Review of Vermont Yankee Thermal Discharge Modeling

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About the Authors

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Ken Hickey is Vice President of HydroAnalysis, Inc. and has twenty years of experience conducting surface water hydrologic and water quality investigations. He has successfully designed and conducted numerous river and estuarine hydrologic and water quality modeling studies. Mr. Hickey has applied a wide range of hydrologic and water quality models, from simple to complex, to quantifying pollutant loads and potential impacts on ambient water quality and ecological receptors. He has conducted river studies for the U.S. Environmental Protection Agency, U. S. Army Corps of Engineers, state agencies and commercial clients throughout New England and the United States. Mr. Hickey holds an M.S in Environmental Engineering from the University of Cincinnati.

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1.0 Introduction

This report provides a review of a report entitled, *Hydrothermal Modeling of the Cooling Water Discharge from the Vermont Yankee Power Plant to the Connecticut River* by Applied Science Associates (ASA 2004). The 2004 hydrothermal modeling report was submitted in support of a 316(a) demonstration for the Vermont Yankee Power Plant. The thermal impact analysis provided in the 2004 demonstration was framed as an incremental update of two previous 316 demonstrations, conducted in 1978 and 1990. As a result, it was necessary to review and briefly summarize the thermal studies associated with the 1978 and 1990 demonstrations in this report.

The scope of this review is focused on characterizations of thermal plumes in the Connecticut River resulting from the Vermont Yankee thermal discharge. The objectives of this review and our findings in brief are:

Objective 1: To determine whether the 2004 ASA model accurately portrayed the extent and character of the Vermont Yankee thermal plume and its influence on the Connecticut River, including Vernon Pool and the areas downstream.

Finding 1: We found that insufficient field data and model results were provided to support assessment of whether the model accurately portrayed the extent and character of the Vermont Yankee thermal plume in the Vernon Pool. The downstream areas below Vernon Pool were excluded from the model and were not characterized at all.

Objective 2: To determine whether and to what extent the ASA model provided the data and information necessary to support assessment of the effect of Vermont Yankee's thermal discharge on aquatic species in the Connecticut River, in particular adult and juvenile Atlantic salmon and American shad.

Finding 2: We found that ASA did not provide sufficient field data and model results to support assessment of potential effects on aquatic species.

This report documents the review that led to the findings above and is organized as follows:

- ***Section 1.1 – Regulatory Overview*** - provides an overview of the EPA's guidance on characterizing thermal effects in order to place the 2004 study in regulatory context;
- ***Section 2.0 – Previous 316(a) Demonstrations*** - provides a description of thermal plume characterization studies conducted at Vermont Yankee in support of 1978 and 1990 316(a) demonstrations to place the 2004 study in context relative to previously conducted studies;
- ***Section 3.0 – Description of 2004 Modeling Evaluation*** - provides a description of the ASA 2004 thermal discharge modeling analysis;
- ***Section 4.0 – Review of the 2004 Modeling Evaluation*** – provides a critical review of the ASA 2004 thermal discharge modeling analysis and an assessment of whether or not the model is sufficient to support the 316(a) demonstration process; and
- ***Section 5.0 – Recommendations*** - provides a set of recommended next steps to support thermal characterization of the Connecticut River

1.1 Overview of EPA Thermal Effects Characterization Guidance

Thermal discharges to receiving waters, including those from nuclear power facilities, are regulated under Section 316(a) of the federal Clean Water Act. In 1977, the United States Environmental Protection Agency (EPA) issued a technical guidance manual to support development of 316(a) demonstration studies (EPA 1977). The EPA manual provides guidance for identifying the appropriate level of effort of demonstration studies and in scoping thermal, fisheries, and other surveys to support assessment of potential adverse impacts. The 1977 manual provides guidance, rather than requirements, and is intended to support regulatory and industrial practitioners in designing and conducting Section 316(a) demonstration studies. Although more than thirty years have elapsed since publication of the guidance document, it has never been updated by EPA. Nonetheless, the document remains a source of advice that is technically sound and it continues to be followed by permit applicants and regulators.

A few key components of the EPA 316(a) demonstration guidance were identified as important relative to the Vermont Yankee thermal modeling review and are summarized below. According to EPA guidance, "a 316(a) demonstration will be judged successful if the applicant can prove that fish communities will not suffer appreciable harm" from cold shock or excess heat, reduced reproduction success or growth, exclusion of unacceptably large areas, or blockage of migration (EPA 1977, pp. 28-29). In terms of thermal discharge analyses, EPA guidance specifies consideration of the near- and far-field areas that could potentially be affected by the discharge. EPA guidance also specifies consideration of additive or synergistic effects, such as other existing thermal discharges, dams, or other factors that could combine with the thermal discharge to increase the adverse effect on fisheries. The EPA guidance further specifies that the complete thermal plume be mapped under a variety of conditions and that the presentation of results should include relevant time-series data, such as facility discharge flow and temperature; ambient river flow, velocity, and temperature; and meteorological data.

EPA guidance specifies that analysis and mapping be conducted to characterize the nature and extent of the thermal discharge and associated plume. Specifically, the EPA guidance states that the applicant should include the five components outlined below. These five components are important in this context because the ASA 2004 modeling report provided none of them.

1. ***Definition of study area*** - Include the discharge vicinity in the study domain (i.e., study area). The discharge vicinity is defined as "described by a radius that is 1.5 times the maximum distance from the point of discharge to within 1°C of ambient" temperature (EPA 1977, p. 75).

2. ***Inclusion of additive or synergistic effects*** - Include "the impact of additive or synergistic effects of heat combined with other existing thermal or other pollutants in the receiving water" (EPA 1977, p. 38).

3. ***Thermal plume map specification*** - Provide maps of "the discharge plume out to the 1°C isotherm" under "worst case, anticipated average conditions, and ideal conditions" (EPA 1977, p. 46). Also, "Plumes shall be detailed showing the instantaneous isotherms at the 2°C intervals to within 1°C of ambient for conditions and variations…" (EPA 1977, p. 49).

4. ***Variety of thermal plume maps*** - Provide maps and profiles of thermal plumes associated with various conditions including monthly, maximum size, and most frequently occurring. "Plumes for average and 7-day, 10-year low flows should be provided" and vertical temperature profiles

along the plume centerline extending to the bottom of the water body at 2°C intervals to within 1°C of ambient" temperature should be provided (EPA 1977, p. 49).

5. ***Presentation of Data*** - Provide tables or illustrations of ambient river flows and velocities over time and river temperatures and thermal gradients over time. Also, provide tables or illustrations of facility discharge flow and temperature over time and meteorological conditions over time (EPA 1977, pp. 47-49).

2.0 Vermont Yankee 316a Thermal Discharge Permitting History

The Vermont Yankee Nuclear Power Station began operation in 1972 and there have been three 316 demonstration reports, submitted in 1978, 1990, and 2004. The facility was originally designed to have a thermal discharge using a once-through cooling system and known as an open-cycle system. During the original permitting process, concerns were expressed regarding the potential for adverse impacts of thermal discharge to the Connecticut River. As a result, mechanical draft cooling towers were constructed and used in a closed-cycle cooling system with no thermal discharge to the river (Aquatec 1978). In 1978, Vermont Yankee requested to discharge thermal effluent to the Connecticut River during the non-summer time period only. In 1990, Vermont Yankee requested to add discharge of thermal effluent during the summertime period, making thermal discharge a year-round activity. Thermal characterization aspects of the 1978 and 1990 demonstration reports are briefly summarized below and the thermal modeling conducted in support of the 2004 demonstration report is summarized in Section 3.

2.1 1978 Demonstration

The Vermont Yankee Nuclear Power Station began operation in 1972 and was permitted for closed-cycle condenser cooling exclusively, meaning that there was no thermal discharge to the Connecticut River. A 316(a) demonstration was submitted in 1978 and sought to allow Vermont Yankee to operate an open-cycle system during the non-summer time period (15 October to 15 May), subject to three conditions, as follows (Aquatec, 1978):

1. Temperature at the downstream monitoring station (Station 3, also called Monitor 3 in some reports) shall not exceed 65°F;
2. The rate of change of temperature at Station 3 shall not exceed 5°F per hour; and
3. The increase in temperature above ambient at Station 3 shall not exceed 13.4°F.

From 1974 to 1977, Vermont Yankee was granted permission to permit discharge of heated water concurrent with hydrologic and biological testing to support determination of potential impacts of heated effluent on the river system. This variance was granted during the non-summer season – from October 15 to May 15 only. The thermal effluent tests were sequentially phased with increasing thermal loads, such that Phases II and III were conducted from 1974 to 1976 and featured 10 to 50% of maximum thermal loading and Phase IV was conducted from fall 1976 through spring 1977 and featured 100% of maximum thermal loading (i.e., full thermal discharge to the river). Numerous hydrologic and biological surveys were conducted during the Phase IV testing period (Aquatec 1978).

