from any thermal blockage. High velocities within the ZIM may deter fish from swimming through that portion of the plume, which amounts to approximately 1.1 percent of the total Estuary cross-section. White perch and striped bass that may prefer to avoid the discharge flows in the ZIM have the remaining 98.9 percent of the Estuary cross-section available for passage.

Because the corridor past the vicinity of Salem is a critical habitat zone for migrating RIS, avoidance cross-sections were also analyzed conservatively using the 95% confidence bound for the predicted avoidance temperatures. On this basis, minimum avoidance ΔT values for white perch and striped bass range from 5.3°F to 12.0°F, and these RIS may avoid plume isopleths beyond the ZIM during a portion of the seasons that they are present at Salem. These avoidance ΔT values occupy less than 4.6 percent of the Estuary cross-section on running tides during a warm year (Table VI-7). On slack tides plume temperature exceeding the conservatively estimated avoidance [ΔTs] occupy less than 17.6 percent of the Estuary cross-section available. However, the slack condition persists for only about 60 minutes of each full tidal cycle, or less than 8 percent of the time, and would therefore not block the migratory movements of the temperate bass RIS.

VI.D.3.d.iii. Conclusions

Salem's thermal discharge is not expected to cause appreciable harm to any of the migratory RIS from blockage of migration for the following reasons:

- Although high velocity and turbulence in the ZIM may block American shad, alewife, blueback herring, white perch, or striped bass from migrating through it, the ZIM only occupies a cross-section of about 4,000 ft^2 in the immediate vicinity of the Station's discharge. This is a negligible portion (about one percent) of the migratory path available to RIS migrating past the Station.

- Using the lower confidence bound on avoidance temperatures to be highly protective of the critical habitat function of migration, over 95 percent of the Estuary cross-section would still be available for migratory passage on running tides during a warm year.
- As a result of all the above findings, no blockage of migration would be expected at Salem; the zone of passage that would be maintained under reasonable worst-case assumptions is much larger than that suggested in regulations and guidance to assure adequate protection of migration.

VI.D.3.e. Potential for Appreciable Harm from Reduced Growth

Depending upon the species, Salem's thermal discharge could potentially either increase or decrease growth of the RIS exposed to the plume by shifting water temperatures toward or away from the species' optimum growth range. Reduction in growth could potentially cause harm to the populations of RIS by decreasing reproduction and survival. The potential for harm is a function of the spatial dimension of the habitat excluded and the extent to which the affected habitat is critical to the reproduction and survival of the population.

The upper end of the optimum range for growth of each RIS was compared to the reasonable worst-case maximum plume temperature at the edge of the ZIM during the species' primary period of occurrence at Salem (Figures VI-31 to VI-34). When possible, reported laboratory study values for the upper end of the species growth range were used for the comparison. Alternatively, the upper growth temperature was derived from laboratory-determined optimum growth temperature by the method of Brungs and Jones (1977), as discussed in Section VI.C.2.a. Laboratory-determined final preferenda were used as a surrogate for optimum temperature, when necessary. The comparison was made for both average and warm ambient temperature conditions based on the mean weekly ambient temperatures recurring once in two years and once in ten years, respectively.

Although temperatures in the higher temperature portions of the plume near the ZIM may exceed the predicted upper growth temperature for some species, reduced growth would be unlikely for at least two reasons. First, plume temperatures earlier in the growth season may be closer to optimum growth temperature than are ambient water temperatures during that season, thus enhancing growth. In addition, growth is dependent on factors other than temperature such as food availability, nutrition quality, and availability of shelter.

Second, organisms would have to be exposed to excessive temperatures for long periods of time to measurably affect growth. For example laboratory growth tests on aquatic organisms are typically conducted for 7 to 28 days or longer in order to detect changes in growth. Planktonic forms, such as scud and opossum shrimp, would only be briefly exposed to the higher plume isopleths as they drift with the discharge flow and tidal currents. Since Salem's thermal plume is highly dynamic and shifts location every few hours, it would be highly unlikely that even the mobile juvenile and adult RIS would remain continuously near the ZIM within the area of temperatures exceeding the upper end of the optimum growth range for a sufficient time to alter their ultimate growth. Further, preferred temperatures for a given species generally lie within the optimal temperature range for growth. Consequently, it is unlikely that fish with temperature avoidance capability, would maintain a position at a specific temperature in a constantly changing and moving plume which is in excess of their preferred and optimal range for growth for periods long enough to have an effect on growth. Within the Estuary, optimal ambient conditions for growth for some species exist for only brief periods, and the thermal plume may provide these conditions sooner or extend them later into the annual ambient temperature cycle.

VI.D.3.e.i. Macroinvertebrates

The upper limit of the optimum temperature range for growth of scud is 86°F (Figure VI-31). The maximum mean weekly summer ambient water temperature of the Delaware Estuary near the Salem discharge is 78°F during average years and 81.5°F during warm years. Thus, plume ΔT values exceed 8°F during an average year or 4.5°F during warm years. Growth of scud will be less than optimal when ambient water temperature peaks in mid-summer. The volume of the plume that exceeds these ΔT values is relatively small and encompasses less than 0.0009 percent and 0.05 percent of the Estuary, respectively. During the remainder of the scud growth season, plume temperatures will be more favorable for scud growth than ambient water temperatures.

Egg and larval development of opossum shrimp occurs in the brood pouch (marsupium) of the female at a temperature-dependent rate. Total in-marsupium time ranges from 13 to 24 days at 60.8°F and 50°F, respectively. Growth of the young and adults is temperature-dependent, with little growth below 39.2°F, but with an exponentially increasing growth rate over a tested range of 39.2° to 77°F (Pezzack and Corey 1979). Pezzack and Corey did not identify an optimal growth range because the instantaneous growth rate had not leveled off at the highest test temperature (77°F). Therefore, 77°F is likely to be an underestimate of the upper limit of optimal temperature for juvenile growth. During fall, winter and spring, plume temperatures are more favorable than background Estuary temperatures for growth of opossum shrimp in both average and warm years. During the summer months, plume temperatures may exceed the optimum temperature range for growth in a warm year.

However, because of the relatively small portion of their populations likely to drift through the Station's plume and the short drift time through the plume (a few hours at most), neither scud nor opossum shrimp are likely to experience any appreciable increase or decrease in their average growth rate in the Estuary.

An upper limit of about 89°F was estimated for optimum growth of adult blue crab (Figure VI-31). Plume isopleths higher than about 11°F and 7.5°F could exceed this optimum growth limit in average and warm years, respectively. The volume of the reasonable worst-case plume that exceeds these ΔT values is relatively small and encompasses less than about 0.0008 percent and 0.002 percent of the Estuary volume, respectively. The laboratory-determined upper optimum temperature for juvenile blue crabs is 86°F. During the peak summer temperatures in the average and warm years, reasonable worst-case plume temperatures higher than this upper optimum temperature would occupy only about 0.0009 percent and 0.05 percent of the volume of the Estuary, respectively.

VI.D.3.e.ii. Fish

VI.D.3.e.ii. (a) Anadromous Herring

American shad, alewife, and blueback herring occur in the vicinity of the Station primarily during the spring adult spawning run and fall juvenile out-migration (Figure VI-8), but the vicinity of the Station is not the primary nursery area for these species (Figures IV-18 to IV-20). The estimated upper limit of the optimal growth range of these species ranges from about 72.5°F to 84°F for adults and from about 75°F to 84.5°F for young-of-the-year (Figure VI-32). During the spring and fall migrations, Station plume temperatures beyond the ZIM are more favorable for growth than the prevailing ambient temperatures in the average year (Figure VI-32a). During warm years, plume temperatures at the edge of the ZIM are more favorable for growth than ambient temperatures during all but a small portion of the spring and fall migrations of American shad and alewife (Figure VI-32b). However, the brief period during which reasonable worst-case maximum plume temperature may exceed the upper growth limits and the brief periods of contact with the plume that these species are likely to experience are too brief to alter their growth.

VI.D.3.e.ii. (b) Temperate Bass

During the primary growth season (mid-spring through mid-fall), white perch and striped bass use lower salinity habitat primarily upriver from the Station and have minimal contact with the thermal plume and peak summer temperatures in the plume. White perch and striped bass in the vicinity of the Station are most abundant from fall through spring (Figure VI-8), the period when cold temperatures reduce metabolic and growth rates to their annual minimum. The predicted upper optimum temperatures for growth of white perch and striped bass are shown in Figure VI-33. If white perch and striped bass young-of-the-year and older in the vicinity of the Station could maintain extended contact with plume temperatures up to the edge of the ZIM, their growth season could potentially begin earlier and extend later in the season. However, the potential for plume temperatures to substantially increase the average growth of the populations of white perch and striped bass is minimal. This is because warmer plume temperatures (greater than about 4°F to 7°F above ambient) are limited to only a small volume (about 0.05 percent to 0.002 percent, respectively, of the volume of the Estuary) and are constantly shifting location. Plume temperatures less than about 4°F to 7°F are within the range of spatial temperature variations in ambient temperature in the Estuary that young white perch and striped bass may normally experience (Appendix C Section VI.D.).

Growth of white perch early juveniles could potentially be enhanced by temperatures from plume contact up to the edge of the ZIM in an average year (Figure VI-33a), although temperatures very near the ZIM would probably exceed upper growth limits for part of their period of occurrence during a warm year (Figure VI-33b). Striped bass early juveniles could potentially experience plume temperatures near the edge of the ZIM that exceed their upper growth limit for part of their period of occurrence at Salem in an average year (Figure VI-33a) or all of it in the warm year (Figures VI-33b). However, the early juveniles of these two species are small (about ½ to 1 inch long), and are only able to sustain average swim speeds of about 0.6 to 0.8 feet per second for a few minutes (Table VI-5). They would be incapable of maintaining residence in the higher plume temperatures for sufficient periods to reduce their ultimate growth, because plume velocities and ambient tidal current exceed their swimming ability.

VI.D.3.e.ii. (c) Oceanic-Estuarine Residents

Juvenile spot, spawned offshore during winter and spring, are transported by currents into the bays and estuaries in the late spring. In the vicinity of the Station, they are most abundant from May through August and again from October to December (Figure VI-8). These two peaks appear to be associated with the movement into preferred nursery habitat (shallow flats, tidal tributaries, and marshes with mud bottoms and reduced salinity) and emigration to offshore wintering areas, respectively (Section IV.G, Appendix C Section VIII). These primary tributary and marsh nursery habitats, where the majority of first-year growth occurs, are not located in the vicinity of the Station's discharge and are therefore not influenced by the plume. In fact, this preferred habitat is itself subject to wide diel fluctuations in ambient temperature due to solar heating (Appendix C Section VI.D). An upper optimum growth temperature of 85.5°F was estimated for spot juveniles based on laboratory data. Estimates of preferred temperatures in the field suggest that optimum temperature for growth may be as high as 93°F (Gallaway and Strawn 1974). Using the more conservative laboratory-based estimate, plume ΔT values that would exceed the upper end of the range for optimum growth of spot juveniles during summer in the average and warm years are 7.5°F and 4°F, respectively (Figures VI-34a and VI-34b). These ΔT isopleths occupy a volume that is about 0.002 percent to 0.05 percent of the total volume of the Estuary. In the fall, plume temperatures are generally closer to the optimum for growth than are ambient temperatures (Figure VI-34).

Juvenile Atlantic croaker, spawned offshore during the late summer and fall, are transported by currents inshore to bays and estuaries during fall and winter (Section IV.G., Appendix C Section VIII). In the vicinity of the Station, juvenile Atlantic croaker are most abundant in December and January (Figure VI-8), the period of minimum annual growth rates. During this time, both the ambient temperatures and maximum plume temperatures are considerably below the reported optimal growth temperature for Atlantic croaker (Figure VI-34). Therefore, Salem's thermal plume would not reduce the growth of Atlantic croaker, even in the unlikely event that they were able to continuously reside in the higher temperature portions of the plume.

Juvenile weakfish in the vicinity of the Station are most abundant from early June to September. Based on laboratory data, the estimated upper limit of the optimum range for growth of juvenile weakfish is about 85°F (Figure VI-34). Areas of Salem's thermal plume with ΔT values that are above about 7°F during the average year, and above about 3.5°F in the warm year, may exceed the optimum growth range of juvenile weakfish during the period of peak summer ambient temperature. The volume of Salem's plume with isopleths exceeding these ΔT values is about 0.002 percent of the total Estuary volume in the average year and less than 0.16 percent in the warm year. Plume temperatures in the remainder of the plume will be more optimal for growth than are ambient temperatures. No overall reduction in growth of the weakfish population is expected. Temperatures in the majority of the volume occupied by the plume would potentially enhance growth rate and, as indicated above, the volume of the plume exceeding 3.5°F to 7°F is very small relative to the extensive habitat available for juvenile weakfish.

Bay anchovy spawn over a broad inshore area of the Atlantic Coast including bays and estuaries such as the Delaware Estuary. Juveniles move farther up into less saline portions of estuaries during the summer and much of the first year's growth occurs in these nursery areas. Juvenile bay anchovy in the vicinity of the Station are most abundant from late April through October. The estimated upper optimum growth temperature based on laboratory data is 83°F, and plume temperatures lower than this value are more optimal for growth than are ambient temperatures (Figure VI-34). During spring and early fall, plume temperatures up to the edge of the ZIM could potentially enhance the growth rate of bay anchovy in both the average and warm years. When ambient temperatures peak in summer, the volume of the plume that exceeds the upper optimum growth temperature for bay anchovy would lie within the 5°F ΔT-isopleth during the average year, and within the entire 1.5°F ΔT-isopleth plume in the warm year. The volume of Salem's plume occupied by these ΔT values is less than about 0.02 percent and 0.72 percent of the volume of the Estuary during the average and warm years, respectively. Because the volume of the plume is very small relative to the extensive habitat available for bay anchovy, the potential for beneficial or detrimental effects on growth are inconsequential.

VI.D.3.e.iii. Conclusions

Salem's thermal discharge is not expected to cause appreciable harm to any of the RIS from reduced growth for the following reasons:

- The dimensions and spatial distribution of the dynamic plume change constantly; therefore, it is unlikely that any of the RIS will remain long enough within those very limited areas of the plume where temperatures exceed those required for optimal growth long enough for any measurable effect to occur.
- American shad, alewife, and blueback herring are present primarily during early spring and fall migrations. Most juvenile growth occurs during the summer in nursery areas upriver of the Station.
- Striped bass and white perch are most common during winter when growth is at its minimum; primary nursery areas for striped bass and white perch are upriver of

the Station in less saline habitat. Plume velocities and ambient tidal currents prevent early juvenile striped bass and white perch, who have limited swimming capacity, from remaining in the higher plume temperatures long enough to reduce their growth.

- The primary nursery habitat for Atlantic croaker and for spot is in shallow, littoral and marsh zones outside of the influence of the plume.
- Plume temperatures could potentially exceed the upper end of the range of optimum growth for weakfish and bay anchovy in some portions of the plume during summer under reasonable worst-case conditions. It is unlikely that this exposure would reduce overall annual growth of these species since plume temperatures in the remainder of the plume, or outside the summer portion of the growth season, would enhance growth rate.
- The volume of the plume with temperatures exceeding the upper optimum temperature for growth is a very small portion of the spawning and nursery area of the bay anchovy and weakfish in the Estuary, and a still smaller percentage of the total extensive spawning and nursery habitat for those populations.

VI.D.3.f. Potential for Appreciable Harm from Reduced Reproductive Success

Salem's thermal discharge could potentially reduce reproductive success of the RIS exposed to the plume by causing excessive shifts in the seasonal onset of spawning, disrupting normal egg development and hatch, or causing thermal mortality of larvae and early juveniles. The potential for harm from such effects is a function of the spatial dimension of the habitat affected and the extent to which the affected zone is critical to the spawning success of the population.

Spawning temperature ranges, upper temperatures for normal egg hatch, and upper temperature tolerance limits for survival of eggs, larvae, and early juveniles were compared to reasonable worst-case maximum plume temperature at the edge of the ZIM during the seasons when the RIS occur at Salem (Figures VI-35 to VI-38). The comparison was made for both average and warm ambient temperature conditions based on the mean weekly ambient temperatures recurring once in two years and once in ten years, respectively.

Even in instances where plume temperatures may exceed the tolerance limit for these effects, the potential for Salem's plume to reduce reproductive success of RIS populations is minimal. The vicinity of the Station is not critical spawning habitat for any of the RIS. The primary spawning habitat for most of the RIS lies well upriver (American shad, alewife, blueback herring, white perch, striped bass) or downriver (blue crab, spot, weakfish and Atlantic croaker) from Salem. Those RIS that do reproduce in relative abundance in the immediate vicinity of the Station spawn throughout extensive geographic ranges extending far upriver (scud) or downriver (opossum shrimp, bay anchovy) from Salem. Although the warmer temperature within the plume could theoretically advance the onset as well as the termination of spawning in spring, this would not necessarily occur. The onset of spawning is conditioned by thermal exposure over a period of days to weeks leading up to the spawning season, as well as by changes in non-thermal factors, especially day-length (Hoar and Randall 1969). Scud and opossum shrimp would only be exposed to temperature elevations exceeding 4°F to 5°F for, at most, several hours as they drift through Salem's plume (Section V.F, Figure V-23). Salem's thermal plume is highly dynamic and peak tidal flow velocities of about 2.4 fps (Appendix C Section III.B.2) exceed the swimming speeds that bay anchovy can sustain (Table VI-5). Bay anchovy would thus also be unlikely to reside continuously within the relatively small area (<250 acres) of the plume that exceeds the 4°F to 5°F ΔT isopleth (Table V-2) for more than a few hours. ΔT values less than about 4°F to 5°F in the far-field plume are within the range of spatial variation in ambient water temperature in the Estuary (Appendix C Section VI.D). Therefore, the potential for Salem's thermal plume to alter the normal seasonal range of spawning of the few RIS that use the area near Salem extensively for reproduction is minimal.

VI.D.3.f.i. Macroinvertebrates

The literature indicates that exposure to elevated temperatures higher than those encountered at the edge of Salem's ZIM is not detrimental to the reproductive success of scud. Ginn (1977) reported that the reproductive activities of mature scud were not affected by up to 60-minute exposures to a sudden 15°F temperature change above an ambient temperature of 79°F. In addition, the same exposure did not affect the release of young by oviparous female scud. Ginn (1977) further reported that a 17-day exposure of scud to a 28°F elevation above an ambient temperature of 50°F stimulated reproductive activities. Since these reported safe temperature increases exceed the temperatures at the edge of Salem's ZIM in both average and warm years, no appreciable detrimental effect of the thermal plume on the reproductive activity of scud is expected. The laboratory-determined upper tolerance temperature of scud is higher than maximum plume temperatures at the edge of Salem's ZIM in both average and warm years (Figure VI-35). Therefore, Salem's plume is not expected to reduce the potential for survival of young in any area beyond the ZIM.

The laboratory-determined upper tolerance limits for newly released young of opossum shrimp are higher than plume temperatures at the edge of the ZIM during spring and fall (Figure VI-35). Although no data for newly released young are available for summer temperature conditions, data for adult opossum shrimp (Figure VI-14) indicate that tolerance would be lower than reasonable worst-case maximum plume temperatures occurring during summer in the average as well as the warm year. However, exposure to the highest plume temperatures for 24 to 96 hours could not conceivably occur for opossum shrimp drifting through the Station's thermal plume. As discussed above in Section VI.D.3.a.(1).(a), opossum shrimp are able to tolerate the maximum temperatures that would be experienced during transit through the entire plume, except during periods of peak summer ambient water temperature in warm years.

Spawning and early development of blue crab occur in the lower Estuary and nearshore ocean waters, far beyond any possible impact from Salem's thermal plume (Section IV.G.c.). Blue crabs reenter the Estuary as post-larval megalops, but the vast majority of megalops are found in the lower Bay. Although megalops may appear in low densities as far upstream as Artificial Island, survival and metamorphosis into juvenile crabs is greatly reduced at the salinities typical of this location (Costlow 1967). Therefore, the potential effect of plume entrainment on the blue crab population is negligible, because those life-stages that drift with the currents are simply not present in abundance and do not normally survive well in the Delaware Estuary near Salem regardless of Salem's operation.

VI.D.3.f.ii. Fish

VI.D.3.f.ii. (a) Anadromous Herring

The Station's thermal plume would not impact the spawning, hatching success, or larval survival and development of American shad, alewife, or blueback herring because these RIS spawn well up-stream of Salem. American shad spawn far up-stream in freshwater portions of the Delaware River, primarily above RM 236 and as far as RM 329 in the mainstem and as far as RM 342 in the East Branch. As a result, no eggs or larvae occur at Salem. Alewife and blueback herring also spawn in upstream freshwater regions of the mainstem as far as RM 195–298 and in freshwater tributaries to which they can gain access throughout the Estuary. No eggs of these two species occur at Salem, but some larvae do drift into the vicinity of Salem. Upper long-term tolerance temperatures reported for *Alosa* spp. larvae are well above reasonable worst-case plume temperatures at the edge of the ZIM in the average as well as the warm year (Figure VI-36). Therefore, those few anadromous herring larvae that could potentially drift downriver into the vicinity of Salem's discharge would survive even long-term exposure to elevated plume temperatures at and beyond the ZIM. As discussed above in Section VI.D.3.a.(1), herring larvae are also able to survive transit through the ZIM.

VI.D.3.f.ii. (b) Temperate Bass

The Station's thermal plume would not impact the spawning, hatching success, or larval survival and development of white perch or striped bass because these RIS spawn primarily upstream of Salem. White perch and striped bass primarily spawn upstream of Salem in freshwater areas above Wilmington, DE (Section IV.G, Appendix C Section VIII). Some of the eggs, larvae, and early juveniles of white perch and striped bass drift into the vicinity of Salem during spring (Figure VI-8). Upper tolerance limits for long-term exposure reported for white perch and striped bass larvae are higher than plume temperatures at the edge of the ZIM during their peak occurrence at Salem in both average and warm years (Figure VI-37). Therefore, those white perch and striped bass larvae that drift downriver into the vicinity of Salem's discharge would survive even long-term exposure to elevated plume temperatures at and beyond the ZIM. As discussed in Section VI.D.3.a.(1), eggs and larvae of white perch and striped bass are also able to tolerate all of the time-temperature conditions in Salem's ZIM.

Salem's thermal plume would not be expected to interfere with normal hatch of striped bass or white perch eggs since the upper optimum hatch temperatures for these RIS are higher than maximum plume temperature at the edge of the ZIM in the average and warm years (Figure VI-37). The reported peak spawning temperature ranges for white perch and striped bass are about 50°F to 70°F and 58°F to 70°F, respectively. Based on the rate of increase in ambient temperatures during the spring spawning season for white perch and striped bass, continuous exposure to elevated temperatures in the plume could potentially advance the spawning season by about 2.8 to 3.5 days per degree(F) ΔT. However, the potential for harm from such shifts are negligible since most spawning of white perch and striped bass occurs in freshwater areas upriver of Salem.

VI.D.3.f.ii. (c) Oceanic-Estuarine Residents

Spot and Atlantic croaker are offshore ocean spawners whose young move into the Estuary mainly at the juvenile stage, where they use tidal creeks and marshes as nursery habitat (Section IV.G; Appendix C Section VIII). No eggs of these two species occur at Salem, and the few larvae that do occur in the vicinity of the Station are well up-Estuary of the primary range of this life stage (Figure IV-21; Figure IV-22). Upper tolerance limits for long-term exposure reported for spot larvae are higher than plume temperatures at the edge of the ZIM during the period that they primarily occur at Salem in both average (Figure VI-38a) and warm years (Figure VI-38b). Thermal tolerance test data indicate that spot and Atlantic croaker are able to tolerate all of the time-temperature conditions in the Station's thermal plume (Section VI.D.3.a.(1)).

Weakfish and bay anchovy spawn over a wide geographic range (Figures IV-25 and IV-17) and the vicinity of the Station is not their primary spawning habitat. Both are pelagic spawners that broadcast their buoyant eggs into the water column. The Station's high velocity discharge, located 500 feet offshore, results in the warmest area of the thermal plume (greater than 4°F delta-T) occupying a very small portion of the pelagic zone. The volume of the plume within the <250 acres above the 4°F isopleth amounts to only approximately 0.05 percent of the volume of the Delaware Estuary, and an even smaller percentage of the regional spawning habitat of these two species.

Weakfish spawn extensively in coastal waters, bays and estuaries along the Atlantic Coast north of Cape Fear, including the lower Delaware Estuary and nearshore ocean. Eggs and larvae are transported into upstream portions of the Estuary during warmer months. Weakfish eggs and larvae occur at Salem in late spring and summer (Figure VI-8). Weakfish peak spawning occurs during May and June at water temperatures between about 61° and 81°F (Figure VI-38). The primary spawning area in Delaware Estuary is located along the southwest shore near the mouth of the Estuary.

Weakfish eggs are buoyant and typically hatch in about 29 to 36 hours at 72°F to 77°F (Appendix C Section VIII). Highest densities of eggs occur near the primary spawning areas, but some are dispersed through the Estuary by tidal and subtidal currents. Weakfish eggs occur in the vicinity of the Station in relatively low densities compared to the lower Estuary, from mid-May through August with primary abundance in June and early July (Figure VI-8). This is rather late in the spawning season for this latitude and ambient temperatures are near or exceed optimum temperatures for egg development and hatch. Upper tolerance limits for long-term exposure reported for weakfish eggs are higher than plume temperatures at the edge of the ZIM during the period that they primarily occur at Salem in both the average (Figure VI-38a) and warm year (Figure VI-38b). However, plume temperatures at the edge of the ZIM exceed the reported upper optimum temperature for hatch in the average year. In warm years, ambient temperatures also exceed upper optimum hatch temperature during most of the period of weakfish egg occurrence at Salem. Weakfish larvae become demersal and are passively transported from the primary spawning areas downbay to less saline nursery areas in the upper Delaware Estuary and Delaware River. Peak densities of weakfish larvae in the Delaware Estuary occur south of the Station. They have been reported at the Station between mid-May to mid-September, but peak density occurs from late May through July (Figure VI-8). Thermal tolerance test data indicate that weakfish are able to tolerate time-temperature conditions in the Station's thermal plume during the average year, although some mortality of weakfish larvae entrained into the highest temperature portions of the plume may be expected during especially warm summers (Section VI.D.3.a.).

Based on the rate of increase in ambient temperatures during the spring spawning season, continuous exposure to elevated temperatures in the plume could potentially advance the weakfish spawning season by about 2.8 days per degree(F) ΔT. However, the potential for harm from such shifts is negligible since most spawning occurs in high salinity areas well downriver of Salem.

Bay anchovy spawn extensively in coastal waters, bays and estuaries along the Atlantic coast, including the Delaware Estuary. The bay anchovy is abundant and widely distributed throughout the Estuary. Most spawning takes place in the lower reaches of the Bay, where salinity exceeds 20 ppt (Appendix C Section VIII). Although bay anchovy eggs have been found as far upriver as RM 73, most occur in the lower Bay below RM 30. Based on collections of eggs, some bay anchovy spawn in the vicinity of the Station during May through September, with primary occurrence from late May through July (Figure VI-8). Both the long-term upper tolerance limit and optimum temperature for hatch of bay anchovy eggs are higher than or equal to reasonable worst-case maximum plume temperature at the edge of Salem's ZIM in the average year (Figure VI-38a). In the warm year, plume isopleths above about 8°F may exceed the optimum temperature for hatch of bay anchovy eggs (Figure VI-38b). This ΔT occupies an area of less than 5 acres and occupies a volume less than 0.0009 percent of the volume of the Estuary.

Thermal tolerance test data indicate that bay anchovy eggs and larvae are able to tolerate time-temperature conditions in the Station's thermal plume during the average year, although some mortality of larvae entrained into the highest temperature portions of the plume may be expected during the warm year (Section VI.D.3.a.(1)).

Based on the rate of increase in ambient temperatures during the spring spawning season, continuous exposure to elevated temperatures in the plume could advance the bay anchovy spawning season by about 3.2 days per degree(F) ΔT. However, the potential for harm from such shifts is negligible since most spawning occurs in high salinity areas well downriver of Salem.

VI.D.3.f.iii. Conclusions

Salem's thermal discharge is not expected to cause appreciable harm to any of the RIS from reduced reproductive success for the following reasons:

- The vicinity of the Station is not critical spawning habitat for any of the RIS. The primary spawning habitat for most of the RIS lies well upriver (American shad, alewife, blueback herring, white perch and striped bass) or downriver (blue crab, spot, weakfish and Atlantic croaker) from Salem. Those RIS that do reproduce in relative abundance in the immediate vicinity of the Station spawn throughout extensive geographic ranges extending far upriver (scud) or downriver (opossum shrimp, bay anchovy) from Salem. American shad, alewife, and blueback herring are present primarily during spring and fall migrations. Most juvenile growth occurs in nursery areas upriver of the Station.
- Most of the RIS early life stages are able to tolerate the maximum temperatures that would be experienced during transit through the entire plume even in warm ambient temperature conditions. During periods of peak summer ambient water temperature in warm years, exposure to maximum plume temperatures may cause some mortality of opossum shrimp, and early life stages of weakfish and bay anchovy. This mortality is unlikely to occur in more than a small fraction of the organisms present near Salem because of the infrequency and short duration of potentially lethal conditions, the infrequency of low flow (high ΔT) operation in summer months, the low probability of larvae experiencing the maximum temperatures throughout their transit through the plume, and the small volume of the plume with temperatures exceeding temperatures at which the RIS could continuously reside.
- Primary habitat for egg and larval development for most of the fish RIS does not occur within the Transition Zone of the Estuary influenced by the Station's thermal plume. The vicinity of Salem is only a small, and not unique, part of the overall range used for spawning and early development activity of those few RIS whose eggs, larvae, and newly released young are found in abundance near the Station.
- The potential for Salem's thermal plume to alter the normal range of spawning dates of the few RIS that use the area near Salem extensively for reproduction is minimal. Portions of the plume with ΔT values exceeding normal variations in ambient water temperature are small; occupying less than about 250 acres and about .05 percent of the volume of the Estuary. The potential for RIS to remain in these higher temperature portions of Salem's plume long enough to affect their reproductive conditioning or the initiation of spawning is minimal, given the small size and shifting location of the plume.

VI.D.3.g. Key Findings from Predictive RIS Evaluation of Direct Thermal Impacts

The potential for Salem's thermal discharge to cause direct thermal effects on survival, growth, reproduction, habitat utilization, and blockage of migration of the RIS was comprehensively evaluated using the predictive RIS method. Relative to earlier biothermal assessments, this predictive RIS evaluation was conducted using an updated and expanded set of biothermal response data obtained from the scientific literature. In addition, the evaluation explicitly examined the inter-annual variability in the potential for biothermal effects by examining the influence of both average and warm ambient temperature conditions on the likelihood and magnitude of effects. Finally, the factors that were used to evaluate the potential for appreciable harm were expanded and updated by augmenting the decision factors provided in the 1977 USEPA 316(a) thermal effects draft guidance with those provided in the 1998 USEPA ecological risk assessment guidance. Key findings from the predictive RIS evaluation are summarized below.

VI.D.3.g.i. Shellfish/Macroinvertebrates

Salem's reasonable worst-case thermal plume would not cause appreciable harm to the macroinvertebrate RIS during either average (1 year in 2) or warm (1 year in 10) ambient temperature conditions.

Survival

The tolerance of scud and juvenile blue crab to high temperatures was found to be greater than the maximum exposure that they could potentially receive from Salem's thermal plume. Opossum shrimp exposed to maximum temperatures along the plume centerline may occur some mortality during peak summer water temperatures in warm years. However, even along the plume centerline, lethal exposures of opossum shrimp would occur very infrequently (about 1 percent of the time), and involve a very small portion of the opossum shrimp population, which is widely distributed in the Estuary.

The tolerance of scud, opossum shrimp, and blue crab to rapid reduction in temperature exceeds the maximum temperature drop that they could conceivably experience in the unlikely event of a sudden shutdown of both of the Station's Units.

Habitat Exclusion

Extremely high temperature tolerance and high avoidance temperatures for blue crab indicate that they would not avoid plume temperatures beyond the high velocity ZIM. While high velocities may prevent blue crab from occupying the area within the ZIM, this is a very small portion (less than 0.0001 percent) of the available habitat in the Estuary.

Growth

Plume ΔT isopleths higher than about 8°F and 4.5°F may exceed the upper optimum temperature for growth of blue crab juveniles and scud during July, August, and early September in the average and warm year, respectively. However, the dynamic nature of the thermal plume makes it unlikely that any of the RIS would remain exposed to these ΔT fields long enough for cause any discernable effect on growth. Harm to macroinvertebrate RIS populations from reduced growth is also unlikely because of the relatively small volume encompassed by these changes in temperature (about 0.0009 and 0.05 percent of the Estuary in the average and warm years, respectively), and the fact that growth rate would be enhanced by exposure to plume temperatures below these ΔT fields during summer and by exposure to all plume temperatures outside the ZIM during non-summer seasons.

Reproduction
Reproductive success of blue crab would not be reduced by Salem's thermal plume because spawning and early development of blue crab occur primarily in the lower Estuary and nearshore coastal waters beyond the influence of the plume. The thermal plume would not detrimentally affect reproduction or development of scud or opossum shrimp. Thermal tolerance data indicate that scud are able to tolerate exposure to the reasonable worst case plume without reduction in reproductive activity. Further, the vicinity of the Station is only a small, and not unique, part of the overall range for spawning and early development of scud and opossum shrimp in the Estuary.

VI.D.3.g.ii. Fish

Survival
Mortality of fish eggs and larvae due to transport through Salem's thermal plume is unlikely. The vicinity of the Station is not a primary spawning location for American shad, alewife, blueback herring, white perch, striped bass, Atlantic croaker, spot or weakfish. Therefore few, if any eggs and larvae of these RIS are susceptible to plume entrainment. The eggs, larvae and early juveniles of RIS that do occur in the vicinity of the discharge are able to tolerate the maximum centerline temperatures to which they could be exposed during transit through the plume in the average year. In the warm year, there is a potential for some mortality of weakfish and bay anchovy should they be exposed to centerline plume temperatures. However, even along the plume centerline, temperatures that are lethal for weakfish and bay anchovy would occur very infrequently (about 1 to 3 percent of the time), and would involve a very small portion of their populations, which are widely distributed in the Estuary.

Juvenile and adult American shad, alewife, blueback herring, white perch, striped bass, Atlantic croaker, and spot are able to tolerate temperature higher than those plume temperatures occurring at the edge of the ZIM. While plume temperatures may exceed the upper tolerance limits for long term exposure of juvenile and adult weakfish and bay anchovy in summer, they will avoid potentially lethal temperatures.

With the possible exception of bay anchovy during early spring, all of the fish RIS are able to tolerate the largest temperature drops to which they could conceivably be exposed during the unlikely event of a sudden shutdown of both Station units. The potential for cold-shock is minimal because the dynamic plume and tidal environment of the Estuary result in little potential for the fish to become physiologically acclimated to the Station's higher plume temperatures, and because the sudden shutdown of two units of the Station is very unlikely.

Habitat Exclusion
Avoidance temperatures for the RIS indicate that American shad, alewife, blueback herring, white perch, striped bass, Atlantic croaker, would not avoid plume temperatures occurring in areas beyond the ZIM during their peak periods of occurrence in either average or warm years. While high velocities may prevent these RIS from occupying the

area within the ZIM, this is a very small portion (less than 0.0001 percent) of the available habitat in the Estuary.

Although spot may avoid plume ΔT fields higher than about 7.5°F during warm years, spot primarily utilize marsh and tributary habitat not influenced by the plume. Bay anchovy and weakfish may avoid plume ΔT fields above about 6.5°F during summer in the warm years. The area encompassed by these fields of ΔT occupies less than about 0.003 percent of the volume of the Estuary. These avoidance areas potentially caused by Salem's plume are a very small percentage of the habitat available for these species in the Estuary. Considering that the vicinity of Salem is not a critical zone for the spawning or nursery functions of the RIS, there is little potential for appreciable harm from habitat exclusion.

Blockage of Migration

The vicinity of Salem is critical for the function of migration. Conservatively estimated avoidance temperatures (lower 95% confidence level), indicate that the thermal plume may cause American shad, alewife, blueback herring, white perch, and striped bass to avoid up to 5 percent of the Estuary cross-section in the vicinity of the Station. Therefore over 95 percent of the cross-section remains available for migration.

Growth

The primary nursery areas for the fish RIS lie well beyond, or are not unique to, the area influenced by plume ΔT fields that exceed natural variation in water temperature. Plume temperatures in both average and warm years are more favorable for growth of the fish RIS in fall, winter, and spring, than are ambient temperatures. Plume differential temperatures higher than about 5°F and 1.5°F may exceed the upper optimum temperature for growth of one or more fish RIS during July, August, and early September in the average and warm year, respectively. The portions of the volume of the Estuary in which plume temperatures exceed upper growth temperatures for spot, weakfish, and bay anchovy in the warm year are 0.03 percent, 0.13 percent, and 0.7 percent, respectively. Plume ΔT values of 1.5°F to 5°F are within the range of normal spatial and daily ambient temperature variations in the Estuary, and therefore are highly unlikely to cause any adverse effect on normal growth of these RIS populations.

Reproduction

The area of the Station is not the primary habitat for spawning and early development for any of the fish RIS. Plume temperatures could hypothetically stimulate reproduction to begin and end earlier than usual. However, this is effect is unlikely to occur because portions of the plume with ΔT values exceeding usual variations in ambient temperature are small; occupying less than about 250 acres and about 0.05 percent of the volume of the Estuary. The potential for RIS to remain in portions of the plume with ΔT values exceeding natural temperature variations long enough to affect their reproductive conditioning or the initiation of spawning is minimal given the small size and shifting location of the plume.[12]

VI.D.4. Interaction of Heat with Other Pollutants

Heat introduced into a water body has the potential to adversely affect aquatic life through its interaction with other pollutants. Such interactions can occur through two processes. First, increased temperature can directly cause a change in the concentration of pollutants or second, increased heat can increase the biological effects of existing pollutant levels. This section evaluates the potential for such interactions to occur through either process between the Station's thermal discharge and dissolved oxygen, chlorine, or other pollutants of concern in the Delaware Estuary. This assessment is consistent with the requirement to assess the potential effects of thermal discharges in conjunction with other stresses, as prescribed by EPA 316(a) guidance (USEPA 1977). The results of this evaluation demonstrate that the Estuary's aquatic communities are not at risk from these potential interactions.

This assessment focuses on two classes of water quality factors that can be affected by temperature: dissolved oxygen (which occurs naturally) and toxic chemicals (most of which are introduced). Both are factors of concern in the Delaware Estuary (Santoro 1998, NJDEP 1998, DRBC 1998). Because Salem's thermal plume occupies only a very small portion of the Estuary, this assessment concentrates on potential interactions in the immediate vicinity of the Station. However, in assessing the possible effects of the Station's operations on the Estuary's biotic communities, the potential for interaction must also be viewed in light of the intensity, frequency, duration, and spatial extent of the effects, particularly with respect to spatial and temporal distribution of each RIS population as a whole.

VI.D.4.a. Dissolved Oxygen

Oxygen is essential to the metabolism of all aquatic organisms that respire aerobically. The concentration of oxygen dissolved in natural waters is determined through a balance of processes that add and remove oxygen to and from the water (Attachment E-3). As a result of these processes, the amount of oxygen dissolved in water, and thus available to aquatic organisms, can vary greatly relative to time and location. The actual quantity of oxygen that water can hold under the most favorable conditions is relatively low in comparison to that continuously available in the atmosphere. Because of the physical limit to oxygen solubility in water and the natural fluctuations in dissolved oxygen levels that occur, dissolved oxygen often can be an important limiting factor for aquatic life in natural systems.

Inadequate dissolved oxygen concentrations have historically been a major environmental problem in the industrialized areas of the Estuary upstream of Salem (Sutton et al. 1996; Santoro 1998; Section IV.E.5). These low dissolved oxygen conditions were a result of the discharge of large quantities of oxygen-demanding substances and nutrients, principally from wastewater treatment plants. Biological communities in these areas of the Estuary were severely impacted by the resulting anoxic or near-anoxic conditions. While substantial improvements in dissolved oxygen concentrations have resulted from large-scale upgrades in water treatment facilities in the past two decades (Sutton et al.

1996), dissolved oxygen remains a water quality parameter of concern in freshwater areas of the Estuary.

In the vicinity of Salem, dissolved oxygen levels have never been depressed to the degree observed in upstream areas. Over the past 20 to 30 years, dissolved oxygen concentrations have typically ranged from 5 to 10 mg/L, with no apparent long-term trend (Appendix C Section IV.E.5). These levels are generally sufficient for the maintenance of healthy aquatic ecosystems and there is no evidence that dissolved oxygen concentrations in the vicinity of Salem have approached levels potentially detrimental to the existing aquatic communities either prior to, or subsequent to, the start of Station operations. The current water quality standard for dissolved oxygen in the Delaware Estuary in the vicinity of the Station is a 24-hour average of 6.0 mg/L (DRBC 1996).

A thermal discharge can potentially affect dissolved oxygen concentrations either directly through temperature- and pressure-mediated effects on the solubility of oxygen in water, or indirectly through temperature effects on the oxygen consumption of organic materials. Each of these two mechanisms is discussed below.

The long-term upper limit of dissolved oxygen concentration is determined by the saturation level which is the maximum capacity of water to hold oxygen in solution at any given temperature, salinity, and pressure. In temperate estuaries such as the Delaware, oxygen solubility decreases with increasing water temperature and, to a lesser extent, with increasing salinity. For example, the saturation levels for dissolved oxygen in seawater decrease from about 10 mg/L at 40°F to 6.6 mg/L at 80°F; in freshwater dissolved oxygen levels would be approximately 1 to 3 mg/L higher at these temperatures. At times, high inputs of oxygen from photosynthesis, rapid increases in temperature, or physical entrainment of air bubbles may cause dissolved oxygen concentrations in natural waters to exceed theoretical saturation levels, a condition called supersaturation. Supersaturated conditions are typically transient as the physical processes of diffusion and aeration tend to return concentrations toward equilibrium saturation levels.

The passage of water through Salem's cooling water system can theoretically have a direct effect on the concentration of dissolved oxygen through the influence of pressure and temperature on saturation levels. During this passage, water is exposed to pressures below atmospheric levels for short periods of time. As a result of these pressure drops, the dissolved oxygen capacity of the cooling water can be temporarily reduced. The temperature of this water increases during its passage through the Station's condensers by about 15°F to 19°F at full generating capacity, depending on circulating water flow (Appendix B Section V.F). These temperatures are rapidly reduced when the water is discharged back into the Estuary and mixed with the receiving waters. These increases in water temperature can also theoretically reduce saturation capacity for dissolved oxygen in the waters affected.

Indirect effects of Salem's thermal discharge can result from the influence of temperature on the rate of oxygen consumption by metabolic breakdown of organic materials in the Estuary. The rates of these metabolic processes are temperature-dependent. Consequently, temperature can increase the rate at which oxygen is consumed, but not the total quantity of oxygen consumed. Increases in oxygen consumption rate can lead to local reductions in oxygen concentrations if these increased consumption rates exceed the rates of input through a combination of mixing, re-aeration, and oxygen production through photosynthesis.

The potential for the thermal discharge to reduce dissolved oxygen levels in the Delaware Estuary through the processes described above is addressed in Attachment E-3. This assessment combines analysis of intensive dissolved oxygen monitoring data collected in the vicinity of the Station with modeling exercises to evaluate the potential effects of temperature and pressure on dissolved oxygen levels in the Estuary. The results of this assessment clearly demonstrate that there are no observable effects of Salem's thermal discharge on dissolved oxygen levels in the vicinity of the Station. Further, the theoretical effects of changes in temperature and pressure on dissolved oxygen levels are so small (< 0.1 mg/L) as to be indistinguishable from the natural short-term spatial and temporal variability in dissolved oxygen concentrations. These data clearly show that the Station's continued operation has not and will not have any effects on the biological community in the Delaware Estuary resulting from reductions in dissolved oxygen concentrations.

VI.D.4.b. Toxic Chemicals

The potential interaction of heat and chemical pollutants can increase the biological effects of toxic pollutants on aquatic organisms. To evaluate the possibility of this interaction, two groups of potentially toxic chemicals were considered. The first group includes chemicals that are discharged from the Station as a part of routine operations. The only toxic chemical in this group is chlorine, a biocide used in the Station's service water system to prevent the buildup of slime and biofouling organisms in equipment critical to Salem's continued operation. The other group of chemicals considered in this analysis includes those designated as contaminants of concern for the Delaware Estuary (NJDEP 1998, DRBC 1998). At present, this group includes PCBs, DDT and metabolites, dieldrin, PAHs, PCE, DCE, and copper. The potential for the Station's thermal plume to exacerbate the effects of these toxic chemicals is discussed below.

VI.D.4.b.i. Chlorine

Chlorine is commonly used as a disinfectant and biocidal agent by users of surface waters, including power plants. At the Station, sodium hypochlorite is continuously introduced into the service water systems (SWS) to prevent the buildup of bacterial slime and other biofouling organisms in critical safety-related systems (Appendix B). In contrast to the practice at many other power plants, Salem's circulating water system (CWS) receives no biocidal treatment, and thus has no potential to contribute chlorine to the Station's discharge. Sodium hypochlorite dosing is targeted to produce a residual chlorine level of 0.3 to 0.5 mg/L after the last heat exchange in the nuclear loop near the beginning of the SWS.

Once sodium hypochlorite is introduced into the SWS, it is rapidly ionized to produce free chlorine, the principal biocidal agent. However, much of this free chlorine is then quickly consumed by the chlorine demand in the water, producing relatively nontoxic chloride compounds. The small concentration of residual chlorine acts as a biocide in the remainder of the SWS. When salinities in the SWS are higher, free chlorine can be replaced by bromine which occurs naturally in seawater, and is also an effective biocide. Consequently, the actual biocidal agent may be residual chlorine or a combination of residual chlorine and naturally occurring bromine, depending on prevailing water chemistry at a specific time. Therefore, this evaluation considers the potential interaction of temperature with total chlorine-produced oxidants (CPOs), both chlorine and bromine.

As noted, SWS is continuously treated with sodium hypochlorite, and the resulting residual oxidant combines with the Station's CWS prior to discharge into the Estuary (Attachment E-4). The unchlorinated CWS water provides considerable oxidant demand and dilution, further reducing CPO concentrations prior to reaching the combined SWS/CWS discharge.

The potential effects that these residual oxidants could have on biological communities in conjunction with the thermal plume were evaluated. A chlorine decay model was developed that took into account chlorine dosing, chlorine demand, and available dilution to estimate the concentrations of residual oxidants expected in the Station's discharge. This modeling took the place of direct measurement because concentrations present are expected to be considerably lower than the current practical quantitation limit for chlorine (0.1 mg/L). The methods and results of this modeling are detailed in Attachment E-4.

Even using conservative estimates of rates of chlorine decay in the combined SWS/CWS discharge, potential residual oxidant levels at the point of discharge under normal circulating pump operations are low (11 μg/L) and substantially less than both the quantitation limit and Salem's current permit limit for chlorine. This estimate is slightly less than the current regulatory criterion for acute exposure (13 μg/L), but potentially slightly greater than the chronic criterion of 7.5 μg/L (NJDEP 1998). Momentum-based dilution and additional chlorine demand in the immediate vicinity of the discharge further reduces the estimated concentrations by almost 50 percent within 7 seconds following discharge. Consequently, chlorine levels under routine operations pose no threat to the biological communities in the Delaware Estuary.

This analysis demonstrates that CPO release through the thermal discharge has no potential to affect the biological community of the Delaware Estuary. Given that CPO discharge concentrations are low and subsequent dilution and natural demand are high, there is also no possibility that interaction of the thermal discharge with these oxidants will increase their likelihood of affecting the biological communities of the Delaware Estuary.

VI.D.4.b.ii. Delaware Estuary Contaminants of Concern

The Delaware Estuary has historically received considerable inputs of potentially toxic chemicals from a combination of point and non-point sources (Frithsen et al. 1995; Sutton et al. 1996; Santoro 1998). Much of the chemical addition occurs in the highly industrialized areas extending from Wilmington to Trenton, well upstream of Salem. In recent years, concerns over the potential biological effects of these chemicals have resulted in considerable efforts being directed toward the identification and control of these potentially toxic inputs. While these pollution-control efforts have enjoyed considerable success, several contaminants remain a concern for the Estuary as a whole.

At present, the toxic contaminants identified by regulatory agencies as being of concern under §303(d) or §305(b) of the Clean Water Act for the Estuary include PCBs (polychlorinated biphenyls), DDT and its two metabolic byproducts DDD and DDE, dieldrin, PAHs (polynuclear aromatic hydrocarbons), PCE (perchloroethylene), DCE (1,2-dichloroethane), and copper (NJDEP 1998, DRBC 1998, Appendix C). This section evaluates the potential for the Station's thermal discharge to exacerbate the toxic effects of these chemicals on aquatic organisms, either by directly increasing their toxicity or by increasing their bioaccumulation and/or biomagnification potential.

The first three of these contaminants of concern are organochlorines which, as a result of their similar environmental behavior, are treated together for this assessment. Polychlorinated biphenyls are a class of organic compounds that were commonly used for industrial purposes from the 1940s through the 1970s. Widely used for mosquito control and as an agricultural pesticide prior to the early 1970s, DDT is a highly persistent insecticide. In the environment, DDT is metabolically broken down into two byproducts, DDD and DDE, which retain much of DDT's toxicity. Dieldrin is an all-purpose insecticide that was widely used prior to the mid-1980s. All three of these contaminants continue to enter the Estuary, principally through non-point source runoff, and to a lesser extent through discharge by wastewater treatment plants (Frithsen et al. 1995).

As a class, these compounds exhibit relatively low solubility in water but relatively high solubility in fats and lipids. As a result, all are rapidly scavenged from the water column and sequestered in sediments and exhibit strong potential for bioaccumulation and biomagnification once they enter the food chain. Coincident with their low solubility in water, organochlorines have been reported in the surface water of the Estuary only at concentrations below those demonstrated to cause toxic effects (ANSP 1991).

These compounds have been found in sediments throughout the Estuary, but at higher concentrations only in the urbanized freshwater areas of the Estuary well upstream of Salem (Costa and Sauer 1994). Although no sampling was conducted in the immediate vicinity of Salem for that study, concentrations of each of the three organochlorines at the closest monitoring stations upstream and downstream were comparably low and similar to those observed throughout Delaware Bay. Concentrations of PCBs, DDT, and metabolites at those monitoring stations were greater than the No Observed Effects Level

(NOEL) and the Effects Range-Low (ER-L) level but less than the Probable Effects Level (PEL), the Effects Range-Median (ER-M) level, and the Sediment Quality Criteria for Protection of Benthic Organisms (SQC) level. This pattern was similar to that observed throughout Delaware Bay and suggests that current PCB and DDT and its metabolite concentrations in sediments near the Station and elsewhere, have the potential to cause some biological effects in the most sensitive species but not to a wide variety of species inhabiting the Estuary. Concentrations of dieldrin were less than all reported sediment effect levels downstream of the Station and only exceeded the ER-L at monitoring stations upstream of the Station. These results suggest minimal potential for biological effects for dieldrin in sediments in the vicinity of Salem.

The potential for interaction between organochlorines in the Delaware Estuary and Salem's thermal plume appears limited to those contaminants and organisms within the sediments exposed to the Station's thermal plume. Water column concentrations of these contaminants are likely to be exceedingly low and well below any toxic threshold. Further, the extremely short duration of the exposure of organisms to both low contaminant concentrations and elevated temperatures essentially eliminates any potential for temperature-related increases in bioaccumulation or biomagnification in surface water.

In sediments, coincidental exposure of organisms to both elevated temperatures and organochlorine concentrations also appears limited for three principal reasons. First, high velocities in the immediate discharge vicinity create a scour zone on the bottom of the Estuary where organochlorine-containing sediments do not typically settle and organisms cannot readily live. Outside of this area, temperature increases at the water-sediment interface are limited to a maximum of approximately 12°F but rapidly decrease to levels within the natural range for the Estuary (Section V.F). Sediment areas exposed to this maximum temperature increase amount to less than 11 acres, most of which is heavily scoured or covered by riprap. Areas exposed to temperature elevations greater than natural variability as a result of the thermal discharge amount to less than 0.05 percent of the Estuary. Second, given the tidal nature of the Estuary, sediment exposure to elevated temperatures would occur for only a relatively small portion of each tidal cycle. Such exposure times are relatively short compared to bioaccumulation time scales for most organisms. Third, elevated temperatures affect only the upper sediment layers and have little effect on the temperature of deeper sediments. All of these factors demonstrate that the exposure of organisms to organochlorines in sediments under elevated temperature conditions is likely limited to several degrees Fahrenheit for a relatively short time each day and in a very small area of the Estuary. These temperature increases are within the range typically experienced in shallow areas of the Estuary each day from natural solar radiation alone. It appears unlikely that such elevated temperatures would result in measurable increases in the toxicity or bioaccumulation/biomagnification rates for any of these organochlorine compounds of concern. Consequently, there is no reason to expect that Salem's thermal discharge has any possibility of increasing the potential toxic effects of organochlorine contaminants of concern through the discharge of its thermal effluent.

Polynuclear aromatic hydrocarbons (PAHs) are released into the environment as a result of the manufacture, use, or combustion of petroleum products. However, there are also natural sources of PAHs, including the burning of forests and sedimentary diagenesis. These hydrocarbons include compounds that span a wide range of physical, chemical, and toxicological properties. Most PAHs are relatively insoluble in water and tend to adsorb to settling particulates. Although many are highly toxic, most are rapidly broken down in the environment by a combination of photoxidation, chemical oxidation, and microbial action. Rapidly metabolized once they are absorbed into body tissues of higher organisms, PAHs exhibit little evidence of bioaccumulation or biomagnification. Large quantities of PAHs continue to enter the Estuary primarily as urban runoff (Frithsen et al. 1995) in the industrialized areas of the Estuary well upstream of Salem.

Although there is little information on water column concentrations of PAHs in the Delaware Estuary, it appears likely that maximum concentrations are low owing to relatively low water solubility, and that concentrations decline to below detection levels outside of the immediate areas of input as a result of dilution, dispersion, and microbial degradation. Thus, there is little likelihood of any potential for interaction with short-term exposure to the Station's thermal discharge.

Sediment concentrations of PAHs are higher in the urbanized areas well upstream of Salem (Costa and Sauer 1994); PAH concentrations observed by these researchers at the closest monitoring stations upstream and downstream of the Station were low and similar to those observed throughout Delaware Bay. Concentrations at these monitoring stations were at or below reported sediment effects levels for all PAH compounds. Exceedances of these sediment effects levels were limited to monitoring stations well upstream of Salem. These results do not suggest any potential for biological effects of PAHs in sediments near the Station.

The possibility of significant coincidental exposure of organisms to both elevated temperatures and elevated sediment concentrations of PAHs, as for the organochlorines, appears extremely limited. It is unlikely that the relatively minor temperature increases resulting from Salem's thermal plume would result in measurable increases in the toxicity or bioaccumulation/biomagnification rates for any PAH. Consequently, there is no reason to expect that the thermal discharge increases the potential toxic effects of PAHs.

Both PCE and DCE are volatile organic compounds released to the environment primarily as point source discharges from industrial processes. However, the magnitude of atmospheric deposition may be greater than currently estimated (Frithsen et al. 1995). Most volatile compounds are lighter than water, water insoluble, and evaporate rapidly from the water surface; however, PCE and DCE are denser than water, water soluble, and are human carcinogens. As a result, they are contaminants of concern in the Delaware Estuary from a human health (drinking water) perspective (DRBC 1998). Although both are highly toxic, they are broken down rapidly by a combination of photoxidation and microbial degradation; neither is known to significantly bioaccumulate or biomagnify.

Little information exists regarding the spatial distribution of either PCE or DCE in the Delaware Estuary; however, concentrations exceeding human health-based criteria appear to be limited largely to the upper Estuary, well upstream of Salem (NJDEP 1998). As these areas are highly industrialized, it is likely that they are also the areas of principal input for these contaminants. Because they are water soluble and degrade rapidly, they are unlikely to occur in the sediments of the Estuary in biologically significant concentrations. Consequently, any potential for interaction between Salem's thermal plume and these two compounds appears nonexistent.

Copper is a naturally occurring element that is an essential nutrient accumulated by all plants and animals. In addition to natural sources, significant quantities of copper can enter the environment as a result of industrial processes and the gradual breakdown of materials manufactured from copper or its alloys. In the Delaware Estuary, principal inputs appear to be point sources (Frithsen et al. 1995). The physical and toxicological properties of this metal depend on pH, organic matter concentration, availability of precipitating metal oxides, biological activity, and competition with other heavy metals. At high concentrations, copper may be toxic, especially in its divalent form. Copper has an affinity for hydrous iron and manganese oxides, clays, carbonates, and organic matter. As a result, copper is readily removed from its dissolved phase (the most bioavailable and toxic form), and sequestered in sediments. Although some organisms are known to accumulate copper, there is little evidence that this element is biomagnified in the food chain.

Throughout the Delaware Estuary, concentrations of dissolved copper in the water column are relatively low, rarely if ever exceeding water quality standards for the protection of aquatic life (Appendix C). Highest levels of copper were reported in the freshwater industrialized areas well upstream of Salem, generally decreasing in concentration downstream (Sutton et al. 1996). In the Transition and Delaware Bay Zones of the Estuary, including areas near the Station, total copper concentrations exhibited a statistically significant decline during the 1970s and 1980s (ANSP 1991). More recent monitoring of surface water at the Station's intake recorded relatively low dissolved copper concentrations, averaging < 2 µg/L (PSE&G 1996) which is less than the regulatory criterion for chronic exposure of 3.4 µg/L (DRBC 1996). The short duration of coincidental exposure of organisms to both low copper concentrations and elevated temperatures results in a negligible potential for any interaction between the thermal plume and copper in the water column with respect to any toxic effects on the biological community.

Copper concentrations in sediments were highest in the industrialized areas upstream of Salem (Costa and Sauer 1994). Near the Station, sediment concentrations were similar to the low levels observed throughout Delaware Bay, and consistently less than all of the reported sediment effects levels. The low concentrations, coupled with the dynamics and sediment temperature exposures discussed above, suggest no possibility of interaction between the plume and copper in sediments with respect to toxic effects on the biological community.

VI.D.4.c. Conclusions

Based on this evaluation, there appears to be no potential for Salem's thermal discharge to interact with other water quality parameters to adversely affect the biological community of the Delaware Estuary. This conclusion is based on the following key findings:

- Dissolved oxygen concentrations in the vicinity of the Station appear adequate to ensure protection of the existing biological community and there is no evidence, either theoretical or empirical, that the Station is causing a measurable decrease in dissolved oxygen availability in the Estuary.
- Concentrations of chlorine-produced oxidants resulting from biocide treatments in the service water system are estimated to be low at the point of discharge compared to those likely to induce biological effects. Further, rapid dilution and consumption by naturally occurring chlorine demand once the discharge enters the Estuary results in much lower CPO concentrations within a few seconds of discharge. The CWS is not chlorinated and therefore poses no interactive risk.
- Concentrations of contaminates of concern in the water column near the Station are well below levels known to have toxic effects in aquatic organisms. Thus, there appears to be no potential that the short-term exposures to small increases in temperature resulting from the thermal plume will lead to or enhance any toxic response in the Estuary to the low concentrations of such contaminants in the water column.
- Concentrations of contaminants of concern in sediments near the Station are comparable to the low levels found throughout Delaware Bay. Higher sediment concentrations, the basis for their inclusion by regulators as contaminants of concern for the Estuary as a whole, are generally limited to urbanized areas well upstream. Thus, there appears to be no potential that the small increases in temperature resulting from the thermal plume, which encompasses only a very small portion of the Estuary, will lead to or enhance any toxic response in conjunction with the low levels of contaminants that may be found in the sediments.

VI.D.5. Retrospective Evaluation

VI.D.5.a. Introduction

The biological community in the Delaware Estuary, identified in Section VI.C.1.a, which have some potential exposure to Salem's thermal plume. The following biotic categories are considered in this analysis: (1) Phytoplankton, (2) Zooplankton, (3) Shellfish/ macroinvertebrates, and (4) Fish. Based on the screening described in Section VI.D.1.b, phytoplankton and zooplankton could be considered low potential impact (LPI). However, this retrospective analysis provides available information on these categories.

The retrospective evaluation is conducted in two parts. First, an analysis of the condition of each biotic category as a whole is made by comparing available information on the current abundance and species composition of that biotic category to what would be expected without the operation of Salem. Second, the long-term trends in abundance for each of the RIS within the Delaware Estuary are analyzed to determine if declines in population abundance have occurred which can be attributed to Salem's operations. Taken together, the biotic category and RIS trends analyses provide a thorough and technically sound assessment of the status of the biological community in the Delaware Estuary consistent with Section 316(a) guidance and practice.

VI.D.5.b. Biotic Category Analysis

Each of the four biotic categories comprises a variety of species which, taken together, characterize the biological attributes of that category. The purpose of this portion of the retrospective analysis is to determine whether there have been changes in the composition and abundance of these biotic categories in the Delaware Estuary that are attributable to Salem's thermal discharge. This determination is based on the following factors identified in the Draft 316(a) Guidance (USEPA 1977) which are used as evidence of appreciable harm to the balanced indigenous community or community components:

- Substantial increase in abundance or distribution of any nuisance species or heat-tolerant community not representative of the highest community development achievable in receiving waters of comparable quality;
- Substantial decrease of formerly indigenous species, other than nuisance species;
- Changes in community structure to resemble a simpler successional stage than is natural for the locality and season in question; and
- Substantial reduction of community heterogeneity or trophic structure.

If the available empirical data demonstrate that such changes have not occurred as a result of Salem's thermal discharge for each of the four relevant biotic categories in the Delaware Estuary, then the existing permit conditions with respect to the Station's thermal discharge are sufficient to ensure the continued protection of those biotic categories (USEPA 1977).

Where adequate empirical data exist, this assessment focuses on that portion of the estuarine biological community which resides in the vicinity of Salem. This focus recognizes that any changes in the biological community induced by Salem's thermal plume would be expected to be most apparent in the local area of exposure. However, where information in the vicinity of Salem is insufficient, this retrospective analysis draws on relevant information for other areas of the Estuary, as appropriate.

<u>VI.D.5.b.i. Phytoplankton</u>

Phytoplankton consist of free-floating microscopic plants that are transported by water currents. In many aquatic systems where water clarity allows for sufficient light penetration, phytoplankton provide the primary source of energy to drive the ecosystem. This is the case in the lower reaches of the Delaware Bay zone, closest to the ocean. However, in areas upstream of this, including the Upper Delaware Bay, Transition, and Tidal River Zones of the Estuary, naturally high turbidity levels severely limit phytoplankton production; the energy to drive the ecosystem in these areas, which include the vicinity of the Station (RM 50), is primarily supplied by detrital materials imported from elsewhere (Section IV.F.4.a). In fact, approximately 90 percent of the total phytoplankton production in the Estuary normally occurs in the less turbid areas downstream of Ship John Light (RM 36) (Pennock and Sharp 1986). The fact that these areas are well removed from the vicinity of the Station further implies a low potential for this biotic category to be influenced by Salem's thermal plume.

The phytoplankton community within the Delaware Estuary is comprised of a diverse mixture of species (Sutton et al. 1996). However, most of the annual phytoplankton production is a result of seasonal blooms of diatoms, especially in the Delaware Bay Zone of the Estuary during spring (USEPA 1995). Typically, overall phytoplankton abundance in the Estuary is relatively low during the colder months of the year, rapidly increasing to a peak during spring and slowly declining through summer and fall to low abundance levels by late fall. This seasonal pattern in phytoplankton abundance in the Delaware Estuary is similar to that observed in most other temperate estuaries.

In the upper Delaware Bay and the Transition Zones of the Estuary, which includes areas near Salem, studies of the phytoplankton community revealed that densities were also dominated by diatoms (93 percent of the individual collections) with two genera (*Skeletonema* and *Melosira*) being especially abundant (IA 1980). Seasonal patterns in phytoplankton densities were similar to those described above for the Estuary as a whole.

Recent studies of the phytoplankton community in the Delaware Estuary were conducted at five fixed monitoring stations along the length of the Estuary (Marshall 1992). A total of 118 genera from each of six phytoplankton divisions were identified:

Diatoms	*Bacillariophyta*	56 genera
Green algae	*Chlorophyta*	25 genera
Blue-green algae	*Cyanophyta*	17 genera
Dinoflagellates	*Pyrrophyta*	12 genera
Euglenoids	*Euglenophyta*	4 genera
Yellow-brown algae	*Chrysophyta*	4 genera

Based on the results of this study, Marshall (1992) concluded that:

- The phytoplankton community throughout the Estuary is diverse and includes a healthy assemblage of species;
- No unusually high concentrations of species or categories were present during the collection periods;
- The dominant diatom populations were similar to those reported 20 to 30 years ago; and
- The dominant species in the area are tolerant of a variety of environmental conditions, and also dominate phytoplankton communities in other estuaries along the east coast of the United States.

These conclusions are supported by observations of Pennock (1988) who found that phytoplankton production within the Estuary remains at healthy levels, and by the conclusions of USEPA (1995) indicating that the Estuary is populated by phytoplankton species that are, in general, considered to be indicative of a healthy ecosystem. Other recent studies indicate there was an increase in primary production in the lower Estuary in the 1980s coincident with an increase in dissolved phosphate concentrations (Sharp 1994).

This evaluation of phytoplankton in the Delaware Estuary demonstrates that this component of the ecosystem is healthy and comparable to that which existed before Salem began operation. There is no evidence of any increase in nuisance phytoplankton species, such as certain dinoflagellates and blue-green algae, since Station operations began. Therefore, the phytoplankton community in the Delaware Estuary appears to be unaffected by all stresses potentially imposed by the continued operation of Salem's cooling water system, including the discharge of its thermal effluent.

VI.D.5.b.ii. Zooplankton

Zooplankton consists of weakly swimming animals, microscopic or near microscopic in size, whose primary method of movement is by water currents. In the Delaware Estuary, zooplankton serves as an important link between the energy from phytoplankton and the detrital complex and higher trophic levels. In general, the zooplankton community in the Estuary is comprised of two components, meroplankton and holoplankton (Herman 1988). Meroplankton refers to egg and larval stages of many aquatic organisms (e.g., fish, shellfish, and benthic macroinvertebrates) that spend a portion of their life cycle as zooplankters. For this retrospective evaluation, individual species that have a meroplanktonic stage are considered under the biotic component analysis that includes the adult form of that species. Holoplankton refers to aquatic organisms that spend their entire life cycle as plankton. Holoplankton abundance in the Delaware Estuary is numerically dominated by rotifers and cladocerans in freshwater areas and by copepods in brackish and saltwater areas. Typically, zooplankton densities are highest in late spring, following the spring phytoplankton bloom, with a secondary peak in late summer/early fall (Herman 1988).

In the upper Delaware Bay and Transition Zones of the Estuary, which include the vicinity of the Station, zooplankton consists of a seasonally varying mix of freshwater and saltwater species, with rotifers being numerically dominant during periods of higher freshwater flow and copepods dominating during low flow, higher salinity periods (IA 1980). Rotifers are small (<0.5 mm) zooplankters that are most closely associated with lower salinity waters. Members of this group are important prey for larger zooplankton and small larval fish and, in this role, serve as an important link between the detrital energy base and secondary consumers, especially in low salinity areas of the Estuary. Rotifer genera common to the Station vicinity include *Notholca*, *Brachionus*, *Keratella*, and *Synchaeta*.

Copepods are small planktonic crustaceans that tend to be most abundant in the brackish and marine waters of the Delaware Estuary. Generally much larger than rotifers, copepods are important prey for larvae and juveniles of many commercially and recreationally important fish species that utilize the Estuary as spawning and nursery grounds (Stearns 1995). Owing to their large size and numerical abundance, copepods comprise 85 percent of the zooplankton biomass in the Estuary (Herman 1988). While present in the vicinity of Salem year-round, copepods tend to be numerically most abundant during the warmer periods of the year. In late winter and spring, true estuarine species, such as *Eurytemora affinis*, are most abundant, whereas in summer and fall, estuarine/marine species, such as *Acartia tonsa*, tend to be most abundant.

Information on the condition and long-term trends of zooplankton in the Delaware Estuary derived from studies conducted since the start of Salem's operations shows that the zooplankton component of the ecosystem is reasonably healthy, with a seasonal succession comparable to historical conditions (Herman and Hargreaves 1988) and an abundance and productivity comparable to that of other East Coast estuaries (Herman 1988; Stearns 1995). These analyses demonstrate that the zooplankton composition and overall abundance are similar to that observed before Salem began operation and are consistent with findings in other nearby estuaries. Therefore, the zooplankton community in the Delaware Estuary is unaffected by all stresses potentially imposed by the continued operation of Salem's cooling water system, including its thermal discharge.

VI.D.5.b.iii. Shellfish/Macroinvertebrates

Shellfish are defined as the larger, shelled, invertebrate organisms, often harvested by humans (e.g., clams, oysters, crabs, etc.). For the purposes of this assessment, macroinvertebrates (including shellfish) are defined as larger invertebrate organisms that are retained by a U.S. Standard No. 30 sieve (0.595-mm openings) and generally can be seen by the unaided eye (USEPA 1977). Members of this biotic category typically reside in specific habitat associations: on or near the bottom (epifauna) or within bottom sediments (infauna). Epifauna consist of organisms that are either physically attached to the bottom (e.g., oysters) or free-swimming (e.g., scud, opossum shrimp, blue crabs). Free-swimming epifauna can often be found in the water column where they are transported by tidal currents. Many species in this biotic category have egg and/or larval stages that are seasonally meroplanktonic. However, as densities of these organisms are typically highest at or near the water-substrate interface, these are not considered part of the zooplankton component for this evaluation. Most members of this category are omnivorous, feeding on a variety of plant and animal materials while in turn serving as important food for larger (especially vertebrate) species. The habitat associations are discussed separately below.

VI.D.5.b.iii. (a) Attached Epifauna

The attached epifauna association within the Delaware Estuary is largely restricted to oysters, which attach to hard substrates in higher salinity areas, and mussels, which are most commonly found in littoral areas or in tidal creeks. These organisms are also considered part of the habitat-forming biotic component because their permanent colonization of certain areas provides habitat for other estuarine species. Because neither of these two groups is exposed to Salem's thermal plume to any appreciable degree, they are not considered further in this analysis (Section VI.D.1.b.iv).

VI.D.5.b.iii. (b) Free-Swimming Epifauna

The free-swimming epifaunal component includes those macroinvertebrates and shellfish that most commonly reside in the water at or near the interface with the bottom and especially in and among detrital material near the bottom. Common members of this group include crabs, shrimp, and amphipods. Members of this group are typically omnivorous and serve as important prey for a variety of fish and other vertebrate predators. Many within this group disperse up into the water column at night to feed, returning to areas near the bottom during the day (Herman 1988). While considered zooplankton in some studies, free-swimming epifauna are considered part of the shellfish/macroinvertebrate biotic category for this evaluation.

Typically, amphipods, decapods, and mysid shrimp numerically dominate this biotic category throughout the Estuary. Amphipods are present year-round in fresh and low salinity brackish waters and numerically dominate this biotic category during the cooler, higher flow months of the year. The most abundant amphipod taxa are a complex of three amphipod species of the genus *Gammarus*, commonly grouped under the common name "scud." Mysid shrimp, of which the opossum shrimp is a common representative, are abundant throughout the higher salinity brackish and saline waters of the Estuary. Decapods are most abundant during the summer months as a result of an influx of larval and juvenile crabs, most commonly mud and fiddler crabs, which are abundant in the intertidal and marsh areas of the Estuary. All three groups are seasonally abundant in the Delaware Bay and Transition Zones of the Estuary, including areas near Salem (IA 1980). While both amphipods and mysids are present in these areas year-round, mysids are especially abundant from late spring through fall. Decapods occur in these areas principally in summer.

Owing to the difficulty in effectively collecting members of this biotic category using traditional methods (Hargreaves 1995), little reliable quantitative data exist to document the status and trends of free-swimming fauna in the Delaware Estuary. However, in a study conducted well after the start of Salem's operations, opossum shrimp were found to be very abundant in the Estuary from mid-summer through early autumn and to occur at densities that were generally higher than those observed in the inlet to the Indian River, DE and in Delaware Bay during the 1950s (Walker 1989). Thus, it appears that the free-swimming component of the Delaware Estuary ecosystem is unaffected by all stresses potentially imposed by the operation of Salem's cooling water system, including its thermal discharge.

VI.D.5.b.iii. (c) Benthic Infauna

Benthic infauna consists of all macroinvertebrate organisms that live within the sediments at the bottom of the Estuary. Their potential exposure to elevated temperatures associated with Salem's thermal plume is limited to areas where the plume makes contact with the bottom for a sufficient length of time to permit heating of the sediments. Because of the shifting tides, plume contact is intermittent and heating is rapidly replaced by cooling in the next tidal cycle (Section V.F). Common components of the benthic infaunal community in open water areas of the Estuary include oligochaete worms and chironomid larvae in low salinity areas and polychaete worms and selected bivalves in more saline areas. In the upper Delaware Bay and Transition Zones of the Estuary, such as near Salem, the benthic infaunal macroinvertebrates are comprised of a mix of fresh and saltwater taxa that can withstand the daily and seasonal changes in salinity typical of this area (IA 1980). Common taxa in the vicinity of the Station included polychaete worms, especially the brackish water genera *Scolecolepides* and *Polydora*, and oligochaete worms especially the brackish water species, *Paranais litoralis*. A single cirriped species, the bay barnacle, *Balanus improvisus*, was also seasonally important.

Actual species composition in areas near Salem, however, is strongly influenced by local substrate characteristics resulting in considerable variability from location to location (IA 1980). For example, collections in sand are dominated by the polychaete worms, *Scolecolepides viridis*, whereas collections in clay are dominated by the polychaete worm, *Polydora* spp. Bay barnacles are most abundant on the sparse gravel-shell substrates while collections in mud are dominated by the oligochaete worm, *P. litoralis*. Near Salem, the bottom consists primarily of sandy sediments in nearshore water and mud in deeper areas (IA 1980). In addition to the influences of substrate and salinity, the benthic infaunal composition and abundance are affected by the high degree of deposition and movement of sediments characteristic of areas near Salem. As a result of this sediment movement, benthic infauna in the vicinity of the Station tends to be limited to species that can rapidly recolonize areas affected by natural deposition and scour.

Recent studies of the benthic infauna in the Tidal River Zone upstream of the C&D Canal, and well outside of the potential influence of the Station, reveal a degraded, yet improving, community (ECSI 1993; USEPA 1995). This degradation is attributed principally to historical organic enrichment and chemical contamination of the sediment, as well as low dissolved oxygen in the overlying water column. Reductions in the number of pollution-tolerant species observed in these recent studies have been attributed to improved water quality resulting from wastewater treatment upgrades in the freshwater portion of the Delaware Estuary (ECSI 1993; Appendix C). In areas downstream of the C&D Canal, the benthic infaunal community has been characterized in recent EPA-sponsored Environmental Monitoring and Assessment Program (EMAP) assessments as healthy, with no severely degraded areas (USEPA 1998b).

In Delaware Bay, earlier studies suggested that the benthic infaunal component of the ecosystem was lower in overall densities compared to other estuaries (Kinner et al. 1974, Maurer et al. 1979). These lower densities were attributed to the decline in oyster reefs (unrelated to Salem) and subsequent creation of unstable, coarse sand habitat in these hydrologically dynamic areas (Section VI.D.1.b). However, a comparison of dominant taxa shows a faunal composition similar to other East Coast estuaries. More recent studies demonstrate that there have been no major changes in benthic infauna in subtidal Delaware Bay since the 1970s, the period spanning Salem's pre- and post-operational periods (Hargreaves and Kraeuter 1991, Foster et al. 1994). Further, the shellfish component of the Delaware ecosystem has been characterized as diverse (Epifanio and Tweed 1988).

This information demonstrates that the benthic infaunal component of the ecosystem presently occurring in the upper Delaware Bay and Transition Zones is generally similar to that observed prior to the start of Salem's operations. There is no evidence of a shift to more pollution-tolerant taxa, as one would expect if the operation of Salem were having an adverse effect on this biotic category. In the Tidal River Zone, the benthic infaunal community has shown improvement coincident with improvements in water quality. Further, the composition and abundance of benthic infauna in the upper Delaware Bay and Transition Zones is comparable to that observed in other East Coast estuaries with similar salinity and substrate characteristics. Consequently, this comparison demonstrates that the continued operation of Salem is not preventing the maintenance of a healthy and balanced community of benthic infauna in the Delaware Estuary.

VI.D.5.b.iii. (d) Conclusion for Shellfish/Macroinvertebrates

This analysis of shellfish and macroinvertebrates in the Delaware Estuary in the vicinity of Salem indicates that this biotic category is similar in composition and overall abundance to that observed before Salem began operation. There is no evidence of any increase in the abundance of any stress-tolerant species since the Station began operation. Therefore, based on available monitoring data, the shellfish/macroinvertebrate community in the Delaware Estuary as a whole appears to be unaffected by all stresses potentially imposed by the continued operation of Salem's cooling water system, including its thermal discharge.

VI.D.5.b.iv. Fish

Approximately 200 species of fish have been reported from the Delaware Estuary (Wang and Kernehan 1979). Each of these species can be broadly categorized as either marine, freshwater estuarine residents or migratory. Migratory species include anadromous (spawning in freshwater) and catadromous (spawning in ocean water) species that move between marine and freshwater areas for spawning. Representatives of each of these four categories can occur seasonally within the Estuary, with the marine group being dominant in the higher salinity areas and the other three groups dominating collections in fresh water and low salinity brackish areas.

In the upper Delaware Bay and Transition Zones of the Estuary, which includes Salem, the only year-round inhabitants are estuarine-resident species. However, marine species and anadromous species can be numerically dominant on a seasonal basis. Freshwater species occur in the area only infrequently during high flow periods. On average, marine species tend to be most abundant and dominate collections during warmer months of the year, whereas the anadromous species tend to be especially abundant during fall migration periods. However, some estuarine-dependent marine species, such as Atlantic croaker and spot, can be numerically dominant in the area at other times of the year in years when their overall stock abundance is high.

Since 1970, a comprehensive monitoring program has been conducted to assess the abundance and species composition of fish in the vicinity of the Station. This program consists of standardized bottom trawl sampling conducted at fixed monitoring stations from April through November of each year, with the exception of 1983 and 1995. Data generated from this near-field sampling program can be used to quantitatively determine whether or not changes have occurred in the species composition and abundance of fish in the vicinity of Salem since the Station began operation.

The analysis of these data focuses on the following four independent measures that can be used as an index of the overall health and condition of the fish biotic category: species richness (the number of species expected in a sample of a fixed number of fish); species density (the mean number of species per sample); and species turnover (changes in the individual species collected among sampling times). Overall, it is reasonable to expect that a robust and healthy fish community should exhibit higher values for some, and perhaps all, of these measures than would a fish community that has been appreciably harmed by anthropogenic stresses.

For this analysis, each of these three measures was calculated separately for spring (April-May), summer (June-August), and fall (September-November) in each year to account for the natural seasonal progression in species composition and abundance. Next, the three measures for each season from each year were graphically displayed and overall patterns across the years were described. Finally, mean values from the pre-operational period (1970-1977) were statistically compared to mean values calculated for 1986-1997, a period well after the startup of full commercial operation of Salem, in an effort to determine if changes were outside the range expected from random chance alone. Means from the period 1978-1985 were excluded from the statistical analysis because they reflect a transitional period during which effects of Salem's operation, if any, would not be fully evidenced. Details of the analytical methods and results for this analysis are briefly summarized below and presented in Appendix F Section VIIA. The results of the three analyses are presented below.

VI.D.5.b.iv. (a) Species Richness

Species richness, which is based on a normalized 650-fish collection, shows no consistent trend for the spring, summer, or fall period from 1970 through 1998 (Figure VI-39). Measures for the operational period (after full commercial operation of the Station commenced) were generally within the range observed for the pre-operational period. Statistical analysis confirmed the lack of any long-term trend, as species richness for the operational period was not significantly different from the pre-operational period for any of the three seasons [$P \geq 0.500$]. In fact, mean species richness was actually slightly higher during the operational period in all three seasons, a pattern also reported by Weisberg et al. (1996) for the freshwater areas of the Estuary upstream of Salem.

VI.D.5.b.iv. (b) Species Density

Species density, the mean number of species per sample, while exhibiting considerable variability both within and between years, showed a generally increasing trend through the transitional period in each of the three seasons (Figure VI-40). As a result, the mean number of species per sample was significantly higher [$P < 0.01$] in the operational period than in the pre-operational period.

VI.D.5.b.iv. (c) Species Turnover

In the operational period, a total of 65 species was collected in the near-field bottom trawl surveys compared to 69 species during the pre-operational period. Fifty-four species were represented in both the pre-operational and operational studies. All 15 species unique to the pre-operational period and all 11 species unique to the operational period are either obligate freshwater or obligate marine species that only periodically stray into the Estuary near Salem. None of these species is uniquely important to ecosystem function in the Estuary and none could be considered a nuisance species. Their occurrence depends on the irregular occurrence of particularly dry or wet hydrological years, which affect river runoff and thus estuarine salinity.

VI.D.5.b.iv (d) Conclusions for Fish Biotic Category (Fish Assemblage Composition)

This analysis of fish species richness, density, and turnover in the Delaware Estuary clearly demonstrates that there has been no appreciable harm to the fish community that can be attributed to the operation of the Station. Species richness measures were consistently higher in the operational period, suggesting improved conditions, although the differences were not statistically significant. Statistical analysis revealed that there was a statistically significant improvement in the species density from the pre-operational to the operational period. There was normal turnover of species during the period of analysis, reflecting natural shifts between wet and dry years that affect estuarine salinity and the mix of marine and freshwater species. Moreover, there is no evidence of any increase in potential nuisance or stress-tolerant species since the Station began operation. Therefore, based on the extensive empirical database available for the vicinity of Salem, the composition of fish assemblage in the Delaware Estuary appears to be unaffected by all stresses potentially imposed by the continued operation of Salem's cooling water system, including its thermal discharge.

VI.D.5.b.v. Conclusions of Biotic Category Analysis

The results of this analysis demonstrate that the operation of Salem, including its thermal discharge, has not caused appreciable harm to any of the four biotic categories potentially exposed to the Station's thermal plume. Analysis of existing information on the lower trophic level categories (phytoplankton, zooplankton, shellfish/macroinvertebrates) show that the present species composition and abundance of these categories are similar to those observed before the start of Salem's operations and are consistent with those observed in other estuarine areas along the East Coast. Analysis of data on the fish community in the vicinity of Salem revealed that there has been a general increase in the average number of fish species collected in that area since Station operations began. The few changes in actual fish species collected were limited to those relatively rare visitor species from fresh and ocean waters. In addition to the lack of any demonstrable change in the composition and abundance of any of the four biotic categories, none of the analyses revealed any increase in potential nuisance species.

