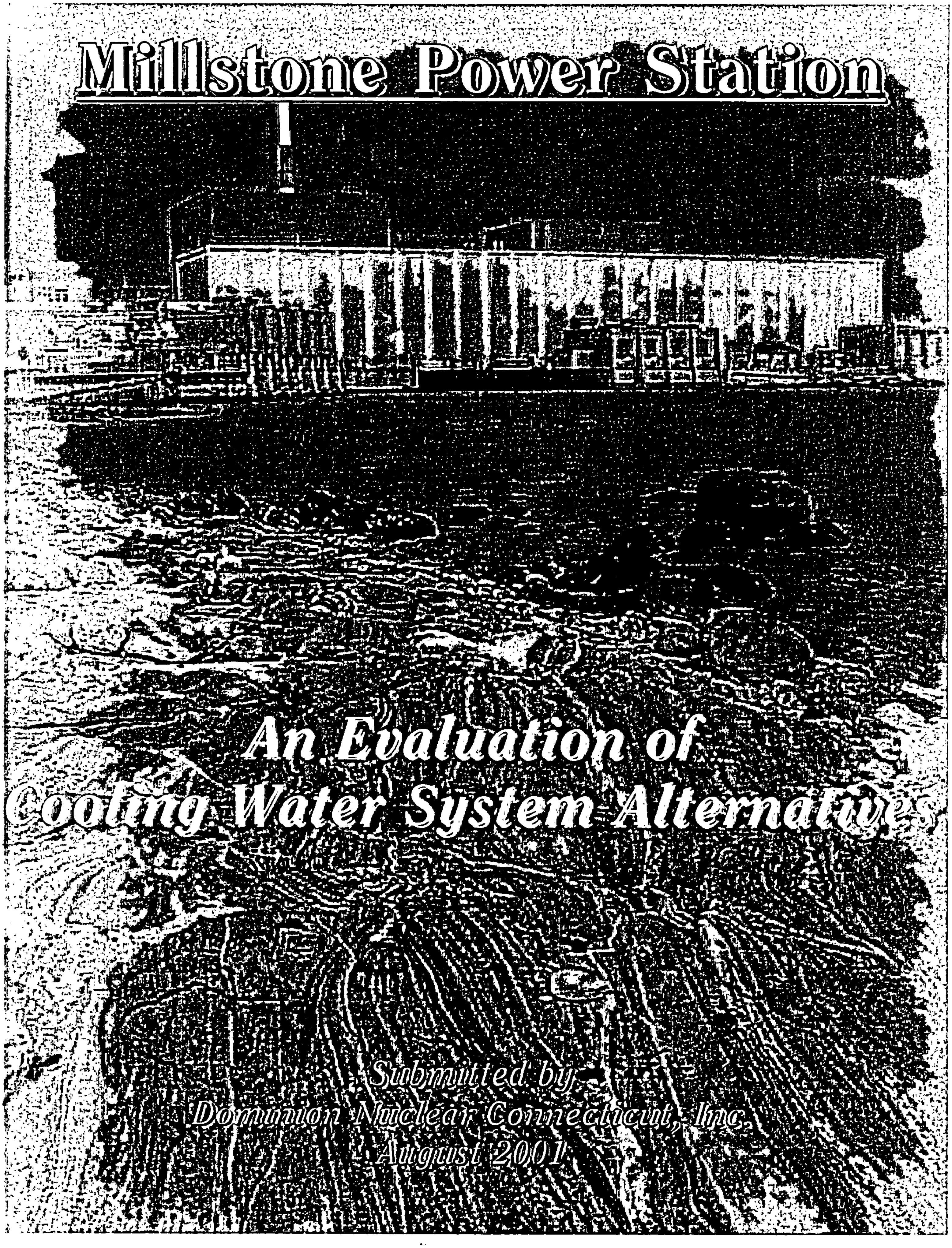
Millstone Power Station



An Evaluation of Cooling Water System Alternatives

Submitted by
Dominion Nuclear Connecticut, Inc.
August 2001

Dominion Nuclear Connecticut, Inc.
Millstone Power Station
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Dominion

August 31, 2001

D17249

Mr. Michael J. Harder
Director, Water Management Bureau
Permitting, Enforcement & Remediation Division
Department of Environmental Protection
79 Elm Street
Hartford, CT 06106-5127

References:

1. Letter C09668, M.J. Harder to F.C. Rothen, dated November 15, 1999.
2. Letter D15309 F.C. Rothen to M.J. Harder, dated December 30, 1999.
3. Letter C09872, M.J. Harder to F.C. Rothen, dated February 16, 2000.
4. Letter C10302, M.J. Harder to F.C. Rothen, dated July 13, 2000.
5. Letter D15614, F.C. Rothen to M.J. Harder, dated March 13, 2000.
6. Letter D16199, F.C. Rothen to M.J. Harder, dated August 30, 2000.
7. Letter C10566, M.J. Harder to F.C. Rothen, dated November 14, 2000.
8. NPDES Permit No. CT0003263, Millstone Nuclear Power Station, Units 1, 2 and 3, Northeast Nuclear Energy Company, issued December 14, 1992.
9. Letter C05513, E.C. Parker to D. Miller, dated January 14, 1994

Millstone Power Station
Final Report
Cooling-Water System Technology Study

Dear Mr. Harder:

In a letter dated November 15, 1999 (Reference 1), the Connecticut Department of Environmental Protection (the "Department") requested, in conjunction with the Millstone Station NPDES permit renewal process, a "new evaluation of all measures available to eliminate or minimize the use of once through cooling water." This evaluation was sought to aid in the Department's efforts to determine whether, pursuant to Section 316(b) of the federal Clean Water Act, "the location, design, construction and capacity of the existing once-through cooling water systems at Millstone represent best technology available for minimizing adverse environmental impact." Similarly, the

Department stated that it must consider "feasible and prudent alternatives in situations where the proposed activity may involve "unreasonable pollution, impairment or destruction of the public trust in the air, water or other natural resources of the state . . .", consistent with the Connecticut Environmental Protection Act ("CEPA"), Connecticut General Statute Section 22a-19(b).

To undertake this evaluation, the Department requested "a scope of study on those alternatives which can be implemented to minimize entrainment caused by once-through cooling water, and a scope of study on measures which would totally eliminate the use of once-through cooling water." In response to the Department's request, a scope of study (Reference 2) was prepared and submitted and, based on comments received from the Department (References 3 and 4), revised scopes of study were submitted (References 5 and 6), which clarified some issues and gave further details of the methods to be used and alternatives to be investigated, and proposed a submission date of August 31, 2001. The Department approved the scope of study on November 14, 2000 (Reference 7). Accordingly, in response to the Department's request and in accordance with the approved scope of study, Dominion Nuclear Connecticut, Inc. ("DNC") hereby submits a study for Millstone Power Station entitled "An Evaluation of Cooling Water System Alternatives" (The 2001 Feasibility Study).

The request to undertake a new study of alternative cooling water intake systems at Millstone follows a determination made in 1992 (Reference 8) that the Millstone "intake structure(s) represent(s) the best technology for minimizing adverse environmental impact from impingement and entrainment pursuant to Section 316(b) of the Federal [Clean Water] Act." In that regard, however, the Department, as a condition of the NPDES Permit (Reference 8), required a report relative to the feasibility of reducing entrainment of winter flounder larvae. This report, entitled "Feasibility Study of Cooling Water System Alternatives to Reduce Winter Flounder Entrainment at Millstone Units 1, 2, and 3" was submitted to the Department in January 1993. The Study concluded that the intake structures and once-through cooling water systems at Millstone remained best technology available.

In approving the 1993 Feasibility Study (Reference 9), the Commissioner determined that additional studies should be conducted to corroborate this finding. These scientific studies, including comprehensive long-term ecological monitoring of the marine environment surrounding Millstone, now span over 25 years. Study results, along with new engineering and economic evaluations of potential technologies and operational changes, provided the basis for the 2001 Feasibility Study. Additional considerations such as avoided air emissions, regional electrical capacity needs and the overall economic benefit of Millstone to the region were also assessed.

After consideration of all of the factors discussed in the 2001 Feasibility Study, DNC concludes that the existing intake structures and associated once-through cooling systems at Millstone continue to represent "best technology available." The evaluations performed demonstrate that the technologies and operational changes considered are not prudent and feasible alternatives to the existing intake structures. Based on the extensive monitoring performed by Millstone Station, the existing intake structures and associated once-through systems do not cause adverse environmental impact nor do they cause "unreasonable pollution, impairment or destruction of the public trust in the air, water and natural resources of the state."

DNC would be pleased to meet with the Department at a convenient time to discuss matters related to this submission and the ongoing NPDES Permit renewal process.

Very truly yours,

DOMINION NUCLEAR CONNECTICUT, INC.

William Matthews, Vice President and Senior Nuclear Executive-Millstone

Enclosure

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EXECUTIVE SUMMARY

MILLSTONE POWER STATION

AN EVALUATION OF COOLING-WATER SYSTEM ALTERNATIVES

August 31, 2001

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EXECUTIVE SUMMARY

ES.1 INTRODUCTION

This report was prepared in response to a request of the Connecticut Department of Environmental Protection (DEP) dated November 15, 1999. It includes information addressed in the Scope of Work submitted for this study on December 30, 1999, revised on August 30, 2000 as a result of DEP comment, and conditionally approved by the DEP on November 14, 2000. The information contained within this report is provided in support of the Commissioner's obligation to make a determination under Section 316(b) of the Federal Clean Water Act as to whether the cooling-water intake structures at Millstone Nuclear Power Station (MNPS) represent Best Technology Available (BTA) for minimizing adverse environmental impact. A previous cooling-water intake alternatives study submitted to the DEP in January 1993 pursuant to an NPDES permit condition was specific to winter flounder. At the request of the DEP, the current report has been expanded to include, in addition to winter flounder, an assessment of tautog, Atlantic menhaden, anchovies, grubby, cunner, and American sand lance.

This evaluation, initially proposed by Northeast Nuclear Energy Company and completed and submitted by Dominion Nuclear Connecticut, Inc. (DNC), provides a comprehensive engineering, biological, economic, and social evaluation of cooling-water intake system alternatives for reducing the entrainment of fish eggs and larvae at MNPS. Design, capacity, construction, location, and operational feasibility of technology options are considered along with their relative costs. In addition to intake technologies, other alternatives considered include seasonal plant shutdowns and planned refueling outages, conversion to a natural gas facility, and stock enhancement of winter flounder. The benefit derived from each of these options to winter flounder, tautog, and other fish species is considered relative to our current understanding of their life histories and historical trends in abundance and occurrence. A conclusion is reached as to the overall feasibility of each option, based on the engineering, scientific, economic, and social analyses set forth in Parts I and II of this report.

The biological and economic analyses of alternatives presented in this report are conservative in nature because they assume an extended period of MNPS operation beyond the existing U.S. Nuclear Regulatory Commission (NRC) license period for both Units 2 and 3. It should be noted, however, that while DNC is currently investigating the possibility of a 20-year license renewal for both units, which would extend their operational lifetimes to 2035 and 2045, respectively, no formal submission has been made to the NRC to date.

ES.2 MILLSTONE NUCLEAR POWER STATION

Located in Waterford, Connecticut, MNPS consists of three nuclear-powered units sited on a peninsula surrounded by Jordan Cove to the east, Niantic Bay to the west, and Long Island Sound (LIS) to the south. Unit 1 is a 660-megawatt (electric) (MWe) boiling water reactor, which was shut down in November 1995 and is now being decommissioned. Units 2 and 3 are pressurized water reactors with net capacities of 870 MWe and 1,150 MWe, respectively. Cooling water for both circulating and service water systems is taken in via traditional shoreline intakes located on Niantic Bay and totals about 1.52 million gpm for Units 2 and 3 when in full operation. The intakes are equipped with 0.375-inch mesh traveling screens and fish return systems. Condenser cooling water along with safety related service water is discharged into LIS at the southern end of the site and is rapidly dispersed due to strong tidal mixing. Together, Units 2 and 3 cooling water use represents approximately 2.8% of the mean tidal flow through Twotree Island Channel, which is just offshore of the plant site.

ES.3 COOLING-WATER SYSTEM ALTERNATIVES EVALUATED

Engineering and operational considerations for various cooling-water alternatives are specifically discussed in Part I of this report and an environmental evaluation for each is found in Chapter 2 of Part II. Part III provides a summary of the technological, environmental, biological, economic, and social evaluations performed in this study.

Behavioral barriers providing an avoidance stimulus to deter fish from entering power plant intakes were found to be inadequate in protecting fish eggs and larvae from entrainment at MNPS. Fish eggs and larvae have no or little horizontal mobility to avoid stimuli, such as lights, acoustics, or air bubbles. Accordingly, these technologies were not evaluated further.

Physical barriers, including a fine-mesh screen, rotary drum screen, Gunderboom, barrier net, infiltration intake, porous dike, sills, and cylindrical wedge-wire screen, were also considered. Of these, only a fine-mesh traveling screen was judged to be a feasible alternative and evaluated in further detail. The other alternatives either would not reduce entrainment, have not proven suitable for large power plants such as MNPS, would likely experience heavy biofouling, occupy or exclude large areas of useful habitat, or represent a significant navigational hazard. The capability of a fine-mesh screen to reduce entrainment mortality of smaller marine fish larvae, including winter flounder, is likely low, however, and this type of screen, in addition to its relatively high costs, would present considerable problems to plant operations because of debris loading.

In addition to a fine-mesh screen, among the technologies fully evaluated from an engineering and construction perspective were those which achieved reductions in cooling-water flow. Included in these technologies were a reduction in the number of operating condenser cooling-water pumps on a seasonal basis, use of condenser bypass

or re-circulation lines, throttled or variable speed pumps, natural and mechanical draft cooling towers, dry cooling towers, conversion of the station to gas-fueled units, and forced shutdowns. An offshore intake was also considered. Although an offshore intake would not reduce cooling-water flow, it was placed in a location that might be expected to reduce the entrainment of Niantic River winter flounder larvae. Dry cooling towers are not feasible for the MNPS units because of space limitations. Natural and mechanical draft cooling towers may be technically feasible based on the preliminary engineering analyses completed for this report. However, considerable engineering and construction difficulties would be expected. Their implementation would impose additional demands on station operation, lower station net generation, impose nuclear licensing difficulties, and raise significant community issues. Environmental impacts for cooling towers include discharge of concentrated blowdown, increased chlorine use, aesthetics, and noise. Other flow reduction schemes, such as reduced number of circulating-water pumps, reduce the margin of safe operation of a unit and make it more susceptible to unscheduled, automatic shutdowns.

A preliminary engineering evaluation of these options is discussed in Part I and total life-of-plant cost estimated for each. All of the major changes to present plant design or operation (cooling towers, offshore intake, gas conversion, forced shutdowns) were found to be very costly to implement. Costs are shown in Part I, Section 12 and Part III, Section 4. In addition to engineering feasibility and cost, relevant factors considered in this report include lost efficiency, nuclear plant safety, operational constraints, decreased energy production, increases in air emissions from outages and lost generation, land use constraints, other environmental impacts, and, in the case of gas conversion, the availability of fuel.