A map of the Connecticut River study area, including Monitoring Station 3 situated 0.65 miles downstream of the Vernon Dam, is provided in Figure 2-1. The most intensive monitoring program (Phase IV) featured temperature measurements under a variety of thermal effluent and ambient river conditions and was conducted from September 8, 1976 through June 2, 1977. Three primary types of monitoring survey were conducted:

1. Vernon Pool temperature characterization – Measurement of thermal plume throughout Vernon Pool;

2. △T data analysis – Comparison and analysis of temperature data collected above (at Station 7) and below (at Station 3) the Vermont Yankee discharge and Vernon Dam; and
3. Downstream river temperature characterization – Thermal plume tracking and modeling downstream of the Vernon Dam.

Each of these types of surveys are briefly summarized below.

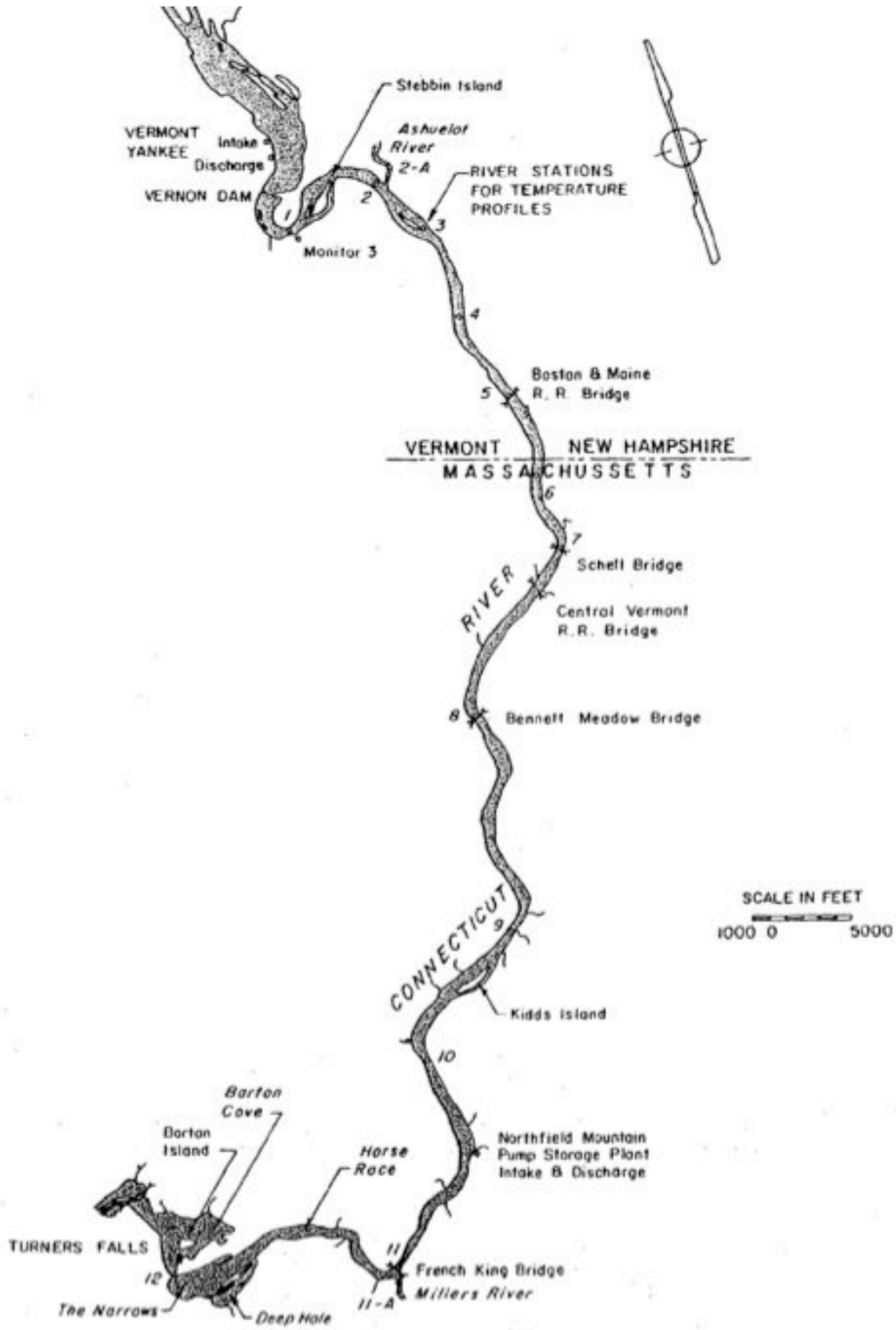

Figure 2-1. Connecticut River with Vermont Yankee facility and downstream monitoring locations indicated (from Aquatec, 1978, Figure 4-2).

Vernon Pool Characterization

From 1974 to 1977, 147 water temperature surveys were conducted in Vernon Pool. A summary of thermal survey results was provided for each survey and included the ambient river flow and water temperature, Vermont Yankee heat rejection rate and discharge, and Vernon Pool elevation. The 1978 Demonstration also provided the areal extent of the thermal plumes at the 15°F, 10°F, 5°F, and 1°F isotherm extent, for each survey (Aquatec 1978, Table 6.1). The tabular data presentation provided (for each of 147 water temperature surveys) is consistent with EPA guidance (1977) and exceeds the data presentation provided as part of the 2004 Demonstration.

△T Data Analysis (September 1976 – May 1977)

Figure 2-2 provides a summary of maximum daily temperature differences between upstream (Station 7) and downstream (Station 3) sampling locations, taken from the 1978 demonstration report. The upper chart provides a tabulation of maximum daily △T in 1°F "bins" for the period of September-May 1977, where △T is defined as the difference (i.e., change) in temperature between the upstream and downstream locations. Figure 2-2 shows, for example, that during the study period there were 38 days when the maximum temperature difference (△T) was between 1 and 2°F and 32 days when the maximum temperature difference was between 7 and 8°F. The lower chart in Figure 2-2 provides the cumulative frequency of specific maximum daily △T observations. As shown in the example, 80% of days had a maximum daily △T of 7°F or less (and 20% had △T of greater than 7°F).

Downstream Temperature Peak and Thermal Plume Tracking (September 1976 – June 1977)

Numerous thermal plume surveys were conducted downstream of the Vernon Dam between September 1976 and May 1977. Figure 2-1 shows the study area with numbered sampling locations indicated. Thermal plume tracking was also conducted by measuring downstream water temperatures and by releasing fluorescent dye into the river and tracking it downstream. Surveys were conducted to measure temperatures downstream of the Vernon Dam, as follows:

- In September 1976 and January 1977, surveys extended from the Vernon Dam for 20 miles downstream to Turners Falls Dam; and
- In May-June 1977, surveys extended from Vernon Dam for 55 miles downstream to the Holyoke Dam.

In some cases, when the unusually warm river water was identified, dye was released to "tag" the parcel of warm water and allow it to be followed as it traveled downstream. These "tagged" warm water parcels were then tracked downstream, recording the temperature, location, and duration of travel. Using this method, the 1976-1977 investigators were able to quantify elevated water temperatures and time of travel for water parcels.

Figure 2-3 shows time-series plots of monitoring results during three six-day time periods and is taken from the 1978 demonstration report (Aquatec 1978). The plots are paired to show both flow and temperature during each time period. The upper plot of each pair shows Vernon Dam flow rates (shown in shaded blocks) and Vermont Yankee heat production (in the partially dashed line) and the lower plot provides concurrent water temperature upstream at Station 7 (solid line) and downstream at Station 3 (dashed line). Investigators used these data to explore the dynamic relationship between river flow rates, Vermont Yankee operations, and downstream river temperature at Station 3. For example, on September 19, 1976 an event of elevated downstream temperature (at 72°F) was identified and marked as "D." As further discussed below, the water associated with event "D" was tracked downstream to determine the spatial extent of this thermal plume event. As shown in Figure 2-3, seven elevated temperature events (denoted A-G) were tracked in September 1976 and nine events (denoted H-P) were tracked in January 1977.