VI.D.5.c. Representative Important Species (RIS) Population Analyses

In addition to the biotic category analysis of the fish assemblage described above, analysis of the trends in the abundance of the RIS populations was also conducted using available monitoring data for the Delaware Estuary (Appendix J). These RIS were selected to be representative of the biotic categories which were identified as having some potential exposure to Salem's thermal plume (Section VI.D.2).

The focus of this species population analysis is on the annual abundance of age-0 individuals in the waters of the Estuary. This focus on age-0 individuals for population trends analysis is based on the following three reasons. First, abundance of age-0 provides a reliable measure of the production of young of that species in the Estuary and is a commonly used index of subsequent recruitment to the adult stock. Second, potential biological stresses associated with power plant operation most directly affect the early life stages. Consequently, use of age-0 provides a measure of abundance for individuals older than those most vulnerable to Station-induced effects. Third, long-term trends in age-0 individuals reflect the cumulative effects of all natural and anthropogenic stresses as modified through any population-level responses such as compensation (Appendix I). As a result, use of age-0 indices as a measure of population status is common in fisheries management.

For this analysis, data from three independent annual monitoring programs were considered: (1) Delaware Department of Natural Resources and Environmental Control Small Trawl Survey (1978-1996); (2) New Jersey Beach Seine Survey (1980-1997); and (3) PSE&G Near-field Trawl Survey (1979-1998, except 1983 and 1995).

Catches observed in these three surveys were used as an index of abundance of each RIS in the areas sampled. Using these indices, statistical analyses of the trends over time were conducted in an effort to determine whether or not changes in abundance have occurred that could be attributable to the operation of Salem, including its thermal discharge. Details on the survey design, analytical method, and results of this analysis are presented in Appendix J and summarized below for each of the RIS. This analysis focused on two factors identified in the Draft 316(a) Guidance (USEPA 1977) that provide evidence of appreciable harm at the population level: (1) substantial decrease in formerly indigenous species, other than nuisance species; and (2) elimination of an established or potential economic or recreational use of the waters.

VI.D.5.c.i. Weakfish

Annual indices of abundance for age-0 weakfish in the Delaware Estuary have been significantly increasing since the late 1970s (Figure VI-41; Appendix J). This pattern is similar to that observed in nursery areas throughout the Atlantic coastal range of this species and has been confirmed in independent evaluations by other scientists (Killam and Richkus 1992; NMFS 1998; USEPA 1998*b*). In addition, the total biomass of spawning adults throughout the species' range has also been increasing since 1991 in response to decreased commercial and recreational fishing (NMFS 1998). Santoro (1998) states that the 1996 weakfish density was the highest recorded for the entire time series that began in 1966. The increase in abundance of young weakfish in the Delaware Estuary during the period of the Station operations provides clear evidence that the stresses potentially imposed by the operation of Salem's cooling water system, including its thermal discharge, have not adversely affected the population of this species within the Estuary.

VI.D.5.c.ii. White Perch

Annual indices of abundance for age-0 white perch in the Delaware Estuary have been increasing significantly since the mid-1980s (Figure VI-42; Appendix J). This pattern has been confirmed in independent evaluations by other scientists (Killam and Richkus 1992; Beck 1995; Sutton et al. 1996; Weisberg et al. 1996; USEPA 1998). The increase in the abundance of young white perch has been widely attributed to improvements in water quality, especially dissolved oxygen in the freshwater Tidal River Zone. This improvement in water quality has been most noticeable near Camden and Philadelphia, which are within the natural spawning and nursery area for this species. The increase in abundance of young white perch in the Estuary during the period of the Station's operation provides clear evidence that the stresses potentially imposed by the operation of Salem's cooling water system, including its thermal discharge, have not adversely affected the population of this species within the Estuary.

VI.D.5.c.iii. Striped Bass

As with white perch, annual indices of abundance for age-0 striped bass in the Delaware Estuary have been increasing significantly since the mid-1980s (Figure VI-43; Appendix J). This pattern has been confirmed in independent evaluations by other scientists (Killam and Richkus 1992; Miller 1995*b*; Weisberg et al. 1996; Kahn et al. 1998; Santoro 1998). The increase in the abundance of young striped bass has been widely attributed to improvements in water quality, especially dissolved oxygen, in the freshwater Tidal River Zone coupled with strict fishery management. This improvement in water quality has been most noticeable near Camden and Philadelphia, which is within the natural spawning and nursery area for this species. In addition, the abundance of Atlantic coast population of striped bass has also been increasing since the late 1980s due to decreased commercial and recreational fishing in response to management initiatives by the Atlantic States Marine Fishers Commission and coastal states. This increase in the abundance of young striped bass in the Delaware Estuary during the period of the Station's operation provides clear evidence that the stresses potentially imposed by the operation of Salem's cooling water system, including the thermal discharge, have not adversely affected the population of this species within the Estuary.

VI.D.5.c.iv. American Shad

Annual indices of abundance for age-0 American shad in the Delaware Estuary have been increasing significantly since the mid-1980s (Figure VI-44; Appendix J). Independent evaluations by other scientists confirm this pattern (Killam and Richkus 1992; Miller 1995*b*; Sutton et al. 1996; Weisberg et al. 1996; USEPA 1998). As with white perch and striped bass, the increase in the abundance of young American shad has been widely attributed to improvements in water quality in the Estuary, especially dissolved oxygen in the freshwater Tidal River Zone. Previously, low dissolved oxygen levels near Camden and Philadelphia served as a block preventing adult shad from reaching spawning grounds in the upper Delaware River. Santoro (1998) states that "all sampling programs document good recruitment of American Shad throughout the river." The increase in abundance of young American shad in the Delaware Estuary during the period of the Station's operation provides clear evidence that the stresses potentially imposed by the operation of Salem's cooling water system, including its thermal discharge, have not adversely affected the population of this species within the Estuary.

VI.D.5.c.v. Alewife

Annual indices of abundance for age-0 alewife in the Delaware Estuary exhibited no consistent trend across the three data sets evaluated (Figure VI-45). There was a significant increasing trend in Delaware Bay from DNREC monitoring with evidence of especially strong year classes in 1993 and 1996. No trend was evident in either areas near Salem or the Tidal River Zone. Independent evaluations of river herring (combined alewife and blueback herring) abundance in the Delaware Estuary found either an increasing trend (Killam and Richkus 1992; Santoro 1998) or no trend (Weisberg et al. 1996). In those studies reporting an increase in alewife abundance, the increase was attributed to improvements in water quality, especially dissolved oxygen, in the freshwater Tidal River Zone. Previously, low dissolved oxygen levels near Camden and Philadelphia served as a block preventing adult alewife from reaching spawning grounds in non-tidal areas of the Delaware River and its tributaries. The absence of any decrease in abundance of young alewife in the Delaware Estuary during the period of the Station's operation provides clear evidence that the stresses potentially imposed by the operation of Salem's cooling water system, including its thermal discharge, have not adversely affected the population of this species within the Estuary.

VI.D.5.c.vi. Blueback Herring

Contrary to the pattern observed in the other two common herring species, American shad and alewife, annual indices of abundance for age-0 blueback herring in the Delaware Estuary have shown a significant decrease over the period of available data (Figure VI-46; Appendix J). However, independent evaluations of trends in river herring (combined alewife and blueback herring) by other scientists suggest that the abundance of this species in the Estuary may have been increasing (Killam and Richkus 1992; Santoro 1998). The declining trend in the Estuary evidenced in this analysis is similar to that observed for this species throughout its natural geographic range This regional decline, which began in the 1960s, has been attributed to the combined effects of overfishing and habitat alteration (ASMFC 1998). The fact that the decline has been coast-wide and began well before the commercial operation of Salem, provides clear evidence that the stresses potentially imposed by the operation of Salem's cooling water system, including its thermal discharge, are not causative. Further evidence that Salem's operation is unlikely to be a contributor to the decline in blueback herring is provided by the increase in abundance of both American shad and alewife, with life histories and thermal exposures at Salem similar to blueback herring.

VI.D.5.c.vii. Spot

Spot in the Delaware Estuary are near the northern extreme of their natural geographic range (Killam and Richkus 1992; Michels 1995; Sutton et al. 1996). ASMFC (1993) found that the area of greatest abundance of spot on the Atlantic Coast extends from Chesapeake Bay to South Carolina. As a result, the abundance of spot within the Estuary is largely determined by the overall abundance of spot throughout its range. When spot populations are high throughout their usual range, their geographic range expands and they become common in the Delaware Estuary, including areas near Salem. This pattern is evident in the annual indices of abundance for age-0 spot in the Delaware Estuary which exhibit considerable variability annual abundance indices. (Figure VI-47; Appendix J). Statistically significant declining trends were determined; however, these declines appear to be an artifact of a single, especially strong year class in 1988. The lack of any trend in juvenile abundance for this species during the period of Salem's operation provides clear evidence that the stresses potentially imposed by the operation of the Station's cooling water system, including its thermal discharge, have not adversely affected the population of this species within the Estuary.

VI.D.5.c.viii. Atlantic Croaker

Like spot, Atlantic croaker in the Delaware Estuary are near the northern extreme of their natural geographic range (Killam and Richkus 1992; Michels 1995; Sutton et al. 1996). Delaware is the northernmost location where Atlantic croaker are caught in inshore fisheries (ASMFC 1987) As a result, the abundance of croaker within the Estuary is largely determined by the overall abundance of this species throughout its range. When Atlantic croaker populations are high throughout their usual range, their geographic range expands and they become common in the Delaware Estuary, including areas near Salem. Since the late 1980s annual indices of abundance for age-0 Atlantic croaker in the Delaware Estuary have been increasing significantly (Figure VI-48; Appendix J). This increasing trend is consistent with a region-wide increase in overall croaker abundance observed in recent years (USEPA 1998b). The increase in abundance of young Atlantic croaker in the Delaware Estuary during the period of the Station's operation provides clear evidence that the stresses potentially imposed by the operation of the Station's cooling water system, including its thermal discharge, have not adversely affected the population of this species within the Estuary.

VI.D.5.c.ix. Bay Anchovy

Annual indices of abundance for age-0 bay anchovy throughout the Delaware Estuary have been generally higher in recent years compared to the late 1970s (Figure VI-49; Appendix J). This species abundance is often spatially and temporally variable. Frithsen et al. (1991) stated that "catch per unit effort data suggest that the bay anchovy population in the Delaware Estuary experiences considerable variation in either absolute or local abundance or recruitment from nearby coastal waters". The statistically significant decline estimated for the Salem near-field appears to be an artifact of high densities observed in a single year (1980). The increase in abundance of bay anchovy throughout the Delaware Estuary during the period of the Station's operation provides clear evidence that the stresses potentially imposed by the operation of Salem's cooling water system, including its thermal discharge, have not adversely affected the estuary-wide population of this species.

VI.D.5.c.x. Blue Crab

Annual indices of abundance for blue crab throughout the Delaware Estuary have been significantly higher in recent years compared to the late 1970s (Figure VI-50; Appendix J). This pattern is evident across almost all size classes evaluated and has been confirmed in independent evaluations by other scientists (Seagraves and Cole 1989). At present, blue crab populations in the Delaware Estuary are characterized as healthy (Epifanio and Tweed 1988; Frithsen et al. 1991). Reasons for this increase in blue crab abundance in the Delaware Estuary are unknown, but the increase during the period of Salem's operation, as well as the species' overall population health, provide clear evidence that the stresses potentially imposed by the operation of Salem's cooling water system, including its thermal discharge, have not adversely affected this species within the Estuary.

VI.D.5.c.xi. Conclusions of RIS Population Trend Analysis

Results of the trends analysis demonstrate that the operation of Salem, including its thermal discharge, has not caused appreciable harm to the populations of any of the ten RIS evaluated. In fact, statistical analysis of these trends reveals a significant increase in the abundance of seven of these RIS during the period of Station operations (Figure VI-51). These increasing trends, which are confirmed by the observations of other researchers, have been attributed to the effects of improving water quality in the upper Estuary and fisheries management activities throughout each species' range. No consistent trend was evident for bay anchovy.

For spot, one of the two remaining species, annual abundance exhibited considerable variability and the statistically significant declining trend estimated appears to be an artifact of a single strong year class in 1988. Only for blueback herring is there consistent and convincing evidence of a declining trend in population abundance in the Delaware Estuary during the period of Salem's operation. This decline, which appears to have started well before Salem's operation, coincides with a coast-wide decline in overall abundance observed for this species. The lack of any decline in other closely related species in the Delaware confirms that the decline in blueback herring can not be attributed to the operation of Salem.

VI.D.5.d. Overall Conclusions of Retrospective Evaluation

This retrospective evaluation utilized existing empirical data to determine whether there is evidence that the operation of the Station's cooling water system has had a demonstrable effect on the balanced, indigenous biological community (BIC) of the Delaware Estuary. The evaluation was conducted in two parts. First, specific biotic components of the aquatic community in the vicinity of Salem deemed potentially vulnerable to the Station's thermal discharge were analyzed to determine if there is evidence of changes in species composition or abundance which are attributable to Salem's operation. The results of this analysis revealed that observed changes in species composition or overall abundance over the years since the Station began operation were within the range expected to occur as a result of natural variation and improvements in general environmental conditions, such as water quality. Furthermore, no increases in either stress-tolerant or nuisance species were evident.

The second part of the evaluation focused on trends in the abundance of RIS populations. These RIS were purposely selected to be representative of those biotic categories potentially at risk from the effects of Salem's operations. The results revealed statistically significant increasing trends in the abundance of young for almost all of the species evaluated. There was a declining trend for only one species, blueback herring. The observed declining trend for this species appears to be a coast-wide phenomenon that commenced well before the start of operations at Salem. Lack of detrimental effects of Salem on species with similar life histories indicates that Salem has not contributed to this decline. The results of these analyses provide clear evidence that the Station's operation has not caused a decline in abundance of any RIS in the Delaware Estuary.

With regard to each of the phenomena indicative of appreciable harm to a balanced indigenous community (USEPA 1977), this evaluation demonstrates that Salem's thermal discharge has not caused:

- A substantial increase in abundance of any nuisance species or heat-tolerant community not representative of the highest community development in the Delaware Estuary or waters of comparable quality;
- A decrease of formerly indigenous species of the Estuary, other than nuisance species;
- Changes in community structure in the Delaware Estuary to resemble a simpler successional stage than is natural for the areas of the Estuary near Salem for the season in question;
- A substantial reduction in community heterogeneity or tropic structure in the Estuary; or
- The elimination of an established or potential economic or recreational use of the Estuary.

Based on these results, it is clear that more than 20 years of operation of Salem's cooling water system, including its thermal discharge, has not had any adverse effect on the biological communities of the Estuary. In fact, much of this retrospective evaluation indicates improvements in RIS populations and the overall community since Salem began operation. These improvements in the aquatic community appear principally attributable to purposeful changes in wastewater treatment and fishery management practices. These practices should continue well into the future. The patterns observed in this retrospective evaluation, coupled with the relatively long operating history of Salem, demonstrate that the Station's operations, including its thermal discharge, will not cause appreciable harm to the biological populations or communities of the Estuary in future years. Consequently, current permit conditions related to Salem's thermal discharge are more than sufficient to ensure continued protection of the biological communities in the Delaware Estuary.

ENDNOTES

[1]The DRBC retained an aquatic biologist, Dr. David Wallace, Director of Marine Fisheries at the New York State Conservation Department (Wright 1969). Dr. Wallace was retained as a biological consultant to assist the DRBC in evaluating biological issues related to the Station's discharge. For example, after the public hearing, the DRBC, with the assistance of Dr. Wallace, formulated questions and requests for supplemental information in connection with their assessment of Salem's discharge and its biological effects on aquatic resources. (Howlett 1970). These questions and requests for additional information were related to the peak temperatures at Artificial Island; studies of the lethal maximum temperatures for the species of fish and shellfish found in the area adjacent to Artificial Island; specific information on striped bass; the effect of abrupt temperature changes on fish; the effect of the thermal plume on aquatic organisms; and the issue of whether the thermal plume would accelerate the growth of coliform or fecal coliform bacteria. Dr. Raney replied to each of the DRBC's questions (Eckert 1970; Raney 1970).
[2] *Environmental Report*. Appendix A of the *Environmental Report* (PSE&G 1971) included the reports, prepared after issuance of DRBC's Docket, listed in the references as Raney et al. 1969 and Schuler et al. 1970*a*. A supplement to the *Environmental Report* was submitted in November 1971, and PSE&G's *Environmental Report* was amended in May 1972 and again in August 1972. Two separate ecological monitoring reports were also submitted to the AEC, listed in the references as Schuler et al. 1970*b* and 1971.
[3] This study was submitted as part of the Environmental Report PSE&G submitted to the AEC in connection with the AEC's EIS process.
[4] In addition to updating its own long-term trend analysis with two years of additional fish abundance data, the 1993 comments also presented the results of two independent assessments of abundance trends and factors controlling fish population abundance prepared for USEPA by Versar.
[5] To provide a safety factor so that none of the organisms will perish, a criterion of 3.6° F below the UUILT is generally sufficient (Coutant 1972; USEPA 1976).
[6] See Section V.F.3 and Attachment E-2 for a description of the "reasonable worst-case" plume characterization. Also see Section VI.C.1.d for a discussion of levels of protective conservatism used in the analysis.
[7] Boston Edison Company (Pilgrim Station Units 1 and 2), NPDES Permit Determination No. MA0025135 (Decision of the Regional Administrator, 11 March 1977) at 17.
[8] Boston Edison Company (Pilgrim Station Units 1 and 2), NPDES Permit Determination No. MA0025135 (Decision of the Regional Administrator, 11 March 1977) at 17.
[9] Clean Water Act Section 316(a), 33 U.S.C.Section 1326(a).
[10] USEPA, NRC, and FWS, 316(a) Technical Guidance Manual (Draft 11 December 1975) at 100, 106.
[11] According to USEPA, "a zone having a critical function is one that provides a major contribution to primary productivity or is one that is limited in extent and necessary for the propagation and survival of a species" (USEPA 1977).
[12] The methodology requires a sufficient data set containing temperature tolerance estimates for each of several exposure durations at a constant, or at least narrow range of acclimation temperature. Data meeting these requirements was available for scud, alewife larvae, white perch larvae, striped bass larvae and early juveniles, weakfish larvae, and bay anchovy early juveniles.

E Table VI-1. History of Biothermal Assessments for the Salem Station

LICENSING AGREEMENTS	PRINCIPAL BIOTHERMAL FINDINGS	PRINCIPAL REFERENCES
DRBC 1970 Docket (1968–1970)	• thermal discharge design configuration was best of 36 alternatives for minimizing thermal impacts • the thermal discharge would have no adverse effect on water resources of the Delaware Basin: effect on biomass would be minimal; effect on anadromous and catadromous fish would be negligible; would not interfere in any way with the recreational use of the Estuary near Artificial Island.	DRBC 1969, 1970 IA 1969 Raney 1969
AEC EIS under NEPA (1968–1973)	• thermal discharge configuration would minimize the potential for adverse thermal effects on aquatic life and would not pose a barrier to migration of fish, nor interfere with recreational use of the Estuary.	Pritchard-Carpenter 1968 IA 1969 PSE&G 1971, AEC 1973
NPDES PERMIT ASSESSMENTS	**PRINCIPAL BIOTHERMAL FINDINGS**	**PRINCIPAL REFERENCES**
1974–1979 Section 316(a) Demonstration	• thermal plume would be protective of the balanced, indigenous community (BIC) • the area is not a unique or preferred area for RIS and does not contain oyster beds or other unique habitats • the thermal plume would potentially preclude use as habitat of only a small area; would not harm any spawning area or block migration of fish; would not affect macroinvertebrates or fish as a result of cold shock; and would not cause a proliferation of nuisance species	PSE&G 1974 Rudavsky 1972 PSE&G 1975 PSE&G 1978 PSE&G 1979
NPDES PERMIT ASSESSMENTS	**PRINCIPAL BIOTHERMAL FINDINGS**	**PRINCIPAL REFERENCES**
1986-1989 Technical Review and Evaluation by NJDEP Consultants	• the effects of the thermal discharge were small and localized and not a major source of impact and so not need to be reduced to protect the balanced indigenous community	Versar 1989
1991 Biothermal Assessment	• the thermal plume does not threaten the protection and propagation of a BIC: only very small portions of the populations of RIS are exposed to higher temperature portions of plume for very short times; the potential for cold shock is low; there is little potential for population effects from plume interactions with other pollutants or plume effects in dissolved oxygen; long-term abundance trends of RIS fish populations reveal no decline in any RIS fish populations	PSE&G 1991
1993 Biothermal Assessment	• the thermal plume is protective of the BIC: the portion of the plume with high temperatures is extremely small and exposure of organisms to it is brief; the plume will not block migration nor adversely affect survival, growth or reproduction of any RIS population, nor cause proliferation of nuisance species	PSE&G 1993
1995 Biothermal Assessment	• the thermal discharge and associated heat dissipation area (HDA) do not have the potential to cause appreciable harm to aquatic life or to relevant beneficial uses of the area. Updated retrospective analysis of abundance data indicated that the population of RIS had remained steady or increased from 1980 through 1994, period during which both the Station's units were operating.	PSE&G 1995

E Table VI-2. Literature Sources and Assigned Codes for Thermal Response Data Used in the Biothermal Assessment

Source Code	Source
1	EA 1978a
2	TI 1976a
3	IA 1978a
4	PSE&G 1974
5	Kellogg and Gift 1983
6	EA 1979
7	IA 1980
9	IA 1978b
10	IA 1979
11	Smith et al. 1979
13	Chung and Strawn 1982
14	Thibault and Couture 1980
15	Savage 1982
17	Wyllie et al. 1976
18	PSE&G 1978b
19	Tagatz 1969
21	Carroll and Norden, cited in Brungs & Jones 1977
22	Reutter and Herdendorf 1976
24	Otto et al. 1976
26	Leggett and Whitney 1972
28	PSE&G 1978a
29	Talbot 1966
30	Morgan and Raisin 1982
31	Harmic 1958
32	Dovel 1971
33	TI 1976b
34	Houde 1974
36	Hodson et al. 1981
37	Copeland et al. 1974
38	Chung and Strawn 1984
39	Ginn et al. 1974
42	Greges and Schubel 1979
43	Kellogg et al. 1984
44	Mihursky and Kennedy 1967
48	Holland et al. 1971
49	IA 1978c
55	Ginn 1977
80	Rebel 1973, cited in LMS 1975
84	Hartwell and Hoss 1979
85	Hoss et al. 1974
86	Dawson 1958
90	NYU 1974
91	IA 1978d
92	Lauer et al. 1974
93	Cox and Coutant 1981
96	Pezzack and Corey 1982
97	Lankford 1997

E Table VI-3. 316(a) Decision Criteria Based on the Draft Interagency 316(a) Technical Guidance Manual, 1977

Introduction	
In 1977, the United States Environmental Protection Agency (USEPA), the Nuclear Regulatory Commission (USNRC), the United States Fish and Wildlife Service (USFWS), and other federal agencies or departments, produced a draft guidance manual (Guidance Manual) suggesting how to conduct 316(a) demonstrations (USEPA 1977). Section 3.3 of the Guidance Manual sets forth the following decision criteria for determining whether a 316(a) Demonstration will be judged successful for each biotic category of concern.	
Phytoplankton	
Areas of Low Potential Impact (LPI)	• Open ocean areas or systems in which phytoplankton is not the food chain base • Ecosystems in which the food web is based on detrital material (e.g., embayments bordered by mangrove swamps, salt marshes, freshwater swamps, and most rivers and streams)
Areas Not Considered LPI	• Phytoplankton contribute a substantial amount of the primary photosynthetic activity supporting the community • A shift towards nuisance species may be encouraged [a] • Operation of the discharge may change the community from a detrital to a phytoplankton-based system
Successful 316(a) Demonstration Judgment for non-LPI Areas	• A shift towards nuisance species of phytoplankton is not likely to occur • There is little likelihood that the discharge will alter the indigenous community from a detrital to a phytoplankton based system • Appreciable harm to the balanced indigenous population is not likely to occur as a result of phytoplankton community changes caused by the heated discharge
Habitat Formers	
Areas of LPI	• Sites that are devoid of habitat formers because of low levels of nutrients, inadequate light penetration, sedimentation, scouring stream velocities, substrate character, or toxic materials • If these limiting factors may be relieved, a heated discharge would not restrict reestablishment of habitat formers within the area
Areas Not Considered LPI	• Sites where the possibility of an impact to a threatened or endangered species through adverse impacts on habitat formers
Successful 316(a) Demonstration Judgment for non-LPI Areas	For sites that are not devoid of habitat formers, • The heated discharge will not result in any deterioration of the habitat formers community, or no appreciable harm to the balanced, indigenous population will result from such deterioration • The heated discharge will not have an adverse impact on threatened or endangered species as a result of impact upon habitat formers
Zooplankton/Meroplankton	
Areas of LPI	• Sites characterized by low concentrations of commercially important species and/or those forms that are important components of the food web • Sites where the thermal discharge will affect a relatively small proportion of the receiving water body
Areas Not Considered LPI	• Most estuarine areas, except areas at the lowest level of abundance where a logarithmic gradient of zooplankton and meroplankton abundance exists
Successful 316(a) Demonstration Judgment for non-LPI Areas	• Changes in the zooplankton and meroplankton community in the primary study area that may be caused by the heated discharge will not result in appreciable harm to the balanced, indigenous fish and shellfish population • The heated discharge is not likely to alter the standing crop, or relative abundance, with respect to natural population fluctuations in the farfield study area from those values typical of the receiving water body segment

E Table VI-3. 316(a) Decision Criteria Based on the Draft Interagency 316(a) Technical Guidance Manual, 1977

	prior to plant operation • The thermal plume does not constitute a lethal barrier to the free movement (drift) of zooplankton and meroplankton
Shellfish/Macroinvertebrates	
Areas of LPI	• Shellfish/macroinvertebrate species of existing or potential commercial value do not occur at the site; this requirement can be met if the applicant can show that the occurrence of such species is marginal • Shellfish/macroinvertebrates do not serve as important components of the aquatic community at the site • Threatened or endangered species of the shellfish/macroinvertebrates do not occur at the site • The site does not serve as a spawning or nursery area for the species described above • The standing crop of shellfish/macroinvertebrates at the time of maximum abundance is less than 1 gram ash-free dry weight per square meter
Areas Not Considered LPI	• Areas that do not meet the above conditions
Successful 316(a) Demonstration Judgment for non-LPI Areas	• No appreciable harm will occur to the balanced, indigenous population as a result of macroinvertebrate community changes caused by the heated discharge
Fish	
Areas of LPI	• The occurrence of sport and commercial species of fish is marginal • The discharge site is not a spawning or nursery area • The thermal plume (bounded by the 2 C isotherm) will not occupy a large portion of the zone of passage which would block or hinder fish migration under the most conservative environmental conditions • The plume configuration will not cause fish to become vulnerable to cold shock or have an adverse impact on threatened or endangered species
Areas Not Considered LPI	• Areas that do not meet the above conditions
Successful 316(a) Demonstration Judgment for non-LPI Areas	Fish communities will not suffer appreciable harm from: • Direct or indirect mortality from cold shocks • Direct or indirect mortality from excess heat • Reduced reproductive success or growth due to plant discharges • Exclusion from unacceptably large areas • Blockage of migration
Other Vertebrate Wildlife	
Areas of LPI	• Most sites in the United States, simply because the projected thermal plume will not impact large or unique populations of wildlife
Areas Not Considered LPI	• Cold areas (such as North Central United States) which would be predicted to attract geese, and ducks and encourage them to stay through the winter unless it could be demonstrate that the wildlife would be protected through a wildlife management plan or other methods from potential sources of harm • Sites where the discharge might affect important (or threatened and endangered) wildlife
Successful 316(a) Demonstration Judgment for non-LPI Areas	• Demonstrate that other wildlife community components will not suffer appreciable harm or will actually benefit from the heated discharge

[a] The Guidance Manual defines nuisance species as: any microbial, plant, or animal species which indicates a hazard to ecological balance or human health and welfare that is not naturally a dominant feature of the indigenous community. Nuisance species of phytoplankton include those algal taxa which in high concentration are known to produce toxic, foul tasting, or odoriferous compounds to a degree that the quality of water is impaired.

E Table VI-4. RIS Selection in the Context of Section 316(a) Guidance and Potential Vulnerability Evaluation Results

USEPA SELECTION CRITERION: SPECIES ADDRESSED	DETAILED RIS EVALUATION	VULNERABILITY EVALUATION	ADDITIONAL EXPLANATION
Commercial & Recreational:			Species selected to address the non-LPI biotic categories: macroinvertebrates and fish.
Alewife	√		
American shad	√		
Atlantic croaker	√		
Blue crab	√		
Blueback herring	√		
Spot	√		
Striped bass	√		
Weakfish	√		
White Perch	√		
Threatened or Endangered:			
Kemp's Ridley turtle (E)		√	LPI finding (Other Vertebrate Wildlife) - evaluated species vulnerability as part of biotic category vulnerability assessment.
Shortnose sturgeon (E)		√	Low species vulnerability - evaluated species vulnerability as part of biotic category vulnerability assessment.
Atlantic loggerhead turtle (T)		√	LPI finding (Other Vertebrate Wildlife) - evaluated species vulnerability as part of biotic category vulnerability assessment.
Green sea turtle (T)		√	LPI finding (Other Vertebrate Wildlife) - evaluated species vulnerability as part of biotic category vulnerability assessment.
Habitat Forming: No Species Selected		√	LPI finding (Habitat Formers) - evaluated aquatic vascular plants in biotic category vulnerability assessment.
Nuisance Species: No Species Selected			Evaluate as appreciable harm decision factor, not as RIS. Evaluated nuisance potential in biotic category vulnerability assessment.
Important Food Web Linkage:			Species selected to address the non-LPI biotic categories: macroinvertebrates and fish.
Alewife	√		
Atlantic croaker	√		
Bay anchovy	√		
Blue crab	√		
Blueback herring	√		
Opossum shrimp	√		
Scud	√		
Spot	√		

E Table VI-4. RIS Selection in the Context of Section 316(a) Guidance and Potential Vulnerability Evaluation Results

USEPA SELECTION CRITERION: SPECIES ADDRESSED	DETAILED RIS EVALUATION	VULNERABILITY EVALUATION	ADDITIONAL EXPLANATION
Other Consideration:			
Thermal sensitivity	√		Eurythermal species selected are characteristic of temperate estuary salinity transition zone.
Involvement with Salem	√		The 12 selected RIS are among the most abundant species entrained and impinged at Salem and/or reside or migrate through the area occupied by the thermal plume.
Guideline of 5-15 species	√	√	12 RIS selected

E Table VI-5. Summary of Swim Speed Literature for Fish Representative Important Species

Species	Fish Length (mm)	Test Type	Average Swim Speed (ft/sec)	Swim Speed Range	Test Temp (F)	Salinity (ppt)	Reference
White perch	105–124	Critical SS (10 minute)	0.94	0.83–1.05	36	3	King (1 Feb 1971)
	171–205	Critical SS (10 minute)	0.83	0.59–1.05	36	3	King (25 Feb 1971)
	126–159	Critical SS (10 minute)	0.80	0.59–0.85	36	6	King (25 Feb 1971)
	77–95	Critical SS (10 minute)	0.85	0.59–1.07	41	3	King (Dec 1970)
	170–208	Critical SS (10 minute)	1.02	.081–1.29	41	3	King (25 Feb 1971)
	70	Critical SS (10 minute)	0.80	—	41	27	Terpin *et al.* (1977)
	105–158	Critical SS (10 minute)	1.29	1.16–1.40	41	27	Terpin *et al.* (1977)
	138–193	Critical SS (10 minute)	1.18	1.06–1.30	43	3	King (1 Feb 1971)
	104–191	Critical SS (10 minute)	1.07	0.81–1.31	43–45	0	King (Apr 1971)
	72–93	Critical SS (10 minute)	0.97	0.81–1.09	45	3	King (Apr 1971)
	140–188	Critical SS (10 minute)	1.01	0.82.1.29	45	6	King (Apr 1971)
	93–132	Critical SS (10 minute)	1.25	1.07–1.31	45	6	King (Apr 1971)
	83–104	Critical SS (10 minute)	1.10	0.82–1.31	45	0	King (Apr 1971)
	145–176	Critical SS (10 minute)	1.34	1.09–1.55	45	0	King (Apr 1971)
	73–80	Critical SS (10 minute)	1.20	1.08–1.33	50	26.5	Terpin *et al.* (1977)
	158–182	Critical SS (10 minute)	1.55	1.50–1.60	50	26.5	Terpin *et al.* (1977)
	80–105	Critical SS (10 minute)	1.25	1.06–1.55	54	3.5	King (Dec 1970)
	147–164	Critical SS (10 minute)	1.37	1.05–1.79	54	0	King (Apr 1971)
	139–154	Critical SS (10 minute)	1.65	1.31–1.80	54	6	King (Apr 1971)
	109–158	Critical SS (10 minute)	1.51	1.06–1.80	54–61	3.5–7.0	King (Nov 1970)
	143–162	Critical SS (10 minute)	1.96	—	57	6	King (18 Jun 1971)
	122–147	Critical SS (10 minute)	1.62	—	61	0	King (18 Jun 1971)
	131–154	Critical SS (10 minute)	1.94	—	66–68	3–6	King (18 Jun 1971)
	130–150	Critical SS (10 minute)	1.99	—	70	0	King (18 Jun 1971)
	139–144	Critical SS (10 minute)	2.36	2.02–2.54	75	0	King (Aug 1971)
	139–198	Critical SS (10 minute)	2.02	1.01–3.26	72–81	0	Meldrim *et al.* (1974)
	141–221	Critical SS (10 minute)	1.46	1.25–2.01	52–59	0	Meldrim *et al.* (1974)
	137–158	Critical SS (10 minute)	0.85	0.76–1.01	41	0	Meldrim *et al.* (1974)
	144–156	Critical SS (10 minute)	1.07	1.00–1.25	41	6	Meldrim *et al.* (1974)
	151	Critical SS (10 minute)	1.53	—	59	6	Meldrim *et al.* (1974)
	128–197	Critical SS (10 minute)	2.45	1.71–3.52	72–81	6	Meldrim *et al.* (1974)
	134–162	Critical SS (10 minute)	1.06	0.76–1.75	41–45	12	Meldrim *et al.* (1974)

E Table VI-5. Summary of Swim Speed Literature for Fish Representative Important Species

Species	Fish Length (mm)	Test Type	Average Swim Speed (ft/sec)	Swim Speed Range	Test Temp (F)	Salinity (ppt)	Reference
White perch	137–160	Critical SS (10 minute)	2.51	1.26–3.76	72–81	12	Meldrim *et al.* (1974)
	31–45	Maximum SS (3 minute)	0.64	0.30–1.00	75	4	Tatham (1970)
	31–40	Maximum SS (3 minute)	0.67	0.50–0.80	80	4	Tatham (1970)
	39–49	Maximum SS (3 minute)	0.87	0.70–1.00	80	4	Tatham (1970)
	49–62	Maximum SS (3 minute)	1.05	0.90–1.20	80	4	Tatham (1970)
	60–72	Maximum SS (3 minute)	0.95	0.70–1.30	80	4	Tatham (1970)
	34–35	Maximum SS (3 minute)	0.60	0.60	85	4	Tatham (1970)
	41–50	Maximum SS (3 minute)	0.89	0.60–1.30	85	4	Tatham (1970)
	51–59	Maximum SS (3 minute)	1.06	1.00–1.20	85	4	Tatham (1970)
	60–73	Maximum SS (3 minute)	1.17	0.90–1.40	85	4	Tatham (1970)
	68–84	Maximum SS (3 minute)	1.24	0.90–1.40	85	4	Tatham (1970)
	39–51	Maximum SS (3 minute)	0.87	0.70–1.00	90	4	Tatham (1970)
	50–61	Maximum SS (3 minute)	1.17	0.90–1.30	90	4	Tatham (1970)
	60–70	Maximum SS (3 minute)	1.10	0.90–1.30	90	4	Tatham (1970)
	73–80	Maximum SS (3 minute)	1.28	1.20–1.40	90	4	Tatham (1970)
	68–88	Maximum SS (3 minute)	0.72	0.51–0.96	50–59	7.5	Leon (1971)
	80–86	Maximum SS (3 minute)	0.65	0.52–0.81	42	4	Leon (1971)
	54–66	Maximum SS (3 minute)	0.69	0.64–0.74	50	3.7	Leon (1971)
	82–103	Maximum SS (3 minute)	1.09	—	61	3	Leon (1971)
Striped Bass	30–41	Maximum SS (3 minute)	0.80	0.60–0.90	75	3	Tatham (1970)
	43–50	Maximum SS (3 minute)	1.00	0.90–1.10	75	3	Tatham (1970)
	32–42	Maximum SS (3 minute)	0.70	0.60–0.90	80	3	Tatham (1970)
	40–51	Maximum SS (3 minute)	1.00	0.80–1.30	80	3	Tatham (1970)
	50–63	Maximum SS (3 minute)	1.20	1.10–1.20	80	3	Tatham (1970)
	88–137	Sustained SS (10 minutes)	1.60	0.90–2.00	63	—	Bibko *et al.* (1974)
	150–212	Sustained SS (10 minutes)	2.10	1.70–2.50	63	—	Bibko *et al.* (1974)
	juveniles	Cruising speed (7 hours)	0.98	—	40	—	Bibko *et al.* (1974)
	juveniles	Cruising speed (7 hours)	1.21	—	52	—	Bibko *et al.* (1974)
	115–120	Critical SS (10 minutes)	2.85	2.58–3.13	50	26	Terpin *et al.* (1977)
Bay anchovy	55–70	Maximum SS (3 minute)	0.50	2.58–3.13	73	8	Tatham (1970)
	21–40	Maximum SS (3 minute)	0.56	0.30–0.70	77–82	6–7	King (Aug 1971)
	30–34	Maximum SS (3 minute)	0.36	0.30–0.93	73–77	0	King (Aug 1971)

E Table VI-5. Summary of Swim Speed Literature for Fish Representative Important Species

Species	Fish Length (mm)	Test Type	Average Swim Speed (ft/sec)	Swim Speed Range	Test Temp (F)	Salinity (ppt)	Reference
Bay anchovy	81–89	Critical SS (10 minute)	0.67	0.60–0.78	50	25	Wyllie *et al.* (1976)
	83–95	Critical SS (10 minute)	1.02	0.85–1.24	59	27	Wyllie *et al.* (1976)
	75–87	Critical SS (10 minute)	0.49	0.40–0.65	41	25	Terpin *et al.* (1977)
	68–72	Critical SS (10 minute)	0.64	0.54–0.80	50	27	Terpin *et al.* (1977)
	66–80	Critical SS (10 minute)	0.99	0.80–1.16	59	29	Terpin *et al.* (1977)
	53–77	Critical SS (10 minute)	1.19	1.10–1.38	70	29	Terpin *et al.* (1977)
	77	Critical SS (10 minute)	—	—	77	26.5	Terpin *et al.* (1977)
Alewife	121–145	Critical SS (10 minute)	1.17	1.05–1.29	84	0	King (Aug 1971)
	128–141	Critical SS (10 minute)	2.08	1.67–2.77	68	27	Wyllie *et al.* (1976)
	90–92	Critical SS (10 minute)	1.27	1.20–1.34	75	28	Wyllie *et al.* (1976)
	98–110	Critical SS (10 minute)	1.32	0.86–1.78	77	28	Wyllie *et al.* (1976)
	111	Critical SS (10 minute)	2.18	—	59	29	Terpin *et al.* (1977)
Blueback herring	110	Critical SS (10 minute)	0.53	—	50	27	Wyllie *et al.* (1976)
	92	Critical SS (10 minute)	0.88	—	70	27	Wyllie *et al.* (1976)
	83–87	Critical SS (10 minute)	0.74	0.60–0.86	50	27	Terpin *et al.* (1977)
	84–94	Critical SS (10 minute)	1.14	1.00–1.30	59	29	Terpin *et al.* (1977)
American shad	Adult	Sustained cruising speed (> 5 hours)	1.30	—	—	0–27	Dodson *et al.* (1972)
	—	Sustained cruising speed	1.30–2.10	—	—	—	Leggett & Jones (1973)[a]
	Adult	Sustained cruising speed	2.50	—	—	28	Dodson *et al.* (1970)[b]
	Adult	Sustained cruising speed	2.50	—	—	28	Leggett (1968)
	Adult	Sustained cruising speed (30 minutes)	1.60	1.00–4.60	50–73	—	Leggett (1968)
	Adult	Maximum SS (10 minutes)	6.00	—	—	—	Terpin *et al.* (1977)
Weakfish	160–165	Critical SS (10 minute)	1.66	1.16–2.00	50	26	Terpin *et al.* (1977)
	115–117	Critical SS (10 minute)	1.40	1.21–1.60	59	27	Terpin *et al.* (1977)
	133	Critical SS (10 minute)	2.30	—	64	27	Terpin *et al.* (1977)
	100–120	Critical SS (10 minute)	1.79	1.70–1.84	70–72	29	Terpin *et al.* (1977)
	130–145	Critical SS (10 minute)	1.97	1.78–2.49	72–77	28	Wyllie *et al.* (1976)
Spot	91–118	Critical SS (10 minute)	2.22	1.78–2.49	75	29	Wyllie *et al.* (1976)

[a] As cited by Beamish (1978).
[b] As cited by Dodson *et al.* (1972).

E Table VI-5. Summary of Swim Speed Literature for Fish Representative Important Species

Species	Fish Length (mm)	Test Type	Average Swim Speed (ft/sec)	Swim Speed Range	Test Temp (F)	Salinity (ppt)	Reference
Spot	61	Critical SS (10 minute)	1.60	1.60	59	28	Terpin *et al.* (1977)
	43	Maximum SS (6 minutes)	0.80	—	77	30	Hettler (1977)[c]
Atlantic croaker	73	Maximum SS (6 minutes)	1.20	—	86	29	Hettler (1977)[c]

Note: A dash (—) indicates information was not reported.

[c] As cited by PSE&G (1984).

E Table VI-6. Results of the Cumulative Exposure Analysis of Potential Mortality During Centerline Plume Entrainment

			Ratio of Cumulative Time-temperature Exposure to Lethal Exposure Threshold (= 1.0) [c]			
	Resistance Time Coefficients[a]		"Average" Year		"Warm" Year	
Species/Life-stage	a	b	Ambient[b] Temperature (F)	Maximum Centerline Exposure	Ambient[b] Temperature (F)	Maximum Centerline Exposure
Macroinvertebrates						
Scud	22.4	-0.22	78	0.01071	81.5	0.09745
Anadromous herring						
Alewife larvae	15.8	-0.16	65	0.00006	69	0.00081
Temperate bass						
White perch larvae	15.1	-0.15	65	0.00006	70	0.00093
White perch juveniles	54.1	-0.56	76	0.01483	79	0.71424
Striped bass larvae	24.8	-0.25	72	0.00040	75	0.00533
Striped bass juveniles	26.6	-0.27	77	0.01012	80	0.14083
Oceanic-estuarine residents						
Weakfish larvae	30.2	-0.32	78	0.53824	81.5	NA [d]
Bay anchovy juveniles	25.2	-0.26	78	0.12805	81.5	1.16037

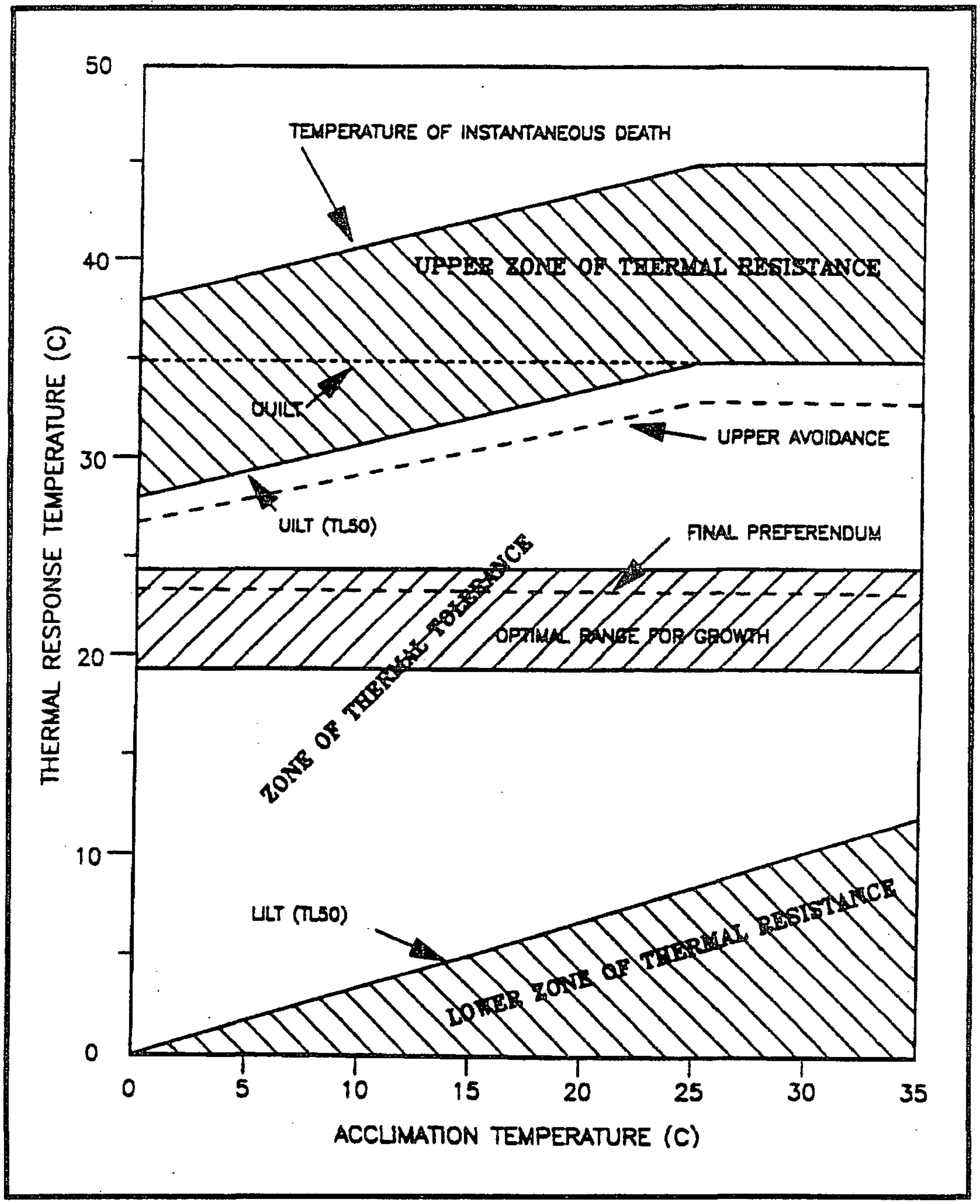
[a] For the resistance time equation log(time) = a + b(temp), where time is in minutes and temperature is in degrees F.
[b] Approximate maximum mean weekly temperature during the primary season of occurrence of each RIS in the vicinity of Salem.
[c] Sum of the ratios of exposure time to resistance time calculated for exposure intervals to 0.003 to 0.176 minutes duration.
[d] Calculation not appropriate: available tolerance data for estimating resistance times are for acclimation temperature 9° F lower than the "warm" year temperature, and would grossly overestimate the potential for mortality.

E Table VI-7. Predicted avoidance delta-Ts (95% confidence level) for the migratory RIS and percent of Estuary cross section potentially blocked[a] by Salem's thermal discharge (ebb tide condition)

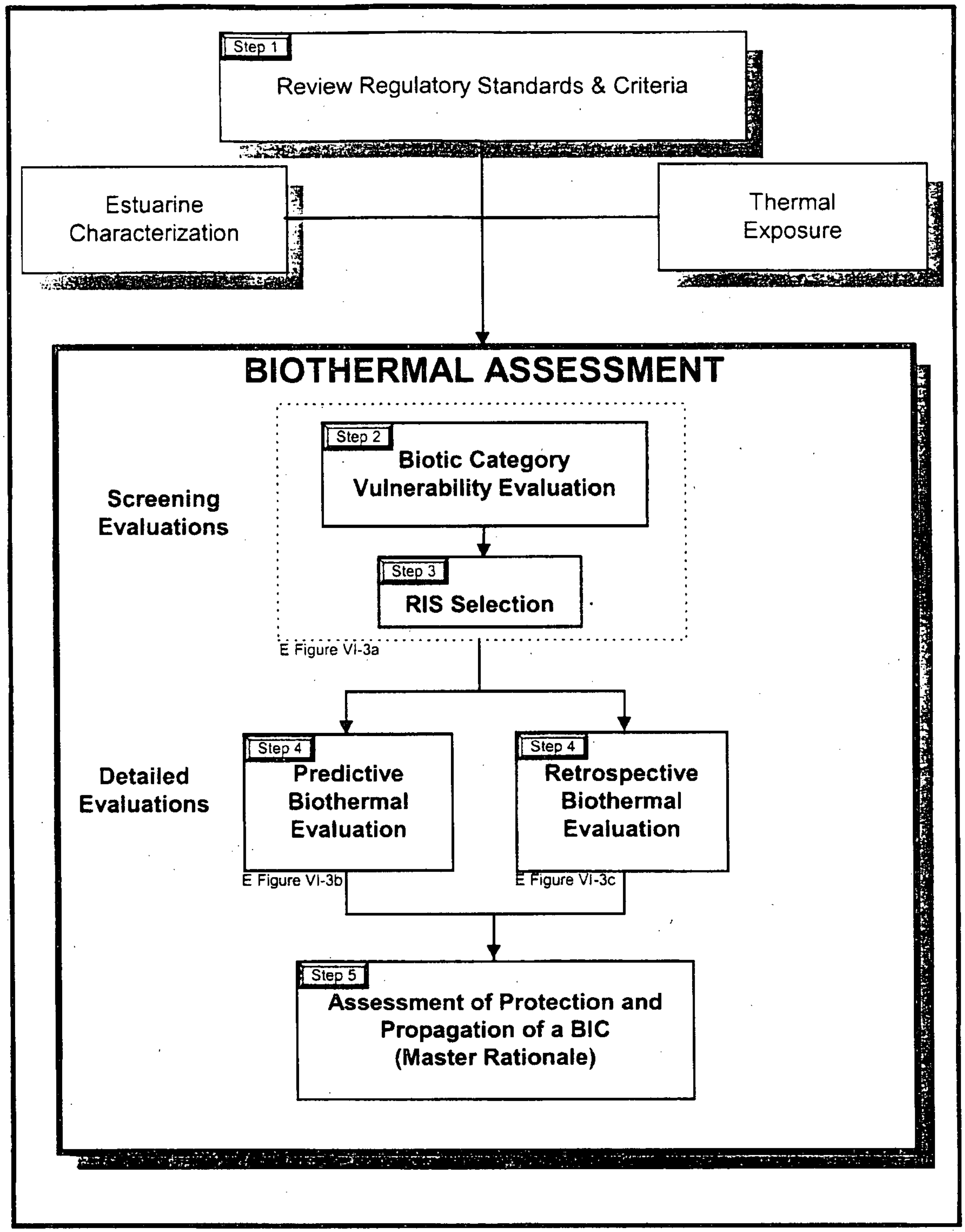
Species		Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Blueback herring YOY	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Blueback herring 1+ & Older	Avoidance Temperature	—	—	—	—	6.9	6.8	6.7	6.8	6.9	7.0	7.2	7.3	7.5	7.7	7.8	8.1	—	—	—	—	—	—	—	—	—	—
	Percent Cross-section	—	—	—	—	2.2	2.2	2.2	2.2	2.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	—	—	—	—	—	—	—	—	—	—
American shad YOY	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
American shad 1+ & Older	Avoidance Temperature	—	—	—	—	21.0	21.4	22.1	21.7	21.2	20.2	19.1	18.5	17.3	15.7	14.9	13.3	11.1	9.2	—	—	—	—	—	—	—	—
	Percent Cross-section	—	—	—	—	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	—	—	—	—	—	—	—	—
White perch YOY	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
White perch 1+ & Older	Avoidance Temperature	19.8	20.7	21.5	21.5	21.7	22.1	22.7	22.4	22.0	21.1	20.3	19.8	18.8	17.5	16.9	15.6	13.9	12.4	12.0	—	—	—	—	—	—	—
	Percent Cross-section	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	—	—	—	—	—	—	—
Striped bass YOY	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Striped bass 1+ & Older	Avoidance Temperature	5.6	5.6	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.6	5.6	5.5	5.5	5.4	5.3	—	—	—	—	—	—	—	—	—	—
	Percent Cross-section	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	—	—	—	—	—	—	—	—	—	—

Species		Week 27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Blueback herring YOY	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10.6	11.6	12.7	13.9	14.8	16.1	—	—	—
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.1	1.1	1.1	1.1	1.1	1.1	—	—	—
Blueback herring 1+ & Older	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
American shad YOY	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5.0	6.3	7.8	9.1	10.6	12.1	13.3	15.1	—	—	—
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.6	2.2	1.1	1.1	1.1	1.1	1.1	1.1	—	—	—
American shad 1+ & Older	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
White perch YOY	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5.9	6.4	7.0	7.6	8.2	8.8	9.3	10.0	10.2	10.7	11.2
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.6	2.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
White perch 1+ & Older	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Striped bass YOY	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	7.9	8.6	9.2	10.8	12.0	13.5	14.8	16.3	17.8	19.1	20.9	21.3	22.5	23.7
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Striped bass 1+ & Older	Avoidance Temperature	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Percent Cross-section	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

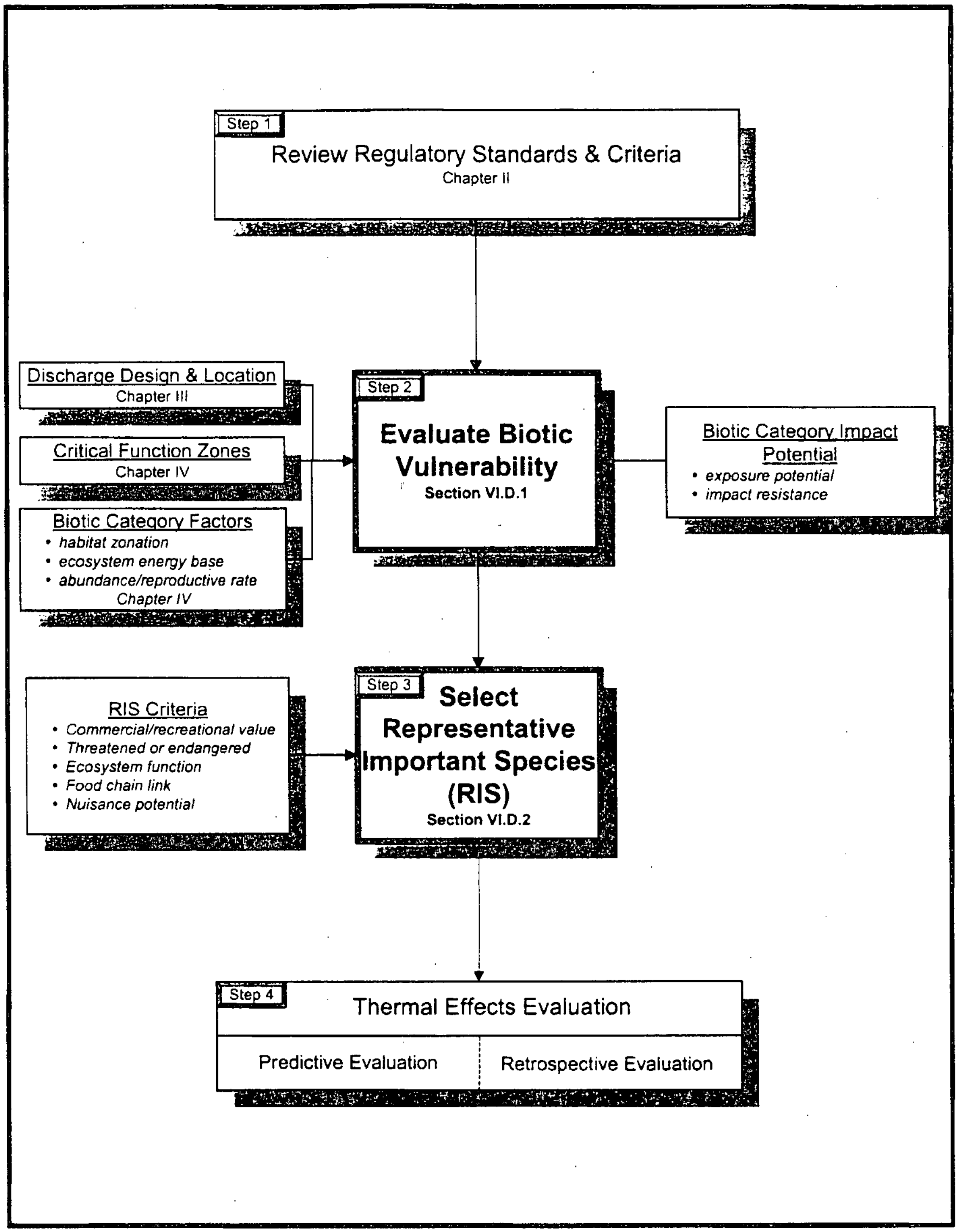
[a] The potential for blockage was identified by the cross-section occupied by discharge velocities within the ZIM exceeding 1.85 ft/sec, and the cross-section beyond the ZIM occupied by delta-Ts exceeding the estimated avoidance delta-T.



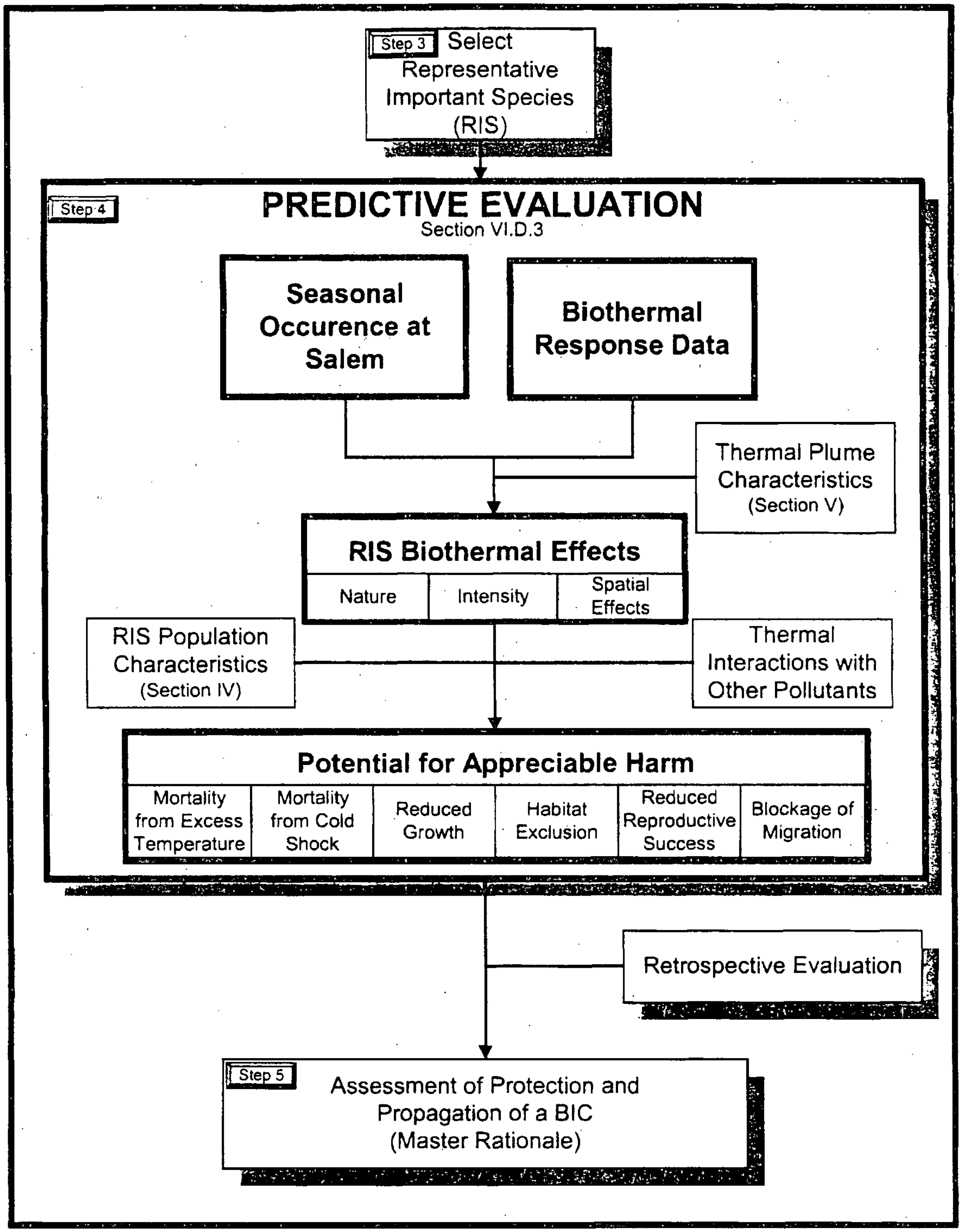
E Figure VI-1. Interrelationship of various thermal effect parameters and acclimation temperature.



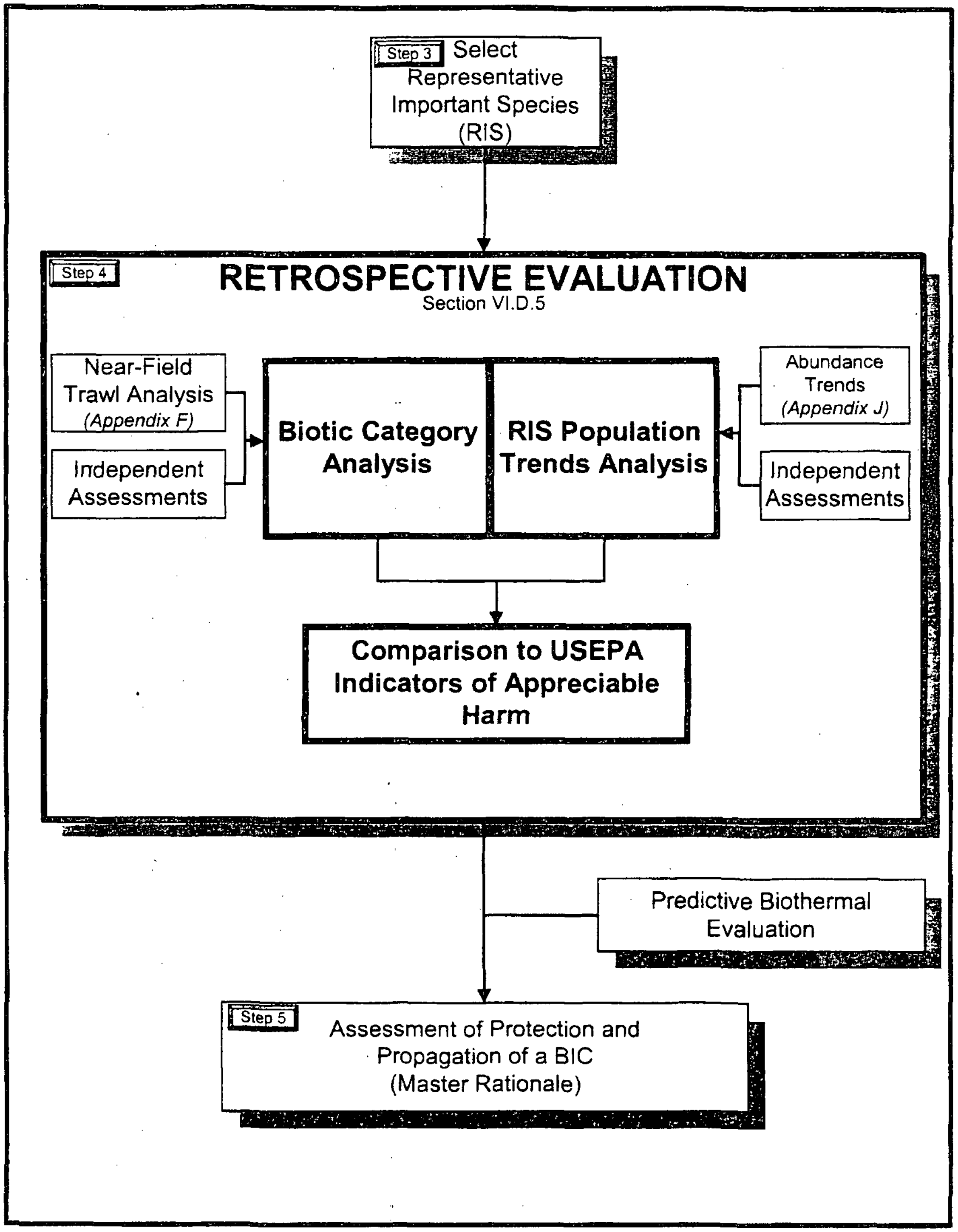
E Figure VI-2. Steps in the biothermal assessment for the Salem Section 316(a) Demonstration.



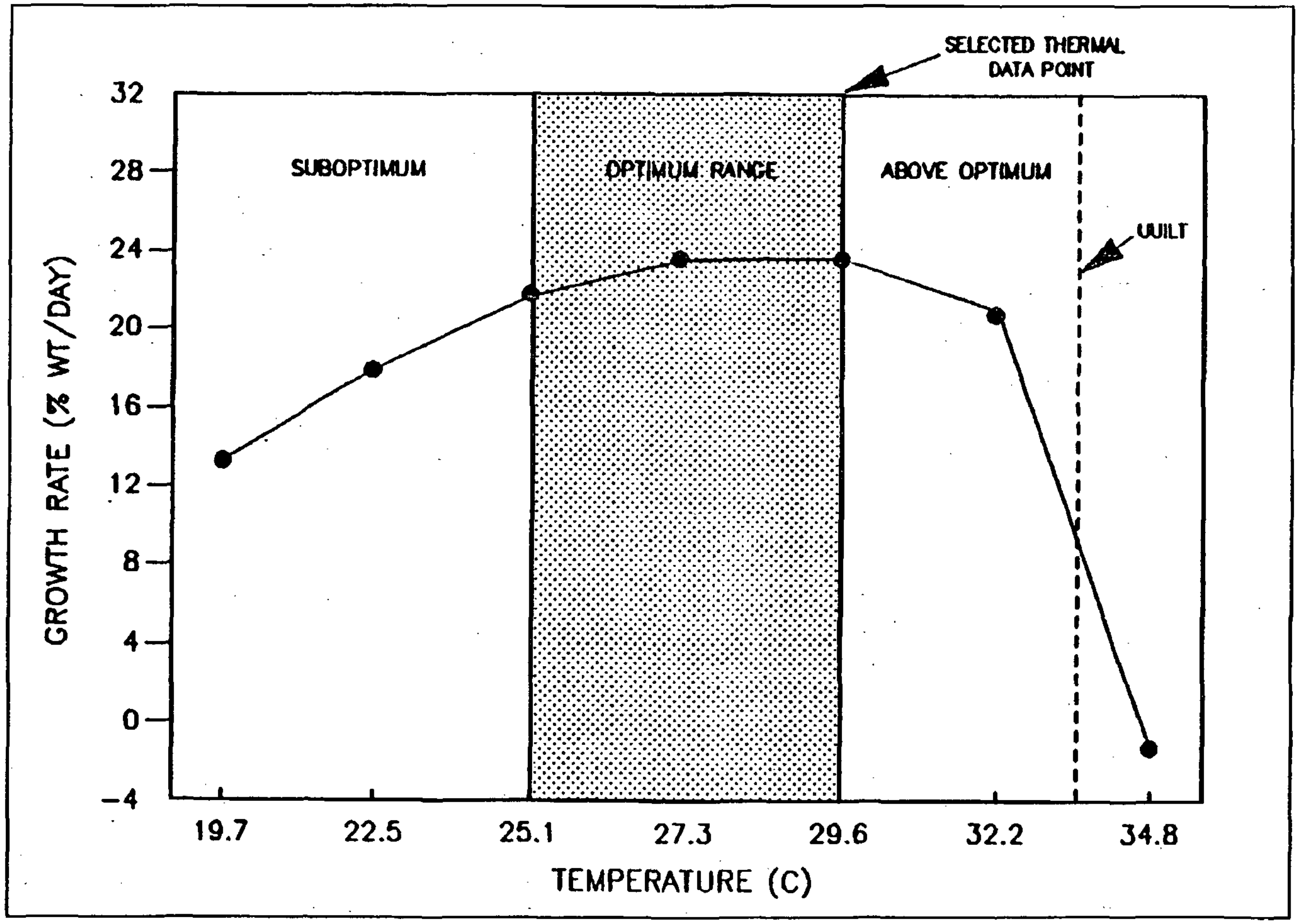
E Figure VI-3a. Biotic category evaluation and representative important species selection for the biothermal assessment for the Salem 316(a) Demonstration.



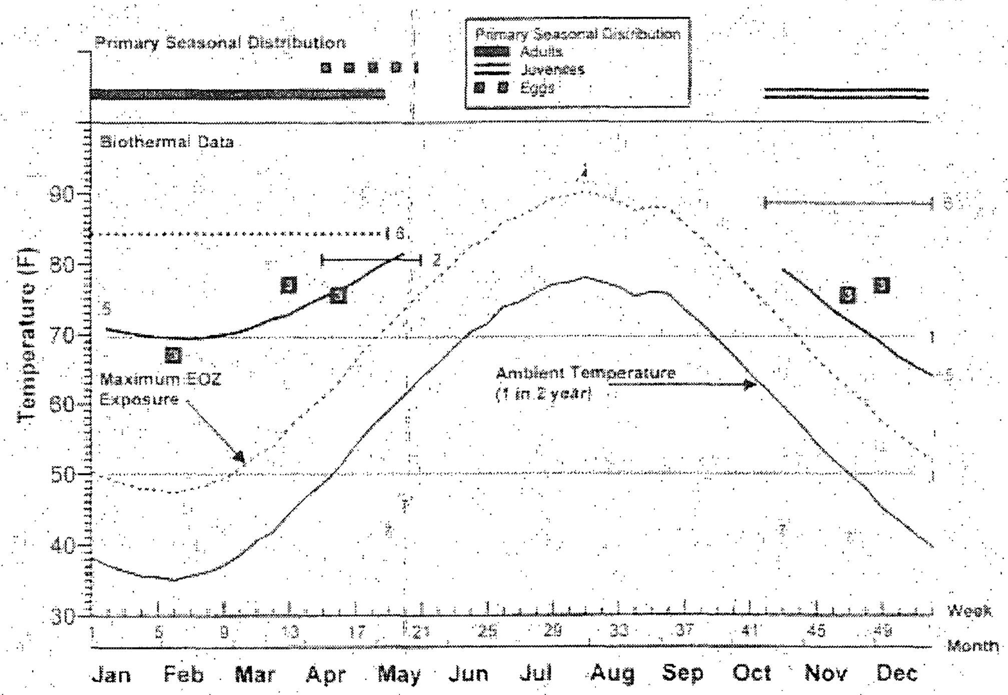
E Figure VI-3b. Predictive evaluation steps in the biothermal assessment for the Salem 316(a) Demonstration.



E Figure VI-3c. Retrospective evaluation steps in the biothermal assessment for the Salem 316(a) Demonstration.



E Figure VI-4. Example of relationship between water temperature, growth, the optimum range for growth, and thermal tolerance (UUILT) for striped bass (adapted from EA 1978a).



Hydrothermal Parameters

The temperature profile consists of curves for background temperature and maximum discharge temperature at the edge of the high velocity zone of initial mixing (ZIM). The background temperature curve was based on the mean weekly ambient temperatures at Salem recurring with a *1 in 2 year or 1 in 10 year frequency*. The delta-T occurring at the edge of the ZIM for reasonable worst case conditions was added to background temperature and plotted to identify the maximum temperature at the "Edge of the ZIM" (EOZ). Although organisms would be unlikely to reside at EOZ temperature for an extended time, this temperature provided a protectively conservative measure of exposure for screening purposes.

Biothermal Effect Parameters

Biothermal effects data were plotted above the appropriate acclimation temperature or for the period of time when the applicable life stage occurred or could be expected to occur in the vicinity of Salem. The line marked "1" represents the spawning temperature range for the species and identifies the normal temperature conditions for peak spawning. The line marked "2" represents the maximum temperature compatible with normal hatching success of eggs, and is plotted as a line spanning the seasonal occurrence of eggs at Salem. The points marked "3" represent upper tolerance limits estimated by 24-hr to 96-hr TL50s. They are plotted directly above the point on the ambient temperature profile equivalent to the acclimation temperature at which the TL50 was determined. When the acclimation temperature exceeds the high ambient temperature, the TL50 is plotted directly above the highest ambient temperature. The UUILT, designated with an upright Δ marked "4", does not change with acclimation temperature. The line marked "5" represent upper avoidance temperatures. In the example, the avoidance temperatures exceed maximum plume temperatures, indicting that the species in question would not actively avoid any portions of the plume. The line marked "6" represents the upper end of the optimum temperature range for growth and performance, which is independent of acclimation temperature and therefore plotted as a line spanning the period of occurrence of the applicable life stage. In the example, the plume temperatures are below the optimum growth temperatures during the period of occurrence. The points marked "7"indicate lower tolerance limits and are plotted against potential maximum acclimation temperatures at the EOZ for an organism residing in the plume. In the example, all lower tolerance limits lie below the background temperature; thus there is no potential for cold shock mortality to organisms acclimated to the thermal plume if they were returned rapidly to ambient conditions during a plant shutdown.

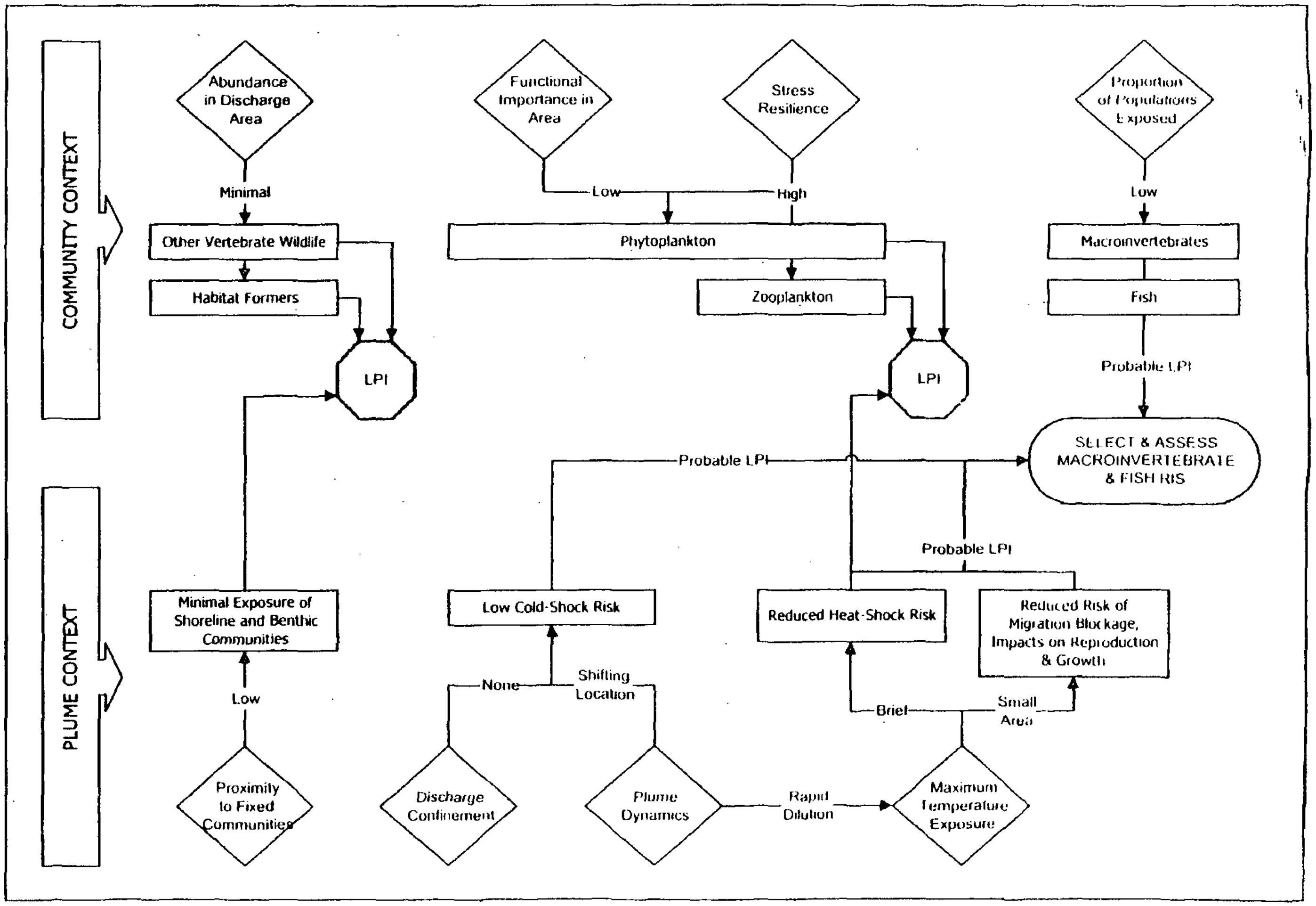
Primary Seasonal Distribution

Above each biothermal effect diagram, the period of occurrence for applicable life stages was plotted as a series of bars. The bars indicate the primary season of occurrence at Salem based on densities measured in impingement and entrainment sampling conducted from 1977 to 1998. The primary season of occurrence spans the period during which relative densities are greater than about 10% of peak density.

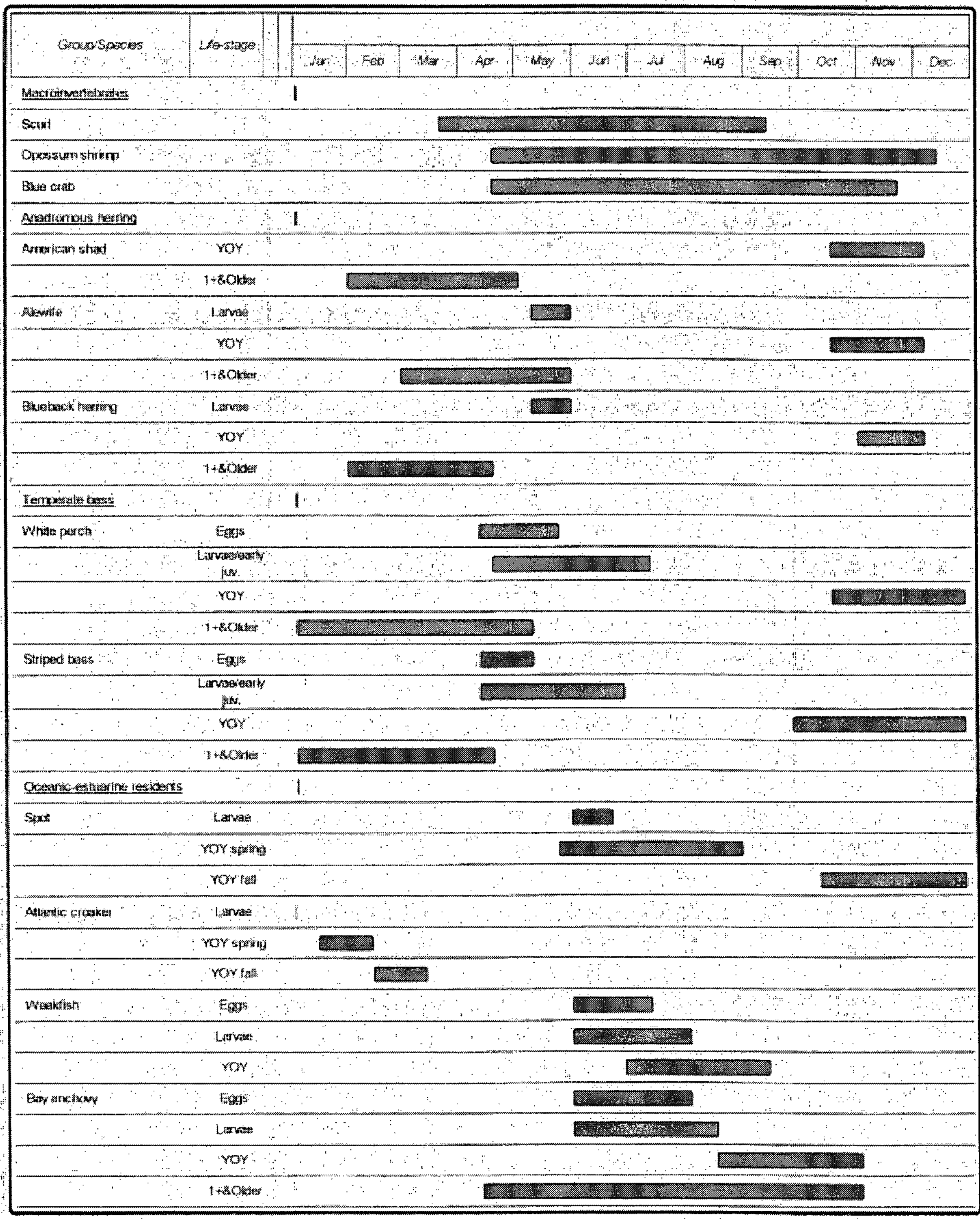
E Figure VI-5. Hypothetical example of the biothermal effect diagrams with explanation.

ERA-Derived Considerations for Characterizing Adverse Ecological Effects		316(a) Criteria: Lines of Evidence Threatening Protection and Propagation of a BIC		
		Step 2 Biotic Category Vulnerability	Step 4 Appreciable Harm to RIS	Step 5 Appreciable Harm to Community
Nature & Intensity	Acute biological/water quality effects occur Many species affected Large proportion of local residents affected Function/structure of community deteriorated	Plume configuration results in high potential for cold-shock.	Direct or indirect mortality from cold-shock. Direct or indirect mortality from excess heat. Net reduction in reproductive success. Net reduction in performance & growth.	Unaesthetic appearance, odor, or taste of the water. Destruction of rare & unique habitat. Excessive growth of "nuisance" species. Substantial increase in heat tolerant community not representative of water body.
Spatial & Biotic Scale	Habitat affected is unique or legally protected Large percent of populations affected Critical spawning or nursery habitat affected Large percent of water body affected Migration or dispersal of species blocked	Plume dimensions large portion of waterbody. Biotic category occurrence/exposure to plume is high.	Exclusion from unacceptably large areas. Blockage of migration.	Zones of passage for normal movements impaired.
Resistance & Recovery	Stressor is persistent Continued recruitment is low Dispersal mechanisms limited Effects not comparable to natural disturbance Compensatory capacity limited		Substantial decrease of formerly indigenous species. Reduction of successful completion of species life-cycles.	Adverse impact on threatened & endangered species. Elimination of established economic or recreational use. Substantial reduction of community heterogeneity or trophic structure.