In Chapter 5 of Part II a non-technology option, a winter flounder hatchery, is evaluated. While methods now exist to spawn and rear winter flounder in a hatchery, contribution to recruitment from winter flounder stocking has not been established. Questions regarding protecting the genetic integrity of the Niantic River and LIS winter flounder stocks need to be resolved. Further research and discussion with the DEP would be needed in this area before any proposal for a stock enhancement program could be prepared in detail.

ES.4 ENVIRONMENTAL AND BIOLOGICAL EVALUATIONS

In addition to the technological evaluations presented, this report assesses the effects of entrainment on seven fishes: winter flounder, tautog, Atlantic menhaden, bay anchovy, grubby, cunner, and American sand lance. The early life history and egg or larval entrainment at MNPS of each of these species is described in Chapter 3 of Part II. As a result of over 25 years of studies in waters near the plant, considerable information has been accumulated on these fishes, particularly for the winter flounder.

With respect to winter flounder, a localized population spawns in the Niantic River and a portion of the larvae produced in the river is entrained at MNPS. The fraction of the annual larval production entrained was determined using a mass-balance model. Sensitivity analyses completed by both DNC and independent consultants showed that this model is conservative with respect to the fraction of Niantic River larval production that was entrained such that the model predicts higher entrainment of river larvae than actually occurs. This estimate of larval production loss was a key input to the Stochastic Population Dynamics Model (SPDM), a computer simulation model which is used in this study to evaluate the long-term benefits of various reductions in larval winter flounder entrainment in Chapter 4 of Part II. This model simulates changes in abundance of Niantic River female spawning stock under various scenarios using parameter estimates or rates as described in the following paragraph.

The evaluation of each selected method of entrainment reduction involved direct comparisons of adult female winter flounder biomass between projections of a baseline with no reduction in larval entrainment and projections with certain reductions in entrainment occurring, with all other factors affecting population growth remaining identical in both projections. A series of five entrainment reduction levels were chosen to represent the suite of cooling-water alternatives deemed technologically feasible at MNPS. The effectiveness of these five reductions was evaluated assuming combinations of three different levels (low, mean, and high) of production losses due to entrainment based on historical records, and two different sets of annual fishing rates (F), one determined for Long Island Sound waters (termed DEP F) and one for the Southern New England region (termed SARC F). Because population dynamics of winter flounder are largely driven by fishing exploitation rates, the choice of a reasonable estimate of fishing mortality was critical for this study. Through an initial calibration of the model, it became apparent that the SARC rate projected forward was too low to represent the current fishing exploitation rate of Niantic River winter flounder. The DEP rate, on the other hand, was found to be consistent with present population levels. Simulated annual population projections between 2002 and 2045 were used to calculate biomass gains resulting from the five levels of entrainment reduction investigated.

As expected, absolute increases in biomass of Niantic River female winter flounder were greater for larger entrainment reductions. For a given reduction in entrainment, gains in biomass were larger under a higher annual assumed entrainment production loss and when a lower fishing rate was assumed. Nevertheless, under both sets of fishing rates, biomass increases were only marginal (<1,000 lbs) for entrainment reductions of 15% or less, even after 43 years. Also, increases did not become apparent until after 10 to 20 years of entrainment reduction effects had accumulated. To provide some perspective on the estimates of biomass gains, the estimated size of the current exploitable Niantic River winter flounder stock is about 4 to 5 thousand pounds of fish. This figure represents less than 2% of the aggregate of winter flounder stocks responsible for total landings of this fish in Connecticut. Model simulation results also indicated that biomass gains achieved by a modest reduction of 15% in the current fishing

exploitation rate were immediate and more than ten times greater than those resulting from the same fractional reduction in the annual larval production entrained at MNPS.

The above results support the conclusion that, although entrainment reduction options should have some positive influence on the Niantic River winter flounder population, significant changes in this population from reducing entrainment alone are highly unlikely. In this regard, the model simulations show that reductions in fishing are of much greater benefit than concurrent entrainment reduction alternatives.

Recent operational history at MNPS provides additional support for this conclusion. Following a permanent reduction of larval entrainment of about 23% from the retirement of Unit 1 in 1995 and temporary, but much larger, reductions from the extended shutdowns of Units 2 and 3 in 1996-98, no large change has occurred in the abundance of the adult stock of Niantic River winter flounder. This further suggests that it is very likely that technologically feasible, but costly, options to reduce larval entrainment will, at best, have small effects in increasing Niantic River winter flounder abundance. The abundance of larvae and age-0 demersal juveniles has varied considerably over the past 25 years independently of station operation. Noticeably, some large year-classes of young in recent years did not result in substantial additions to the spawning population. Many factors that affect the formation of winter flounder year-class strength operate after the period of plant entrainment impact. Since the Niantic River population size is correlated with abundance of winter flounder throughout LIS and with populations in other areas of Southern New England, it appears that region-wide factors, including exploitation by the fisheries and naturally occurring events (e.g., environmental influences on spawning success and early life stage survival; increased predation on juveniles; regional warming trend), are most likely responsible for determining winter flounder abundance.

Effects of reducing entrainment of non-Niantic River winter flounder larvae (fraction determined from the mass-balance model), tautog, and the other fishes evaluated were determined using an equivalent-adult model as well as an examination of long-term abundance trends. The equivalent-adult model is also conservative because it does not assume any compensatory mortality (i.e., density-dependent effects resulting in, for example, higher survival at reduced density). Relevant data (fecundity, spawning frequency, mortality rates) are lacking for some of the species, so certain assumptions that were made based on life history information led to some uncertainty in these estimates. Despite numerically high entrainment of tautog eggs, mean annual equivalent-adult losses were relatively small. Also, another analysis indicated that MNPS removes a very small fraction of annual tautog egg production in the area near the plant. Although other species had numerically larger equivalent-adult estimates, monitoring data indicated no adverse impacts to any of these fishes due to plant entrainment. Atlantic menhaden and grubby show no declining trends in abundance despite nearly 30 years of plant operation. The Atlantic menhaden is also evaluated using a quantitative population dynamics impact assessment model, which indicated it could withstand

very high rates of loss without appreciably affecting population size. Despite relatively high calculated equivalent-adult losses, the grubby has been among the most stable of the fishes residing near MNPS. The grubby presents an interesting contrast to the winter flounder. Like the winter flounder, it most likely has a localized population, spawns a demersal egg in inshore waters during winter, and has a larva with a lengthy developmental period. It differs mostly in that it is not exploited by the fisheries and has shown no negative trend in abundance during MNPS operation, whereas the heavily fished winter flounder has shown a considerable decrease. Decreases in bay anchovy and American sand lance abundance have occurred over wide areas of the Atlantic coast and were apparently due to natural causes, such as interactions with their predators. Thus, based on evaluations set forth in this report, MNPS is not adversely affecting the populations of these species.

ES.5 ECONOMIC AND SOCIAL BENEFITS OF STATION OPERATION

A study performed by the University of Connecticut at the request of MNPS used a 20-year planning horizon to provide information useful to assess the relative contribution of the station to Connecticut's economy and the state's electrical capacity needs. For example, the Gross Regional Product (GRP), defined as the dollar value of final goods and services produced in a county, and attributed to MNPS, was about $486 million in New London County over the 20 years. State-wide, the GRP present-valued and summed over the same 20 years was estimated to total about $12 billion due to MNPS operations. The station's payroll, procurement, and taxes total about $204 million annually.

With respect to regional capacity needs, both the University of Connecticut study and the Connecticut Siting Council (CSC) have estimated the overall contribution of MNPS. Units 2 and 3 represent about 31% of Connecticut's generating capacity. However, in 2000, they contributed up to 45% of the state's electrical energy. Projected load is expected to grow between 0.7 and 1.5% at a compound growth rate. Despite the recent approval in Connecticut of some additional capacity, a shortage of power is predicted by the CSC if growth rates similar to those experienced in the last decade occur. The University of Connecticut study postulates that, without the capacity of MNPS, electricity prices will increase above the already high regional rates, thereby increasing the cost of doing business in Connecticut and creating a disincentive to new business development.

In addition to the economic benefits resulting from the operation of MNPS, the plant benefits air quality of the state and region. Since MNPS began operation in 1970, the station has avoided the burning of more than 400 million barrels of oil. As a result and with respect to available fossil-fueled alternatives, the station avoids the emission of large quantities of air pollutants, including sulfur dioxide (SO_2), nitrogen oxides (NO_X), various hazardous air pollutants, carbon dioxide (CO_2), carbon monoxide, particulates, and ash. For example, if Units 2 and 3 operate at 80% of capacity in one day, the station avoids the emissions of approximately 200 tons of SO_2, 48 tons of NO_X, and more than 37,000 tons of CO_2. Over a year, this would amount to 58 thousand tons of SO_2, 14 thousand tons of

NO_X, and more than 10 million tons of CO_2. For perspective, the NO_X emissions for the entire state during the 2000 ozone season totaled 4,697 tons and total greenhouse gas emissions for Connecticut in 1995 were approximately 43 million tons of CO_2 equivalent.

ES.6 CONCLUSION AND RECOMMENDATION

The determination as to whether the current cooling-water intakes at MNPS represent BTA for minimizing adverse environmental impact is made through engineering, biological, economic, and social analyses contained in this report. The design, capacity, construction, location, operational feasibility, and ecological consequences of potential intake cooling-water alternatives are evaluated. Together, the weight of evidence from impact analyses, monitoring data, and regional information indicates that the relationship between plant operation and changes in the abundance of the species evaluated is tenuous at best. No adverse environmental impacts are associated with the present cooling-water intake structure.

The engineering, biological, and economic analyses performed for all the cooling-water intake system technology options evaluated in this report demonstrate that only marginal benefits may occur to Niantic River winter flounder stock size. These benefits would be obtained at costs that are disproportionate to potential benefits of stock improvement. Furthermore, almost all options investigated present other potential unfavorable risks related to air quality, visual aesthetics, and plant and system reliability. Reductions in cooling-water flow already achieved by the retirement of Unit 1 and a 3-year shutdown of Units 2 and 3 did not result in significant increases in the Niantic River population. Moreover, local and regional trends in abundance indicate that ecological processes, natural events such as climatic factors, and fishing mortality rates all play critical roles in regulating adult population size.

Balancing the ecological benefits to be gained against the costs of the various cooling-water system technologies, their technical feasibility and related factors, such as nuclear plant safety and operational constraints, and considering the benefits provided by the station to the region's electric capacity needs, air quality, and economic well-being, it is the conclusion of this report that the options considered are neither BTA nor represent prudent and feasible alternatives to the existing once-through cooling systems. Thus, open-cycle cooling using the existing intake structures and equipment remains BTA at MNPS.

Alternatively, DNC believes that beyond the stock enhancement measure evaluated in this report for winter flounder, there are habitat protection and enhancement options offering opportunities to achieve outcomes consistent with the goals of the Magnuson-Stevens Fishery Conservation and Management Act (Sustainable Fisheries Act) in preserving essential fish habitat. Such options would complement DEP efforts to improve water quality and habitat in LIS through reductions in nutrient loadings. This type of initiative requires further evaluation and is one DNC would like to discuss further with the DEP.

INTRODUCTION

AN EVALUATION OF SELECTED COOLING-WATER SYSTEM ALTERNATIVES AT MILLSTONE NUCLEAR POWER STATION

August 31, 2001

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INTRODUCTION

AN EVALUATION OF SELECTED COOLING-WATER SYSTEM ALTERNATIVES AT MILLSTONE NUCLEAR POWER STATION

IN.1 MILLSTONE POWER STATION

The Millstone Nuclear Power Station (MNPS), an electrical generating facility consisting of three nuclear power units, is operated by Dominion Nuclear Connecticut, Inc. (DNC). Unit 1, a 660-MWe boiling water reactor, began commercial operation on November 29, 1970. This unit was shut down on November 4, 1995 and on July 17, 1998, the then owner and operator, Northeast Utilities, announced its retirement. Unit 2 is an 870-MWe pressurized water reactor that began commercial operation on December 26, 1975 and Unit 3 (1,150-MWe pressurized water reactor) commenced commercial operation on April 23, 1986.

The station is situated on the Connecticut shore of Long Island Sound (LIS) at Millstone Point, about 5 miles west-southwest of New London (Fig. IN-1). The property, covering an area of about 500 acres, is bounded to the west by Niantic Bay, to the east by Jordan Cove, and to the south by Twotree Island Channel. Environmental data are provided by a number of monitoring programs, many of which have been in place for 25 years or more. These data are assessed by DNC environmental staff and presented in an annual report (e.g., DNC 2001a) to the Connecticut Department of Environmental Protection (DEP). For this work, a study area of approximately 20 mi^2 is sampled, which extends from the northern portions of the Niantic River and Jordan Cove to Giants Neck, 1.25 miles south of Twotree Island, and 1.25 miles east of White Point. Sampling takes place from the shoreline into areas as deep as 65 feet southwest of Twotree Island. More detailed descriptions of the station, many of the plant operating systems, and aspects of the local marine and terrestrial environments may be found in NUSCO (1983).

The marine environment in the vicinity of Millstone Point is dominated by strong tidal currents that influence the physical characteristics of the area. Average tidal flow through Twotree Island Channel is approximately 900 thousand $gal \cdot sec^{-1}$ and at maximum is about 2.2 million $gal \cdot sec^{-1}$ (NUSCO 1983). Based on flow through Twotree Island Channel, three-unit operation utilized 3.6% of the mean tidal flow (NUSCO 1976); the present two operating units use 2.8% of the mean flow. Current velocities are about 1 to 1.8 knots in the channel, slightly less (1 to 1.5 knots) near the plant and in Niantic Bay, and relatively weak in Jordan Cove and in the upper Niantic River. The currents are driven by semi-diurnal tides that have a mean and maximum range of 2.6 and 3.3 ft, respectively. Thermal- and salinity-induced stratification may occur in regions unaffected by strong tidal currents. The greatest temperature variation has been observed in nearshore areas where water temperature can vary seasonally from about 30 to 77°F. Salinity varies much less and typically ranges between 26 and 30 ppt. The bottom is generally composed of fine to medium sand throughout the area, but also includes some rock outcrops and muddy sand, especially near the shoreline. Strong winds, particu-

larly from the southwest, can at times result in locally heavy seas (to 5 ft or greater) near Millstone Point. Additional information on local hydrography and meteorology in the vicinity of the plant can be found in NUSCO (1976, 1983).