In the thermal plume study of 1976-1977, investigators evaluated the dynamic effects of the Vermont Yankee discharge and the Vernon Dam on downstream water temperatures. They found that peaks in downstream water temperature occurred after river flows increased from minimum flow levels and

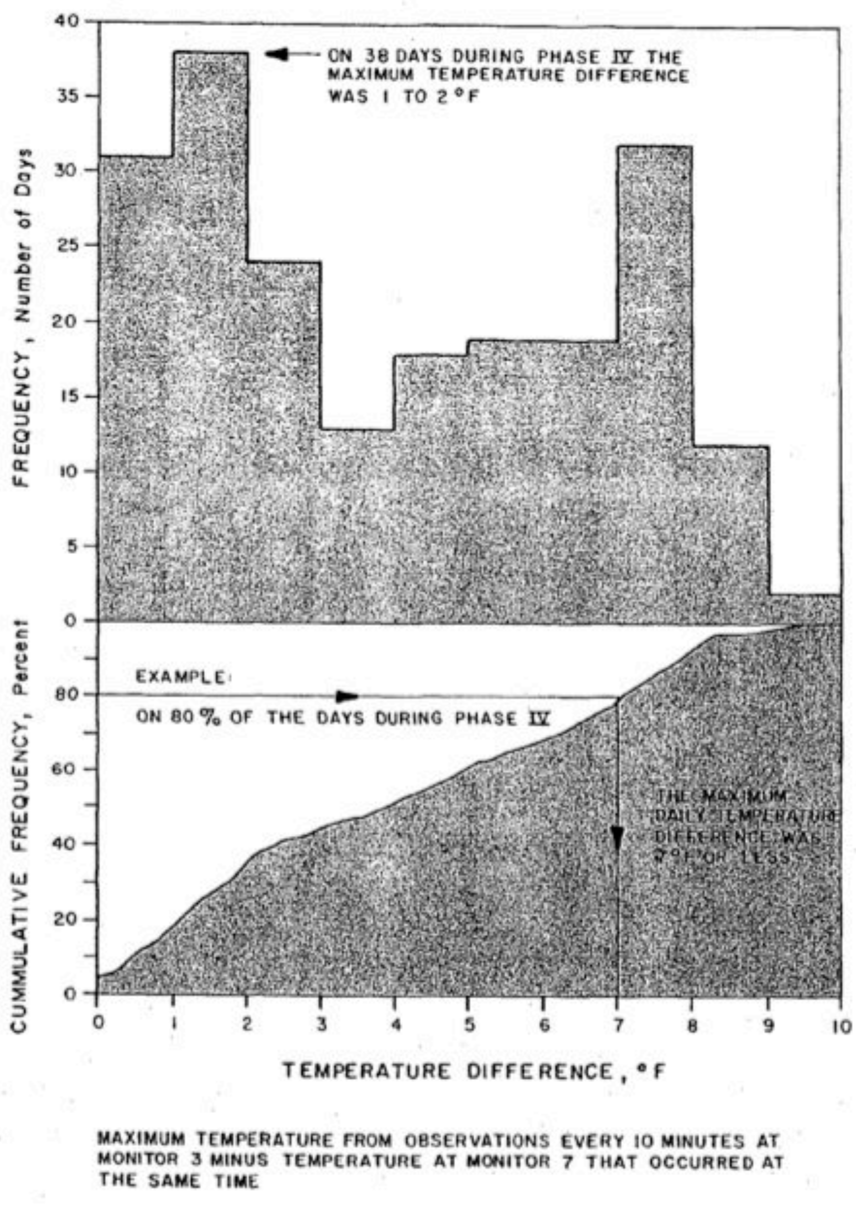

Figure 2-2. Maximum daily △T distribution for the period September 1976 – May 1977 (Aquatec 1978, Figure 5-5).

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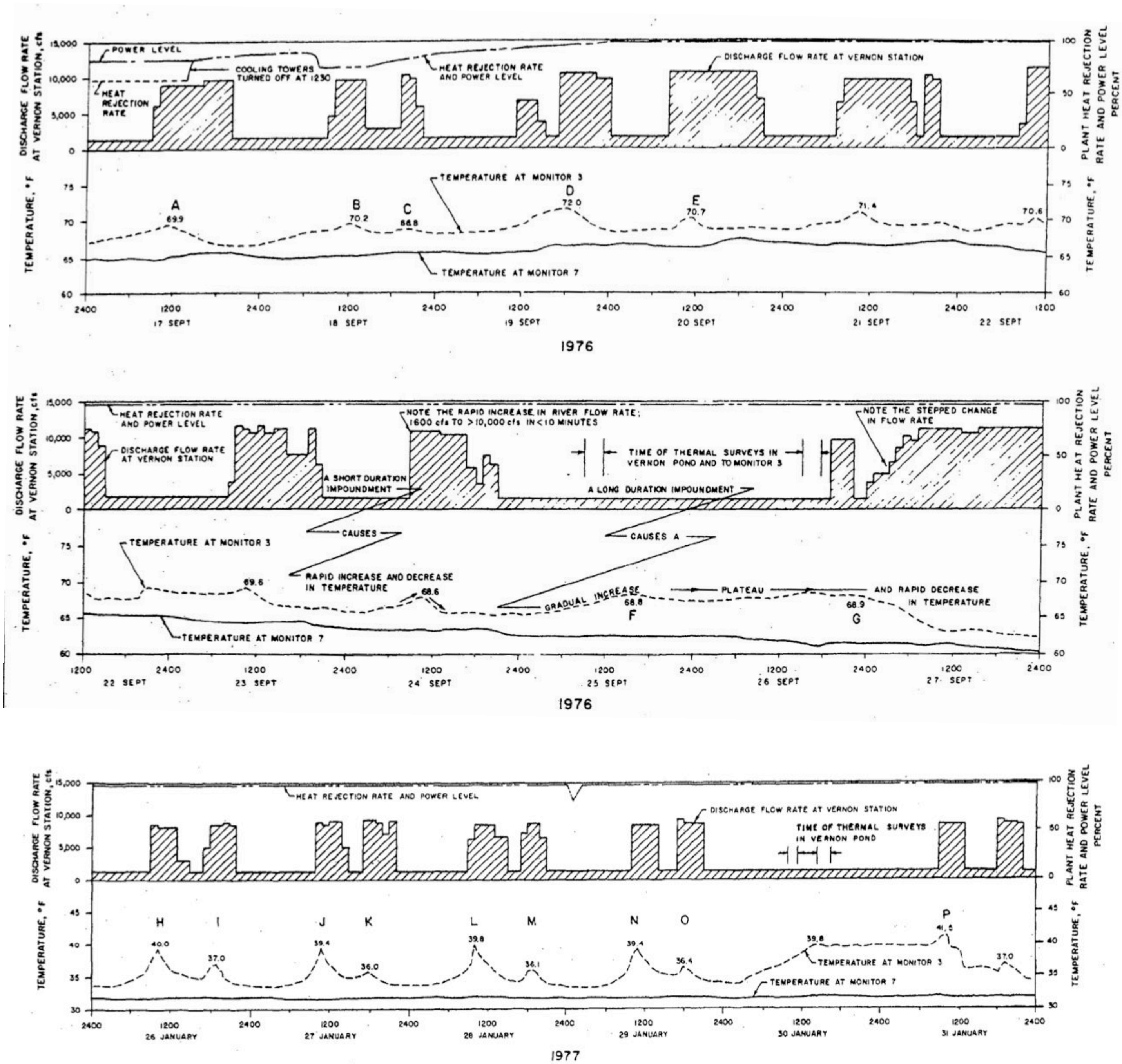

Figure 2-3. Time-series plots of Vernon Dam flow rate, Vermont Yankee heat production rate (%), and water temperature above and below the Dam (at Stations 7 and 3) during the periods of September 17-27, 1976 and January 26-31, 1977 (Aquatec 1978, Figures 5-7 and 5-8).

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warmer water from Vernon Pool was transported downstream (Aquatec 1978). Events identified as A through E in Figure 2-3 are examples of conditions with increasing river flows followed by elevated downstream temperatures.

The expected thermal response of the river downstream of Vernon Dam was also estimated using a simple heat budget equation (Aquatec 1978). The results of the thermal plume field investigation and the heat budget equation analysis were combined to estimate downstream temperature under low river flow conditions. Figure 2-4 provides results of the 1976-1977 downstream temperature investigation in the form of a temperature ratio. Downstream distance on the river is shown on the x-axis, starting at Vernon Dam (at mile 0) and including the Turners Fall Dam (at mile 20) and Holyoke Dam (at mile 54). A temperature ratio equal to the downstream temperature divided by initial upstream temperature is shown on the y-axis. The temperature ratio is the fraction of the initial $\triangle$T (at Station 3) that still remains at a point downstream. For example, for a survey conducted from May 30 to June 2, 1977 (and indicated by triangles connected by a dashed line), the temperature ratios are approximately 0.55 at Turners Falls Dam and 0.40 at Holyoke Dam. The temperature ratio provided in Figure 2-4 appears to have been obtained using a combination of the field survey data (temperature and dye measurements) and the simple heat balance model. The report does not provide a full description of the method used to obtain the plot or the backup data and documentation.

Summary

Vermont Yankee thermal discharges associated with 100% open-cycle operations (i.e., full thermal discharge) were evaluated during non-summertime conditions (from September 1976 to June 1977) and resulted in a set of findings in the 1978 316(a) demonstration (Aquatec 1978) that included:

- Maximum increase in temperature between upstream Station 7 and downstream Station 3 observed during a single day ranged from 0 to 10°F, with 40% of days experiencing a greater than 5°F increase and 20% of days experiencing a greater than 7°F increase (Figure 2-2);
- Dynamic river flow releases at the Vernon Dam were observed to result in large changes in peak downstream temperatures and associated $\triangle$T (Figure 2-3); and
- A downstream dye tracer and temperature survey was conducted during May 30-June 2 1977 under low river flow conditions. This survey found that approximately 55% of the $\triangle$T introduced by the Vermont Yankee discharge remained in the river at the Turners Falls Dam and approximately 40% of the $\triangle$T remained in the river at Holyoke Dam. This dye tracer survey also found that, under minimum river flow conditions, water takes four days to move from the Vernon Dam to the Holyoke Dam, 55 miles downstream (Figure 2-4).