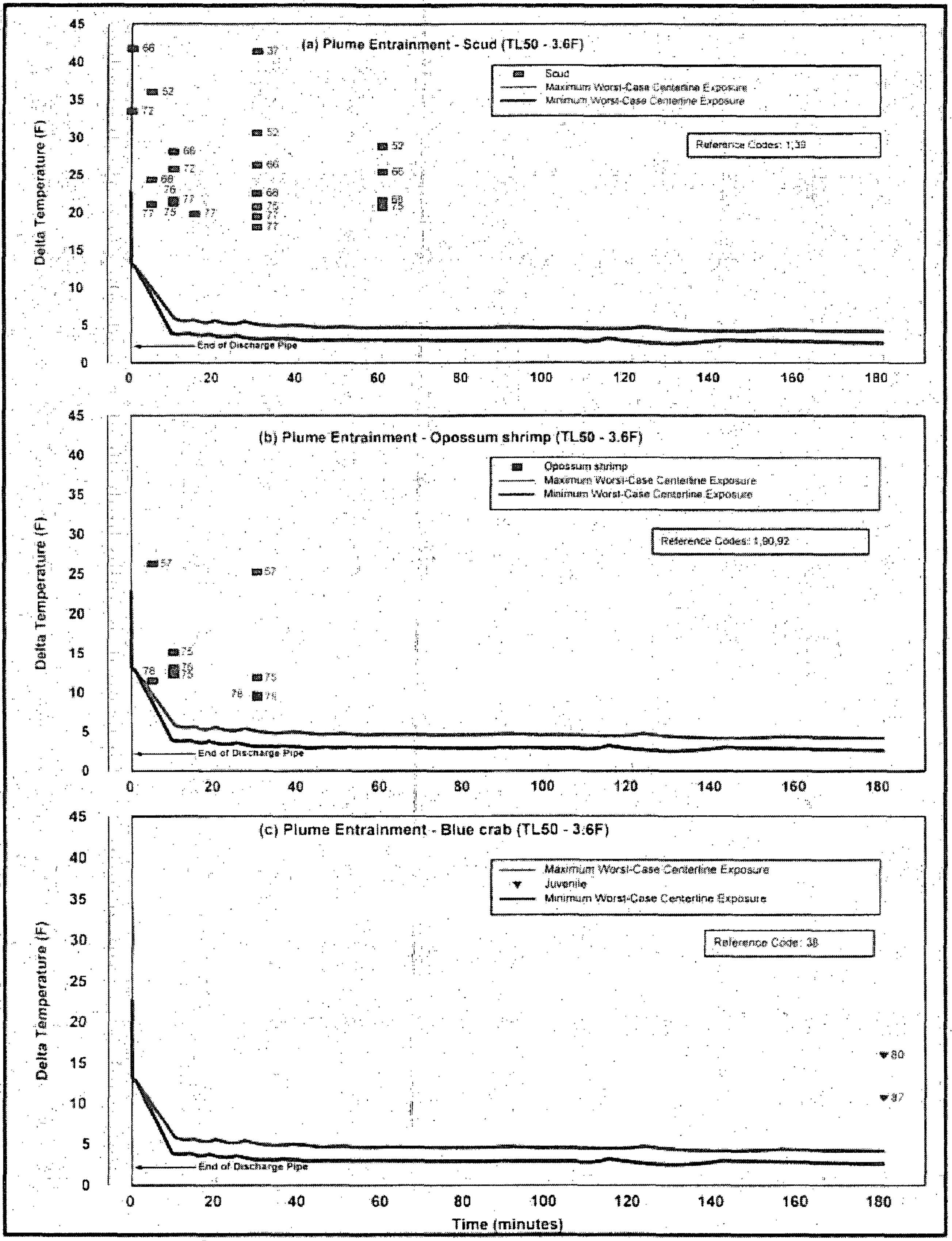
E Figure VI-6. Decision criteria for the Salem Biothermal Assessment drawn from 316(a) and ERA guidance.



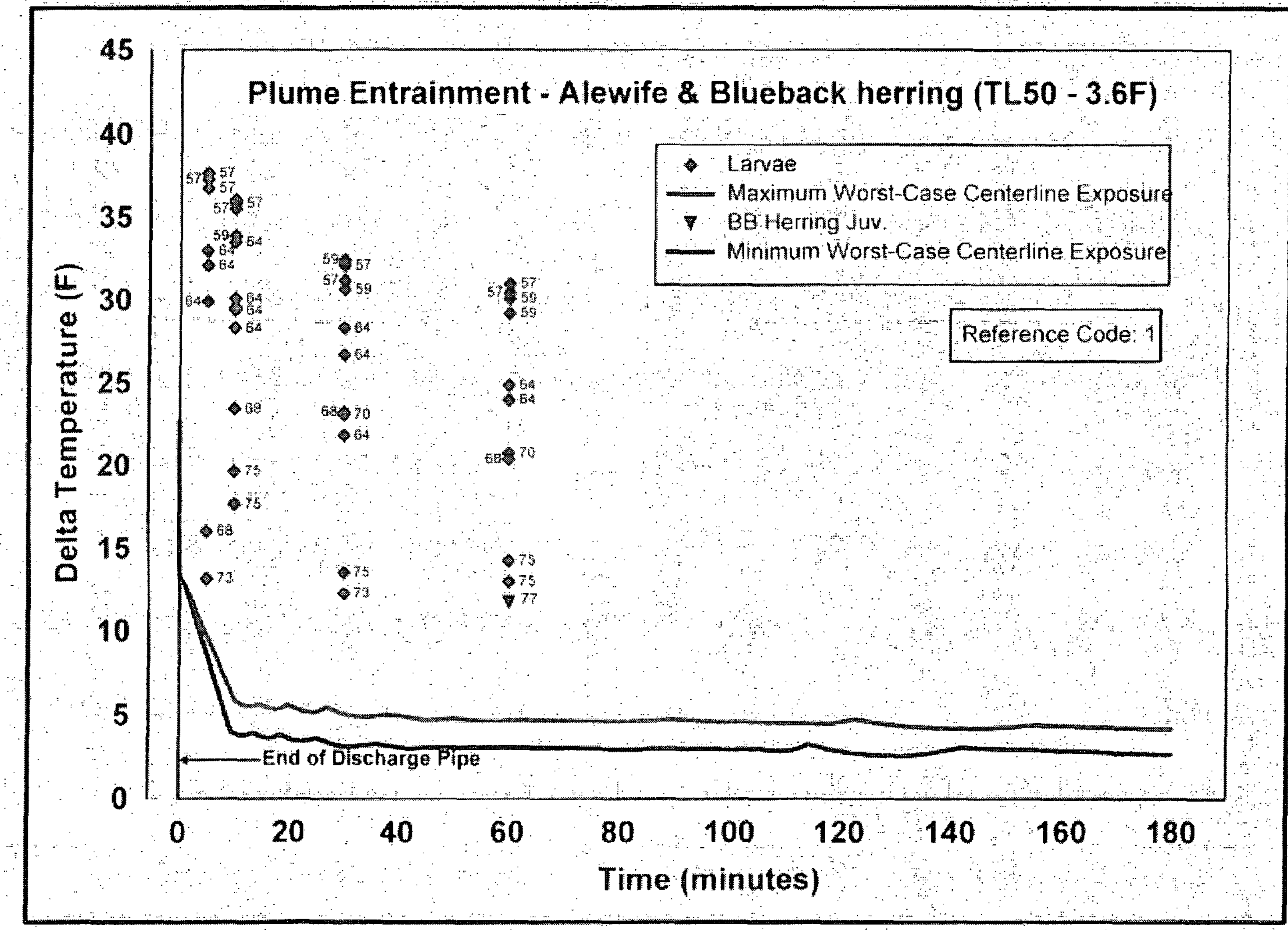
E Figure VI-7. Summary of the screening process and conclusions of the BIC vulnerability assessment.



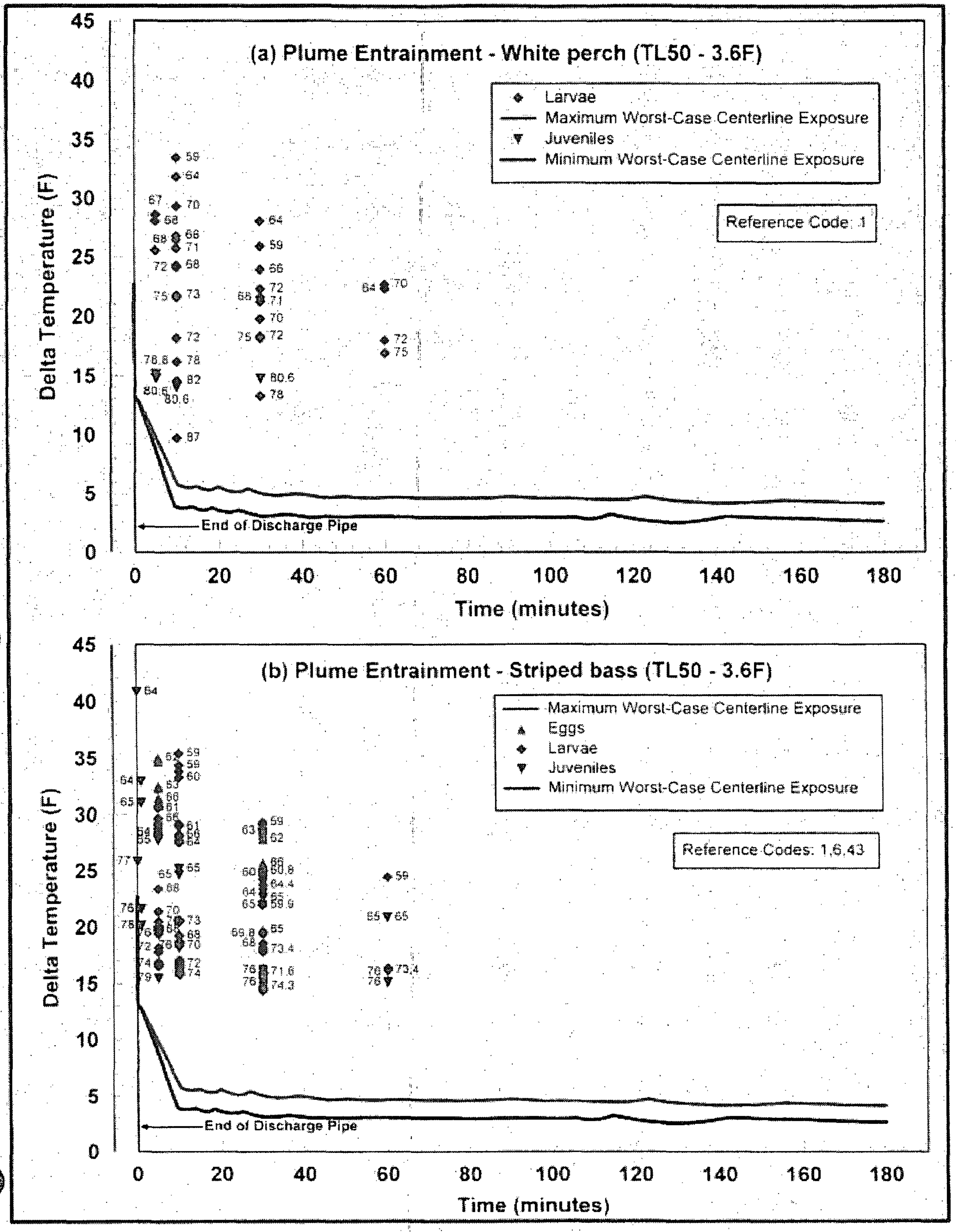
E Figure VI-8. Seasonal distribution of macroinvertebrate and fish RIS in the vicinity of Salem



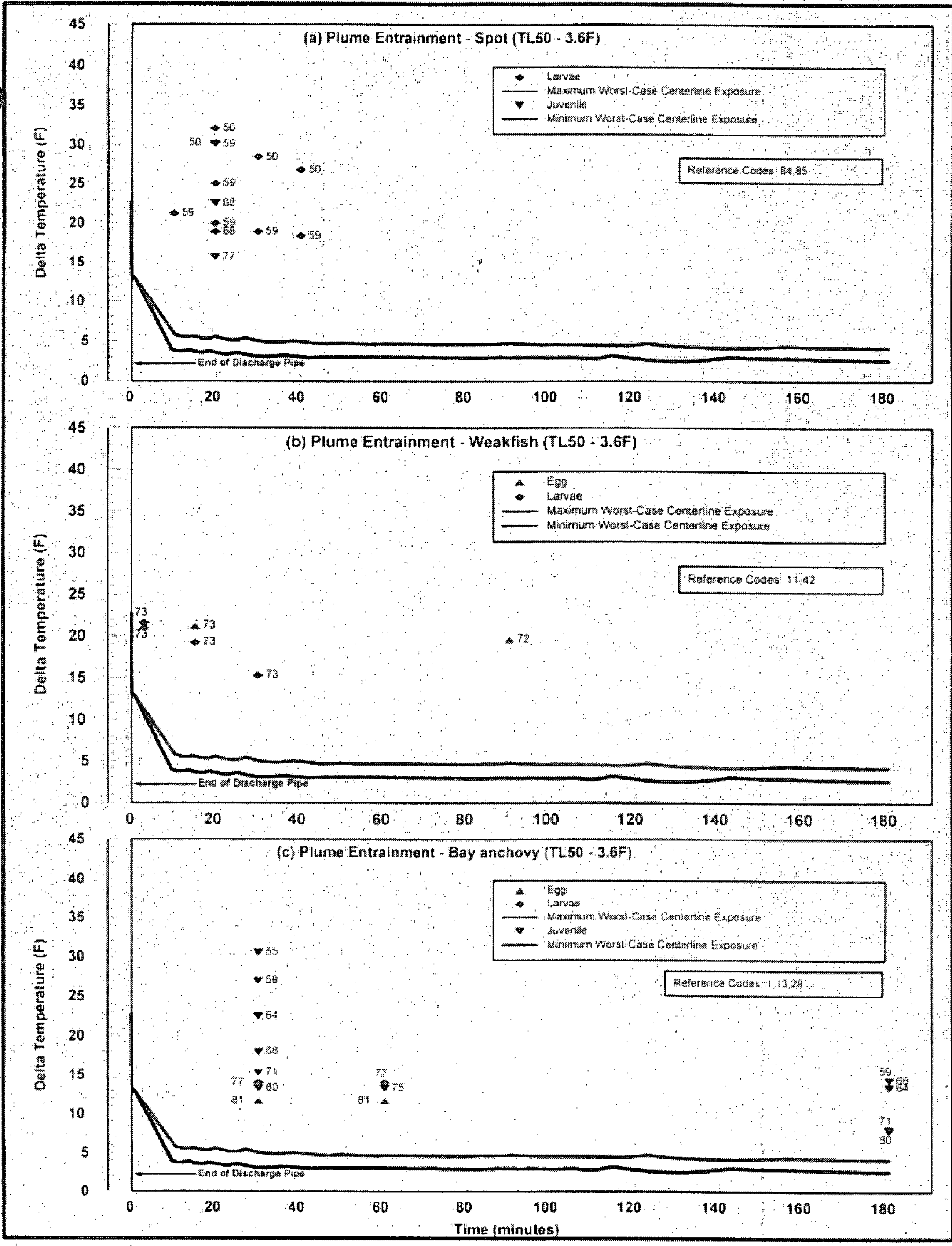
E Figure VI-9. Short-term thermal tolerance of macroinvertebrates relative to temperature decrease with time along the centerline of Salem's thermal plume. (Data labels indicate test acclimation temperature.)



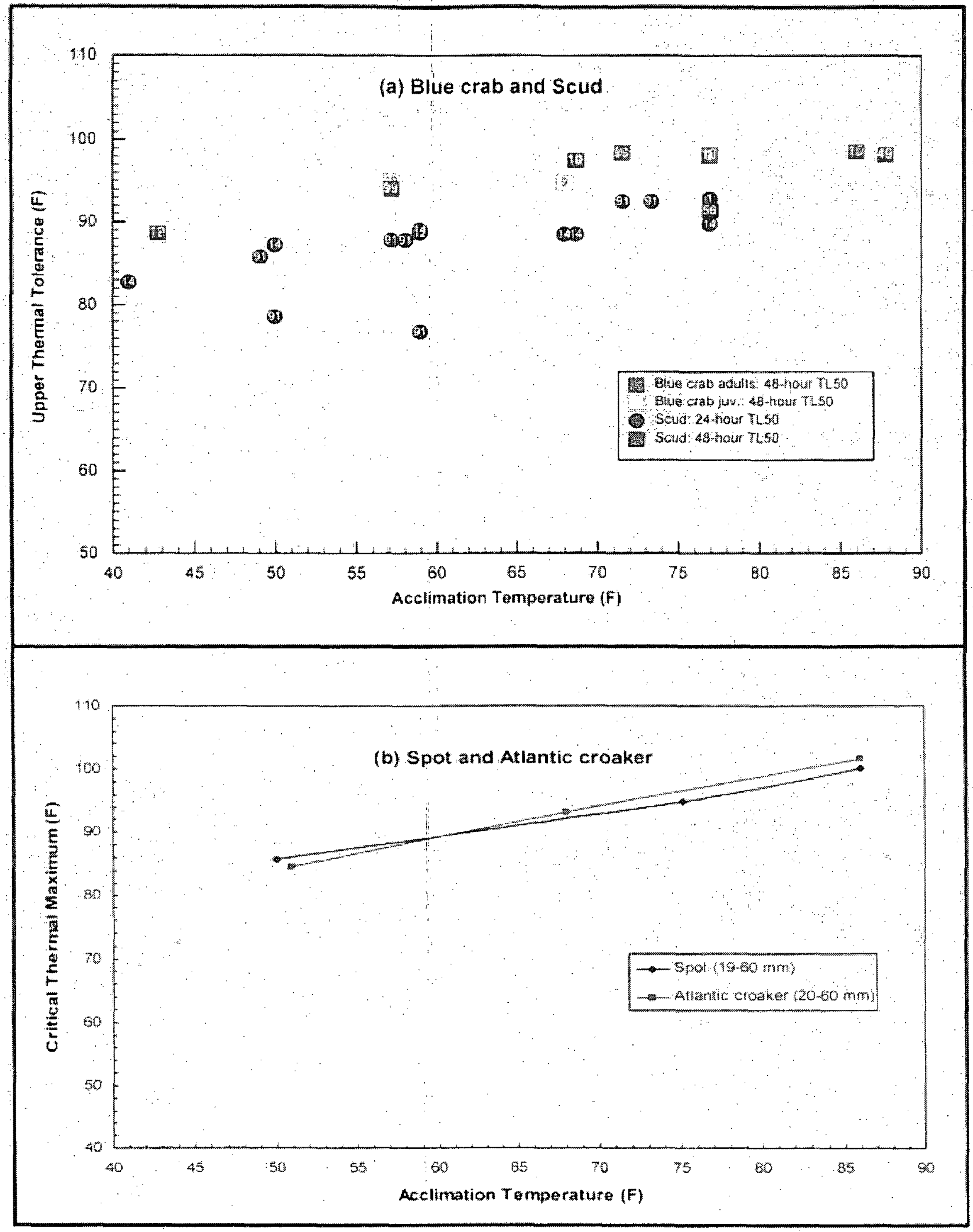
E Figure VI-10. Short-term thermal tolerance of anadromous herring relative to temperature decrease with time along the centerline of Salem's thermal plume. (Data labels indicate test acclimation temperature.)



E Figure VI-11. Short-term thermal tolerance of temperate bass relative to temperature decrease with time along the centerline of Salem's thermal plume. (Data labels indicate test acclimation temperature.)



E Figure VI-12. Short-term thermal tolerance of oceanic-estuarine residents relative to temperature decrease with time along the centerline of Salem's thermal plume. (Data labels indicate test acclimation temperature.)



E Figure VI-13. Comparison of upper temperature tolerance.

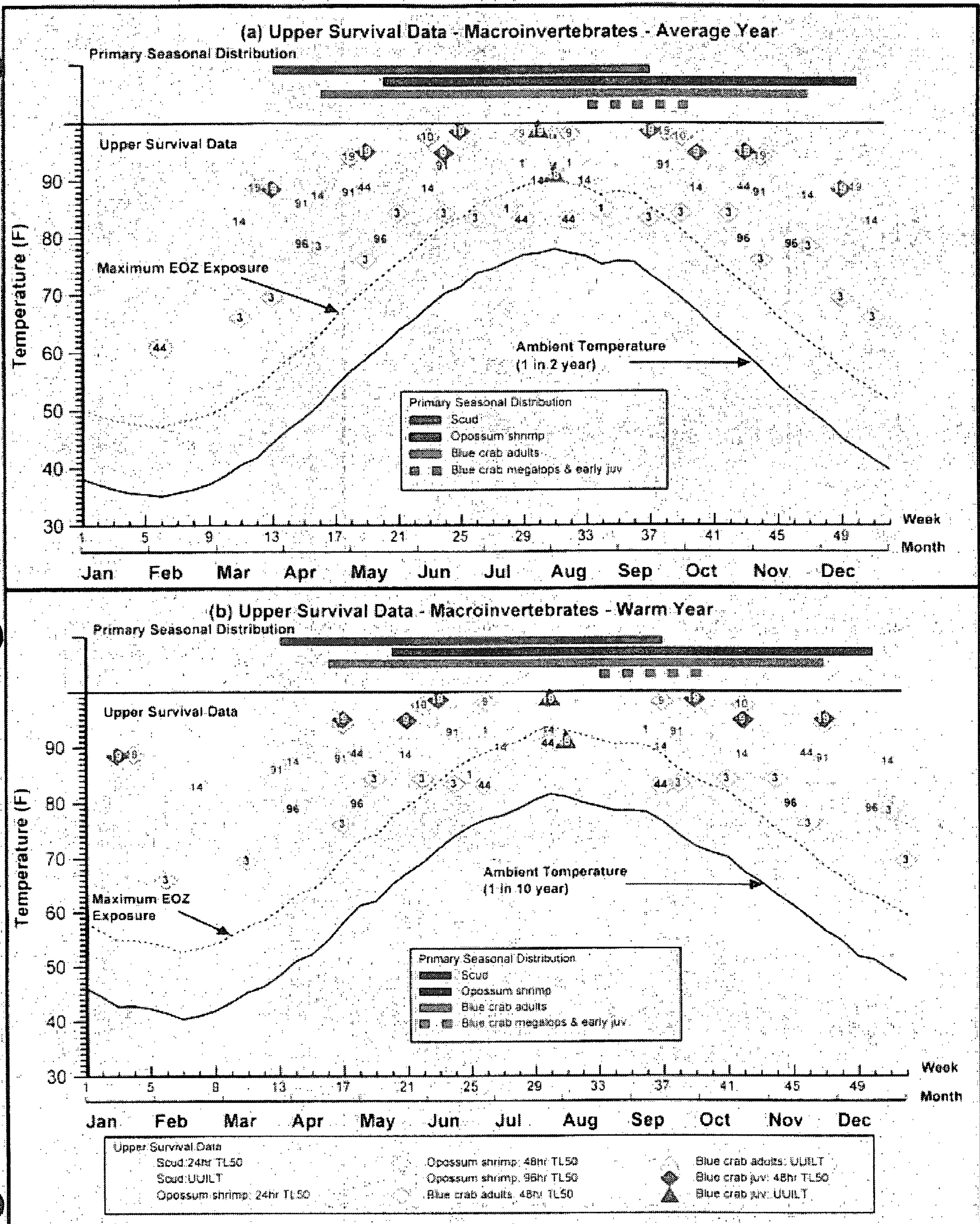
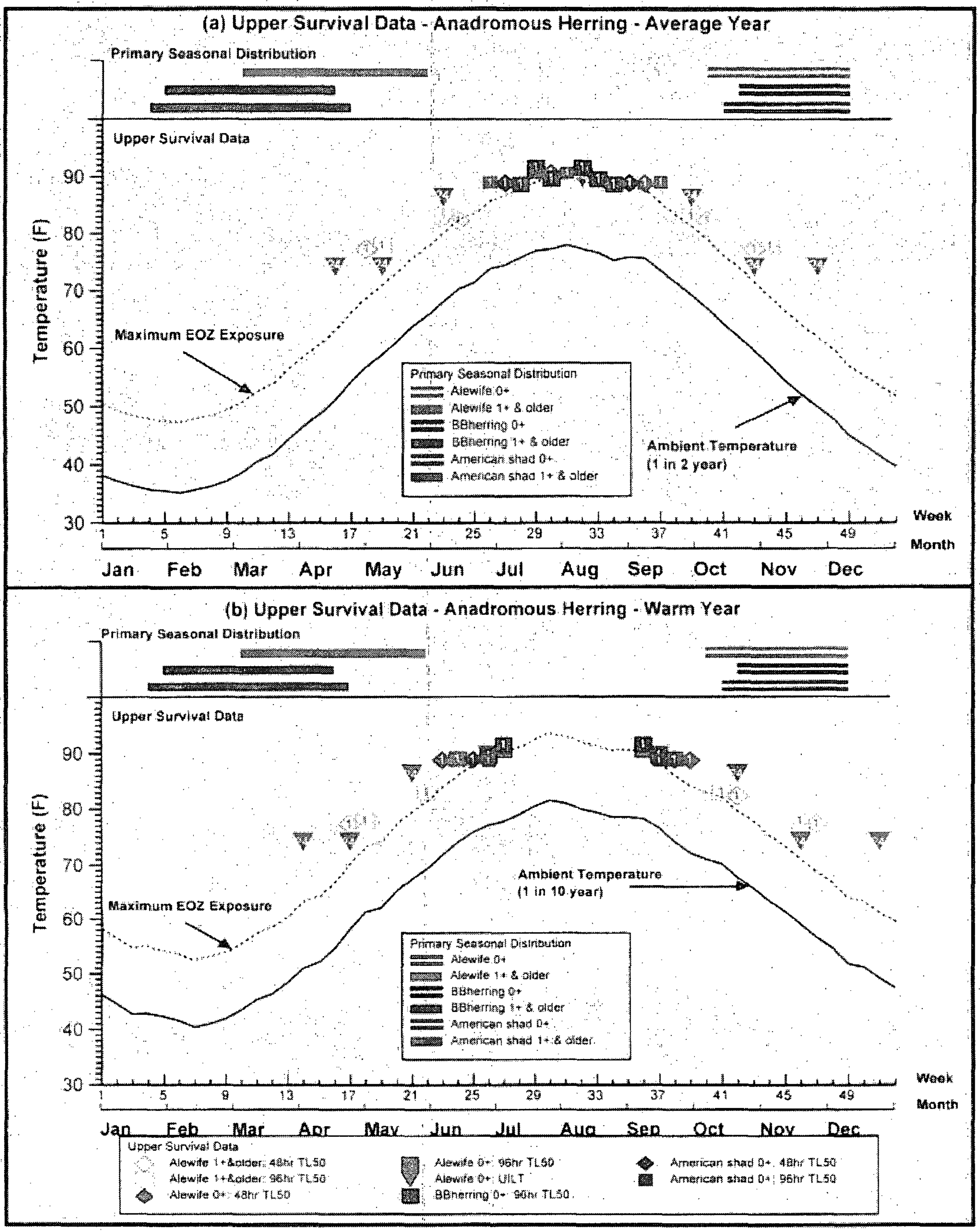
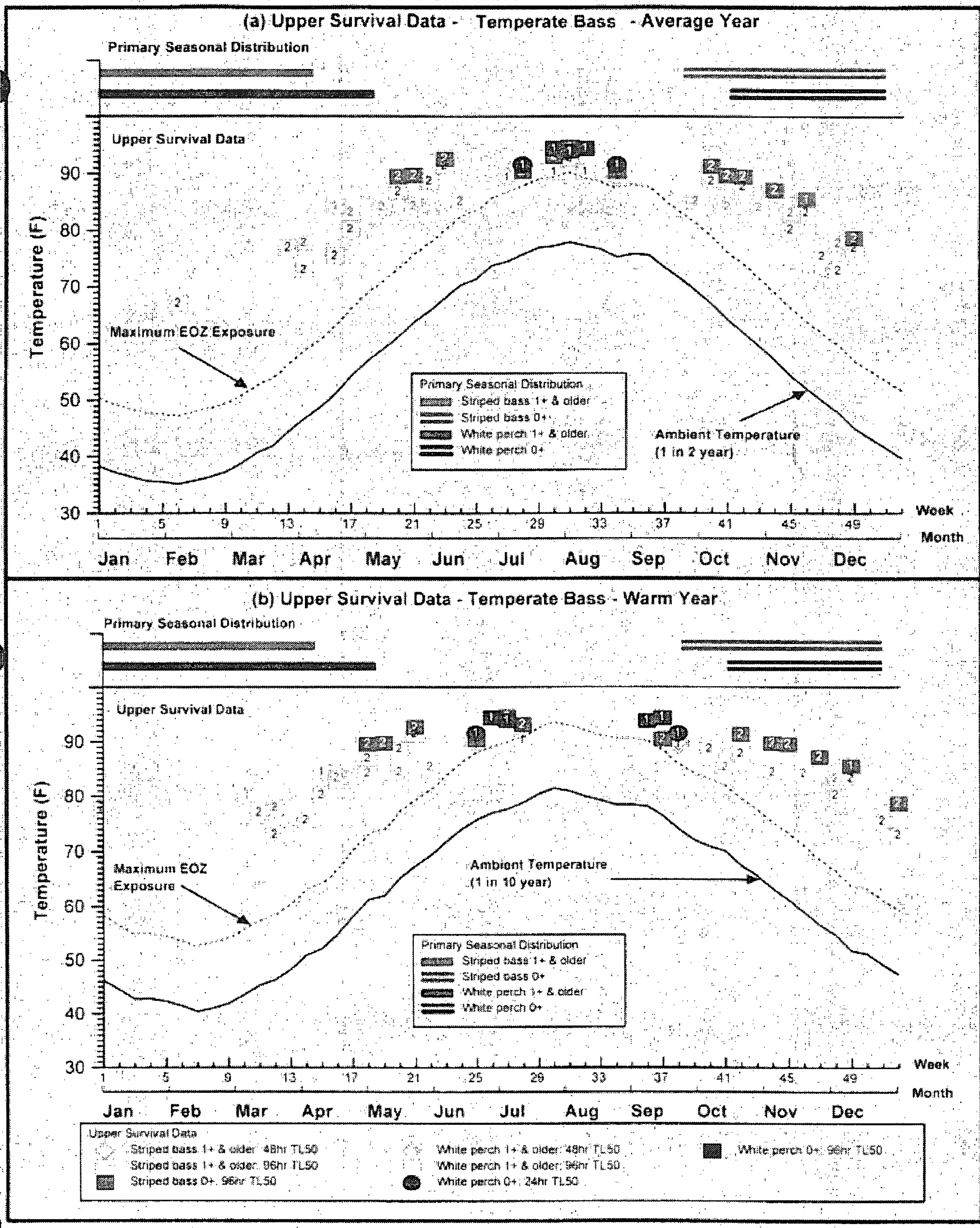


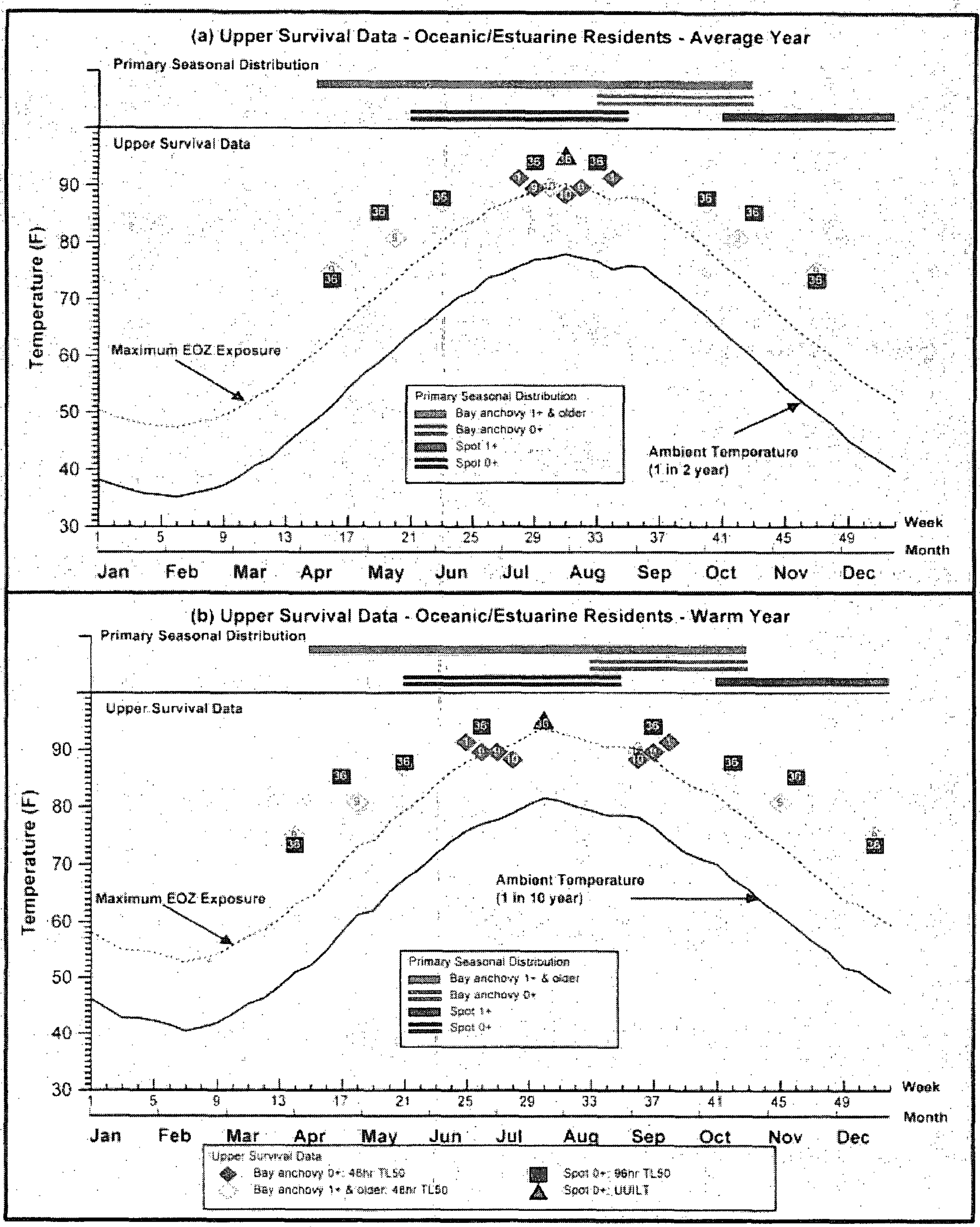
Figure VI-14. Upper survival data for macroinvertebrates relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasonsdiscussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)



E Figure VI-15. Upper survival data for anadromous herring relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasonsdiscussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)



E Figure VI-16. Upper survival data for temperate bass relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)



E Figure VI-17. Upper survival data for oceanic-estuarine residents relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)

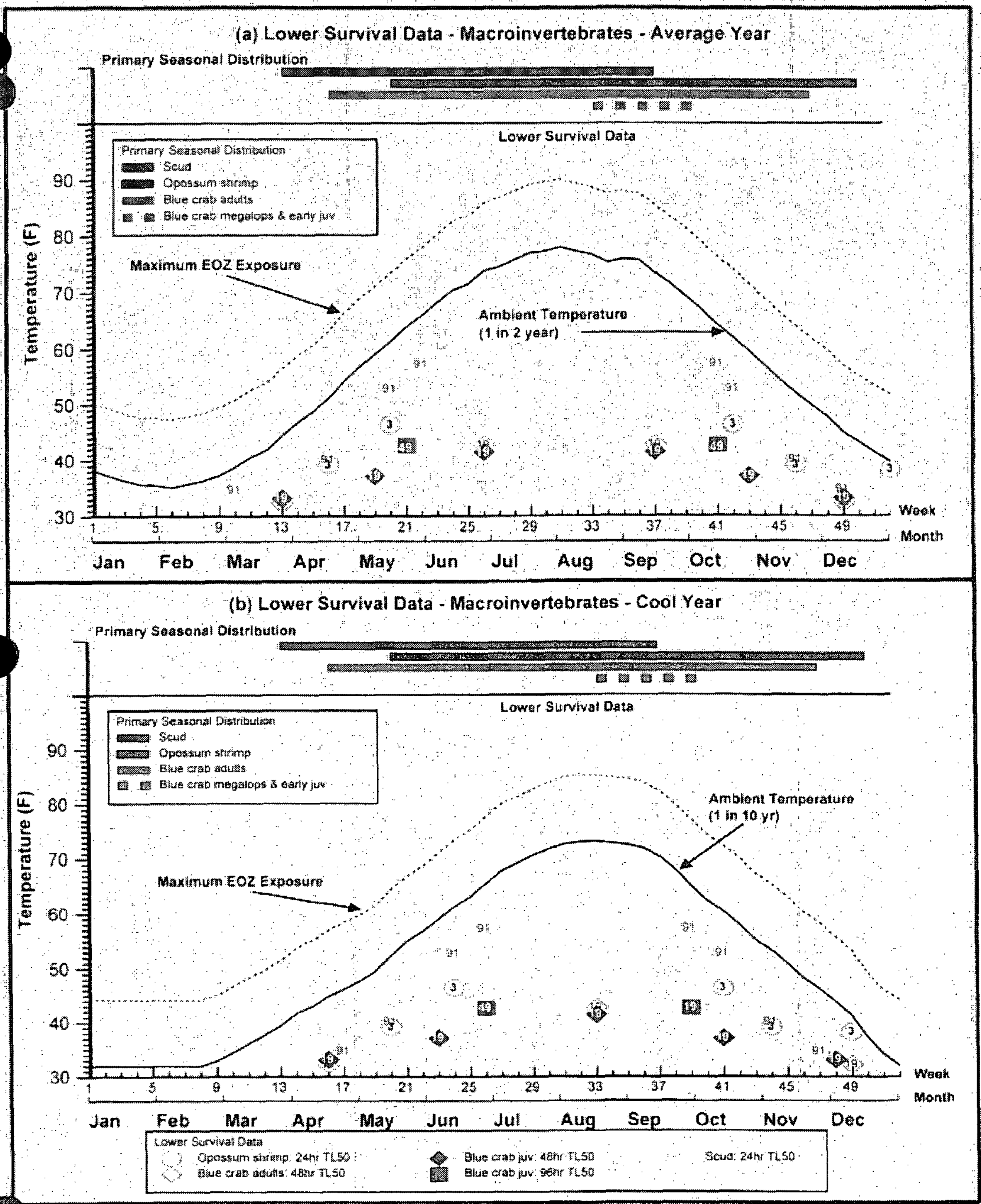


Figure VI-18. Lower survival data for macroinvertebrates relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)

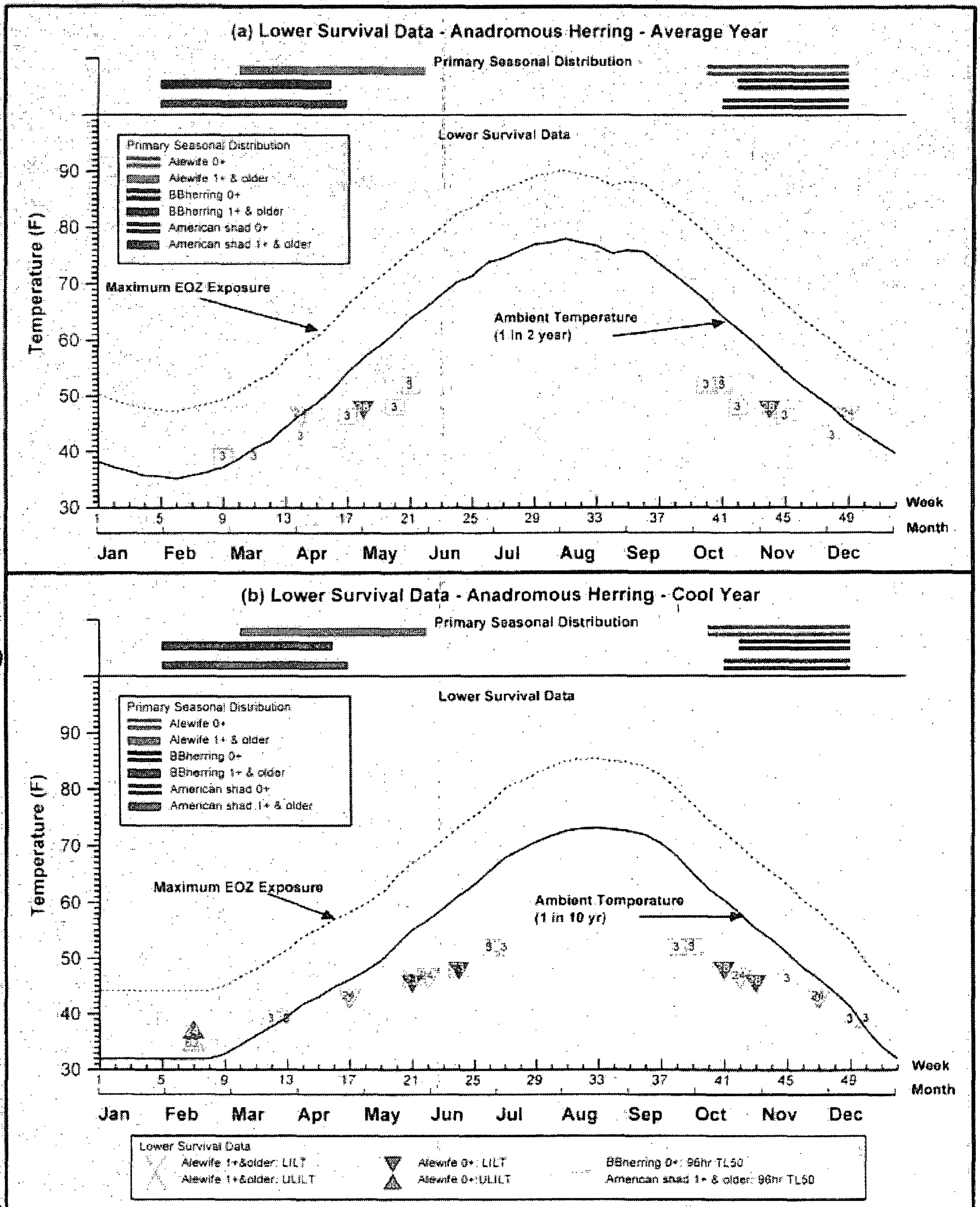
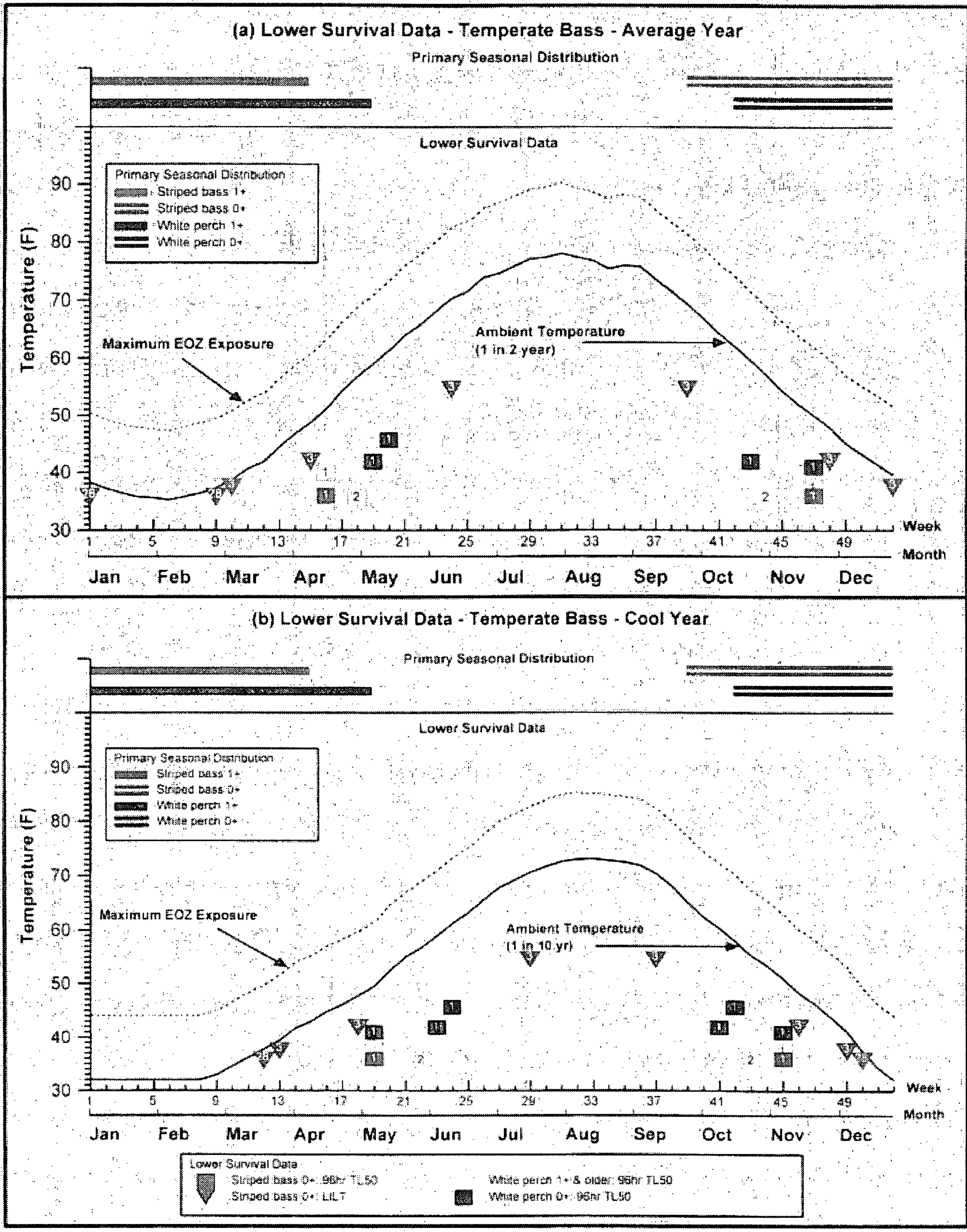
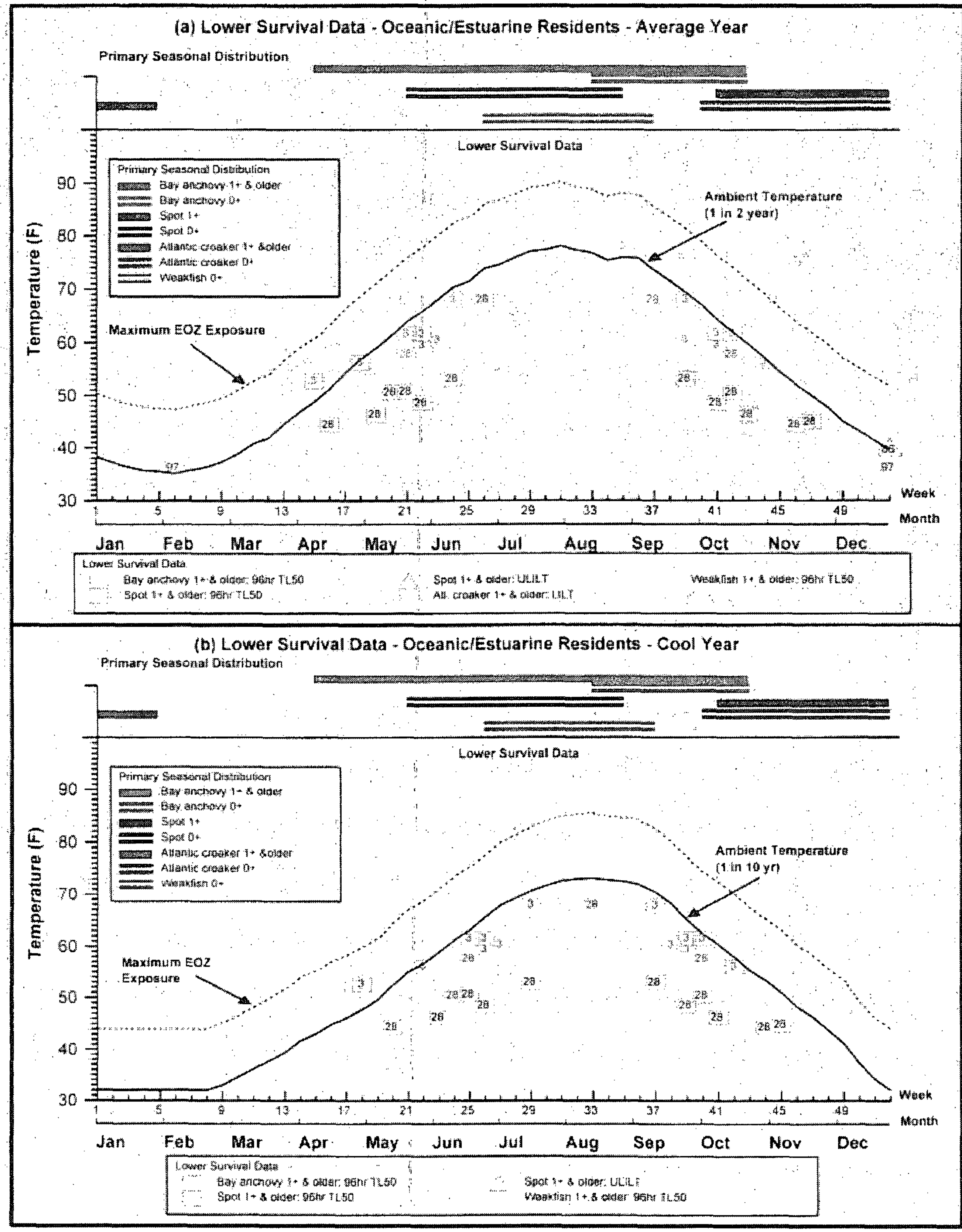


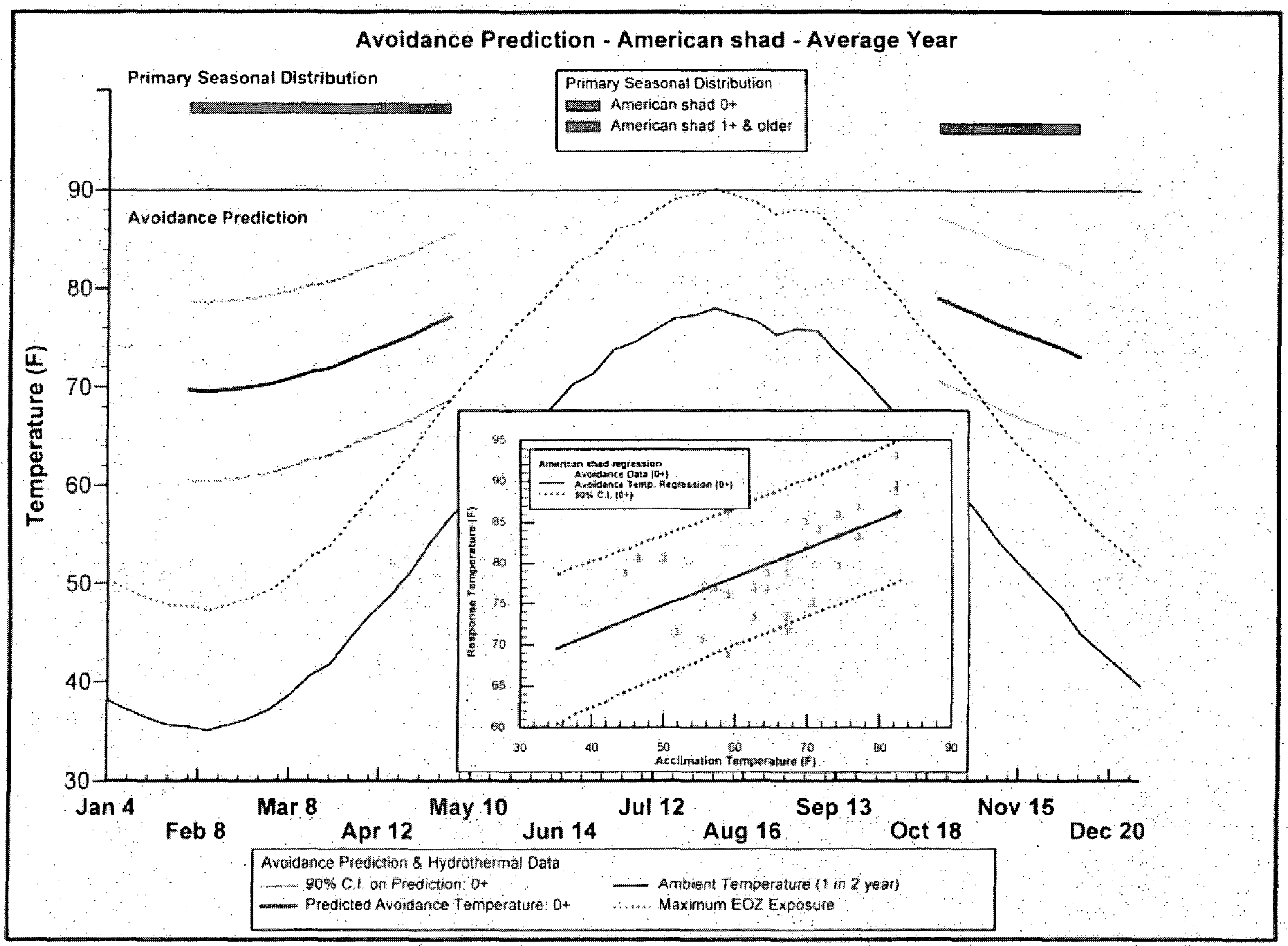
Figure VI-19. Lower survival data for anadromousherring relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)



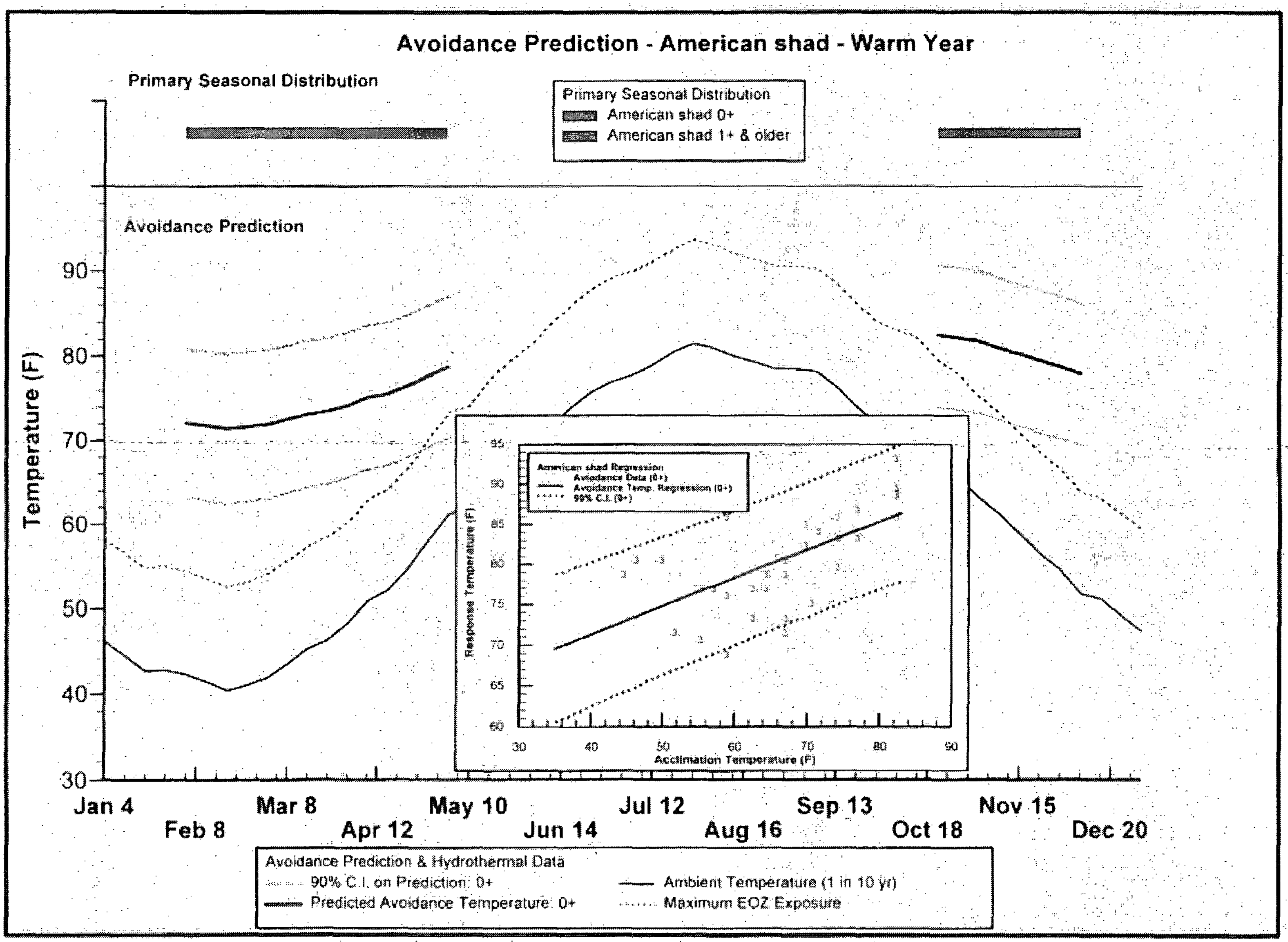
E Figure VI-20. Lower survival data for temperate bass relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)



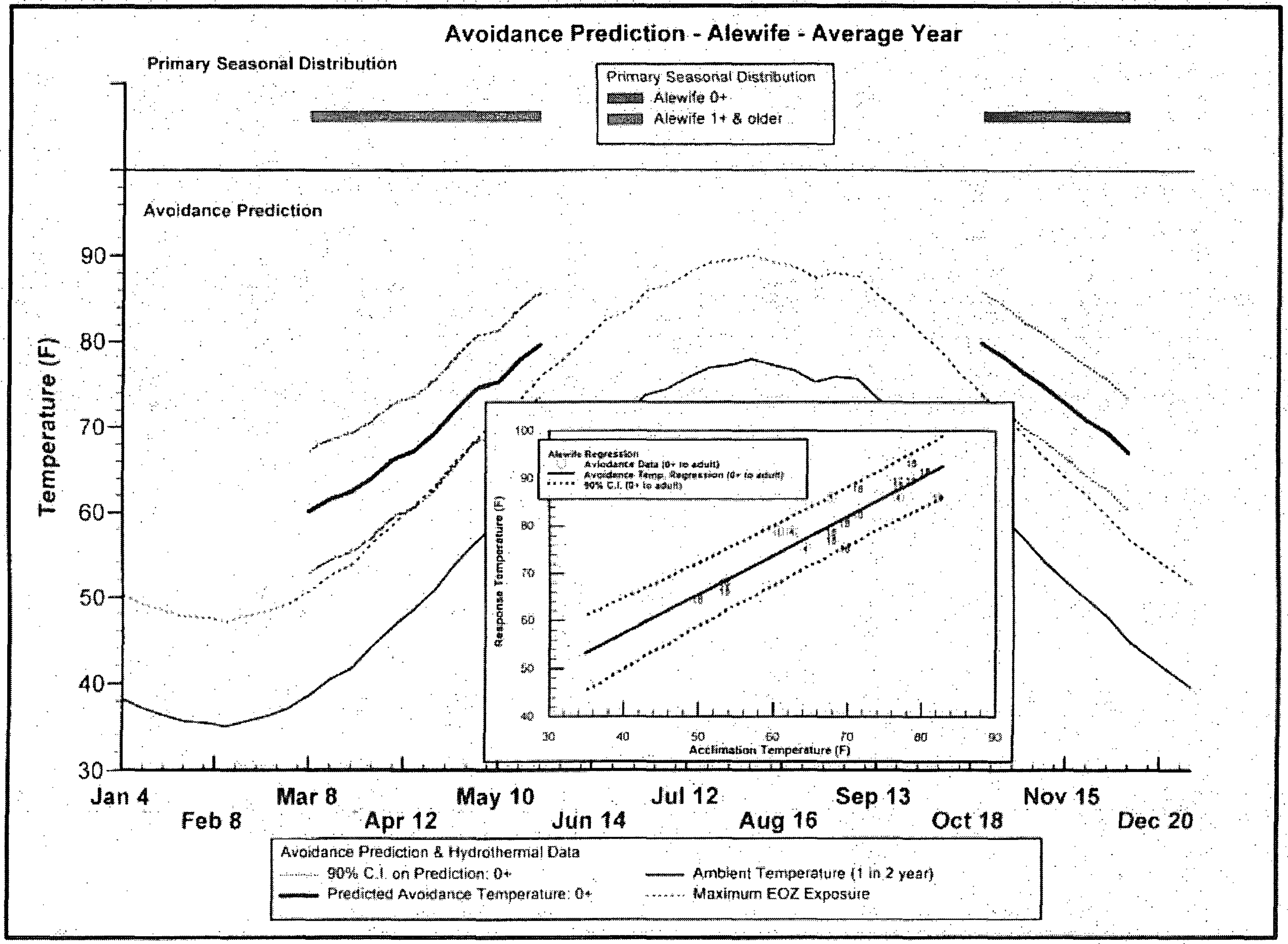
E Figure VI-21. Lower survival data for oceanic-estuarine residents relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasonsdiscussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)



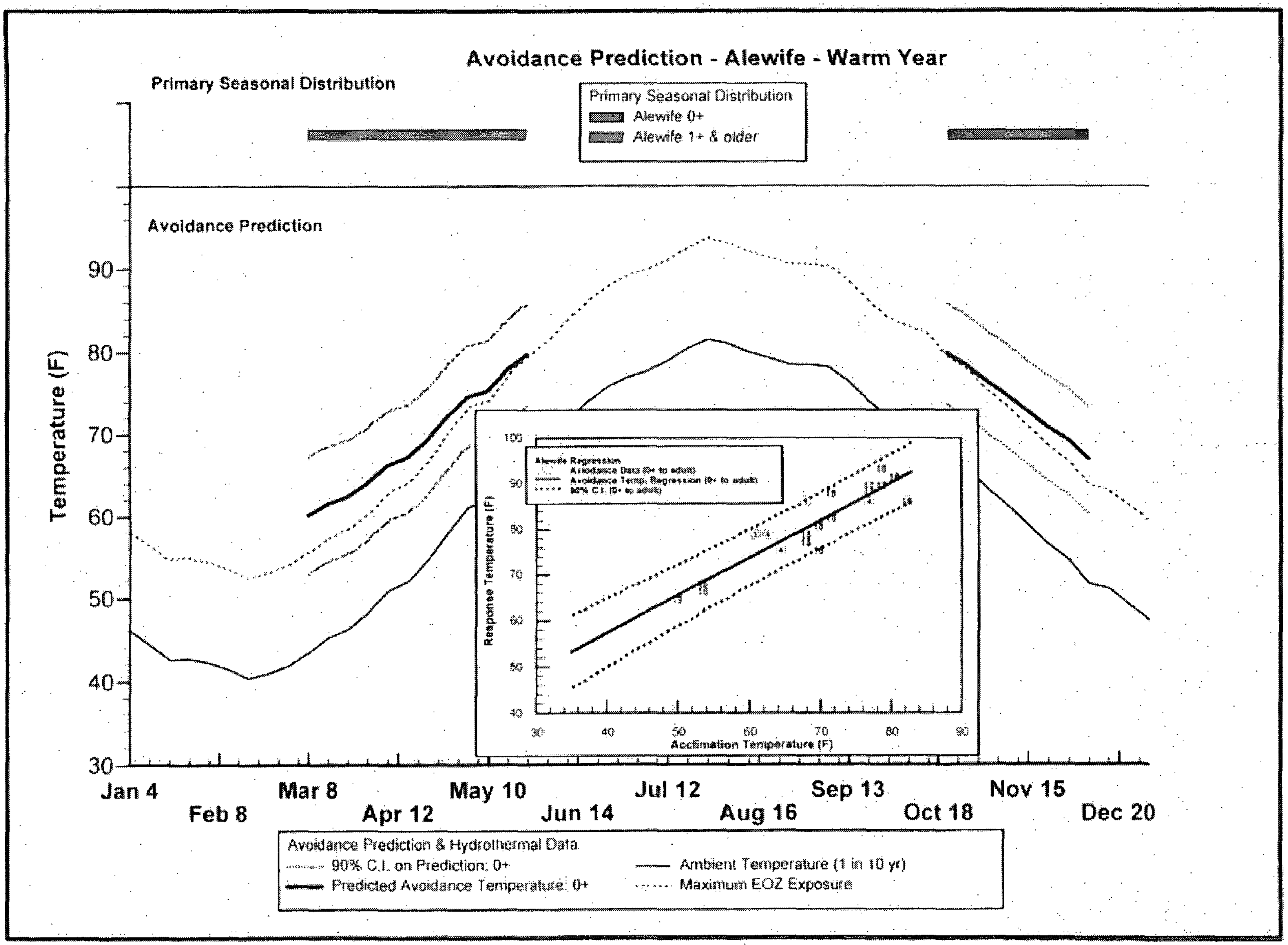
E Figure VI-22a. Avoidance prediction for American shad for an average year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



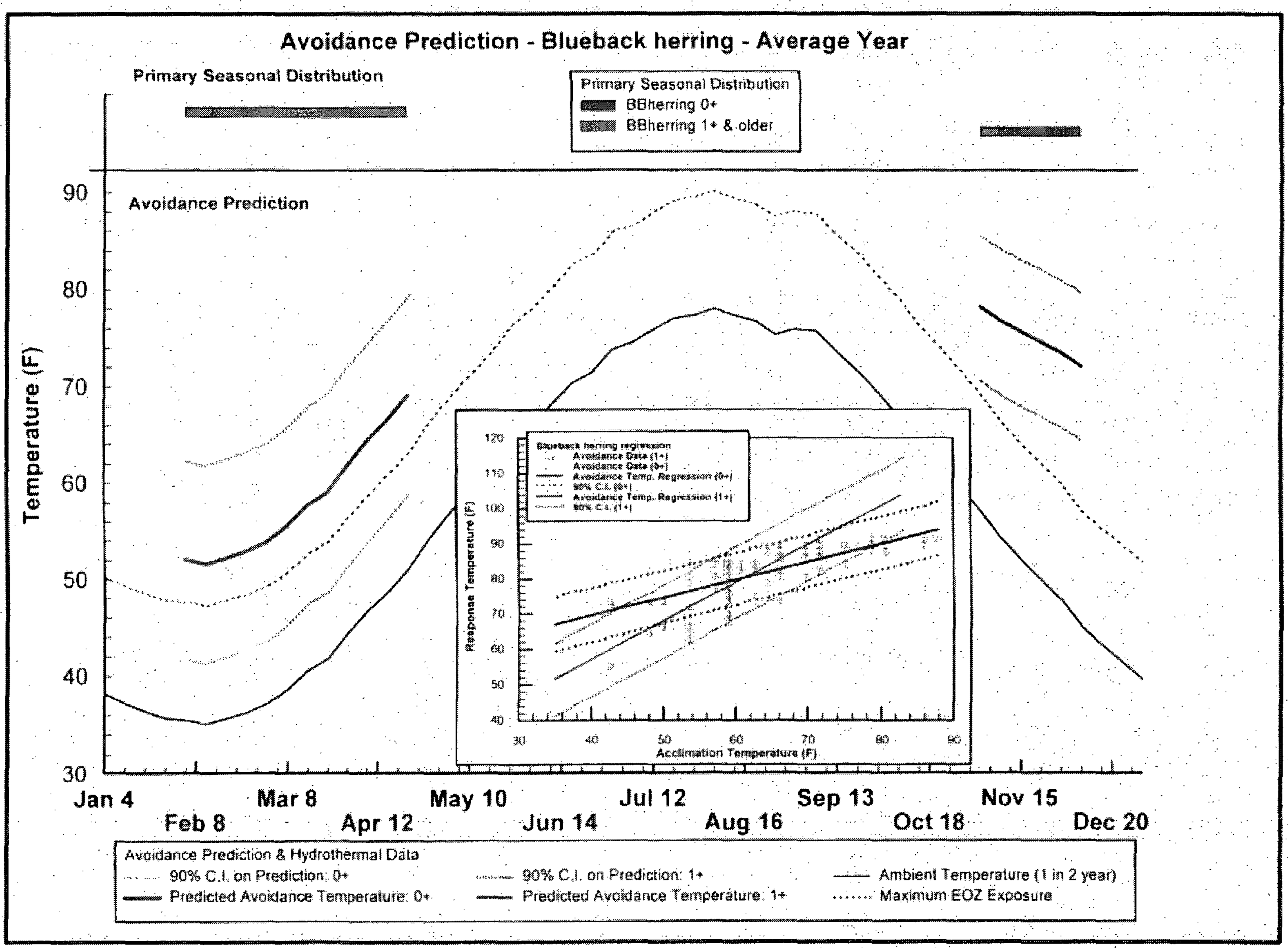
E Figure VI-22b. Avoidance prediction for American shad for a warm year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



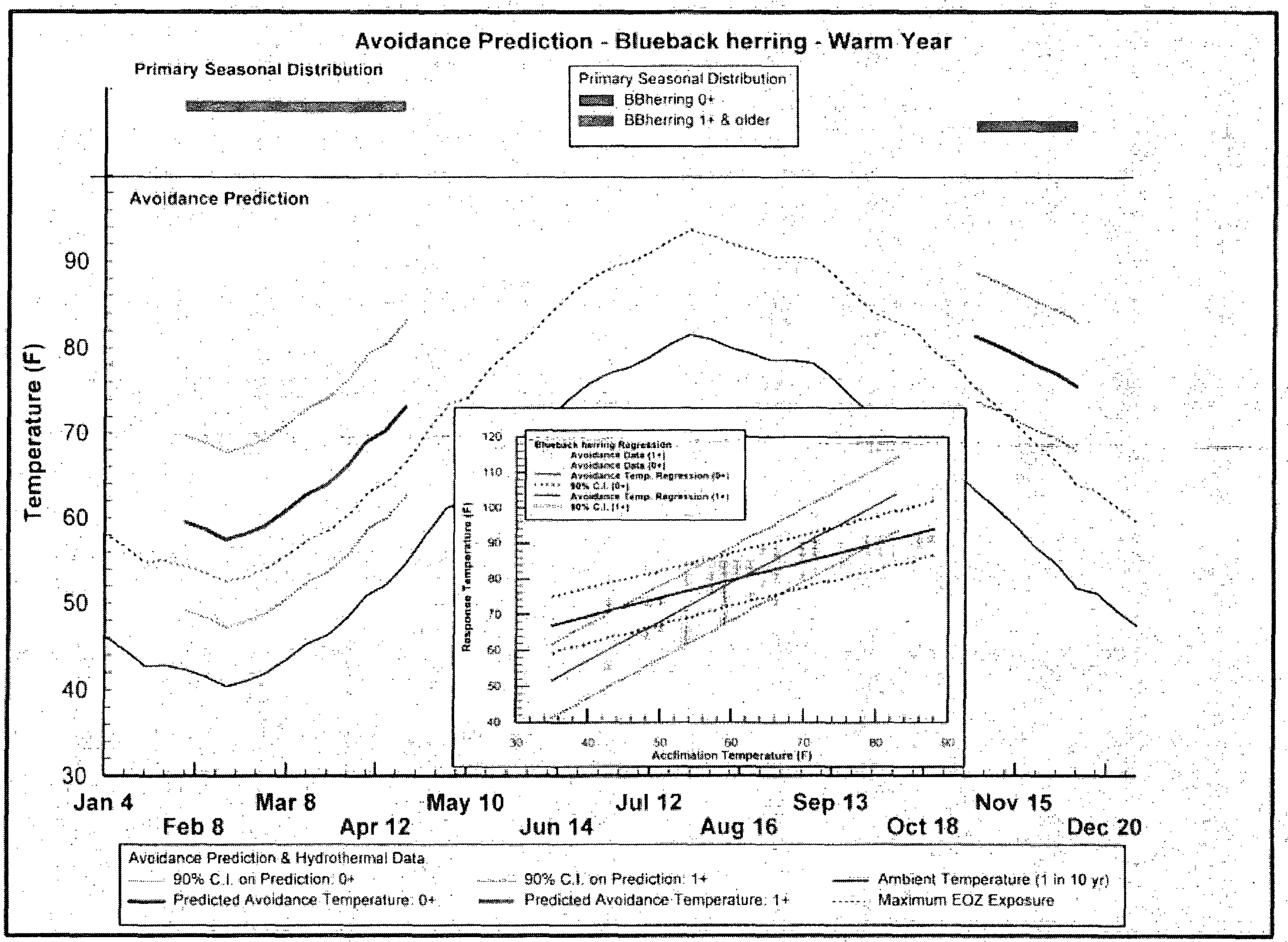
E Figure VI-23a. Avoidance prediction for alewife for an average year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



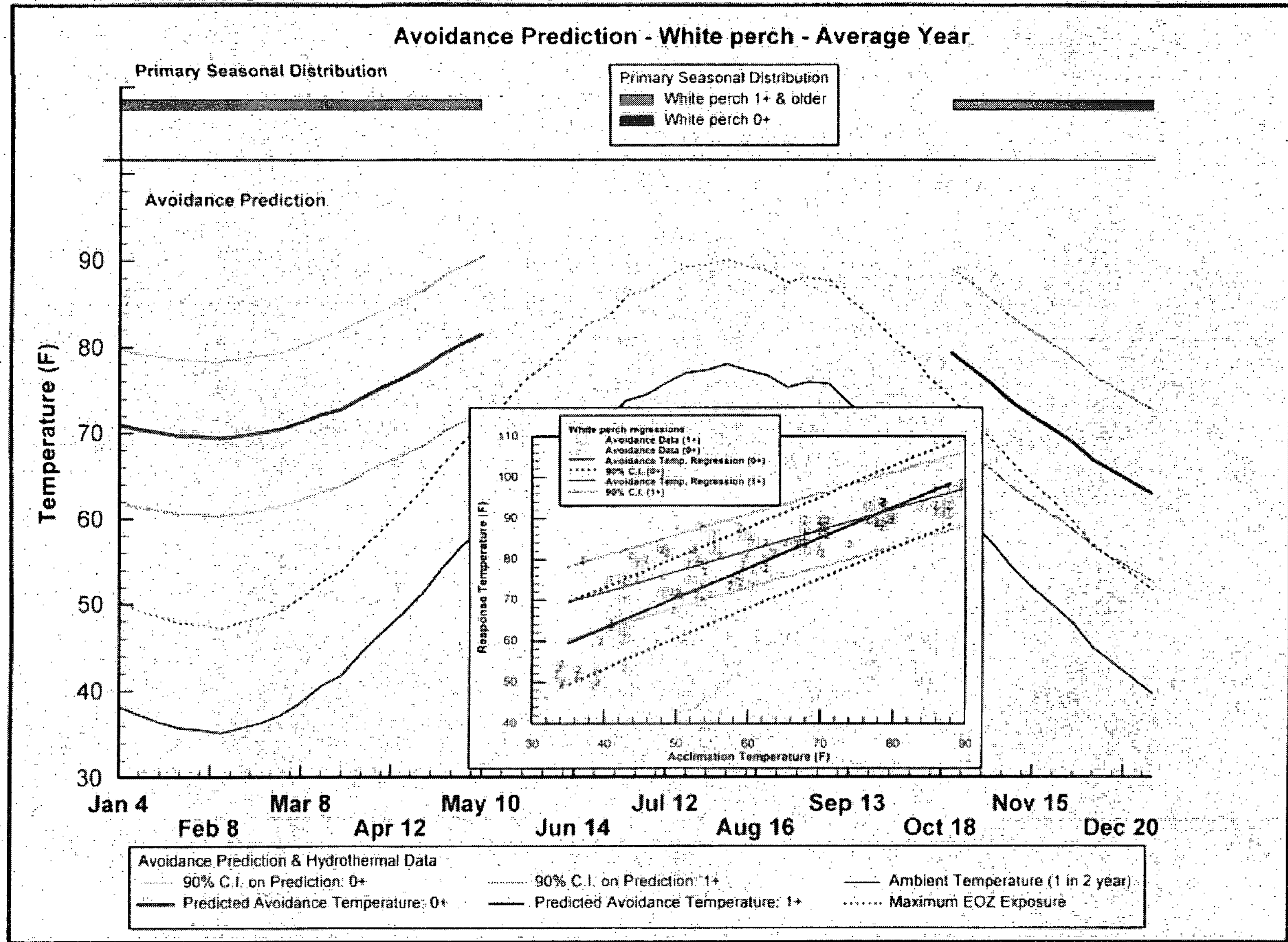
E Figure VI-23b. Avoidance prediction for alewife for a warm year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



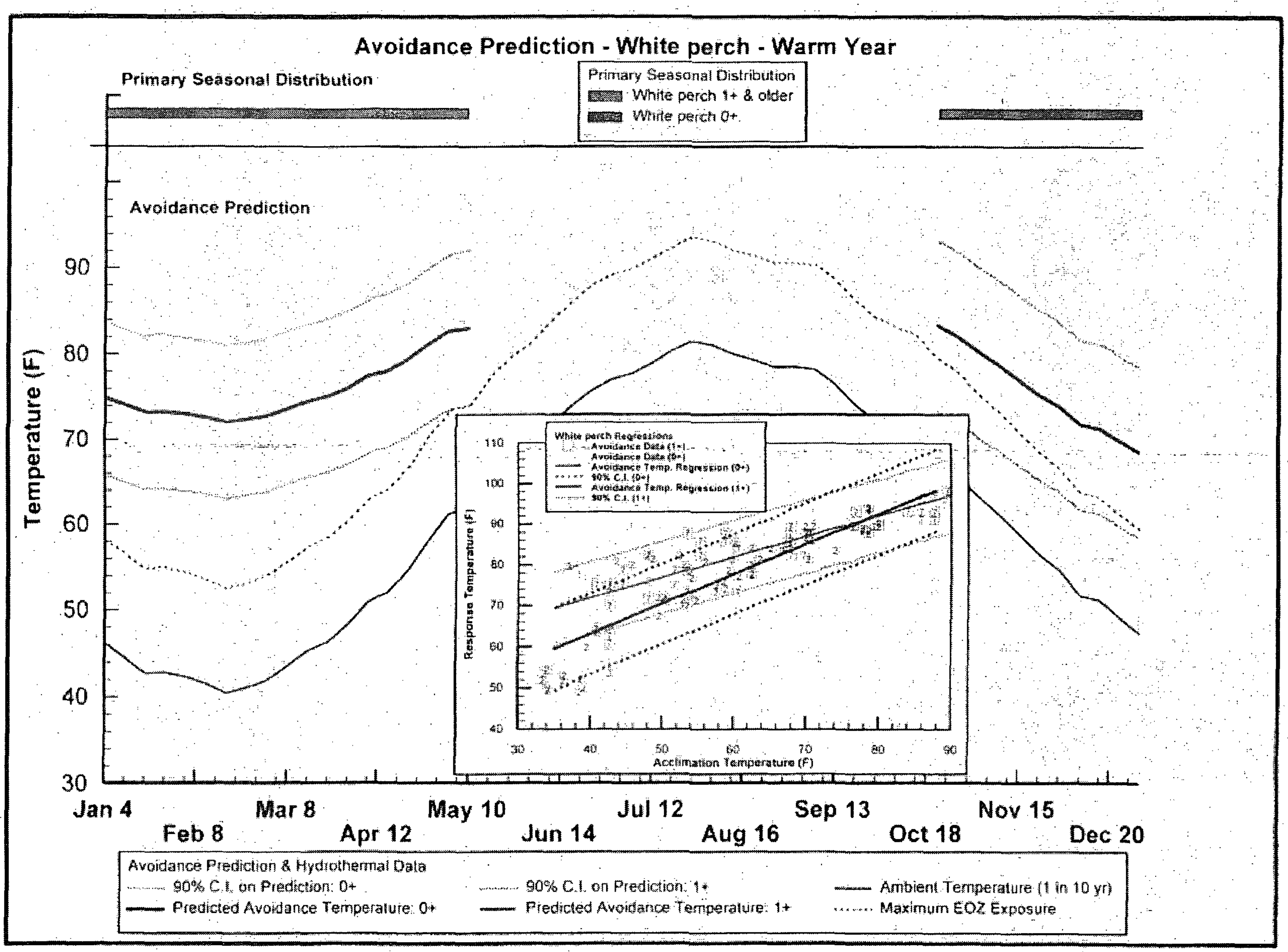
E Figure VI-24a. Avoidance prediction for blueback herring for an average year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



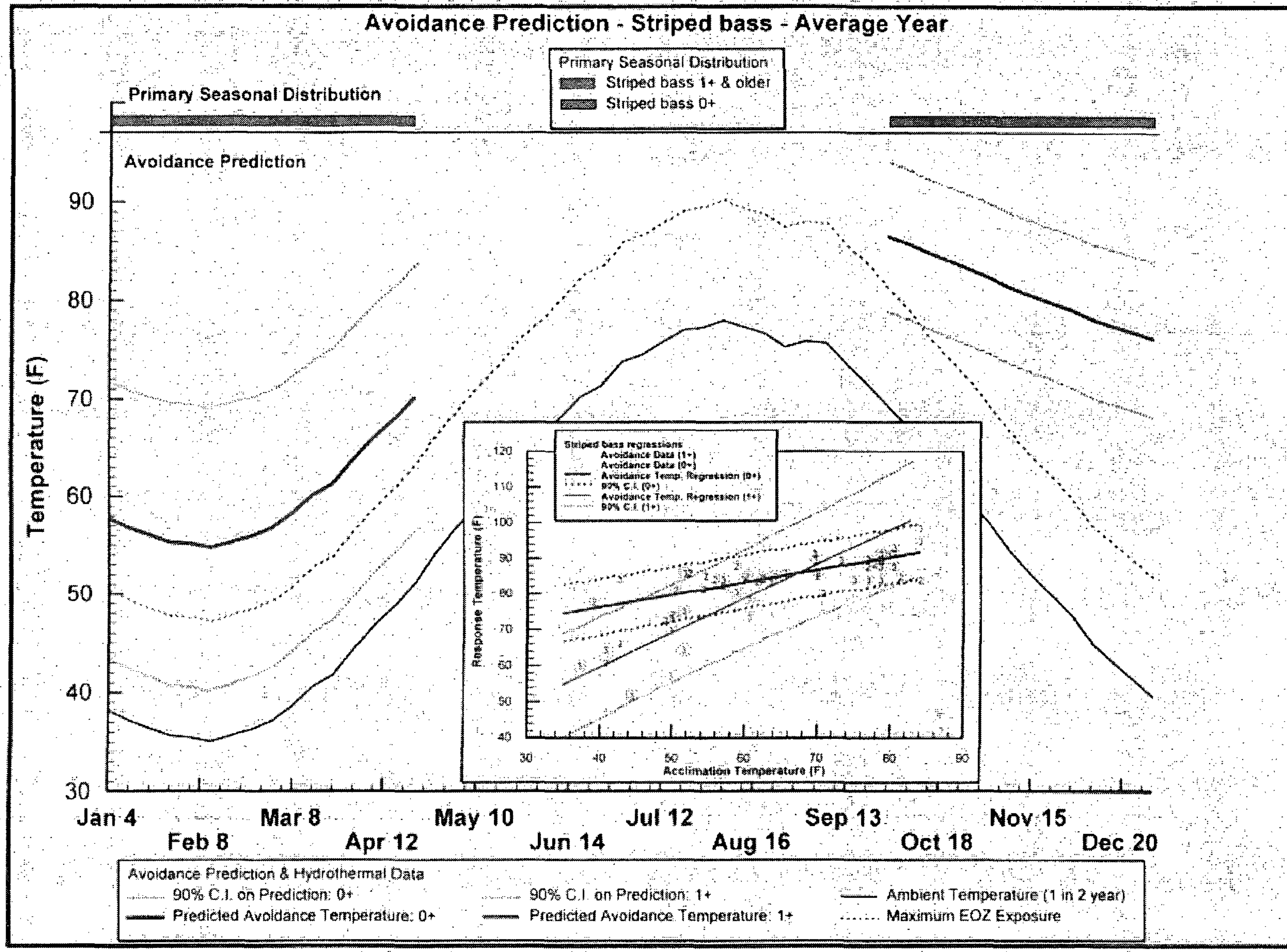
E Figure VI-24b. Avoidance prediction for blueback herring for a warm year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