Condenser and service water flow rates and additional details of the once-through cooling-water system at MNPS are described below in Part I, Section 1.0. Briefly, cooling water for the station is drawn from depths below the lowest level of tide by separate shoreline intakes located on Niantic Bay (Fig. IN-2). The station utilizes conventional once-through cooling water system with shoreline intake structures. Effectively since the fall of 1995 when Unit 1 ceased to be operational, cooling-water flow has been reduced by 23%. With respect to Units 2 and 3, four and six circulating-intake bays, respectively, each contain a traveling screen with 0.375-inch metallic woven mesh (originally 0.188-inch mesh at Unit 3), preceded by a coarse bar rack with a 2-inch gap to keep out large debris and aquatic organisms. A surface skimmer wall extending about 3 feet below mean sea level also keeps out floating objects. The present traveling screen systems at MNPS have been modified over the years to successfully return impinged organisms to LIS. Both operating units have fish return sluiceways, the most recent of which was installed and became operable at Unit 2 on May 23, 2000 (NNECO 1999b, 2000b). Several studies have affirmed the effectiveness of the sluiceways in reducing impingement mortality (NUSCO 1986, 1988; NNECO 1994b) and the effect of impingement at MNPS to local fish populations has been largely reduced. A chronology of major construction, milestones, and operational events (e.g., 2-week or longer shutdowns) to date is given in Table IN-1 and plant cooling-water use from 1976 through 1999 is shown in Figure IN-3.

IN.2 BASIS FOR BIOLOGICAL AND ECOLOGICAL MONITORING AND COOLING-WATER SYSTEM ALTERNATIVE STUDIES AT MNPS

The basis for the biological and ecological studies at MNPS is the National Pollutant Discharge Elimination System (NPDES) permit (CT0003263), last issued by DEP on December 14, 1992 to Northeast Nuclear Energy Company (NNECO), on whose behalf Northeast Utilities Service Company (NUSCO) initiated the biological studies. The permit was transferred from NNECO to DNC as of March 31, 2001, under whose auspices the present work was completed. In accordance with Section 22a-430 of the Connecticut General Statutes and Section 301 of the Federal Clean Water Act (CWA), as amended, the permit allows MNPS to withdraw cooling water and discharge it into Long Island Sound. Paragraph 5 of the MNPS NPDES permit states that:

> *The permittee shall conduct or continue to conduct biological studies of the supplying and receiving waters, entrainment studies, and intake impingement monitoring. The studies shall include studies of intertidal and subtidal benthic communities, finfish communities and entrained plankton and shall include detailed studies of lobster populations and winter flounder populations.*

In addition, paragraph 7 of the permit requires that:

> *On or before April 30, 1993 and annually thereafter, submit for review and approval of the Commissioner a detailed report of the ongoing biological studies required by paragraph 5 and as approved under paragraph 6.*

The NPDES Permit also states:

The Commissioner has determined that the location, design, construction and capacity of the cooling water intake structure represents the best available technology for minimizing adverse environmental impact from impingement and entrainment pursuant to Section 316(b) of the Federal Act. The Commissioner has also determined that additional evidence based on actual operating experience of Millstone Nuclear Power Station, Units 1, 2 and 3 would be desirable in order to corroborate the Commissioner's findings. Such data will be generated by the studies to be conducted pursuant to paragraphs 5 and 8 of this permit.

Paragraph 8 notes:

On or before January 31, 1993 submit for the review and approval of the Commissioner a report on alternatives to reduce entrainment of winter flounder larvae in accordance with "Scope of Work for Cooling Water Alternatives Feasibility Study to Reduce Larval Winter Flounder Entrainment, May 1992."

Paragraph 8 resulted in the submission to DEP in January 1993 of a cooling-water alternatives feasibility study (NUSCO 1993). Subsequent to this submission, DEP noted in a letter to NNECO that this report satisfied the requirements of paragraph 8 of the NPDES permit and was approved (DEP 1994). As a result of the agency review, DEP noted that NNECO was subject to the following conditions:

1. *The permittee will continue efforts to schedule refueling outages to coincide with the period of high winter flounder larvae abundance at the intake (typically April 1st through June 15th). Within 60 days following completion of a refueling outage, the permittee shall submit a report to the Commissioner which identifies important factors which contributed to the timing of the outage. The report shall also describe the timing of the outage relative to winter flounder larvae abundances at the intake.*
2. *In order to verify model predictions, the permittee will continue to monitor Niantic River winter flounder population characteristics, in accordance with paragraphs 5, 6 and 7 of NPDEP Permit No. CT0003263 issued on December 14, 1992.*

Refueling outage reports (NNECO 1994a, 1995, 1999a, 2000c; NUSCO 1996; DNC 2001b) have been submitted to DEP as required. Also, winter flounder and other biological and ecological studies in the vicinity of MNPS have continued and annual reports submitted each April to DEP in accordance with paragraph 7 of the NPDES permit (e.g., DNC 2001a). Additional history of regulatory submissions, particularly for winter flounder, is provided in Chapter 3 of Part II, which discusses the entrainment of fish eggs and larvae at MNPS.

The present cooling-water alternatives study results from a letter sent from DEP to NNECO in November 1999 requesting a new evaluation of feasible measures to minimize entrainment caused by once-through cooling water at MNPS (DEP 1999). A Scope of Study was submitted by NNECO to DEP in December 1999, outlining various

alternatives to be investigated and methodologies to be used in this report (NNECO 1999c). Based on comments received from DEP (DEP 2000a, 2000b), revised Scopes of Study were submitted by NNECO (2000a, 2000d) clarifying some issues and giving further details of the methods to be used and alternatives to be investigated. DEP approved the final Scope of Study on November 14, 2000 (DEP 2000c).

IN.3 REGULATORY BACKGROUND

Section 316(b) of the CWA requires that "the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." At present, there are no state or federal regulations related to the preparation of CWA Section 316(b) cooling water intake Best Technology Available (BTA) demonstrations. However, the U.S. Environmental Protection Agency (EPA) did publish draft guidance addressing the implementation of Section 316(b) evaluations (EPA 1977). The EPA draft guidance document states that "environmental interactions...are highly site-specific and the decision as to best available technology for the intake design, location, construction, and capacity must be made on a case by case basis." Both EPA and DEP have historically followed this approach.

In employing the case by case approach, EPA and DEP are at liberty to consider numerous factors, including cost and ecological impact. Specifically, as part of the CWA Section 316(b) demonstration associated with the MNPS 1992 NPDES Permit re-issuance, alternative cooling water intake technologies were reviewed to determine whether the costs associated with an alternative technology were disproportionate to the ecological benefits to be gained through its installation and use (NUSCO 1993). This same analysis has been employed as part of this report.

The role of restoration measures is neither addressed in Section 316(b) of the CWA nor in the Draft Guidance document (EPA 1977). While not requested to do so, DNC has examined one restoration option (winter flounder stock enhancement) and believes that a study of additional environmental restorative measures is worthy of further consideration, especially in those instances where the cost of the proposed technology is disproportionate to the environmental benefits projected to be achieved.

In addition to the review of BTA required under CWA Section 316(b), the DEP has requested that DNC consider whether "feasible and prudent" alternatives exist for the present cooling water intake structures at MNPS (DEP 1999). This review is similar to the BTA review under CWA Section 316(b) and requires both a determination of whether an alternative is "feasible" from an engineering standpoint and whether an alternative is "prudent" or economically reasonable after a balancing of the costs and benefits, social or otherwise, of the proposed activity. A prerequisite to this analysis, as set forth in DEP (1999), is a specific finding of "unreasonable pollution." No adverse finding in this regard has been made by DEP with respect to MNPS.

IN.4 REPORT STRUCTURE

Part I of this report is an engineering evaluation of alternative cooling water technologies and operational alternatives proposed in the DEP-approved Scope of Study, most of which was completed by personnel from Stone & Webster, Inc., with the exception of refueling outage planning (prepared by DNC) and the economic evaluation (completed by Dominion Resources Services, Inc. and DNC). Part I consists of thirteen sections. In general, each alternative was examined for its ability to reduce the entrainment or entrainment mortality of fish eggs and larvae. If the option showed promise for reducing entrainment or entrainment mortality, a partial engineering evaluation was performed. If this evaluation indicated that the technology was incompatible with station design or could otherwise not be implemented at MNPS, no further work was done. For those options deemed compatible with station design or operation, a complete evaluation was performed, which included an engineering and cost analysis. Part I also includes economic information for the feasible alternatives, with capital costs estimated for feasible alternatives, increased operation and maintenance costs, and costs associated with lost energy and capacity.

Part II was prepared by DNC and examines environmental and biological considerations for the intake technology alternatives. Due to its length, this part was divided into five chapters. Several chapter appendices provide supplementary information, many of which were prepared by independent consultants. Following a brief introductory chapter, Chapter 2 examines each selected cooling-water alternative, including the status of its technology, effectiveness in reducing entrainment mortality, relevant experience within the electric utility industry, and likelihood of applying it at MNPS. Chapter 3 describes the biology, entrainment, and monitoring of the important fish species evaluated in this report. A quantitative analysis of the effectiveness of various entrainment reduction alternatives in increasing numbers or biomass of the important fishes is provided in Chapter 4. The baseline for comparison is continued two-unit operation of MNPS until unit retirement with present once-through cooling-water flow. Each alternative evaluated resulted in either reduced flow or entrainment mortality; it was assumed that entrainment would be reduced commensurately with flow for these analyses. Chapters 3 and 4 draw on the extensive database available from the continuous long-term (approximately 25 years or more) monitoring of the environment in the vicinity of MNPS, which has enabled the assessment of plant impact to marine biota, including impingement and entrainment, thermal effects, and other effects (e.g., construction, dredging, discharge scour). Chapter 5 completes Part II with a discussion of the potential enhancement of winter flounder by hatchery production and stocking.

The report concludes with Part III, which reviews the information contained in Parts I and II in light of the costs and benefits and environmental impacts associated with each of the technology alternatives. This part includes the results of biological assessments of entrainment, a comparison of the costs of each alternative with the estimated increase in biomass of selected fishes as a result of implementing the proposed technology, and information on the economic and social benefit of MNPS to the local region and state. A final conclusion is then reached as to whether each alternative is considered BTA or feasible and prudent at MNPS. It should be noted that the biological and economic analyses of

alternatives presented in this report are conservative because they assume an extended period of MNPS operation beyond the existing U.S. Nuclear Regulatory Commission (NRC) license period for both Units 2 and 3. Although no formal submission has been made to the NRC, DNC is investigating the possibility of a 20-year license renewal for both units, which would extend their operational lifetimes to 2035 and 2045, respectively.

IN.5 REFERENCES

DEP (Connecticut Department of Environmental Protection). 1994. Letter C05513 dated January 14, 1994 from E. Parker, DEP, to D. Miller, NNECO. Approval letter.

DEP. 1999. Letter C09668 dated November 15, 1999 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Request for cooling water alternatives study.

DEP. 2000a. Letter C09872 dated February 16, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Comments on proposed cooling water alternatives scope of study.

DEP. 2000b. Letter C10302 dated July 13, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Comments on proposed cooling water alternatives scope of study.

DEP. 2000c. Letter C10566 dated November 14, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Approval of "Revised scope of study to reduce cooling water use at Millstone Nuclear Power Station" and associated correspondence (D16199).

DNC (Dominion Nuclear Connecticut, Inc.). 2001a. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 2000. Millstone Environmental Laboratory, Waterford, CT.

DNC. 2001b. Letter D17219 dated May 29, 2010 from K.M. McMullin, DNC, to A. Rocque, Commissioner, CT DEP. Reduction in winter flounder larval entrainment at Millstone Units 1, 2, and 3 as a result of refueling outages.

EPA (U.S. Environmental Protection Agency). 1977. Draft guidance for evaluating the adverse impact of cooling water intake structures on the aquatic environment: Section 316(b) P.L. 92-500. May 1977.

NNECO (Northeast Nuclear Energy Company). 1994a. The winter-spring 1994 refueling outage at Millstone Nuclear Power Station Unit 1 relative to the larval winter flounder season. Enclosure 1 to letter D07790 dated July 20, 1994 from D. Miller, NNECO, to T. Keeney, Commissioner, CT DEP.

NNECO. 1994b. Progress report on the MNPS fish return systems. Enclosure 1 to letter D08071 dated October 20, 1994 from D. Miller, NNECO, to T. Keeney, Commissioner, CT DEP.

NNECO. 1995. The 1994-95 winter-spring refueling outages at Millstone Nuclear Power Station Units 2 and 3 relative to the larval winter flounder season. Enclosure 1 to letter D08983 dated August 3, 1995 from D. Miller, NNECO, to S.J. Holbrook, Commissioner, CT DEP.

NNECO. 1999a. The spring 1999 refueling outage at Millstone Nuclear Power Station Unit 3 relative to the 1999 larval winter flounder season. Enclosure 1 to letter D14793 dated August 19, 1999 from P.M. Jacobson, NNECO, to A. Rocque, Commissioner, CT DEP.

NNECO. 1999b. Letter D14813 and enclosures dated October 8, 1999 from H.M. Blinderman, Updike, Kelly & Spellacy, P.C. on behalf of NNECO, to K. Zawoy, Long Island Sound Programs, CT DEP.

NNECO. 1999c. Scope of study for the evaluation of intake technology alternatives at Millstone Nuclear Power Station. Enclosure 1 to Letter D15309 dated December 30, 1999 from F.C. Rothen, NNECO, to M.J. Harder, CT DEP.

NNECO. 2000a. Scope of study for the evaluation of intake technology alternatives to reduce cooling water use. Letter D15614 dated March 13, 2000 from F.C. Rothen, NNECO, to M.J. Harder, CT DEP.

NNECO. 2000b. Notification of completion of construction and start of operation of the Unit 2 aquatic organism return. Letter D15953 dated June 1, 2000 from P.M. Jacobson, NNECO, to J. Grier, CT DEP.

NNECO. 2000c. The spring 2000 refueling outage at Millstone Nuclear Power Station Unit 2 relative to the 2000 larval winter flounder season. Enclosure 1 to letter D16204 dated July 31, 2000 from P.M. Jacobson, NNECO, to A. Rocque, Commissioner, CT DEP.

NNECO. 2000d. Revisions to scope of study for the evaluation of intake technology alternatives to reduce cooling water use. Letter D16199 dated August 30, 2000 from F.C. Rothen, NNECO, to M.J. Harder, CT DEP.

NUSCO (Northeast Utilities Service Company). 1973. Environmental effects of site preparation and construction. Pages 4.4-1 to 4.5-1 *in* Millstone Nuclear Power Station, Unit 3, environmental report, construction permit stage.

NUSCO. 1976. Millstone Nuclear Power Station Units 1, 2 and 3. Environmental assessment of condenser cooling water intake structures (316 (b) demonstration). Vol. I.

NUSCO. 1978. Impingement studies. Millstone Units 1 and 2, 1977. Pages 1-1 to 4-2 *in* Annual report, ecological and hydrographic studies, 1977. Millstone Nuclear Power Station.

NUSCO. 1983. Millstone Nuclear Power Station Unit 3 environmental report. Operating license stage. Vol. 1-4.

NUSCO. 1986. The effectiveness of the Millstone Unit 1 sluiceway in returning impinged organisms to Long Island Sound. 18 pp.

NUSCO. 1988. The effectiveness of the Millstone Unit 3 fish return system. Appendix 1 to Enclosure 3 to Letter D01830 dated January 29, 1988 from E.J. Mroczka, NUSCO, to L. Carothers, Commissioner, CT DEP. 21 pp.