The 1978 thermal characterization study was more comprehensive than the more recent 2004 thermal characterization study in several ways, including:

- Study domain – the 1978 study includes the 55-mile downstream river reach from the Vernon Dam to the Holyoke Dam, while the 2004 study is limited to Vernon Pool;
- Data presentation – Vernon Pool temperature data were presented in tabular format including concurrent Vermont Yankee and ambient river conditions and the areal extent of the thermal plume to the 1°F isotherm for each of 147 surveys.

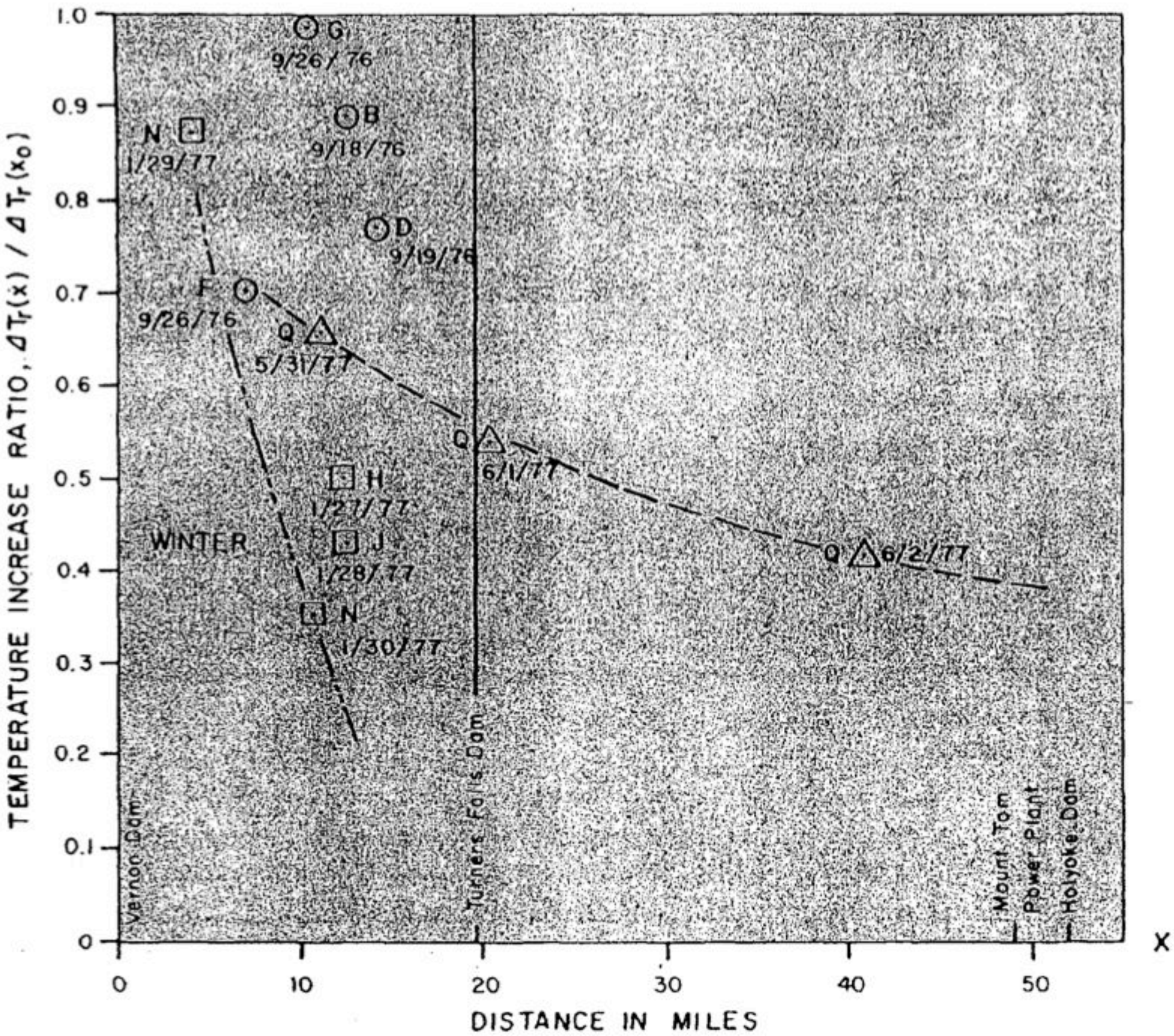

Figure 2-4. Temperature Increase Ratios Verses Distance Downstream during Minimum River Flows Periods (Aquatec 1978, Figure 5.16).

- Time-varying characterization of the thermal plume – the 1978 study evaluates the thermal plume under time-varying conditions and provides insights into the dynamic effects of dam operations on downstream temperatures. The 2004 study is limited to evaluating steady-state or constant conditions and would not have identified the peak temperature events shown in Figure 2-3.

With respect to requirements listed in EPA 316(a) guidance (EPA, 1977), the 1978 study lacks analysis of long-term temperature conditions, does not adequately identify average and worst-case conditions, and does not provide sufficient presentation of results in the form of maps and tables. Despite these weaknesses, the 1978 study of non-summertime conditions provides a more complete thermal characterization than the 2004 study. The 1978 316(a) Demonstration illustrates the large effects of dynamic operations at Vermont Yankee and the Vernon Dam on the river's temperature regime and asserts that the thermal plume extends to the Holyoke Dam.

2.2 1990 Demonstration

In 1990, Vermont Yankee submitted a 316 demonstration report in support of a request to discharge heated effluent during summertime conditions (Aquatec 1990). The 1990 demonstration is important because it is the first time that Vermont Yankee requested a thermal discharge during summertime conditions. The requested permit conditions specified a range of $\triangle$T increases of 2 to 5°F, with incremental increases in $\triangle$T between the ambient temperature range of 55 through 63°F (see Table 2-1).

Table 2-1. Requested Temperature Increases (Aquatec 1990)

Ambient Water Temperature (°F)	Temperature Increase Standard (°F)
Above 63	2
>59, ≤63	3
>55, ≤59	4
Below 55	5

The 1990 demonstration was based on a 10-year biological study conducted from 1981 to 1990 and was focused on fisheries investigations. The thermal plume characterization component of the 1990 demonstration consisted of three primary elements:

1. Vernon Pool characterization - Ten thermal plume monitoring surveys conducted under different conditions between May and October of 1989;
2. $\triangle$T data analysis - Graphical presentation and statistical analysis of large sets of time-series temperature data from Stations #7 and 3 (i.e., upstream, downstream, and $\triangle$T); and
3. Downstream river characterization - Simple river temperature modeling of the downstream reach from Vernon Dam to the Holyoke Dam under a variety of conditions.

Each of these thermal analyses is briefly summarized below.

Vernon Pool Characterization

Ten synoptic surveys featuring measurement of water temperature at numerous locations throughout Vernon Pool were conducted between May and October of 1989 (Binkerd et al. 1990). The surveys were designed to capture "synoptic" conditions—snapshots of temperature at one point in time—and were typically conducted over two- or three-hour periods. The surveys found that the surface area of the thermal plume with temperature increases of more than 5°F above ambient temperature covered 12 to 25 acres in Vernon Pool. Survey results are summarized in an analytical bulletin that features plan view and cross-sectional view figures depicting the thermal plume in Vernon Pool during each synoptic survey (Binkerd et al. 1990).

△T Data Analysis

The 1990 demonstration report refers the reader to two analytical bulletins (Johnston 1984 and Luxenberg 1990) for an analysis of upstream and downstream temperature data. Together these two bulletins provide a set of annual plots of upstream (Station 7) and downstream (Station 3) water temperature and △T from 1968 through 1989.

Downstream River Temperature Characterization

The thermal discharge analyses performed in support of the 1990 demonstration are briefly described in the report (Aquatec 1990). Specifically, Section 4 entitled "Engineering and Hydrologic Information" provides only three pages of text, five pages of summary figures, and one table. The downstream river characterization should have provided a large set of maps and tables illustrating the nature and extent (e.g., the △T and area of the plume) under a variety of conditions. These illustrations should have been accompanied by a narrative describing time-varying temperature conditions in the river.

Regarding downstream thermal plumes, the 1990 demonstration report refers the reader to a 1985 analytical bulletin (Luxenberg 1985). The Luxenberg bulletin provides the following description:

> *Temperature increases in the Connecticut River due to the discharge of heat from Vermont Yankee were simulated for various plant operation modes. Predictions were made by numerical simulation of the Connecticut River's mass and thermal balance from 3.5 miles upstream of Vermont Yankee to 58 miles downstream near Holyoke Dam. In general, initial temperature increase can be relatively high for low river discharge conditions, but significant cooling between Vernon and Holyoke results in low downstream temperature increases. High river discharge reduces the initial temperature increase resulting in low temperature increases throughout the river. The numerical simulations indicate that mixed river temperature increases of 0.3F to 2.5F near Holyoke Dam would be expected for initial mixed temperature increases of up to 13F during the ice-free portion of the period from October 15 to May 15. The remainder of the year simulated temperature increases were limited to 1F to 5F depending on upstream ambient river temperature; simulated temperature increases near Holyoke Dam were 0.1 to 1.5F for this period.*

The 1985 bulletin includes a partial description of a simple heat budget model used to estimate downstream water temperature and partial model results. The Luxenberg model represented the river in a simplified, steady-state (i.e., not dynamic) mode and, under these conditions, low river flows resulted in the largest predicted downstream △Ts. This is a logical prediction because at low river flow the heated Vermont Yankee effluent represents a relatively larger proportion of the total river flow. The simplified, steady-state model applied by Luxenburg was not capable of capturing potentially important dynamic conditions, such as those observed during the 1978 field surveys and presented in Figure 2-3.