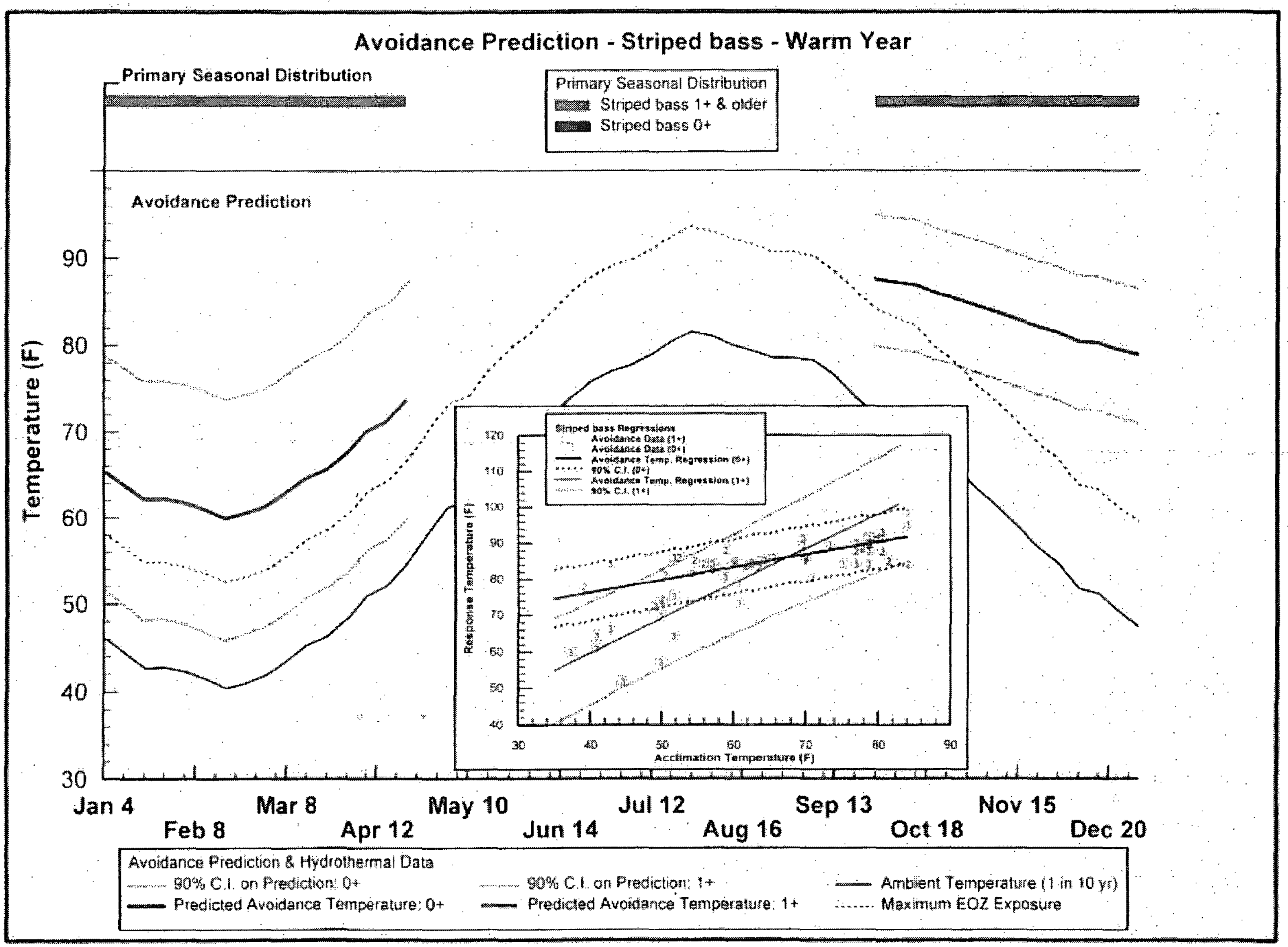
E Figure VI-25a. Avoidance prediction for white perch for an average year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



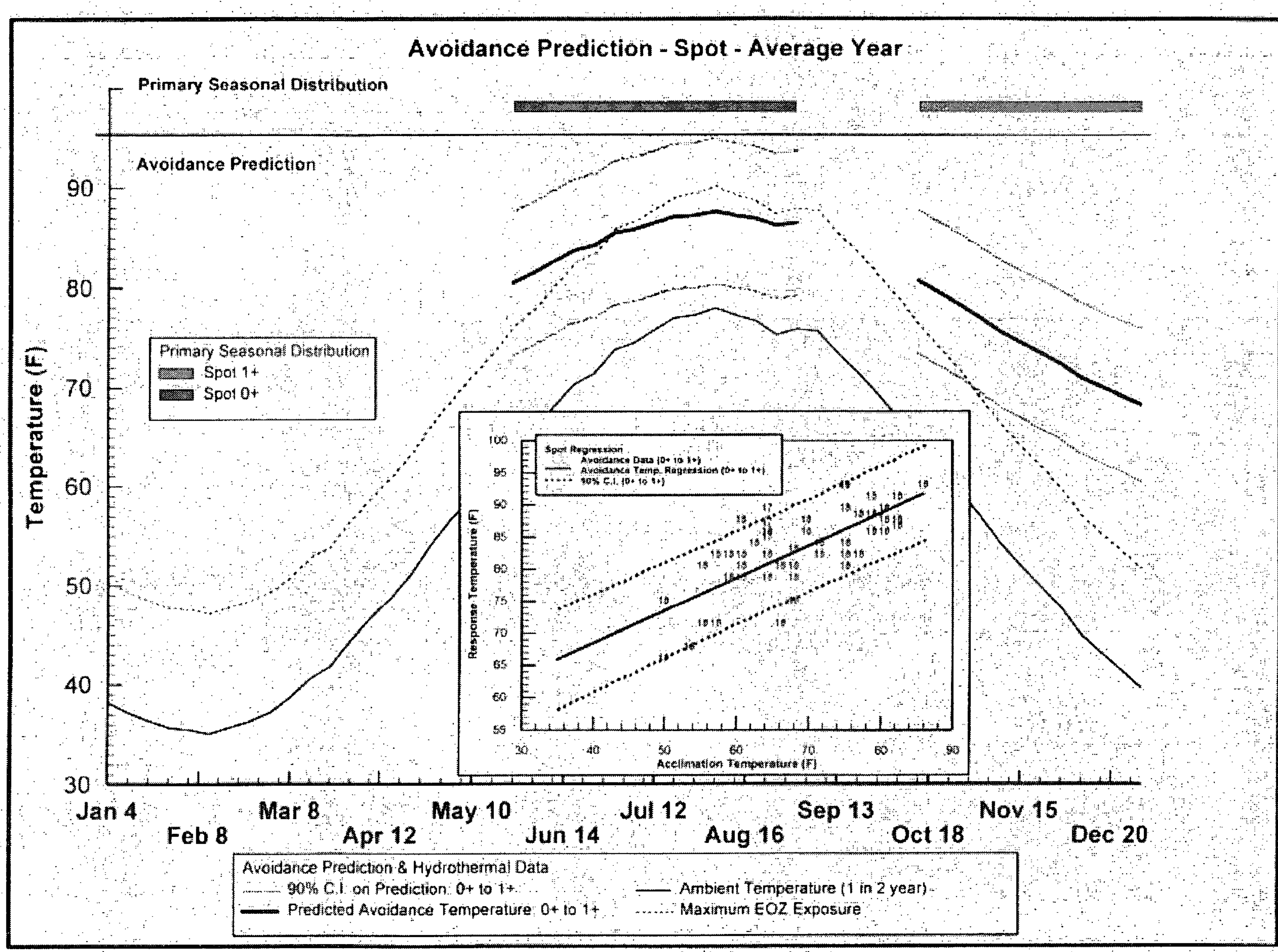
E Figure VI-25b. Avoidance prediction for white perch for a warm year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



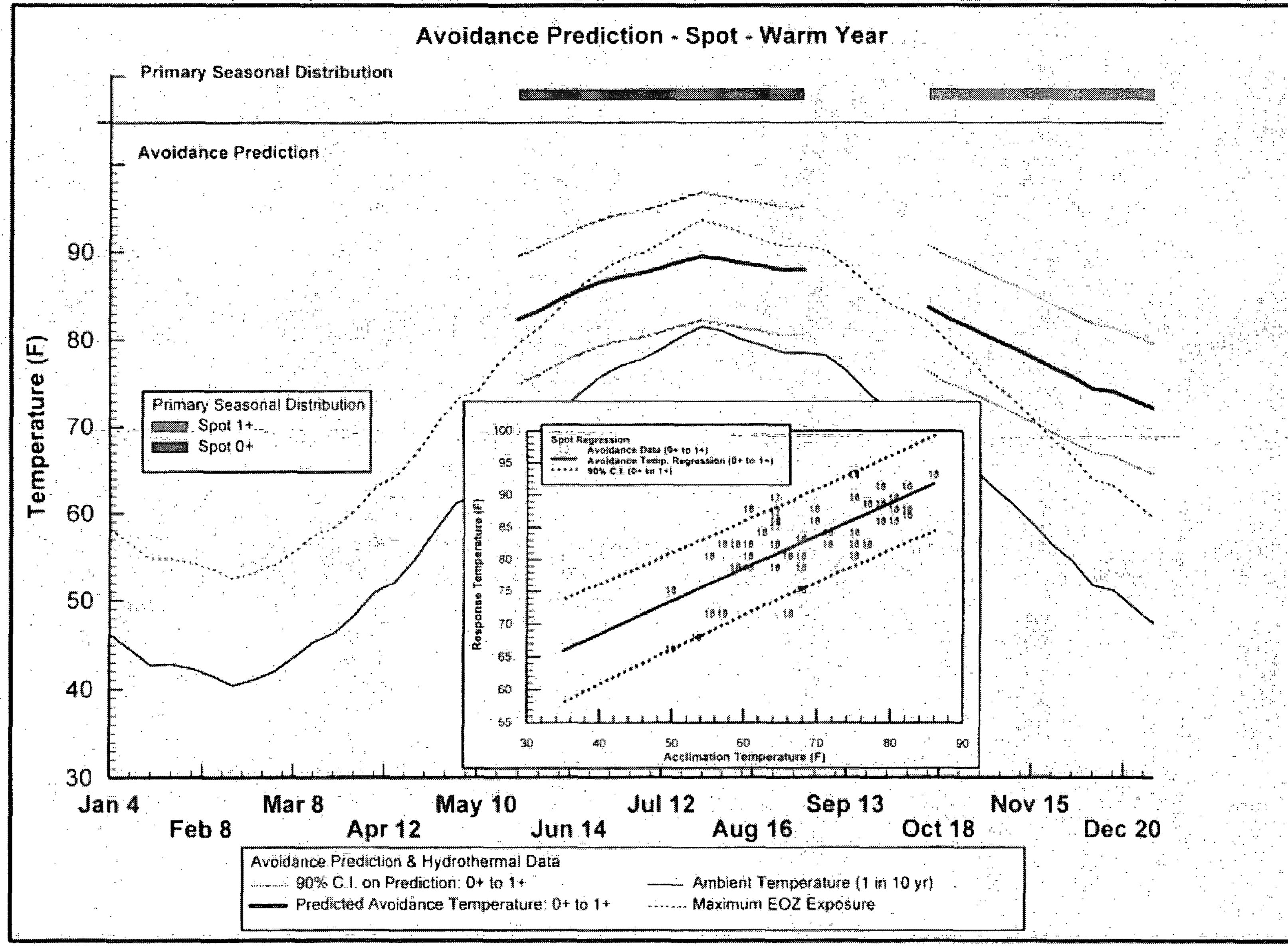
E Figure VI-26a. Avoidance prediction for striped bass for an average year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



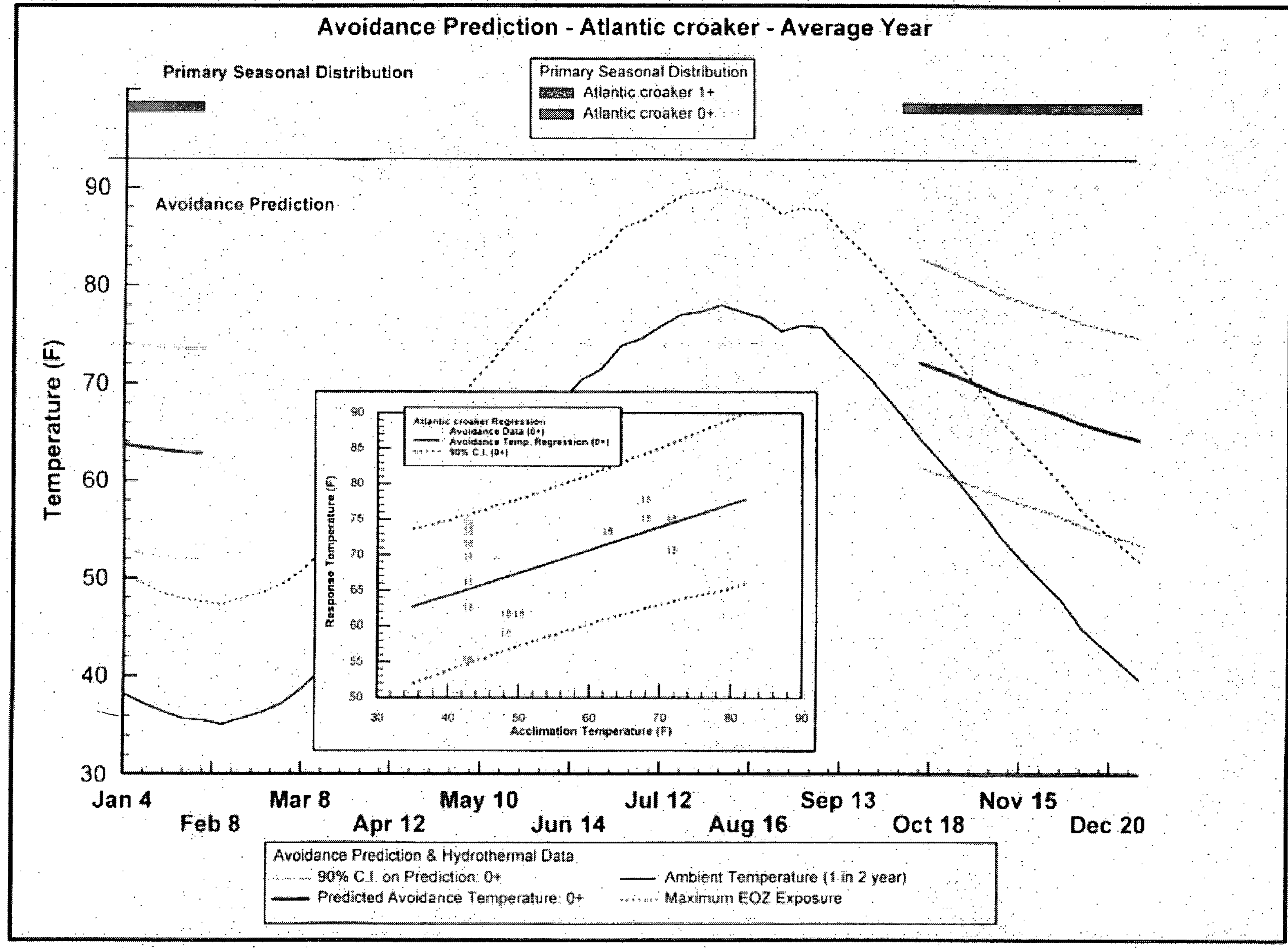
E Figure VI-26b. Avoidance prediction for striped bass for a warm year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



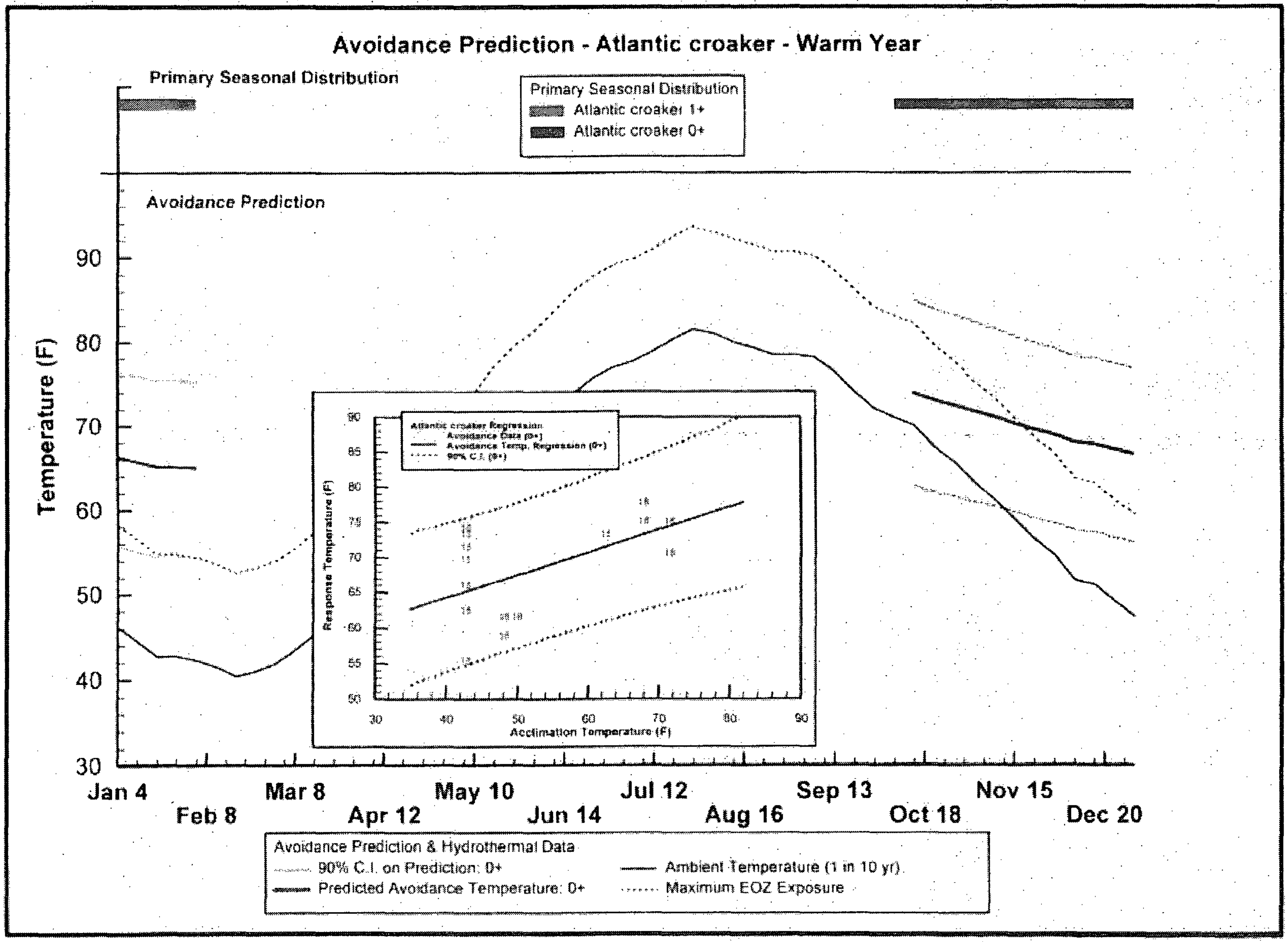
E Figure VI-27a. Avoidance prediction for spot for an average year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



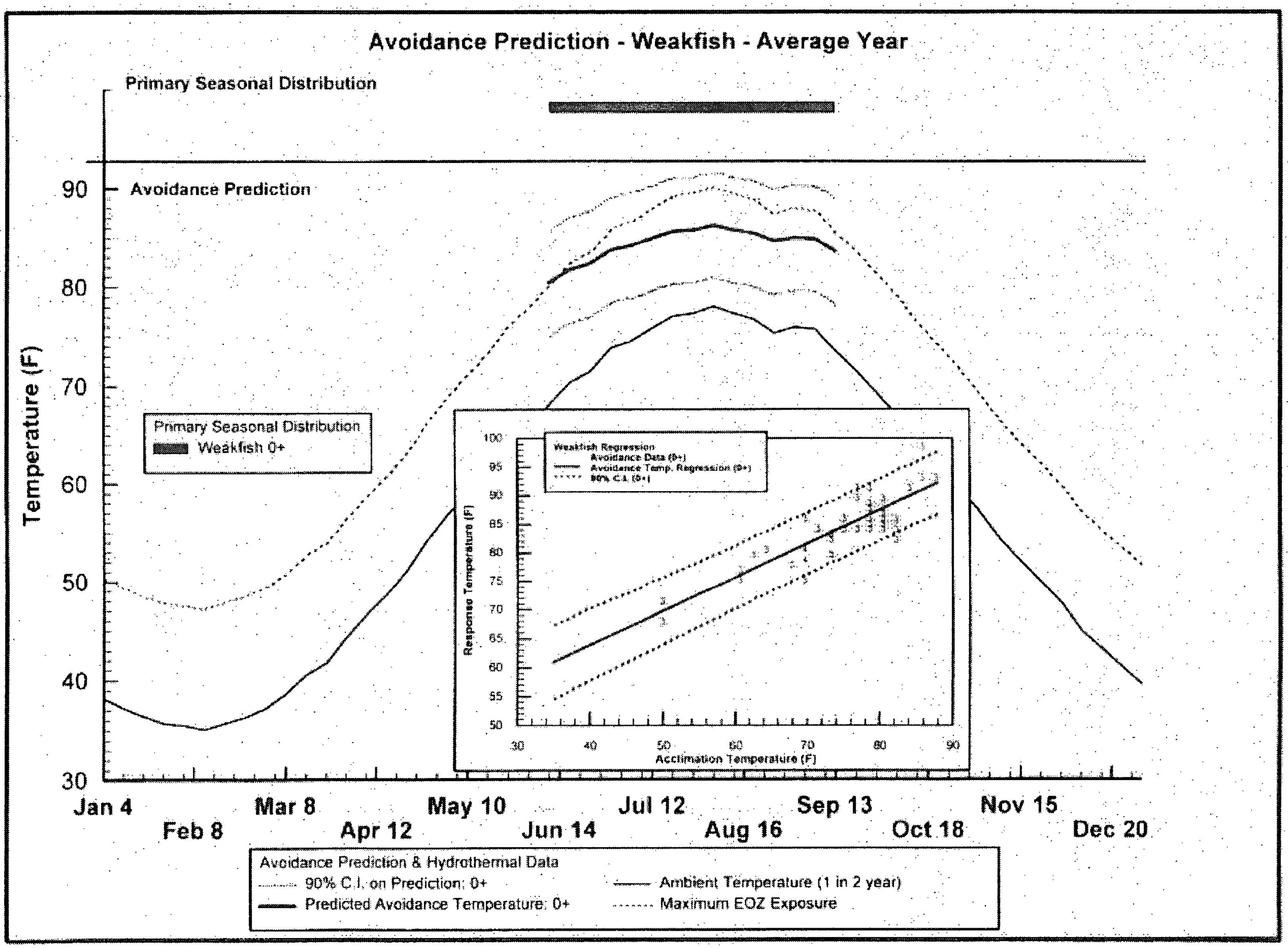
E Figure VI-27b. Avoidance prediction for spot for a warm year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



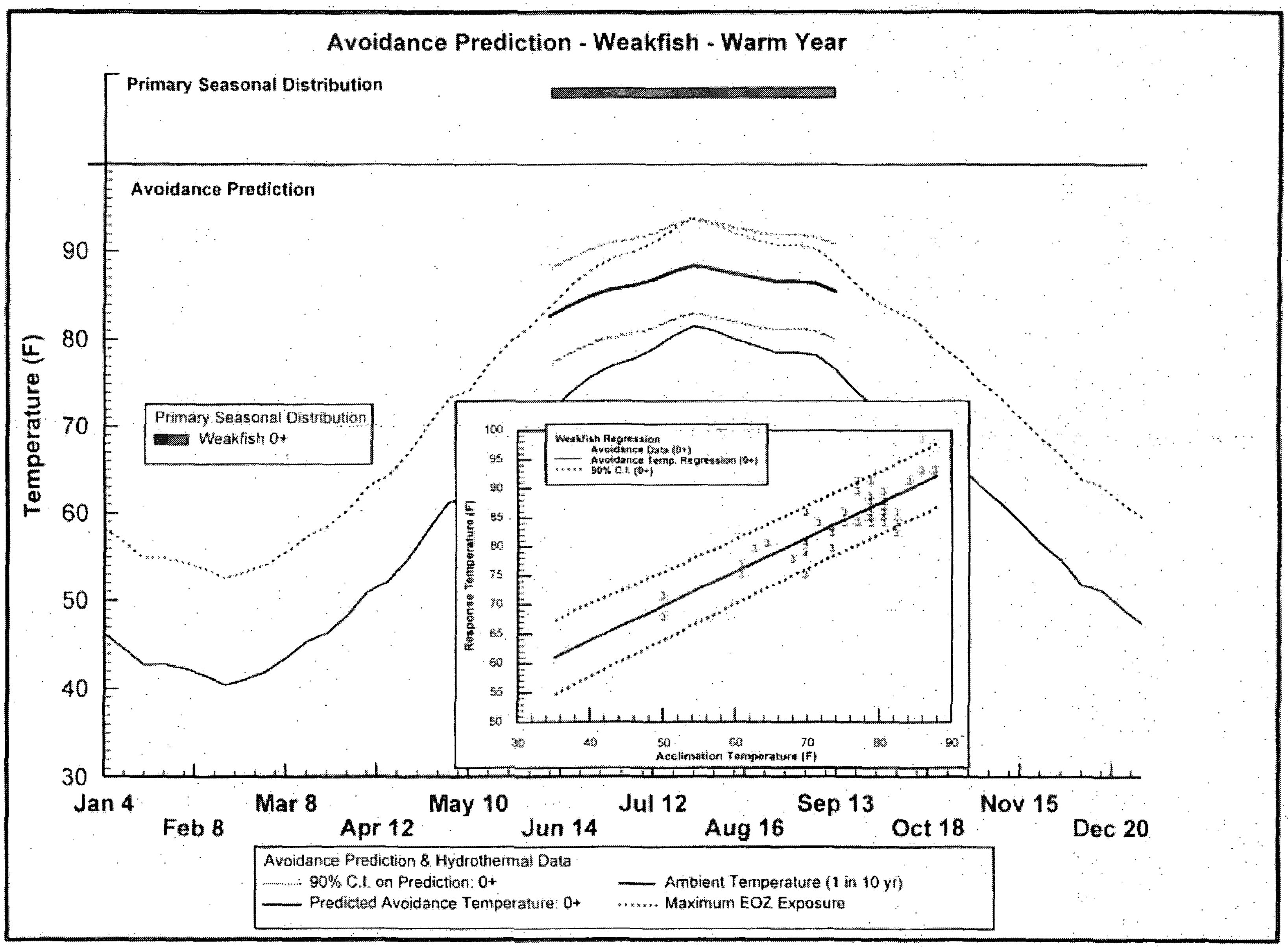
E Figure VI-28a. Avoidance prediction for Atlantic croaker for an average year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



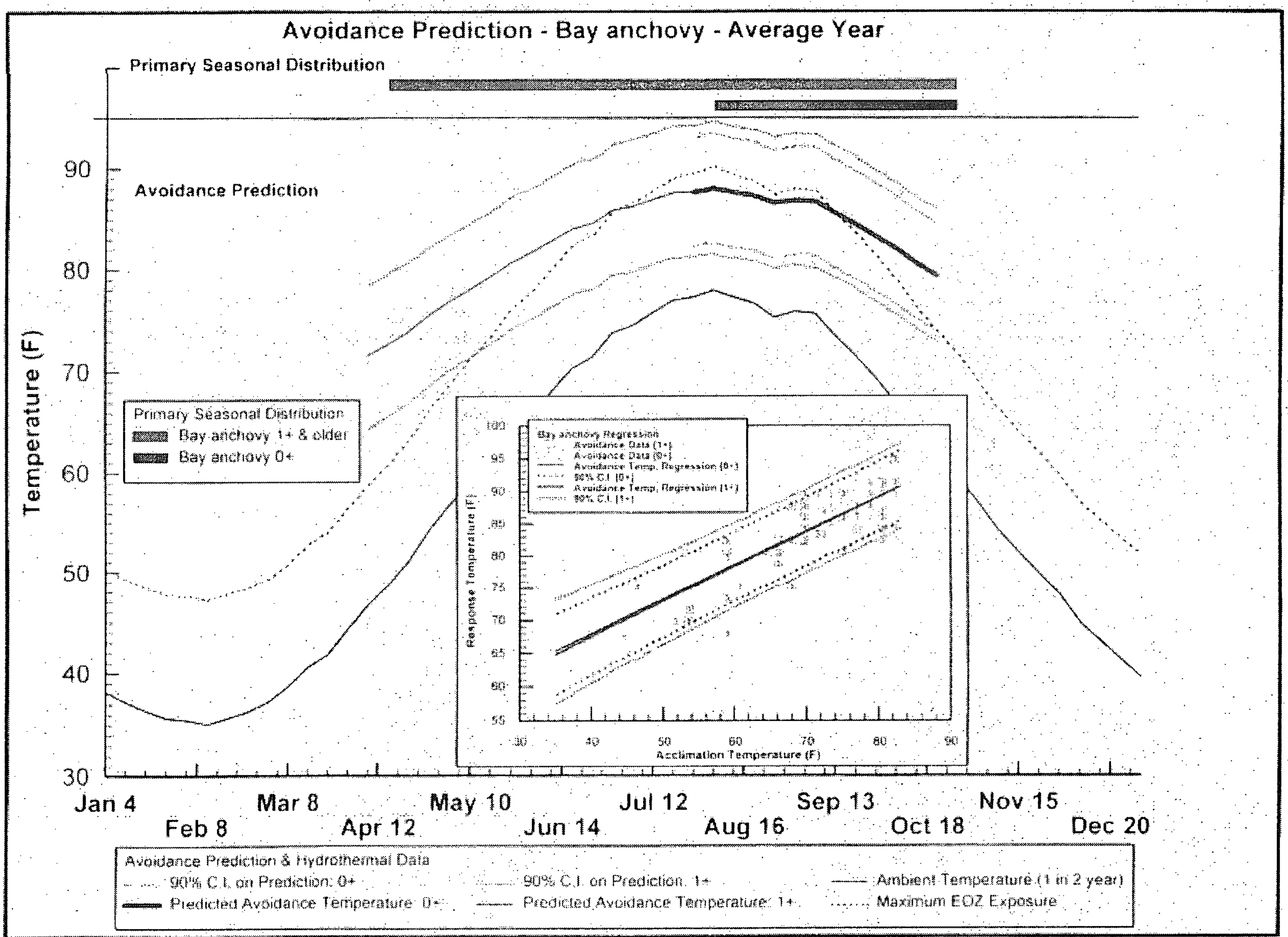
E Figure VI-28b. Avoidance prediction for Atlantic croaker for a warm year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



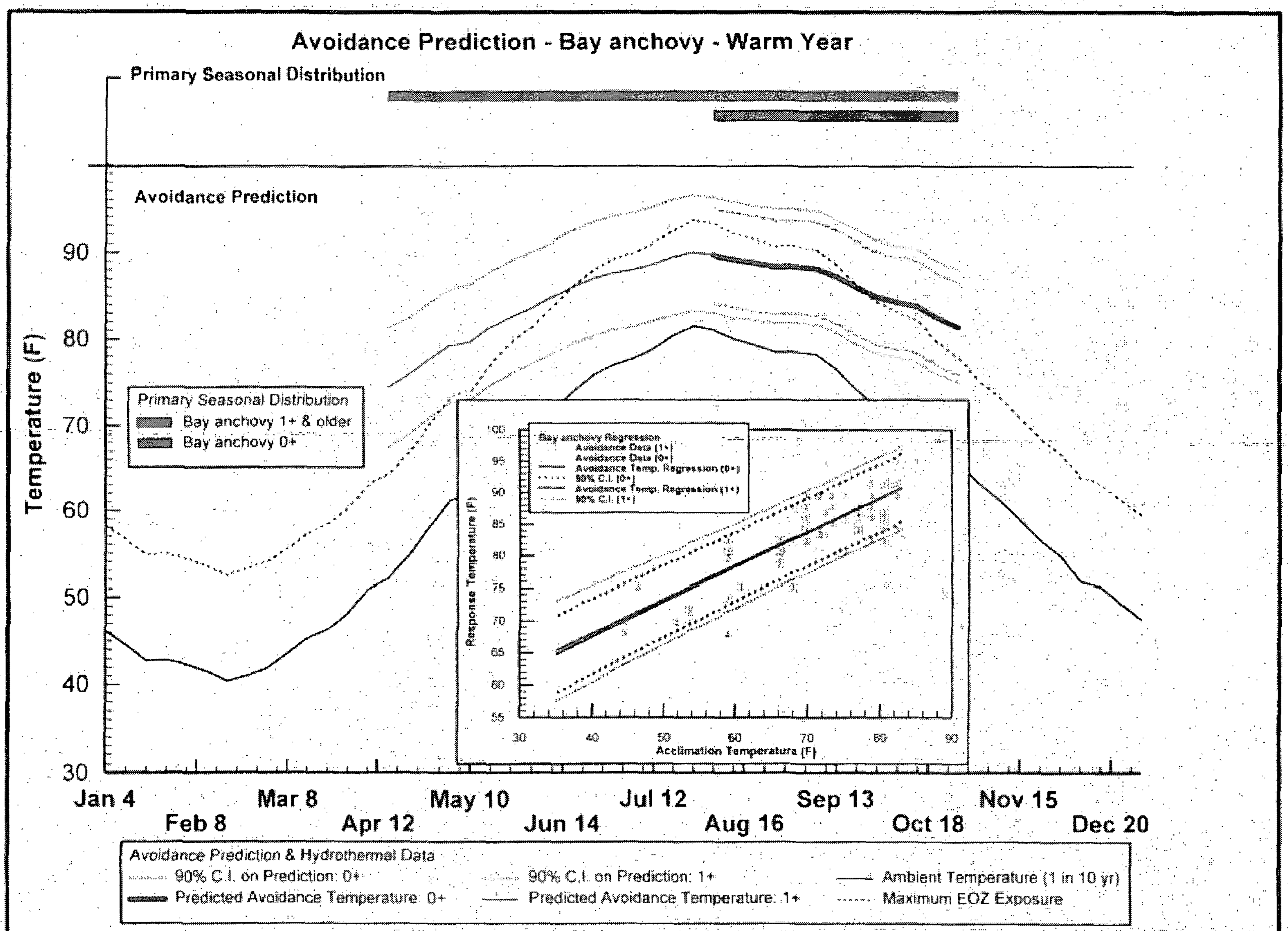
E Figure VI-29a. Avoidance prediction for weakfish for an average year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



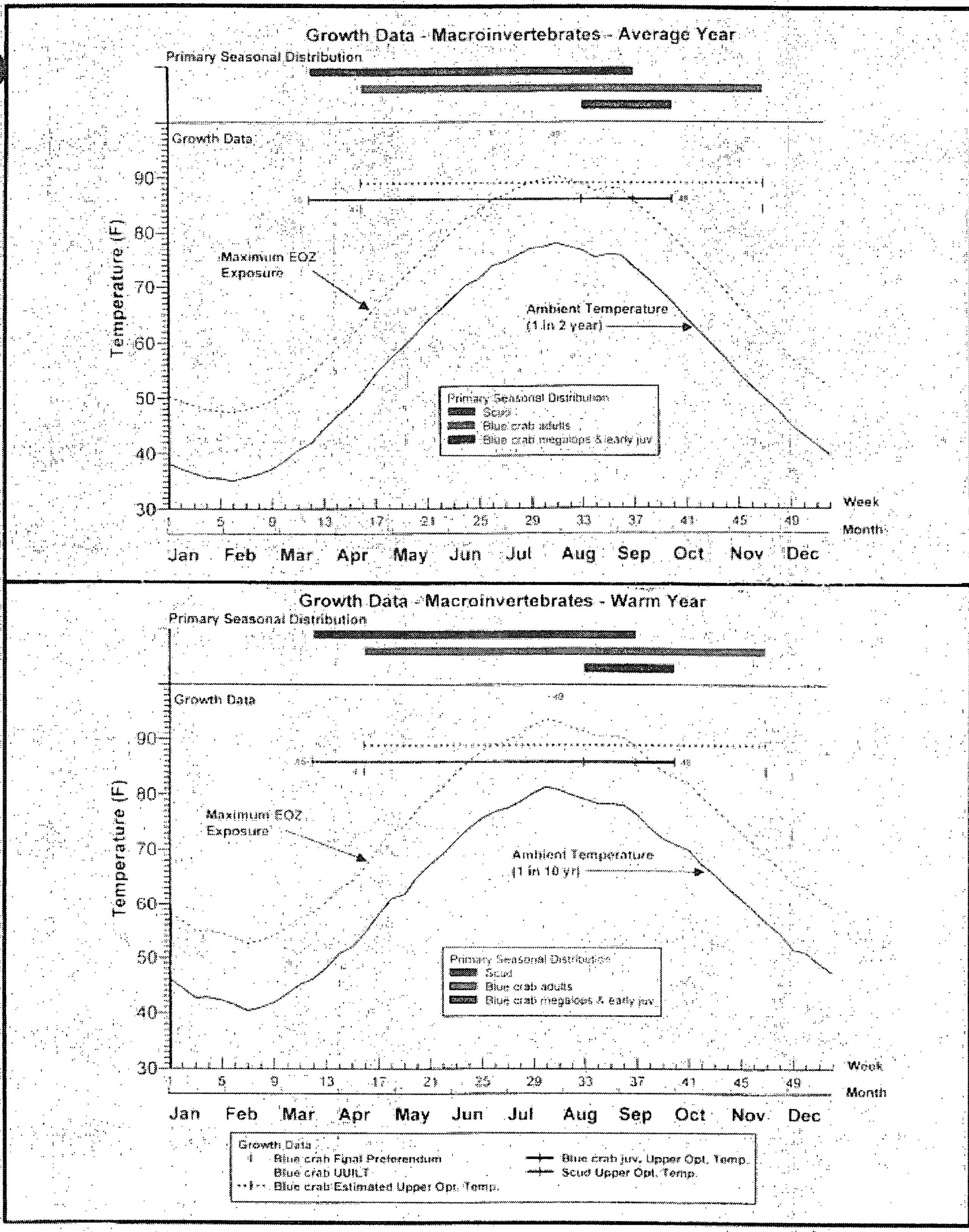
E Figure VI-29b. Avoidance prediction for weakfish for a warm year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)



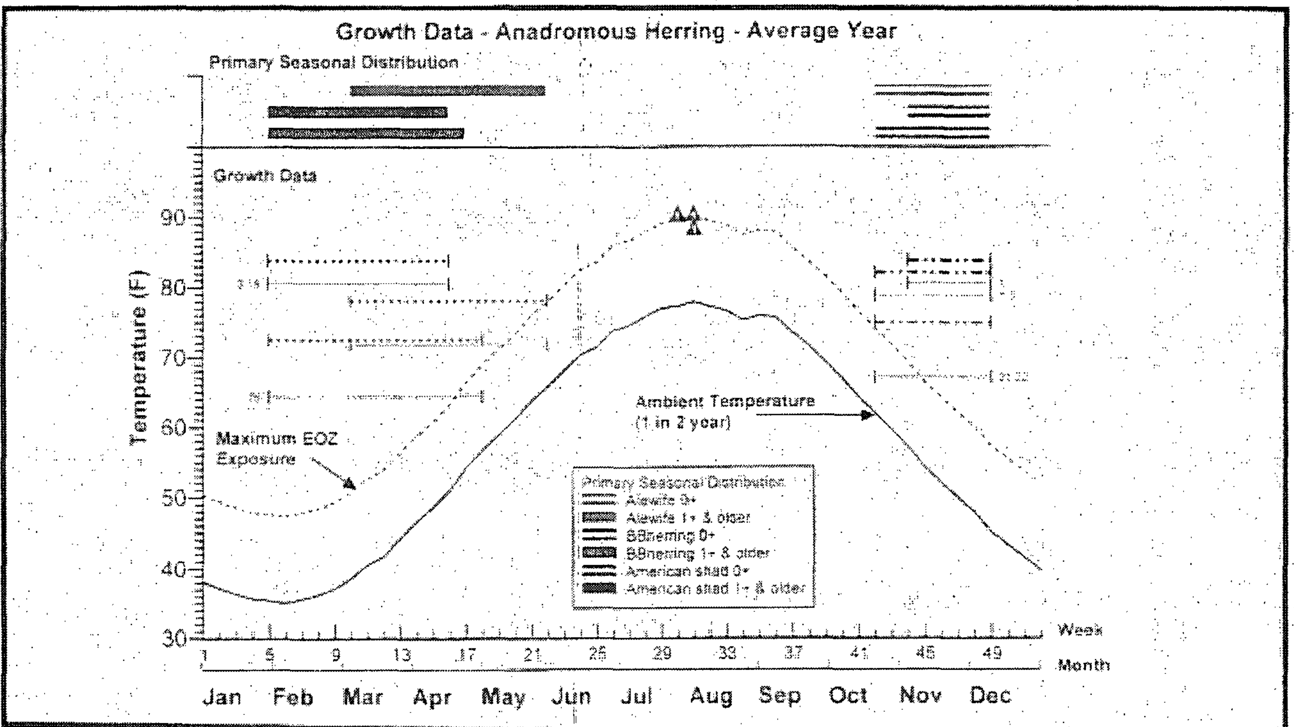
E Figure VI-30a. Avoidance prediction for bay anchovy for an average year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)

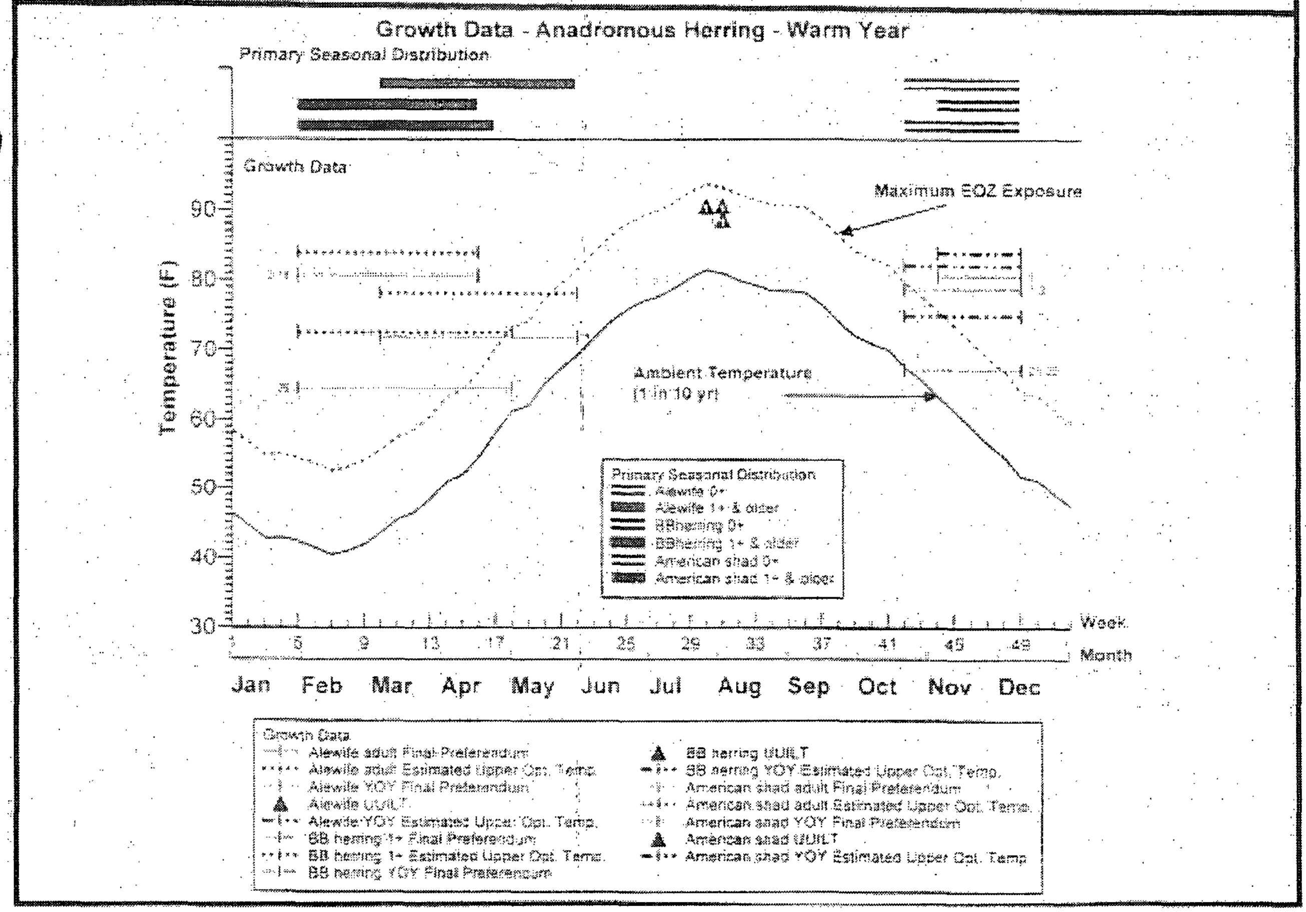


E Figure VI-30b. Avoidance prediction for bay anchovy for a warm year relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Data labels indicate reference codes.)

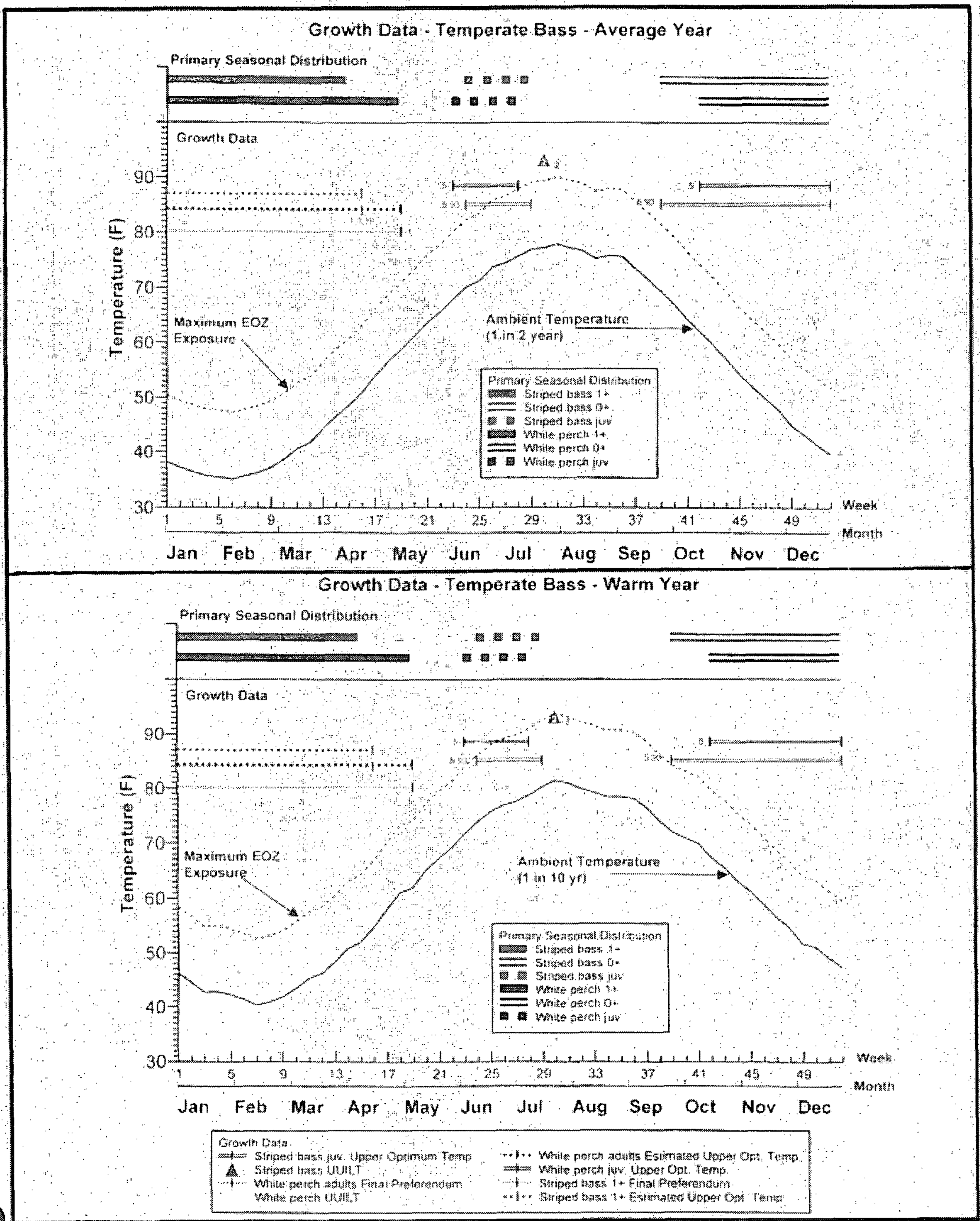


E Figure VI-31. Growth data for macroinvertebrates relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)

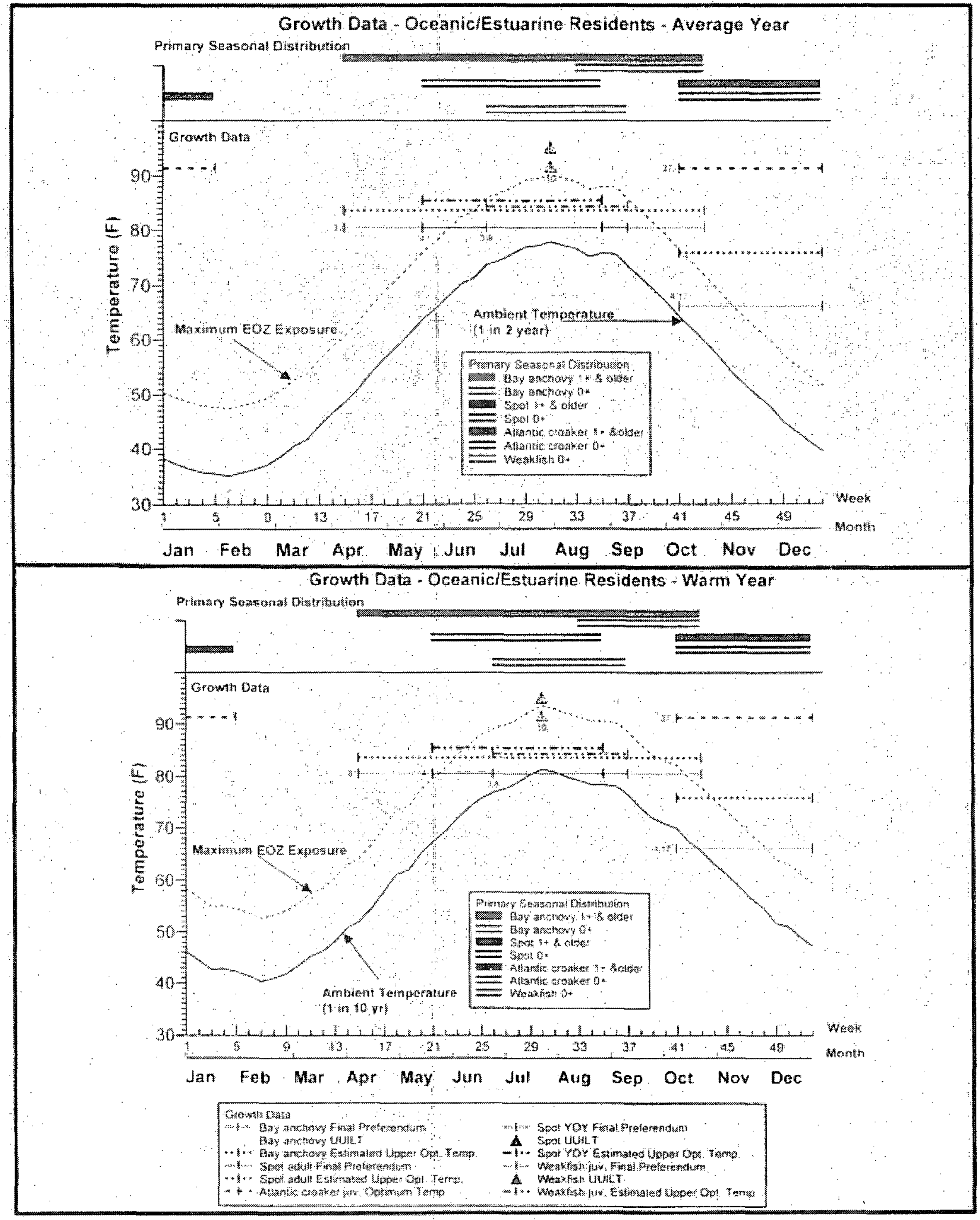




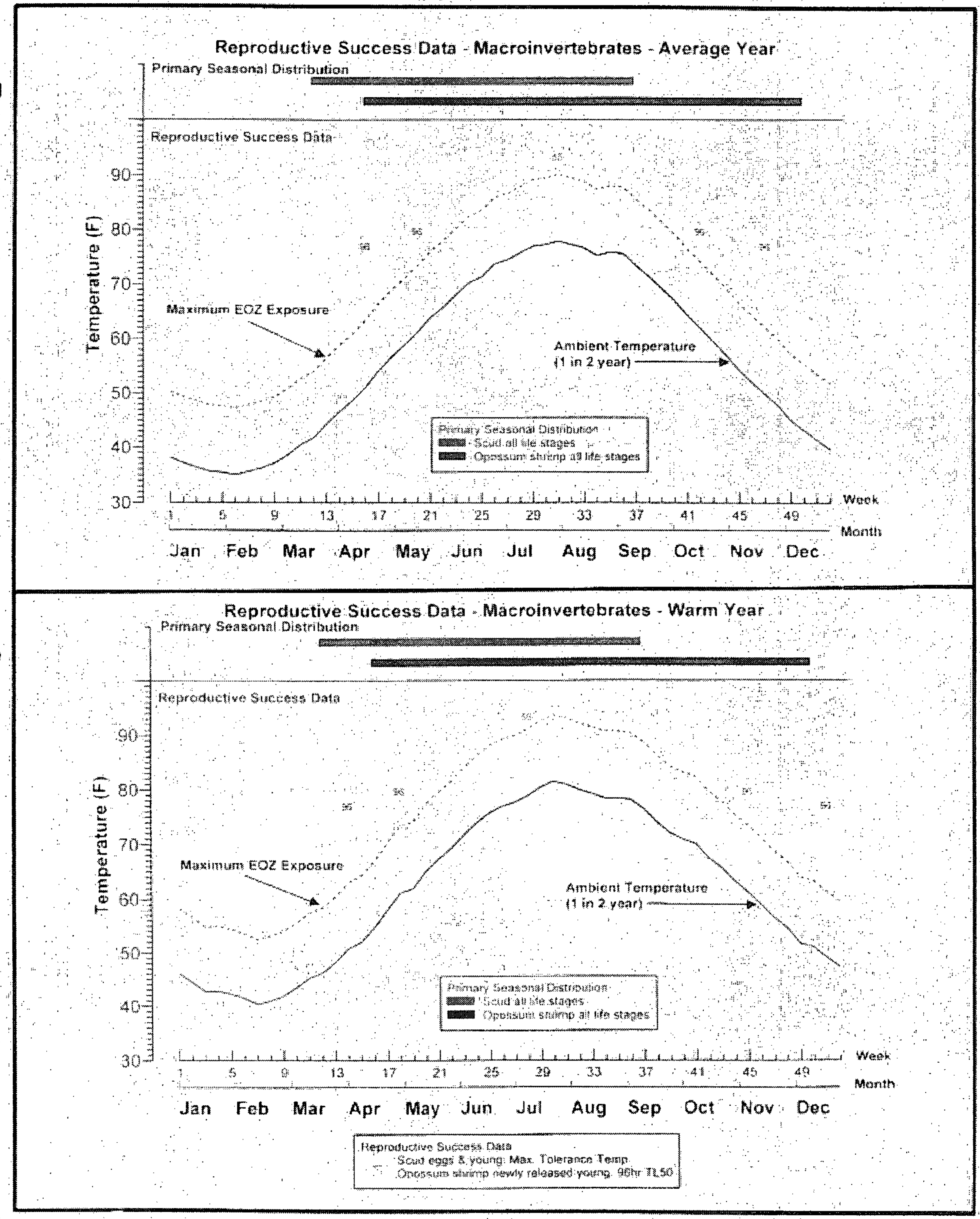
E Figure VI-32. Growth data for anadromous herring relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)



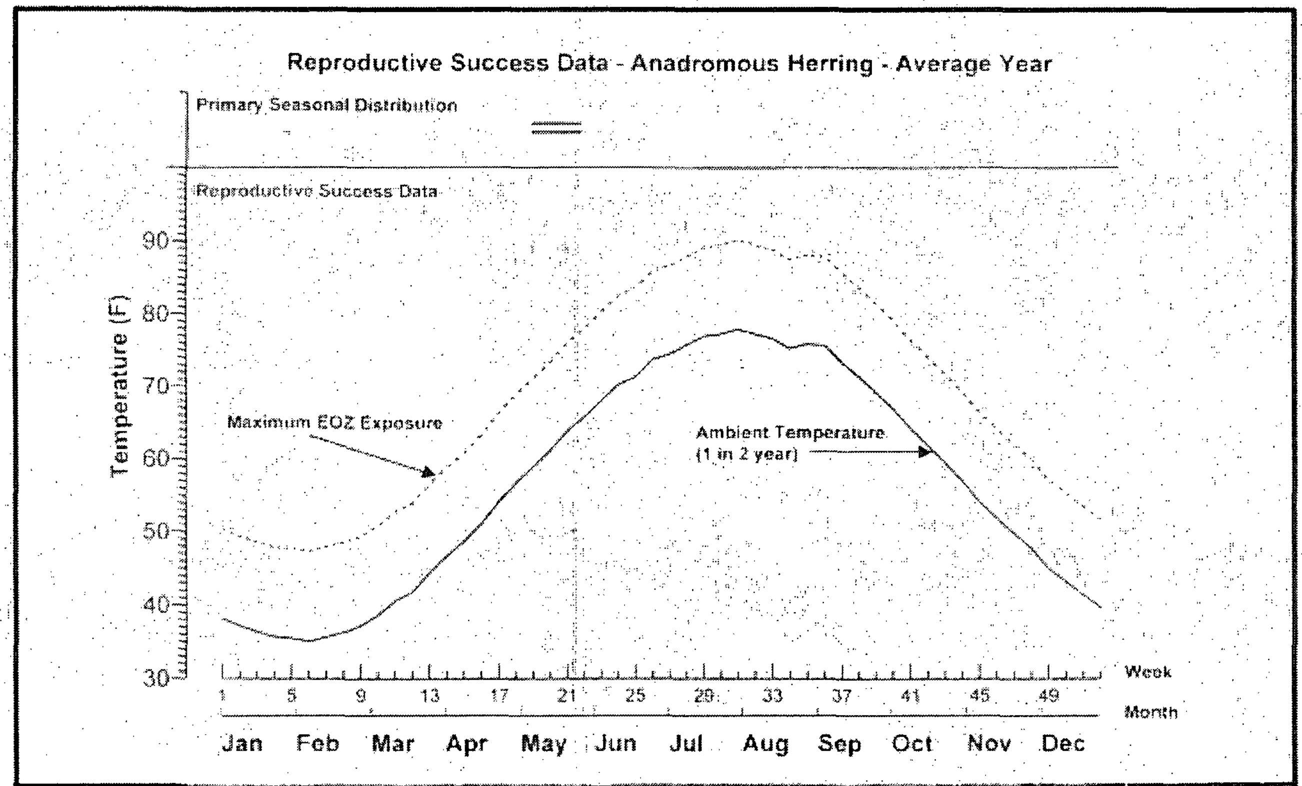
E Figure VI-33. Growth data for temperate bass relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)

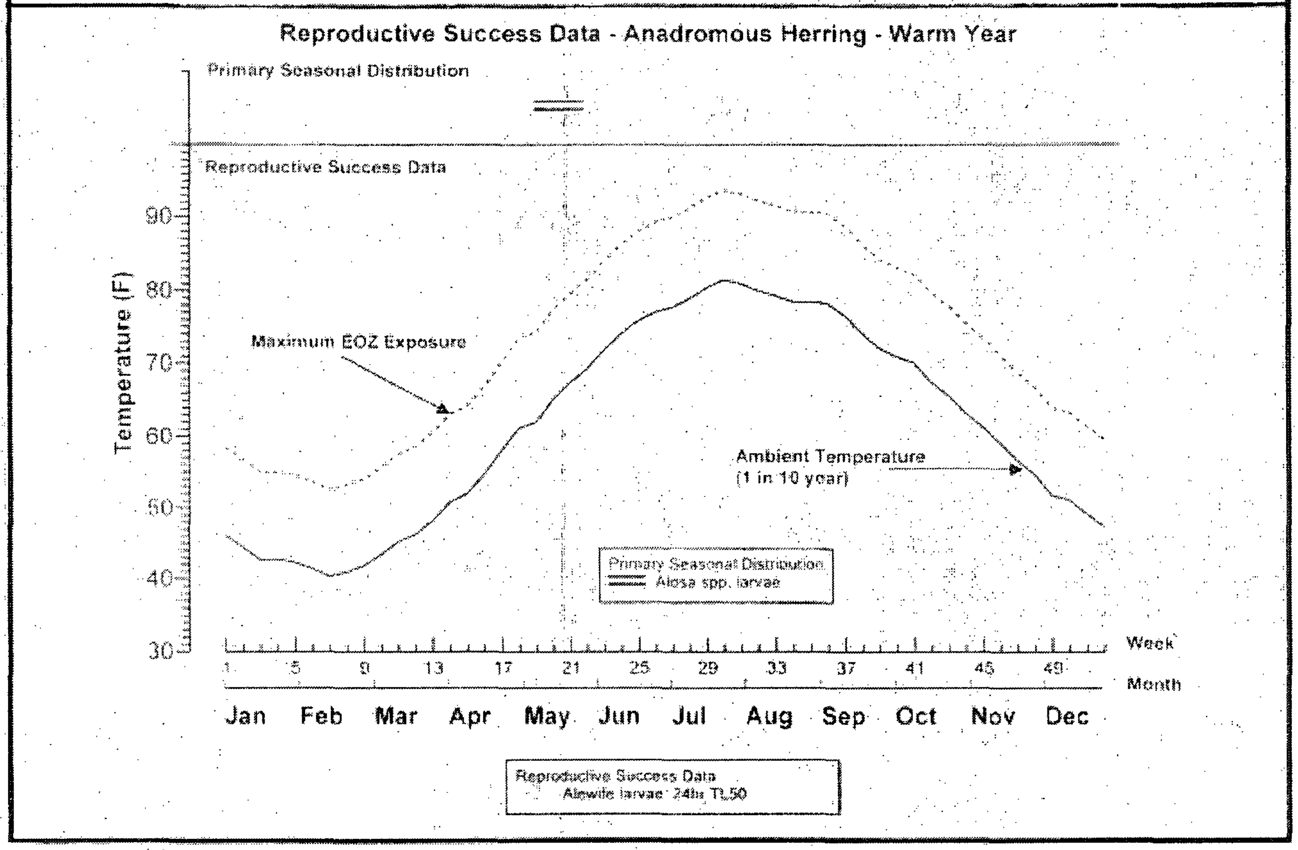


E Figure VI-34. Growth data for oceanic-estuarine residents relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)

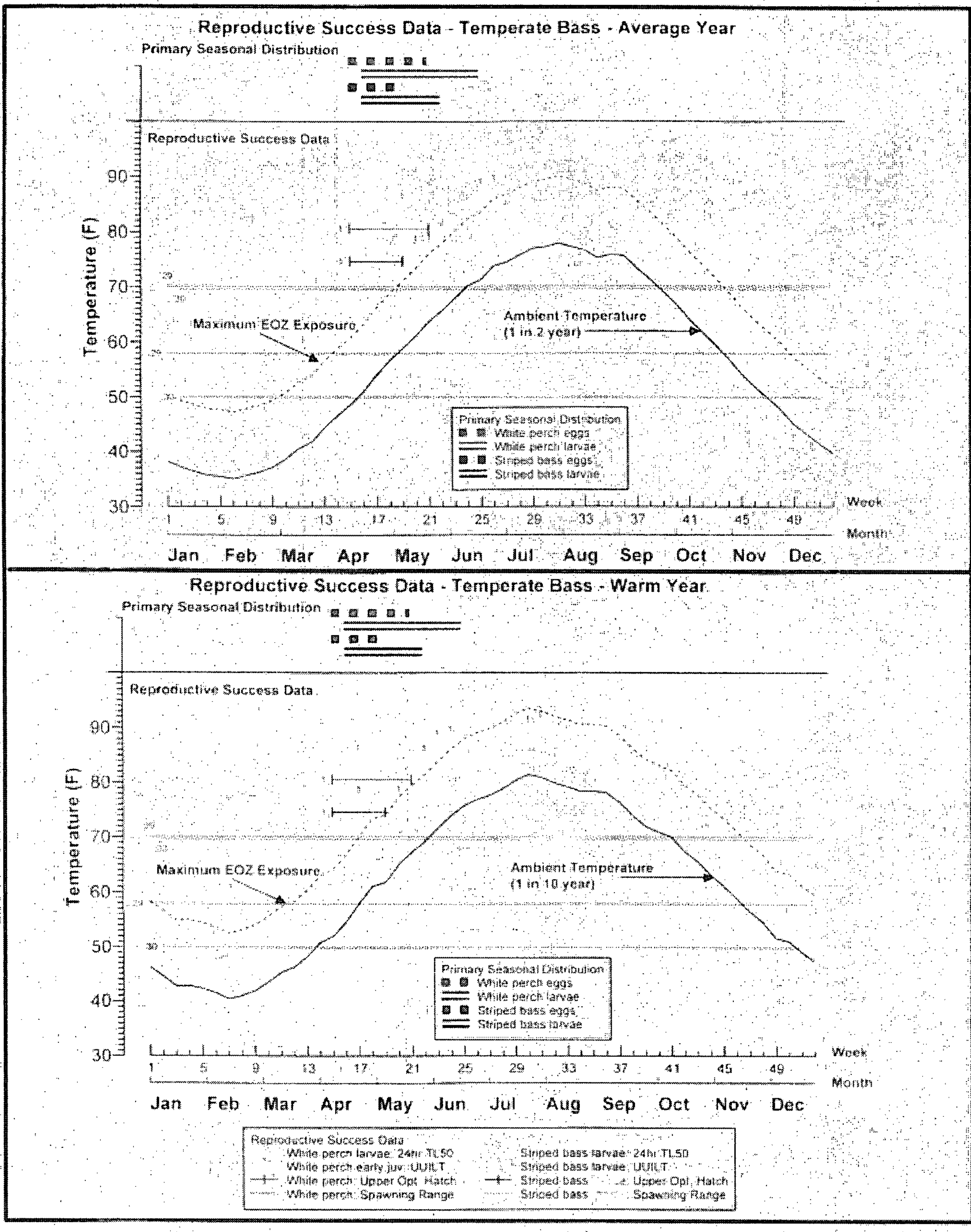


E Figure VI-35. Reproductive success data for macroinvertebrates relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)

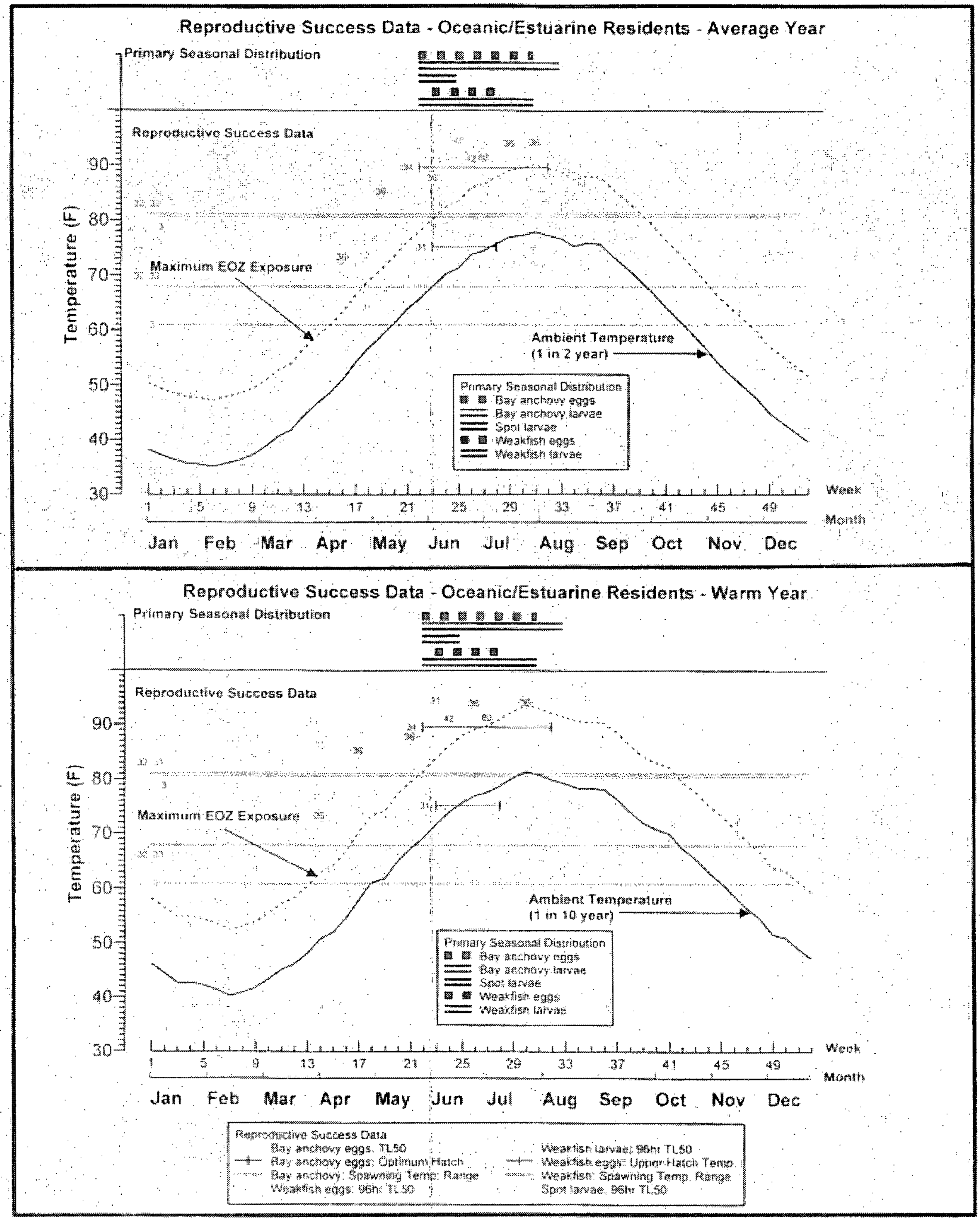




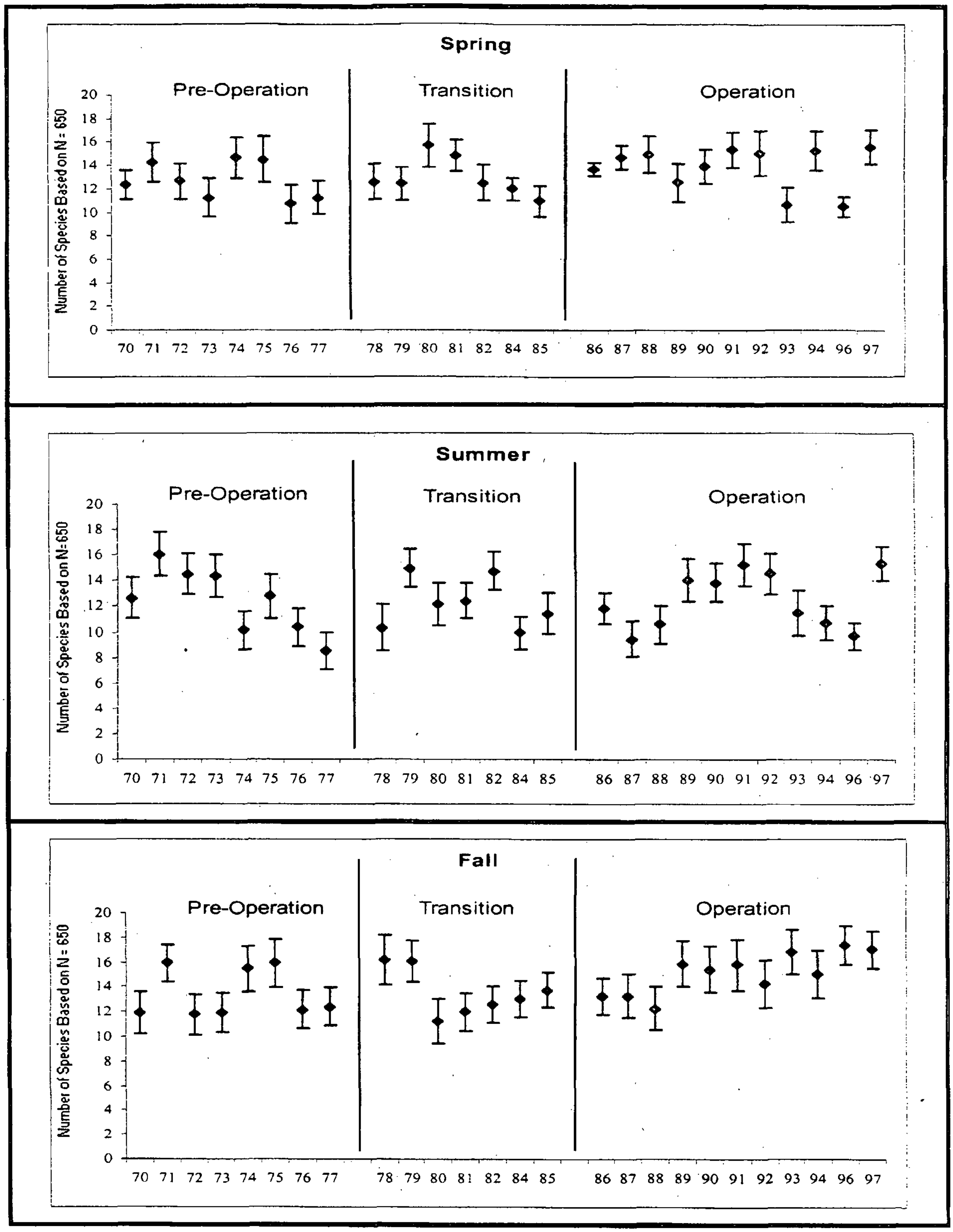
E Figure VI-36. Reproductive success data for anadromous herring relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)



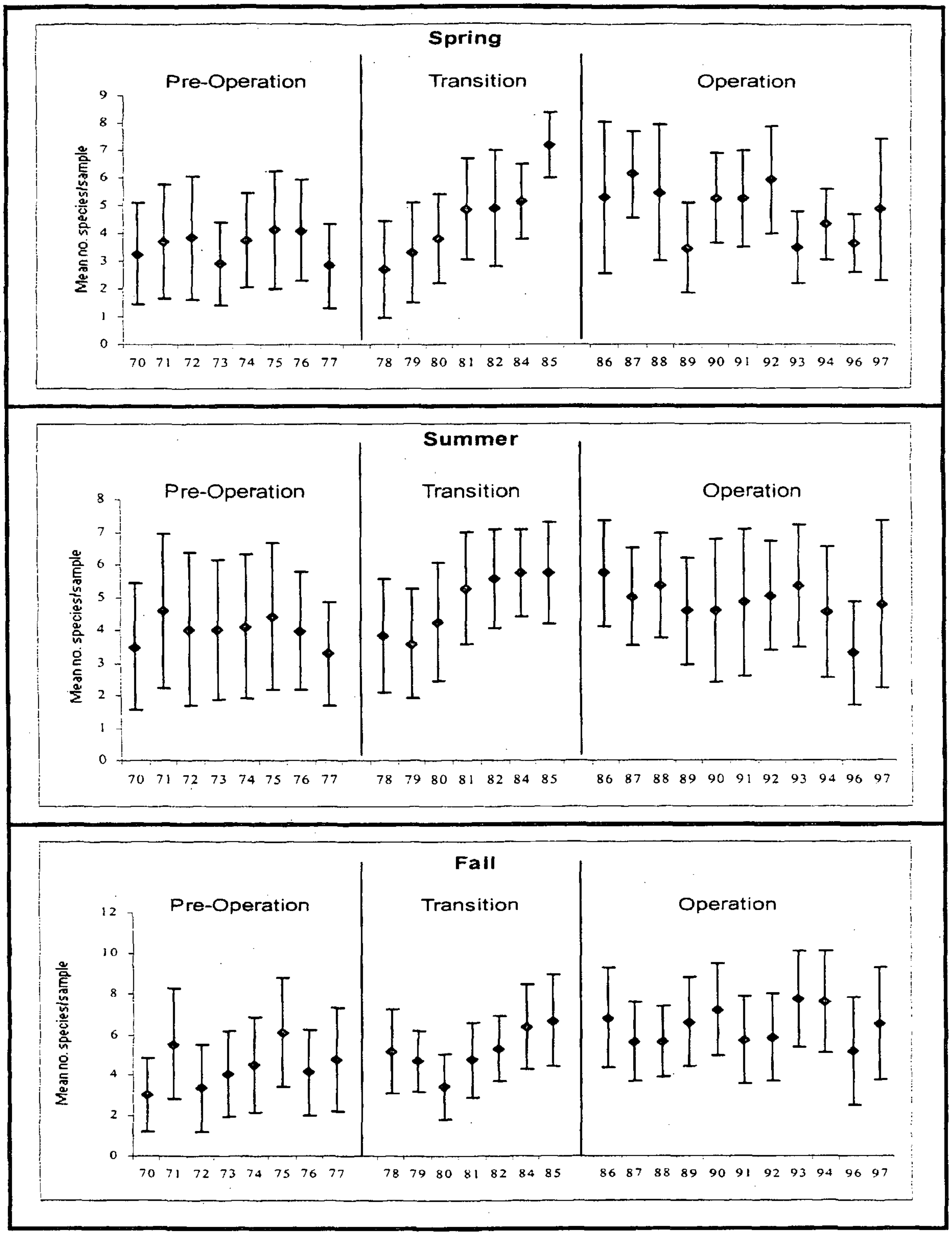
E Figure VI-37. Reproductive success data for temperate bass relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)



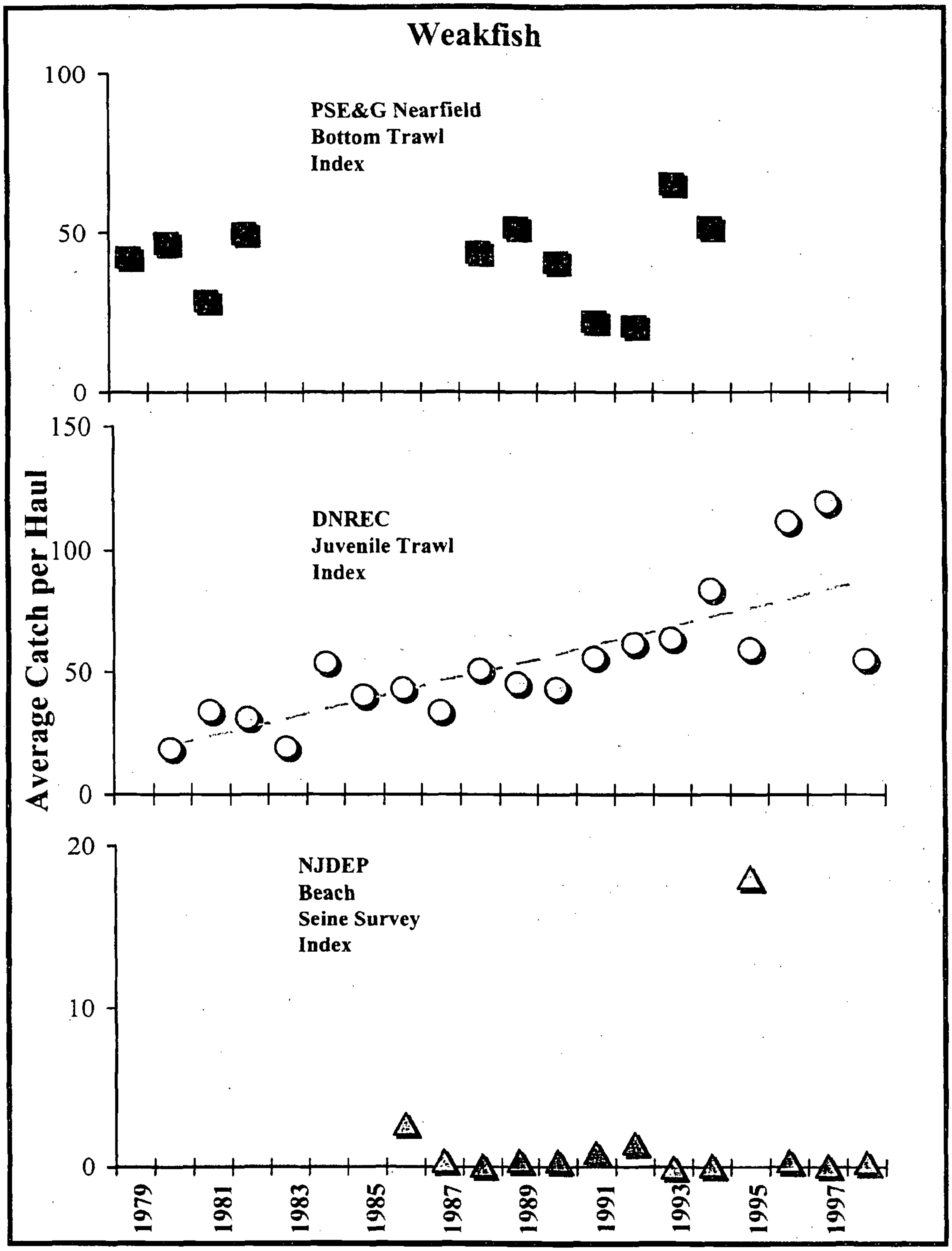
E Figure VI-38. Reproductive success data for oceanic-estuarine residents relative to their primary seasonal occurrence near Salem, and to the estimated ambient temperature and maximum plume temperature at the edge of the zone of initial mixing (EOZ). (Reader Caution: Continuous residence of the RIS at the EOZ plume temperature is highly unlikely for various reasons discussed in the text, and the chart must be interpreted in that context.) (Data labels indicate reference codes.)