NUSCO. 1993. Feasibility study of cooling water system alternatives to reduce winter flounder larval entrainment at Millstone Units 1, 2, and 3. Parts I and II. Berlin, CT. Submitted by Letter D06112 dated January 27, 1993 from C.F. Sears, NUSCO, to T. Keeney, Commissioner, DEP.

NUSCO. 1996. The fall 1995-winter 1996 refueling outage at Millstone Nuclear Power Station Unit 1 and extended shutdowns of all MNPS units relative to the 1996 larval winter flounder season. Enclosure 1 to letter D10154 dated September 26, 1996 from D.E. Welch, NUSCO, to S.J. Holbrook, Commissioner, CT DEP.

TABLE IN-1. Chronology of major construction and operation events at MNPS from December 1965 through summer 2001.

Date	Activity	Reference[a]
December 1965	Construction initiated for Unit 1	NUSCO (1973)
November 1969	Construction initiated for Unit 2	NUSCO (1973)
October 26, 1970	Unit 1 initial criticality; produced first thermal effluent	DNGL
November 29, 1970	Unit 1 initial phase to grid	DNGL
December 28, 1970	Unit 1 began commercial operation	DNGL
January 15, 1971 to February 22, 1971	Unit 1 shutdown	DNGL
August-December 1972	Surface boom at Unit 1	NUSCO (1978)
November 1972	Fish barrier installed at quarry cut	EL
September 3, 1972 to March 20, 1973	Unit 1 shutdown	DNGL
November 1972	Unit 2 coffer dam removed	NUSCO (1973)
April 18 to July 28, 1973	Unit 1 shutdown	DNGL
August-December 1973	Surface boom at Unit 1	NUSCO (1978)
July-December 1974	Surface boom at Unit 1	NUSCO (1978)
September 1 to November 5, 1974	Unit 1 shutdown	DNGL
July-October 1975	Surface boom at Unit 1	NUSCO (1978)
July 1975	Bottom boom installed at Unit 1	NUSCO (1978)
August 5, 1975	Unit 3 coffer dam construction began	EL
September 10 to October 20, 1975	Unit 1 shutdown	DNGL
October 7, 1975	Unit 2 produced first effluent	EDAN
November 7, 1975	Unit 2 initial criticality; produced first thermal effluent	EDAN
November 13, 1975	Unit 2 initial phase to grid	DNGL
December 1975	Unit 2 began commercial operation	EL
March 19, 1976	Unit 3 coffer dam construction finished	EL
June-October 1976	Surface boom at Unit 2	NUSCO (1978)
October 1 to December 2, 1976	Unit 1 shutdown	DNGL
December 20, 1976 to January 20, 1977	Unit 2 shutdown	DNGL
May 6 to June 25, 1977	Unit 2 shutdown	DNGL
June-October 1977	Surface boom at Unit 2	NUSCO (1978)
November 20, 1977 to May 1, 1978	Unit 2 shutdown	DNGL
March 10 to April 15, 1978	Unit 1 shutdown	DNGL
March 10 to May 21, 1979	Unit 2 shutdown	DNGL
April 28 to June 27, 1979	Unit 1 shutdown	DNGL
August 10 to 25, 1979	Unit 2 shutdown	DNGL
November 1 to December 5, 1979	Unit 2 shutdown	DNGL
May 7 to June 19, 1980	Unit 2 shutdown	DNGL
June 1 to June 18, 1980	Unit 1 shutdown	DNGL
August 15 to October 19, 1980	Unit 2 shutdown	DNGL
October 3, 1980 to June 16, 1981	Unit 1 shutdown	DNGL
January 2 to 19, 1981	Unit 2 shutdown	DNGL
December 5, 1981 to March 15, 1982	Unit 2 shutdown	DNGL
March 1981	Bottom boom removed at Unit 1	EL
September 10 to November 18, 1982	Unit 1 shutdown	DNGL
March 2 to 18, 1983	Unit 2 shutdown	DNGL
April-September 1983	Unit 3 coffer dam removed, intake maintenance dredging	EL
May 28, 1983 to January 12, 1984	Unit 2 shutdown	DNGL
December 1983	Fish return system installed at the Unit 1 intake	EL
August 1983	Second quarry cut opened	EL
April 13 to June 29, 1984	Unit 1 shutdown	DNGL
February 15 to July 4, 1985	Unit 2 shutdown	DNGL
June 1985	Intake maintenance dredging	EL
September 28 to November 7, 1985	Unit 2 shutdown	DNGL
October 25 to December 22, 1985	Unit 1 shutdown	DNGL
November 1985	Unit 3 produced first effluent	EDAN
February 12, 1986	Unit 3 produced first thermal effluent	EDAN
April 23, 1986	Unit 3 began commercial operation	DNGL

TABLE IN-1 (continued).

Date	Activity	Reference[a]
July 25 to August 17, 1986	Unit 3 shutdown	DNGL
September 20 to December 18, 1986	Unit 2 shutdown	DNGL
December 1 to 15, 1986	Unit 1 shutdown	DNGL
January 30 to February 16, 1987	Unit 2 shutdown	DNGL
March 14 to April 10, 1987	Unit 3 shutdown	DNGL
June 5 to August 17, 1987	Unit 1 shutdown	DNGL
November 1, 1987 to February 17, 1988	Unit 3 shutdown	DNGL
December 31, 1987 to February 20, 1988	Unit 2 shutdown	DNGL
April 14 to May 1, 1988	Unit 3 shutdown	DNGL
May 7-22, 1988	Unit 2 shutdown	DNGL
October 23 to November 8, 1988	Unit 3 shutdown	DNGL
February 4 to April 29, 1989	Unit 2 shutdown	DNGL
April 8 to June 4, 1989	Unit 1 shutdown	DNGL
May 12 to June 12, 1989	Unit 3 shutdown	DNGL
October 21 to November 24, 1989	Unit 2 shutdown	DNGL
March 30 to April 20, 1990	Unit 3 shutdown; installation of some 9.5-mm intake screen panels	DNGL; EL
May 8 to June 15, 1990	Unit 2 shutdown	DNGL
September 14 to November 9, 1990	Unit 2 shutdown	DNGL
February 2 to April 17, 1991	Unit 3 shutdown; installation of new fish buckets and sprayers	DNGL; EL
April 7 to September 2, 1991	Unit 1 shutdown	DNGL
April 23 to May 11, 1991	Unit 2 shutdown	DNGL
May 26 to July 7, 1991	Unit 2 shutdown	DNGL
July 25, 1991 to February 6, 1992	Unit 3 shutdown; installation of new fish buckets and sprayers	DNGL; EL
August 7 to September 11, 1991	Unit 2 shutdown	DNGL
October 1, 1991 to March 3, 1992	Unit 1 shutdown	MOSR
November 6 to December 27, 1991	Unit 2 shutdown	MOSR
January 28 to February 14, 1992	Unit 2 shutdown	MOSR
March 22 to April 6, 1992	Unit 1 shutdown	MOSR
May 16 to June 4, 1992	Unit 3 shutdown; installation of new fish buckets and sprayers	MOSR; EL
May 29, 1992 to January 13, 1993	Unit 2 shutdown	MOSR
July 4 to August 15, 1992	Unit 1 shutdown	MOSR
August 15, 1992	Completed installation of new fish buckets and sprayers at Unit 3	EL
September 30 to November 4, 1992	Unit 3 shutdown	MOSR
July 31 to November 10, 1993	Unit 3 shutdown	MOSR
September 15 to October 10, 1993	Unit 2 shutdown	MOSR
January 15 to May 23, 1994	Unit 1 shutdown	MOSR
April 22 to June 18, 1994	Unit 2 shutdown	MOSR
July 27 to September 3, 1994	Unit 2 shutdown	MOSR
September 8-22, 1994	Unit 3 shutdown	MOSR
October 1, 1994 to August 4, 1995	Unit 2 shutdown	MOSR
April 14 to June 7, 1995	Unit 3 shutdown	MOSR
November 30 to December 15, 1995	Unit 3 shutdown	MOSR
November 4, 1995	Unit 1 shutdown; retirement of unit announced July 17, 1998	MOSR; EL
February 20, 1996 to May 11, 1999	Unit 2 shutdown	MOSR
March 30, 1996 to July 5, 1998	Unit 3 shutdown	MOSR
December 11-29, 1998	Unit 3 shutdown	MOSR
June 4, 1999	Original Quarry Cut Fish Barriers replaced	EL
April 30 to June 29, 1999	Unit 3 shutdown	MOSR
April 22 to June 1, 2000	Unit 2 shutdown	MOSR
May 23, 2000	Commenced operation of Unit 2 fish return sluiceway	EL
February 3 to March 30, 2001	Unit 3 shutdown	MOSR

[a] DNGL refers to the daily net generation log, EL to Millstone Environmental Laboratory records, EDAN to the environmental data acquisition network, and MOSR to the monthly nuclear plant operating status report.

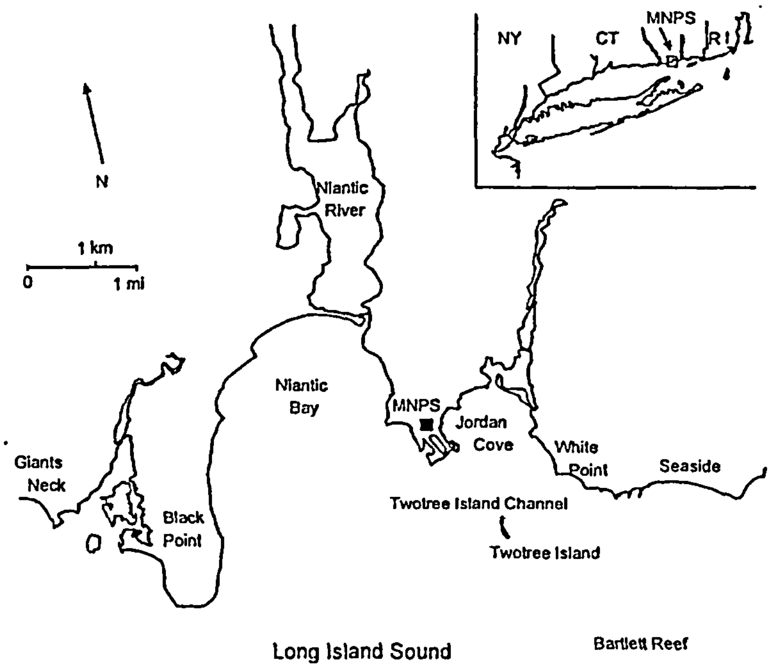

Fig. IN-1. Location of Millstone Nuclear Power Station and the study area for biological monitoring.

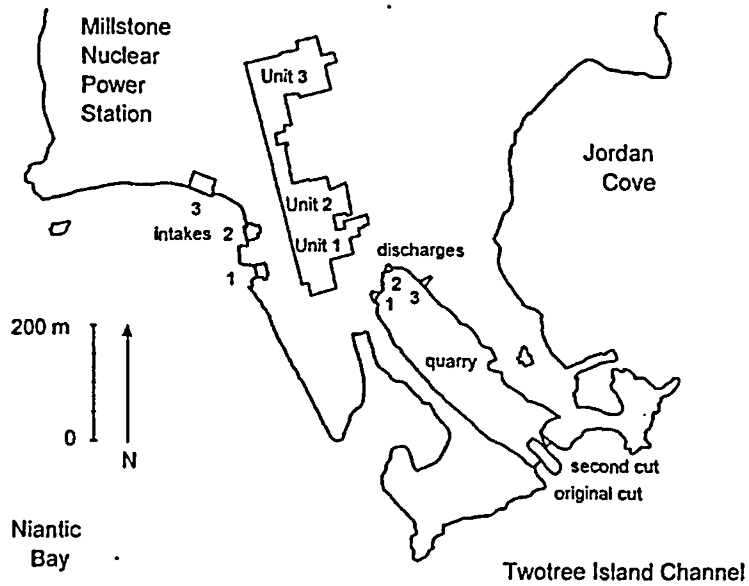

Fig. IN-2. The MNPS site, showing the intake and discharge of each unit, the Quarry, and the two Quarry discharge cuts.

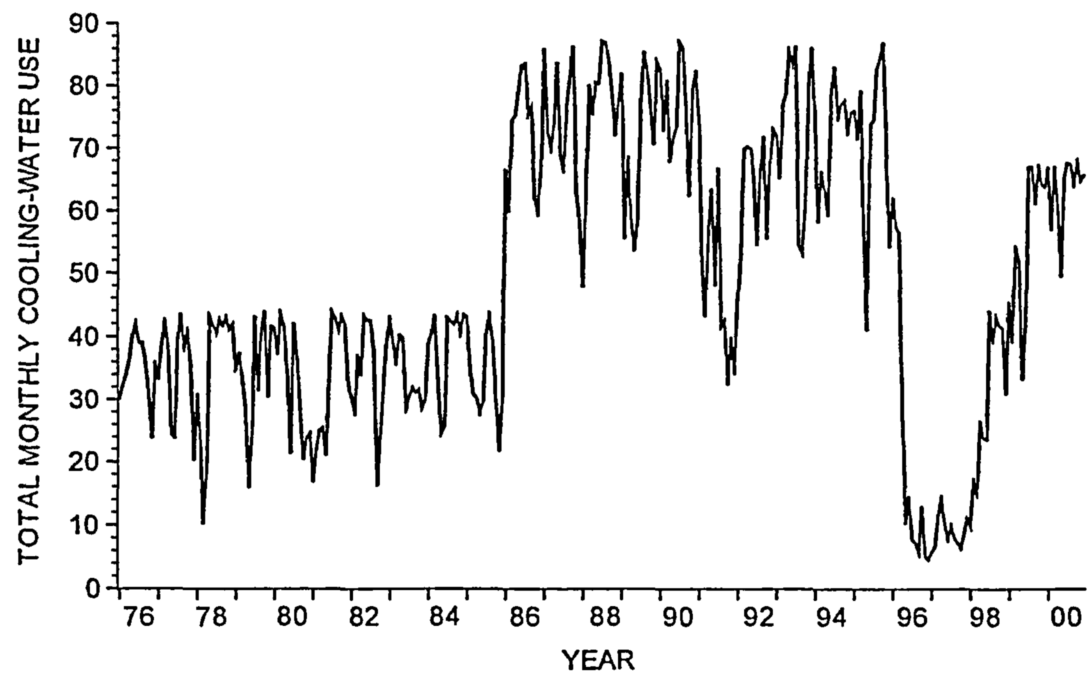

Fig. IN-3. Total monthly cooling-water use in billions of gallons at MNPS from January 1976 through December 2000.

PART I

ENGINEERING AND ECONOMIC EVALUATION OF SELECTED COOLING-WATER SYSTEM ALTERNATIVES AT MILLSTONE NUCLEAR POWER STATION

August 31, 2001

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1 CURRENT DESIGN AND OPERATION

There are two main heat dissipation systems for each of the Millstone Nuclear Power Station (MNPS or Millstone) units that draw water from Niantic Bay in Long Island Sound (LIS):

- Circulating Water Systems (condenser cooling, non-nuclear safety-related)
- Service Water Systems (nuclear safety-related)

The pumps for both circulating and service water systems are installed in common intake structures. Each unit has its own separate intake structure. Both systems draw water from Niantic Bay, pass the water through either steam surface condensers (circulating water systems) or heat exchangers (service water systems) where the water temperature is increased. The heated water is discharged into the quarry and ultimately into Twotree Island Channel. The location of the intake and discharge facilities for each unit is shown on Figure 1-1.