Summary

There is a paucity of thermal plume data and study area temperature characterization in the 1990 demonstration report and associated reference documents, aside from the continuous record provided at two locations (Stations 3 and 7). This is remarkable given that the 1990 demonstration represented the first time that the Vermont Yankee facility was requesting to discharge heated effluent to the Connecticut River during the ecologically critical summertime period (May 15 to October 15).

The 1990 thermal characterization study of summertime conditions fails to include several important components required to support a 316(a) demonstration including:

1. Evaluation of long-term temperature measurements and identification of average and worst-case thermal conditions;
2. Modeling of time-varying temperature conditions in the Connecticut River;
3. Maps or tables illustrating the nature and extent of the thermal plume; and,
4. Adequate characterization of the downstream thermal plume (the simple heat budget model used to predict downstream temperatures is not fully described and model results are not presented).

The 1990 316(a) demonstration's summertime thermal study is less comprehensive than the 1978 non-summertime thermal study because it does not include an analysis of time-varying downstream conditions and presents few temperature data or any other analysis results. Of the four failures listed immediately above for the 1990 316(a) demonstration, all four continue to be shared by the 2004 demonstration. Moreover, the 1990 study area includes the downstream thermal plume (extending to the Holyoke Dam) as part of the study area and states that the thermal plume extends to the Holyoke Dam. In contrast, the 2004 study area extends only the short distance to its downstream boundary at the Vernon Dam.

3.0 ASA 2004 Hydrothermal Modeling Analysis

3.1 Overview

In 2004, Vermont Yankee submitted a 316(a) demonstration report requesting an increase in its summertime thermal discharge permit limits (for the time period of May 15 to October 15 of each year) (NAI 2004). The 2004 demonstration requested new limits, as shown in the Table 3-1, for an increase of 1°F when ambient river temperatures are in the range of 55°F to 78°F.

Table 3-1. Existing and Proposed Temperature Increases (NAI 2004).

Upstream Station 7 Ambient Temperature	Calculated Temperature Increase Above Ambient at Downstream Station 3	
	Present Limits	Proposed New Limits
>78 °F	2 °F	2 °F
>63 °F, ≤78 °F	2 °F	3 °F
>59 °F, ≤63 °F	3 °F	4 °F
≥55 °F, ≤59 °F	4 °F	5 °F
<55 °F	5 °F	5 °F

A thermal discharge modeling study was conducted in support of the 316(a) request for increased summertime thermal discharges. Applied Science Associates (ASA) developed and applied a hydrothermal model to support the 2004 demonstration. ASA selected a dynamic, three-dimensional model called WQMAP to evaluate water temperature in the Vernon Pool. WQMAP is a proprietary software package developed by ASA. WQMAP is described as a "state-of-the-art" computer model and was applied "to predict pool elevations, flow, velocities and temperature distributions in the Vernon Pool" (ASA, 2004). The WQMAP model is three-dimensional, meaning that it is designed to predict temperature changes in the x (downstream), y (across the pool), and z (with depth) directions. WQMAP is also a dynamic model, meaning that it is designed to predict changes in temperature over time.

In 2009, the U.S. Environmental Protection Agency published a guidance document for development, evaluation, and application of environmental models within a regulatory decision-making framework (EPA 2009). This guidance document provides recommendations for effective use of models and follows a set of basic steps outlined in Table 3-2. The 2009 EPA modeling guidance provides documentation of long-estabilshed best practices for environmental modeling. EPA (2009) states that the modeling evaluation process consists of a set of steps designed to addressing modeling issues and support project goals (Table 3-2). We will compare the ASA modeling report to the EPA modeling guidance to evaluate whether ASA followed modeling best practices in conducting the modeling investigation.

Table 3-2. Basic Steps in the Process of Modeling for Environmental Decision Making (EPA 2009)

Box 2: Basic Steps in the Process of Modeling for Environmental Decision Making
(modified from Box 3-1, NRC *Report on Models in Regulatory Environmental Decision Making*)

Step		**Modeling Issues**
Problem identification and specification: *to determine the right decision-relevant questions and establish modeling objectives*	Definition of model purpose	▪ Goal ▪ Decisions to be supported ▪ Predictions to be made
	Specification of modeling context	▪ Scale (spatial and temporal) ▪ Application domain ▪ User community ▪ Required inputs ▪ Desired output ▪ Evaluation criteria
Model development: *to develop the conceptual model that reflects the underlying science of the processes being modeled, and develop the mathematical representation of that science and encode these mathematical expressions in a computer program*	Conceptual model formulation	▪ Assumptions (dynamic, static, stochastic, deterministic) ▪ State variables represented ▪ Level of process detail necessary ▪ Scientific foundations
	Computational model development	▪ Algorithms ▪ Mathematical/computational methods ▪ Inputs ▪ Hardware platforms and software infrastructure ▪ User interface ▪ Calibration/parameter determination ▪ Documentation
Model evaluation: *to test that the model expressions have been encoded correctly into the computer program and test the model outputs by comparing them with empirical data*	Model testing and revision	▪ Theoretical corroboration ▪ Model components verification ▪ Corroboration (independent data) ▪ Sensitivity analysis ▪ Uncertainty analysis ▪ Robustness determination ▪ Comparison to evaluation criteria set during formulation
Model application: *running the model and analyzing its outputs to inform a decision*	Model use	▪ Analysis of scenarios ▪ Predictions evaluation ▪ Regulations assessment ▪ Policy analysis and evaluation ▪ Model post-auditing

3.2 Description of Key Components of the ASA 2004 Hydrothermal Modeling Process

A set of key components of the ASA (2004) modeling evaluation is described below to provide context for review of the adequacy of the modeling evaluation to support the 316 demonstration (Section 4). The key components are drawn from the EPA modeling guidance (EPA 2009) and include:

a. Identification of project goals and objectives
b. Determination of modeling application domain (i.e., study area)
c. Determination of modeling temporal scale (i.e., time period)
d. Specification of required inputs
e. Calibration and confirmation of the model
f. Application of the model to characterize thermal conditions
g. Presentation of model results

A brief summary of how each of these key issues was addressed in the ASA (2004) hydrothermal modeling evaluation is provided below followed by a review and discussion.

a. Identification of project goals and objectives

The 2004 model report states the modeling objectives as follows (ASA 2004, p. 1):

> *The purpose of this study was to determine what effects, if any, the increased Vermont Yankee thermal discharge would have on the thermal structure of the River, particularly during the late summer period of low River flow and warm River temperatures. The study included a field program (i.e., collection) component to characterize the physical thermal regime in the Vernon Pool. A hydrothermal modeling study designed to characterize the circulation and temperature distribution in the River followed. The modeling study was designed to evaluate the potential effects of Vermont Yankee's proposed increase on the temperature distribution in the River under expected and worst-case conditions.*

The 2004 hydrothermal model objective was focused on determining the effects of the proposed increase in the summertime Vermont Yankee thermal discharge rather than on the effects of the entire thermal discharge. This focus resulted in an analysis of river water temperature change associated with the difference between the existing and proposed thermal discharges, rather than on the net effect of the thermal discharge. As a result, the model application provides an assessment of only the change in temperature associated with the proposed 1°F increase in the thermal discharge and does not fully assess the complete effect of the thermal discharge relative to ambient conditions.

b. Determination of modeling application domain (i.e., study area)

The study area for the 2004 model application included all of Vernon Pool, beginning at the Bellows Falls Dam, 25.5 miles upstream, and ending at the Vernon Dam, 0.5 miles below the Vermont Yankee discharge. The Connecticut River below Vernon Dam is not included in the study area. This means that the downstream regulatory compliance point, Monitoring Station #3 (situated 0.65 miles below the

Vernon Dam), and the downstream Connecticut River receiving-water body (55 miles in length) were not included in the modeling evaluation.

c. Determination of modeling temporal scale (i.e., time period)

The 316 demonstration (NAI 2004) requests a change in the permit for the period of May 15 to October 15 of every year. In support of this request, field temperature data were collected during the period of May through December 2002, a period of approximately 240 days. Receiving-water temperature was measured by a network of sensors deployed throughout the Vernon Pool area adjacent to the Vermont Yankee facility and upstream of the Vernon Dam. Specifically, temperature was measured continuously at 11 sampling locations and at three depths at each location (33 sensors total). River flow and temperature, Vermont Yankee discharge flow and temperature, and meteorological conditions were monitored throughout the May through December 2002 study period.