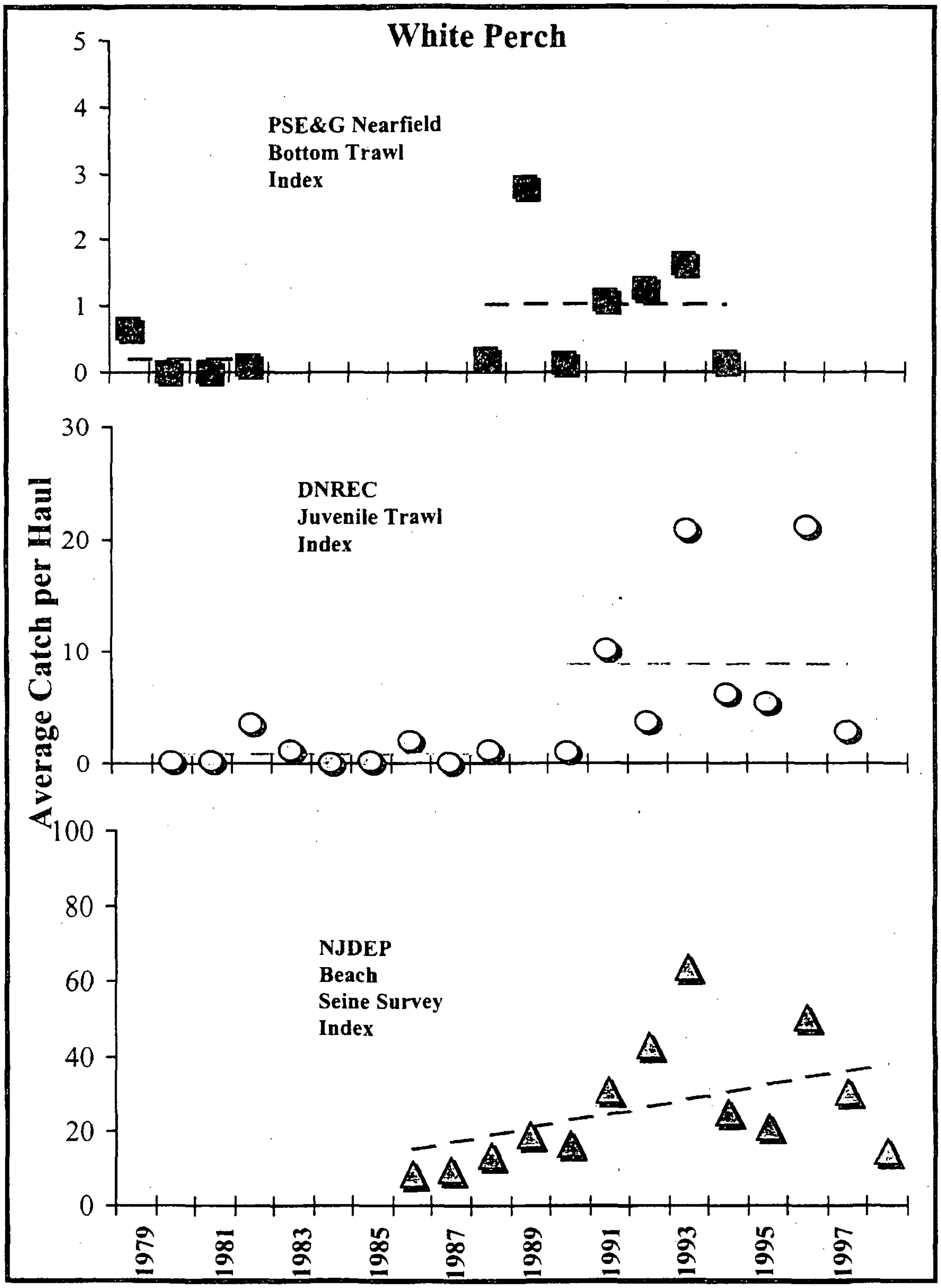
E Figure VI-39. Long-term trends in species richness of fish collected by bottom trawl in the vicinity of Salem, 1970 - 1998.



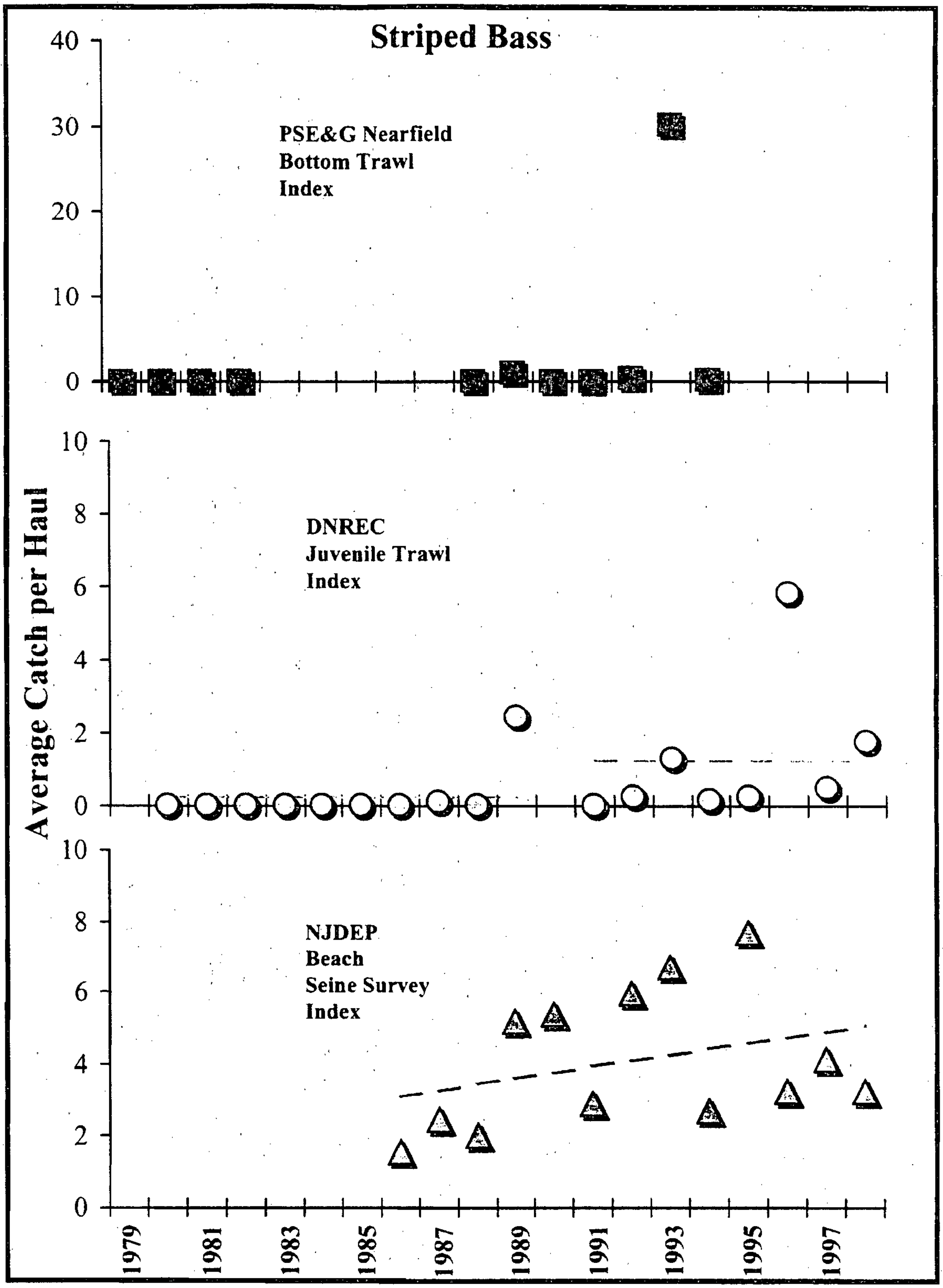
E Figure VI-40. Long-term trends in species density of fish collected by bottom trawl in the vicinity of Salem, 1970 - 1998.



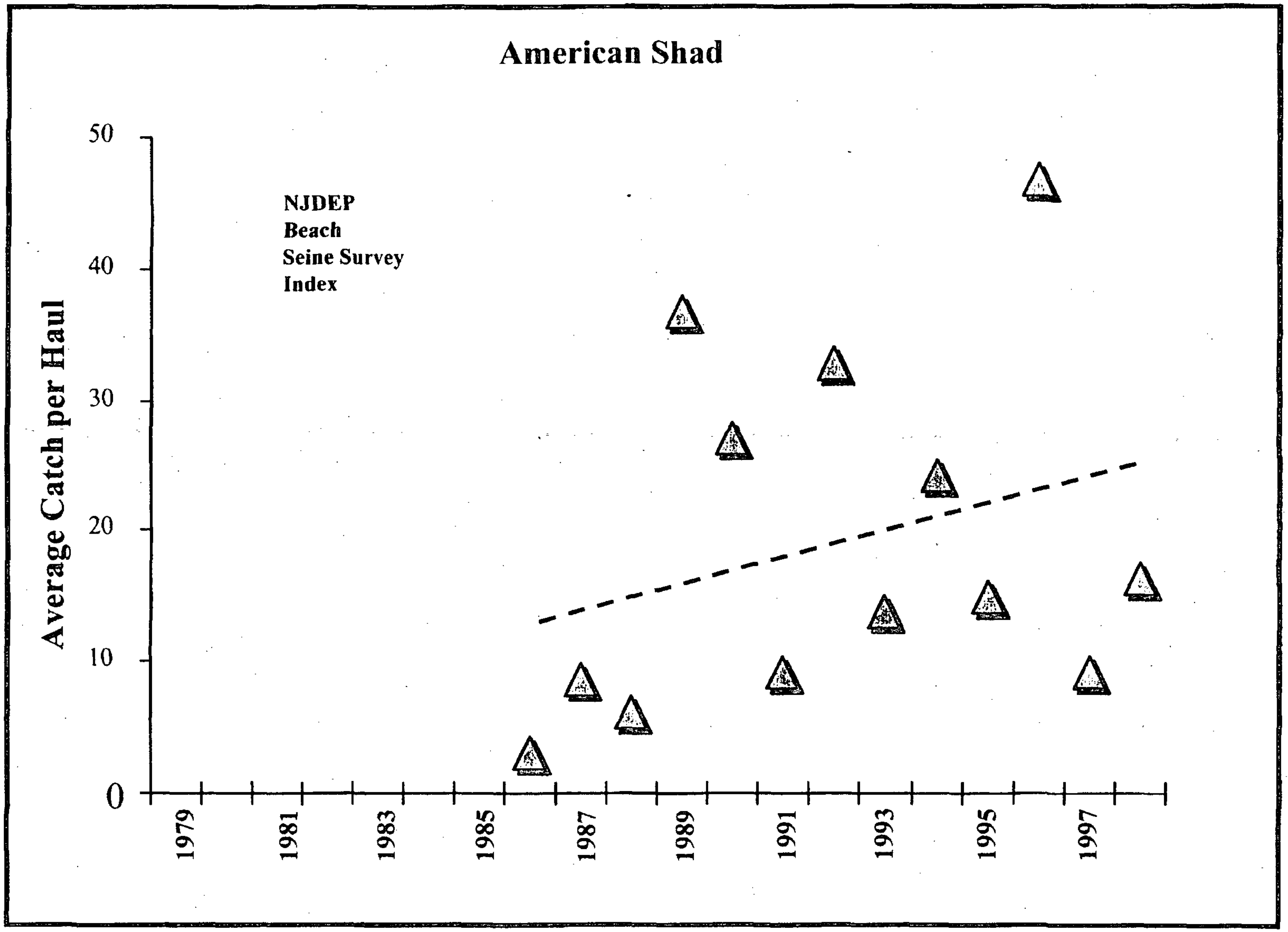
E Figure VI-41. Long-term trends in the abundance of age-0 weakfish in the Delaware Estuary based on three independent monitoring programs, 1979-1998.



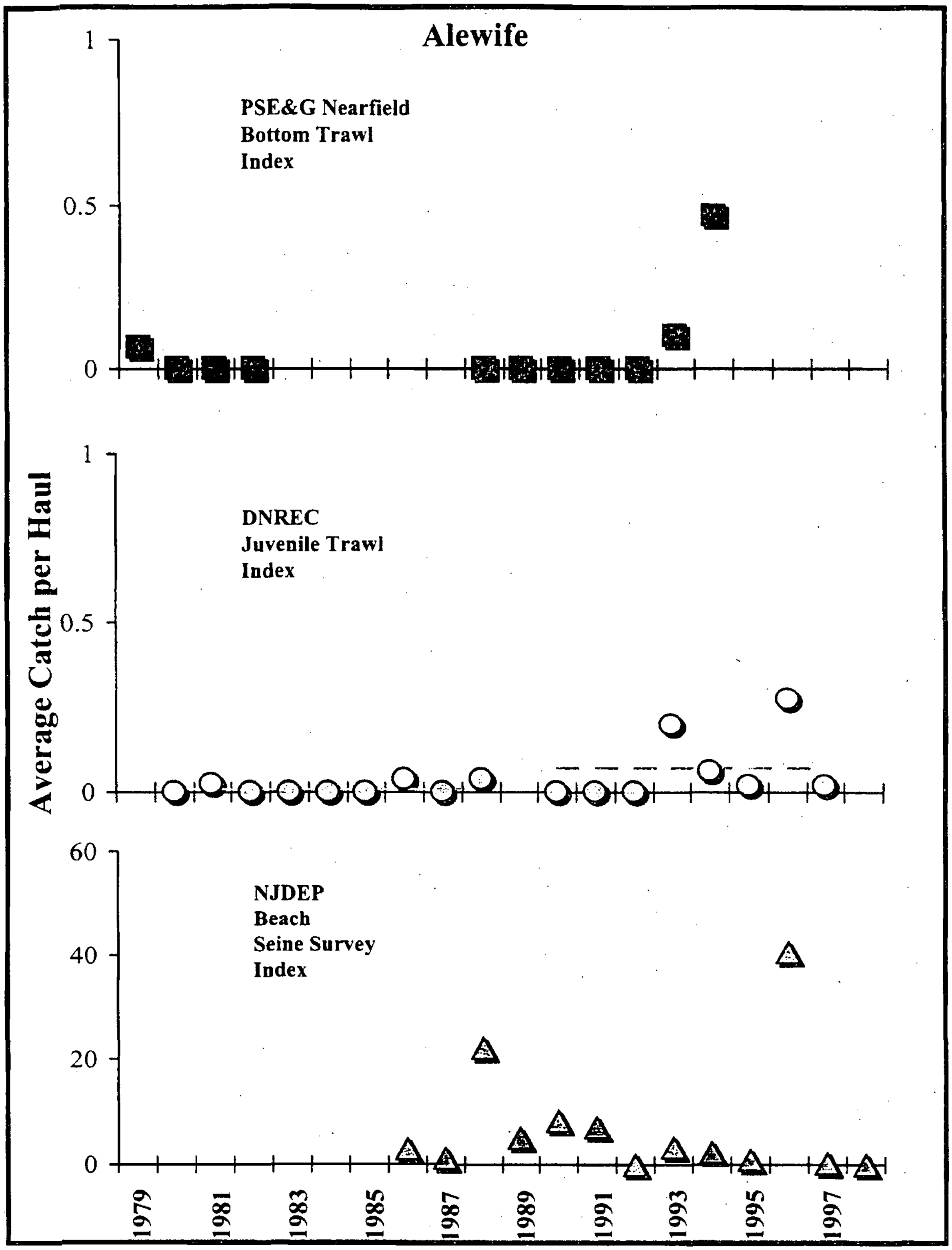
E Figure VI-42. Long-term trends in the abundance of age-0 white perch in the Delaware Estuary based on three independent monitoring programs, 1979-1998.



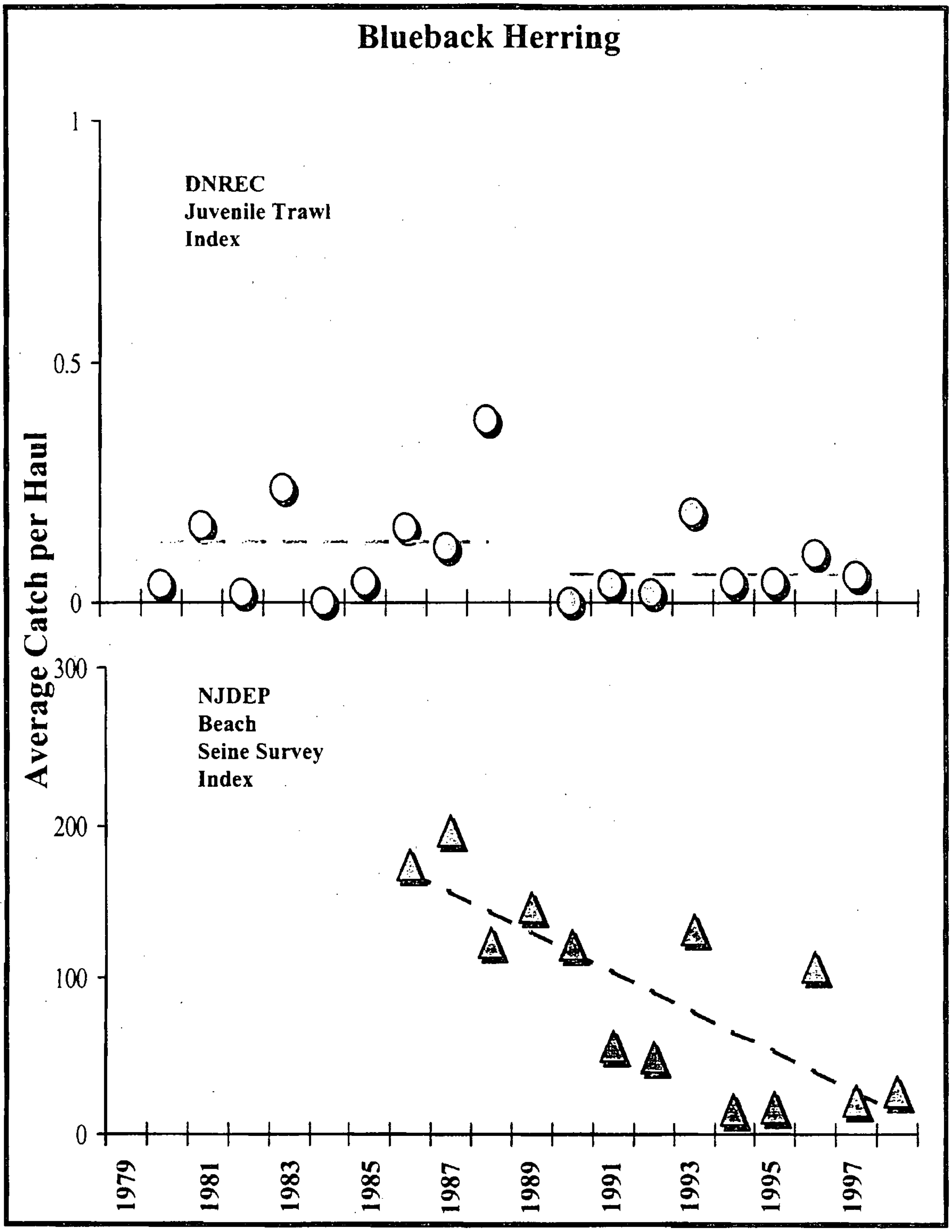
E Figure VI-43. Long-term trends in the abundance of age-0 striped bass in the Delaware Estuary based on three independent monitoring programs, 1979-1998.



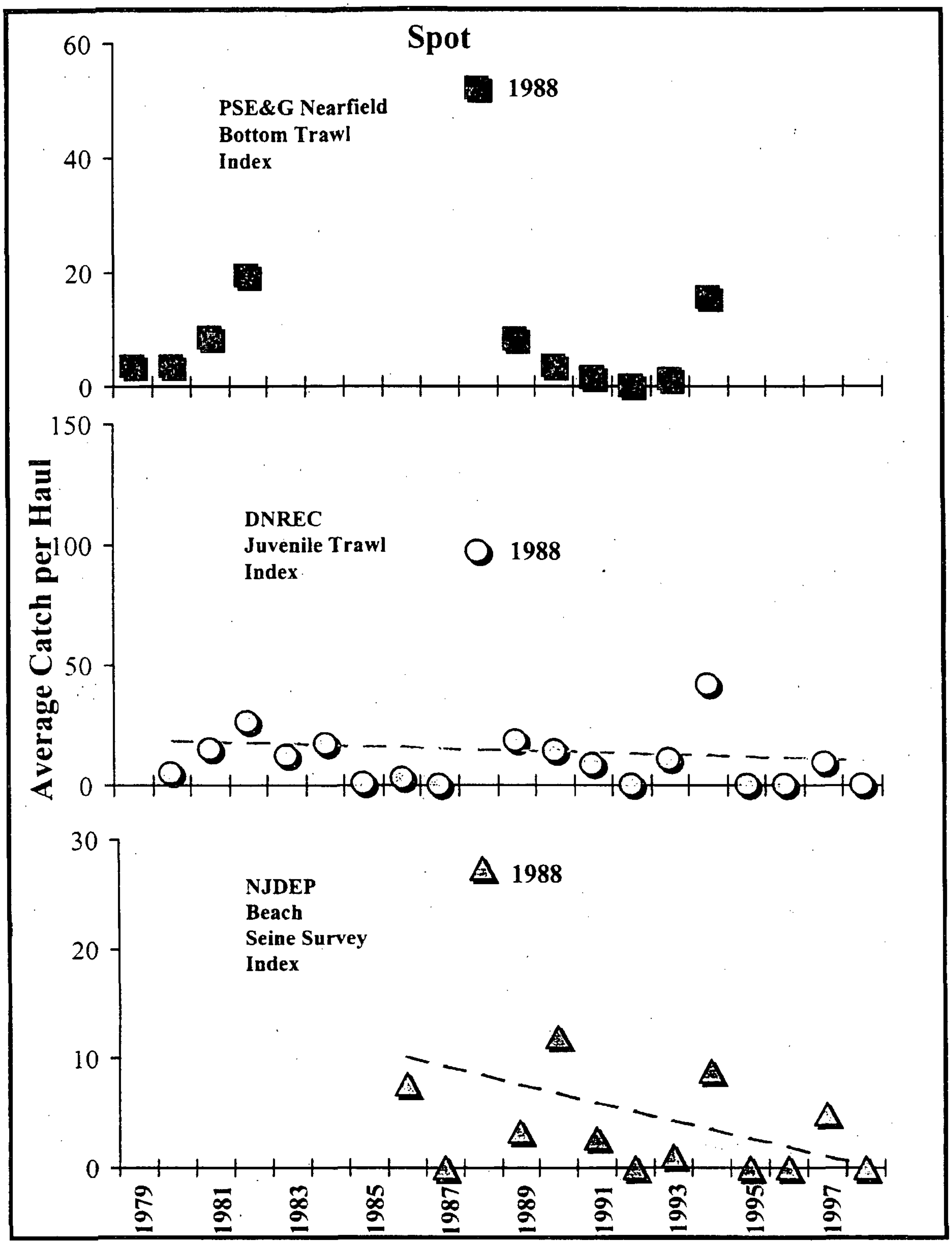
E Figure VI-44. Long-term trends in the abundance of age-0 American shad in the Delaware Estuary, 1979-1998.



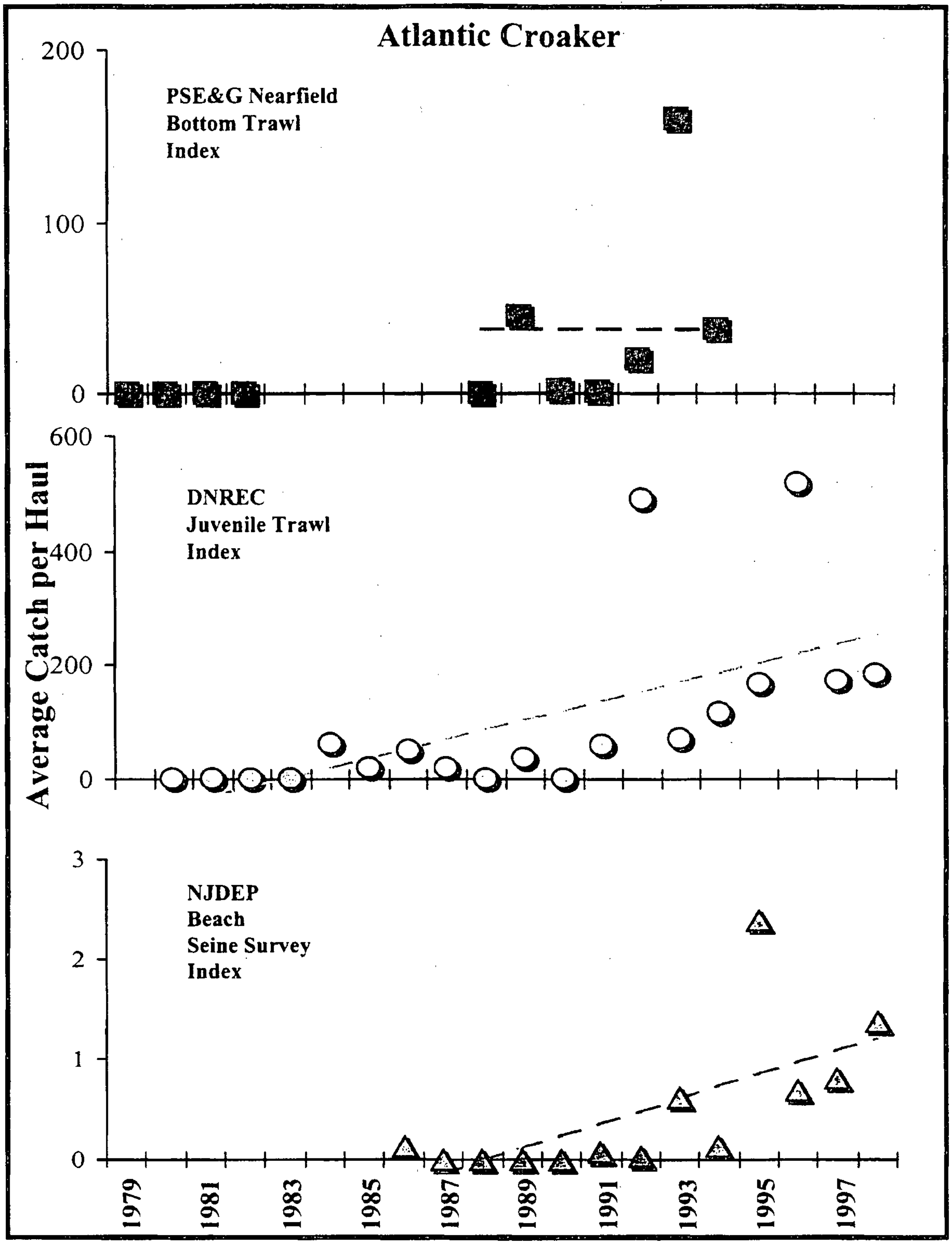
E Figure VI-45. Long-term trends in the abundance of age-0 alewife in the Delaware Estuary based on three independent monitoring programs, 1979-1998.



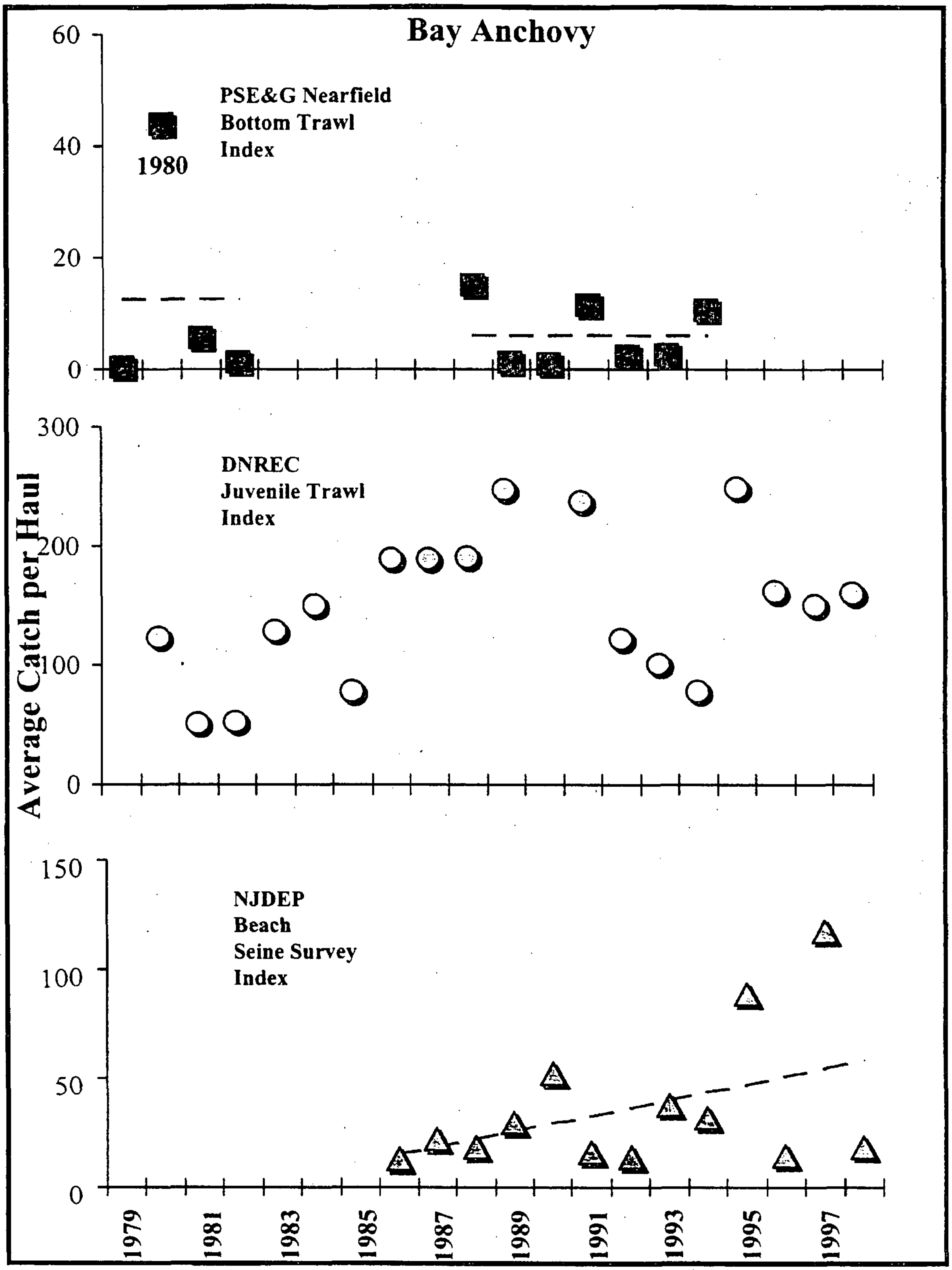
E Figure VI-46. Long-term trends in the abundance of age-0 blueback herring in the Delaware Estuary based on two independent monitoring programs, 1979-1998.



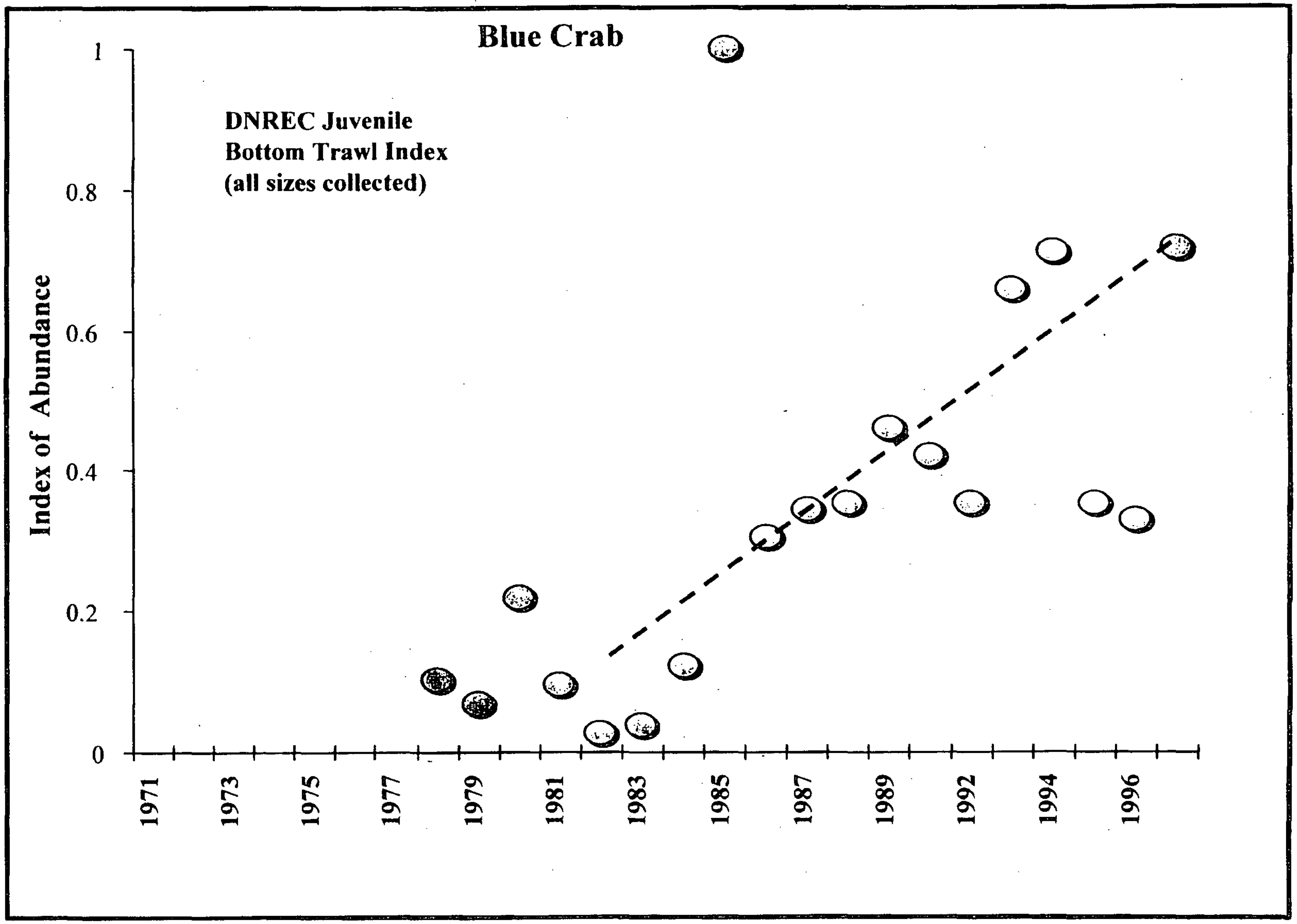
E Figure VI-47. Long-term trends in the abundance of age-0 spot in the Delaware Estuary based on three independent monitoring programs, 1979-1998.



E Figure VI-48. Long-term trends in the abundance of age-0 Atlantic croaker in the Delaware Estuary based on three independent monitoring programs, 1979-1998.



E Figure VI-49. Long-term trends in the abundance of age-0 bay anchovy in the Delaware Estuary based on three independent monitoring programs, 1979-1998.



E Figure VI-50. Long-term trends in the abundance of blue crab in the Delaware Estuary, 1971 - 1997.

Summary of Trends in Abundance

	DNREC Juvenile Trawl	NJDEP Beach Seine	PSE&G Nearfield Bottom Trawl
Alewife	⇧		
American shad	⊘	⇧	⊘
Atlantic croaker	⇧	⇧	⇧
Bay anchovy		⇧	⬇
Blueback herring	⬇	⬇	⊘
Spot	⬇	⬇	
Striped bass	⇧	⇧	
Weakfish	⇧		
White perch	⇧	⇧	⇧
Blue crab	⇧	⊘	⊘

⇧ Statistically Significant Increase

⬇ Statistically Significant Decrease

Blanks Indicate No Statistically Significant Trend (p<0.05)

⊘ Insufficient Data for Calculating Abundance Index

E Figure VI-51. Summary of long-term trends in the abundance of selected RIS in the Delaware Estuary based on three independent monitoring programs, 1979 - 1998.

VII. OVERALL ASSESSMENT OF PROTECTION AND PROPAGATION OF THE BIC (MASTER RATIONALE)

VII.A. Introduction

The term master rationale is used in the draft 316(a) Guidance (USEPA 1977) to describe a summary section of a 316(a) Demonstration that provides a synthesis of the results of the biothermal evaluations in 12 context with identified decision criteria. The purpose of this section is to present concisely the key findings of this 316(a) Demonstration to form convincing evidence that the balanced indigenous community (BIC) has been and will continue to be protected (USEPA 1977). PSE&G has previously submitted six biothermal assessments to various regulatory agencies. This is the seventh environmental assessment of Salem Generating Station's thermal discharge in 30 years. The first assessment was undertaken prior to obtaining regulatory approval to construct Salem; the most recent assessment was developed for this 316(a) Demonstration (Appendix E) and was performed using results of a comprehensive thermal monitoring program and sophisticated mathematical modeling. Consistent with technical guidance for preparation of Section 316(a) Demonstrations (USEPA 1977), the master rationale for this Demonstration (Master Rationale) synthesizes results from four methods of evaluation to demonstrate that the propagation and protection of the BIC is protected by the Section 316(a) variance in place for Salem. The four methods are: critical function zone (CFZ) screening; biotic category (BC) screening; predictive/representative important species (RIS) evaluation; and retrospective/no prior appreciable harm (NPAH) evaluation (Section VI.C).

This master rationale sets out the basis for the conclusion that the evaluations presented in this Appendix (CFZ, BC, RIS, and NPAH) fulfill all of the USEPA decision criteria (Section II) required for a successful 316(a) Demonstration that the protection and propagation of a balanced indigenous community (BIC) is assured.

A brief summary of the characteristics of the Delaware Estuary ecosystem (from Appendix C to this submittal) and the Station's thermal discharge provides the background needed for the evaluations. Then the assessment portion of the Master Rationale is provided for definition of the thermal plume (thermal exposures) and the Biothermal Assessment of this 316(a) Demonstration.

VII.B. Overall Picture of the Delaware Estuary

The following section summarizes detailed information on the Estuary (contained in Appendix C).

VII.B.1. Size, Shape, and Volume (Appendix C Section II)

The Delaware Estuary is the receiving water for the Station's thermal discharge at RM 50 (Figure VII-1). The Estuary is the second largest on the North Atlantic Coast. It includes all of the tidally influenced water area (680,000 acres) from the mouth of Delaware Bay (RM 0) to the falls in the Delaware River at Trenton, NJ (RM 133). It includes about 480,000 acres of open water area (the pelagic zone) and 200,000 acres of tidal wetlands distributed along portions of its 280 miles of shoreline, mostly down-Estuary from the

Station (Figure VII-1). The pelagic zone of the Estuary varies in width. It is 11 miles across the mouth of the Bay, 27 miles at its widest point, 2.5 miles at the Salem Station (RM 50), and 1,000 feet across at Trenton.

Water depth in the Bay is less than 30 feet in 80 percent of the Bay and the maximum depth is 150 feet near the mouth. Much of the tidal river area is less than 10 feet deep. An exception occurs in the shipping channel where dredging maintains depth at 40 feet. The total volume of the Estuary at mean high tide is approximately 16.6 billion cubic yards (448 billion cubic feet).

The dominant tidal period in the Estuary is 12.42 hours. The mean tidal range averages 4.8 feet at the mouth of the Estuary (RM 0), 5.9 feet at Artificial Island (RM 50), and 8.1 feet at Trenton, NJ (RM 133). This tidal prism has a volume of approximately 4.3 x 10^9 cubic meters (140 billion cubic feet) which represents about one third of the total volume of the Estuary.

The Estuary is the central link in a continuum of environments: nontidal freshwater lakes and tributary streams, the tidal freshwater river and smaller tidal streams, tidal brackish river and streams, the tidal near-marine Delaware Bay, and the marine Atlantic Ocean (Figure VII-1). The hydrological linkages among these environments determine the dynamics of temporal and spatial distribution of salinity, water quality, sediment quality, and biological characteristics of the Estuary. The Salem Station is located near the middle of this continuum, in the Transition Zone, where salinity changes markedly and often, turbidity is high, tidal currents are strong, and the biological community is in transition between fresh water and marine, and between open water and marshes.

VII.B.2. Hydrology and Salinity

The Delaware Estuary's watershed consists of the entire Delaware River Basin and includes numerous branching tributaries and reservoir systems. Major tributaries in the upper basin (above Trenton) include the West Branch, East Branch, Neversink River, Mongaup River, Lackawaxen River, Lehigh River, and the Delaware and Raritan Canal. The Schuylkill River is the largest tributary in the lower basin.

The total annual mean freshwater inflow to the Delaware Estuary is approximately 20,243 cfs. Two tributaries to the upper Estuary contribute approximately 72 percent of the inflow: the nontidal Delaware River and the Schuylkill River. Only 10.2 percent of the total average freshwater inflow is discharged to the Estuary below the Chesapeake and Delaware (C&D) Canal (Figure VII-1).

Based on USGS data, mean annual flows at Trenton have ranged from 4,708 cfs (water year 1965) to 19,810 cfs (water year 1928). The highest mean monthly flows have occurred during March and April, and the lowest have occurred during August and September. Mean daily discharges have ranged from 1,240 to 279,000 cfs, with pronounced variations among seasons and years.

The C&D Canal (RM 59), about 9 miles north of the Salem Station, provides a sea-level connection between the Estuary and the upper Chesapeake Bay through which a significant exchange of water occurs. Reversing, semidiurnal tidal currents of roughly 1.2 knots (0.6 m/s) occur within the Canal. Net (tidally-averaged) flows through the Canal also occur. On average, the net flow is from Chesapeake Bay to the Delaware Estuary, but it may reverse direction at any time. Results of a recent Army Corps of Engineers (USACE) simulation of net (seasonally-averaged) flows during each spring and fall from 1957 through 1987 suggest that the net flow for every spring in this period was from Chesapeake Bay to the Delaware Estuary, with net flows ranging from roughly 700 to 3,000 cfs (Hsieh and Richards 1996).

Some exchange of water between the Estuary and its watershed also occurs via groundwater. Aquifers within the Coastal Plain sediments contain large quantities of high-quality freshwater. Groundwater seepage from unconfined aquifers may provide some freshwater to the Estuary, and recent studies of radon concentrations suggest that seepage into the Bay is occurring (e.g., Bachman and Ferrari 1995). On the other hand, exploitation of freshwater within these aquifers can direct flow from the Estuary into the aquifer. For example, the USGS estimated that the Delaware River contributes almost 130 cfs to the Potomac-Raritan-Magothy aquifer where the aquifer intersects the River near Philadelphia (USGS 1986).

Flow from numerous tributary streams in the drainage basin and groundwater fills the tidal fresh water portions of tributaries and the main stem Delaware River. In the main stem this freshwater Tidal River Zone or "Upper Zone" extends from Trenton (RM 133) to about RM 80. Marine saltwater (approximately 6,500,000 cfs) flows in and out of the 11-mile wide mouth of the Bay (RM 0) during each of the ebb and flood phases of the (12.42-hour) tidal cycle. Average tidal flow past the Station (RM 50) is approximately 450,000 to 500,000 cfs. The mixing of the tidal-river freshwater with saltwater from the Bay portion of the Estuary produces a salinity Transition Zone (0-15 ppt) between RM 80 and RM 50 (the Transition Zone) (Figure VII-1). Seasonal and annual variation in freshwater inflow has a major influence of more than 20 miles on the location of low salinity isopleths (isohalines) in this zone. In addition, position of any given low isohaline may differ by about 8.5 miles during a single tidal cycle.

VII.B.3. Water and Sediment Quality

The massive tidal flow (6,500,000 cfs) between the ocean and the Estuary during each 6-hour phase of the tide dominates currents, circulation patterns and distribution of water-quality parameters, sediment types, organic detritus, and passive organisms throughout the Estuary. The intermixing of turbid freshwater flow from numerous tributaries with saline water, as well as scouring due to wind-driven waves, causes peak turbidity and minimal light penetration in the salinity Transition Zone and the suspended sediment null zone (RM 40-80) of the tidal River and results in high turbidity in a band of shallow water along both shorelines of Delaware Bay. Attenuation of light by turbidity restricts the contribution of primary production by aquatic plants in these areas. The bottom sediment composition also reflects the transport of an estimated 200 to 350 thousand tons per year of sand from the ocean into the Bay and transport and deposition of fine sediment and organic detritus into the Estuary from tributaries. The grain size and organic content of the sediments influence benthic species composition and abundance.

Water temperature also influences species composition and distribution. Water temperatures in the lower Bay are warmer in the winter and cooler during the summer than water temperatures in the upper portion of the Estuary. Seasonal temperature gradients along the length of the Estuary from Trenton to the mouth of the Bay can be as large as 7° to 9°F (3.9° to 5°C). Similarly, more rapid warming and cooling of the shallow waters in the extensive wetlands along both sides of the Bay produce horizontal gradients in water temperature that vary by 4° F or more on daily cycles. As tidal flows move in and out of the Estuary, the temperature at any point can also vary by 4°F or more on a daily cycle (Figure VII-2).

Concentrations of dissolved oxygen (DO) that are of fundamental importance for the maintenance of aquatic life, are affected by the mixing of freshwater inflow with tidal marine water. Other factors influencing DO levels are photosynthetic production, consumption by respiration and decomposition of organic matter, water temperature, and diffusion at the air-water interface. Oxygen consumption due to respiration and decomposition of organic matter is especially notable in flow from marshes where daily swings in dissolved oxygen may be 50 percent of its average value. The severe summer oxygen depletion between RM 70 and RM 108 due to excessive organic pollutant loading that occurred during the 1930 to 1980 period has lessened substantially in response to improved wastewater treatment (Section IV.E.5). The gradual improvement of DO levels in that segment of the River during the past 20 years has removed a previous impediment to spawning migrations of anadromous species such as American shad, blueback herring, and alewife, which now regularly migrate past Salem, and has been accompanied by the dramatic recovery of some other resident and seasonal aquatic life (e.g., white perch and striped bass). Severe oxygen depletion did not extend downriver to the Station's location at RM 50 (Section IV.E.7).

Historical discharge of potentially toxic pollutants, their adsorption to suspended particles and subsequent sedimentation were generally most pronounced in the same upper segment of the Estuary (RM 70-108) up-Estuary of the Station that experienced severe DO depletion. There are few industrial discharges in the vicinity of Salem. Sediment contaminant levels generally have been decreasing over the last decade (Section IV.E.6).

VII.B.4. Hydrological Transport of Organisms

The volume of organisms, detritus, nutrients, and other substances, including warm and cool water, transported in the massive tidal flow between the ocean and the Estuary and between the littoral/wetlands and pelagic zones of the Estuary contributes to the complexity, robustness, and resiliency of its biological community (Figure VII-3). Tidal currents have a substantial direct influence on the spatial distribution, abundance, and species composition of organisms in the Estuary. Numerous species such as striped bass, American shad, alewife, and blue crab, utilize tidal currents to migrate within the Estuary and between the ocean and the Estuary.

Many other organisms, including phytoplankton, zooplankton, drift macroinvertebrates, eggs, larvae, and small fish, are physically transported throughout the ocean/Estuary system. During each 6-hour ebb tide, water flushes from the wetlands and tidal ditches and creeks into the littoral and pelagic Estuary; somewhat freshened water surges predominantly along the east and west sides of the Bay to the coastal zone in a strong buoyancy-driven current about 12 miles wide, until about 30 percent of the volume of the Estuary has been evacuated. This ebb current, which contains nutrients, suspended solids, and organisms, typically moves with the prevailing coastal current southward along the Delaware shoreline. The Estuary is refilled during the next 6-hour flood tide mostly by a vigorous land-directed saline flow at depth over most of the inner shelf (from 24.8 miles offshore) toward the Estuary. The inflowing tides tend to enter the Estuary via the deeper center channel; maximum tidal current speeds of 3.7 ft/sec are reported in the deep entrance channel to Delaware Bay. These near-bottom flows, and the organisms, sand and other substances that they transport, may extend to at least 80 RM into the Estuary (the typical limit of salinity intrusion). Salem is located in the narrowing reach of Estuary, where tidal flows are particularly intense and mixing is strong.

Tidal current patterns are established by phase of the tide, geometry and topography of the bottom, freshwater inflow, and salinity gradients. Tidal current velocities accelerate as the tide moves from the funnel shaped Bay into the more constricted triple-bend portion of channel in the Transition Zone (Figure VII-1). Substantial flow in and out of the C & D Canal and several tidal creeks with each change of tidal direction further complicates flow patterns in the Estuary in the vicinity of the Station. These already complex current patterns are made even more so by changes in the direction and strength of local and regional wind forcing. As a result, currents flowing in opposite directions are a common phenomena during the brief periods of "slack" between changes in direction of the running tides (ebb and flood). Water masses often separate from large currents to form discrete cells in adjacent waters. This phenomenon probably contributes to the highly variable or clumped distribution characteristics of plankton populations.

VII.B.5. The Biological Community (Appendix E Section IV.F)

The biological community comprises all individuals of the many species (populations) that occur throughout the Estuary. The species include year-round residents, seasonal residents, migrants moving through the Estuary to and from nontidal freshwater spawning areas, and incidental stragglers from their usual habitats outside the Estuary. Relatively few species can survive the full range of extremely low to high salinity (0.1 to 32 ppt) that occurs in the Delaware and other estuaries. The three salinity zones (Tidal River Zone, Transition Zone, and Delaware Bay Zone) have a dominant influence on the spatial distribution and abundance of organisms relative to the location of the thermal discharge at RM 50. Obligate freshwater and marine organisms which perish as a result of transport to unfavorable salinities in the Transition Zone contribute to the detrital food supply for euryhaline species that can survive in the Transition Zone.

To facilitate the impact assessment process, the biological community is traditionally further divided into six biotic categories based on type of organism, the habitat resource zone they occupy, and their role in the community food web. These categories are phytoplankton, zooplankton (excluding meroplankton), habitat formers, macroinvertebrates/shellfish, fish, and other vertebrate wildlife (USEPA 1974, 1977). Meroplankton are eggs and larvae of certain invertebrate and fish species that are in the plankton category temporarily. In this Demonstration these planktonic early life stages are evaluated with the juvenile and adult stages of the same species. Assessment rationales were developed for each biotic category (BC) (Section VI.D.1.b) to determine which are unlikely to be affected by the Station and thus qualify for "low potential impact" status. Because it is neither practical nor necessary to perform detailed evaluations of all species in each category, representative important species (RIS) were selected and assessment rationales were developed for them in biotic categories that did not qualify for low impact status in Section VI.D.3.

VII.C. Salem Station's Thermal Discharge and Plume in the Delaware Estuary (Appendix E Section V.F)

The Station's thermal discharge location and design were selected in the late 1960s from 36 alternatives that were evaluated to minimize potential for appreciable harm to aquatic life (Sections V.F and VI.A). A moderate discharge ΔT combined with a high-velocity discharge approximately 500 feet offshore at a depth of about 30 feet was selected to produce a very small zone of initial mixing (ZIM) relative to the size of the Estuary (Figure VII-4). Due to high velocity and turbulence induced by the thermal discharge, discharge temperature in the ZIM during a running tide is reduced by approximately 50 percent within about 50 feet from the discharge in about 7 second; (Section V.F) (Figure VII-5). Temperature reduction is somewhat more gradual during the brief transitions between ebb and flood running tides. Beyond the ZIM, the thermal plume has more moderate temperatures. For example, discharge delta temperatures drop to within about 5°F within a distance of about 1,000 feet, while delta temperatures above 1.5°F extend to distances of about 40,000 feet (on an instantaneous basis). This combination of discharge location and plume characteristics is a key reason why the Station's thermal discharge has not and will not cause appreciable harm to the BIC, as the results from all four methods of evaluation indicate.

The Salem Generating Station is located on Artificial Island and its thermal discharge enters the Estuary at RM 50 (Figure VII-1). The Estuary is about 2.5 miles wide at that location and average tidal flow is approximately 450,000 to 500,000 cfs. The Station's thermal discharge is about 1 percent of the tidal flow past Salem (Section V.E). In this Transition Zone of the Estuary, mixing occurs between freshwater from the upper Estuary and saltwater from the Ocean and Bay. Ranging from near zero to 15 ppt, this salinity in the Transition Zone varies annually and seasonally in response to the amount of freshwater flow from the upper Estuary, and daily with each change of tidal direction. Suspended sediment and turbidity are high (Section IV.C).

VII.D. Critical Function Zone (CFZ) Rationales

The concept of critical function zones is highlighted in the USEPA (1977) guidelines. These zones are defined as areas that provide a major contribution to primary productivity or ones that are limited in extent and necessary for the propagation and survival of a species. CFZs may include spawning sites, food-producing areas, nursery areas, or migratory pathways. For example, there is concern regarding migration pathways that, in some cases, are very circumscribed; and total blockage could result in extermination of a population in a water body (USEPA 1977). The effect of low DO in the upper Estuary in the 1960s and its drastic effect on spawning migrations and spawning grounds of shad and striped bass is a perfect example of impacts on a CFZ.

The objective of this screening method of assessment is to evaluate thermal discharges in relation to such habitat areas and to establish whether their location and design are likely to ensure minimum adverse impact (USEPA 1977). The location and design configuration of the Station's thermal discharge does minimize potential for adverse effects on aquatic resources in the following respects:

- The Station's thermal plume does not adversely impact unique or rare habitats, e.g. coral reef. There are no unique or rare habitats in the vicinity (Sections IV.F and VI.A).
- Salem's thermal plume does not adversely impact critical function zones. The definition of a CFZ refers to an area of "limited extent" or which is "very circumscribed" (USEPA 1977, pp. 66-68). The vicinity of the discharge has no special food production, nursery, or spawning CFZs necessary for the propagation and survival of a species; the cross-sectional area available for migration is large enough to supersede these criteria (Sections IV.F and VI.D.1). The Estuary at Salem Station is 2.5 miles wide and has a cross-sectional area of approximately 358,900 ft^2. The ZIM is a small portion of this cross section, occupying less than two percent during running tides (92 percent of the time). (Section V.6.) Oyster beds, which might be considered a CFZ, are located downbay, beyond the area occupied by the plume (Figure VII-1).
- The offshore location of the discharge in the Transition Zone avoids exposing obligate freshwater and marine pelagic populations to the discharge and plume, and limits the exposure of the more productive bottom habitats in nearshore (littoral) and wetland zones to low plume temperatures ($\Delta T = 4°F$ and less) in a very small percentage (Figures VII-2 and VII-4) of those habitat zones (Sections V.G and VI.D.1). For euryhaline species, such as bay anchovy and weakfish, with large ranges that extend into the salinity Transition Zone, the thermal discharge is located near or at the edge of their extensive geographical ranges, rather than in a central zone of occurrence that would be considered critical for the population.
- The combination of offshore location and rapid dilution by tidal currents results in a very small ZIM relative to the size of the Estuary, for the potentially most stressful plume velocities and temperatures (Figure VII-4). This is a frequently stated criterion for achieving a low potential impact thermal discharge (NAS/NAE 1973; USEPA 1974, 1977, 1998). The estimated area of the benthic zone contacted by scouring velocities in the ZIM during a full tidal cycle (ebb, slacks

and flood) is a very small portion (3.7 acres or .0008 percent) of the 480,000 acres of the benthic zone in the Estuary. The volume of the ZIM is approximately 0.0002 percent of the volume of the total Estuary. Plume temperatures may on occasion exceed avoidance temperatures of fish in warm (1-in-10-year recurrence) summer periods in up to about 5 percent of the cross-section (Figure VII-2, Panel C). This leaves 95 percent in (warm summers) to 98 percent (other seasons) of the cross-section available for migration and other forms of organism movement up and down the Estuary (Sections V.F and VI.D.1). This large availability of area for migration compares very favorably with Agency guidance criteria that migratory function will be considered protected when at least one-third to three-quarters of the cross-section is available for passage (NAS/NAE 1973, USEPA 1974) (Section VI.D.3.a)

- High velocities in the ZIM and high ambient velocities beyond the ZIM in the pelagic zone minimize potential adverse time-temperature exposure for species that have long generation times and high or low fecundity as well as for organisms, such as plankton, that have short generation times and high fecundity. Populations with both combinations of life history characteristics, such as striped bass and weakfish and the forage species, scud and bay anchovy, were selected as RIS (Section VI.D.2).

The offshore location of the discharge in the Transition Zone (Figure VII-1), the small size of the ZIM (Figures VII-2 and VII-4), the low temperatures of the plume that contact the shoreline relative to daily variability of ambient temperatures (Figure VII-2) and the low temperatures in the plume beyond the ZIM (Figure VII-2) minimize potential that any CFZs will be affected for the biological community in the Estuary. Thus, the Station's thermal discharge does not impact any CFZ, and the spatial extent and magnitude of potential effects are low for the populations with ranges that extend into the area occupied by the thermal plume.

VII.E. Biotic Category Rationales

Biotic category evaluations were performed to determine for each of the six biotic categories their potential for incurring appreciable harm due to the Station's thermal discharge (USEPA 1977). When the entire category is unlikely to incur appreciable harm, the category can be judged to have low potential impact and assessment attention to this category can be reduced. When such a designation cannot be made, these evaluations indicate whether one or more representatives of a given biotic category should be studied in detail and included as an RIS. Key factors considered are the ability of component populations to rapidly recover from local perturbations, the location and size of the plume relative to the geographical range of the biotic category, and the relative contribution of primary production in the vicinity of the Station to primary production in the entire Estuary. The results are briefly summarized as follows.

VII.E.1. Phytoplankton and Zooplankton Biotic Categories

Populations of these biotic categories live unattached in water throughout the Estuary. Organisms of euryhaline species with ranges that extend into the Transition Zone are transported through Salem's thermal plume as mixing occurs. Numerous studies have thoroughly documented that phytoplankton and zooplankton (Figure VII-5) tolerate transport through moderate temperature plumes with little effect (Section VI.D.1.b).

Salem does not use chlorine or other biocides for biofouling control of the condenser circulating water system but it does for the lower-volume service water system. Residuals of such biocides in combination with the thermal component of the discharge can increase the potential for adverse impacts on organisms transported through thermal plumes. Even then, their quick recovery from localized perturbations is well documented (USEPA 1977). Salem's thermal discharge does not contain toxic levels of biocide residuals.

In addition, Salem's thermal plume is too small for low level effects on phytoplankton or zooplankton to cause proliferation of thermally tolerant nuisance species and associated aesthetic, taste or odor problems (Section VI.D.1.b). Phytoplankton is a low potential impact biotic category in most cases, primarily because of their well-documented ability to recover quickly from local perturbations (USEPA 1977). Photosynthesis by phytoplankton in the Transition Zone contributes little to primary production in the Estuary because of the high turbidity (Section VI.D.1). For these reasons, no RIS are designated for more detailed assessment of these biotic categories. The retrospective evaluation has, however, made use of studies of this biotic category in the Estuary by independent scientists.

VII.E.2. Habitat Formers

Habitat formers are any aggregated assemblages of plants and/or animals that provide substrate for attachment of other organisms, function as a direct or indirect food source for other organisms and/or provide areas for spawning, nursery and protective cover for other organisms. Oyster beds function as habitat formers, but there are no active oyster beds in the area occupied by Salem's thermal discharge and plume (Figure VII-1). Submerged aquatic vegetation (SAV) are also habitat formers, but the Delaware Estuary historically has virtually none of this type of habitat former throughout the system. The predominant habitat formers in the Estuary are the dense growths of marsh plants on the 200,000 acres of tidal wetlands that are distributed along both sides of the Estuary, mostly from the C&D Canal down to the mouth of the Bay (Figure VII-1) (Section IV.F.5.a). In addition to functioning as habitat formers, vascular plants in the wetlands contribute to the primary production food base for animal consumers in the Estuary (Section VI.D.1).

Because of the offshore location of Salem's thermal discharge, there is no contact of the potentially stressful temperatures in the ZIM with marsh plants. Thermal plume contact with unbulkheaded shoreline with stands of marsh plants is limited to low ΔTs, i.e., less than 4°F, along about three miles of shoreline during alternate phases of each 6-hr running phase of the tide. The exposed shoreline is less than one percent of the 280 miles of shoreline along the Estuary. These low temperature exposures (Figure VII-2, Panel a) are within the range of daily variation of ambient temperature and are not sufficient to cause any appreciable damage to the marsh plants or their habitat functions for populations of fish, shellfish or wildlife. Due to low exposure to the thermal plume, habitat formers have low potential for impact and no RIS were selected for this biotic category.

VII.E.3. Other Vertebrate Wildlife

This biotic category includes all populations of vertebrate animals exclusive of finfish. The channel area occupied by Salem Station's thermal plume does not contain unique or high concentrations of vertebrate wildlife populations, nor is it a CFZ for any population of vertebrate wildlife. The nearest CFZ in the Estuary is a heronry on Pea Patch Island (Appendix C), up-Estuary and beyond the area occupied by the plume (Figure VII-1). Most other concentrations of wildlife populations occur downbay in and over the wetlands and the adjacent littoral zone along both sides of the Estuary. Exceptions to that generality are a variety of marine mammals and sea turtles that occur in open water during the summer, mostly in the mid- to lower Bay. Individuals of some of these populations, such as sea turtles, are observed occasionally farther up the Estuary in the Transition Zone. These include three species of semi-tropical to tropical sea turtles that are listed as either threatened or endangered. These are Kemp's ridley (endangered), loggerhead (threatened) and green (threatened) sea turtles. The green and loggerhead populations are distributed globally in tropical and sub-tropical waters and occur rarely in the summer temperate zone waters. The Kemp's ridley population range is principally in the tropical and sub-tropical waters of Central America and the United States. Their spawning beaches are far distant from the location of the Station's thermal plume. Turtles that have been observed in the vicinity of the Station during the summer show no affinity for the thermal plume and are quite capable of avoiding stressful temperatures, if any, that they may encounter (Section VI.D.1.b.). These species are adapted to warm water. These turtle species are subject to protective management plans administered by the National Marine Fisheries Service (NMFS). NMFS has issued a "No Jeopardy Opinion" to PSE&G and Salem Station for these species (Section VI.D.1.b.). This means that the responsible agencies do not consider the Salem thermal discharge to be a threat to these threatened or endangered species.

Because of low, if any, involvement and low potential for impact to populations with the Station's thermal plume, no RIS were selected for more detailed evaluation of this biotic category.

VII.E.4. Shellfish and Macroinvertebrates

This biotic category includes all species of invertebrate animals larger than zooplankton including amphipods (scud), shrimp, mussels, clams, oysters, blue crab, polychaete worms, and oligochaetes. Populations of this category living in the bottom (infauna) include oligochaetes, polychaetes, clams, and insect larvae; those living in the water near or on the bottom (epifauna) include scud, opossum shrimp, oysters, and blue crab; those living in the open waters (pelagic zone) include scud and opossum shrimp; and in the littoral and wetland zones include scud, opossum shrimp, blue crab, mussels, clams, worms, and insect larvae and the planktonic (meroplankton) early life stages of invertebrates.

The ranges of many obligate freshwater and marine species in this category do not extend into the Transition Zone. Exposure to the thermal discharge and plume is negligible for populations of sessile and other macroinvertebrates/ shellfish sequestered in the 200,000 acres of wetland habitat located in the Estuary. The principal effect on benthic infauna is the exclusion from benthic habitat in the ZIM due to high scouring velocities. Scouring velocities in the ZIM contact only a very small portion (0.0008 percent) of the total bottom area of the pelagic zone (approximately 480,000 acres) in the Estuary, so the potential impact on the total infaunal populations is negligible. The members of this biotic category with the most potential exposure to Salem's thermal plume are those pelagic and epibenthic euryhaline organisms of species with ranges extending into the Transition Zone, such as scud, opossum shrimp, blue crab, and planktonic early life stages (meroplankton) of certain shellfish/macroinvertebrate species. There are no listed threatened or endangered species of this biotic category in the Estuary (Section IV.G.3).

This biotic category does not qualify for low potential impact status because there are important recreational and commercial species that have annual or longer generation times, such as blue crab. Therefore, three RIS were selected for more detailed biothermal assessment (Section VII.F.5). These RIS comprise two forage species, scud and opossum shrimp, and one important recreational and commercial species, the blue crab.

VII.E.5. Fish

Because the Station's thermal discharge is located in the Transition Zone, the following fish populations are subject to little, if any, exposure to plume temperatures: obligate freshwater and marine species; wetland species such as mummichog and goby; and portions of populations when sequestered in tidal creeks and associated wetlands, such as spot, croaker, and white perch. Species that are exposed to the thermal plume are euryhaline species or life stages with ranges that extend into the salinity Transition Zone (Section VII.C.3). These include important forage species such as bay anchovy, recreational and commercial species such as weakfish, striped bass, and American shad, and early life stages (meroplankton) of some of these species. The shortnose sturgeon is a listed endangered species, but is found predominantly up-Estuary in the Tidal Freshwater Zone. Many of these species reproduce annually and others require several years to reach sexual maturity.

As this biotic category has the potential to be affected by the presence of the thermal plume, nine RIS were selected for detailed evaluation (Section VI.D.2). These include the anadromous herrings, American shad, alewife, and blueback herring; two temperate basses, the anadromous striped bass and estuarine white perch; and four estuarine-dependent marine species: weakfish, spot, Atlantic croaker, and bay anchovy.

VII.F. Synthesis of the Screening Results (CFZ, BC), Predictive (RIS) and Retrospective (NPAH) Rationales

Consistent with 316(a) technical guidance (USEPA 1977), this section first provides, for each of the low potential impact biotic categories (phytoplankton, zooplankton, habitat formers, and other vertebrate wildlife), brief summaries of key findings from the screening (CFZ and BC) evaluations. Then, findings from studies of the biological community summarized in the retrospective (NPAH) evaluation are added to confirm that the Station's thermal discharge has not caused appreciable harm to the LPI biotic categories.

A similar synthesis is provided for each of the biotic categories requiring detailed evaluations, i.e., shellfish/macroinvertebrates and fish, except that the synthesis for these two biotic categories also include key findings from the predictive RIS evaluations. These syntheses are intended to address applicable 316(a) Master Rationale decision criteria (Section VI.C.3.c) and ERA factors for evaluating the adversity of changes and assessment endpoints (USEPA 1994 and 1998) (Section VI.C.3). For this case the endpoints are no prior appreciable harm and protection and propagation of a balanced indigenous community. Before presentation of the biotic category synthesis a few summary remarks are in order regarding characteristics of the predictive (RIS) and retrospective (NPAH) methods of evaluation, as follow.

The detailed predictive RIS biothermal assessment was performed at four levels of protective conservatism (that is, using environmental and Station conditions most likely to demonstrate any possible effects, or conversely, to screen for low likelihood of effects). First, the excess temperatures (ΔTs) used to characterize exposure of the RIS are based on a "reasonable worst case" thermal plume (Section V.F). This plume was modeled based on a full generating load and low cooling water system (CWS) flow conditions, which result in a maximum ΔT over ambient of 22.7°F at the point of discharge in the Estuary (Section V.F.4.a). In addition, the plume was modeled based on hydrological and meteorological conditions that result in higher near-field plume temperatures than would occur during most times of the year (Section V.F).

Second, the total plume temperatures to which the RIS may potentially be exposed at various times of the year are characterized based on both warm (which have 1-in-10-year recurrence) and average (1-in-2-year recurrence) ambient water temperatures occurring in the vicinity of the Salem Station. For the assessment of potential effects of exposure to elevated temperatures, the warm year was conservatively represented by all of the highest mean weekly temperatures in 10 years, and for cold shock the extreme year was conservatively represented by all of the lowest mean weekly temperatures in 10 years (Section V.F). The historical record for these statistics was the past 50 years (1948 to 1998).

Third, the potential effects on individuals of the RIS exposed to the plume are assessed using highly conservative assumptions about the location and duration of their residence in the thermal plume. Potential effects on organisms drifting through the plume are conservatively evaluated based on the highest centerline ΔTs that could be experienced for the longest duration under reasonable worst-case conditions. Potential chronic effects on more mobile life-stages of RIS are assessed based on the highly unlikely case that they could and would maintain position in the warmest regions of the plume.

Fourth, the conservative assumption was made that all of these conditions would occur together. In reality, the likelihood of these three situations occurring at the same time is extremely low (next to impossible).

The retrospective (NPAH) evaluation, on the other hand, is based on data from numerous studies of the actual biological community in the Estuary. Some of the studies were performed both prior to and after the Salem Station began operations in 1977. Other of the studies have been conducted throughout most of the period since Salem began operation (Section VI.D.5). The populations in the Estuary reflect the cumulative effects of the thermal discharge and all other factors, both natural and anthropogenic, that affect entire life cycles. The balance of these numerous factors is documented in historical trends in populations.

VII.F.1. Phytoplankton

The screening evaluations indicate that phytoplankton is a low potential impact biotic category. Studies of phytoplankton in the Estuary prior to commencement of Station operations indicated that the species composition and abundance, predominated by diatom flora, was typical for East Coast estuaries (Section VI.D.5). The vicinity of the thermal discharge is not a CFZ for phytoplankton (Section IV.F). There are no threatened or endangered species of phytoplankton in the Estuary (Section IV.F). The Biotic Category rationale for phytoplankton concluded that phytoplankton is a LPI category (Section VII.E.1). Therefore, more detailed RIS evaluation was not needed for reasonable assurance that phytoplankton populations in the Estuary are not appreciably harmed by the Station's thermal discharge. The principal reasons for this conclusion are the thoroughly documented fact that phytoplankton rapidly recover from local perturbations due to their rapid dispersal rates and their rapid and prolific rate of reproduction. Moreover, the nature and intensity of effects (positive or adverse) on survival and growth in the plume are expected to be low, and the volume impacted by the thermal plume is very small relative to the volume of the Estuary (Figure VII-1) and adjacent waters occupied by the phytoplankton biotic category. (Section VI.D.1.b).

The retrospective evaluation, based on field studies conducted by independent researchers, concluded that the present phytoplankton mixture in the Estuary in which a diatom flora predominates with a minor representation of nuisance species is an optimal one (Section VI.D.5.b). Thus, the conclusions of all four methods of evaluation are in agreement: there has not been and will not be appreciable harm to the phytoplankton populations in the Estuary due to Salem's thermal discharge. Therefore this 316(a) Demonstration succeeds with respect to all Section 316(a) Guidance decision criteria related to phytoplankton (Section VI.C).

VII.F.2. Zooplankton

The screening evaluations demonstrate that zooplankton (exclusive of meroplankton) is a low potential impact biotic category. Studies of zooplankton in the Estuary prior to the Station's operation found that the species composition and abundance, predominated by rotifers, cladocerans, and copepods, was typical for East Coast estuaries (Section VI.D.5). The vicinity of the thermal discharge is not a CFZ for zooplankton (Section IV.F) nor are there any threatened or endangered species of zooplankton in the Delaware Estuary (Section IV.F). The Biotic Category Rationale concluded that zooplankton is a LPI category (Section VI.D.1.b). More detailed evaluations were, therefore, not needed to achieve reasonable assurance that zooplankton populations will not incur appreciable harm due to the discharge causing changes beyond normal spatial and temporal variability in species composition, standing crop, or relative abundance. Principal reasons for this conclusion are the well documented tolerance of zooplankton transported through thermal plumes such as at the Station (Figure VII-5) so the nature of adverse impact, if any, is on growth an reproduction and the probability is low that there could be any meaningful change (positive or negative) in growth or reproduction of organisms transported through the plume (6-hr exposure time); the capacity of zooplankton populations to rapidly recover from local perturbations due to their short generation time and prolific reproductive rate (within hours); the rapid transport and dispersal of individuals by currents; and the spatial insignificance of the area of potentially most stressful plume temperature (the ZIM) relative to the volume of the Estuary and adjacent waters occupied by the zooplankton biotic category (Section VI.D.1.b).

The retrospective evaluation, based on field studies by independent researchers, concluded that the Station's thermal discharge has not caused appreciable harm to zooplankton populations (Section VI.D.5.b.ii). The researchers' publications indicated that the pattern of seasonal succession in copepod species in the Delaware Bay had not changed in the previous forty years and that overall zooplankton abundance in the Delaware Estuary was similar to that reported in nearby East Coast estuaries and nearshore waters (Section VI.D.5.b.ii).

Based on these screening and retrospective evaluations, it is reasonable to conclude that the Station's thermal discharge has not and will not cause appreciable harm to the zooplankton biotic category, and that this 316(a) Demonstration is successful with respect to all EPA 316(a) Master Rationale decision criteria related to zooplankton (Section VI.C).

VII.F.3. Habitat Formers

The vicinity of Salem Station is not a CFZ for habitat formers (Section VII.D). Neither vascular plants in the littoral zone, nor oyster beds (both of which are common in estuaries) occur in the area occupied by the Station's thermal plume. There are no listed threatened or endangered species of habitat formers in the Delaware Estuary.

The predominant habitat formers in the Estuary are the prolific stands of vascular marsh land plants that grow on some 200,000 acres of wetlands distributed along both shores of the Estuary primarily from the C&D Canal southward to the mouth of Delaware Bay (Figure VII-1). These stands are one of the most important sources of primary production in the Estuary (Figure VII-3). Wetland plants and associated wetlands, tidal creeks, and ditches provide habitats for a number of other organisms such as attached algae and small invertebrates; numerous species of larger invertebrates such as scud, opossum shrimp, crayfish, crabs and horseshoe crabs; a variety of birds including song birds, shorebirds, waterfowl, and raptors; and mammals including voles, muskrat, fox, and white-tail deer (Section IV.F.5).

The Biotic Category Rationale concluded that habitat formers were a low potential impact category (Section VI.D.1.b). The primary reason is that only a small portion (about 1 percent) of the existing 280-mile littoral/wetland habitat zone is contacted by a low-temperature portion (4°F and lower ΔT isopleths) of the thermal plume during each running phase of the tide. The exposure to this low range of plume differential temperatures is within the daily range of material ambient temperatures experienced by marshland plants. There is thus reasonable assurance that the Station's thermal discharge does not result in any deterioration of the habitat formers in the Estuary or to populations of animals, including threatened or endangered species, as a result of impact upon habitat formers.

Based on these evaluations, the Station's thermal discharge satisfies all relevant factors for determining that potential for adverse impacts is low and provides assurance that the thermal discharge and plume characteristics have not caused and will not cause appreciable harm to the populations of vascular plants in the Estuary. The primary reason is the minimal contact of these populations with the thermal plume. Therefore, this Section 316(a) Demonstration successfully complies with all 316(a) Master Rationale decision criteria applicable to the habitat formers biotic category.

VII.F.4. Other Vertebrate Wildlife

This biotic category includes all populations of vertebrate animals other than finfish. As described in Section VII.F.3 above, most populations in this biotic category rely on habitat and food provided by wetland vascular plants and associated habitats along the 280 miles of shoreline (mud flats, tidal creeks, and littoral zone of the Estuary).

The Estuary in the vicinity of Salem is not a CFZ for any population of other vertebrate wildlife (Section VII.D). The predictive Biotic Category Rationale concluded that this is a LPI category primarily because of the low exposure to the Station's thermal plume (Section VI.D.1.b). This biotic category includes three tropical/subtropical species of sea turtles (loggerhead, Kemp's ridley, and green sea turtles) that occasionally are found as far north as the Estuary and are adapted to warm water. Even if subject to more frequent exposure to temperature changes in the plume than in the natural environment, animals in this biotic category could avoid excessive temperatures and appreciable harm due to the thermal plume (Section VI.B.3). The spatial extent, nature, and intensity of potential effects of exposure of populations to the Station's thermal plume are very low.

Therefore, there is reasonable assurance that populations of other vertebrate wildlife, including turtles, incur no appreciable harm due to Salem's thermal discharge.

The three turtle species are subject to protective habitat conservation plans administered by the National Marine Fisheries Service (NMFS). These conservation efforts have reversed the process of extinction for most species associated with estuaries. According to USEPA (1998), the Kemp's ridley turtle population is increasing and none of the threatened or endangered species related to estuaries are currently declining. NMFS has issued a "No Jeopardy Opinion" to PSE&G/Salem Station for these species (Section VI.D.1.b).

The conclusions from the CFZ and BC screening rationales (Section VI.D.1.b) agree that there is negligible potential for appreciable harm to populations of other vertebrate wildlife, including threatened and endangered species, due to exposure to the Station's thermal discharge. The current status of the three threatened or endangered sea turtle species that occasionally occur as far north as the Estuary confirm that the Station's thermal discharge has not caused appreciable harm to these species. Therefore this biotic category passes all applicable Master Rationale Decision Criteria (Section II) to achieve a successful 316(a) Demonstration.

VII.F.5. Shellfish/Macroinvertebrates

This biotic category includes all populations of invertebrate animals larger than zooplankton, including shellfish and their planktonic early life stages (meroplankton), that live in or on the bottom, in the open water pelagic zone, in the nearshore littoral zone, and in the wetlands zone. There are no listed threatened or endangered species of this biotic category in the Estuary. The CFZ assessment concluded that there are no unique or rare habitats or CFZs necessary for survival of shellfish/macroinvertebrate species in the vicinity of Salem. Oyster beds are down-Estuary, mostly in shallow water in the middle and lower Bay.

The predictive Biotic Category Rationale concluded that this is not a low potential impact category primarily because important recreational and commercial species such as blue crab are among those euryhaline populations that have ranges extending into the Transition Zone; and because there is the potential for exposure to the thermal plume for those organisms that occupy the pelagic zone (Section VI.D.1.b). Thus, RIS were selected for detailed scrutiny.

Studies performed before the Station began operation found that species composition and relative abundance of macroinvertebrates in the pelagic zone included substantial quantities of planktonic eggs and other invertebrate early life stages (meroplankton), abundant quantities of species such as scud and opossum shrimp, and some blue crab. This assemblage of species is characteristic for mid-Atlantic East Coast estuaries.

The predictive biothermal assessment concluded that macroinvertebrates exposed to a reasonable worst-case thermal discharge from the Station would incur no adverse effects on survival (Section VI.D.3.a), growth (Section VI.D.3.e), or reproduction (Section VI.D.3.f) during any season of an average (1-in-2-year recurrence) ambient temperature year. More thermally sensitive organisms such as opossum shrimp may potentially incur some mortality during warm (1-in-10-year recurrence) summers in the unlikely event that some organisms would be transported along the centerline of the entire thermal plume. Strong swimmers like blue crab would avoid lethal temperatures during those occasions (Section VI.D.3.c).

The same scenario applies to effects on growth and reproduction. In a warm year (1 in 10 year recurrence), temperatures in approximately 0.05 percent (scud) to 0.0009 percent (blue crab) of the Estuary plume volume would exceed the optimum and normal temperature ranges for growth and reproduction respectively during intermittent periods of July, August, and early September or warm (1 in 10 year recurrence) summers. During the cooler seasons in average as well as warm years, plume temperatures would not be lethal, and would in fact be more favorable for growth and reproduction than ambient temperatures (Section VI.D.3.e). Theoretically, reproduction of organisms exposed to the plume during spring and fall seasons could begin and end a few days early relative to normal periods of reproduction (Section VI.D.3.f). However, the duration of potential exposure to the plume during a running (ebb or flood) tide, up to 6 hours, is too short a time to effect significant increases or decreases in growth or reproduction for these invertebrate organisms. These factors indicate that no appreciable net increase or decrease in growth or reproduction should be expected for populations of those organisms transported through the thermal plume.

There is negligible potential for the infrequent and low-level thermal exposures to cause appreciable harm to populations of macroinvertebrates and shellfish in the Estuary. Macroinvertebrate/shellfish populations in all of the habitat zones other than euryhaline species in the pelagic zone have very little, if any, potential exposure to the plume. For the euryhaline populations potentially exposed, the volume of the plume is small relative to the volume of the Estuary. The geographic ranges of populations in this biotic category are large, indicating negligible potential for the low-level effects in the thermal plume to cause adverse effects on the populations in this biotic category.

The retrospective (NPAH) evaluation indicates that the euryhaline macroinvertebrate/ shellfish community has remained intact for the duration of the Station's operating period. Species composition is similar to that which existed before Station operation and is consistent with that observed in other mid-Atlantic estuaries. Additionally, the number of blue crab in the Estuary continues to grow even though exploitation by fishing has increased (Section VI.D.5).

The concurrence of the conclusions from the screening (CFZ and BC), predictive (RIS) and retrospective (NPAH) evaluations provides reasonable assurance that the macroinvertebrate/shellfish biotic category of populations has not incurred and will not incur appreciable harm due to the Station's thermal discharge. All Master Rationale decision criteria applicable to this biotic category (Section VI.C) for a successful 316(a) Demonstration have been met.

VII.F.6. Fish

This biotic category includes all of the finfish and their planktonic life stages (meroplankton) that live throughout all habitat zones of the Delaware Estuary. The CFZ assessment found that there are no unique or rare habitats and no CFZs necessary for survival of a fish species in the vicinity of the Station's thermal discharge and plume, except for the Estuary cross-section at the Station, which may be considered as critical because of spawning migrations of anadromous species (Section VII.C above).

The Biotic Category evaluation concluded that none of the fish populations other than euryhaline species and early life stages of fish (meroplankton) with ranges that extend into the Transition Zone are more than incidentally exposed to the thermal plume. As some of these species are important to recreational and commercial fisheries, this is not a LPI category. Nine species were selected for detailed RIS predictive assessment: American shad, alewife, blueback herring, striped bass, white perch, weakfish, spot, Atlantic croaker, and bay anchovy (Section VII.E.4).

The RIS biothermal evaluation found that the Station's thermal discharge and plume do not have the potential to cause any appreciable harm to populations of obligate freshwater, obligate marine, and species sequestered in the 200,000 acres of wetlands in the Estuary because they have only incidental, if any, exposure to the plume. The potential for appreciable harm is negligible for the euryhaline component of the fish biotic category which does have more exposure to the plume (Sections VI.D.3). This finding is based on the following:

- There is little if any potential for mortality of fish eggs and larvae due to transport through the Station's thermal plume. Many of the RIS such as American shad, blueback herring, alewife, Atlantic croaker, striped bass, white perch and weakfish do not spawn in the vicinity of Salem and therefore few, if any, eggs and larvae are present. Exceptions are the potential mortality of eggs and larvae of bay anchovy and weakfish transported the entire center-line of the plume in the unlikely coincidence of a worst-case plume and a warm (1 in 10 year) recurrence summer ambient temperature year (Section VI.D.3.a.ii).
- No appreciable mortality of stronger swimmers (juveniles and adults) is predicted even during periods of warm ambient temperatures. It is well documented that fish in open water avoid lethal temperatures (Section VI.D.3.a.iii).
- There is no potential for appreciable mortality due to cold shock. High flow velocities prevent fish from remaining long enough to become acclimated to the higher plume temperatures which could result in cold shock mortality in the event of a total two-Unit shutdown (Section VI.D.3.b).
- There is virtually no potential habitat avoidance of the plume beyond the ZIM during either average ambient temperature years or warm ambient temperature years (Section VI.D.3.c). In the unlikely event of high discharge ΔT occurring

coincident with especially warm periods of warm ambient temperature years, only the more thermally sensitive species; (i.e., bay anchovy and weakfish) may avoid the region of highest ΔT fields. Such plume volume is very small, ranging from less than 0.002 percent of the Estuary for bay anchovy and 0.003 percent of the Estuary for weakfish.