The circulating water systems condense steam by means of once-through steam surface condensers. The waste heat from the condensing process is transferred to the circulating water as it passes through the condenser tubes. In the normal operating mode, the service water system provides cooling water to numerous station facilities. Major users are the reactor plant component cooling heat exchangers and the turbine plant component cooling heat exchangers. In the event of an accident, such as a loss of coolant accident (LOCA), service water is diverted to the containment recirculation coolers (Unit 3 only) to remove heat from the reactor, also the emergency diesel generator engine coolers are supplied by service water.

The intake structures for each unit are similar in design. Each intake structure contains service and circulating water pumps in common bays. The intakes have traveling water screens with 3/8-inch mesh, coarse bar racks, and curtain walls that extend below the lowest tide water level. The coarse bar rack excludes debris and large fish and the traveling screen prevents smaller fish and debris from entering the pump bay. The curtain wall prevents warm surface water, ice, and surface marine organisms from entering the intake. Each intake has lateral fish passageways installed in the intake bay walls upstream of the traveling screens to allow fish to escape the screen faces. A typical intake section, which is similar for the intake structures of Units 1, 2, and 3, is shown on Figure 1-2.

The intake structure for Unit 1 contains four circulating water pumps, that are designed to deliver a total flow rate of approximately 420,000 gpm of cooling water to the condenser, and four service water pumps, each rated at 12,000 gpm. However, Unit 1 has been shutdown and the circulating and service water pumps are not in operation.

The intake structure for Unit 2 contains four circulating water pumps that have a maximum flow rate of approximately 548,800 gpm (137,200 gpm/pump) of cooling water to the condensers. The intake structure also contains three service water pumps, rated at 12,000 gpm each. The normal service water flow is 24,000 gpm. The water velocity approaching the traveling screen is approximately 1.0 fps.

The intake structure for Unit 3 houses six circulating water pumps, each rated at approximately 153,000 gpm, for a total circulating water flow rate of 918,000 gpm. The intake also contains four service water pumps; each rated at approximately 15,000 gpm. Normal service water system flow is 30,000 gpm. The water velocity approaching the traveling screen is approximately 1.0 fps.

Table 1-1 provides a summary of station maximum flow withdrawals from Niantic Bay (NUSCO 1998).

Table 1-1: Millstone Nuclear Power Station Flow Withdrawal From Niantic Bay

Unit No.	System	Flow Withdrawal (gpm)
Unit 1	Circulating Water Service Water	0 (Note 1) 0 (Note 1)
Unit 2	Circulating Water Service Water	548,800 24,000
Unit 3	Circulating Water Service Water	918,000 30,000
	Total Station Withdrawal	**1,520,800**

Note 1: Millstone Unit 1 has been shutdown since November 4, 1995 with no plans to restart. This table assumes no operation of the Unit 1 circulating and service water pumps.

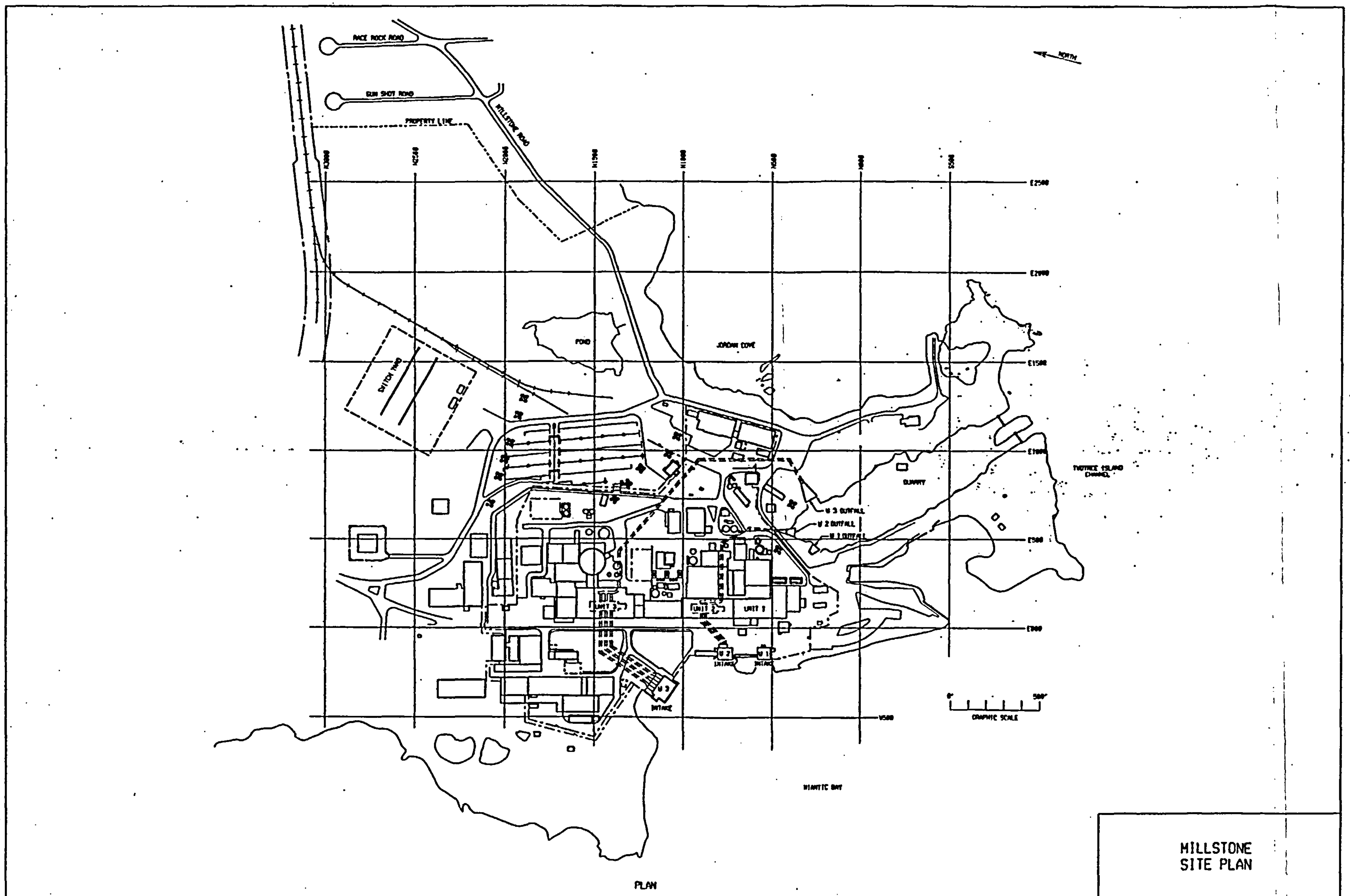

Figure 1-1: Millstone Units 1, 2, and 3 Site Plan

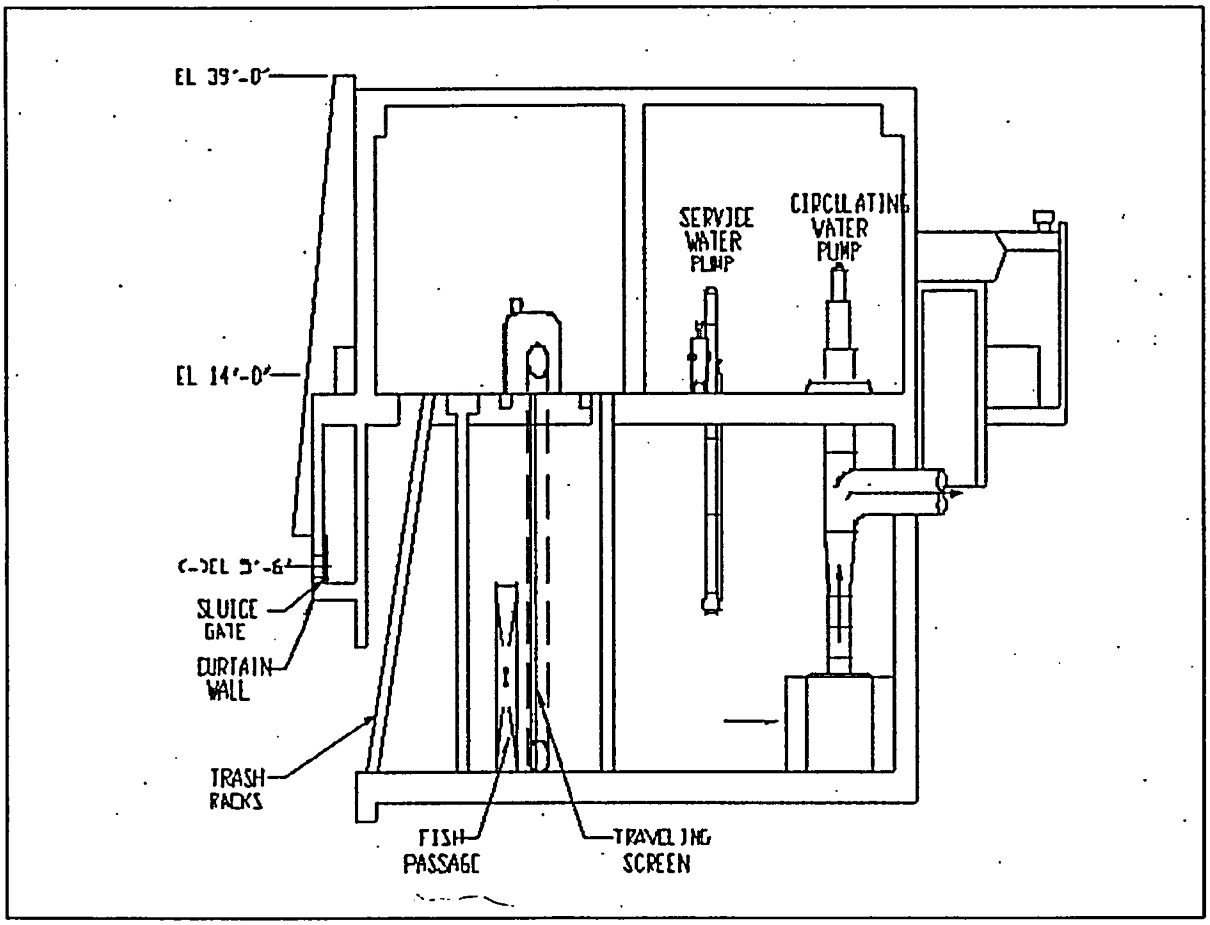

Figure 1-2: Units 1, 2, and 3 – Typical Section of Circulating Water Intake Structures

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2 IDENTIFICATION OF FISH SPECIES

In order to determine the suitability of various mitigation alternatives, the seasonal occurrence of entrainable species was evaluated for this report. The following species of fish have historically been evaluated in the entrainment impact analyses for Millstone Nuclear Power Station (MNPS) include the Atlantic menhaden, anchovies, grubby, tautog, cunner, American sand lance, and winter flounder. The reasons for which these species were chosen as important at MNPS are discussed in Chapter 1 of Part II. The early life history stages of each species have well-known seasons of occurrence in entrainment samples. For this report, two such periods were defined for analyses. The primary season of occurrence included the dates, which, on average, encompass 95% of the egg or larval entrainment of the above species. In addition, an optimal season was determined that took into consideration the temporal distribution of each species. Entrainment mitigation methodologies relying on seasonal reductions in cooling-water flow will have varying effectiveness, depending upon when they are scheduled. Cooling-water flow reductions may either be applied to nearly all of a particular entrainment season or to that portion of a season which would potentially optimize reductions in entrainment for a specific species. Determining an optimal season will protect a majority of early life history stages from entrainment, but with fewer restrictions to plant operation and economics. The methodology for determining the optimal entrainment seasons is given in detail in Chapter 3 of Part II.

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3 IDENTIFICATION OF AVAILABLE INTAKE TECHNOLOGIES FOR FISH PROTECTION

Biologists and engineers have conducted extensive research to develop methods to protect fish and larvae at water intakes beginning in the late 1960s. Their efforts focused on the biological effectiveness and engineering practicability of screening systems for use at steam electric stations. In the early 1980s, the design and construction of new steam electric plants in this nation was greatly reduced; however, fish protection research continued. Information derived from ongoing research efforts that are pertinent to the issue of fish impingement and entrainment at MNPS is presented within this report and provides the best information available for the evaluation of potential alternatives.

Most fish protection systems in use today are designed primarily to protect juvenile and adult fish from impingement. Few systems have been developed to reduce entrainment. The limited development of entrainment reduction systems is a result of contested expectation of effectiveness, cost, and practicality of suitable alternatives.

There are several types of mitigation measures for minimizing the impingement of adult fish and entrainment of fish larvae at cooling-water intakes. For organizational purposes, the fish protection technologies have been grouped into the following categories:

- Behavioral Barriers
- Physical Barriers
- Diversion Systems
- Flow Reduction Concepts

The results of the screening of these technologies for application to MNPS are provided in Sections 4, 5, 6, and 7. A review of the available industry information on the ecological and environmental effectiveness of Behavioral Barriers, Physical Barriers, and Diversion Systems is provided in Part II of the report.

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4 BEHAVIORAL BARRIERS EVALUATION

Behavioral barriers were developed to repel juvenile and adult fish from water intakes by creating a condition that would elicit a fright or other behavioral response. These technologies were developed beginning in the late 1970s in an attempt to identify a low-cost way of using the visual or sound receptors on fish, and the self-motive (swimming) abilities of fish to divert individuals or schools of fish from approaching a water intake structure. Studies of swimming speed and the behavior of fish in intake screenwells and in front of intake structures resulted in development of specific criteria for once-through cooling water intake structures. In the mid-1980s, there was considerable study of the behavioral barriers. Behavioral barriers were implemented and studies were conducted at many projects throughout the United States, Canada, Germany, and France (Brown 1997; Dunning 1997; EPRI 1986; EPRI 1994a; EPRI 1994b; EPRI 1998; Hanson et al. 1997; Klinect et al. 1992; Knudsen et al. 1997; Loeffelman et al. 1991; Nestler et al. 1992; Ploskey et al. 1998; Ross et al. 1993; Schilt et al. 1997).

In spite of the extensive studies and many successes for some species of fish at some project intakes, as yet, there is no one behavioral barrier or other fish protection measure that is effective with all species and lifestage of fish. There is no basis to advance for further consideration any of the following behavioral barriers as a potential solution to the issues that have been raised by the agencies at Millstone Station, particularly regarding the entrainment of fish eggs and larvae:

- Acoustic Devices
- Infrasound
- Strobe Lights
- Mercury Lights
- Electric Screens
- Air Bubble Curtain
- Water Jet Curtain
- Hybrid Barriers

Each of these technologies is intended to elicit an avoidance response from an organism, which has the swimming ability to overcome the ambient currents and flows and either be attracted to or repelled from a specific location. The lifestages of the species that are to be addressed at Millstone (i.e., entrainable organisms) are planktonic and, by definition, these species have no practical motive power to avoid the behavioral systems or the flows entrained to the Millstone intake structures. The open coastal environment at Millstone, which so effectively disperses the waste heat discharge, is very dynamic and has high current velocity. Planktonic or very early lifestages of fish can not be expected to effectively overcome these conditions with their limited swimming ability to avoid a behavioral barrier.