The modeling report presents data from only two time periods, June 25-July 9, 2002 (15 days) and August 1-24 (24 days), totaling 39 days within this 240-day study period. As a result, only 16% of the collected data are presented in the report. The model was applied to simulate a set of ten steady-state (i.e., constant) conditions obtained from within the 39-day period. As a result, the modeling application is only representative of a set of ten constant “snapshots” in time, rather than a time-series record of the May to December time period.

d. Specification of required model input

A wide range of input data were required to support development of the 2004 hydrothermal modeling including hydrologic, thermal, and physical characteristics of the study area. Key required model input data included time-varying records of Vermont Yankee discharge flow rates and temperatures, ambient river flow rates and temperatures, and meteorological conditions. These time-varying records were readily available and appear to have been obtained in 2002 to support model calibration. Time-varying records were not, however, applied as part of the analysis to predict temperatures characteristics (i.e., in the model scenarios considered in the ASA (2004) analysis).

e. Model calibration and confirmation

ASA (2004) indicates the model was calibrated to dynamic river conditions over a 24-day period, August 1-24, 2002, “when air temperature was in general warmer than any other month and river temperatures were warmest.” (ASA 2004, p. 32). The model was confirmed during a 15-day period from June 25 to July 9. Time-series plots and statistical summaries of predicted vs. measured temperature data during the two calibration periods are provided in the report. An example plot is included here as Figure 3-1. The report does not indicate the corresponding Vermont Yankee discharge flow rates and temperatures or river flow rates that occurred during the calibration and confirmation time periods (e.g., in a format similar to Figure 2-3 from the 1978 study).

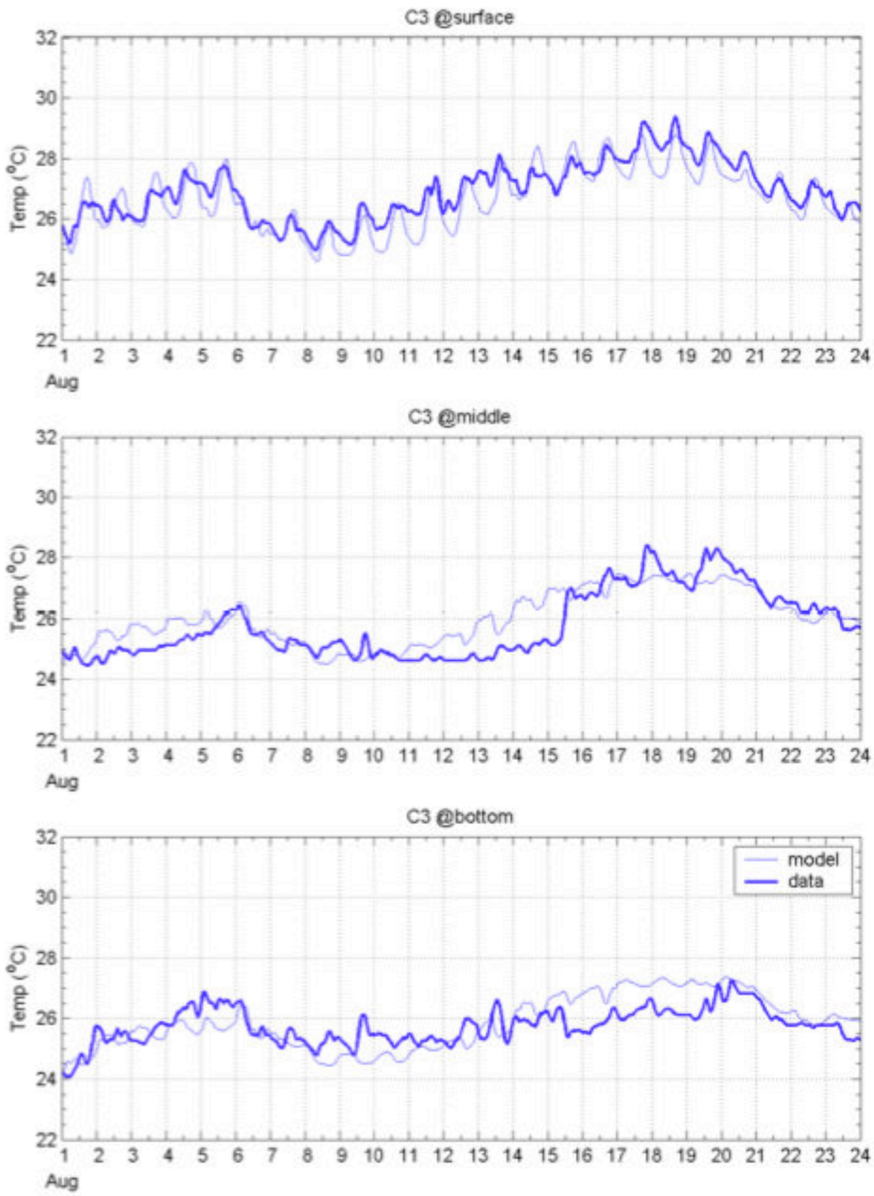

Figure 4-7. Comparison of observed (thick) and simulated temperatures (thin) at the surface, middle and bottom layers for string C3.

Figure 3-1. Example of model calibration figures from 2004 report (ASA 2004).

f. Model application

The model application was conducted using a set of steady-state scenarios (ASA 2004). The model was not run in dynamic mode to obtain river water temperature predictions over time. Rather, ten scenarios were specified that included constant river flow rates, constant Vermont Yankee flow rates, and constant Vermont Yankee discharge temperatures. Six of the ten model application scenarios are described in Table 3-3. Meteorological conditions represented one typical day (e.g., in August 2002). The ten scenarios represent “snap shots” of river conditions at one point in time and do not represent time-varying conditions. The use of constant (steady-state) conditions for the model scenarios resulted in a set of model predictions that are not representative of actual conditions in the Connecticut River.

g. Presentation of model results

The 2004 hydrothermal model output requirements were not explicitly stated in the ASA (2004) report and the model report provides limited output. A narrative description of model results is included in the report and is framed as predicted temperature change associated with the proposed discharge temperature increase (as described in a. above). A set of three plan-view maps is provided for only one of the ten model scenarios. The three maps represent predicted temperatures at surface, mid-depth, and near-bottom in Vernon Pool. The surface temperature map is reproduced here as Figure 3-2. Maps of the other nine model scenarios results were not included in ASA’s report. Lastly, predictions are summarized through temperature-exceedance plots covering the ten simulation scenarios. The exceedance plots show:

- the percentage of the bottom area over which the bottom water temperature exceeds a given temperature;
- the percentage of the pool volume in which the water exceeds a given temperature; and,
- the percentage of the time that surface water temperature at the fishway exceeds a given temperature.

The ASA report did not provide results consistent with those specified in the EPA 316(a) guidance (EPA 1977). Specifically, the ASA report did not provide maps of the thermal discharge plume out to the 1°C isotherm under a variety of conditions. The ASA report also did not provide the areal extent of the thermal plume and the associated conditions (i.e., Vermont Yankee operations, ambient river conditions, and Vernon Dam operations) under a variety of conditions. The ASA report failed to provide a sufficient temperature characterization of the Connecticut River study area.

Table 3-3. Six of ten model scenarios presented in the 2004 modeling report (ASA 2004).

Table 4-2. Summary of parameters for the June –July scenarios. Vermont Yankee Temp denotes the plant discharge temperature.

Scenario	River Flow	Vermont Yankee Flow	Intake Temp	Vermont Yankee Temp	Vermont Yankee ΔT	Heat	Description
	m^3/s (ft^3/s)	m^3/s (ft^3/s)	°C (°F)	°C (°F)	°C (°F)	MW	
1%-2°F rise	45.2 (1,660)	3.6 (128)	23.9 (75.1)	37.8 (100)	13.8 (24.9)	208	1% occurrence of low flow and high temperature conditions with existing permit ΔT of 2°F
1%-3°F rise	45.2 (1,660)	5.4 (192)	23.9 (75.1)	37.8 (100)	13.8 (24.9)	323	1% occurrence of low flow and high temperature conditions with proposed new permit ΔT of 3°F
10%-2°F rise	47.6 (1,685)	3.4 (120)	22.6 (72.6)	37.8 (100)	15.2 (27.4)	217	10% occurrence of low flow and high temperature conditions with existing permit ΔT of 2°F
10%-3°F rise	47.6 (1,685)	5.2 (184)	22.6 (72.6)	37.8 (100)	15.2 (27.4)	329	10% occurrence of low flow and high temperature conditions with proposed new permit ΔT of 3°F
50%-2°F rise	156.8 (5,558)	9.2 (325)	18.8 (65.0)	37.8 (100)	18.9 (34.1)	726	50% occurrence of low flow and high temperature conditions with existing permit ΔT of 2°F
50%-3°F rise	156.8 (5,558)	13.8 (488)	18.8 (65.0)	37.8 (100)	18.9 (34.1)	1,090	50% occurrence of low flow and high temperature conditions with proposed new permit ΔT of 3°F