- The plume does not appreciably block the migration pathways of anadromous species that occur during the spring and fall seasons (Section VI.D.3.d). The ZIM, which occupies about three percent of the Estuary cross-section, and the plume temperatures above avoidance temperatures which may occasionally occupy up to about five percent of the Estuary cross-section for the worst case, may inhibit free passage for RIS such as American shad, blueback herring, alewife, striped bass, and white perch. However, ninety-five to ninety-eight percent of the cross-section remains available for migration.
- Many of the RIS spawn at locations distant from Salem Station. As a result their eggs and larvae are not exposed to the discharge and plume. No appreciable net effects on growth (Section VI.D.3.e) and reproduction (Section VI.D.3.f) of drift organisms exposed to the plume are predicted. Plume temperatures in both average and warm years are more favorable than ambient temperatures for the growth of organisms exposed to them during the fall, winter and spring seasons. Reproduction could potentially be stimulated to begin and end a few days earlier than usual. In periods of the summer in warm years which might coincide with worst-case discharge ΔT, a portion of plume temperatures would exceed the optimum temperature range for growth and the normal temperature range for reproduction for bay anchovy, weakfish, and spot (Section VI.D.3.f). The portion of the Estuary involved with these predicted exceedances would be 0.7 percent for bay anchovy, 0.13 percent for weakfish, and 0.03 percent for spot (Section VI.D.3.f). However, the duration of exposure (approximately 6 hours) of organisms transported through the plume is too short relative to the time required to achieve a significant increase or decrease in growth and reproduction.
- Salem's ZIM and thermal plume are very small relative to the portions of the Estuary occupied by species like bay anchovy, spot, and weakfish. The intermittent and low level of potential impact on survival, growth, and reproduction of such organisms even when exposed to Salem's summer plume based in the unlikely event of concurrent high discharge temperatures, warm years, and prolonged centerline drift are not sufficient to cause appreciable harm to the relevant RIS of the fish biotic category. Therefore, the more common scenarios of the lower temperatures more characteristic of the plume have even less potential for causing appreciable harm to the fish biota (Section VI.D.3).

The conclusion of the predictive biothermal assessment is that the low level of impact predicted is not sufficient to cause appreciable harm to the euryhaline population component of the fish biotic category throughout the Estuary. Euryhaline populations are the only ones exposed more than incidentally to Salem's thermal plume.

The retrospective (NPAH) evaluation reached the following conclusions (Section VI.D.5) regarding the fish biotic category that confirm the conclusions of the predictive evaluations:

- There has been a general increase in the average number of fish species collected in the area since Station operations began.
- Long-term abundance of RIS in the Estuary has been increasing for nine of the ten fish and shellfish RIS. Populations, including weakfish, white perch, striped bass, and American shad, that were severely depleted less than two decades ago are experiencing a resurgence in abundance. This is probably due to a combination of vastly improved water quality well upstream of Salem, between RM 80 and RM 115, and resource agencies' restrictions on the harvest of these populations. Bay anchovy have also shown increased abundance estuary-wide. Blueback herring continue to decline in abundance (due to overfishing and possible habitat loss), as they have since the mid-1960s. Alewife have recently produced a few strong year classes. Atlantic croaker, an ocean-spawning species, has increased in abundance dramatically in recent years. Spot, another ocean-spawning species, occasionally enters the Estuary in large numbers, but its abundance varies considerably among years, and is absent most of the time as the Estuary is at the northern most extreme of its range. Spot abundance trends have been up recently. The abundance of spot in the Estuary varies substantially from year to year because of fluctuations in its range; the apparent abundance trends up or down are most likely an artifact of this interannual variability. Observed declines in blueback herring cannot be attributed to the operation of the Station for the following reason: blueback herring spawn in freshwater tributaries away from the Station, so only a small fraction of their total population could be impacted by its operation.

The retrospective evaluation results indicate that the Station's thermal discharge has not caused appreciable harm either to fish species richness or density in the region it immediately occupies or to the long-term abundance of RIS fish populations throughout the pelagic zone of the Estuary (Section VI.D.5).

The results of the screening (CFZ and BC), predictive (RIS) and retrospective (NPAH) evaluations converge and reinforce the conclusion that the Station's thermal discharge has not and will not cause appreciable harm to the fish biotic category. All decision criteria (Sections II and VI.C) for a successful 316(a) Demonstration have been met to assure the protection and propagation of this biotic category.

VII.F.7. Conclusion

The results of the screening (CFZ and BC), predictive (RIS), and retrospective (NPAH) assessments for all six biotic categories reinforce the general conclusion that the Station's thermal discharge and plume have not caused and will not cause any of the phenomena indicative of appreciable harm to the BIC. Many of the populations in the Estuary are exposed only incidentally, or not at all, to Salem's thermal plume because their usual spatial distributions do not include the location of the plume. Euryhaline populations are the only ones that are exposed more than incidentally to the plume. The highly conservative predictive (RIS) evaluations indicated that even under extremely warm environmental conditions the spatial scale of potential adverse impacts on those populations are very small; the magnitude and severity of the potential impacts are low, and the duration of potential impacts and recovery times are short. There are no detrimental impacts from interactions of temperature with chemicals in the Estuary. All Master Rationale decision criteria (Section VI.C) for achieving a successful 316(a) Demonstration have been met.

The current status of the biological community reflects its response to all natural and anthropogenic influences. The assessments in this Demonstration indicate that the Station's thermal discharge, in addition to all other impacts, positive and negative, has not and will not increase undesirable heat-tolerant or nuisance populations to the detriment of structure of the BIC.

Analysis of existing information on the lower trophic level categories (phytoplankton, zooplankton, shellfish/macroinvertebrates) show that the present species composition and abundance of these categories are similar to that observed before the start of Salem's operations and consistent with that observed in other estuarine areas along the East Coast. Analysis of data on the fish community in the vicinity of Salem revealed that there has been a general increase in the average number of fish species collected in that area since Station operations began. The few changes in actual fish species collected were limited to those relatively rare visitors from fresh and ocean waters. In addition to the lack of any demonstrable change in the composition and abundance of any of the four biotic categories, none of the analyses revealed any increase in potentially nuisance species.

Results of the trend analysis demonstrate that the operation of Salem, including its thermal discharge, has not caused appreciable harm to the populations of any of the 10 RIS evaluated. In fact, statistical analysis of these trends reveals a significant increase in the abundance of seven of these RIS during the period of Station operations. These increasing trends, which are consistent with the observation of other researchers, have been attributed to the effects of improving water quality in the upper Estuary and fisheries management activities throughout each species' range. No consistent trend was evident for bay anchovy.

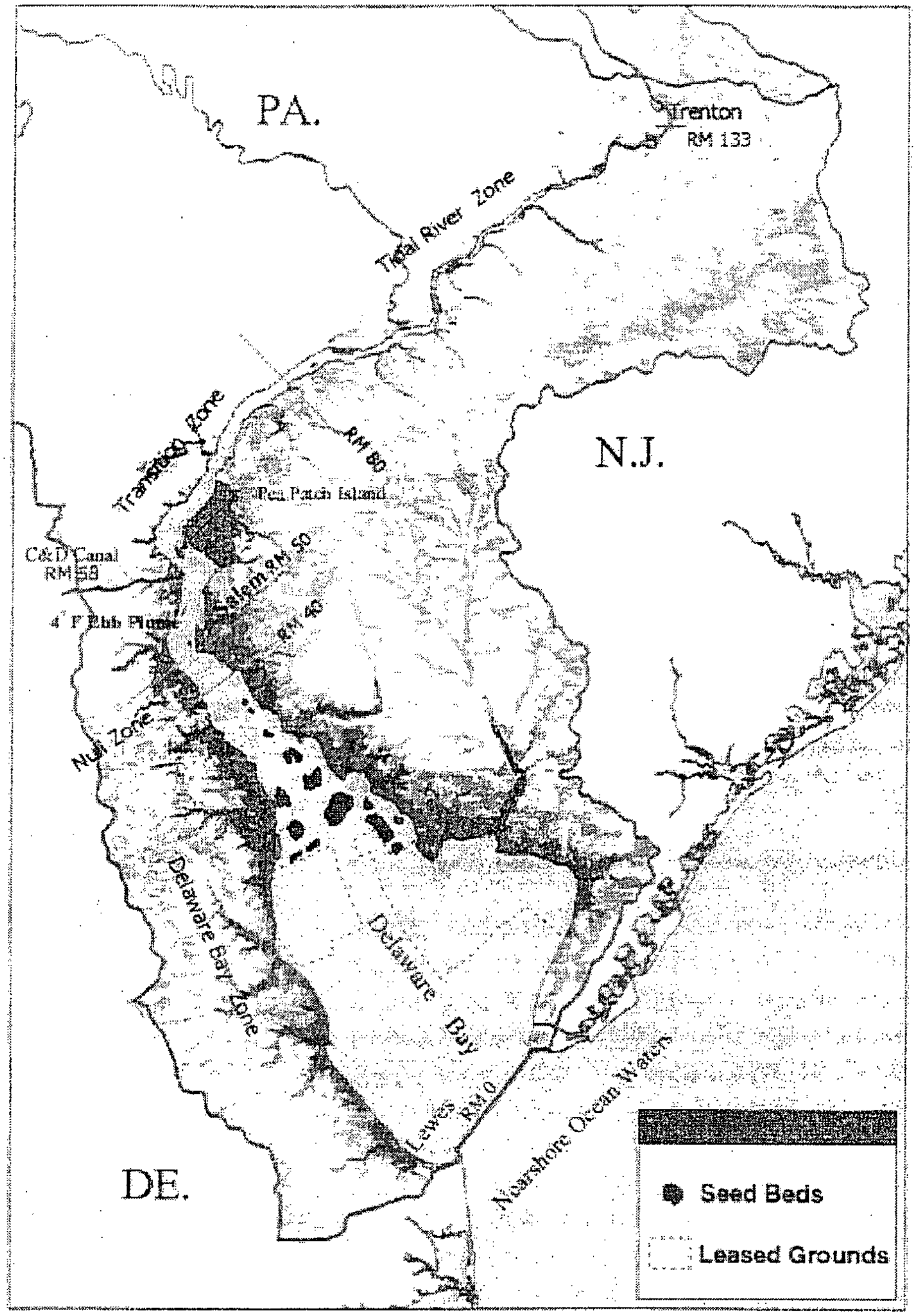
For one of the two remaining species, spot, annual abundance exhibited considerable variability and the statistically significant declining trend estimated appears an artifact of a single strong year class in 1988. For only one species, blueback herring, is there consistent evidence of a declining trend in population abundance in the Delaware Estuary during the period of Salem's operation. The trend for this species, which appears to have begun well before the start of Salem's operations, coincides with a coast-wide decline in overall abundance observed for this species. The lack of any decline in other closely related species in the Delaware confirms that the decline in blueback herring can not be attributed to the operation of Salem.

VII.G. Consistency with Previous Assessments of Salem's Thermal Discharge

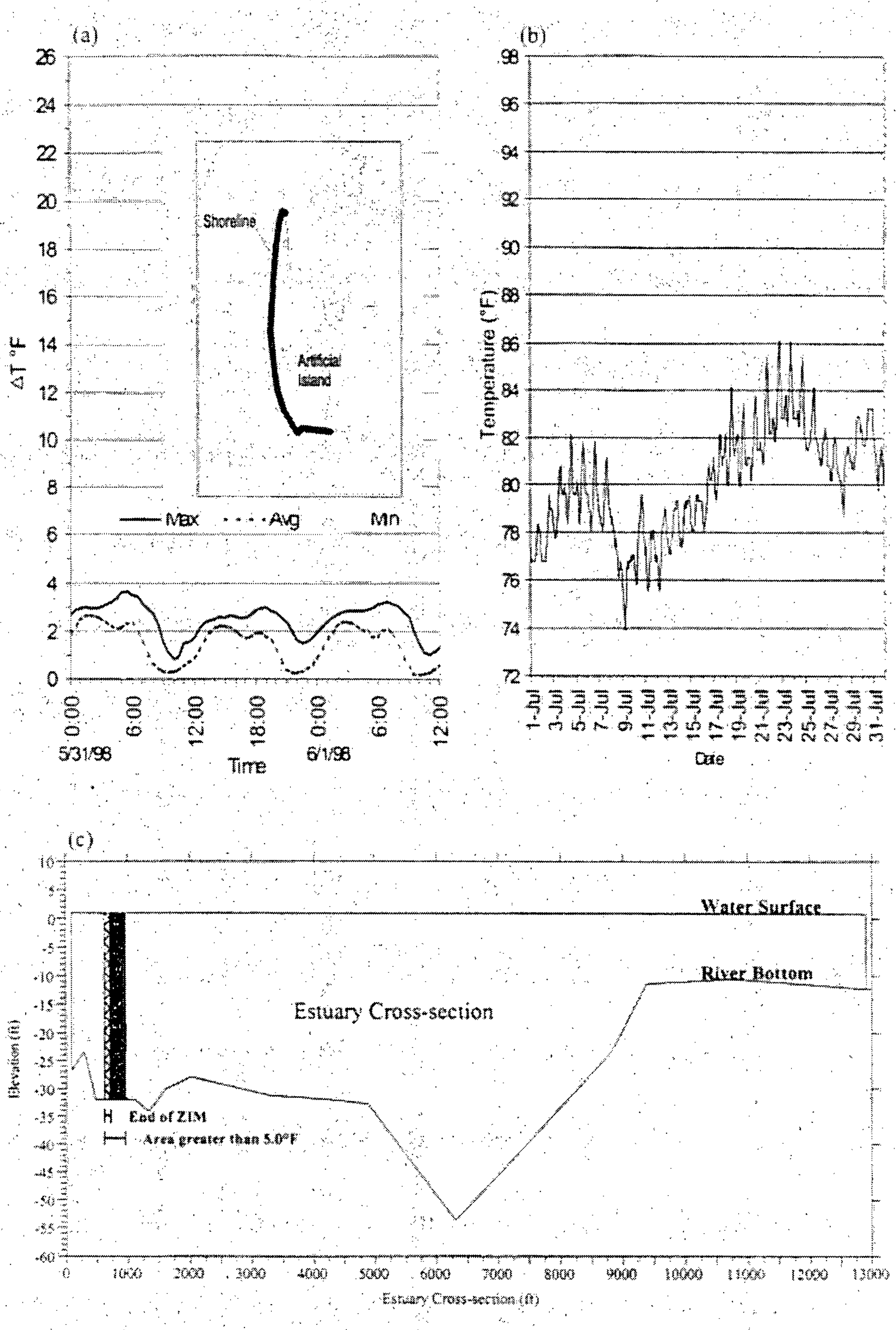
The amount and kind of information concerning characteristics of the Delaware Estuary have increased dramatically over the past 30 years. Methods of assessment have changed and improved. The format and level of detail are different among the reports on the seven assessments of the Station's thermal discharge. The final conclusions in all seven are essentially the same (Section VI.A.2.): Salem's thermal discharge has not, and will not, cause appreciable harm to the BIC in the Estuary. The biological effects from the Station's thermal discharge are small and localized and not a major source of impact, and, therefore, the thermal discharge and plume do not need to be reduced. The principal factors responsible for this consistency follow:

- The location and design configuration of the thermal discharge were selected to minimize biological harm, and they have not changed (Section III.B.2).
- The actual characteristics of the thermal plume have not changed, although its descriptions have been refined over time (Section V.F).
- The most important water quality parameters, including dissolved oxygen, salinity, and toxic substances, have not changed substantially in the region occupied by the plume. There has been some improvement in DO levels, and dissolved oxygen levels have generally been adequate throughout the past 30 years to sustain aquatic life (Section IV.E and Appendix C).

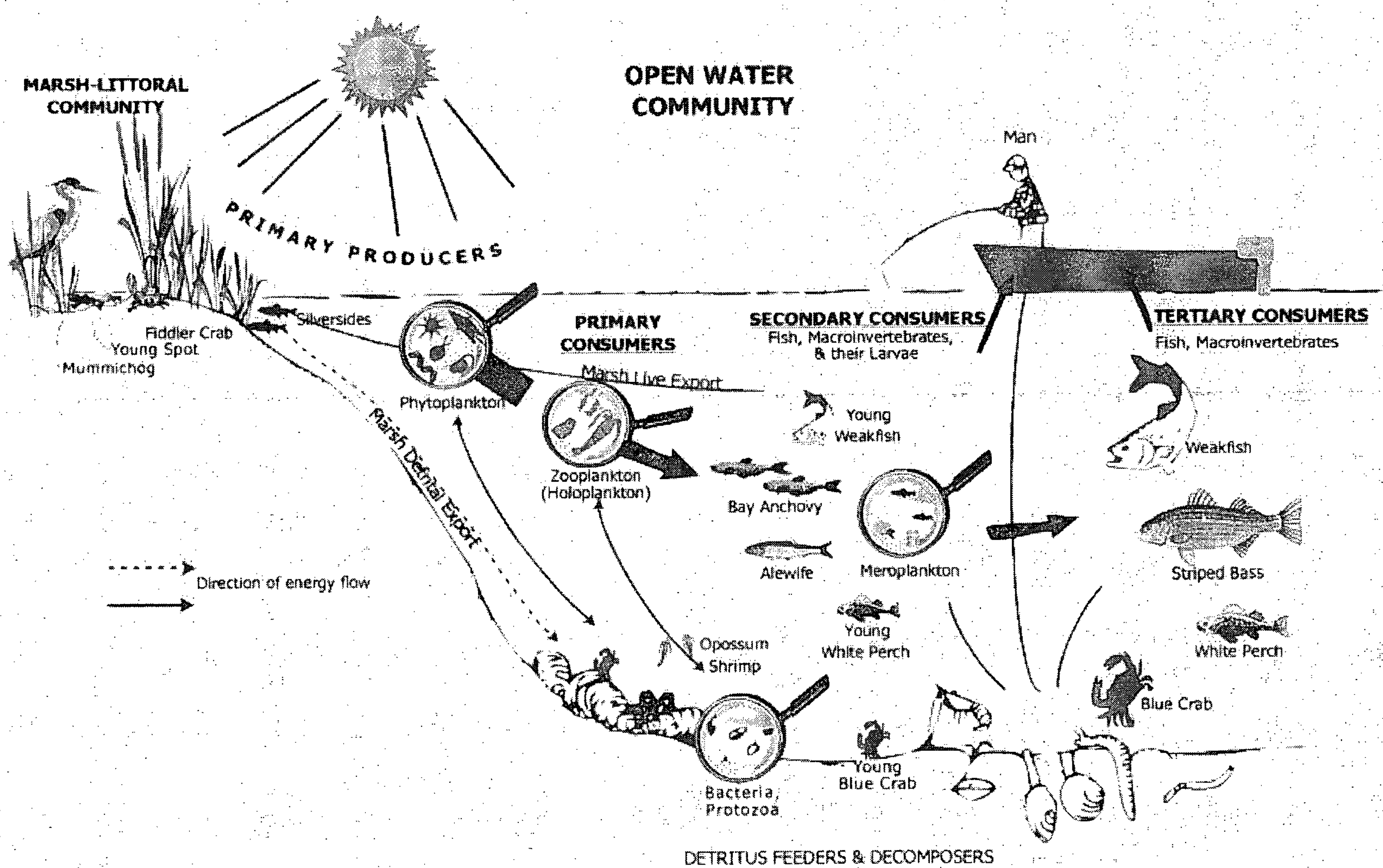
There is no expectation that these fundamental factors will change sufficiently to result in future appreciable harm or to alter assurance of the protection and propagation of a balanced indigenous community in and on the Delaware Estuary.



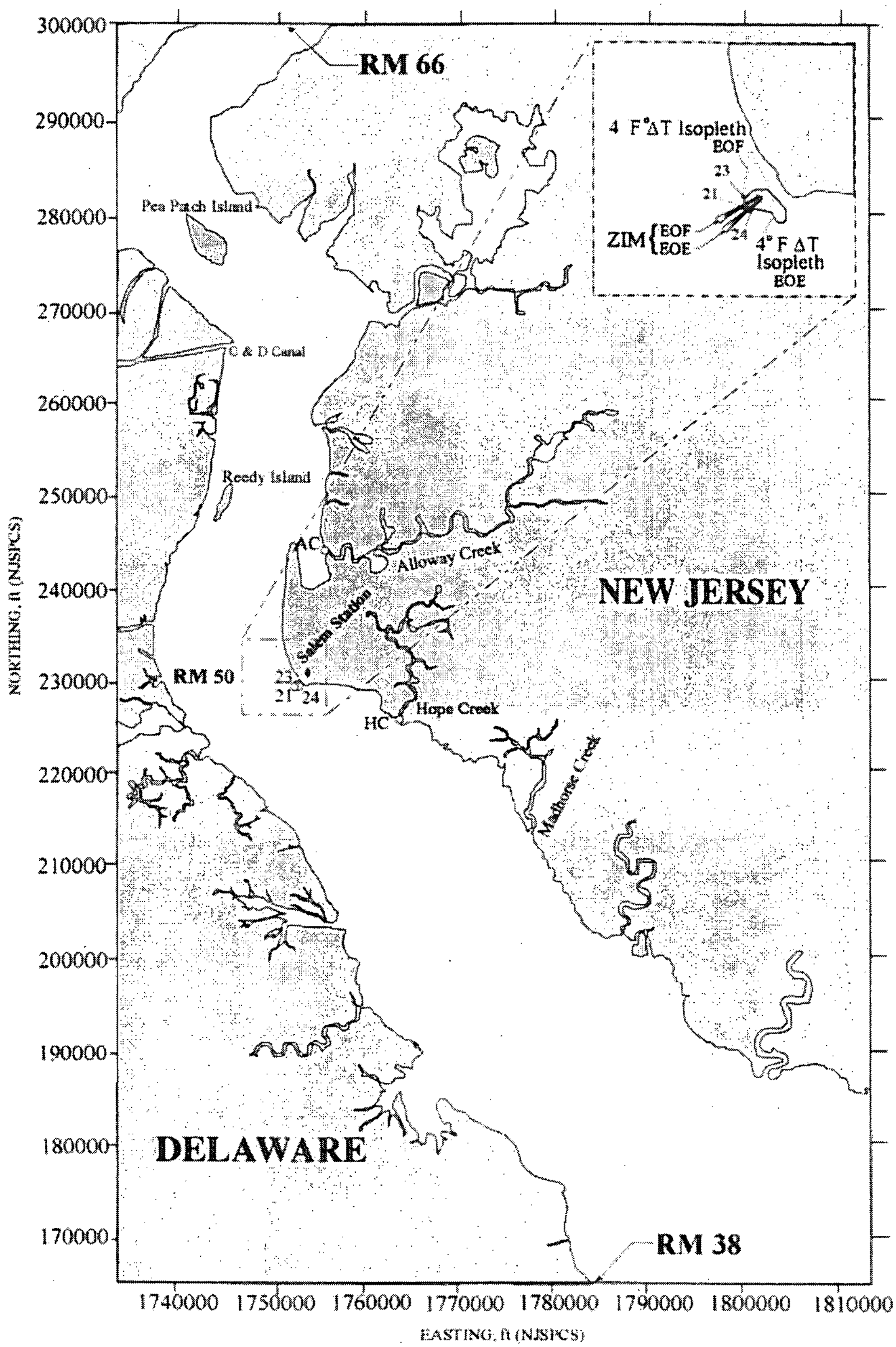
E Figure VII-1. The Delaware Estuary, including the wetlands and oyster beds (from Ford et al. 1995) , super-imposed with marker lines showing three salinity zones: the Delaware Bay zone (RM 0-50), the transition zone (RM 50-80), and the tidal river zone (above RM 80) ; the null zone (RM 40-50); and the 4°F ΔT isopleth (ebb).



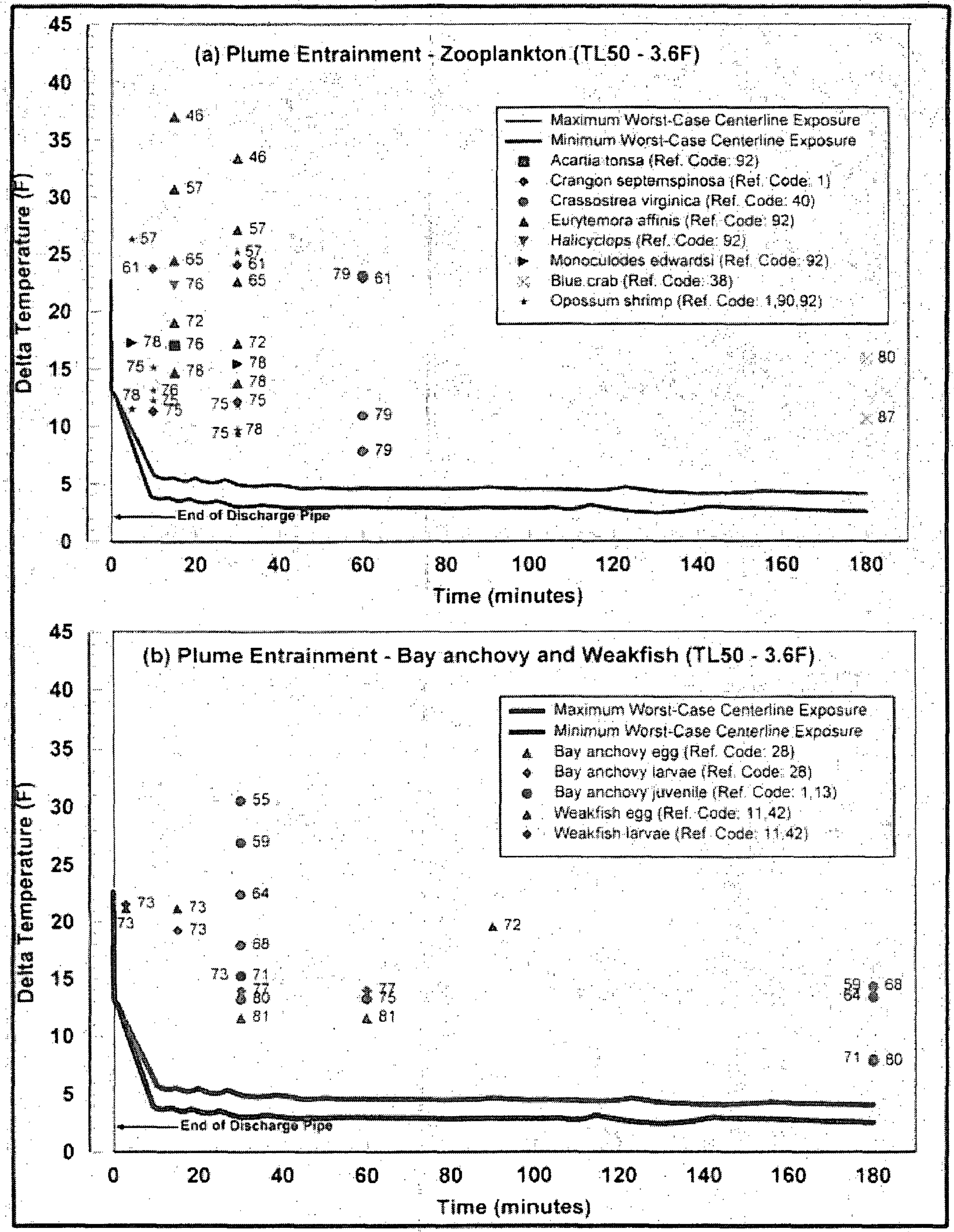
E Figure VII-2. (a) Representative tidal time-series of shoreline exposure to Salem's thermal plume. (b) Daily variability of ambient temperature during July 1997. (c) Delaware River cross-section looking down-estuary on flood tide showing the ZIM and temperatures beyond the ZIM that may exceed the avoidance temperature for migratory fish species; 95 percent of cross-section is unimpeded for migration.



E Figure VII-3. The conceptualized food-energy web for the Delaware Estuary.



E Figure VII-4. Map showing size of Salem's ZIM and 4^0 ΔT Isopleth relative to a section of the Delaware Estuary (from RM 38 to RM 66).



E Figure VII-5. Illustration of the rapid reduction of Salem's discharge temperature and resulting moderate temperature plume that enables organisms to survive transport through the plume.

REFERENCES

Academy of Natural Sciences of Philadelphia (ANSP). 1991. Status and trends of toxic pollutants in the Delaware Estuary. DELEP Report No. 91-14. Prepared for the Delaware Estuary Program.

Albert, R.C. 1988. The historical context of water quality management for the Delaware Estuary. *Estuaries* 11:99-107.

Akar, P.J. and G.H. Jirka. 1990. CORMIX2: An Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Multiport Diffuser Discharges (July Draft). Environmental Research Laboratory, U.S. Environmental Protection Agency. Athens, Georgia.

Arnold, G.P. 1969. The orientation of plaice larvae *Pleuronectes platessa* in water currents. *J. Exper. Biol.* 50:785-801.

Arnold, G.P. 1981. Movements of fish in relation to water currents, in *Animal Migration* (D.J. Aidley, ed.), Cambridge University Press, London.

Atlantic States Marine Fisheries Commission (ASMFC). 1987. Atlantic Croaker Fisheries Management Plan. October.

ASMFC. 1993. Proceedings of a Workshop on Spot and Atlantic Croaker.

ASMFC. 1998. Amendment No. 5 to the Interstate Fishery Management Plan for Atlantic Striped Bass, Addendum III, 1999-2000 Fisheries, Albemarle/Roanoke Stock Recovery, Delaware Stock Recovery.

Aubrey Consulting, Inc. 1996. Analysis of Water Temperature Variability in the Delaware River near Artificial Island. Cataumet, Massachusetts.

Bachman, J. and M. Ferrari. 1995. Quality and Geochemistry of Groundwater in New Castle County Delaware. USGS-Geo Survey Report of Investigation No. 52.

Baumeister, T. (editor-in-chief). 1979. Marks Standard Handbook for Mechanical Engineers. Eighth Edition, McGraw-Hill Book Company, New York, New York.

Beamish, F.W.H. 1978. Swimming capacity, in *Fish Physiology* (W.S. Hoar and D.J. Randall, eds.), Vol. VII - Locomotion. Academic Press, New York. Pp101-187.

Beck, S. 1995. White perch. In *Living Resources of the Delaware Estuary*, (L. E. Dove and R. M. Nyman, eds.), pp. 235-244. The Delaware Estuary Program.

Bibko, P.N., L. Wirtenan, and P.E. Kueser. 1974. Preliminary studies on the effects of air bubbles and intense illumination on the swimming behavior of the striped bass (*Morone saxitalis*) and the gizzard shad (*Dorosoma cepedianum*), in *Proceedings of the Second Workshop on Entrainment and Intake Screening: Cooling Water Studies for Electric Power Research Institute* (L.D. Jensen, ed.), pp. 293-304. Electric Power Research Institute, Palo Alto, California.

Biggs, R.B. and T.M. Church. 1983. Bottom Sediments, in *The Delaware Estuary Research as Background for Estuarine Management and Development* (J.H. Sharp, ed.), pp. 95-106. University of Delaware College of Marine Studies and New Jersey Maine Sciences Consortium, Lewes, Delaware.

Biggs, R.B. and T. Church. 1984. Bottom sediments, in *The Delaware Estuary* (J. Sharp, ed.), University of Delaware Sea Grant Program, Newark, Delaware.

Biggs, R.B. and B.A. Howell. 1988. The estuary as a sediment trap, in *The Estuary as a Filter* (V.S. Kennedy, ed.), pp. 107-130. Academic Press, New York.

Biggs, R.B., J. Sharp, and T. Church. 1983. Optical properties, suspended sediments and chemistry associated with the turbidity maxima in Delaware Bay. *Can. J. Fish. Sci.* 40:172-179.

Blaxter, J.H.S. 1974. The eyes of larval fish, in *Vision in Fishes* (M.A. Ali, ed.), pp. 427-443. Plenum, New York.

Blaxter, J.H.S. and M.E. Staines. 1971. Food searching potential in marine fish larvae, in *Fourth European Marine Biological Symposium* (D.J. Crisp, ed.), Cambridge University Press, Cambridge.

Bliss, C.I. 1937. Calculation of the time-mortality curve. *Ann. appl. Biol.* 22:815-852.

Boehlert, G.W. and B.C. Mundy. 1988. Roles of behavioral and physical factors in larval and juvenile fish recruitment to estuarine nursery areas. *Amer. Fish. Soc. Symp.* 3:51-67.

Boicourt, W.C. 1982. Estuarine larval retention mechanisms on two scales, in *Estuarine Comparisons* (V.S. Kennedy, ed.), pp. 445-457. Academic Press, New York.

Bostater, C.R. 1988. Remote Sensing of Suspended Sediment and Light Attenuation for Estuarine and Near Coastal Waters. Research Report, Marine Studies. University of Delaware, Newark, Delaware.

Boston Edison Company. 1977. Pilgrim Station Units 1 and 2, NPDES Determination No. MA0025135. Decision of the Regional Administrator. 11 March.

Bousfield, E.L. 1955. Ecological Control of the Occurrence of Barnacles in the Miramichi Estuary. National Museum of Canada Bulletin No. 137.

Brett, J.R. 1941. Tempering versus acclimation in the planting of speckled trout. *Trans. Am. Fish. Soc.* 70:397-403.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus. J. Fish. Res. Board Can.* 9:265-323.

Brett, J.R. 1956. Some principles in the thermal requirements of fishes. *Quart. Rev. Biol.* 31:75-87.

Brett, J.R. 1970. Temperature--Pisces, in *Marine Ecology* (O. Kinne, ed.), Vol. 1, pp. 515-560. Wiley, New York.

Brett, J.R. 1971. Energetic responses of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon *Oncorhynchus nerka. Am Zool.* 11:99-113.

Brungs, W.A. and B.R. Jones. 1977. Temperature Criteria for Freshwater Fish: Protocol and Procedures. Environmental Research Laboratory, Duluth Office of Research and Development, U.S. Environmental Protection Agency, Duluth, Minnesota.

Burton, D.T., and J.F. Garey. 1986. Chlorine minimization and chlorine decay studies at PSE&G's Salem nuclear generating station, Hancocks Bridge, New Jersey (1984-1985). Prepared for PSE&G.

Chung, K.S. and K. Strawn. 1982. Predicted survival of the bay anchovy (*Anchoa mitchilli*) in the heated effluent of a power plant on Galveston Bay, Texas. *Environmental Biology of Fishes* 7:57-62.

Chung, K.S. and K. Strawn. 1984. Seasonal change in the thermal tolerance of common estuarine crustaceans. *Bull. Japanese Soc. Sci. Fish.* 50:451-456.

Conover, D.O. and B. E Kynard. 1984. Field and laboratory observations of spawning periodicity and behavior of a northern population of the Atlantic silverside, *Menidia menidia* (Pisces: Atherinidae). *Environmental Biology of Fishes* 11:161-171.

Conover, D.O. and M.R. Ross. 1982. Patterns in seasonal abundance, growth, and biomass of the Atlantic silverside, *Menidia menidia*, in a New England estuary. *Estuaries* 5:275-286.

Copeland, B.J., R.W. Laney, and E.C. Pendleton. 1974. Heat influences in estuarine ecosystems, in *Thermal Ecology*. National Technical Information Service, Springfield, Virginia. Pp. 423-437.

Costa, H., and T.C. Sauer. 1994. Distributions of chemical contaminants and acute toxicity in Delaware Estuary sediments. DELEP Report No. 94-08. Prepared for the Delaware Estuary Program.

Costlow, J.D., Jr. 1967. The effect of salinity and temperature on survival and metamorphosis of megalops of the blue crab *Callinectes sapidus*. *Helgolander wiss. Meeresunter* 15:84-97.

Costlow, J.D., Jr. and C.G. Bookhout. 1971. The effect of cyclic temperatures on larval development in the mud crab, *Rhithropanopeus harrisii*, in *Fourth European Marine Biology Symposium* (D.I. Crisp, ed.), pp. 211-220. Cambridge University Press, London.

Coutant, C.C. 1970. Biological aspects of thermal pollution. I. Entrainment and discharge canal effects. *CRC Critical Rev. in Environ. Cont.* 3:341-381.

Coutant, C.C. 1972. Biological aspects of thermal pollution. I. Entrainment and discharge canal effects. *CRC Critical Rev. in Environ. Cont.* 3:341-381.

Coutant, C.C. 1975. Biological aspects of thermal pollution. II. Scientific basis for water temperature standards at power plants. *CRC Critical Rev. in Envron. Cont.* 3:1-24.

Coutant, C.C. 1977. Physiological considerations of future thermal additions for aquatic life, in *World Conference Toward a Plan of Actions for Mankind, Vol. 3, Biological Balance and Thermal Modifications* (M. Marois, ed.), Vol. 3, pp. 251-266. Pergamon Press, Oxford.

Cox, D.K. and CC. Coutant. 1981. Growth dynamics of juvenile striped bass as functions of temperature and ration. *Trans. Am. Fish. Soc.* 110:226-238.

Creutzberg, F. 1961. The orientation of migrating elvers (*Anguilla anguilla* Turt.) in a tidal area. *Neth. J. Sea Res.* 1:257-338

Cronin, T.W. and R.B. Forward, Jr. 1979. Tidal vertical migration and endogenous rhythm in estuarine crab larvae. *Science* 205:1020-1022.

Daiber, F.C. and C.T. Roman. 1988. Tidal marshes, in *The Delaware Estuary: Rediscovering a Forgotten Resource* (T.L. Bryant and J.R. Pennock, eds.). University of Delaware Sea Grant College Program, Newark, Delaware. Pp. 85-108

Daiber, F.C., L.L. Thornton, K.A. Bolster, T.G. Campbell, O.W. Crichton, G.L. Esposito, D.R. Jones, and J.M. Tyrawski. 1976. An Atlas of Delaware's Wetlands and Estuarine Resources. Delaware Coastal Management Program, Technical Report 2. Delaware State Planning Office, Dover, Delaware.

Dawson, D.E. 1958. A study of the Biological and Life History of the Spot, *Leiostomus xanthurus* Lacepede, with Special Reference to South Carolina. Contri. Bears Bluff Lab No. 28. 48 pp.

De Wolf, P. 1973. Ecological observations on the mechanisms of dispersal of barnacle larvae during planktonic life and settling. *Netherlands Journal of Sea Research.* 61:1-129.

Delaware River Basin Commission (DRBC). 1968. DRBC Basin Regulations-Water Quality. March.

DRBC. 1969. DRBC Public Hearing on Proposed Nuclear Generating Station at Artificial Island. 10 December. pp. 62-65, 70-73.

DRBC. 1970. Docket No. D-68-20 CP Delaware River Basin Commission Public Service Electric and Gas Company Salem Nuclear Generating Station Lower Alloways Creek Township, Salem County, New Jersey. 27 October.

DRBC. 1991. Water Quality Regulations: Administrative Manual Part III. Zone 5 Thermal Standards. West Trenton, New Jersey. 22 May.

DRBC. 1996. Water Quality Regulations. Administrative Manual--Part III. Revised to include Amendments through 23 October 1996.

DRBC. 1998. Delaware River and Bay Water Quality Assessment: 1996-7 305(b) Report. West Trenton, New Jersey.

Denny, M.W. and M.F. Shibata. 1989. Consequences of surf-zone turbulence for settlement and external fertilization. *Amer. Nat.* 134:859-889

DiLorenzo, J.L., G.R. Marino, P. Huang, T.O. Najarian, and L. Thatcher. 1992. Hydraulic controls on Delaware Estuary water quality, in *Hydraulic Engineering Saving a Threatened Resource - In Search of Solutions. Proceedings of the ASCE Hydraulic Engineering Sessions at Water Forum '92* (M.E. Jennings and N.G. Bhowmik, eds.), Baltimore, Maryland, August 2-5, 1992.

DiLorenzo, J.L., P. Huang, M.L. Thatcher, and T.O. Najarian. 1992. Effects of Historic Dredging Activities and Water Diversions on the Tidal Regime and Salinity Distribution of the Delaware Estuary. Prepared for the USEPA Delaware Estuary Program.

DiLorenzo, J.L., P. Huang, M.L. Thatcher, and T.O. Najarian. 1993. Effects of Historic Dredging Activities and Water Diversions on the Tidal Regime and Salinity Distribution of the Delaware Estuary. Prepared for the Delaware Estuary Program.

Dodson, J.J., W.C. Leggett, and R.A. Jones. 1972. The behavior of adult American shad (*Alosa sapidissima*) during migration from salt to freshwater as observed by ultrasonic tracking techniques. *J. Fish. Res. Board Can.* 29:1445-1449.

Doneker, R.L. and G.H. Jirka. Undated. CORMIX1: An Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Submerged Single Port Discharges (DRAFT). Environmental Research Laboratory, U.S. Environmental Protection Agency. Athens, Georgia.

Dovel, W.L. 1971. Fish Eggs and Larvae of the Upper Chesapeake Bay. NRI Special Report No. 4. Contribution No. 460. N atural Resources Institute, University of Maryland, College Park, Maryland.

EA Engineering Science and Technology (formerly Ecological Analysts, Inc.). 1978a. Hudson River Thermal Effects Studies for Representative Species-Final Report. Prepared for Central Hudson Gas and Electric Corporation, Consolidated Edison Company of New York, Inc., and Orange and Rockland Utilities, Inc.

EA Engineering Science and Technology (formerly Ecological Analysts Inc). 1978b. Biological Effects of Once-Through Cooling. Estuaries and Tidal Rivers. Prepared for the Utility Water Act Group. June.

EA Engineering Science and Technology (formerly Ecological Analysts, Inc.). 1978c. Thermal Effects Literature Review for Hudson River Representative Important Species. Prepared for Central Hudson Gas and Electric Corporation, Consolidated Edison Company of New York, Inc. and Orange and Rockland Utilities, Inc. EA, Middletown, New York.

EA Engineering Science and Technology (formerly Ecological Analysts, Inc.). 1979. Effects of Heat Shock on Predation of Striped Bass Larvae by Yearling White Perch. Appendix A: Thermal Tolerance Data for Young Striped Bass and Development of an Empirical Prediction Equation. Prepared for Central Hudson Gas and Electric Corporation, Consolidated Edison Company of New York, Inc., Orange and Rockland Utilities, Inc., and Power Authority of the State of New York. EA, Newburgh, New York.

Eckert, R.M. 1970. Public Service Electric and Gas Company. Personal communication. Letter to H.A. Howlett, Delaware River Basin Commission. 27 April.

Edinger, J. E., D. K. Brady and J. C. Geyer. 1974. Heat Exchange and Transport in the Environment. Cooling Water Studies for the Electric Power Research Institute, Research Project RP-49, Report 14. Palo Alto, California. EPRI Publication Number 74-049-00-3. November.

Edinger, J. E., and E. M. Buchak. 1978. Analysis of Temperature Distributions on the Delaware River-Estuary, Vol. I Summary, Vol. II Analysis. Delaware River Basin Commission. West Trenton, New Jersey.

Edmondson, U.T., G.W. Comita, and G.C. Anderson. 1962. Reproductive rates of copepods in nature and its relation to phytoplankton population. *Ecology* 43(4):625-634.

Emery, K.O. and D.G. Aubrey. 1991. Sea Levels, Land Levels and Tide Gauges. Springer-Verlag, New York.

Environmental Consulting Services, Inc. (ECSI). 1993. Survey of benthos: Delaware Estuary from the area of the C&D Canal through Philadelphia to Trenton. Prepared for Delaware Estuary Program, Delaware River Basin Commission, Environmental Protection Agency.

Epifanio, C.E. 1988a. Transport of invertebrate larvae between estuaries and the Continental Shelf. *Amer. Fish. Soc. Symp.* 3:104-114.

Epifanio, C.E. 1988b. Dispersal strategies of two species of swimming crabs on the Continental Shelf adjacent to Delaware Bay. *Marine Ecology Progress Series* 49:243-248.

Epifanio, C.E. and A.I. Dittel. 1982. Comparison of dispersal of crab larvae in Delaware Bay, USA, and the Gulf of Nicoya, Central America, in *Estuarine Comparisons* (V.S. Kennedy, ed.), pp. 477-487. Academic Press, New York.

Epifanio, C., and S. Tweed. 1988. Shellfish. In: *The Delaware Estuary: Rediscovering a Forgotten Resource*, (T.L Bryant and J.R. Pennock, eds.), pp. 81 – 89. University of Delaware Sea Grant Program, Newark, Delaware.

Federal Register. 1972. 37 Fed. Reg. 23198. 31 October.

Fischer, H.B., E.J. List, J. Imberger, and N.H. Brooks. 1979. *Mixing in Inland and Coastal Waters*. Academic Press.

Fitzgerald, M. and M. Karlinger. 1983. Daily water and sediment discharge from selected rivers of the U.S. USGS Water Supply Paper 2216.Ford, S.E., H.H. Haskin, and J.N. Kraeuter. 1995. Eastern oyster, in *Living Resources of the Delaware Estuary*, pp. 105-111. The Delaware Estuary Program.

Fluchter, J. 1965. Versuche zur Brutaufzucht der Seczunge *Solea solea* in kleinen Aquarien. *Helgolander Wissenschaftliche Meeresuntersuchungen* 12:395-403.

Foster, K.L., F.W. Steimle, W.C. Muir, R.K. Kropp, and B.E. Conlin. 1994. Mitigation potential of habitat replacement: Concrete artificial reefs in Delaware Bay – preliminary results. *Bull. Mar. Sci.* 55:783-795.

Frithsen, J.B., D.E. Strebel, S. Schreiner, and T. Schawitsch. 1995. Estimates of contaminant inputs to the Delaware Estuary. DELEP Report No. 95-03. Prepared for the Delaware Estuary Program.

Frithsen, J.B., K. Killam, and M. Young. 1991. An assessment of key biological resources in the Delaware River estuary. Prepared for the Delaware Estuary Program and the United States Environmental Agency.

Fry, F.E.J. 1971. The effect of environmental factors on the physiology of fish, in *Fish Physiology* (W.S. Hoar and D.J. Randall, eds.) Vol. VI. Environmental Relations and Behavior, pp. 1-98. Academic Press, New York.

Fry, F.E.J., J.S. Hart, and K.F. Walker. 1946. Lethal temperature relations for a sample of young speckled trout, *Salvelinus fonintalis*. *Univ. Toronto Biol. Series* 54:9-35.

Furch, K. 1972. Der Einfluss enier Vorbehandlung mit konstanten und wechselnden Temperaturen auf die Hitzeresistencz von *Gammarus salinus* and *Idotea balthic*. *Mar. Biol.* 15:12-34.

Greges, M.P. and J.R. Schubel. 1979. Thermal Resistance of Weakfish Eggs and Larvae. Special Report 22, Ref. 79-5. Stony Brook Marine Resource Center, State University of New York, Stony Brook, New York.

Gallaway, J. and K. Strawn. 1974. Seasonal abundance and distribution of marine fishes at a hot-water discharge in Galveston Bay, Texas. *Cont. Mar. Sci.* 18:71-137.

Garvine, R.W. 1991. Sub-tidal frequency estuary shelf interaction: Observations near Delaware Bay. *J. Geophys. Res.* 96:7049-7064.

Garvine, R.W., R. McCarthy, and K.C. Wong. 1992. The axial salinity distribution in the Delaware Estuary and its weak response to river discharge. *Est. Coast. Shelf Sci.* 35:157-165.

Geyer, W.R. and H. Nepf. 1996. Tidal pumping of salt in a moderately stratified estuary, *in Buoyancy Effects on Coastal and Estuarine Dynamics, Coastal and Estuarine Studies*, Vol. 53, pp. 213-226. American Geophysical Union.

Ginn, T.C., W.T. Waller, and G.J. Lauer. 1974. The effects of power plant condenser cooling water entrainment on the amphipod, *Gammarus* spp. *Wat. Res.* 8:937-945.

Ginn, T.C. 1977. An Ecological Investigation of Hudson River Macrozooplankton in the Vicinity of a Nuclear Power Plant. Ph.D. dissertation. New York University, New York.

Graf, W.H. 1971. *Hydraulics of Sediment Transport.* McGraw-Hill, New York.

Hall, D.J. 1964. An experimental approach to the dynamics of a natural population of *Daphnia galeata mendotae. Ecology* 45(1):94-112.

Hardy, J.D., Jr. 1978. *evelopment of Fishes of the Mid-Atlantic Bight. An Atlas of Egg Larval and Juvenile Stages.* Fish and Wildlife Service, U.S. Department of the Interior.

Hargreaves, B.R. 1995. Crustaceans, Mysid. In: *Living Resources of the Delaware Estuary*, (L. E. Dove and R. M. Nyman, eds.), pp. 59-68. The Delaware Estuary Program.

Hargreaves, B.R. and J.N. Kraeuter. 1991. The state of living resources in the Delaware estuary, *in The State of the Delaware Estuary* (J.H. Sharp, ed.). U.S. Environmental Protection Agency.

Harmic, T.L. 1958. Some Aspects of the Development and the Ecology of the Pelagic Phase of the Gray Squeteague, *Cynoscion regalis* (Bloch and Schneider), in the Delaware Estuary. MS dissertation. University of Delaware, Newark.

Hartwell, S.I. and D.E. Hoss. 1979. Thermal Shock resistance of spot (*Leiostomus xanthurus*) after acclimation to constant or cycling temperature. *Trans. Am. Fish. Soc.* 108:397-400.

Hastings, R.W. and J.C. O'Herron II. 1987. Occurrence and distribution of shortnose sturgeon, *Acipenser brevirostrum*, in the upper tidal Delaware River. *Estuaries* 10:337-341.

Herman, S.S. 1988. Zooplankton, in *The Delaware Estuary: Rediscovering a Forgotten Resource* (T.L. Bryant and J.R. Pennock, eds.), pp. 60-69. University of Delaware Sea Grant College Program, Newark, Delaware.

Herman, S.S. and B.R. Hargreaves. 1988. First order estimate of secondary productivity in the Delaware Estuary, in *Ecology and Restoration of the Delaware River Basin* (S.K. Majumdar, E.W. Miller, and L.E. Sage, eds.), pp. 148-156. Pennsylvania Academy of Science, Easton, Pennsylvania.

Hoar, W.S. 1951. The behavior of chum, pink, and coho salmon in relation to their seaward migration. *J. Fish. Res. Board Can.* 8:241-263.

Hoar, W.S. 1969. Reproduction, in *Fish Physiology* (W.S. Hoar and D.J. Randall, eds.), Vol. III. Reproduction and Growth. Bioluminescence, Pigments, and Poisons, pp. 1-72. Academic Press, Inc., New York.

Hoar, W.S. and D.J. Randall. 1969. *Fish Physiology*. Academic Press, Inc, New York.

Hochachka, P.W. and G.N. Somero. 1971. Biochemical adaptation to the environment, in *Fish Physiology* (W.S. Hoar and D.J. Randall, eds.), Vol. VI. Environmental Relations and Behavior, pp. 99-156. Academic Press, Inc., New York.

Hodson, R.G., R.G. Fechhelm, and R.J. Monroe. 1981. Upper temperature tolerance of spot, *Leiostomus xanthurus*, from the Cape Fear River Estuary, North Carolina. *Estuaries* 4:345-356.

Hokanson, K.E.F. 1977. Temperature requirements of some pereids and adaptations to the seasonal cycle. *J. Fish Res. Board Can.* 34:1524-1550.

Holland, A.F., A.T. Shaughnessy, L.C. Scott, V.A. Dickens, J. Gerritsen, and J.A. Ranasinghe. 1989. Long-term Benthic Monitoring and Assessment Program for the Maryland Portion of Chesapeake Bay: Interpretive Report. Prepared for Maryland Department of Natural Resources Power Plant Research Program, Annapolis, Maryland. Versar, Inc., Columbia, Maryland.

Holland, J.S., D.V. Aldrich, and K. Strawn. 1971. Effects of Temperature and Salinity on Growth, Food Conversion, Survival, and Temperature Resistance of Juvenile Blue Crabs, *Callinectes sapidus* Rathbun. Sea Grant Publication TAMU-SG-71-222. Texas A&M University and The Moody Foundation, Galveston, Texas.

Horton, D.B. and D.W. Bridges. 1973. A Study to Predict the Effects of Thermal Additions in the Bay River and Neuse River Area of North Carolina (Research Report). Research Institute of the Gulf of Maine, Portland, Maine. Sponsored by Office of Water Research and Technology, Washington, D.C. Report No. W75-01208; OWRT-B-004-NC(13)

Hoss, D.E., L.C. Coston, J.P. Baptist, and D.W. Engel. 1975. Effects of temperature, copper, and chlorine on fish during simulated entrainment in power plant condenser cooling systems, in *Proceedings of a Symposium, Physical and Biological Effects on the Environment of Cooling Systems and Thermal Discharges at Nuclear Power Plants*, Oslo, August 1974, pp. 519-527. International Atomic Energy Agency.

Hoss, D.E., W.F. Hettler, Jr., and L.C. Coston. 1974. Effects of thermal shock on larval estuarine fish - Ecological implications with respect to entrainment in power plant cooling systems, in *The Early Life History of Fish: The Proceedings of an International Symposium Held at the Dunstaffnage Marine Research Laboratory of the Scottish Marine Biological Association at Oban, Scotland, from May 17-23, 1993* (J.H.S. Blaxter, ed.), pp. 357-371. Springer-Verlag, New York.

Houde, E.D. 1974. Effects of temperature and delayed feeding on growth and survival of larvae of three species of subtropical marine fishes. *Mar Biol.* 26:271-285.

Howlett, H.A. 1970. Delaware River Basin Commission. Personal communication. Letter to R.M. Eckert, Public Service Electric and Gas Company. 29 January

Howlett, H.A. 1968. Delaware River Basin Commission Memorandum to James F. Wright. 7 May.

Hsieh, B., and D. Richards. 1996. Three Dimensional Numerical Simulation of Seasonal Flow and Salt Transport for the C&D Canal. Technical Report; 96-114. US Army Corps of Engineers, Waterway Experiment Station, Philadelphia, Pennsylvannia.

Hughes, D.A. 1969. Responses to salinity change as a tidal transport mechanism of pink shrimp *Penaeus duorarum*. *Biol. Bull.* 136:43-53.

Hulburt, E.M. 1957. The distribution of *Neomysis americana* in the estuary of the Delaware River. *Limnology and. Oceanogaphy* 2:1-11.

Huzzey, L.M. 1988. The lateral density distribution in a partially mixed estuary. *Est. Coast. Shelf Sci.* 9:351-358.

Ichthyological Associates (IA). 1969. An ecological study of the Delaware River in the Vicinity of Artificial Island, Progress Report, July.

IA. 1978a. Predictive Biological Information to Demonstrate the Passage and Maintenance of Representative Important Species Demonstration Type III-316(a) of Federal Water Pollution Control Act Amendments of 1972, PL 92500 for Essex Generating Station. Prepared for Public Service Electric and Gas Company, Newark, New Jersey.

IA. 1978b. Ecological Studies for Oyster Creek, September 1976-August 1977. December.

IA. 1978c. Predictive Biological Information to Demonstrate the Passage and Maintenance of Representative Important Species Demonstration Type III-316(a) of Federal Water Pollution Control Act Amendments of 1972, PL 92500 for Linden Generating Station. Prepared for Public Service Electric and Gas Company, Newark, New Jersey.

IA. 1978d. Predictive Biological Information to Demonstrate the Passage and Maintenance of Representative Important Species Demonstration Type III-316(a) of Federal Water Pollution Control Act Amendments of 1972, PL 92500 for Bergen Generating Station. Prepared for Public Service Electric and Gas Company, Newark, New Jersey.

IA. 1979. Ecological Studies for Oyster Creek, September 1977-August 1978. April.

IA. 1980. An ecological study of the Delaware River near Artificial Island, 1968-1976. A summary. Prepared for Public Service Electric and Gas.

Jay, D.A. and J.D. Musiak. 1994. Particle trapping in estuarine tidal flows. *J. Geophys. Res.* 99:20445-20461.

Jensen, L.D. 1974. *Proceedings of the Second Workshop on Entrainment and Intake Screening: Cooling Water Studies for Electric Power Research Institute.* Ecological Analysts, Inc., Melville, New York.

Jensen, L.D. 1978. *Fourth National Workshop on Entrainment and Impingement.* EA Engineering, Science, and Technology, Sparks, Maryland.

Johnson, D.R. 1985. Wind-forced dispersion of blue crab larvae in the Middle Atlantic Bight. *Continental Shelf Reseach* 4:733-745.

Johnson, D.R. and K.W. Hess. 1990. Numerical simulations of blue crab larval dispersal and recruitment. *Bulletin of Marine Science* 46(1):195-213. (RT: BW sent)

Johnson, D.R., B.S. Hester, and J.R. McConaugha. 1984. Studies of a wind mechanism influencing the recruitment of blue crabs in the Middle Atlantic Bight. *Cont. Shelf Res.* 3:425-437.

Jones, B.R., K.E.F. Hockanson, and J.H. McCormick. 1976. Winter temperature requirements for maturation and spawning of yellow perch *Perca flavescens* (Mitchell). Environmental Research Laboratory, U.S. EPA, Duluth, Minnesota. Manuscript for publication.

Kahn, D.M., R.W. Miller, C.A. Shirey, and S. Grabowski. 1998. Restoration of the Delaware River stock of striped bass. Report submitted to the Atlantic States Marine Fisheries Commission, Striped Bass Technical Committee. May.

Kawamura, G. and K. Ishida. 1985. Changes in the sense organ morphology and behavior with growth in the flounder *Paralichthys olivaceus*. *Bull. Japanese Soc. Sci. Fish.* 51:155-165.

Keiner, L. and X. Yan. 1997. Empirical orthogonal function analysis of sea surface temperature patterns in Delaware Bay. *Trans. IEEE* 35:1299-1306.

Kellogg, R.L., R.J. Ligotino, and S.M. Jinks. 1984. Thermal mortality prediction equations for entrainable striped bass. *Trans. Am. Fish. Soc.* 113:794-802.

Kellogg, R.L. and J.J. Gift. 1983. Relationship between optimum temperatures for growth and preferred temperatures for the young of four fish species. *Trans. Am. Fish. Soc.* 112:424-430.

Kelly, J.T. 1980. Sediment introduction and deposition in a coastal lagoon, *in Estuarine Perspectives* (V. Kennedy, ed.), pp. 379-388. Academic Press.

Ketchum, B.H. 1952. The Distribution of Salinity in the Estuary of the Delaware River. Ref. 52-103. Woods Hole Oceanographic Institution., Woods Hole, Massachusetts.

Killam, K.A. and W.A. Richkus. 1992. An Assessment of Fisheries Landings Records in the Delaware River Estuary. Prepared for Delaware River Basin Commission, Delaware Estuary Program, West Trenton, New Jersey. Versar, Inc., Columbia, Maryland. September.

King, I.P. 1985. Strategies for finite element modeling of three Dimensional Hydrodynamic systems. *Advances in Water Resources* 8:69-76.

King, I.P. 1992. A Finite Element Model for Stratified Flow, *RMA-10 Users Guide, Version 4.3*. May. Resource Management Associates.

King, I.P. 1993. RMA-10, A Finite Element Model for Three-Dimensional Density Stratified Flow (January Working Draft). Department of Civil and Environmental Engineering, University of California at Davis.

King, I.P., and L.C. Roig. 1988. Two-dimensional finite-element models for flood plains and tidal flats. Proceedings of Computational Methods in Flow Analysis (Niki, H., and M. Kawahara, eds.), Okayama University of Science, Japan.

King, L.R. 1970. Results of Swimming Speed and Endurance Studies on White Perch as Determined by the Beamish Respirometer - 25 November. Prepared for Consolidated Edison Company of New York, Inc., New York. Ichthyological Associates, Inc., Ithaca, New York.

King, L.R. 1970. Supplementary Results of Swimming Speed and Endurance Studies on White Perch as Determined by the Beamish Respirometer - 23 December. Prepared for Consolidated Edison Company of New York, Inc., New York. Ichthyological Associates, Inc., Ithaca, New York.

King, L.R. 1971. Supplementary Report on Swimming Speeds of Bay Anchovy and Other Estuarine Fishes (June-July 1971) - 17 August. Prepared for Consolidated Edison Company of New York, Inc., New York. Ichthyological Associates, Inc., Ithaca, New York.

King, L.R. 1971. Supplementary Results of Swimming Speed and Endurance Studies on White Perch as Determined by the Beamish Respirometer - 1 February. Prepared for Consolidated Edison Company of New York, Inc., New York. Ichthyological Associates, Inc., Ithaca, New York.

King, L.R. 1971. Supplementary Results of Swimming Speed and Endurance Studies on White Perch as Determined by the Beamish Respirometer - 25 February. Prepared for Consolidated Edison Company of New York, Inc., New York. Ichthyological Associates, Inc., Ithaca, New York.

King, L.R. 1971. Supplementary Results of Swimming Speed and Endurance Studies on White Perch as Determined by the Beamish Respirometer - 15 April. Prepared for Consolidated Edison Company of New York, Inc., Ichthyological Associates, Inc., Ithaca, New York.

King, L.R. 1971. Swimming Speed and Endurance Studies on White Perch, *Morone americana* - 18 June. Prepared for Consolidated Edison Company of New York, Inc., New York. Ichthyological Associates, Inc., Ithaca, New York.

Kinner, P., D. Mauer, and W. Leathem. 1974. Benthic invertebrates in Delaware Bay: Animal sediment associations of the dominant species. *Int. Revue ges. Hydrobiologia* 59:685-701.

Knebel, H. 1989. Modern sedimentary environments in a large tidal estuary, Delaware Bay. *Mar. Geol.* 86:119-136.

Krone, R.B. 1972. A field study of flocculation as a factor in estuarial shoaling processes. United States Army Corps of Engineers Committee on Tidal Hydraulics Technical Bulletin No. 19.

Lankford, T.E., Jr. 1997. Estuarine recruitment processes and stock structure in Atlantic croaker, *Micropogonias undulatus* (Linnaeus). Ph.D. dissertation. University of Delaware.

Lauer, G.J., W.T. Waller, D.W. Bath, W. Meeks, R. Heffner, T. Ginn, L. Zubarik, P. Bibko, and P.C. Storm. 1974. Entrainment studies on Hudson River organisms, in *Entrainment and Intake Screening. Proceedings of the Second Entrainment and Intake Screening Workshop* (L.D. Jensen, ed.), pp. 37-82. Electric Power Research Institute, Palo Alto, California.

Lawler, Matusky & Skelly Engineers (LMS). 1975. Arthur Kill Generating Station Section 316(a) Demonstration. Final Report. Appendix D. Prepared for Consolidated Edison Company of New York, Inc. LMS, Tappan, New York.

LMS. 1990. Modeling and Data Assessment of Dilution of Chambers Works Discharge in the Delaware River. Task A III Report.

Lawler, J.P., M.P. Weinstein, H.Y. Chen, and T.L. Englert. 1988. Modeling of physical and behavioral mechanisms influencing recruitment of spot and Atlantic croaker to the Cape Fear estuary. *American Fisheries Society Symposium* 3:115-131.

Leggett, W.C. and R.R. Whitney. 1972. Water temperature and the migrations of American shad. *Fish. Bull.* 70:659-670.

Leon, K.A. 1971. Low Temperature Swim Speed Study of White Perch (*Morone americana*) Using a Modified MacLeod Apparatus - 14 January. Prepared for Consolidated Edison Company of New York, Inc., New York. Ichthyological Associates, Inc., Ithaca, New York.

MacAthur, R.C., J.R. Dexter, D.J. Smith, and I.P. King. 1990. Two dimensional finite element simulation of the flooding characteristics in Kawainui Marsh, Hawaii. Proceedings of the 1990 ASCE Conference of Hydraulic Engineering, San Diego, California.

Mansue, L.J. and A.B. Comings. 1974. Sediment Transport by Streams Draining into the Delaware Estuary. USGS Water Supply Paper 1532-H.

Marino, G.R., J.L. DiLorenzo, H.S. Litwach, T.O. Najarian and M.L. Thatcher. 1991. General water quality assessment and trend analysis of the Delaware Estuary. Prepared for USEPA Delaware Estuary Program.

Marquez, R. 1989. Status Report of the Kemp's Ridley Turtle, *in Proceedings of the Second Western Atlantic Turtle Symposium* (L. Ogran, F. Berry, K. Bjorndal, H. Kumpf, R. Mast, G. Medina, H. Reichart, and R. William, eds.), pp. 159-174. NOAA, Panama City, Florida.

Marshall, H.G. 1992. Assessment of Phytoplankton Species in the Delaware River Estuary. Final Report. Prepared for the Delaware Estuary Program. Old Dominion University Research Foundation, Norfolk, Virginia.

Martin Marietta Environmental Systems (MMES). 1985. Impact Assessment Report: Chalk Point Steam Electric Station Aquatic Monitoring Program. Report No. PPSP-CP-85-1. Prepared for Maryland Department of Natural Resources, Power Plant Siting Program, Annapolis, Maryland. MMES, Columbia, Maryland.

Masnik, M.T. and J.H. Wilson. 1980. Assessment of the Impacts of the Salem and Hope Creek Stations on Shortnose Sturgeon, *Acipenser brevirostrum* Le Sueur. NUREGO671. U.S. Nuclear Regulatory Commission, Washington, D.C.

Maurer, D., W. Lethem, P. Kinner, and J. Tinsman. 1979. Seasonal fluctuations in coastal benthic invertebrate assemblages. *Estuarine and Coastal Marine Science* 8: 181-193.

McNair, J.N., J.D. Newbold, and D.D. Hart. 1997. Turbulent transport of suspended particles and dispersing benthic organisms: How long to hit bottom? *J. Theoret. Biol.* 188:29-52.

Meldrim, J.W., J.J. Gift, and B.R. Petrosky. 1974. The Effect of Temperature and Chemical Pollutants on the Behavior of Several Estuarine Organisms. Bulletin No. 11. Ichthyological Associates, Inc., Middletown, Delaware. December.

Michels, S. 1995. Drums. In:. *Living Resources of the Delaware Estuary*, (L. E. Dove and R. M. Nyman, eds.), pp. 167-174. The Delaware Estuary Program.

Middaugh, D.P. 1981. Reproductive ecology and spawning periodicity of the Atlantic silverside, *Menidia menidia* (Pisces: Atherinidae). *Copeia* 4:766-776.

Miglarese, J.V., C.W. McMillan, and M.H. Shealy Jr. 1982. Seasonal abundance of Atlantic croaker (*Micropogonias undulatus*) in relation to bottom salinity and temperature in South Carolina estuaries. *Estuaries* 5:216-223.

Mihursky, J.A. and V.S. Kennedy. 1967. Effects of temperature on invertebrates and vertebrates, in *Effects of Thermal Pollution on Productivity and Stability of Estuarine Communities*, pp. 21-39a. University of Maryland, Water Resources Research Committee, Natural Resources Institute.

Miles, S.C. 1968. Rheotaxis of elvers of the American eel *Anguilla rostrata* in the laboratory to water from different streams in Nova Scotia. *J. Fish. Res. Board Can.* 25:1591-1602.

Miller, E.W. 1988. Physical environment of the Delaware Basin, in *Ecology and Restoration of the Delaware River Basin* (S.K. Majumdar, E.W. Miller, and L.E. Sage, eds.), pp. 1-29. Pennsylvania Academy of Science.

Miller, R. W. 1995a. Striped bass. In: *Living Resources of the Delaware Estuary*, (L. E. Dove and R. M. Nyman, eds.), pp. 135-142. The Delaware Estuary Program.

Miller, R. W. 1995b. American shad. In: *Living Resources of the Delaware Estuary*, (L. E. Dove and R. M. Nyman, eds.), pp. 251-258. The Delaware Estuary Program.

Miller, J.M., L.B. Crowder, and M.L. Moser. 1985. Migration and utilization of estuarine nurseries by juvenile fishes: An evolutionary perspective. *Cont. Mar. Sci.* 27:338-352.

Morgan, R.P., II, and V.J. Rasin, Jr. 1982. Influence of temperature and salinity on development of white perch eggs. *Trans. Am Fish. Soc.* 111:396-398.

Munchow, A. and R.W. Garvine. 1993. Dynamical properties of a buoyancy-driven coastal current. *J. Geophys. Res.* 98:20063-20077.

National Academy of Sciences and National Academy of Engineering (NAS/NAE). 1973. Water Quality Criteria 1972. Prepared for U.S. Environmental Protection Agency. NAS/NAE, Washington, D.C.

National Marine Fisheries Service (NMFS). 1987. Final Supplement to the Final Environmental Impact Statement Listing and Protecting the Green Sea Turtle, Loggerhead Sea Turtle, and Pacific Ridley Sea Turtle under the Endangered Species Act Of 1973.

NMFS. 1993. Endangered Species Act Section 7 Consultation Biological Opinion for the Salem and Hope Creek Generating Stations on Loggerhead Turtle (*Caretta caretta)*, Green Turtle (*Chelonia mydas*), Leatherback Turtle (*Dermochelys coriacea*), Kemp's Ridley Turtle (*Lepidochelys kempi*) and, Shortnose Sturgeon (*Acipenser brevirostrum*).

NMFS. 1998. Public Review Workshop. 26th Assessment Workshop.

NMFS. 1999. Revision to Endangered Species Act Section 7 Consultation Opinion for the Salem and Hope Creek Generating Stations on the Loggerhead Turtle (*Caretta caretta*), Green Turtle (*Chelonia mydas*, Leatherback Turtle (*Dermochelys coriacea*), Kemp's Ridley Turtle (*Lepidochelys kempi*), and Shortnose Sturgeon (*Acipenser brevirostrum*).

National Oceanic and Atmospheric Administration (NOAA). 1987. Delaware River and Bay Tidal Circulation and Water Level Forecast Atlas. Estuarine and Ocean Physics Branch, Physical Oceanography Division, Office of Oceanography and Marine Assessment, National Ocean Service.

National Research Council. 1990. Decline of the Sea Turtles: Causes and Prevention. Committee on Sea Turtle Conservation. Board on Environmental Studies and Toxicology, Board on Biology, Commission on Life Sciences. National Academy Press, Washington, D.C.

National Technical Advisory Committee to the Secretary of the Interior. 1968. Water Quality Criteria. 1 April.

Neill, W.H. and J.J. Magnuson. 1974. Distributed ecology and behavorial thermoregulation of fishes in relation to heated effluent from a power plant at Lake Monona, Wisconsin. *Trans. Am. Fish. Soc.* 103:663-710.

Nelson, B. 1960. Clay minerals of the bottom sediments: Rappahannock River, Virginia. *Clays and Clay Minerals* 7:135-147.

New Jersey Department of Environmental Protection (NJDEP). 1998. 1998 Identification and Setting of Priorities for § 303(d) Water Quality Limited Waters in New Jersey. 15 September. State of New Jersey, Department of Environmental Protection, Trenton, New Jersey.

NJPDES. 1990. Draft NJPDES/DSW Permit No. NJ0005622. PSE&G Salem Nuclear Generating Station, Lower Alloways Creek Township, Salem County. October.

NJPDES. 1993. Draft NJPDES/DSW Permit No. NJ0005622. PSE&G Salem Nuclear Generating Station, Lower Alloways Creek Township, Salem County. 24 June.

NJDEP. 1994. Final NJPDES/DSW Permit No. NJ0005622. PSE&G Salem Nuclear Generating Station, Lower Alloways Creek Township, Salem County. 20 July.

New York University Medical Center (NYU). 1974. Effects of Entrainment by the Indian Point Power Plant on Hudson River Biota: Progress Report for 1973. Prepared for Consolidated Edison Company or New York, Inc. New York University Medical Center, Institute of Environmental Medicine, Laboratory for Environmental Studies, New York.

Nichols, M. 1974. Development of the turbidity maximum in the Rappahannock River. *Memoires de l'Institute de Geologie du Bassind'Aquitaine* 7:19-25.

Nichols, M.M. and R.B. Biggs. 1988. Estuaries, in *Coastal Sedimentary Environments* (R.A. Davis, ed.), pp. 77-173. Springer-Verlag, New York.

Norcross, B.L. and R.F. Shaw. 1984. Oceanic and estuarine transport of fish eggs and larvae: A review. *Transactions of the American Fisheries Society* 113:153-165.

Officer, C.B. and M.M. Nichols. 1980. Box model applications to study of suspended sediment distribution in partially mixed estuaries, in *Estuarine Perspectives* (V.S. Kennedy, ed.), pp. 329-340. Academic Press, New York.

Odum, E.P. 1971. *Fundamentals of Ecology*. Third Edition. W.B. Saunders Company, Philadelphia, Pennsylvania.

Okubo, A. 1973. Effect of shoreline irregularities on streamwise dispersion in estuaries and other embayments. *Neth. J. Sea Res.* 6:213-224.

Otto, R.G., M.A. Kitchel, and J. O'Hara Rice. 1976. Lethal and preferred temperatures of the alewife (*Alosa pseudoharengus*) in Lake Michigan. *Trans. Am. Fish. Soc.* 1:96-106.

Pape, E.H., III and R.W. Garvine. 1982. The subtidal circulation in Delaware Bay and adjacent shelf waters. *J. Geophys. Res.* 87:7955-7970.

Pennock, J.R. 1988. Phytoplankton. In: *The Delaware Estuary: Rediscovering a Forgotten Resource*, (T.L Bryant and J.R. Pennock, eds.), pp. 55 – 60. University of Delaware Sea Grant Program, Newark, Delaware.

Pennock, J.R. and S.S. Herman. 1988. Plankton, *in The Delaware Estuary: Rediscovering a Forgotten Resource* (T.L. Bryant and J.R. Pennock, eds.), pp. 55-67. University of Delaware Sea Grant College Program, Newark, Delaware.

Pennock, J.R. and J.H. Sharp. 1986. Phytoplankton production in the Delaware estuary: Temporal and spatial variability. *Mar. Ecol. Prog. Ser.* 34:143-155.

Pezzack, D.S. and S. Corey. 1979. The life history and distribution of *Neomysis americana* (Smith) (Crustacea, Mysidacea) in Passamaquoddy Bay. *Can. J. Zool.* 57:785-793.

Pezzack, D.S. and S. Corey. 1982. Effects of temperature and salinity on immature and juvenile *Neomysis americana* (Smith) (Crustacea: Mysidacea). *Can. J. Zool.* 60:2725-2728.

Phelan, D. and M. Ayers. 1994. Delaware River basin characteristics water supply and water use, in *Sensitivity of Water Resources in the Delaware River Basin*. USGS Water Supply Paper 2422.

Pritchard and Carpenter. 1968. Salem Nuclear Generating Station Nos. 1 and 2 Units Artificial Island Site, Dispersion and Cooling of Waste Heat Released into the Delaware River Estuary.

Public Service Electric and Gas Company (PSE&G). 1971. Salem Nuclear Generating Station Units 1 and 2 Environmental Report. Docket nos. 50-272 and 50-311. June.

PSE&G. 1972. Salem Nuclear Generating Station Units 1 and 2 Environmental Report. Docket nos. 50-272 and 50-311. May.

PSE&G. 1972. Nuclear Generating Station Units 1 and 2 Environmental Report. Docket nos. 50-272 and 50-311. August.

PSE&G. 1974. Salem Nuclear Generating Station 316(a) Type II Demonstration: Protection of Representative, Important Species. Newark, New Jersey. 11 November.

PSE&G. 1975. A Report on the Salem Nuclear Generating Station, Artificial Island, Salem County, New Jersey. Supplement to Section 316(a), Demonstration Type 3 (dated 18 September 1974). Newark, New Jersey. 5 December.

PSE&G. 1978a. 1977 Annual Environmental Operating Report (Nonradiological). January 1 through December 31, 1977. Salem Nuclear Generating Station--Unit 1. Volume 3 of 3. Special Surveillance and Study Activities. PSE&G, Newark, New Jersey. 31 March.

PSE&G. 1978b. A Report on the Salem Nuclear Generating Station Artificial Island, Salem County, New Jersey. Second Supplement to 316(a) Demonstration Type 3 (dated 18 September 1974). Newark, New Jersey. 3 February.

PSE&G. 1978c. 1977 Annual Environmental Operating Report (Nonradiological). January 1 through December 31, 1977. Salem Nuclear Generating Station--Unit 1. Volume 2 of 3. Biotic Environmental Surveillance. PSE&G, Newark, New Jersey. 31 March.

PSE&G. 1979. A Report on the Salem Generating Station, Artificial Island, Salem County, New Jersey: U.S. Environmental Protection Agency Section 316(a), Demonstration Type 3: A Supplement to Studies Reported in PSE&G, 1978. Second Supplement to Section 316(a) Demonstration, Type 3 (dated September 18, 1974). Newark, New Jersey. 31 December.

PSE&G. 1980. An Ecological Study of the Delaware River near Artificial Island, 1968-1976: A Summary. Newark, New Jersey.

PSE&G. 1984b. Spot (*Leiostomus xanthurus*): A Synthesis of Information on Natural History, With Reference to Occurrence in the Delaware River and Estuary and Involvement With the Salem Generating Station. Appendix VII. Newark, New Jersey

PSE&G. 1984a. Salem Generating Station 316(b) Demonstration. NPDES Permit No. NJ0005622; NRC Operating Licenses DPR-70 and DPR 75; NRC Docket Numbers 5-272 and 50-311. Newark, New Jersey. February.

PSE&G. 1989. Assessment of the Impacts of the Salem and Hope Creek Generating Stations on Kemp's Ridley (*Lepidocholys kempi*) and Loggerhead (*Caretta caretta*) Sea Turtles. Newark, New Jersey.

PSE&G. 1991. Post-§ 316(a) Thermal Studies at Salem. PSE&G § 316 Comments on NJPDES Draft Permit No. NJ0005622, 14 January.

PSE&G. 1993. Comments on Draft NJPDES Permit No. NJ0005622. Newark, New Jersey. 16 September.

PSE&G. 1995. Delaware River Basin Commission Docket No. D-68-20 CP. Public Service Electric and Gas Company Salem Generating Station Request for Revision of Docket. Volume 1. 30 June.

PSE&G. 1996. Salem Generating Station Effluent Characterization Study Interim Report. Newark, New Jersey. 4 March.

PSE&G. 1997. Evaluation of Macrohabitat Utilization by Loggerhead Sea Turtles in Delaware Estuary Using Sonic and Satellite Tracking Techniques. PSE&G Nuclear Business Unit. June.

Ramsey, J.S., R.P. Hamilton, and D.G. Aubrey. 1995. Nested three-dimensional hydrodynamic modeling of the Delaware Estuary, in *Estuary and Coastal Modeling, Proceedings of the 4th International Conference* (Spaulding, M.L., and R.T. Cheng, eds.), 53-65. San Diego, California, 26-28 October 1995. Coastal Zone Management Committee, Waterways, Ports, Coastal and Ocean Division, and the Computational Hydraulics Committee of the Hydraulics Division, ASCE.

Raney, E.C. 1969. Public Hearing on Proposed Nuclear Generating Station at Artificial Island before the Delaware River Basin Commission. 10 December.

Raney, E.C. 1970. Ichthyological Associates, Inc. Personal communication. Letter to F.W. Schneider, Public Service Electric and Gas Company. 8 March.

Raney, E.C., V.J. Schuler, and R.F. Denoncourt. 1969. Ecological Study of the Delaware River in the Vicinity of Artificial Island. Ichthyological Associates Progress Report for June-December 1968. Middletown, Delaware.

Reutter, J.M. and C.E. Herdendorf. 1976. Thermal discharge from a nuclear power plant: Predicted effects on Lake Erie fish. *The Ohio Journal of Science* 76:39-45.

Reynolds, W.W. 1977. Temperature as a proximate factor in orientation behavior. *J. Fish Res. Board Can.* 34:734-739.

Ross, J.P., S. Beavers, D. Mundell, and M. Airth-Kindree. 1989. The Status of Kemp's Ridley. Prepared for Center for Marine Conservation, Washington, D.C. Caribbean Conservation Corporation, Gainesville, Florida.

Roy F. Weston, Inc. 1978. Special Heat Flux Study - Alloway, Hope, and Mad Horse Creeks, Salem Nuclear Generating Station, Delaware River Estuary. 27 October 1977. Prepared for PSE&G, Newark, New Jersey. February.

Roy F. Weston, Inc. 1979. Thermal Monitoring Program Salem Nuclear Generating Station Delaware River Estuary, Analysis of Pre-Operational and Post-Operational Current and Water Temperature Data. June. Prepared for Public Service Electric and Gas Company. West Chester, Pennsylvania.

Roy F. Weston, Inc. 1982. Near-field and Far-field Current Velocity and Circulation Studies in the Vicinity of the Salem Nuclear Generating Station Delaware River Estuary. Prepared for Public Service Electric and Gas Company. West Chester, Pennsylvania. Final Report, December.

Roy F. Weston, Inc. 1983. Thermal Plume Survey in the Vicinity of the Salem Nuclear Generating Station Delaware River Estuary. Prepared for Public Service Electric and Gas Company. West Chester, Pennsylvania, Final Report, June.

Roy F. Weston, Inc. 1984. Sedimentation Trends in the Near-Field Vicinity of the Circulating and Service Water Systems, Salem Nuclear Generating Station, Delaware River Estuary - Draft Report. Prepared for PSE&G, Newark, New Jersey. August.

Roy F. Weston Inc. 1985. Shoal Sediment Core Analysis Circulating Water Intakes Salem Nuclear Generating Station Delaware River Estuary - Draft Report. Prepared for PSE&G, Newark, New Jersey. February.

Roy F. Weston Inc. 1986. Sedimentation Trap Analyses in the Vicinity of the Circulating Water System, Salem Generating Station, Delaware River Estuary. Prepared for PSE&G, Hancocks Bridge, New Jersey. October.

Roy F. Weston Inc. 1990. Bathymetric Survey Salem Generating Station, Hope Creek Generating Station, Delaware River Estuary. Survey 69: April 1990. Prepared for PSE&G, Newark, New Jersey. June.

Rudavsky, A.B. 1972. Circulating Water Outlet Hydraulic Studies No. 1 and 2 Units Salem Nuclear Generating Station. Prepared for Public Service Electric and Gas Company, Newark, New Jersey. May.

Santoro, E.D. 1998. 1998 Delaware Estuary monitoring report. DRBC, Trenton, NJ.

Savage, A.A. 1982. The survival and growth of *Gammarus tigrinus* Sexton (Crustaces: Amphipoda) in relationship to salinity and temperature.

Seagraves, R.J., and R.W. Cole. 1989. Monitoring fish populations in Delaware's estuaries. Period covered 1 February 1988 -31 January 1989. Stream and Inland Bay Survey. Project F-37-R-3. Delaware Division of Fish and Wildlife.