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5 PHYSICAL BARRIERS EVALUATION

The existing cooling water intake at Millstone Station incorporates a physical barrier that limits the potential for the intake to impact adult fish through impingement. The flow-through traveling water screens collect impinged fish and returns them via a sluiceway to Long Island Sound. As discussed in Part II of this report, the existing Unit 3 traveling water screens have been modified over the years of operation to ensure their reliability in the harsh operating environment and to ensure good survival of impinged fish. Part II of this report also discusses and references studies that determined the biological effectiveness of a variety of physical barriers that have either been tested in the laboratory, by prototype studies, or tested in full-scale applications at operating power plants.

The following physical barriers are also discussed in Part II, Chapter 2.3 related to providing potential solutions for preventing entrainment of fish:

- Fine-Mesh Traveling Water Screens (Chapter 2.3.2)
- Rotary Drum Screens (Chapter 2.3.3)
- Gunderboom (Chapter 2.3.4)
- Barrier Nets (Chapter 2.3.5)
- Cylindrical Wedge-Wire Screen Intakes (Chapter 2.3.8)
- Infiltration Intakes (Chapter 2.3.6)
- Porous Dike (Chapter 2.3.7)

- ***Fine-Mesh Traveling Screens***

  A traveling water screen backfit of fine-mesh screens with lift buckets and spray wash pressures capable of gently removing the egg and larval stages (10 to 15 psi) can be performed. However, seaweed and eelgrass could quickly foul these screens. Laboratory testing of fine-mesh screens to retain and collect larvae with species that have a similar hardiness has shown some success. Fine-mesh traveling water screens have been installed at other large-scale steam electric cooling intakes including marine applications at Big Bend Station in Tampa (EPRI 1986), and at an operating nuclear generating station at Prairie Island on the Mississippi River (Kuhl and Mueller 1988). Results from field and lab studies of fine-mesh traveling water screens generally show higher survival at lower approach velocities and with shorter impingement duration (EPRI 1986). In addition, many regulatory agencies have adopted an expectation that traveling water screen approach velocities should be 0.5 fps or less. Therefore, in order to use the existing intake to backfit the screens, the approach velocities to the screens at Millstone must be reduced to 0.5 fps or less. For this reason, fine-mesh traveling water screens will only work if they are a part of a solution that includes a significant flow reduction (at least 50%) or if a new and larger cooling water intake structure is constructed (i.e., approximately twice as

large as the existing structure). Section 5.1 and 5.2 of this report provides additional discussion on this alternative, which may be the only physical barrier that might be suitable for use at Millstone Station.

- *Rotary Drum Screens*

  Rotary drum screens are not a practical solution with the size of screen required for the tidal range, the size of the mesh necessary to retain entrainable lifestages, and especially because of the unproven fish and heavy debris removal capability of this design. This design would require a much larger intake structure than a fine mesh traveling water screen design. Given the well characterized debris problem at Millstone and the unproven fish removal capability of the rotary drum screen, this design could not be recommended without extensive site evaluation of a prototype.

- *Gunderboom*

  The Gunderboom is simply a floating dredge curtain more commonly used to reduce the discharge of fine silt during dredge construction projects. The Gunderboom was not proven to be reliable (LMS 1996a; LMS 1997) in an initial large-scale (approximately 500 feet long) application at Lovett Generating Station (Lovett) in 1996 through 1998. However, in 1998, the Gunderboom was effectively deployed at Lovett for about a month before tidal fluctuations deteriorated the flotation billets and crimped the floatation hood. The stress and crimping of the floation billets caused the net to lift about 1 or 2 feet off the bottom of the river for the remainder of the season (about 3 more months) (LMS 1998). During one 25-day period, the measured effectiveness was a 76% reduction in ichthyoplankton density and thereafter the boom was not effective (ASA 1999). Although the small Lovett Gunderboom deployment was effective for a short period of time, there is no application experience with a deployment of the size necessary for the Millstone application (i.e., a semi-circle of approximately 1 to 2 miles in length based on a Gunderboom, Inc range of recommended (5 to 10 gpm/ft^2) filtration rates and an average water depth of approximately 30 feet). More importantly, there is no experience in an open coastal environment like Niantic Bay. This technology is not developed or proven with enough success to ensure that it could be applied on the large scale of flows and in the open ocean conditions found in Niantic Bay. In addition, failure of the Gunderboom could result in blocking the flow to the safety-related service water pumps, which could impact the safety of the station.

- *Barrier Nets*

  Barrier nets alone would not be effective in limiting the passage of entrainable lifestages of fish. The mesh sizes of most conventional barrier nets used at power plants are too large. To be effective for the species and lifestages of interest at Millstone, one would need to use a mesh similar in dimension to that of the Gunderboom or to the size recently tested at the Bowline Station located on an embayment of the Hudson River (LMS 1994; LMS 1996b). Even on the relatively quiescent waters at Bowline

Station, there were maintenance problems associated with the fine-mesh barrier net. In addition no barrier net has been installed in the type of sea conditions commonly found on Niantic Bay.

- *Cylindrical Wedge-wire Screens*

  Cylindrical wedge-wire screens would require a very fine opening size. The screens of this type installed at Eddystone Station (Veneziale 1991) and at Campbell Station were of a mesh size that would pass all the entrainable lifestages of interest at Millstone Station. This design is not recommended for further consideration at Millstone, since these screens are more prone to clogging (unless there is a unidirectional flow i.e., a river or tidal situation with much cross flushing) and the wedge-wire design has proved to have a cleaning problem with leafy-type debris on the Black River in New York. If seaweed and eelgrass at Millstone is not effectively dispersed with the conventional air burst system, the abundant filamentous material found in Niantic Bay could clog the slots of the wedge-wire.

- *Infiltration Intakes like the Porous Dike*

  The infiltration intake is a concept similar to that of the cyclindrical wedgewire screen which has been developed for small flows. The latest commercial infiltration intake materials are well suited only for small power plant flows (Elarbash et al. 1994). These infiltration systems are generally considered for flows less than 268,800 gpm (600 cfs) and only where the hydraulic conductivity of the substrate is relatively high. The porous dike concept does not work reliably unless there is a mechanism to clear/clean accumulated materials from the outside of the dike (EPRI 1986). Unless the overall solution also includes a major reduction in flows, the infiltration intake would require too much area and too great of a collection system to effectively pass the once through cooling water flows currently used at Millstone.

Of all the physical barrier alternatives discussed above only the fine mesh traveling screen alternative has any potential for use at Millstone and is discussed in more detail in Section 5.1 and 5.2. The remainder of the alternatives discussed above, are not suitable for use at Millstone Station for various reasons. Rotary drum screens are not appropriate at Millstone primarily because of the unproven capability to remove heavy debris and entrained organisms. Use of a Gunderboom raises reliability performance and debris loading concerns. Moreover, there is no experience either with a Gunderboom the size (1 to 2 miles in lenth) required at Millstone Station or with its ability to be effectively deployed in the open coastal conditions of Niantic Bay. Barrier nets are also not suitable due to performance and reliability concerns. Wedge-wire screens, infiltration intakes, and porous dikes raise significant maintenance and fouling issues. In addition, wedge-wire screens and infiltration intakes have never been applied at a plant the size of Millstone Station.

5.1 FINE-MESH SCREEN FACILITY FOR UNIT 3

5.1.1 Description of Facility

Because of the uncertainty of how seasonally abundant filamentous debris would affect the clogging potential of the fine-mesh screens and the expectations that the regulatory agencies would require approach velocities of 0.5 fps for any major modification of the intake, replacing the existing 3/8-inch opening screens with fine-mesh screens does not appear to be a practicable alternative for MNPS. However, since this is the only physical barrier that could be used to reduce fish entrainment, a discussion of the design is provided in this report. The description of this alternative is the same as provided in the 1993 report.

The preliminary design for fine-mesh screens, as shown on Figure 5.1-1, would consist of constructing an entirely new through-flow screen structure for Unit 3 in front of the existing screen structure. The existing intake structure would remain functional with the existing traveling screens serving as backup screens in the event the fine-mesh screens become blocked. Bypass gates would be provided to direct flow around the fine-mesh screen structure.

A 0.5 mm fine-mesh screen, applied to Unit 3 for fish eggs and larvae, would be designed to block organisms from entering the circulating water system and to safely transport impinged eggs and larvae back to Niantic Bay. Stage 3 winter flounder larvae, which are most susceptible to entrainment into the MNPS intakes, are mostly from 5.5 to 7.5 mm in length. The existing seasonal heavy trash loading at the MNPS intakes of eelgrass and seaweeds would require a design screen approach velocity of 0.5 fps for fine-mesh screens to prevent overloading of the screens during periods of heavy trash loading. The April and May time frame for greatest winter flounder entrainment is also a period of heavy debris loading on the intake.

Unit 3 design parameters for the screen structure are as follows:

Screen mesh size	0.5 mm
Deck elevation	14 feet 6 inches
Invert elevation	-28 feet 0 inches
Design flow	918,000 gpm
Approach flow velocity to fine-mesh screen	0.5 fps
Screen unit width	10 feet

The deck elevation, invert elevation, and design flow would be the same as the existing intake. The 10-foot screen unit width would be selected because experience has shown that wider screen widths tend to result in less reliable operation and more maintenance. Through-flow screen units are available in widths up to 14 feet.

The number of screen units required was determined by calculating the required cross sectional area needed to achieve a 0.5 fps approach flow velocity or less to the traveling screen. A 20% unscreenable area was assumed to account for the screen boot area and structural metal frame area between screen mesh. Flow velocity calculations were made at mean low water (0.0 feet). This would result in eighteen 10-foot-wide screen units as shown on Figure 5.1-1.

The screen structure would be approximately 40 feet wide by 275 feet long. It would include both upstream and downstream curtain walls extending down to a depth of -5 feet for ice, cold weather, and floating debris protection. Bar racks would be provided to catch large debris that could damage the traveling screens. The structure would include open sluice fish return and a separate trash removal system. It was assumed the fish would be sluiced to the west side of Bay Point and returned to Niantic Bay. A detailed study of the location of the sluice discharge would be required if this alternative were selected. The study would determine the most suitable discharge location to ensure that winter flounder larvae and tautog eggs were not drawn back into the intake. In addition, the study would need to determine the winter flounder larvae and tautog egg survival. Other equipment associated with the structure, in addition to the 18 fine-mesh traveling screens, would included:

- Mechanical trash rake
- Screenwash systems including 6 screenwash pumps, each rated at 5000 gpm at 200 feet total dynamic head
- Gantry crane
- Fish return sluicing system
- Trash sluicing system
- HVAC for enclosure structure
- Control equipment
- Electric supply equipment

The fine-mesh screen structure would be joined to the existing Unit 3 intake by double sheet pile walls with tremie concrete placed between the sheet pile. Each wall would have a 12-foot by 30-foot bypass gate. These bypass gates would be sized to bypass ½ of the total design flow to the Unit 3 intake. The bypass system would be provided in the event that some or all of the fine-mesh screen units become blocked or inoperable and to ensure the flow to the safety-related service water system.

The forebay, formed between the new fine-mesh screen structure and the existing Unit 3 intake, would have a system of flow guide vanes to create uniform flow conditions entering the existing intake. Hydraulic model studies would be required to properly design the guide vane system. The guide vanes shown on Figure 5.1-1 are conceptual and were used to develop material quantity estimates.

It has been estimated that the capital cost for this alternative is $31,200,000. This cost does not include the cost associated with the prototype testing of the screens and return system or the additional studies for determining the preferred return location.

5.1.2 Testing the Suitability & Effectiveness of Fine-Mesh Screens

Before attempting the extensive engineering challenges, licensing and permitting costs of backfitting a new fine-mesh traveling water screen to Millstone Station, it would be prudent to field test a prototype. Field testing at the site would identify the likely effectiveness of the design on the species and lifestages present in Niantic Bay. The prototype would also identify any possible operating problems with eelgrass and other debris that have posed operational challenges at Millstone in the past. Although there are already ichthyoplankton abundance data, the abundance counts from the prototype screen would provide a more realistic estimate of the entrainable lifestages at the site.

There are many ways to conduct prototype studies using laboratory or field installed prototypes. In this case, a prototype constructed and operated in Niantic Bay would be the only alternative that would effectively resolve outstanding concerns on the feasibility, reliability, and species and lifestage specific effectiveness of fine-mesh screens at Millstone Station. Before the fine-mesh traveling water screens were constructed at Big Bend Units 3 and 4, a full depth but much narrower prototype was constructed and tested in the immediate vicinity of the existing Unit 3 intake. That study provided the data to demonstrate that a full-scale fine-mesh screening system at the site would operate reliably and achieve the larval survival rates necessary to offset the entrainment impact of the new unit (Unit 4) proposed for the project (Brueggemeyer, et al. 1988).

The Millstone site potentially has a ready-made platform for testing a prototype fine-mesh traveling screen. The Unit 1 intake structure could provide an opportunity to conduct tests without incurring the cost and permitting time necessary to construct a new temporary test structure in Niantic Bay. If the existing screens supports and pumps are available for use for the tests, costs for testing may be greatly reduced. If enough of the existing screen panels can be replaced with the fine-mesh screens to create a representative velocity condition, and a new spray wash and spray washwater collection facility could be constructed in or on the pumphouse structure, a suitable test facility can be developed. If the existing screens and pumps cannot be operated for a test of the prototype, the intake structure could still have some value as a platform for erecting a small-scale prototype. Depending on the timing of any prototype testing and the decommissioning of Unit 1, the necessary permits for organism collection and test facility modifications could be pursued with the federal, state and local regulatory authorities.

In addition to the screen structure, the prototype test facility would require a larval counting, sorting, and holding facility to evaluate the species and lifestage composition, the initial survival, and the long-term (usually 48 to 96 hour) survival of the larvae collected on the fine-mesh screen.

In conjunction with the larval fish survival testing, the engineering suitability of the fish-mesh screens can also be evaluated from the test platform. Under different wind, sea, and storm conditions the prototype test facility could be operated to evaluate the effectiveness of the fine-mesh screens for collecting and removing seaweeds, eelgrass, jellyfish, and other debris. The volumes of debris collected from the standard 3/8-inch and the fine-mesh screens equipped with lifting and collection buckets could be compared. In addition, the effectiveness of either a single- or dual-spraywash system could be evaluated with the debris that is actually and commonly collected from the waters of Niantic Bay.

In summary, this alternative could only be recommended for use at Millstone after additional site specific study proves the effectiveness of this device for the species and lifestages in Niantic Bay, and the most appropriate return location is identified. Additionally, as discussed in Part II, these are significant survivability, debris loading, reliability, and biofouling issues associated with this alternative.