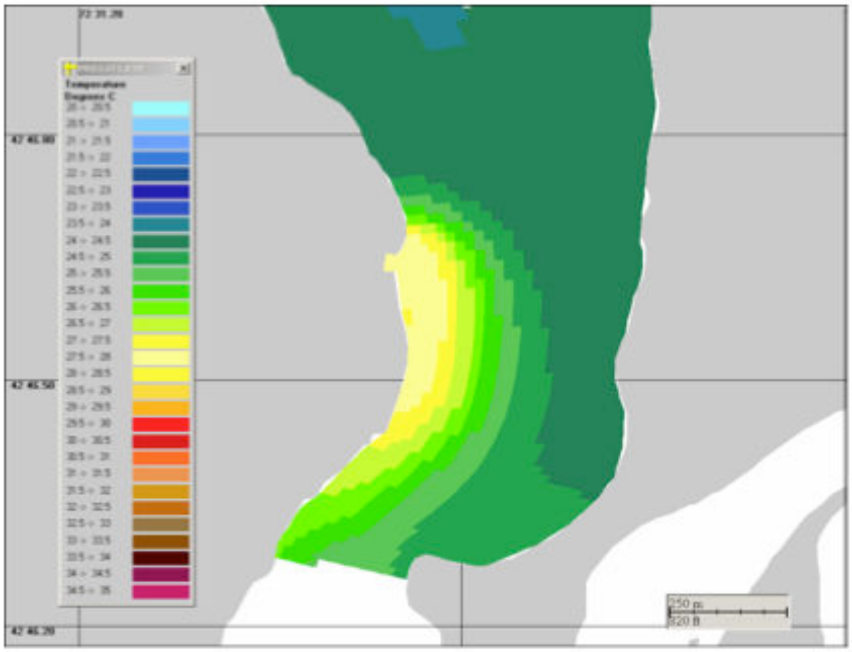

Figure 5-1. Predicted surface temperature distribution for August scenario 50%-3°F.

Figure 3-2. Predicted surface temperature from a 2004 model scenario (ASA 2004).

4.0 Review of the 2004 ASA Hydrothermal Model

HydroAnalysis has reviewed the 2004 hydrothermal modeling report and finds that it provides an inadequate thermal characterization to support the 316(a) demonstration process. The 2004 hydrothermal modeling evaluation is flawed in several fundamental and important ways. The 2004 model:

1. Was based on a false presumption of historic thermal characterization;
2. Excluded the majority of the study area;
3. Applied inappropriate model scenarios; and
4. Failed to provide sufficient data to support a balanced indigenous fish population analysis.

Each of these flaws is described below.

4.1 False Presumption of Historic Thermal Characterization

The 2004 hydrothermal model is seemingly based on the presumption that previous 316 demonstrations had adequately characterized the thermal conditions in the Connecticut River. The 2004 modeling study is not designed to evaluate the thermal conditions of the Connecticut River associated with the Vermont Yankee thermal discharge. Instead, the 2004 evaluation is designed to evaluate the change in thermal conditions associated with a requested 1°F discharge temperature increase. The 2004 study design is apparently based on the assumption that only the proposed increase in thermal discharge needed to be evaluated. This assumption is incorrect for several reasons including that previous 316(a) demonstrations did not provide adequate thermal characterizations, as described in Section 2 above. This critical design flaw in the 2004 modeling study yields it incapable of supporting 316(a) demonstration requirements.

The 1990 316(a) demonstration is the only previous summertime demonstration. The 1990 demonstration featured only a set of "snapshot" field temperature surveys of Vernon Pool, an analysis of temperature data at one upstream and one downstream location, and a narrative description of a simple downstream modeling analysis without a presentation of modeling results (Aquatec 1990, Luxenberg 1985). Thus, a comprehensive analysis of summertime thermal plume characteristics had not been conducted prior to 2004.

The 2004 modeling report states in the closing statement of the executive summary (ASA 2004, p. ii):

> *Based on the hydrothermal modeling results, a 1°F (0.6°C) increase in the permit limit from 2°F (1.1°C) to 3°F (1.7°C) resulted in de minimus changes in the thermal structure of the Vernon Pool.*

The analysis describes only incremental differences and fails to address the net impact of the requested permit limits on water temperatures. A full analysis of the thermal discharge is required for a 316(a) demonstration (EPA 1977). Specifically, the applicants failed to provide the following critical components of a 316(a) demonstration, as described in the 1977 EPA guidance document:

a. ***Inclusion of the entire thermal plume in the study area*** - this issue is addressed in Section 4.2 below.

b. ***Inclusion of additive or synergistic effects associated with Vernon Dam Operations*** – The Vermont Yankee thermal discharge and the Vernon Dam operational flows are major dynamic forces acting on the Connecticut River. These two activities have the potential to adversely impact the fishery. For example, the 1978 Demonstration (Aquatec 1978) provided a limited analysis of the combined thermal discharge and dam effects and showed that these dynamic effects were correlated with "worst-case" conditions during non-summer conditions. The dynamic, combined effects of the thermal discharge and the dam operations should be evaluated both upstream and downstream of the Vernon Dam.

c. ***Sufficient thermal plume maps*** – Maps of the entire thermal plume should be provided under a variety of conditions. These maps should include "worst-case" average, and ideal conditions identified by reviewing a dynamic record of model predictions. Thermal plumes should be mapped out to the 1°F isotherm. The 2004 ASA report provides a total of three thermal plume prediction figures representing surface, mid-depth, and near-bottom water temperature in Vernon Pool under one model scenario.

d. ***Sufficient overall presentation of data*** - Tables and figures illustrating ambient river flows, velocities, and water temperatures concurrently with Vermont Yankee discharge volume and temperatures, Vernon Dam operational data and meteorological conditions over time should have been provided. These data would have enabled review of the river's temperature response to major activities such as thermal discharge, dam flow changes, and weather factors.

The applicants have failed to provide these basic elements of a 316(a) demonstration by conducting only an incremental analysis in 2004 and incomplete analyses in 1978 and 1990.

4.2 Exclusion of the Majority of the Study Area

The ASA (2004) model study area does not include the vast majority of the river reach affected by the thermal discharge. During the 316(a) demonstrations conducted in 1978 and 1990, the thermal plume was measured and/or predicted to extend to at least the Holyoke Dam, 55 miles downstream of the Vermont Yankee plant (Aquatec 1978, Aquatec 1990, Luxenberg 1985). The 2004 modeling evaluation includes the Vernon Pool area (extending only 0.5 miles downstream), but excludes the 55 miles downstream of the Vernon Dam from the analysis. The downstream area of the 1978 and 1990 studies was 55.5 miles in length, but the downstream area of the 2004 study was only 0.5 miles in length.

EPA 316(a) guidance states that the thermal plume associated with thermal discharges should be delineated and mapped to within 1°C of ambient river temperatures (EPA 1977). Each of the two previous 316(a) demonstrations (in 1978 and 1990), stated that thermal plumes of 2.5°F (1.4°C) were expected at the Holyoke Dam, 55 miles downstream of the Vermont Yankee discharge (Aquatec 1978, Luxenberg 1985). In the 1978 Demonstration (Aquatec 1978), thermal plumes were tracked during events of elevated water temperature downstream. Thermal plumes with temperatures elevated several degrees above ambient were frequently observed many miles downstream of the Vermont Yankee discharge. These plumes were observed to vary significantly in magnitude and in downstream extent over time. These are important observations because they illustrate that large-magnitude time-varying thermal plumes affect the river many miles below the Vernon Dam.

A long and variable thermal plume was measured and predicted as part of previous 316(a) demonstrations (Aquatec 1978). The downstream plume could have an adverse impact on fisheries and other ecological receptors and should have been included in the 2004 hydrothermal model to support a 316(a) demonstration. This omission from the 2004 hydrothermal model is important because it results in an analysis that is missing the majority of the thermal plume associated with the Vermont Yankee discharge.

4.3 Inappropriate Model Application Scenarios

The model was not applied to predict time-varying water temperature conditions in the river. Instead, ASA chose to predict river water temperatures under constant conditions that represent only a small set of steady-state "snapshots" of river conditions. The ten steady-state scenarios that were selected and presented in the 2004 modeling report (e.g., Table 3-3 of ASA, 2004) provide only a narrow window into the hydrothermal behavior of the Connecticut River. ASA (2004) states that these conditions are representative of "worst-case" conditions. However, the ten cases were selected arbitrarily rather than by systematic analysis of the long-term data record or model simulation over time. It is speculative to assume that the ten scenarios capture actual worst-case conditions. In making this assumption, ASA has pre-judged what the actual worst-case conditions are and has denied the dynamic model the opportunity to provide valuable insights into the actual hydrothermal conditions of the river.

A central goal of developing models in support of regulatory decision making is to create tools that can be used to answer a set of "what if" questions. Model applications typically emphasize long-term predictions that extrapolate from the past in order to answer such "what if" questions (NRC 2007). The 2004 ASA hydrothermal model application should have been designed to support regulatory decision making by predicting time-varying water temperatures throughout the study domain and over an extended period of time. Long-term time series of temperature, flow, and weather measurements are readily available to be input into the model enabling long-term simulations. The model should have been run with no thermal discharge, with the summertime thermal discharge limits established in 1990, and with the proposed thermal discharge limits proposed in 2004 over time durations of 10 years or more. A comparative time-series analysis of these three thermal discharge scenarios would have provided the characterization of water temperature conditions in the Connecticut River required under the EPA's 316(a) guidance (EPA 1977).