Schoelkoph, R. and E. Stetzar. 1995. Marine turtles, in *Living Resources of the Delaware Estuary* (L.E. Dove and R.M. Nyman, eds.), pp. 305-309. The Delaware Estuary Program

Schubel, J.R. 1972. Distribution and transportation of suspended sediment in upper Chesapeake Bay, *in Environmental Framework of Coastal Plain Estuaries*, pp. 91-117. Geo. Soc. Amer. Memoir 133.

Schuler, V.J., L.D. Anselmini, S.H. Eaton, and J.W. Meldrim. 1970a. An Ecological Study of the Delaware River in the Vicinity of Artificial Island. Progress Report for the Period January-December 1969. Ichthyological Associates Progress Report 2. Part 1.

Schuler, V.J., W.H. Bason, R.F. Denoncourt, J.G. Ferrante, P.L. Harmon, L.R. King, J.W. Meldrim, T.W. Robbins, B.A. Smith, D.L. Thomas, and J.C.S. Wang. 1970b. An Ecological Study of the Delaware River in the Vicinity of Artificial Island. Progress Report for the Period January-December 1969. Ichthylogical Associates Progress Report 2 Part III.

Schuler, V.J. 1971. An Ecological Study of the Delaware River in the Vicinity of Artificial Island. Ichthyological Associates Progress Report 3. Progress Report for the Period January-December 1970.

Seliger, H.H., J.A. Boggs, R.B. Rivkin, W.H. Biggley, and K.R.H. Aspden. 1982. The transport of oyster larvae in an estuary. *Marine Biology (Berlin)* 71:57-72.

Sharp, J.H. 1994. What not to do about nutrients in the Delaware Estuary? in *Changes in Fluxes in Estuaries* (K.R. Dyer and R.J. Orth, eds.), pp. 423-428. Olsen and Olsen, Denmark.

Smith, C.L. 1985. *The Inland Fishes of New York State*. New York Department of Environmental Conservation, Albany, New York.

Smith, C.F., J.R. Schubel, M.P. Greges, N. Itzkowitz, S.J. DiPiero, J. Longo, and M.A. Morgan. 1979. Thermal Resistance Characteristics of Early Life History Stages of Finfish From Long Island Waters. Marine Sciences Research Center Special Report 26, Reference 79-9. State University of New York, Stony Brook, New York.

Sneddon, L.A., K.J. Metzler, and M. Anderson. 1995. A classification and description of natural community elements of the Delaware Estuary, in *Living Resources of the Delaware Estuary* (L.E. Dove and R.M. Nyman, eds.), pp. 3-90. The Delaware Estuary Program, USEPA.

Stearns, D.E. 1995. Copepods, in *Living Resources of the Delaware Estuary* (L.E. Dove and R.M. Nyman, eds.), pp. 33-42. The Delaware Estuary Program.

Stein, M., M. Docherty, R. Jung, and J.P. Myers. 1988. Migratory shorebirds, *in The Delaware Estuary: Rediscovering a Forgotten Resource* (T.L. Bryant and J.R. Pennock,eds.), pp. 115-121. University of Delaware Sea Grant College Program, Newark, Delaware.

Stumpf, R.P. 1984. Analysis of suspended sediment distribution in the surface waters of Delaware Bay, Ph.D. Dissertation, Newark, Delaware: University of Delaware.

Sulkin, S.D. 1984. Behavioral basis of depth regulation in the larvae of brachyuran crabs. *Mar. Ecol. Prog. Ser.* 15:181-205.

Sulkin, S.D. and W. Van Heukelem. 1982. Larval recruitment in the crab, *Callinectes sapidus* Rathbun: An amendment to the concept of larval retention in estuaries, in *Estuarine Comparisons* (V. Kennedy, ed.), pp. 459-475. Academic Press, New York.

Sutton, C.C., J.C. O'Herron II, and R.T. Zappalorti. 1996. The Scientific Characterization of the Delaware Estuary. DRBC Project No. 321. The Delaware Estuary Program. Herpetological Associates, Inc., Forked River, New Jersey.

Tagatz, M.E. 1969. Some relations of temperature acclimation and salinity to thermal tolerance of the blue crab, *Callinectes sapidus*. *Trans. Am. Fish. Soc.* 4:713-716.

Talbot, G.B. 1966. Estuarine Environmental requirements and limiting factors for striped bass. *Am. Fish. Soc.* 3:37-49.

Tatham, T.R. 1970. Swimming Speed of the White Perch, *Morone americana*, Striped Bass, *Morone saxatilis*, and Other Estuarine Fishes. Final Report on Summer Studies Using the MacLeod Apparatus. Prepared for Consolidated Edison Company of New York, Inc., No.0-26156. Ichthyological Associates, Inc., Ithaca, New York.

Terpin, K.M., M.C. Wyllie, and E.R. Holmstrom. 1977. Temperature Preference, Avoidance, Shock, and Swim Speed Studies with Marine and Estuarine Organisms from New Jersey. Report for the period January-December 1976. Prepared for Public Service Electric and Gas Company, Newark, New Jersey. Ichthyological Associates, Inc., Ithaca, New York. May.

Tetra Tech, Inc. 1978. Biological Effects of Once-Through Cooling on the Marine Environments. Prepared for the Utility Water Act Group. June.

Tewskbury, H.T., II and D.O. Conover. 1987. Adaptive significance of intertidal egg deposition in the Atlantic silverside *Menidia menidia*. *Copeia* 1:76-83.

Texas Instruments Incorporated. 1976a. Hudson River Ecological Study in the Area of Indian Point Thermal Effects Report. Prepared for Consolidated Edison Company of New York, Inc., New York, New York. TI, Dallas, Texas.

Texas Instruments Incorporated. 1976b. Fisheries Survey of the Hudson River. March-December 1973. Volume IV. Prepared for Consolidated Edison Company of New York, Inc. New York, New York. Revised.

Thibault, Y. and R. Couture. 1980. Etude de la TL50 24h de *Gammarus fasiatus* say (Crustace, Amphipode) a differents niveaux d'acclimation thermique. *Rev. Can. Biol.* 39:149-152.

Tiner, R.W., Jr. 1985. Wetlands of New Jersey. U.S. Fish and Wildlife Service, National Wetlands Inventory, Newton Corner, Massachusetts.

Uncles, R.J., R.C.A. Elliot, and S.A. Weston. 1985b. Dispersion of salt and suspended sediment in a partially mixed estuary. *Estuaries* 8:256-269.

Uncles, R.J., R.C.A. Elliot, and S.A. Weston. 1985a. Observed fluxes of water, salt and suspended sediment in a partially mixed estuary. *Est. Coast. Shelf Sci.* 20:147-167.

United States. 1998. Criteria for Determining Alternative Effluent Limitations Under Section 316(a) of the Clean Water Act. Code of Federal Regulations 40 §125.71(b). July 1.

United States. 1998. Criteria for Determining Alternative Effluent Limitations Under Section 316(a) of the Clean Water Act. Code of Federal Regulations 40 §125.71(c). July 1.

United States. 1998. Criteria for Determining Alternative Effluent Limitations Under Section 316(a) of the Clean Water Act. Code of Federal Regulations 40 §125.73. July 1.

United States. 1998. Criteria for Determining Alternative Effluent Limitations Under Section 316(a) of the Clean Water Act. Code of Federal Regulations 40 §125.73(b). July 1.

United States. 1998. Criteria for Determining Alternative Effluent Limitations Under Section 316(a) of the Clean Water Act. Code of Federal Regulations 40 §125.73(c). July 1.

U.S. Atomic Energy Commission (USAEC). 1973. Final Environmental Statement Related to the Operation of Salem Nuclear Generating Station Units 1 and 2. Public Service Gas and Electric Company. Docket Nos. 50-272 and 50-311.

U.S. Environmental Protection Agency (USEPA). 1973. Memorandum from Robert V. Zener, USEPA Acting Deputy General Counsel, to Deputy Assistant Administrator for Water Planning and Standards. 28 December.

USEPA. 1974. 316(a) Technical Guidance - Thermal Discharges. Water Planning Division, Office of Water and Hazardous Materials, USEPA, Washington, D.C. September.

USEPA. 1975. 316(a) Technical Guidance Manual and Guide for Thermal Effects Sections of Nuclear Power Plant Environmental Impact Statements. December.

USEPA. 1976. Quality Criteria for Water. Office of Water and Hazardous Materials. EPA-440/9-76-023. USEPA, Washington, D.C.

USEPA. 1977. Draft Interagency 316(a) Technical Guidance Manual and Guide for Thermal Effects Sections of Nuclear Facilities Environmental Impact Statements. USEPA Office of Water Enforcement, Washington, DC. 1 May.

USEPA. 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Editions). Athens, Georgia. June

USEPA. 1991. Technical Support Document for Water Quality-Based Toxics Control. Office of Water Enforcement and Permits, Office of Water Regulations and Standards. Washington, D.C.

USEPA. 1995 . The Delaware Estuary: Discover its Secrets. Comprehensive Conservation and Management Plan for the Delaware Estuary. Public review draft. December.

USEPA. 1998a. Guidelines for ecological risk assessments. Risk Assessment Forum. EPA/630/R-95-002F. Washington, D.C. April.

USEPA. 1998b. Conditions of the Mid-Atlantic Estuaries. Office of Research and Development, EPA 600-R-98-147. November.

U.S. Geological Survey (USGS). 1986. Atlas of Hydrologic Investigations. Hydrologic Atlas 697. Washington, D.C.

U.S. Nuclear Regulatory Commission (USNRC). 1991. Endangered Species Act Section 7 Consultation Biological Opinion for Salem and Hope Creek Generating Stations on Loggerhead Turtle (*Caretta caretta*), Green Turtle (*Chelonia mydas*), Leatherback Turtle (*Dermochelys coriacea*), Kemp's Ridley Turtle (*Lepidochelys kempii*) and Shortnose Sturgeon (*Acipenser brevirostrum*).

Utility Water Act Group (UWAG). 1978a. Biological Effects of Once-Through Cooling, Volume 4, Rivers and Reservoirs. Submitted to the U.S. Environmental Protection Agency by the Utility Water Act Group. June.

UWAG. 1978b. Biological Effects of Once-Through Cooling. 3(4). Tidal Rivers and Estuaries. Prepared by Ecological Analysts, Inc. June.

UWAG. 1982. Effects of Thermal Discharges from Ocean-Sited Power Plants. Submitted to USEPA. February.

Valle-Levinson, A. and K.M. Lwiza. 1995. The effects of channels and shoals on exchange between the Chesapeake Bay and the adjacent ocean. *J. Geophys. Res.* 100:18551-18563.

Versar, Inc. 1986. Technical Review and Evaluation of Thermal Effects Studies and Cooling Water Intake Structure Demonstration of Impact for the Salem Nuclear Generating Station: Preliminary Report. Prepared for New Jersey Department of Environmental Protection and Energy, Trenton, New Jersey.

Versar, Inc. 1989. Technical Review and Evaluation of Thermal Effects Studies and Cooling Water Intake Structure Demonstration of Impact for the Salem Nuclear Generating Station: Revised Final Report. Prepared for New Jersey Department of Environmental Protection and Energy, Trenton, New Jersey.

Walker, W.J. 1989. Abundance and distribution of *Neomysis americana* in the Delaware River estuary. Master's Thesis, University of Delaware.

Walters, R.A. 1991. A study of salt transport process in Delaware Bay, in *Estuary and Coastal Modeling, 2nd International Conference* (M.L. Spaulding, ed.). WW Division of the American Society of Civil Engineers.

Wang, J.C.S., and R.J. Kernehan. 1979. Fishes of the Delaware Estuaries: A guide to the early life stages. EA Communications, Ecological Analysts, Inc. Towson, Maryland.

Weinstein, M.P.,ed. 1988. Larval Fish and Shellfish Transport Through Inlets. Proceedings of a Workshop held in Ocean Springs, Mississippi, USA. 19-20 August 1985. Amer. Fish. Soc. Symposium 3. American Fisheries Society, Bethesda, Maryland.

Weinstein, M.P., S.L. Weiss, R.G. Hodson, and L.R. Gerry. 1980. Retention of three taxa of postlarval fishes in an intensively flushed tidal estuary, Cape Fear River, North Carolina. *Fish. Bull.* 78:419-436.

Weisberg, S.B., H.T. Wilson, P. Himchak, T. Baum, and R. Allen. 1996. Temporal trends in abundance of fish in the tidal Delaware River. *Estuaries* 19(3): 723-729.

Weston Environmental Consultants. 1978. Special Heat Flux Study-Alloway, Hope, and Mad Horse Creeks Salem Nuclear Generating Station Delaware River Estuary. Prepared for PSE&G. West Chester, Pennsylvania. February.

Wong, K.C. 1994. On the nature of transverse variability in a coastal plain estuary. *Journal of Geophysical Research* 99(C7):14209-14222.

Wong, K.C. and A. Munchow. 1995. Buoyancy forced interaction between the estuary and inner continental shelf. *Continental Shelf Research* 15:59-88.

Wright, J.F. 1969. Delaware River Basin Commission. Personal communication. Letter to D. Wallace, New York Conservation Department. 26 November.

Wyllie, M.C., E.R. Holmstrom, and R.K. Wallace. 1976. Temperature Preference, Avoidance, Shock, and Swim Speed Studies with Marine and Estuarine Organisms from New Jersey. Report for the period January-December 1975. Prepared for Public Service Electric and Gas Company, Newark, New Jersey.

APPENDIX E
ATTACHMENT E-1

ASSESSMENT OF PSE&G RIVER MONITORING AND MODELING PROGRAMS

SPONSOR: DR. ERIC E. ADAMS
PSE&G RENEWAL APPLICATION
SALEM GENERATING STATION
PERMIT NO. NJ0005622
4 MARCH 1999

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APPENDIX E
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ASSESSMENT OF PSE&G RIVER MONITORING AND MODELING PROGRAMS

I. INTRODUCTION

This attachment provides an overall assessment of PSE&G's Estuary monitoring and modeling programs, with the goal of increasing the understanding of physical processes and features of the Estuary. Section I states the objectives (Section I.A) and approach (Section I.B) of assessment. Section I.C establishes the context for the Estuary monitoring/modeling programs assessment based on prior characterizations of the thermal plume and permit requirements for comprehensive thermal monitoring.

Section II follows with a review of the recent field data that have been collected and numerical models that have been implemented to support the 1999 permit renewal application. The primary data set used for this assessment is the "Two-Unit Survey" performed in accordance with the Modified Thermal Monitoring Program ("Modified TMP"), which is described in detail in Section V.D. Several other thermal monitoring programs have been implemented previously as well, and these are reviewed briefly in this Attachment. Sections I and II together establish the framework for the following Sections.

Section III compares historical literature, field data, and numerical modeling results addressing estuarine processes pertinent to the understanding of the Salem thermal plume. Finally, Section IV summarizes the physical processes that dominate the behavior of the Salem plume. Section IV also concludes that the models adequately simulate the temperatures and character of the Salem plume.

The comparisons between the model and data presented in this assessment were developed from a physical processes point of view. Other documents included in this submittal describe the observations or modeling independently; however, this Attachment merges the two. The observations collected and models applied specifically to support the 1999 permit renewal application are presented in the following documents which accompany this submittal:

- Appendix E: Section 316(a) Variance Demonstration – Section V focuses on the characterization of the thermal discharge.
- Exhibit E-1-2: 1997 Thermal Monitoring Program (Chapter 11) – This comprehensive field data collection program characterized ambient conditions in the Estuary at a time when the Station was not operating (July 1997), as well as the thermal plume when one of the two electric generating units at the Station was in operation (October 1997).
- Exhibit E-1-3: 1998 Annual Monitoring Report (Chapter 10) – This comprehensive field data collection program characterized the thermal plume at a time when both electric generating units were in operation (May 1998).

- Exhibit E-1-4: Bathymetric Survey in the Vicinity of Salem's Discharge – This survey was conducted to map the water depth and bottom morphology in the vicinity of the discharge pipes.
- Attachment E-2: Hydrothermal Modeling Program – This attachment provides detailed descriptions of the models and modeling methods, including calibration and verification procedures.

Other field observations from previous investigations not specifically intended to support the 1999 permit renewal application are described in detail in Appendix E Section V.C and Exhibit E-1-1: 1995 Monitoring Summary.

I.A. Objectives

The primary purposes of this Attachment are to:

1) compare recent field observations with historical literature and previous Salem thermal plume studies to determine consistency with previous understanding of Estuary dynamics, and to describe new and/or more detailed physical observations;
2) examine the recent near-field observations to provide a detailed empirical description of the thermal plume (the data collected in the vicinity of the discharge to support the 1999 permit renewal application offer a level of detail regarding Salem plume processes that has not been available from previous studies);
3) evaluate the far-field observations compared to the far-field plume and Estuary dynamics as a whole; and
4) most importantly, demonstrate consistency between the observations and the numerical models. Although the model calibration and verification processes ensure that model predictions and data are similar at individual points within the study region, it is necessary to compare on a larger scale. For instance, a comparison between modeled and measured tides at two locations may reveal that the modeled tide is similar to the measured tide; however, small differences may translate into water surface gradients on a larger scale that can generate unrealistic currents in the model that do not exist in nature.

The conclusions of this attachment identify the adequacy of the model as an analysis tool appropriate for characterizing the Salem plume.

I.B. Approach

This attachment is based on all available information relevant to characterizing the thermal discharge. This information includes field observations, published literature, and results from numerical models. Field observations and numerical modeling results are available from various studies that were previously conducted to characterize the Station's plume. These previous studies are reviewed and summarized in Section I.C.1 below. The foci of this assessment are the recent field observations and numerical models implemented to support the 1999 permit renewal. These recent field observation are reviewed and summarized in Section II.

The following specific processes are examined:

- tidal flow and water-level change,
- meteorological effects,
- freshwater discharge from the rivers flowing into Estuary,
- thermal discharge plume dynamics,
- circulating water intake processes,
- tidal marsh flow and heat exchange, and
- the influence of the C&D Canal.

Each of these processes is examined in Section III based on historical literature, field observations, and results from numerical models.

I.C. Context

A brief overview of the background information relevant to this assessment of the Estuary monitoring and modeling programs is presented in this section. Two major topics are reviewed:

- Prior characterizations of the thermal plume (Section I.C.1), and
- Permit requirements for comprehensive thermal monitoring (Section I.C.2).

I.C.1. Prior Characterizations of Salem's Thermal Plume

Numerous investigations have been conducted previously to characterize the thermal plume associated with the Station discharge. Most of these investigations were conducted to support permit applications, or as requirements of a permit for the Station. PSE&G and its consultants also have conducted additional investigations, not associated with permit requirements, to gain a better understanding of the processes surrounding the Station. The results of the additional studies have completed results of previous plume characterization studies by providing more detailed information. The more recent detailed information supports and strengthens previous plume characterizations, and is consistent with these previous studies.

The previous investigations that have been conducted are reviewed briefly in the following sub-sections.

I.C.1.a. Physical Modeling in Support of PSE&G's Initial Section 316(a) Demonstration

The description of the plume provided in the 1974 316(a) Demonstration was based on a physical model developed by Pritchard and Carpenter (1968). The physical model was constructed at the United States Army Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi. It was utilized to evaluate alternative discharge configurations in light of, among other factors, the thermal plumes produced by each alternative. This physical modeling study provided baseline predictions of the temperature and extent of the Salem plume for worst-case meteorological conditions prior to construction of the facility. A more detailed overview of this study and its findings are presented in Appendix E Section V.C.1.

I.C.1.b. Thermal Monitoring Program One-Unit Operation (1977-1978)
Field observations were collected in 1977-1978 as part of a permit requirement to characterize the thermal plume after Unit 1 was put into operation. Monthly and semi-monthly measurements of temperature, salinity, and current velocities were collected for one year. In addition to providing a description of the One-Unit plume, the measurements also were used to evaluate heat recirculation between the discharge and the intake, and to evaluate the importance of natural heat inputs to the Estuary from nearby marshes and tidal creeks. A more detailed overview of this study and its conclusions is presented in Appendix E Section V.C.2.

I.C.1.c. Thermal Monitoring Program Two-unit Operation (1982-1985)
Beginning in 1982, when Unit 2 first came online, additional field measurements were collected as part of a permit requirement to characterize the Two-Unit plume. The goal of the Two-Unit monitoring program was to characterize the Two-Unit plume as a function of tidal stage, transport velocity and direction, Station operations, and other related parameters. The Two-Unit monitoring program consisted of fixed station and mobile temperature mapping, as well as aircraft-carried infrared thermal remote sensing imagery. Two surveys were conducted; one during relatively high freshwater inflow and one during relatively low freshwater inflow conditions. A more detailed summary of this study, including results and conclusions, is presented in Appendix E Section V.C.3.

I.C.1.d. 1991 Hydrothermal Studies
To support the first post-operational 316(a) Demonstration for Salem, a computerized numerical model was applied in 1991 to characterize the near-field thermal plume. The computer model provided more detailed information related to near-field plume dynamics under a wider range of estuarine and discharge conditions than had been studied previously. The model was applied for the time period when the 1982-1985 Two-Unit thermal monitoring data were available. The far-field thermal plume was represented by the 1982 Two-Unit monitoring field observations. A summary of the results and conclusions of the 1991 hydrothermal study is presented in Appendix E Section V.C.4.

I.C.1.e. 1993 Hydrothermal Modeling Program
To support the Station's NJDPES permit renewal in 1993, an expanded hydrothermal modeling program was implemented, consisting of a set of models of both the near- and far-field thermal plume, as well as hindcasts of historical ambient and plume-induced estuarine temperatures. The fundamental improvement of the 1993 modeling program over the previous modeling effort was its ability to predict numerically the temperature and extent of the worst-case Two-Unit thermal plume. Details regarding the models, results, and conclusions from the 1993 permit renewal are presented in Appendix E Section V.C.5.

I.C.1.e. 1995 Hydrodynamic Field Data Collection and Modeling Program
PSE&G implemented a detailed field data collection and numerical modeling program in 1995 to investigate hydrodynamic processes in the vicinity of the Station. The 1995 investigation provided detailed information on current patterns that was used to improve

the models used for the 1999 permit renewal. Exhibit E-1-1 provides a summary of the 1995 program.

I.C.2. Permit Requirements for Comprehensive Thermal Monitoring

Comprehensive thermal monitoring has been required as part of the permits for the Station since it was put into operation in 1977. As described above, previous thermal monitoring studies consisted of field surveys during periods of One- and Two-Unit operation under a variety of estuarine conditions.

Currently, PSE&G operates the Salem Station under NJPDES Permit number NJ0005622. The Permit provides, among other things, for of a Section 316(a) variance from otherwise applicable thermal discharge limitations.

Special Condition H.6. of the Permit requires PSE&G to submit to NJDEP a Biological Monitoring Program Work Plan (BMWP) which includes a comprehensive thermal monitoring program and a biothermal assessment. PSE&G submitted a detailed description of the BMWP, including the thermal monitoring program, to the Monitoring Advisory Committee in December, 1994 in a document entitled, "Biological Monitoring Program for Delaware Estuary – Work Plan." This document is referred to as the Original TMP. The thermal monitoring component of the Original TMP was approved by the NJDEP by letter dated 6 April 1996.

It was not possible, however, to implement the Original TMP within permit timeline requirements, because both of Salem's Units were unexpectedly taken out of operation in Spring 1995 for an extended outage. Units 2 and 1 were returned to steady-state full power in mid-October 1997, and May 1998, respectively. The extended outage precluded the implementation of the Original TMP, which required a six-month survey when both of the Station's Units were operating at or near full power. Once the Units were both on line, insufficient time was available to collect the data, use the data to characterize the thermal plume utilizing hydrodynamic models, conduct a biothermal assessment, and then present the results in a renewal application by 4 March 1999.

Consequently, to meet permit requirements, a Modified Thermal Monitoring Plan ("Modified TMP") was proposed by PSE&G in March 1998, and approved by the NJDEP. The data that form the basis of this assessment were collected in accordance with the Modified TMP. Appendix E Section V.D provides a summary of the elements of the Modified TMP.

II. RECENT OBSERVATIONS AND MODELS USED TO SUPPORT THE 316(A) DEMOSTRATION

Four surveys were completed to support the 1999 permit renewal application:

- 1997 Ambient Conditions Survey
- 1997 One-Unit Survey
- 1998 Two-Unit Survey
- 1998 Bathymetry Survey

The data collected during these surveys provide support for this 316(a) Demonstration. Therefore, the components of the survey are reviewed briefly in Sections II.A through II.D below. Additionally, Section II.E provides an overview of the Estuary Modeling Studies that complement the data used in this assessment.

II.A. 1997 Ambient Conditions Survey

The 1997 Ambient Survey was conducted on behalf of PSE&G by Lawler, Matusky, & Skelly Engineers (LMS) from 11 through 16 July 1997. This survey was not a part of the Original TMP. The Station had not been discharging cooling water for several months prior to or during the survey. The prevailing meteorological and hydrological conditions during the survey consisted of fair summer weather and relatively low freshwater inflow. The survey was useful to characterize typical ambient summer conditions in the Estuary.

Data collected during the Ambient Survey included:

- Moorings – measurement equipment was deployed at two Estuary stations and at the mouths of three tributary creeks from 11 through 16 July, 1997. Each mooring was equipped with sensors that recorded water conductivity, temperature, and dissolved oxygen (DO) concentrations. The sensors were deployed near the water surface, at mid-depth, and near the bottom. Salinity was computed from the conductivity and temperature sensors. Additionally, a tide gauge was deployed at the Station's barge slip.
- Mobile – three survey ships occupied transects of the Estuary on 14 July and the mouths of four tributary creeks on 15 July 1997. Data collected during the mobile surveys included surface water temperature and salinity along transect lines, vertical temperature and salinity profiles at various monitoring stations along the transect lines, and profiles of current patterns throughout the water column along the transect lines. These data were collected during the four stages of the tide on 14 July (Estuary conditions) and 15 (marsh mouth conditions).

The data collected by LMS as part of the Ambient Survey were combined with data sets collected by others to characterize ambient summer conditions. These data include tidal elevation data collected by National Oceanic and Atmospheric Administration (NOAA); freshwater inflow data collected by the United States Geological Survey (USGS); and meteorological data collected by PSE&G at the Artificial Island observatory station, including air temperature, air pressure, atmospheric radiation, relative humidity, and wind speed and direction. Exhibit E-1-2 provides a detailed summary of the data collection materials and methods, as well as a presentation of the results.

II.B. 1997 One-Unit Survey

The 1997 One-Unit survey was conducted by PSE&G between 21 and 30 October 1997 when only Unit 2 was in operation. This survey was not part of the Original TMP. The approach to the One-Unit survey was similar to the Ambient Survey in that both moored instruments and mobile ships were used to collect the data. However, the scope of the One-Unit survey surpassed the Ambient Survey in several aspects:

- 24 moorings were deployed that measured temperature and conductivity at three locations over depth, and dissolved oxygen (DO) was measured at selected locations;
- detailed initial conditions were measured at the beginning of the survey, including vertical profiles of conductivity and temperature at 16 stations spaced at 5-to-10 mile increments between RM 0 and RM 120 using two ships on 21 October;
- vertical profiles of conductivity and temperature were measured at three locations spanning the mouth of Delaware Bay on October 27;
- six tide gauges were deployed between October 14 and 28;
- a fixed-station current profiler was deployed near the discharge between 16 and 18 October; and
- five survey ships occupied transects of the Estuary on October 28 and four tributaries on 29 October.

The materials, methods, and results of the One-Unit survey are presented in detail in Exhibit E-1-2.

II.C. 1998 Two-Unit Survey

The 1998 Two-Unit survey provided the primary data set used for this Attachment, and also the primary data set for set-up and calibration of the numerical models. This survey provided a vast quantity of high quality data. The Two-Unit Survey was conducted in accordance with the Modified TMP, and consisted of six major components described in detail in the Modified TMP. The relative success of each component of the Modified TMP is discussed in Appendix E Section V.D.

- Moorings: Moorings were deployed at 34 sites. Water temperature sensors were deployed on all 34 moorings, conductivity sensors were deployed on 16 of the moorings, and dissolved oxygen sensors were deployed on 5 of the moorings. Instruments were deployed near the water surface, at mid-depth, and near the bottom. All of the moorings were deployed for a minimum period of 21 May 1998 through 4 June 1998 (the Intensive Survey). Ten moorings were maintained for six months from May through October, 1998. The moorings spanned a 24-mile segment of the Estuary, 12 miles up-and down-Estuary from the Station. The density of the moorings was highest in the near vicinity of the Station and beyond to characterize spatial gradients.
- Shipboard-intensive surveys: Intensive shipboard surveys were conducted to characterize detailed spatial characteristics of the thermal plume throughout a tidal cycle tide. Data collected during the shipboard survey characterized the distribution of water temperature and salinity across and along a 12-mile (six miles in either direction from the Station) segment of the Estuary at four times in the tide cycle (approximately at maximum ebb, end-of-ebb, maximum flood, and end-of-flood). Five vessels were deployed to collect these measurements during the second week of the Intensive Survey (29 May 1998). Surface measurements and vertical profiles were collected during the shipboard surveys.
- Dye-tracer study: A dye-tracer survey was performed in concert with the shipboard surveys on 29 May 1998. The dye survey was performed to track and

measure how the Station's thermal effluent mixes in the Estuary over space and time.

- Infra-red survey: Infra-red photography was used to provide synoptic views of the water surface temperature over various times within the tidal cycle. The infrared photographs were taken on 29 May 1998.
- Hydrodynamic survey: Various types of hydrodynamic surveys were conducted, including water levels, currents, temperature and conductivity.
- Water level data were recorded during the two-week Intensive Survey at Cape May, Ship John Shoal, Artificial Island, the C&D Canal, and Philadelphia, PA.
- Current data were collected using Acoustic Doppler Current Profilers (ADCPs). A mobile ADCP was mounted to a vessel during the intensive shipboard survey to characterize vertical profiles of current speed and direction across the Estuary for the four phases of the tide. Measurements were also made across marsh mouths. Additionally, a bottom-mounted ADCP was deployed during the Intensive Survey approximately 1,000 feet offshore of the discharge location.
- A temperature and conductivity survey was conducted at the Estuary entrance and at the C&D Canal. Vertical distributions of these variables were measured during the two week intensive survey at three locations across the Estuary entrance mouth during a flood tide. Additionally, temperature and conductivity gauges were deployed at the Estuary entrance and at the C&D Canal during the two-week intensive survey.
- The initial conditions survey recorded vertical profiles of water temperature and conductivity at discrete points near the shipping channel along the entire axis of the Bay from the its mouth to Trenton, NJ. These measurements were collected on 21 May 1998. Similar surveys was conducted on 29 May and 2 June 1998.
- Marsh survey: Moorings were placed in the mouths of Alloway Creek, Mad Horse Creek, and Hope Creek to measure water depth and temperature over the two week intensive survey period. Moorings at Alloway Creek and Hope Creek measured conductivity and dissolved oxygen as well. A shipboard survey also was conducted at the creek mouths over one tidal cycle during the two-week intensive period. The shipboard survey included vertical profiles of current velocity across the mouth, and discrete vertical profiles of temperature and conductivity at several points across the mouth of the creek. The shipboard survey was repeated for Hope and Alloway Creek approximately one month following the intensive survey.

A detailed summary of methods associated with the two-unit survey data is provided in Exhibit E-1-3, along with a graphical presentation of the data.

II.D. 1998 Bathymetric Survey

A detailed bathymetry survey was conducted to characterize the Estuary bottom in the vicinity of the discharge structure. This information was required to support the near-field computer modeling. The survey covered a region that included the discharge pipes, the discharge structure, and the region in front of the discharge structure. The survey identified the point offshore of Artificial Island at which the submerged discharge pipes are no longer buried by sediment, the location and depth of the discharge structure, as well as the varying bottom depths in front of the structure. A detailed description of the 1998 bathymetry survey methods and results is provided by Exhibit E-1-4.

II.E. 1998 River Modeling Studies

Since Sections III and IV of this assessment compare the field observation with the results generated from the numerical models utilized to support the 1999 permit renewal application, a brief overview of the models and modeling approach is provided here.

The models were applied to characterize the discharge of heated once-through-cooling-water from Salem, and specifically how the plume affects water temperatures in the Estuary. These temperature increases are expressed relative to the ambient water temperature ($T_{ambient}$), which would exist in the absence of Salem's thermal plume. These temperature differences are called excess temperatures (delta temperature or ΔT). The time-varying spatial distribution of ΔT defines Salem's thermal plume ("Salem's plume"), and includes a region exhibiting sharp spatial gradients in ΔTs (the near-field) where the discharge is rapidly mixing with the Estuary, and a region with much smaller temperature gradients (the far-field) where more passive mixing occurs. Water temperatures within Salem's plume can be estimated by adding $T_{ambient}$ to ΔT.

Three numerical hydrothermal models were used to characterize Salem's plume and to calculate seasonal variations in water temperatures in Salem's plume. The Ambient Temperature Model (ATM) was used to produce estimates of $T_{ambient}$, CORMIX was used to produce the near-field component of ΔT, and RMA-10 was used to produce the far-field ΔT. The procedure for combining the output from these models is conceptually illustrated in E Figure V-26 for a segment of the Estuary, including a reach that passes near Salem's discharge.

ΔT at a point within the near-field thermal plume is the sum of the discharge-specific and far-field components of ΔT. This linkage is produced by combining the results from CORMIX and RMA-10 (referred to as the Delta Temperature Model). ΔT at a point in the far-field thermal plume is equal to the far-field RMA-10 generated ΔT only.

The total water temperature at any point is the sum of $T_{ambient}$ and ΔT; hence, the total water temperature is produced by combining the results from the ATM, CORMIX, and RMA-10 (referred to as the Total Temperature Model (TTM)). The basis for this approach and specific details are provided in Attachment E-2, which is a description of the Hydrothermal Modeling Program.

III. RIVER PROCESSES NEAR SALEM GENERATING STATION: SYNTHESIS OF LITERATURE AND OBSERVATIONS

This section uses field observations and literature to understand the different physical processes and their forcing mechanisms in the Estuary, with specific emphasis on the region near the Station. "Physical process" here refers to motions of the water and the air that arise from a specific cause. The ebb and flow of the tide in the Estuary, which is caused by the rise and fall of sea level in the adjacent coastal ocean outside the Estuary, is an example of a physical process; the wind-driven component of the estuarine circulation is another example. In this section, physical processes are analyzed using actual observations and historical data sets. Data collected under PSE&G's Modified Thermal Monitoring Program Modified TMP (Appendix E Section V.D.2 for details) are the principal source of process information. However, other data sets (from previous programs and historical reports) are included to check for consistency of the Modified TMP data with other information or when additional data (e.g. inter-annual means) were needed. In this section, the estuarine processes are described via their forcing mechanisms and interactions with other processes. The modeling results are compared with the observations for consistency in Section IV below.

The objective of these process analyses is to provide a solid observational basis for comparison with the far-field numerical model results, to verify that the models are correctly representing the essential physical reality in the Estuary. Numerical models compute the currents and water properties from the basic equations of motion, subject to boundary conditions and forcing inputs, using simplified parameterization of complex phenomena such as friction and mixing. If the parameterizations, boundary conditions, and forcing inputs are correct, the model should simulate those same physical processes that are observed in the real world. By comparing the separate physical processes observed in the field data with those predicted by the model, the model's accuracy can be assessed.

The Estuary is defined at the landward limit by the "head-of-tide" at Trenton, New Jersey, and seaward by a line connecting Cape May, New Jersey, with Cape Henlopen, Delaware (Figure III-1). The Estuary has a narrow, relatively deep main channel with extensive subtidal flats and marsh areas, particularly on the New Jersey shoreline in the lower Bay. The Estuary is coupled to the upper Chesapeake Bay through the man-made C&D Canal (Figure III-2).

The Estuary stretches approximately 133 miles in length (DRBC, 1988). The width of the system varies considerably, increasing from about 11 miles at the Bay mouth to a maximum width of 27 miles in the lower Bay, and decreasing nearly exponentially upstream to a width of 1,000 feet at Trenton (Polis and Kupferman, 1973). The main navigation channel is maintained at approximately 40-feet depth along its axis from the Station to Philadelphia. Maximum depths exceeding 100 feet occur in the lower Bay region. Since the Estuary receives a relatively small freshwater inflow relative to the volume of water exchanged during a single tide, most of the Bay Zone waters are saline except near the head of the Bay Zone (RM 50) and during extreme rainfall runoff conditions.

III.A. Tidal Processes

The hydrodynamics of the Estuary are dominated by reversing ocean tides at semi-diurnal frequency (dominant period of 12.42 hours). The average tidal range at Cape Henlopen is approximately 4.5 feet, increasing to approximately 6 feet in amplitude at Artificial Island, and 8.2 feet at Trenton (NOS Tide tables 1998).

III.A.1. Tidal Propagation

Tides in the Estuary are caused primarily by the rise and fall of sea level outside the Estuary; i.e., by the ocean tide. Although the ocean tide is ultimately caused by the gravitational attraction of the moon and the sun, the direct effect of astronomical gravity is negligible in small bodies of water such as the Estuary. The rise and fall of ocean water levels at the mouth of the Estuary causes inflow and outflow of water, resulting in a shallow-water gravity wave propagating up and down the Estuary, with increasing amplitude toward the head of the Estuary. Wave speed depends on water depth, so as the wave propagates into shallow waters the speed decreases, increasing the time lag toward the head of the Estuary. The relationship also causes higher speeds in the navigation channel compared to the shallower edges of the Estuary, giving rise to horizontal shear which causes friction. This is the basic mechanism governing the Estuary's response to tidal forcing which should be represented in a hydrodynamic model. There is also some contribution due to tidal inflows through the C&D Canal.

Tidal dynamics in shallow estuaries cause modulation, or distortion, of the tide as it propagates from the mouth to the head of the Estuary. Open ocean tides preserve their sinusoidal shape due to the lack of significant modulating influences. Coastal tides, on the other hand, become distorted in shape as they propagate landward, primarily due to the increased influence of shallow water effects, bottom friction, River discharge, and the effects of Estuary geometry such as width decreases and tidal flat or wetland drainage (Parker 1991).

The effects of bottom friction are complex. Essentially, friction removes energy from a progressive wave and retards it. The quadratic approximation of friction (the force of friction is proportional to the square of the speed) has a greater effect at high speeds (maximum flood and ebb velocities) than at low speeds. A "flattening" of the peak of the tidal current speed at maximum flow can result. However, even though friction removes energy from the propagating tide wave, the effect of decreasing Estuary width outcompetes friction and results in increased tidal amplitude, at least part way up the Estuary. Since the tide in the Estuary is predominately a propagating wave, there is a phase lag associated with the propagation of the tide up the Estuary. Friction increases the phase lag due to changes in the propagation speed of the wave (tide). An analysis of the wave speed shows that frictional retardation is small compared to the phase lag due to wave propagation itself.

III.A.1.a. The M_2 Semi-Diurnal Tide

The dominant tidal constituent in the Estuary is the principle lunar semi-diurnal, or M_2, constituent (Table III-1), which has a periodicity of 12.42 hours. For the month of May 1998, the amplitude (which is one half of the tidal range) of the M_2 tide was 2.03 feet at Lewes, Delaware. The amplitude increased to 2.86 feet at the mouth of Hope Creek, New Jersey (SNJ). A slight decrease in amplitude was observed between SNJ and the northern tip of Artificial Island (NNJ), followed by a continued increase at Philadelphia (Figure III-3). Results of previous studies (Parker 1984) showed a similar amplification from Lewes to Artificial Island, followed by a decrease in M_2 amplitude from Artificial Island to approximately the C&D Canal, where the M_2 tide amplified again towards Trenton, New Jersey.

The variation of M_2 amplitude as it propagates into the Estuary is due to the opposing effects of friction and exponential width decrease of the Estuary. Friction tends to decrease the wave amplitude and slow its propagation. A convergence of the shoreline tends to increase the tidal amplitude, as the energy is funneled into a narrower space. South of the Station, it appears that amplification mechanisms (shoaling, convergence) overwhelm the attenuation mechanisms (friction, discharge). North of Hope Creek to Alloway Creek (and further to the C&D Canal, based on the results of Parker 1984) it appears that friction and discharge (attenuating effects) overwhelm the amplifying mechanisms.

The phase angle of the M_2 component illustrates at Hope Creek the arrival times of the M_2 tide at the different measurement locations (Table III-2). If high water occurred at Lewes at time T=0, high water would occur, approximately 1 hour and 55 minutes later, 2 hours and 22 minutes later for the northern tip of Artificial Island (taking 27 minutes to propagate from Hope Creek to Alloway Creek), and 5 hours and 22 minutes later in Philadelphia (Figure III-4).

Tide data were collected during a modeling study by Aubrey Consulting, Inc. (ACI) in April and May of 1995 (ACI 1995). Comparison of the M_2 amplitudes during the Two-Unit Survey and the ACI study, showed that the amplitudes in May of 1998 were approximately 0.1 feet higher than in April of 1995 at Artificial Island, yet remain unchanged at Lewes and Philadelphia. Phases indicate high water in Philadelphia occurred approximately 5 hours and 15 minutes after high water at Lewes. The decreased volume of fresh water transported downstream in the late spring/early summer months allowed the M_2 constituent to propagate through the system at a faster speed and without the amplitude attenuation expected during periods of higher runoff (Parker 1991).

The distribution of predominately semi-diurnal tidal current in the Estuary also reflects effects of width variations. As illustrated in Appendix C (C Figure 28), maximum tidal current speeds generally decrease from the Estuary entrance to the wider portions of the Bay Zone. At the entrance, maximum flood current speeds range from about 1.0-2.2 knots. In the wider reaches of the Bay Zone, maximum flood speeds vary from 0.25-0.75 knots in the shallows to about 1.0 knot in the navigation channel (NOAA 1987). Further upstream (near Salem), the Estuary's width decreases and maximum flood current speeds increase to about 1.0-1.5 knots, enhancing tidal mixing processes.

III.A.1.b. The Overtides

The constituents M_4 and M_6 have periodicities of 6.21 hours and 4.14 hours, respectively. These periodicities are harmonic multiples of the primary M_2 tidal frequency. Referred to as overtides, these constituents are not gravitationally forced. There is little M_4 or M_6 energy in the ocean tide at the mouth of the Bay zone. These constituents result from frictional distortion of the tide wave as it propagates up the Estuary, combined with other nonlinear hydrodynamic effects associated with tidal propagation in shallow water.

Overtides are important inasmuch as they may distort the magnitude and duration of both rising/falling tides and flooding/ebbing currents. Harmonic analysis of the data collected during the ACI study revealed that the M_4 amplitude increased approximately seven-fold between Lewes and Philadelphia. There appeared to be no significant variation of these values during the April to July 1995 time periods. Growth of the M_4 constituent is typically produced when the tidal wave propagates into shallow water. The ratio of the M_4 amplitude to the M_2 amplitude is one quantitative indicator of the degree of distortion due to nonlinear mechanisms. Analysis showed that the M_4/M_2 amplitude ratio grew by a factor of 5 from the mouth of the Bay to Philadelphia. The magnitude of this ratio is about 0.05 near the Station.

The M_6 constituent increased in amplitude in a manner similar to the M_4, yet by different physical mechanisms. M_6 is typically generated by quadratic friction, proportional to the square of velocity, but can also be generated by freshwater discharge effects. The amplitude of the M_6 constituent is largest at Philadelphia, amplified by a factor of about 7.5 from Lewes. M_6 is 5-6 times larger at Artificial Island than at Lewes.

III.A.1.c. Tidal Duration Asymmetry

The duration of flood/ebb phases are nearly symmetrical at Lewes. The symmetry in the flood/ebb durations is indicative of the relative lack of tidal hydrodynamic modulating influences found at the mouth of the Estuary. As the tide propagates up the Estuary, the durations of flood and ebb phases begin to change. The approximate durations of the flood and ebb cycles were determined by averaging the time between the first ten and last ten maxima/minima points of the tidal elevation time series. South of Artificial Island, the flood stage takes 5.63 hours, the ebb stage 6.79 hours. At Philadelphia, it takes 5.52 hours to turn from low water to high water and 6.90 hours to return from high to low. The ebb durations are longer due to the addition of a mean flow to the tide, while correspondingly the flood durations are shorter.

III.A.1.d. Tidal Amplitude Variations with Time

Variations in tide range are considerable at points along the Estuary due to the spring-neap variability of the astronomical tides over approximately 14.7-day periods. At Lewes, a maximum range of approximately 6.3 feet occurred in mid-July. The minimum range of approximately 2.3 feet occurred in early April. At the Station, the maximum range was 8.2 feet and the minimum neap tide range was approximately 4.3 feet. At Philadelphia, the greatest range (7.6 feet) occurred in mid-June; the smallest range (5.2 feet) occurred during an early April neap tide.

III.A.2. Mixing Processes/Fronts

The fresh/salt water interface is not abrupt but rather is smooth transition from saline (approximately 31-32ppt) coastal waters to brackish/fresh (0.1-18ppt) waters near the Station. During periods when the lateral gradients are intensified, low salinity waters along the shores may be separated from more saline water in the middle of the Bay Zone by sharp frontal boundaries- -with up to 5 ppt variation in salinity over a distance of about 150 m. Both the sharpness of the frontal boundaries and the positions of the fronts can change significantly with phase of the tide.

III.A.3. Stratification effects

The Estuary is partially-to-weakly stratified. Typical vertical salinity variations range from 1–4 ppt (Garvine et al. 1992) However, horizontal salinity variations are significant in the Bay Zone, especially in the along-channel direction and also in the cross-channel direction at some places. Results from a set of intensive hydrographic observations across the Bay mouth indicate the presence of significant lateral variability in the tidally averaged salinity distribution (Wong, 1995). The evidence also suggests the existence of two branches of buoyant estuarine outflow along the shores. Near the Bay mouth these branches are separated by more saline waters that dome upward toward the surface in the deep channel.

The tidal motion can produce significant intra-tidal variability in the lateral structure of salinity. It appears that the salinity distribution on the adjacent continental shelf, and the presence of the Delaware coastal current offshore from Cape Henlopen, are important factors controlling the intra-tidal variability at the mouth. Within the Bay Zone, the lateral salinity gradients may be strengthened by effects of the relatively higher velocities in the deep channel compared to the shallow areas ("differential tidal advection"). Near the Station (RM50), historical salinities range from about 0-18 ppt, with a mean value of about 5.5ppt (C Table 6).

Vertical salinity profile data collected throughout the Estuary show the absence of stratification up-river from the Station (Longitudinal Surveys, Figure III-5). Between the mouth and the RM 45, these data show the presence of a weak fresh/salt water interface, which slopes downward away from the mouth of the Estuary.

The vertical profiles (Figures III-6 and III-7) of salinity at RMs 30 and 40 show a relatively freshwater surface layer on top of slightly more saline and colder waters from the ocean. Comparison of the vertical profile data measured at the same locations at different times shows that the fresh/salt water front is not stationary and has some intra-tidal advance and retreat. During the 27 May 1998 Longitudinal Survey during ebb tide, the vertical profile of Salinity at RM 45 (near the Station, Figure III-6) showed no stratification, whereas the 2 June survey during flood tide showed the presence of a weak salt front (Figure III-7).

The key point is that dynamically significant stratification does not usually penetrate as far as the Station. At the Station, the Estuary's salinity may not be zero, but the water is only slightly stratified in the vertical and the salt has little effect on the density and hence negligible effect on mixing or motion of the water.

III.A.4. Nonlinear Tidal Interactions with River Flow

Clarification of nonlinear mechanisms for coupling tidal and non-tidal phenomena has occurred relatively recently, even though non-tidal effects on the tide have been observed for some time. Parker (1984) observed that the tide range in the upper part of the Estuary was closely related to river discharge. Dronkers (1964) mentioned that when runoff is high the tides will be damped more than during low runoff.

When a mean flow (e.g., River flow) is present, additional momentum will be lost from the main tidal constituent. As the ratio of River flow to tidal flow increases, the frictional momentum loss from the tide increases (Figure III-8); thus an increase in a River flow will decrease the tide range. At Artificial Island, Parker (1984) computed a 12 percent reduction in M_2 tidal ranges under high-flow conditions relative to low-flow conditions (Parker 1984). When a mean flow (or River) is present, the M_4 tidal constituent increases by transfer of momentum from the M_2 constituent. During high River runoff, the distorted shape of the tide curve, the delay of low water, and the higher M_4/M_2 amplitude ratio are thus a result of the quadratic frictional interaction of the M_2 tide with River flow. On the other hand, the M_6 amplitude decreases with increasing mean flow, reaching zero when the River current velocity equals the tidal current velocity.

III.B. Meteorological Effects

Estuarine currents vary over time scales other than tidal scales. Variability occurring on time scales longer than about 24 hours (the longest dominant tidal periodicity) is referred to as "subtidal." Subtidal circulation is to a significant extent controlled by meteorological factors such as winds, solar radiation, precipitation, and air-sea temperature difference. Wind-induced circulation typically has a 2-to-10 day time scale, corresponding to the dominant time scale of synoptic weather systems. Wind-driven currents can be caused by local or remote wind forcing. Local wind forcing (wind stress) can move water due to direct momentum transfer across the air-sea interface. Remote (non-local) wind forcing influences the Estuary's waters indirectly by changing sea surface elevations at the mouth of the Estuary. Also, solar radiation and air-sea temperature differences affect the total air-sea heat flux (and thus the temperature) over a wide range of time scales (diurnal to seasonal).

III.B.1. Spatial and Temporal Variability

Wind data were collected during the month of May 1998 at the Station as part of the Two-Unit Survey (Figure III-9). The winds were mostly southeastward except during a few days between 3-14 May, 1998, when they were generally westward. Wind speeds varied from 2 to 15 mph, with no evidence of strong winds during the time period. Long-term wind records at Wilmington, Delaware, indicate that the prevailing wind directions are from the northeast and west-northwest directions, with a secondary peak from the south (Figure III-10). Significant precipitation was observed in the 7 to 10 May 1998 time period (significant cloud cover and low solar insolation were also observed). The precipitation was also accompanied by a drop in the atmospheric pressure to about 29.5 inches of Hg. The solar radiation in the subsequent days heated the air, which increased the air temperature from 60 °F to 80 °F.

III.B.2. Vertical Mixing/Destratification

The Estuary is classified as a tidally dominated estuary. Substantial tidal mixing keeps the estuarine water column well-mixed to weakly stratified. An observational study on the wind-induced, subtidal variability in the Estuary by Wong and Garvine (1984) suggests that the large subtidal sea level fluctuations at the mouth of the Estuary are forced primarily by the shore-parallel wind stress component over the continental shelf, which results in coastal Ekman transport—an average motion of the upper 30-40 m of the water column at right angles to the wind direction due to a balance between wind forcing at the surface, friction and the Coriolis force. Downcoast (southward) winds result in a rise in sea level at the mouth of the Estuary. Local wind forcing within the Estuary was found to be insignificant compared to the offshore forced transport. The subtidal sea level variability in the interior of the Estuary was found to be driven by the wind through a combination of two remote forcing mechanisms: one acting at the mouth of the Estuary through direct Estuary-shelf coupling and a second acting locally over the Chesapeake Bay and being transmitted from the upper Chesapeake through the C&D Canal, which links the two estuaries. In the upper Delaware Estuary, Wong observed predominantly depth independent subtidal current fluctuations superimposed on a much weaker two-layer gravitational circulation. The subtidal currents were produced primarily by the local, subtidal sea surface slope generated by the difference between the two remote forcing mechanisms. This suggests that C&D Canal plays a critical role in the subtidal circulation of the Estuary.

III.B.3. Tidal Propagation Interaction with Winds

The wind-induced variability has a 2-10 day time scale typically associated with synoptic weather systems, whereas the dominant tides in the Estuary are semi-diurnal (twice-a-day period). Though the response of the estuarine waters to the two forcings occurs over different frequencies, studies have presented observational evidence showing that there are interactions between the two processes. Wong and Trowbridge (1990) suggest that high frequency wind waves and low frequency subtidal variability can interact nonlinearly with the tide and modify the tidal response of an Estuary. Their current and sea-level observations in the upper Estuary provide evidence that suggests tidal variability in the interior of the Estuary was appreciably modified during two moderately strong atmospheric events during the months of October and November in 1982. The dominant mechanism suggested was wave-current interaction in the turbulent wave boundary layer, which enhances the frictional attenuation of the tide. Changes in propagation and attenuation characteristics due to subtidal depth changes were found to have a smaller, but probably still observable, effect (Figure III-11).

III.C. Freshwater Discharge Processes

By definition, an estuary is a semi-enclosed coastal body of water within which seawater is measurably diluted with fresh water derived from land drainage (Cameron and

Pritchard 1963). Long-term variations in the River discharge significantly affect the salinity distribution of the Estuary, as described below.

III.C.1. Spatial Variability

The Estuary is a major coastal plain estuary situated on the middle Atlantic coast of the United States. The Estuary drains a 3.5 x 10^4-km^2 watershed located in New York, New Jersey, Pennsylvania, and Delaware (Figure III-12). The Delaware River, with a mean discharge of 11,700 cfs (332m^3/sec) at the head of the Estuary, contributes approximately 58 percent of the mean freshwater inflow into the Estuary (C Table 2). The Schuykill River, entering the Estuary at Philadelphia, Pennsylvania, contributes approximately 14 percent (2,723 cfs). No other single source is responsible for more than 1 percent of the total discharge. The total mean freshwater inflow to the Estuary is estimated at 20,243 cfs (C Table 2). More than 95 percent of the total freshwater discharge enters the Estuary landward of the mean salt intrusion limit which is located some 62 miles (100 km) upstream from the mouth of the Estuary (Garvine et al. 1992).

III.C.2. Time Variability

Freshwater inflow is derived from rainfall and snow melt and, therefore, shows significant seasonal variation. Though the annual average of Delaware River inflow is about 11,700 cfs (332m^3/sec) (C Table 2), it may vary from 12,184 cfs in winter to 19,035 cfs in spring and 7,310 cfs in summer (Table III-3). The River discharge is highest in the months of March (20,600 cfs or 583 m^3/s) and April (22,410 cfs or 635 m^3/s) due to snow melt, and is at its lowest in the summer months of July (7,070 cfs or 200 m^3/s) and August (5,933 cfs or 168 m^3/s) due to low rainfall and lack of snow melt (Appendix C).

Freshwater discharge data for the Delaware River at Trenton and the Schuylkill River at Philadelphia was collected as part of the Two-Unit Survey during the 1 May – June 4 1998 period (Figure III-13). Comparison of the discharge data for the two rivers shows that the Delaware River discharge was 3 to 4 times larger than the Schuylkill River discharge. The data also show a large freshwater pulse during the 9-19 May 1998 period, with the Delaware River discharge reaching a maximum of 69,869 cfs. This pulse was mostly due to heavy precipitation during the 7-17 May 1998 period.

III.C.3. Interaction with Meteorology and Tides

The salinity distribution in the tidal Estuary system is controlled primarily by the interaction of freshwater inflow from the upstream drainage area and saltwater tidal inflow from the Atlantic Ocean. The salinity distribution and flow regime near the mouth of the Estuary is the determinant of the amount of saltwater entering the Estuary. Salinity at the mouth typically varies from about 30 to 31 ppt (Smullen et al. 1984). Freshwater discharged from River sources dilutes the saltwater entering from the ocean. Waters at Trenton generally average less than 0.3 ppt.

At mean River flow rates, the Estuary is considered to be vertically well-mixed, with little sustained variation in salinity from surface to bottom. Under typical high-flow conditions, the upstream limit of salt intrusion (e.g., as represented by the 1 ppt isohaline) is displaced seaward toward the C&D Canal (RM 59) (C Figure 18). Under typical low-flow conditions, salinities of about 1 ppt intrude landward toward Chester, PA (RM 83), while more saline waters (15–25 ppt) migrate upstream toward the head end of the Bay Zone.

Using long-term salinity and River discharge data, Garvine et al. found that the salinity response to freshwater discharge is surprisingly weak, implying that powerful processes reduce salinity response. This process may be the action of vertical shear flow dispersion in a tidally stirred regime and the action of lateral shear coupled to strong lateral salinity gradients (Appendix C Sections III.B.1 and V.A.2.b).

In addition to the effect on salinity distribution, fresh water discharge also affects the tides through non-linear interaction mechanisms (discussed in Section III.A.4). Greater quantities of water are received during times of heavy rainfall, severe thunderstorms, or in winter and spring when ice and snow melt upstream. There were no significant correlations between variations in freshwater discharge and calculated mean current speeds from drifter experiments (Hires et al. 1984). A tentative conclusion is that the effects of wind forcing on subtidal circulation is considerably more important than is the variability in freshwater discharge.

Though moored temperature and salinity data were collected only for the 19 May to 4 June 1998 period, the effect of heavy precipitation can be seen in the time-series data. The intra-tidal salinity variation (range) during 9-10 May 1998 appears to be diminished due to the large fresh water pulse. The effect of the pulse is greatest upstream and decreases towards the ocean. Reduced salinity variations are apparent in time-series at surface, mid-depth and bottom (wherever sensors were deployed) at all the mooring locations (Two-Unit Survey Report, Figure III-14) up-river from RM 45. However, at the Delaware-M9 mooring location (about RM 40, Figure III-15), the surface salinity time-series data display limited variability while the bottom salinity time-series data actually show an increase in the intra-tidal variability. This suggests some salinity-induced stratification in the Estuary near Delaware-M9 mooring, so that the pulse of freshwater flowed non-interactively over the saltier water below.

III.D. Thermal Discharge Plume Dynamics

Conceptually, the thermal plume may be described as the region within which the water temperature is affected by the discharge. In the regulatory context, the thermal plume typically is characterized by reference to an applicable legal standard limiting the discharge-induced increase in temperature (i.e., the excess temperature) over some ambient or background temperature.

III.D.1. Momentum Effects

The hydrodynamics of an effluent discharged into a water body can be conceptualized as a mixing process occurring in several steps. The degree and method of mixing represent an interplay between ambient and discharge conditions. Ambient conditions are those factors that describe the receiving environment such as the geometry and depth of the receiving body; the bottom roughness, turbulence, and tides that contribute to the velocity field; and the temperature, salinity, and stratification that define the density field. Discharge conditions include the geometry of the discharge pipes and the volume, momentum, and buoyancy fluxes of the effluent.

When the heated effluent first enters the receiving water, the plume trajectory and mixing characteristics are dominated by discharge pipe geometry, discharge momentum, and buoyancy forces. Initially, mixing is caused by turbulent shear, as the high velocity of the flow leaving the discharge pipes rapidly entrains ambient fluid and causes a high degree of dilution. In a multi-pipe discharge, the jets initially behave independently, but soon they merge to form a plane jet (Figure III-16). The momentum of this jet induces a current that can increase mixing intensity. Vertical variations in the flow, or stratification, can further increase the mixing intensity.

As the plume travels away from the discharge, the width of the turbulent zone caused by the entrainment of ambient water increases. Eventually the plume will surface and the mixing characteristics will change. In general, approximately half the heat discharged is dispersed by the time the plume reaches the surface. At the surface, the plume trajectory may still be influenced by the horizontal component of the discharge momentum, but the effects of the diffuser geometry are significantly reduced. As the plume travels farther from the discharge location, the influence of the discharge momentum reduces and eventually becomes negligible, relative to the influence of ambient flow conditions.

The flow regime discussed above is called the "near-field" zone. It encompasses the flow from the point of discharge to the point where the discharge momentum no longer has a significant effect on the plume dynamics. Subsurface flow and any surface or bottom interaction are included in the near-field zone. If the near-field flow structure breaks down, resulting in re-circulation zones or mixing over the entire water depth, the flow is then considered unstable (Figure III-17). This generally occurs when the discharge buoyancy is relatively weak and the momentum is strong. If, however, both buoyancy and momentum are strong, unstable re-circulation zones can still occur and are usually accompanied by an upstream density current and subsequent stratification due to buoyancy.

III.D.2. Temperature Effects

The "far-field" zone begins where the near-field zone ends, i.e., where the plume is no longer carried by its own momentum, but rather is advected by ambient currents. Two physical processes exist in the far-field: buoyant spreading followed by passive diffusion. In buoyant spreading, the plume spreads horizontally but thins vertically, as buoyancy forces draw the plume toward the surface. For instance, heated plume water has a lower density than the receiving water and tends to rise to the surface. Buoyant spreading may induce mixing at the head region or "frontal zone" of the plume, but the mixing is usually relatively small (Figure III-18). Generally, the significance of the buoyant spreading process decreases with increasing distance from the diffuser because the density difference between the plume and the ambient decreases with increasing distance and time from the diffuser due to heat transfer. In passive diffusion, the dilution is controlled mainly by the presence of turbulent mixing in the flowing ambient water body. The plume grows both laterally and vertically and the intensity of diffusion depends on the production of turbulent shear within the receiving water. Thus, the far-field zone considers the effect of spreading due to buoyancy forces, ambient currents, turbulent diffusion and heat loss due to air-sea interaction.

III.D.3. Interaction with River Dynamics

At the end of the near-field, the velocity of the far-field plume becomes almost identical to the tidally driven velocity of the Estuary's waters. At this point, the temperature of the far-field plume is determined primarily by: (1) meteorological factors governing surface heat exchange; and (2) dilution via mixing driven by local currents. Thus, the characteristics of the thermal plume in the far-field will vary over time as the determining meteorological and receiving water conditions change.

III.D.4. Zone of Influence of Discharge

Given the tidal processes in the Estuary in the vicinity of the Station, the plume moves alternatively up-Estuary for approximately 5.5 hours during incoming flood flow, then down-Estuary for approximately 7 hours, during ebb flow. Slack tides occur for a few minutes between floods and ebbs. Therefore, the area defined as the thermal plume is dynamic, occupying a given region intermittently during a complete tidal cycle (12.42 hours).

III.E. Circulation Water Intake Processes

The Station's Circulation Water ("CW") intake structure is located southwest (Figure III-19). The Station draws water from a dredged basin directly off the intake structure seawall. The orientation of the seawall face runs parallel to the 300 degree WNW (60 degrees west of north) direction. The area in front of the intake structure basin is maintained to a depth of approximately 45 feet.

The south eastern edge of the basin features a steep upward depth gradient into Sunken Ships Cove where depths are approximately 5-10 feet. The upstream (northern) edge of the basin features a similar, but less severe upward gradient over the network of Station Circulating Water discharge pipes. The pipes are covered by sediments between the Circulating Water intake and the Service Water intake structure (see Exhibit E-1-4 for details of the Bathymetric Survey).

III.E.1. Zone of Influence of CW Intake

The CW intake structure is located in an area of the Estuary where local current velocities (ebb and flood) are relatively low. River bend dynamics contribute significantly to complex flow patterns in the area of the intake. To the south of the intake basin, extensive shallow areas located along the New Jersey shoreline distort the tidal current behavior relative to flows in mid channel. The presence of Sunken Ships Cove and Hope Creek Jetty to the South affects the flow patterns creating complex local recirculation patterns. The cooling water discharge pipes provides further complexity to the flow, blocking flow at low river/tidal flows, and contributing to recirculation of water and suspended materials to either side of the discharge.

III.E.2. Tidal Variability

Tidal elevations were measured at the CW intake basin by a Real Time System (RTS) during a previous modeling study (ACI 1995). The results of harmonic analysis performed on those tidal elevation data are summarized and compared to River values in Table III-1. Similar to the tides at other locations in the Estuary, the intake basin tides are also dominated by the M_2 constituent (2.85 feet), while N_2 and K_1 had the largest secondary influences on the tidal amplitude. The M_4 constituent was found to be larger in the intake region than at other tide gauge sites. The M_4/M_2 ratio, an indicator of the degree of nonlinear distortion in the harmonic data, increased in the region. It was also noted that distortion producing mechanisms (friction, shallow water effects, etc.) were relatively larger in the intake basin than at locations to the north or south.

The intake basin is located approximately 1.88 nautical miles (11,423 feet) from the SNJ site and 2.74 nautical miles (16,648 feet) from the NNJ site. While the intake basin high tide lags the SNJ high tide by approximately 14 minutes (6.6 degrees difference), the NNJ tide lags the RTS tide by 13 minutes. Though phasing was found to be consistent with other gauges, it takes longer for the tide to propagate a shorter distance (from SNJ to the intake) than the time for the tide to travel from the basin to NNJ (a 50percent greater distance). This delay in the tide propagation between the three sites suggests the influence of the shallow regions in slowing the tide. To the north, the depths are greater and more uniform than in the south.

The flood durations (approximately 5.6 hours) in the intake basin were shorter relative to those in the Estuary and the ebb durations (approximately 6.9 hours) slightly longer.

III.F. Tidal Marsh Processes

III.F.1. Heating/Cooling of Marsh Surface

The marshes are characterized by depths of only a few feet on average, with relatively large horizontal spatial scales. They act as large shallow pans, where water can be heated significantly during the day due to solar radiation or cooled due to contact with the atmosphere. At low tide, nearly all the surface area is drained, so the accumulated heat (or cooling) is transported to the Estuary in only a few hours.

The temperature time series retrieved from the moorings located at the mouth of the creeks (Alloway, Hope and Mad Horse; Figures III-20 through III-22) clearly show a diurnal variation (period of 24 hours), unlike the temperature time series from moorings located away from the creek mouths which show a predominantly semi-diurnal variation (period of about 12 hours). This suggests that while the temperatures in most of the Estuary are dominated by the tides, water temperatures in the creeks and marshes are dominated by solar radiation. But the temperature time series show a semi-diurnal variation on 20 and 21 May 1998. This could be due to sea-to-air latent heat loss caused by low dew point and air temperatures on the 20 and 21 May 1998. The latent heat loss could have balanced the heat input into the water due to solar radiation on those two days, so that the temperature at the creek mouths varied only due to the tides.

III.F.2. Contributions to Heat Balance of River

The Estuary's natural thermal variability is controlled by heat inputs of different kinds, such as, solar radiation, thermal conduction and convection, as well as the less obvious inputs such as solar heating of marsh waters which are discharged directly to the river through creek mouths during tidal ebbs. or cooled due to contact with the atmosphere. At low tide, nearly all the marsh area is drained, so the accumulated heat (or cooling) is transported to the Estuary in only a few hours.

Heat transfer mechanisms can be broken down into three classes:

- Conduction: Due to the differences in temperature between one body (or mass) and another
- Convection: Due to conduction within a fluid enhanced by motion within the fluid
- Radiation: Energy transferred by electromagnetic waves.

III.F.3. Tidal Interactions with the Estuary

The moored temperature time series at the creek mouths show evidence of point-source discharges from the creek into the River during the ebb tide. The flow and heat load temporal profiles (Figures III-23 through III-25) clearly show that heat input into the River starts at the beginning of the ebb phase and decreases rapidly around mid-tide. This is due to the fact that the vast shallow marshes contain large amounts of water in the flood phase, but as the water recedes to the mean level at the reversal of the tide, the marshes are rapidly emptied.

III.G. Exchange Processes through the C & D Canal

The C&D Canal provides a sea-level connection between the upper Chesapeake Bay and the middle Delaware Estuary (RM 59[RK 95]). The Canal is located approximately 8 mi. (12 km) upstream from Salem. Observational studies indicate that the mean salinity at the Chesapeake Bay end of the Canal is typically 2-3 ppt lower than the mean salinity at the Delaware end (e.g., Wong 1990b). The salinity difference has two primary causes: the greater rate of freshwater inflow to the Upper Chesapeake Bay, and the fact that the Chesapeake Bay end of the Canal is situated further from the ocean than the Delaware Estuary end.

The mean tidal range (5.6 feet[1.7m]) on the eastern (Delaware) side of the Canal exceeds the mean range on the western (Chesapeake) side (2.3 feet[0.7m]). In addition, the tide at the Chesapeake end lags the tide on the Delaware end by about 11 hours (Wong 1990b). These boundary differences drive reversing, semi-diurnal tidal currents amplitudes on the order of 0.6 m/sec (1.2 knots) within the Canal (Wong 1990b). These strong currents do not extend far into the interior of the Estuary because of the limited volume discharge of the Canal (Wong 1990b; Najarian et al. 1980), but their effect is felt locally because the net transport is significant compared to the tidal transport in the Estuary (about 10 percent of the instantaneous tidal transport).

Subtidal flows (i.e., flows having periods longer than about 24 hours) also develop within the Canal in response to the different tidal amplitudes, tidal phases, and water densities at the two Canal boundaries, and in response to local or regional wind patterns or storm water discharge. For example, Wong (1990b) observed spatially uniform, subtidal currents that may exceed 0.7 m/sec (1.4 knots) in the Canal. Also, he observed a large, subtidal volume flux through the Canal that was on the same order of magnitude as the Delaware River discharge during the spring freshet period (Wong 1987). On average, this subtidal flow is directed eastward (from the Chesapeake Bay to the Delaware Estuary), but reverses direction commonly. For example, a statistical analysis of Canal data collected between 1969 and 1972 revealed that a net easterly, nontidal flow occurred 59percent of the time (Pritchard and Gardner 1974).

Recently, the US ACE completed a numerical model study of C&D Canal hydraulics (Hsieh and Richards 1996). Their results suggest that the net transport of water and salt through the Canal may be seasonal and depends primarily on the total amount (and relative strength) of the freshwater inflows to the Chesapeake and Delaware Estuaries. Using representative freshwater inflow data for the period 1957-1987, Hsieh and Richards simulated seasonally averaged eastward transport (i.e., from the Chesapeake Bay to the Delaware Estuary) when Susquehanna River discharges to the upper Chesapeake Bay were relatively high, including all 31 spring seasons. On occasion, these eastward Canal flows were sufficient to depress salinities on the Delaware side by several ppt. Results from Hsieh and Richard (1996) also suggest that there can be net westward Canal flows when the freshwater discharge is low (e.g., during the median and lowest-ranked fall seasons). These results show that subtidal fluctuations induce significant volume exchange between the Chesapeake Bay and Delaware Estuary and influence the long-term transport of nutrients, suspended matter and biota (e.g., fish larvae).

E-1 Table III-1. Amplitudes of the tidal constituents at six locations in the Delaware Estuary.

Constituent	Period (hours)	Lewes DE	SDEL	SNJ	NDEL	NNJ	Phila. PA
K_1	23.93	0.38	0.43	0.44	0.41	0.40	0.42
M_2	12.42	2.03	2.77	2.86	2.66	2.71	2.74
M_4	6.21	0.04	0.20	0.21	0.20	0.19	0.29
M_6	4.14	0.02	0.09	0.10	0.11	0.11	0.19
S_2	12.00	0.24	0.27	0.28	0.26	0.26	0.23
N_2	12.66	0.54	0.62	0.64	0.58	0.59	0.54
O_1	25.82	0.24	0.25	0.26	0.24	0.24	0.24
L_2	12.19	0.07	0.23	0.24	0.22	0.24	0.30
M_4/M_2 ratio	–	0.02	0.07	0.07	0.08	0.07	0.11

Source: Hires et al. 1984.

E-1 Table III-2. Phases of the tidal constituents at six locations in the Delaware Estuary.

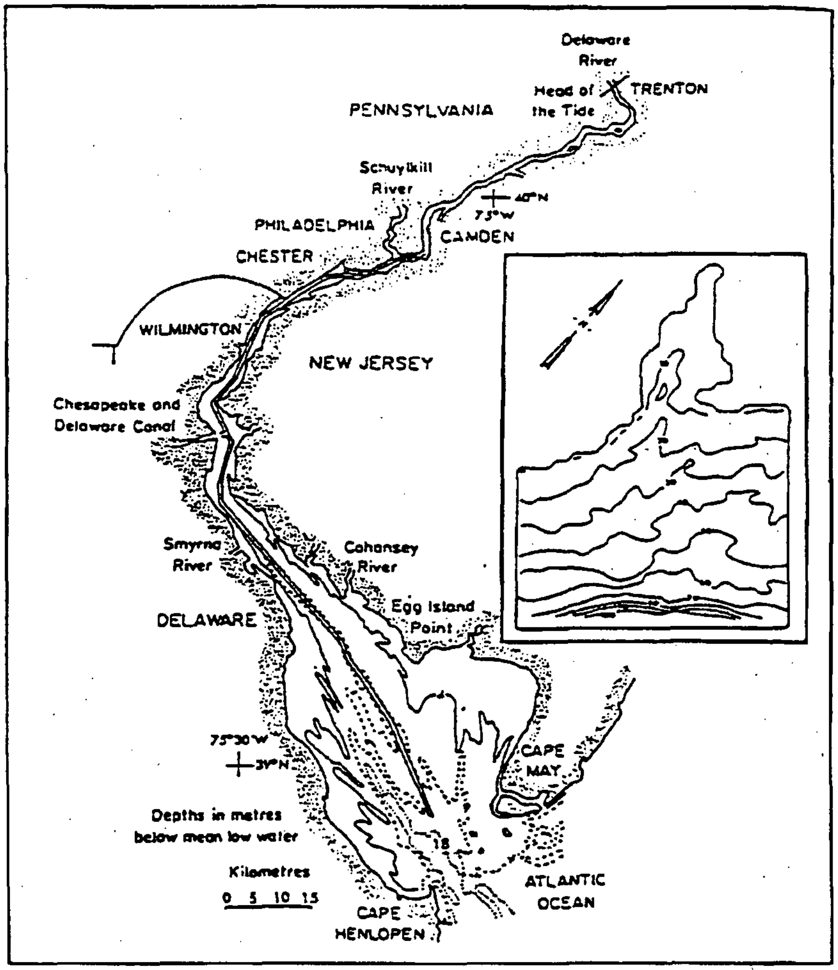
Constituent	Period (hours)	Lewes DE	SDEL	SNJ	NDEL	NNJ	Phila. PA
K_1	23.93	33.4	56.4	53.6	62.0	62.0	107.8
M_2	12.42	-104.6	-48.6	-50.9	-38.0	-38.5	47.9
M_4	6.21	-79.3	153.6	151.3	178.6	-179.8	-27.9
M_6	4.14	-70.1	-85.1	-88.9	-43.8	-45.0	-176.2
S_2	12.00	67.3	122.0	121.2	133.9	132.5	-142.8
N_2	12.66	-74.9	-26.4	-28.9	-17.2	-18.0	63.3
O_1	25.82	-127.5	-101.2	-103.3	-95.4	-95.0	-46.1
L_2	12.19	-81.1	-18.6	-21.0	-7.5	-7.5	83.9
$2\Phi M_2$-M_4 difference	–	-129.9	109.2	106.9	105.4	102.8	123.7

E-1 Table III-3. Monthly, seasonal and annual averages of freshwater inflow to the Delaware Estuary at Trenton, NJ (Data Source: C Table 3).

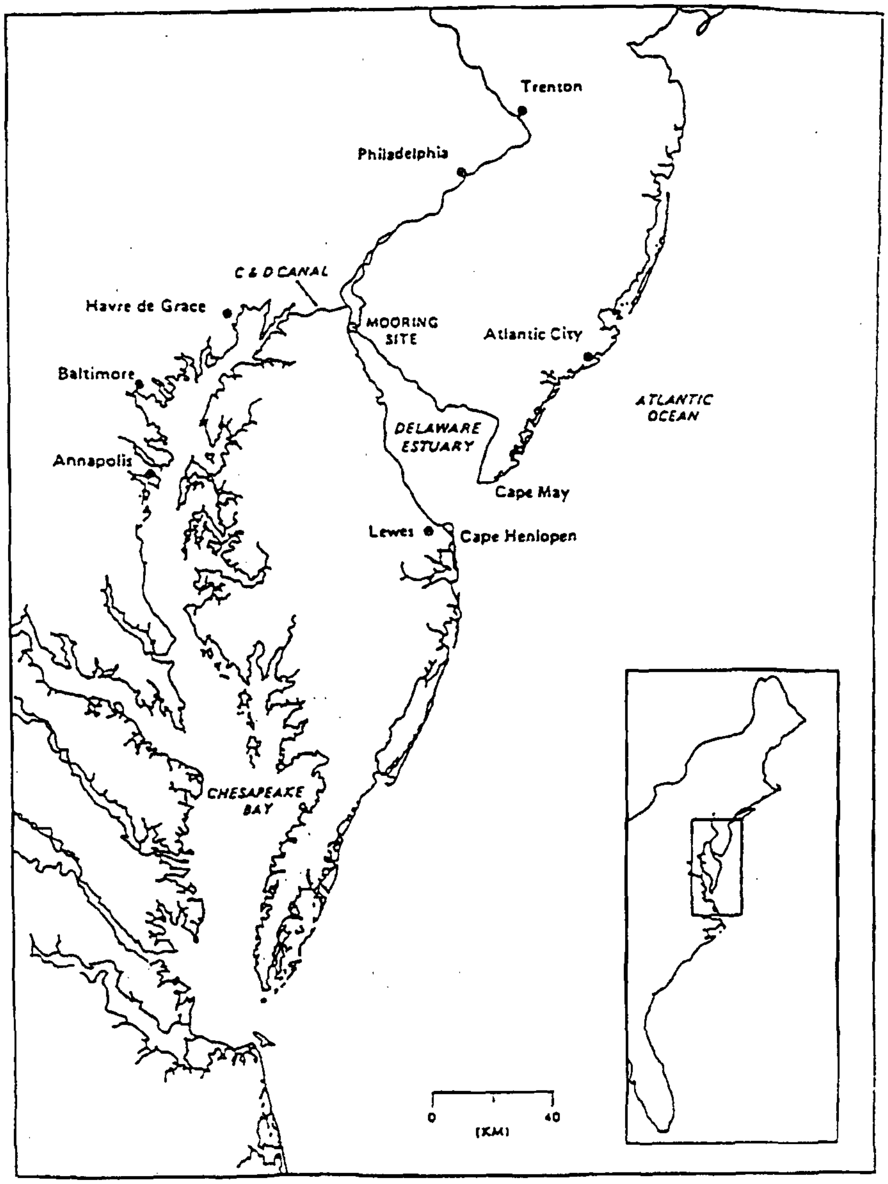
Monthly Averages	(m^3/s)
January	353
February	363
March	583
April	635
May	400
June	254
July	200
August	168
September	168
October	196
November	301
December	363

Seasonal Averages	(m^3/s)
Winter (Nov-Feb)	345
Spring (Mar-May)	539
Summer (June-Oct)	207

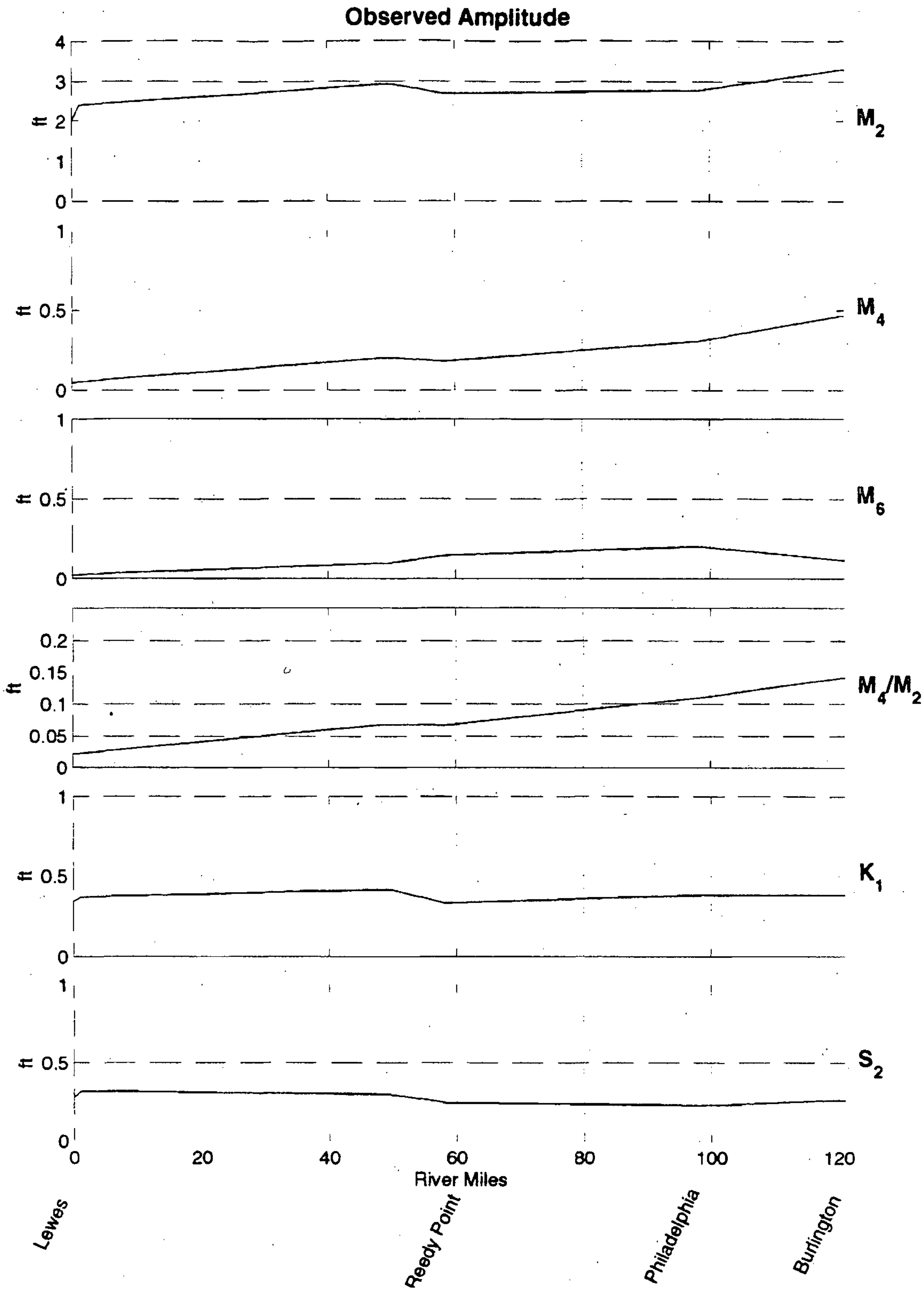
Annual Average	(m^3/s)
Oct-Sept	332



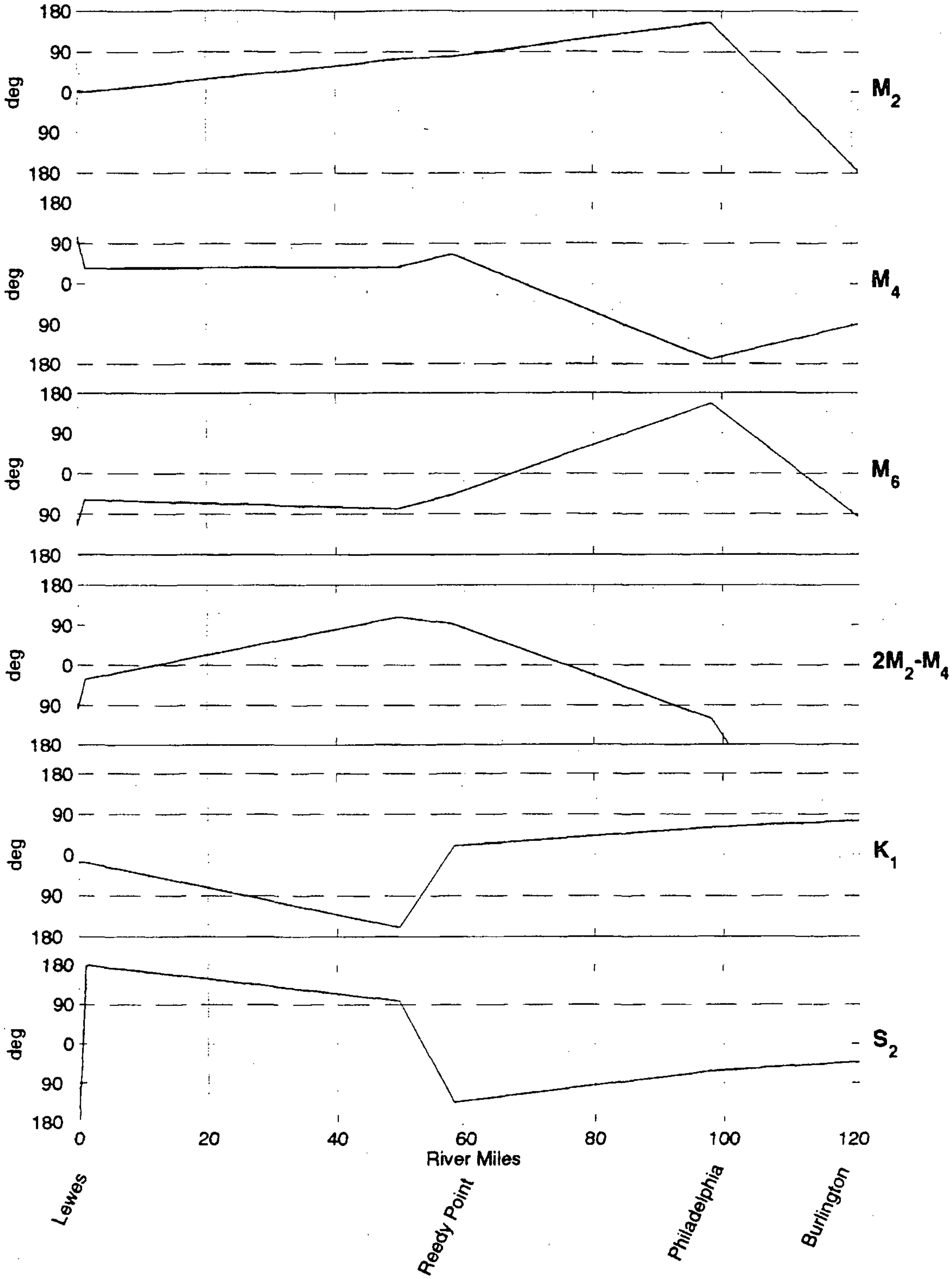
E-1 Figure III-1. Geographic map of the Delaware Bay and River including the navigational channel. Insert: the Delaware Bay and adjacent continental shelf. Depth in meters (from Galperin and Mellor 1990).