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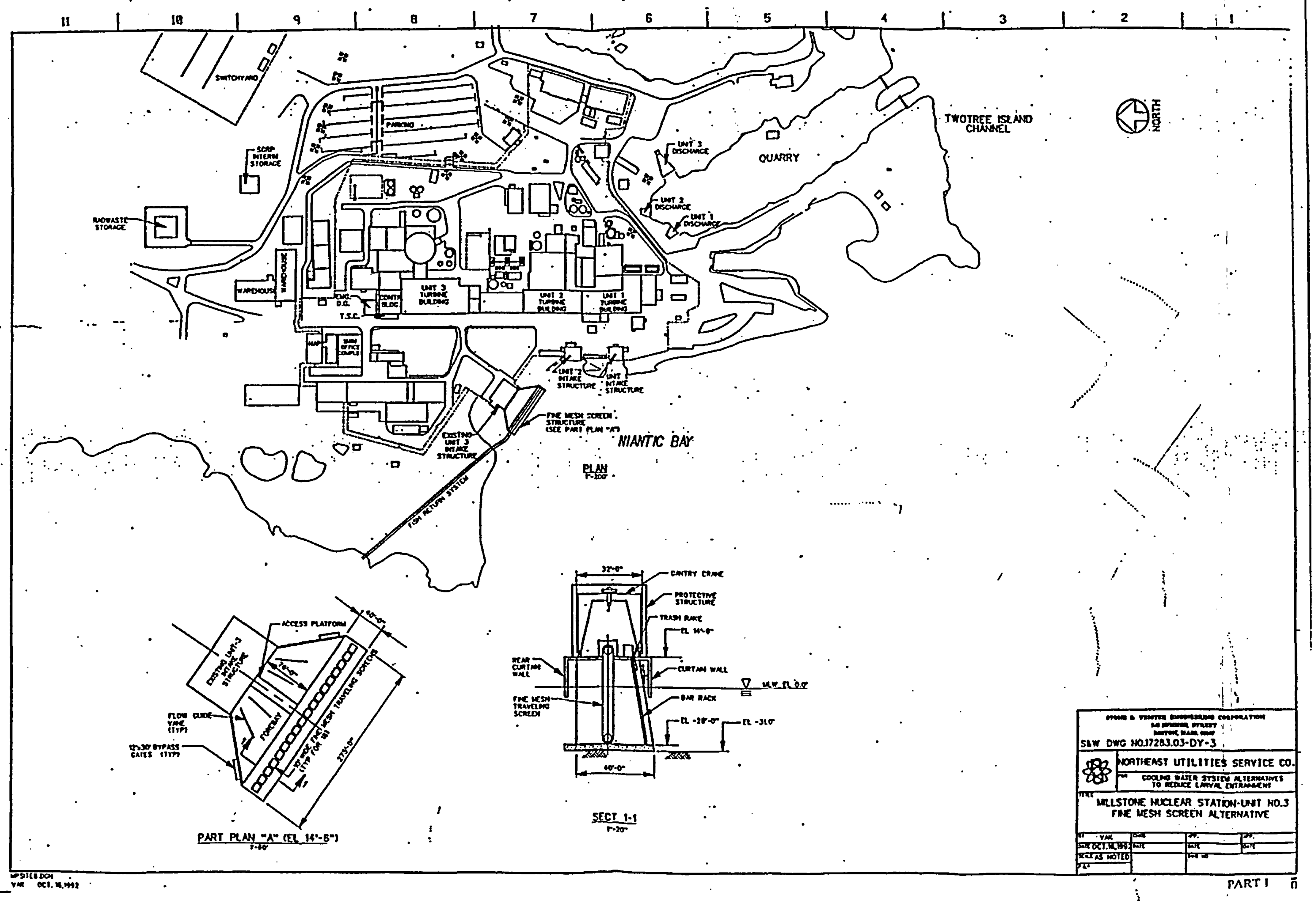

Figure 5.1-1: Millstone Unit 3 – Fine-Mesh Screen Alternative

5.2 FINE-MESH SCREEN FACILITY FOR UNIT 2

Application of through flow fine-mesh screens to Millstone Unit 2 would require a new screen structure, constructed in front of the existing intake structure, similar in design concept to that presented for Unit 3. The existing intake structure would remain functional with the existing traveling screens serving as back-up screens in the event the fine-mesh screens become blocked. Bypass gates would be provided to direct flow around the fine-mesh screen structure.

The existing traveling screens were sized for an approach velocity of approximately 1 fps. Because of concerns about the potential impact of debris, the recommended design approach velocity for backfit of fine-mesh screens would be 0.5 fps. Replacement of the existing traveling screens, in place, with new fine-mesh screens would not be recommended because of the high approach velocity.

The calculated Unit 2 circulating water flow rate with the re-tubed condenser would be approximately 500,000 gpm. Other Unit 2 design parameters for the fine-mesh screen facility would be as follows:

Screen mesh size	0.5 mm
Deck elevation	14 feet 0 inches
Invert elevation	-27 feet 0 inches
Approach flow velocity	0.5 fps
Screen basket width	10 feet

Eight screen units would be adequate to meet these design requirements.

The screen structure would be approximately 40 feet wide by 135 feet long. It would include both upstream and downstream curtain walls extending down to a depth of –5 feet for ice, cold weather and floating debris protection. Bar racks would be provided to catch large debris that could damage the traveling screens. The fine-mesh screens would incorporate a dual-pressure spray-wash system, which first removes impinged fish with low-pressure spray to a separate fish trough and then removes clinging trash with high-pressure spray to a separate trash trough. It was assumed the fish would be sluiced south of the Unit 2 intake and returned to Niantic Bay near the existing Unit 1 intake. A detailed study of the location of the sluice discharge would be required if this alternative were selected. The study would determine the most suitable discharge location to ensure that winter flounder larvae and tautog eggs were not drawn back into the intake. In addition, the study would need to determine the winter flounder larvae and tautog egg survival. Other equipment associated with the structure, in addition to the eight fine-mesh traveling screens, would include:

- Mechanical trash rake
- Screen-wash system including 4 screen-wash pumps, each rated at 5000 gpm at 200 feet total dynamic head
- Gantry crane
- Fish return sluicing system
- Trash sluicing system
- HVAC for enclosure structure
- Control equipment
- Electric supply equipment

The fine-mesh screen structure would be joined to the existing Unit 2 intake by double sheet pile walls with tremie concrete placed between the sheet pile. Each wall would have a 12-foot by 15-foot bypass gate. These bypass gates would be sized to bypass ½ of the total design flow to the Unit 2 intake. The bypass system would be provided in the event that some or all of the fine-mesh screen units become blocked or inoperable and to insure the flow to the safety-related service water system.

Flow guide vanes may be required in the fore bay to create uniform flow conditions entering the existing intake. Hydraulic model studies would be required to reliably evaluate fore-bay flow conditions and provide design of flow straightening features, if required.

It has been estimated that the capital cost for this alternative is $17,400,000. This cost does not include the costs associated with the hydraulic model or costs associated with prototype testing of the screens and fish return system.

As discussed in Section 5.1, this alternative could only be recommended for use at Millstone after additional site specific study proves the effectiveness of this device for the species and lifestages in Niantic Bay, and the most appropriate return location is identified. Additionally, as discussed in Part II, these are significant survivability, debris loading, reliability, and biofouling issues associated with this alternative.

6 DIVERSION SYSTEM EVALUATION

A diversion system typically uses a physical barrier to induce entrainable or impingeable organisms to either avoid the intake or concentrate in a section of the intake where they can be removed.

There are a variety of diversion systems that have been successfully installed and tested, and have proven that adult fish can be guided to a bypass structure and then pumped back to the receiving water or relocated at a downstream point in a river without pumping (EPRI 1986). At the Danskammer Point Generating Station, a test facility consisting of two 10-foot wide traveling water screens equipped with 1 mm mesh screen and set at a 25 degree angle to the flow has been used to experiment with adult, juvenile and larval fish diversion. Another full-scale angled fine-mesh traveling water screen diversion system was constructed for Unit 4 at Brayton Point Generating Station. Louvers have been installed and tested at the John Skinner Fish Facility at the Delta water intake facility and at a test facility at Southern California Edison's Redondo Beach Generating Station. More recently, a long array of angled louvers was installed in front of a hydroelectric intake in Holyoke, Massachusetts, and the system successfully diverted juvenile salmon and river herring (Harza and RMC 1993). Submerged traveling screens have been used with limited success to divert salmon smolts from hydroelectric intakes on the Columbia River. The Eicher Screen and a modification of the Eicher, the Modular Inclined Screen, have been used with some success to divert salmon smolts and some resident fish as small as 2 inches (EPRI 1994a; EPRI 1996a). Angled screens with fish bypass and pumping systems have been used with success for adult alewives drawn into an offshore intake for a steam electric generating facility on Lake Ontario (EPRI 1986).

However, diversion systems were developed and implemented primarily for adult species that can swim against the flow and move laterally along an angled screen to a bypass where the fish are then pumped back to the water body. The fine-mesh screens at Brayton Point Unit 4 were replaced with standard 3/8-inch mesh panels and the screen continues to function suitably to reduce the effects of impingement of juvenile and adult fish. To make these diversion concepts suitable for larval stages, the spacing and change of scale from currently suitable designs would result in the design being vastly different. The entrainable fish would not guide to a bypass on the scale necessary for an intake as big as Millstone based on the studies and diversions system tested to date. For this reason, diversions systems cannot be considered suitable for diverting early life-stages of fish found in Niantic Bay.

Part II of this report provides additional discussion of the effectiveness of some cooling water intake diversion systems tested in laboratory or prototype studies or installed at some operating steam electric plants. As discussed in Part II, the only diversion systems designed and tested with the intent of reducing entrainment also included fine-mesh screens in their design.

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7 FLOW REDUCTION CONCEPTS

As stated previously, Unit 1 has been shutdown with no plans for restart. Therefore, this Section will only discuss flow reduction alternatives for Units 2 and 3.

7.1 INTRODUCTION

The Millstone circulating water systems for Units 2 and 3, including the cooling water intake structures, condensers and piping, were designed and constructed to operate as a once-through cooling water system. Millstone Units 2 and 3 were designed to operate at a continuous 100% power level referred to as "base load units." The original design goal was to provide an efficient water system while minimizing effects on the fish and other aquatic organisms.

This Section addresses flow reduction alternatives which may reduce larval entrainment. The objective of any flow reduction is to reduce the circulating water intake volume, thereby reducing the number of organisms that become impinged or entrained. The flow reductions considered for Units 2 and 3 ranged between 8 to 92% of the values presented in the January 28, 1998 letter to DEP (NUSCO 1998). This range of flow reduction was selected to establish the relationship between the effect of flow reduction on the Station's output (i.e., electrical generation rate) and the reduction in mortalities of aquatic organisms. It should be noted that the shutdown of Unit 1 has already resulted in a 23% flow reduction.

The flow reduction methods considered in this Section are grouped into two major categories:

1. Station operational changes that could be implemented without major retrofits and/or replacement of any key circulating water system components, and
2. Station design modifications that would require major changes to the circulating water system.

The flow reduction alternatives, by category, that are addressed in this Section are listed below.

Changes in the station operation that were considered include:

- Reducing the number of operating circulating water pumps (CWPs). This alternative would require cross-connecting condenser water boxes, since each CWP discharges directly through a separate waterbox.

System design modifications that were considered include:

- Installing cross-connect lines on the discharge of the CWPs. This arrangement in combination with cross-connecting the condenser waterboxes and shutdown of a CWP would result in reduced flow;
- Throttling the CWP flow rate;
- Installing dual speed CWPs;
- Installing variable speed CWPs;
- Opening a recirculation line from the CWS discharge tunnel. This would reduce the flow into the Station by diverting a portion of the discharge flow back to the intake structure;
- Installing natural- or mechanical-draft cooling towers; and
- Installing dry cooling towers.

Tables 7.11-1 and 7.11-2 at the end of this Section, summarizes the percent flow reduction alternatives and identifies the change in Unit performance for each alternative, respectively.

7.1.1 Thermal Performance

The circulating water system flow is particularly critical to electrical output during the summer when peak electrical demand occurs simultaneously with high ambient water temperatures. With high ambient water temperatures, a reduction in circulating water flow reduces the thermal capacity of the condenser, decreasing turbine efficiency and electrical output. In addition, a reduction in the CWS flow rate increases the turbine backpressure toward its operating limit (i.e., 4.5 inch Hg) which, in turn, requires the Station to reduce reactor power and corresponding electrical output to maintain the turbine backpressure within the acceptable operating range. The CWS flow reduction also increases the ΔT across the condenser and the absolute temperature of the discharged water. Part II of this report discusses the potential impacts on survival of entrained organisms when the entrainment duration is extended and the ΔT is increased as a result of a reduction in cooling water flow rate through the condensers.

The evaluation of the thermal performance of the flow reduction alternatives used the daily mean seawater temperatures as input. These daily mean seawater temperatures are provided in Figure 7.1-1. This figure was developed from daily mean temperatures taken over a 24-year period (i.e., 1976 – 1999). The daily mean seawater temperature varies from a low of 36.8 °F in February to a high of 69.3°F in August.

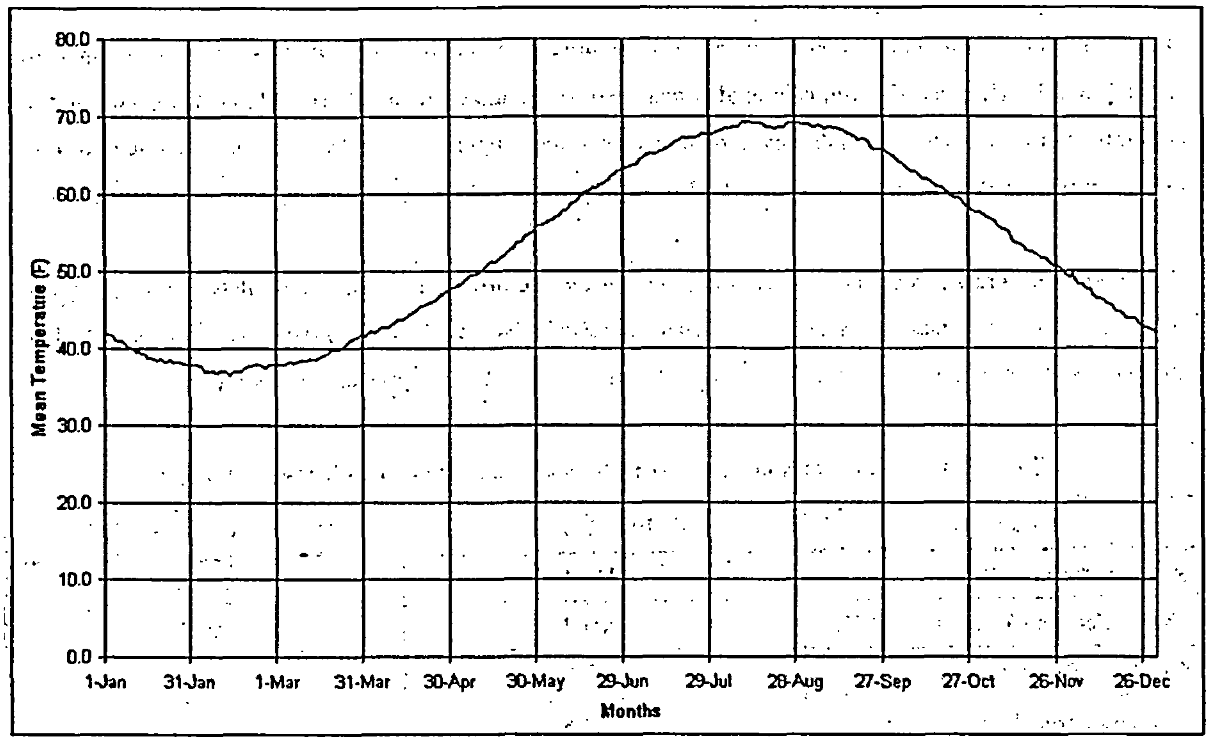

Figure 7.1-1: Daily Mean Seawater Temperature

During the summer, an increase in discharge water temperature due to flow reduction could result in discharge water temperatures that exceed levels currently specified by the NPDES permit. To prevent such increases in discharge water temperature, Station power levels would have to be reduced. Thus, the flow reduction could result in a Station derating at peak summer electrical load periods. The lost capacity at the Station would have to be replaced by other sources that have their own environmental effects. Fortunately, the period of greatest winter flounder larval abundance (March 22 through May 5) precedes the period of peak summer water inlet temperatures. However, the period of abundance for tautog eggs (May 3 through August 22) occurs during the peak water inlet temperatures.