This application of a time-varying model would have provided meaningful insights into the potential impacts of the thermal discharge on the river. Such model results would have included predictions of the nature and extent of the thermal discharge plume and its potential effect on fisheries. Long-term prediction would have supported identification and characterization of the actual average and worst-case conditions in the Connecticut River. The WQMAP model used by ASA (2004) was in fact designed to be applied dynamically over extended time periods and has an animation feature that enables dynamic model predictions to be viewed and analyzed efficiently.

A dynamic model is essential to characterizing the thermal discharge. As an example, prior studies have shown that dynamic flow releases from Vernon Dam cause the elevated downstream temperatures (i.e., a worst-case scenario) (Aquatec 1978). Unfortunately, the steady-state model scenarios of 2004 are equivalent to one "snapshot" in time (i.e., a single point in the time series shown in Figure 2-3). In addition, since the temperature peaks observed in the 1978 report (as indicated with letters in Figure 2-3) were the result of preceding dynamic flow events, the steady-state 2004 model is unable to predict these peaks. In summary, the 2004 model, as applied in steady-state mode, is not capable of simulating the time-series results presented in Figure 2-3 from the 1978 report. This is a major concern because it demonstrates that the 2004 modeling application was not capable of predicting worst-case conditions.

In summary, applying the 2004 model in steady-state rather than time-varying mode is inconsistent with EPA 316(a) guidance (EPA 1977) and with the intended use of the WQMAP model. The steady-state model application is inappropriate and insufficient to support the 316(a) demonstration process.

4.4 Thermal Modeling and Balanced Indigenous Fish Population Analyses

The ASA thermal modeling analysis (ASA 2004) was insufficient to support fisheries studies submitted as part of the 2004 demonstration report (NAI 2004). In general, fundamental flaws identified in the thermal modeling review, and summarized above, were also found in the fisheries analysis.

The fisheries studies associated with the 2004 demonstration were not designed to characterize the potential impact of the Vermont Yankee thermal plume on fisheries. Rather, the 2004 demonstration was designed to characterize the incremental impact of the requested 1°F temperature increase. As a result, the 2004 demonstration does not provide sufficient fisheries assessment information to support a 316(a) determination.

The 2004 fisheries studies were also limited to a small portion of the overall study area for potential fisheries impact. The fisheries evaluations in the 2004 316(a) demonstration were limited to the lower 1.4 miles of the Vernon Pool and the area in the vicinity of the Vernon Dam and tailwater (downstream to Station 3). Habitat and biota affected by the Vermont Yankee thermal plume in the Bellows Falls pool was not fully addressed nor was the downstream 55-mile reach of the Connecticut River addressed.

The portions of the Vernon Pool affected by the Vermont Yankee thermal plume are described in the 2004 demonstration report as being relatively small in terms of the total volume and the bottom habitat of Vernon Pool (NAI 2004). However, the Vermont Yankee plume represents a substantial amount of potential aquatic habitat; a volume of about 500 acre-feet and bottom area of about 20 acres represent a large volume and area of aquatic habitat. Additionally, the demonstration provides a discussion of temperature changes to the tailwater area downstream of Vernon Dam, but it does not describe the volume or area affected by the Vermont Yankee thermal plume in this portion of the river.

The ASA 2004 model discusses predicted temperature within the fishway (ASA 2004). The current period of operation for the upstream fishway is mid-May to early July and the periods for operation for the downstream fishway are April-July and September-October (NAI 2004). The fishway input data set utilizes the period of mid-May-early July (for the 5-year period 1998-2002). However, periods of elevated temperature and low flow can also occur in September. The ASA model does not evaluate the dynamic or long-term effects of the hydroelectric facility on river water temperatures. ASA also does not evaluate instantaneous differences in water temperature released from the fishway or from power generation, or gated or spill releases. Total flow through the upstream and downstream fishway facilities can be as high as 455 cfs; these fishway flows represent a significant portion of the minimum flow at Vernon Dam. The 2004 fisheries studies were limited to selected time periods and did not include portions of the year that are critically important for fish.

In summary, the ASA (2004) thermal model formed part of the basis for the NAI (2004) fisheries analyses. However, the ASA (2004) study, as discussed above, failed to consider the entire reach of the river affected by the thermal discharge, the synergistic effects of the Vernon Dam operations, and the appropriate worst-case conditions. As a result, there is insufficient information for the fisheries anlayses to determine if the river can support a balanced indigenous fish population. In addition, there is a need for thermal conditions of the Vernon Dam Fishway to be more thoroughly characterized.

4.5 Summary

EPA 316(a) demonstration guidance states that applicants will be judged successful if they can prove that fish communities will not suffer appreciable harm from cold shock or excess heat, reduced reproduction success or growth, exclusion from unacceptably large areas, or blockage of migration (EPA 1977). Thermal characterization studies conducted in support of Vermont Yankee's 316(a) demonstrations have not provided sufficient information to support a finding that (in the language of Section 316(a) of the Clean Water Act) the "protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on the body of water" is assured.

The thermal studies in support of the 1978, 1990, and 2004 316(a) demonstrations failed to characterize the nature and extent of the thermal plumes associated with the Vermont Yankee discharge. Long-term predictions of temperature conditions in the study area were not presented in any of the demonstration reports, as specified by EPA 316(a) guidance and EPA modeling guidance documents (EPA 1977, EPA 2009). Dynamic temperature conditions throughout the study area have not been evaluated. Only a partial dynamic analysis was conducted in support of the 1978 non-summertime demonstration. Because of these inadequacies in previous demonstrations, it is not possible to map the thermal plume or assess whether or not the fish exclusion area is too large or whether or not fish migration is blocked. Also, due to the lack of time-varying analyses, it is not possible to assess the potential for fish to suffer appreciable harm from cold shock or excess heat.

Methods and modeling tools are readily available for conducting appropriate thermal characterization studies to support determination of whether or not the thermal discharge is harmful to the Connecticut River fishery. Unfortunately, the applicant has elected to employ inappropriate methods and misuse a potentially suitable model. As a result, the 2004 thermal modeling evaluation by ASA (2004) provides insufficient information to support a 316(a) determination.

5.0 Recommendations

A comprehensive thermal modeling evaluation should be designed and conducted to support Vermont Yankee's 316(a) demonstration process. A comprehensive thermal modeling analysis has not been conducted as part of any of the three previous 316(a) demonstrations and is needed to support assessment of potential adverse impact. A brief overview of the recommended comprehensive thermal modeling evaluation is provided below. More detailed specification of the scope and design of the recommended modeling evaluation is required prior to initiating the study.

The modeling evaluation should include two models, linked together to simulate water temperature conditions in the Vernon Pool and in the downstream reach of the Connecticut River. The model study area should extend from Bellow Falls Dam to the Holyoke Dam, a distance of approximately 80 river miles. An upper-area model should simulate temperatures from the Bellows Falls Dam to the Vernon Dam and a lower-area model should simulate conditions from the Vernon Dam to the Holyoke Dam.

The model should be developed using at minimum a 10-year record of river flow and temperature, Vermont Yankee discharge flow and temperature, and meteorology. The model should then be applied dynamically to simulate temperature over the 10-year period including both summer and non-summer seasons. Analysis of the predicted time series of river temperature, along with the time-series record of Vermont Yankee, river, and weather conditions, would enhance understanding of the river's thermal characteristics. This modeling evaluation would meet the U.S. EPA's 316(a) and modeling guidance specifications (EPA 1977, 2009).

The existing WQMAP model, developed for the 2004 hydrothermal analysis, may be an appropriate model for the upper study area (above Vernon Dam). Unfortunately, the WQMAP model is proprietary and not available for widespread use. For this reason, it may be preferable to select a public domain model that can be thoroughly reviewed by regulatory agencies and more easily verified by third-party reviewers.

Normandeau Associates, Inc. (NAI) wrote a study plan for conducting a downstream field investigation and modeling evaluation (NAI 2008). The 2008 study plan specified use of the model CE-QUAL-W2 for simulation of downstream temperature. The CE-QUAL-W2 is a dynamic, two-dimensional model and is likely an appropriate modeling tool for the lower area temperature modeling evaluation. This model is also in the public domain.

The NAI (2008) study plan also specified a field investigation to support the modeling evaluation. Based on preliminary review, the field plan appears to be appropriately designed to capture the data required to support model development. The study plan contains a major flaw in terms of the proposed model application because it calls for application of the dynamic CE-QUAL-W2 model in steady-state mode. This approach is inappropriate for the reasons described above in Section 4.3 and must be revised to specify long-term dynamic simulation.

These recommendations constitute the outline of a comprehensive thermal modeling evaluation that is needed to provide sufficient information to support Vermont Yankee's 316(a) demonstration process.

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