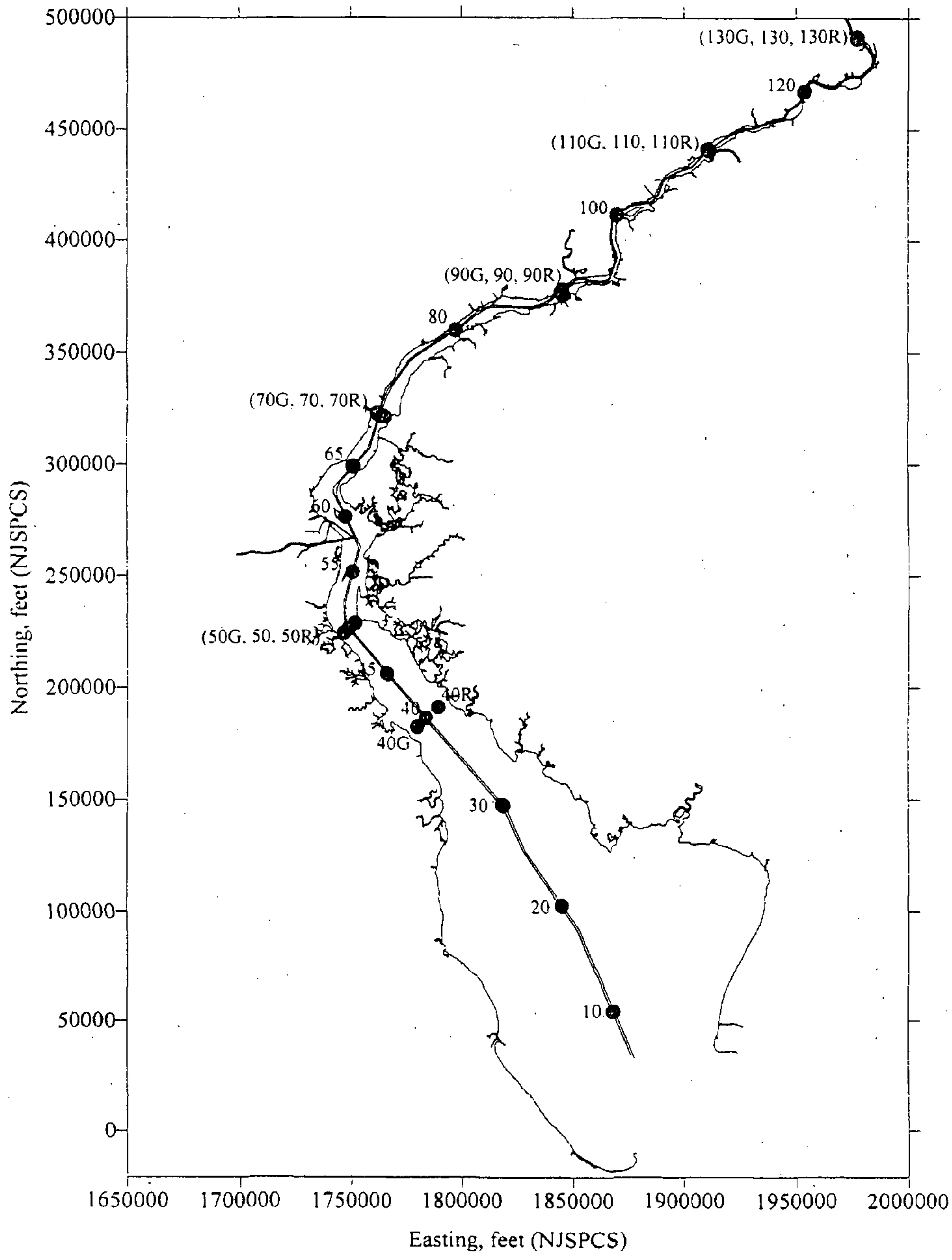
E-1 Figure III-2. Location map of the Chesapeake Bay–C&D Canal-Delaware Estuary system. The eastern end of the C&D Canal enters Delaware Estuary at Reedy Point. Location of the mooring site is marked (Wong 1991).



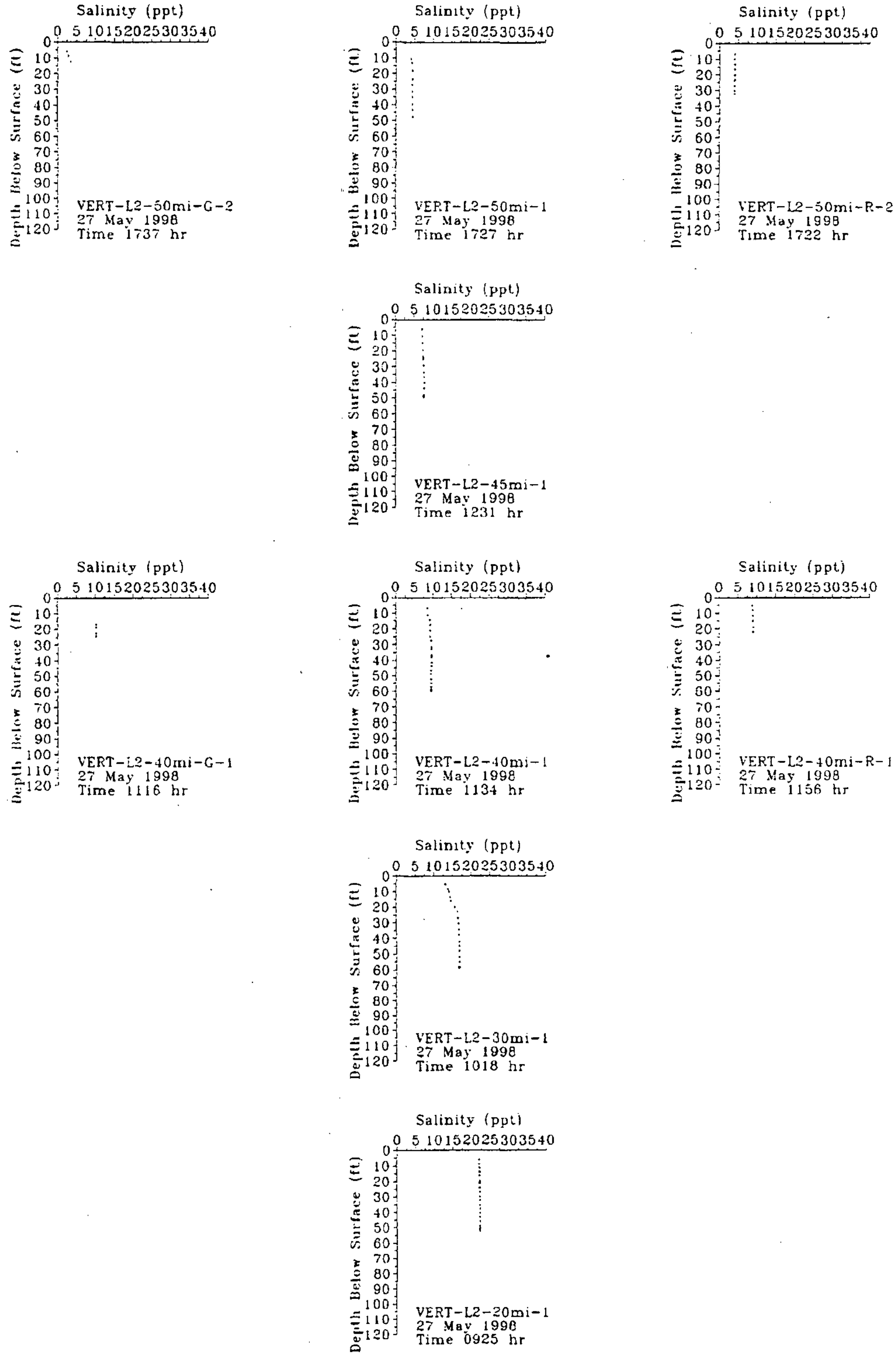
E-1 Figure III-3. The amplitude variation of the seven major tidal constituents and the M_4/M_2 amplitude ratio in the Delaware Estuary.



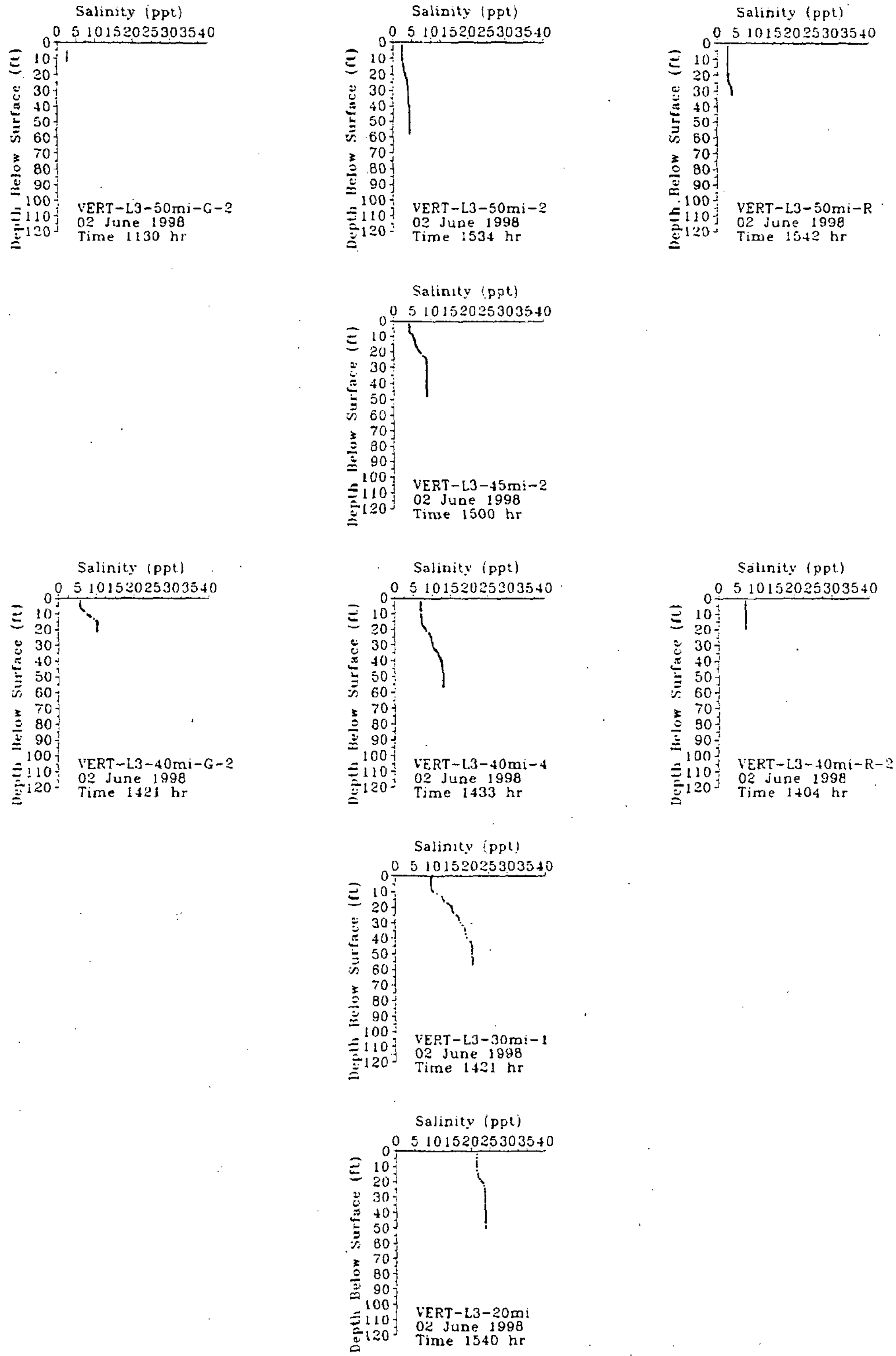
E-1 Figure III-4. The phase variation of the seven major tidal constituents and the $2M_2$-M_4 value in the Delaware Estuary.



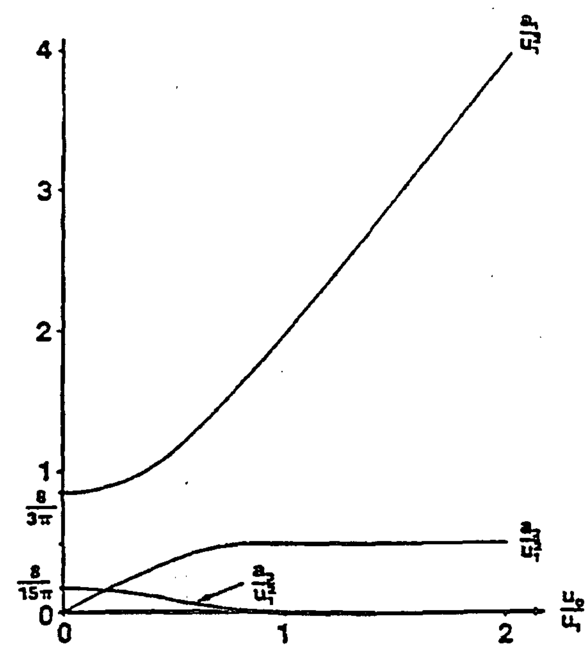
E-1 Figure III-5. Locations of shipboard vertical profiles collected along the axis of the Estuary on 27 May and 2 June 1998.



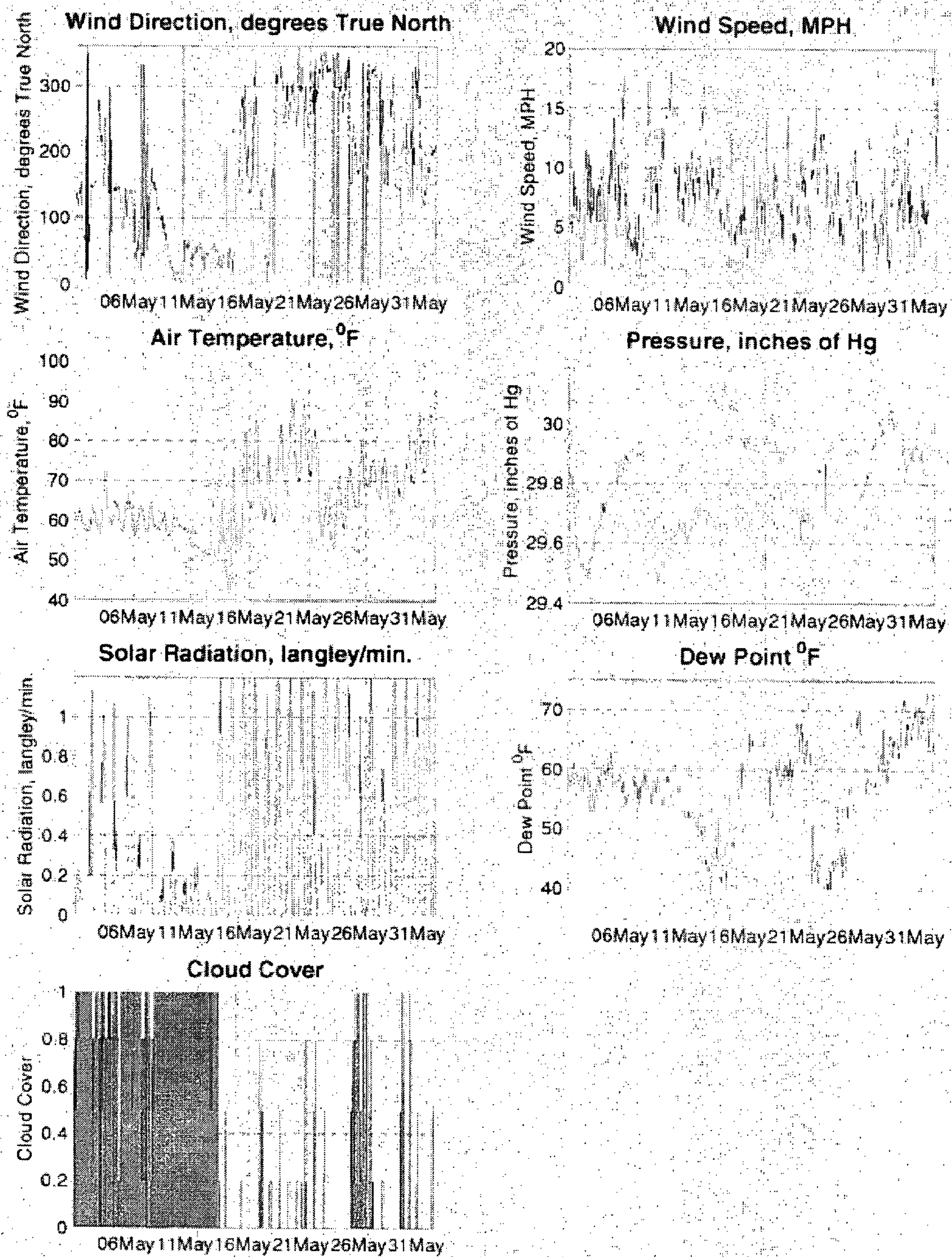
E-1 Figure III-6. Measured salinities along the axis of the Estuary for 27 May 1998 (RM 50 to 20).



E-1 Figure III-7. Measured salinities along the axis of the Estuary for 2 June 1998 (RM 50 to 20).

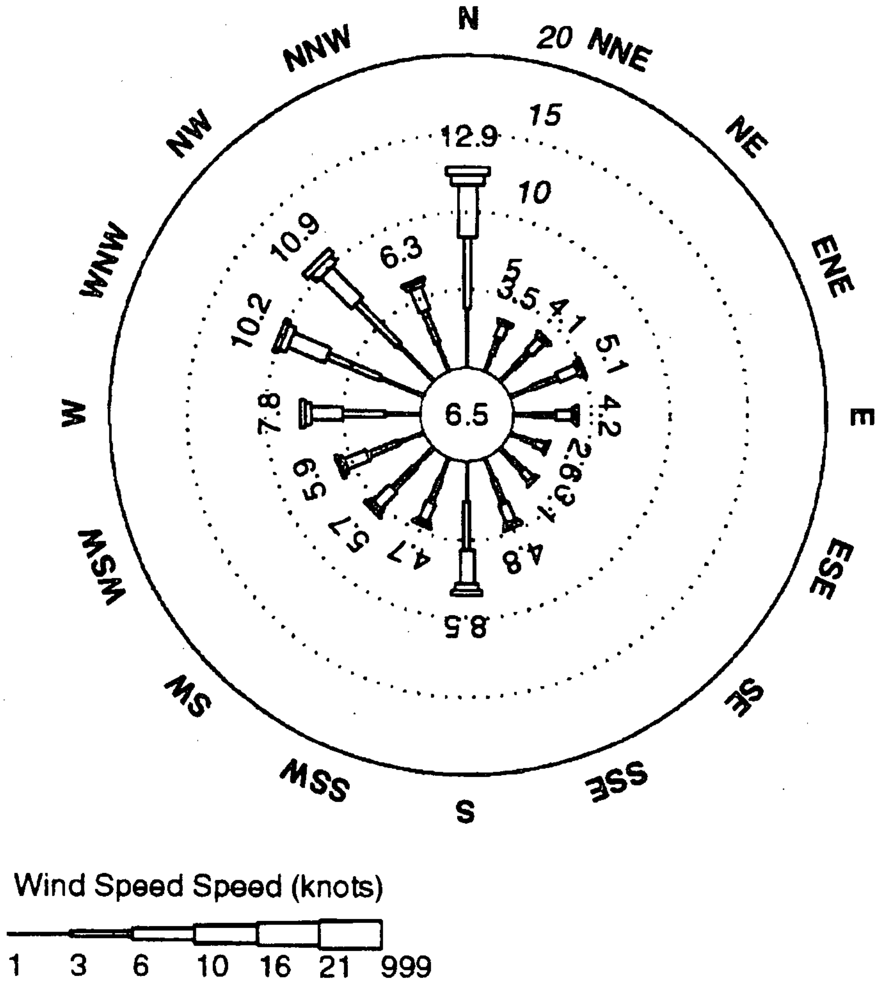


E-1 Figure III-8. The effect of mean flow on the first three tidal harmonics. The mean current speed is u_0 and the tidal current amplitude is u_1. The increase in the friction coefficient a_1 with increasing u_0/u_1 increases the momentum loss from the main tidal constituent (M_2). Coefficients a_2 and a_3 represent momentum input to the second and third harmonics (M_4 and M_6) (from Parker 1984).

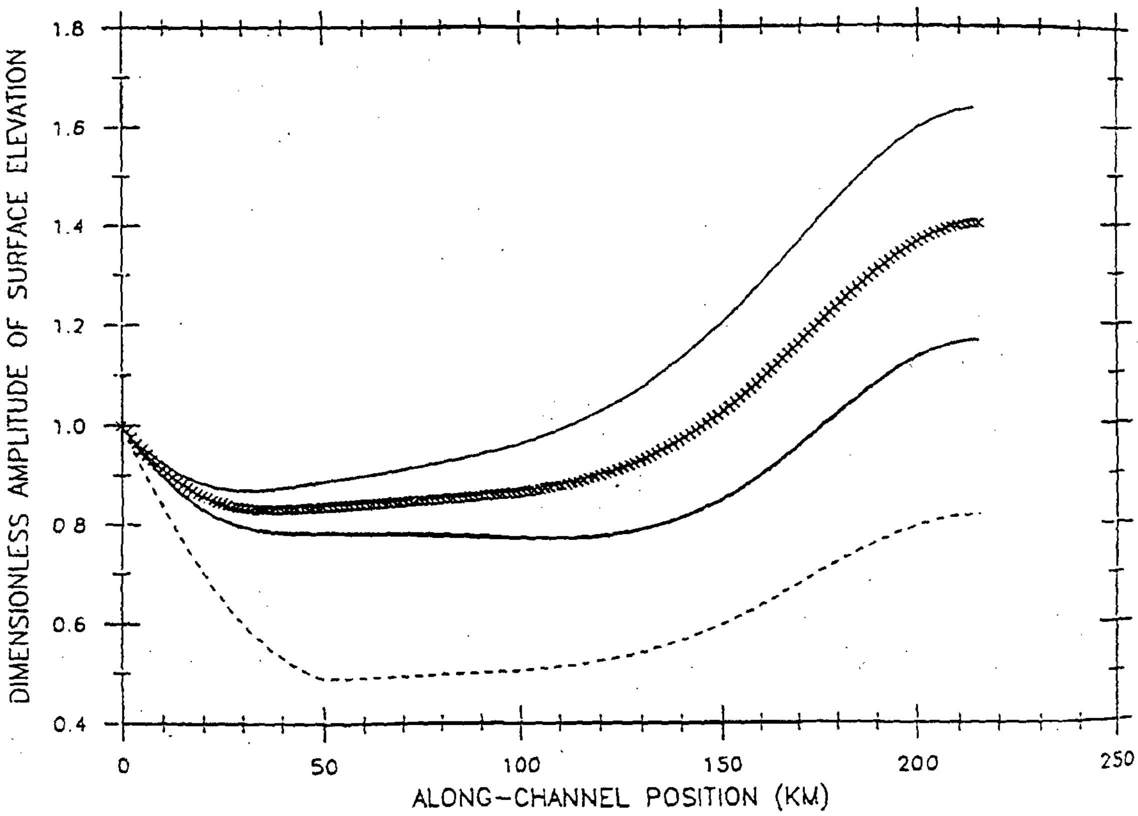


E-1 Figure III-9. Meteorological data collected at Artificial Island during the month of May 1998.

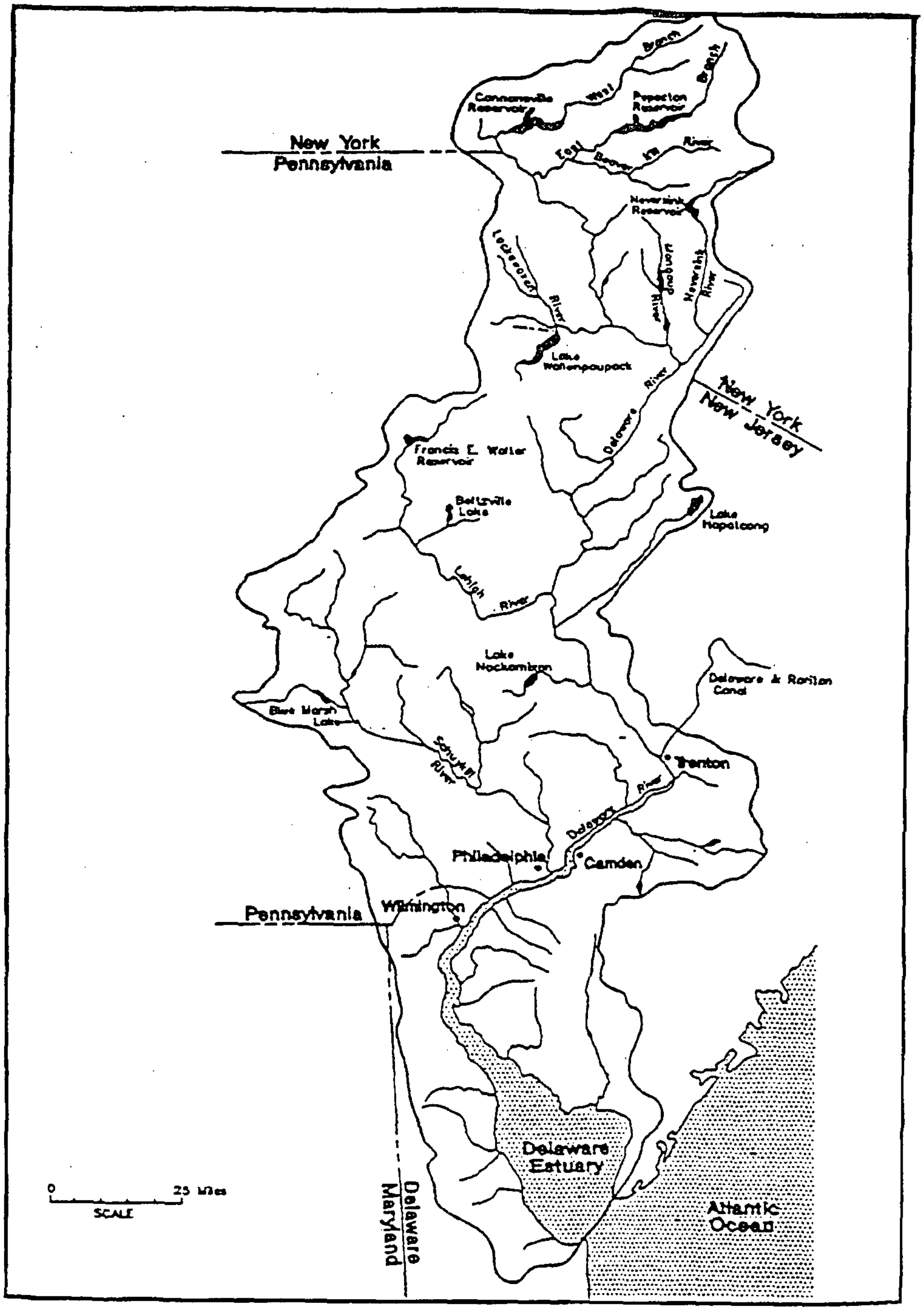
Percentage Occurrences of Wind Speeds



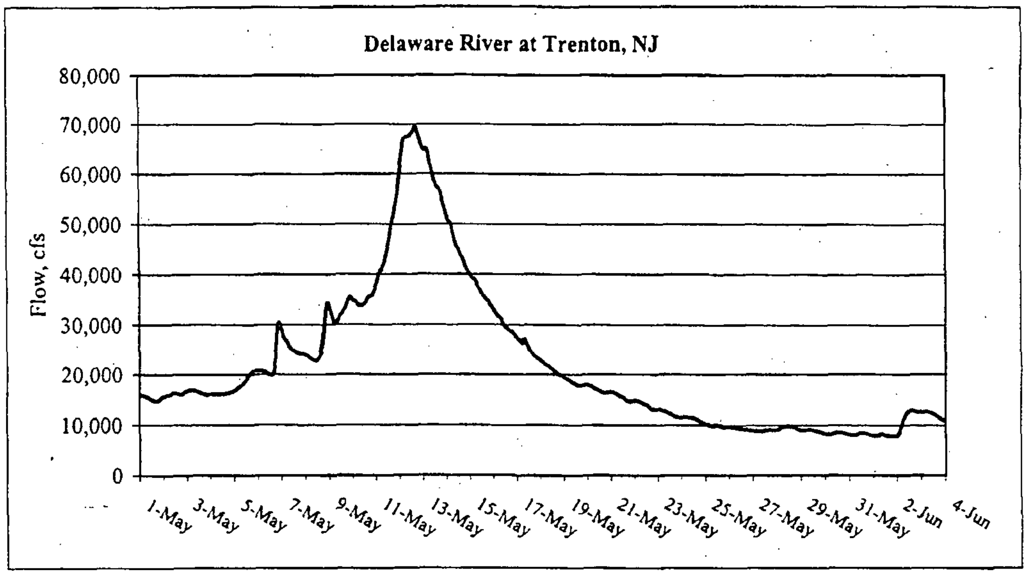
E-1 Figure III-10. Historically hourly wind rose plot for Wilmington, DE. (Data source: NCDC hourly winds at Wilmington New Castle Airport station from January 1948 to November 1998.)

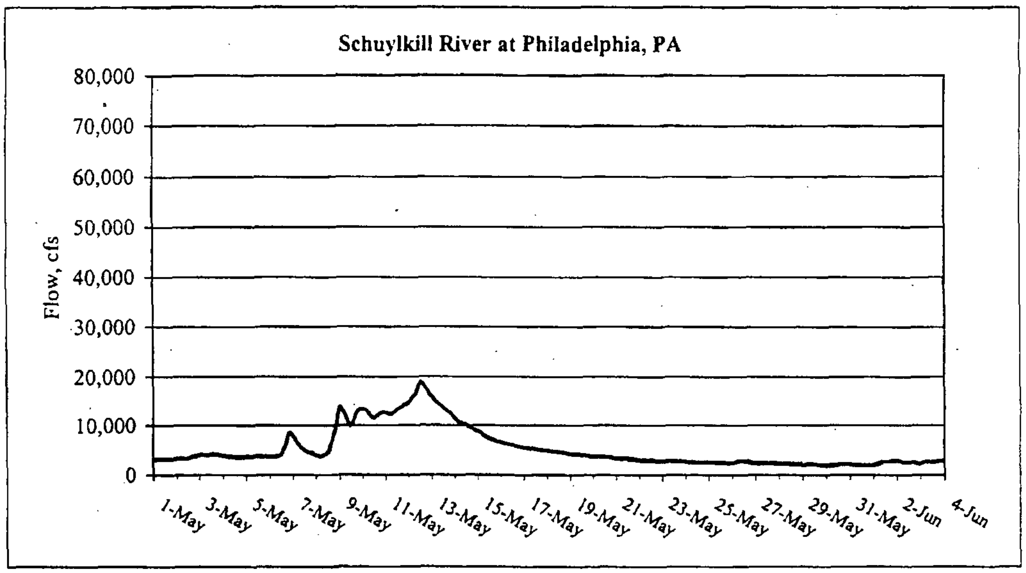


E-1 Figure III-11. Tidal surface elevation normalized by the amplitude A of the forcing as a function of position. Crosses: linearized friction coefficient is assumed (no wave-current interaction), depth 7 m, Solid line: linearized friction coefficient is assumed, depth 7.5 m. Heavy line: linearized friction coefficient is assumed, depth 6.5 m. Dashes: variable nonlinear friction coefficient is assumed (simulated wave-current interaction), depth 7 m (Wong and Trowbridge 1990).

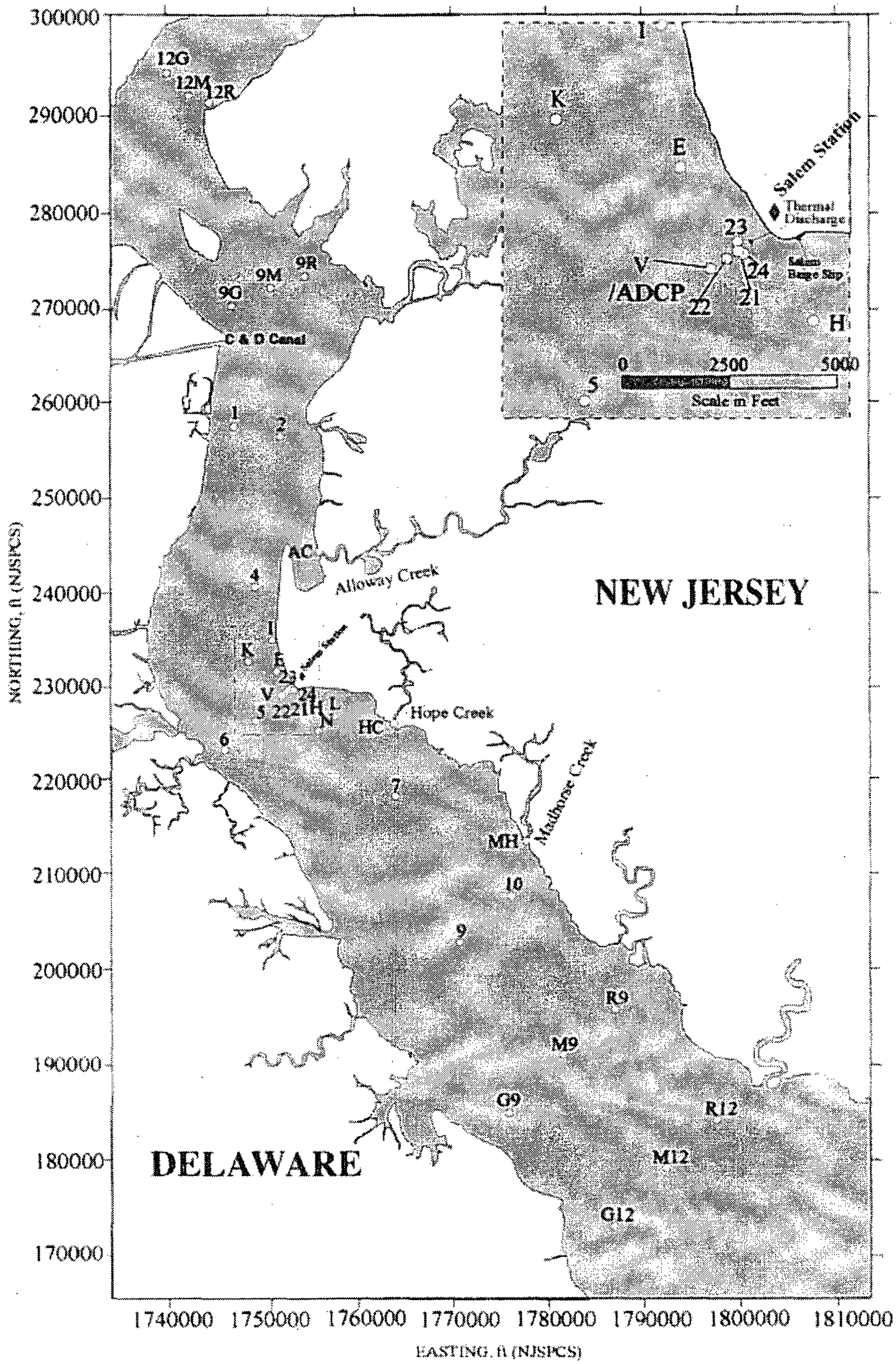


E-1 Figure III-12. The Delaware River Basin encompasses 33,040 square kilometers (12,757 square miles) whereas the lower Delaware River Basin that drains into the Estuary itself includes 15,500 square kilometers (5,987 square miles) as shown in this illustration. About 70 percent of the water received by the Estuary is discharged by the Delaware and Schuylkill Rivers. (Source: Tavit Najarian Associates, Inc. 1991).

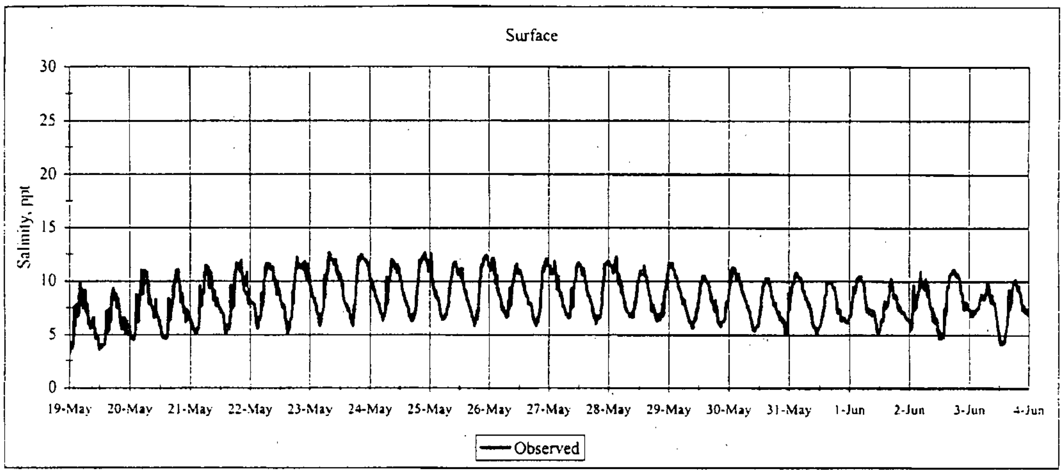


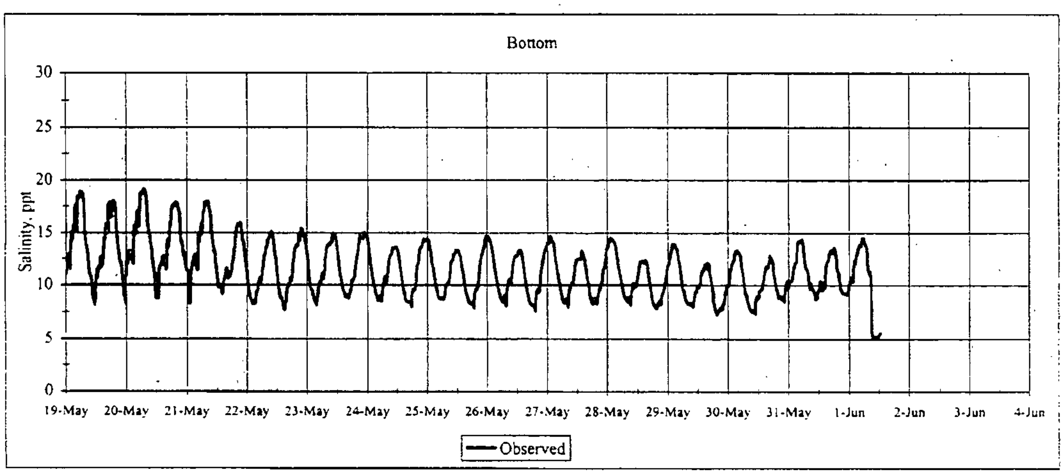


E-1 Figure III-13. Freshwater flow from the Delaware and Schuylkill Rivers during the month of May 1998 (model calibration period).

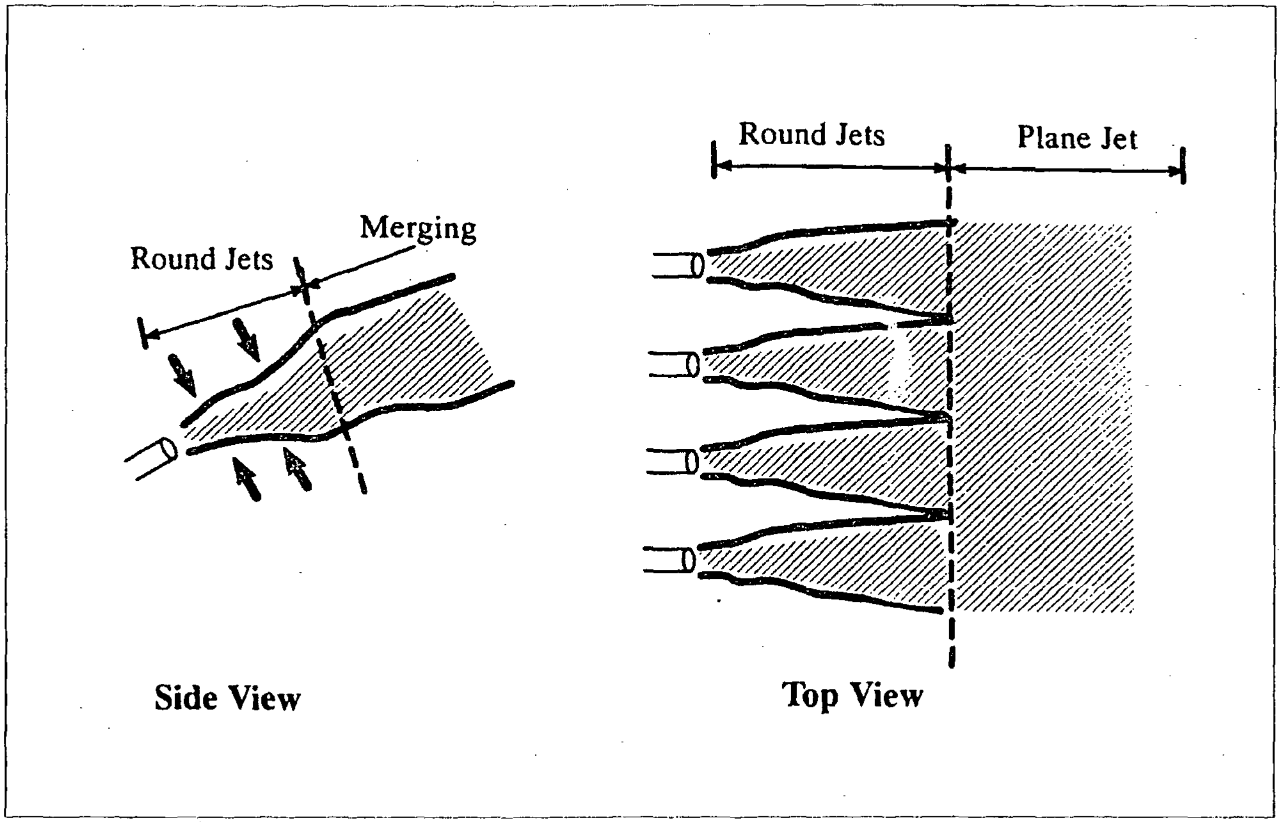


E-1 Figure III-14. Map showing the locations of the moorings deployed during the mooring study conducted as part of the Two-Unit Survey.

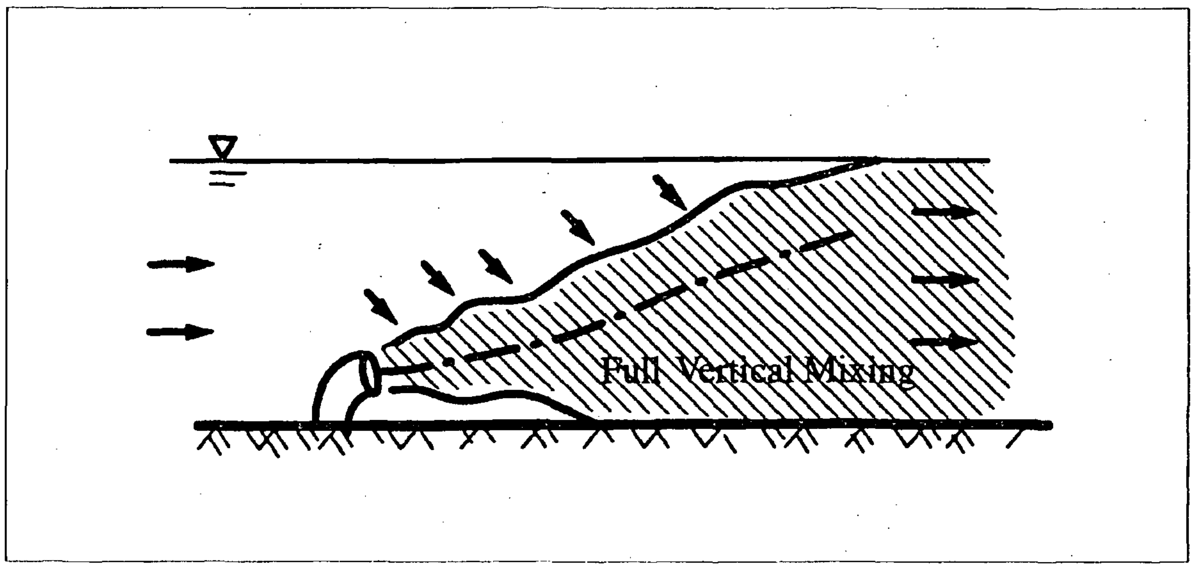




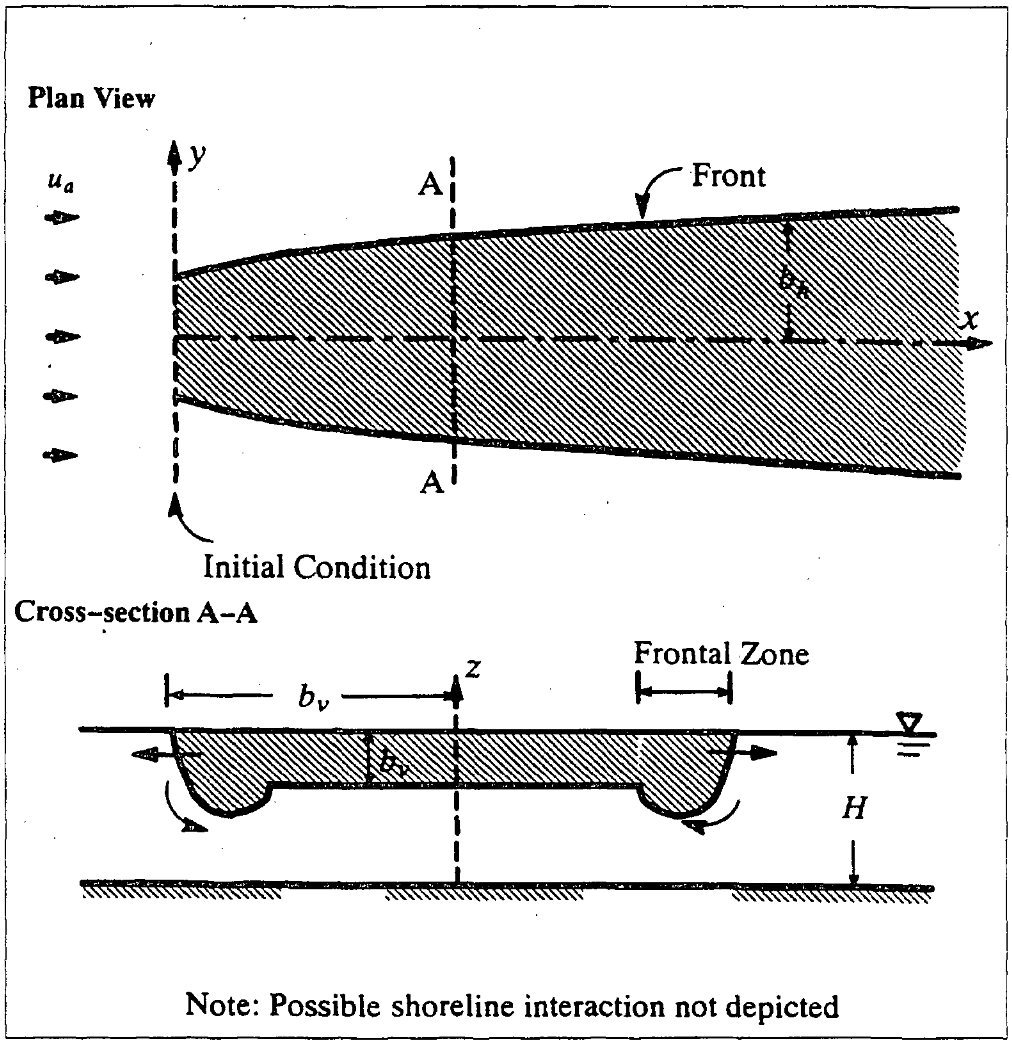
E-1 Figure III-15. Measured salinity at Mooring M9, which is located 9 miles south of the Station near the shipping channel, for the calibration period (19 May - 4 June 1998).



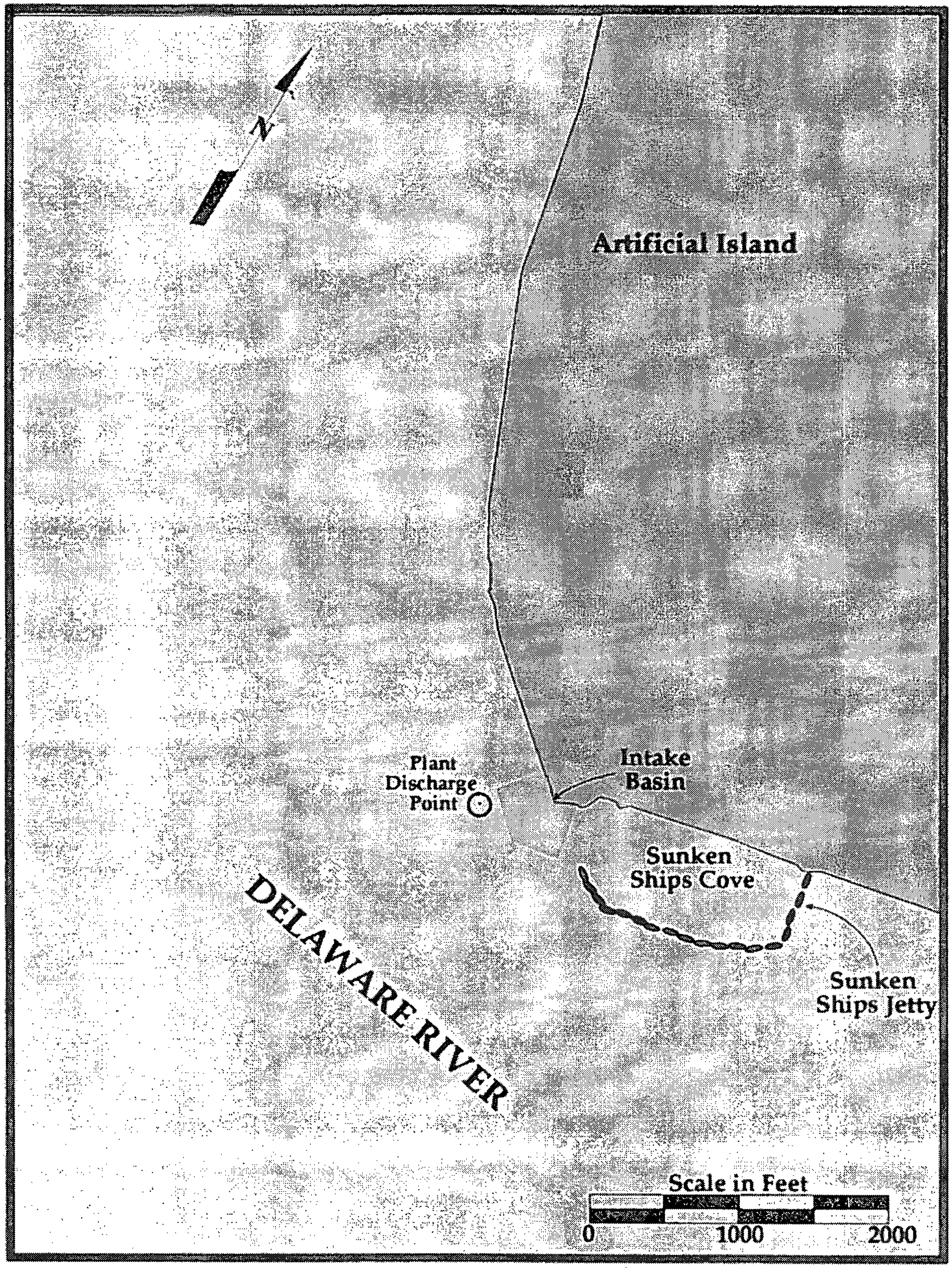
E-1 Figure III-16. Schematic depicting the process of jet merging at a unidirectional multiport diffuser forming a plane bouyant plume.



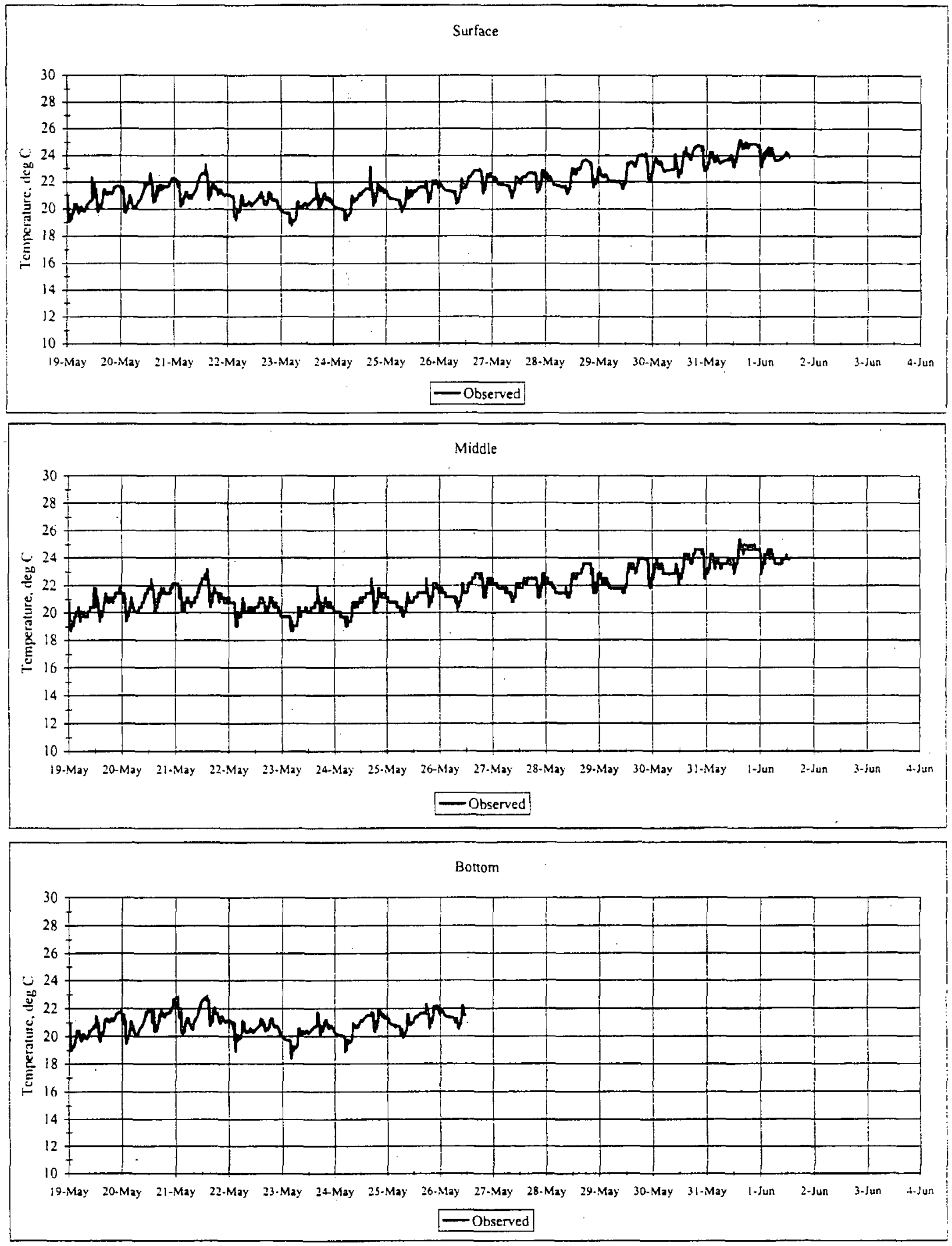
E-1 Figure III-17. Schematic showing the shallow water, low buoyancy, near-horizontal situation in an unstable near field with vertical mixing.



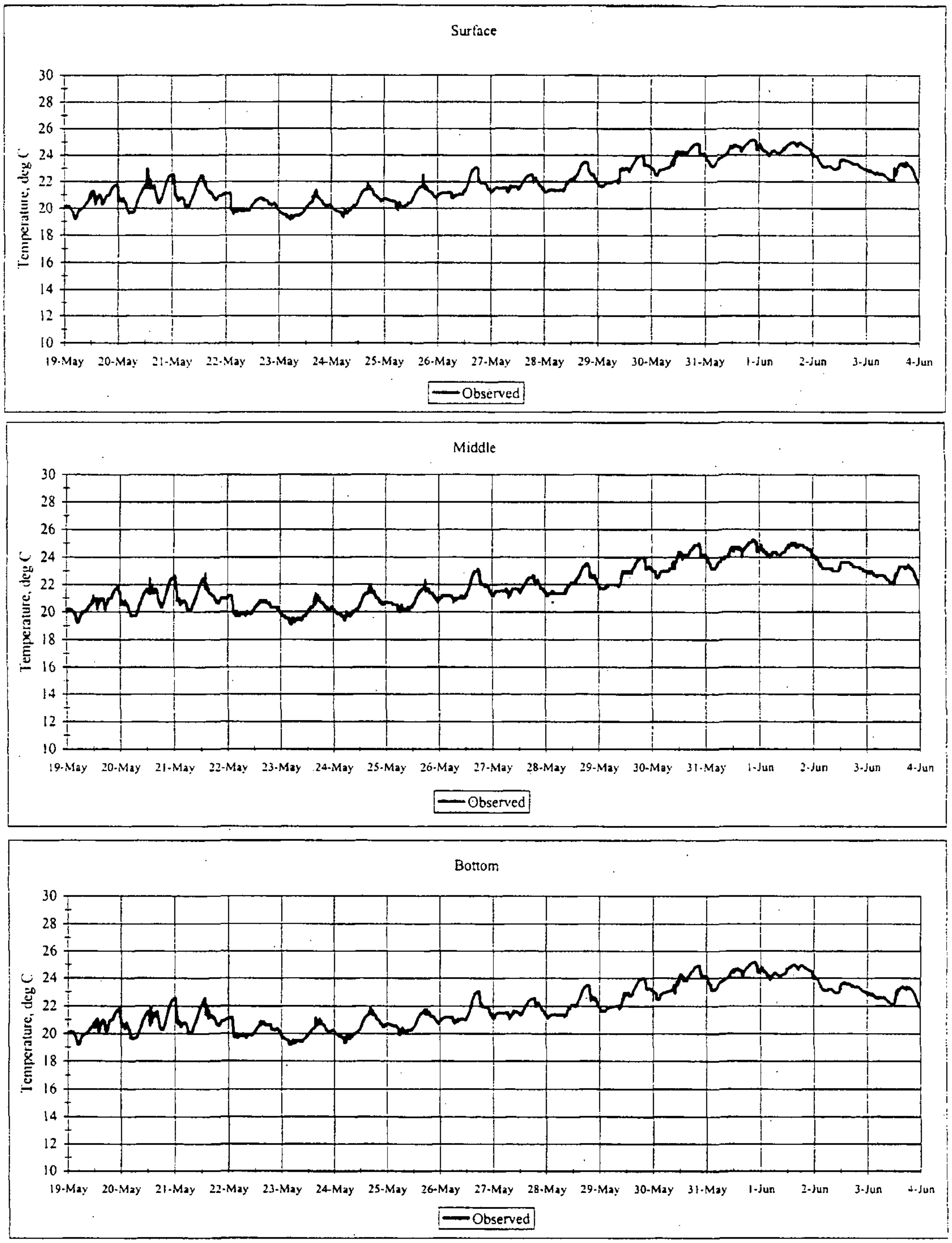
E-1 Figure III-18. Sketch showing a typical buoyant surface jet mixing flow patterns.



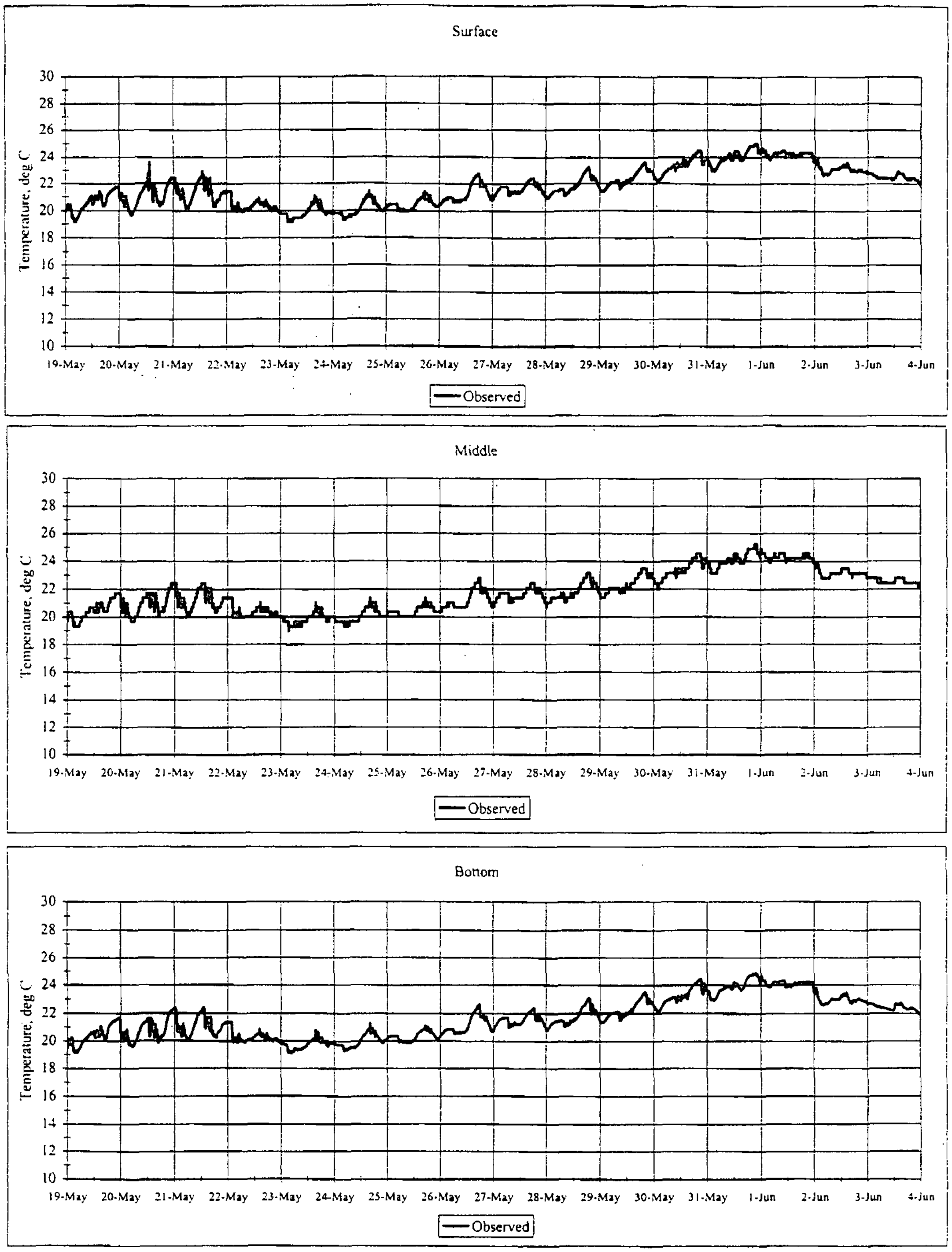
E-1 Figure III-19. Map of the Salem circulating water intake basin featuring Sunken Ships Cove, the basin, and the approximate location of the plant discharge point.



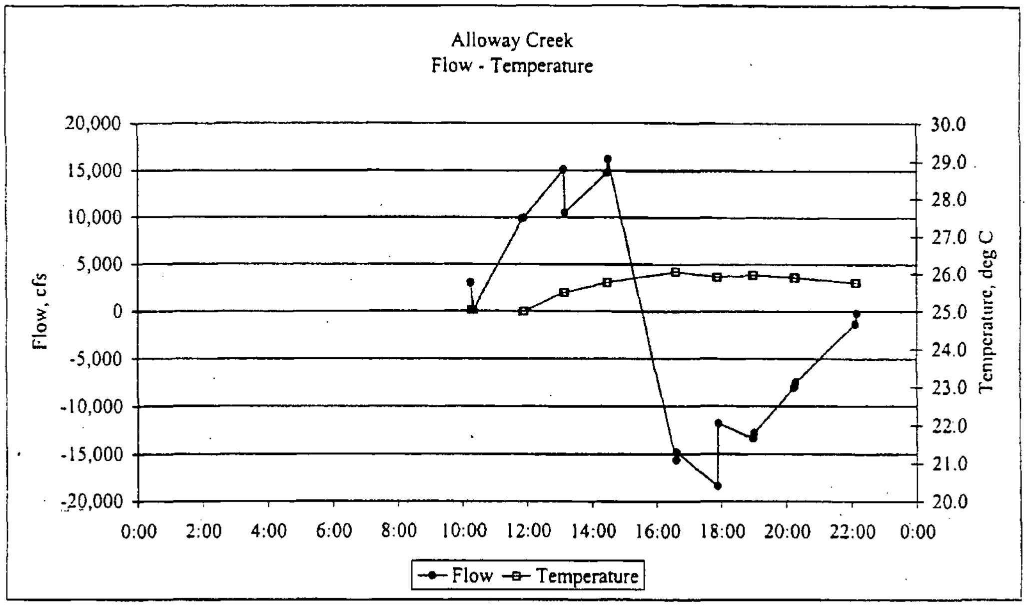
E-1 Figure III-20. Measured temperature at the Alloway Creek mooring for the calibration period (19 May - 4 June 1998).

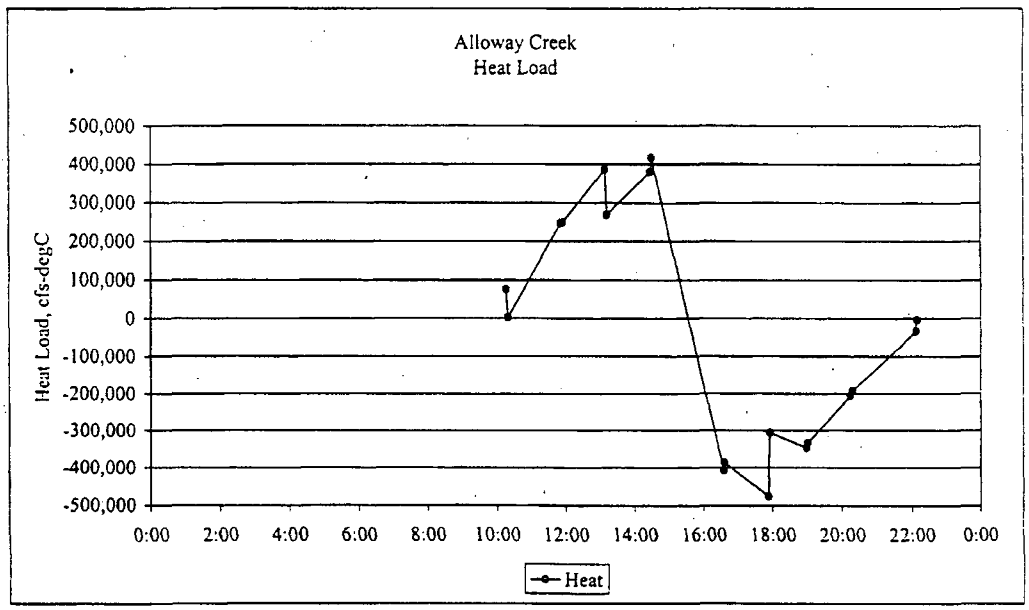


E-1 Figure III-21. Measured temperature at the Hope Creek mooring for the calibration period (19 May - 4 June 1998).

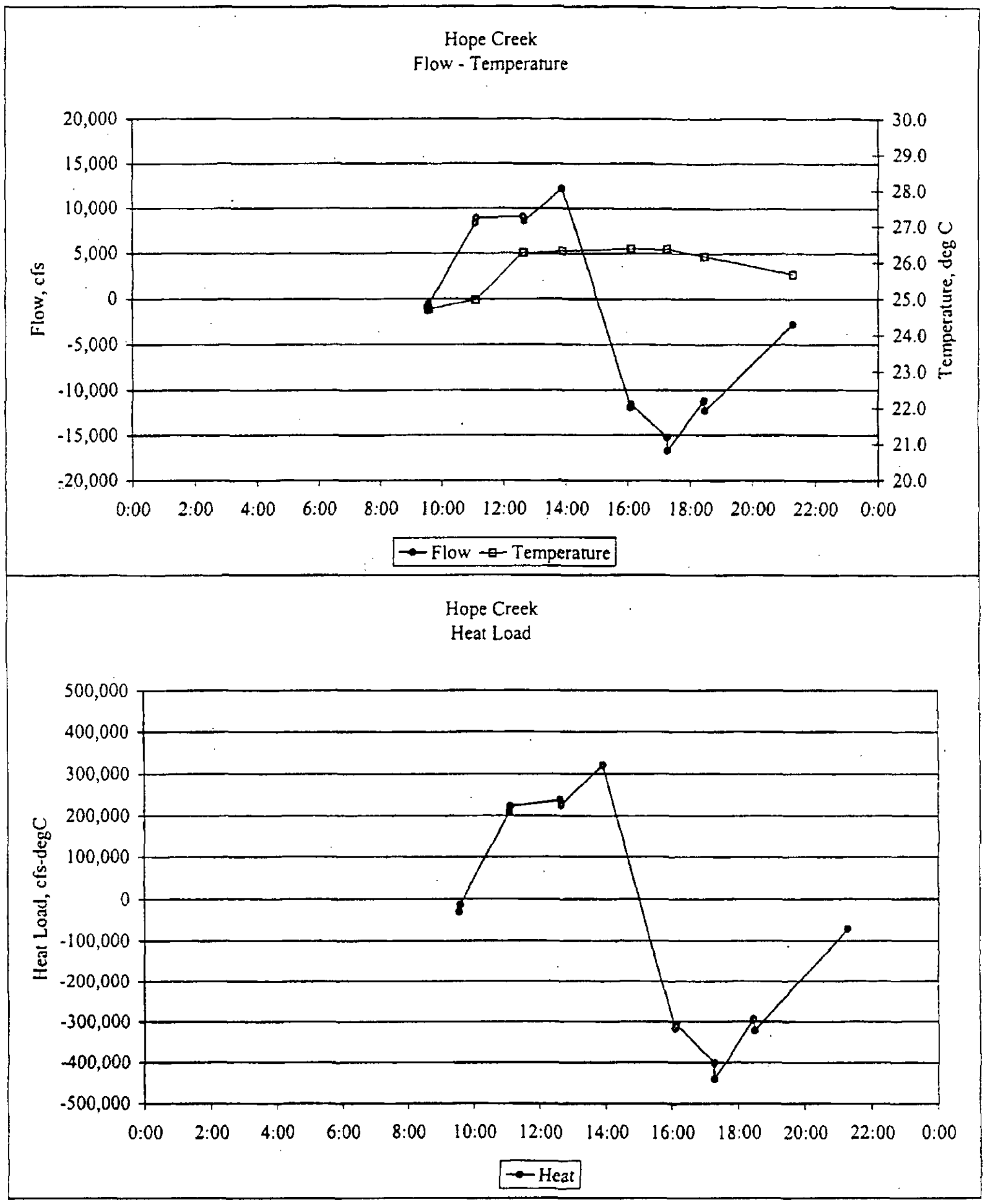


E-1 Figure III-22. Measured temperature at the Mad Horse Creek mooring for the calibration period (19 May - 4 June 1998).

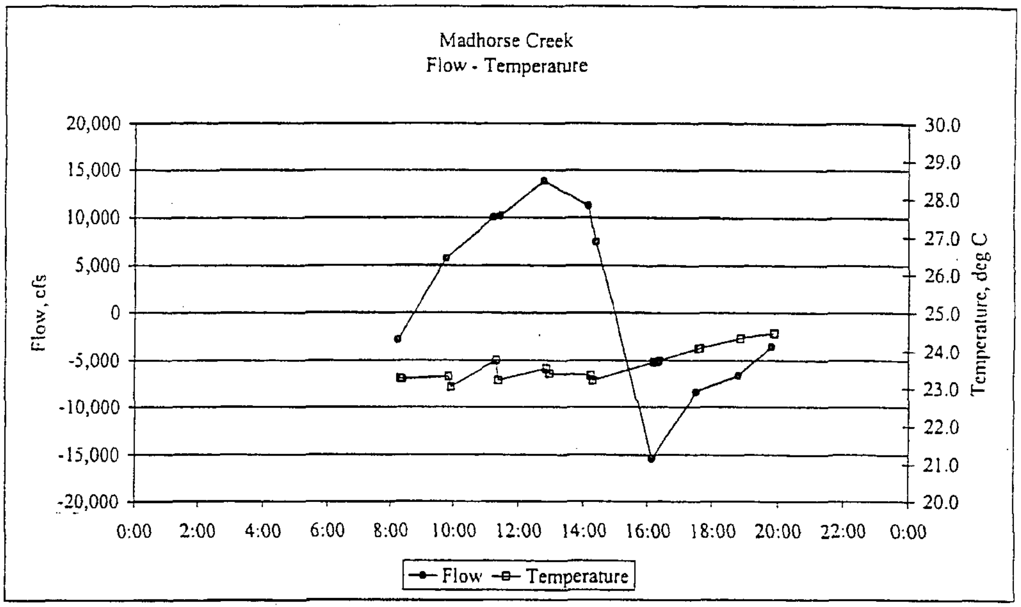


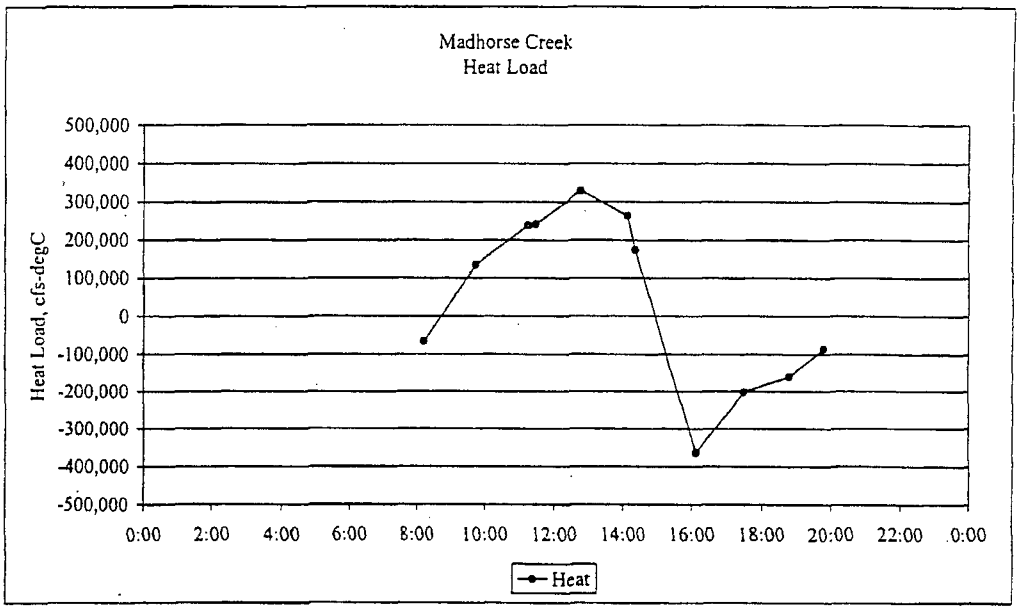


E-1 Figure III-23. Temporal Profiles of measured flow, temperature and heat for Alloway Creek on June 29, 1998.



E-1 Figure III-24. Temporal Profiles of measured flow, temperature and heat for Hope Creek on June 29, 1998.





E-1 Figure III-25. Temperature profiles of measured flow, temperature, and heat for Mad Horse Creek on May 30, 1998.

Attachment E-1 References

Aubrey Consulting Inc. (ACI). 1995. Public Service Electric and Gas Salem and Hope Creek Nuclear Generating Stations: Modeling and Data Analysis Report. Cataumet, Massachusetts.

Cameron, W.M., D.W. Pritchard. 1963. Estuaries in *The Sea*, 2nd Edition. Insurance Publishers, New York. (M.N. Hill, ed.), 306-324.

Delaware River Basin Commission. 1998. The Delaware River Basin Stream Mileage System, staff Paper 105.

DiLorenzo, J.L., P. Huang, M.L. Thatcher, and T.O. Najarian. 1992. Effects of Historic Dredging Activities and Water Diversions on the tidal regime and salinity distribution of the Delaware Estuary. Prepared for USEPA Delaware Estuary Profram.

Dronkers, J.J. 1964. Tidal Computations in Rivers and Coastal Waters. North-Holland Publishing Company, Amsterdam.

Friedrichs, C.T., and D.G. Aubrey. 1988. Non-linear tidal distortion in shallow well-mixed estuaries: a Synthesis. *Estuarine, Coastal, and Shelf Science* 27:521-545.

Garvine, R.W., R.K. McCarthy, and K.C. Wong. 1992. The Axial Salinity Distribution in the Delaware Estuary and its weak response to River Discharge. *Estuarine, Coastal, and Shelf Science* 35:157-165.

Galerpin, B., and G.L. Mellor. 1990. A time dependent, three-dimensional model of the Delaware Bay and River system. Part I: Description of the model and tidal analysis. *Estuarine, Coastal, and Shelf Science* 31:231-253.

Hires, R.I., G.L. Mellor, L.Y. Oey, and R.W. Garvine. 1984. Circulation of the Estuary. The Delaware Estuary: Research as background for estuarine management and development. (J.H. Sharp, ed), University of Delaware Sea Grant College Program. Newark, Delaware.

Hsieh, B., D. Richards. 1996. Three Dimensional Numerical Simulation of Seasonal Flow and Salt Transport for the C&D Canal. Philadelphia: US Army Corps of Engineers, Waterway Experiment Station. (Technical Report; 96-114).

Najarian, T.O., M.L. Thatcher, and D.R.F. Harleman. 1980. C&D Canal Effect on Salinity of Delaware Estuary. *J. Waterway Port Coastal and Ocean Division.*

National Oceanic and Atmospheric Administration (NOAA). 1987. Delaware River and Bay Tidal Circulation and Water Level Forecast Atlas. Estuarine and Ocean Physics Branch, Physical Oceanography Division, Office of Oceanography and Marine Assessment, National Ocean Service.

National Ocean Service. 1998. Tidal Current Tables 1998: Atlantic Coast of North America. International Marine, Camden, Maine.

NJPDES. 1993. NJPDES Draft Permit. 24 June 24.

Parker, B.B. 1984. Frictional effects on the Tidal Dynamics of a shallow Estuary. Ph.D. Dissertation, Johns Hopkins University.

Parker, B.B. 1991. The relative importance of the Various Nonlinear Mechanisms in a wide Range of Tidal Interactions (Review). *Tidal Hydrodynamics*, (B.B. Parker, Ed.), New York: Wiley and Sons, Inc.

Polis, D.F. and S.L. Kupferman. 1973. Delaware Bay Report Series: Physical Oceanography. Volume 4. University of Delaware, Newark, Delaware.

Pritchard, D.W., and G.B. Gardner. 1974. Hydrography of the C&D Canal. Technical Report No. 85, Chesapeake Bay Institute, The Johns Hopkins University, Baltimore, MD. February.

Smullen, J.T., J.H. Sharp, R.W. Garwine, and H.H. Haskin. 1984. River Flow and Salinity. *The Delaware Estuary: research as background for estuarine management and development.* University of Delaware Sea Grant College Program, Newark, Delaware.

Wong, K.C. 1987. Subtidal volume exchange through the Chesapeake and Delaware Canal. *Journal of Geophysical Research* 92:10,870-10,874. (Submitted by App C #57150)

Wong, K.C. 1990. The current and sea level variability in the Chesapeake and Delaware Canal. *Journal of Geophysical Research* 95(C10):18,343-18,352.

Wong, K.C. 1991. The Response of the Delaware Estuary to the Combined Forcing from Chesapeake Bay and the ocean. *Journal of Geophysical Research* 96(C5):8797-8809.

Wong, K.C. 1995. The Hydrology at the Mouth of Delaware Bay: Tidally Averaged Distribution and Intratidal Variability. *Estuarine, Coastal, and Shelf Science* 41(6):719-736.

Wong, K.C. and R.W. Garwine. 1984. Observations of Wind Induced, Subtidal Variability in the Delaware Estuary. *Journal of Geophysical Research* 89(C6):10589-10597.

Wong, K.C., and J.H. Trowbridge. 1990. Some Observational Evidence on the Effect of Atmospheric Forcing on Tidal Variability in the Upper Delaware bay. *Journal of Geophysical Research* 95(C9):16229-16240.