The electric output performance of each Unit is interrelated with the individual operating parameters such as inlet temperatures, rates of cooling water flow throughout the Unit condensers, and operating power level. The computer program PEPSE (Scientech 1998) was used to aid in the modeling of the various alternatives. PEPSE analyzes the steady-state performance characteristics of thermodynamic systems and models individual components and streams. The program allows system performance to be calculated when system inputs are varied. Given a constant rate of power generation from the reactor, the heat rejection rate from the condensers to the cooling water would be constant. The more water which flows through the condenser in a specific interval of time, the smaller the amount of heat that would be taken up by a given unit of the water, and the lower the corresponding temperature rise (ΔT) would be across the condenser. However, if less water flows through the condenser, the heat transfer per unit of water would be

higher and the corresponding condenser ΔT will be larger. A separate PEPSE model was developed for Units 2 and 3. The PEPSE computer model was used to calculate the condenser ΔT, heat transfer, and to determine the loss of turbine efficiency at higher inlet water temperatures. This reduced efficiency, in turn, results in increased heat being transferred to the cooling water and consequently, higher condenser ΔTs.

The condenser performance and the electrical generation rate are the parameters of interest for this report. A comparison was made between the values calculated by the PEPSE model and the actual plant parameters at 100% power. Tables 7.1-1 and 7.1-2 summarize this comparison for each Unit.

Table 7.1-1: Comparison between Calculated and Measured Values – Unit 2

Parameter	PEPSE Values	Unit 2 Values (2/10/00)
Reactor Power (MWt)	2697.4	2697.4
Gross Electric Generation (MWe)	904.3	907.2
CW Inlet Temperature (°F)	35.8	35.8
CW Discharge Temperature (°F)	63.8	64.3

Table 7.1-2: Comparison between Calculated and Measured Values – Unit 3

Parameter	PEPSE Values	Unit 3 Values (2/10/00)
Reactor Power (MWt)	3410.6	3410.6
Gross Electric Generation (MWe)	1204.6	1209.7
CW Inlet Temperature (°F)	36.6	36.6
CW Discharge Temperature (°F)	55.5	55.7

The comparison shows that the PEPSE calculated values for gross electric generation and CW discharge temperature compare well and are within 1% of the measured values.

7.1.2 Circulating Water Pump Flow Rates

The CWS for Unit 2 has four CWPs and the CWS for Unit 3 has six CWPs. The CWPs were manufactured by Babcock & Wilcox Canada Ltd. and are motor-driven vertical wet pit pumps. Based on the manufacturer's pump curves, the CWP design points for maximum efficiency are 137,000 gpm at a total dynamic head (TDH) of 25 ft for Unit 2 and 152,000 gpm at a TDH of 25 ft for Unit 3. During the mid-1980s, the condenser for Unit 2 was replaced with a new condenser that had smaller diameter titanium tubes. Based on this new condenser, the design flow rate for the Unit 2 CWPs was specified to be approximately 130,625 gpm. The CWP design flow rate decreased due to increased system resistance because of the smaller diameter of the condenser tubes. The current flow rate for Units 2 and 3 CWPs were determined, based on calculations, to be 126,000 and 153,000 gpm, respectively (S&W 1982; S&W 2000).

The actual flow rate delivered by each CWP is a function of the pump design, tide elevation, and the resistance that the pumped fluid encounters, which is dependent of the design of the downstream components and impediments to flow. Impediments to flow are generally caused by an increased restriction in the main condenser such as fouling of the tubes or the buildup of debris preventing or reducing flow through the specific condenser tubes. Also, debris buildup on the intake screens and racks results in an impediment to flow. The flow rate for each CWP varies between a minimum value and some maximum value, but the design flow rate represents an average, debris-free condition of the cooling water system.

The minimum CWP flow rates for Units 2 and 3 are a function of the pump's performance (i.e., pump curve), design of the CWS, and tide elevations as well as the maximum temperature rise across the condensers as established by the NPDES permit. The discharge permit allows a maximum temperature rise across the condenser for Units 2 and 3 of 32° and 24°F, respectively. Using the PEPSE computer model, these maximum temperature rises correspond to a minimum flow rate per pump of approximately 96,700 and 107,400 gpm for Unit 2 and Unit 3 CWPs, respectively.

The design flow rates will be used to evaluate the effects of the flow reduction alternatives. This is conservative for evaluating the effects of flow reductions on both the electrical generation rate and entrainment.

7.2 REDUCED NUMBER OF OPERATING CIRCULATING WATER PUMPS

The CWS for Units 2 and 3 are designed as a once-through system for removing heat from the power conversion cycle. Each CWP (i.e., 4 for Unit 2 and 6 for Unit 3) provides cooling water flow to individual condenser waterboxes. The condenser waterboxes have cross-connect valves (i.e., 2 for Unit 2 and 3 for Unit 3) that allows continued cooling water to be supplied to each condenser waterbox with one or more CWPs inoperable or following a trip of a CWP.

Limiting the number of CWPs in operation to reduce flow would require taking either the respective unit condenser waterbox out of service, since each circulator discharges directly through separate waterboxes, or opening the condenser waterbox cross-connect. Operating with more than one circulator/waterbox out of service or operating with one CWP out of service for an extended time would result in an increased condenser load on the remaining condenser waterboxes. This increased load results in an increase in the turbine backpressure and reduces turbine efficiency. This condition is currently addressed in Millstone operating procedures (i.e., OP 2325A and OP 3325A), which consider this an abnormal Circulating Water System alignment, and requires caution in order not to exceed the turbine backpressure limit of

4.5 inch Hg. Also, operating with one CWP shutdown, makes the entire plant vulnerable to a trip due to a loss of a second CWP from environmental, maintenance, or single component failure. Operating with the condenser waterboxes cross-connected would be a preferable arrangement compared to isolation of a waterbox.

The following section provides a discussion of operating with a reduced number of operating CWPs for each unit.

7.2.1 Unit 2 Operation with Reduced Number of CWPs

During normal operation, the flow rate for each CWP can vary from a design value to a minimum value of approximately 102,000 gpm. The flow rate is a function of tide elevation and CWS design, as well as pump wear, condenser cleanliness, and screen/rack cleanliness. Industry experience suggests that operation at or near 75% of the CWP's best efficient point would result in stable hydraulic and mechanical performance if the pump and intake are in sound condition. Operating for an extended period below this value could result in pump damage due to vibration. Note that the CWPs were originally purchased with a design point of 137,000 gpm. As discussed previously, the Unit 2 condenser was replaced in the mid-1980s and the new condenser has smaller tubes. The design flow, per CWP, for the new condenser is 126,000 gpm. Operating with reduced CWPs below this flow rate would result in an increase in the turbine backpressure and reduction in the electrical generation rate. The reduction in electrical generation rate would be higher during the summer months when the circulating water inlet temperature is higher.

An evaluation was performed to determine the impact of operating the Unit with one CWP shutdown and the corresponding condenser waterbox cross-connect valve open. Operating in this configuration would result in a reduction in the Unit 2 CWS inflow of approximately 7% compared to the maximum station inflow. Note that the percent reduction in station inflow does not include the flow reduction associated with the shutdown of Unit 1. As stated previously, the electrical generation rate is a function of CW inlet water temperature and the heat transfer to the cooling water. Therefore, as the inlet water temperature increases and the CWP flow rate decreases, the electrical generation rate would decrease. Figure 7.2-1 shows the relationship between the change in electrical generation rate as a function of the inlet water temperature and operating CWPs. The impact on unit performance for this alternative is summarized in Table 7.11-2 for both winter flounder larvae and tautog eggs.

Operating in this configuration would be acceptable from a system performance viewpoint. However, this configuration would result in reduced flow through the condenser tubes, which increases maintenance requirements (e.g., waterbox cleaning). In addition, this configuration would result in an increased turbine backpressure in the shells with reduced circulating water flow rates and electric generation. Increased operator action may be required in order to maintain the condenser backpressure below the 4.5 inch Hg

limit as well as maintaining the differential pressure between the condenser shells below 2 inch Hg. This alternative also reduces the ability of the Unit to respond to transient flow or electrical load conditions because of the reduced number of operating pumps and the high turbine backpressure. The higher condenser backpressure reduces the time available for the operator to respond to a Unit transient before the backpressure limit would be reached. Although the Unit could operate under these conditions, the transients and high backpressure combine to influence the operational safety of the facility. Moreover, this option only reduces cooling water flow by 7%.

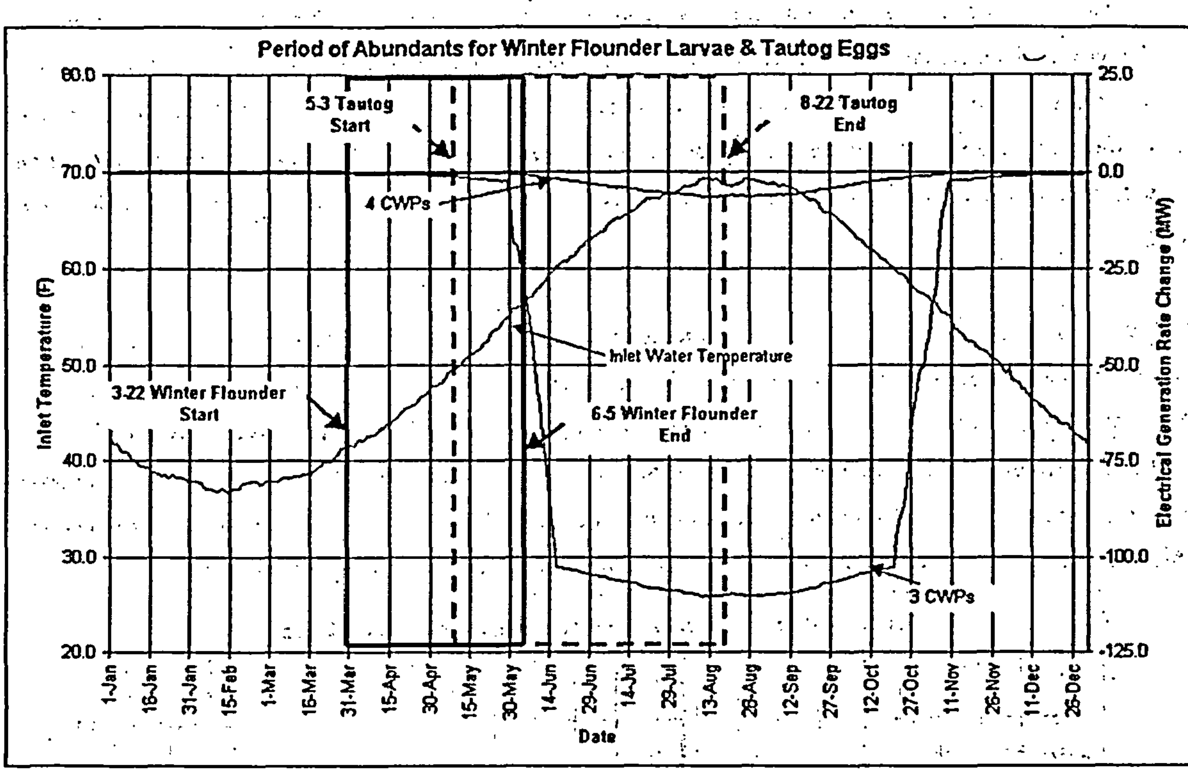

Figure 7.2-1: Millstone Unit 2 – Electric Generation Rate Change vs Operating CWPs & Inlet Temp

7.2.2 Unit 3 Operation with Reduced Number of CWPs

During normal operation, the flow rate for each CWP could vary from a design value of 153,000 gpm to a minimum value of approximately 114,750 gpm. The flow rate for each CWP is a function of tide elevation and CWS design, as well as pump wear, condenser cleanliness, and screen/rack cleanliness. As discussed previously, industry experience suggests that operation at or near 75% of the CWP's best efficient point would result in stable hydraulic and mechanical performance if the pump and intake are in sound condition. Operating for an extended period below this value could result in pump damage due to vibration. Operating with reduced CWPs would result in an increase in the turbine backpressure and a corresponding reduction in the electrical generation rate. The reduction in electrical generation rate would be higher during the summer months when the circulating water inlet temperature is higher. An evaluation was

performed to determine the impact on the Unit's performance with one and two CWPs shutdown and the corresponding waterbox cross-connect valves open.

Two cases were evaluated for this alternative: five CWPs operating and four CWPs operating. A 8% reduction in the CWS flow rate would be obtained with five CWPs operating and 16% flow rate reduction would be obtained with four CWPs operating. These flow rate reductions are based on a comparison to the CWS maximum flow rates without taking credit for the shutdown of Unit 1 (NUSCO 1998). As stated previously, the electrical generation rate is a function of CW inlet water temperature and the resultant performance of the condenser. Therefore, as the inlet water temperature increases and the CWP flow rate decreases, the generation rate would decrease. Figure 7.2-2 shows that there is no change in electrical generation rate as a function of the inlet water temperature and number of operating CWPs. The impact on unit performance for this alternative is included in Table 7.11-2 for both winter flounder larvae and tautog eggs.

The condenser pressure for Unit 3 is limited to approximately 4.5 inch Hg . The results of this evaluation show that with reduced number of operating CWPs, the condenser pressure would not exceed 4.5 inch Hg. No reduction in reactor power would be required when operating only four or five CWPs, based on an inlet water temperature of 70°F. Figure 7.2-2 shows the relationship between the change in electrical generation rate as a function of the inlet water temperature and operating CWPs. The impact on unit performance for this alternative is summarized in Table 7.11-2 for both winter flounder larvae and tautog eggs.

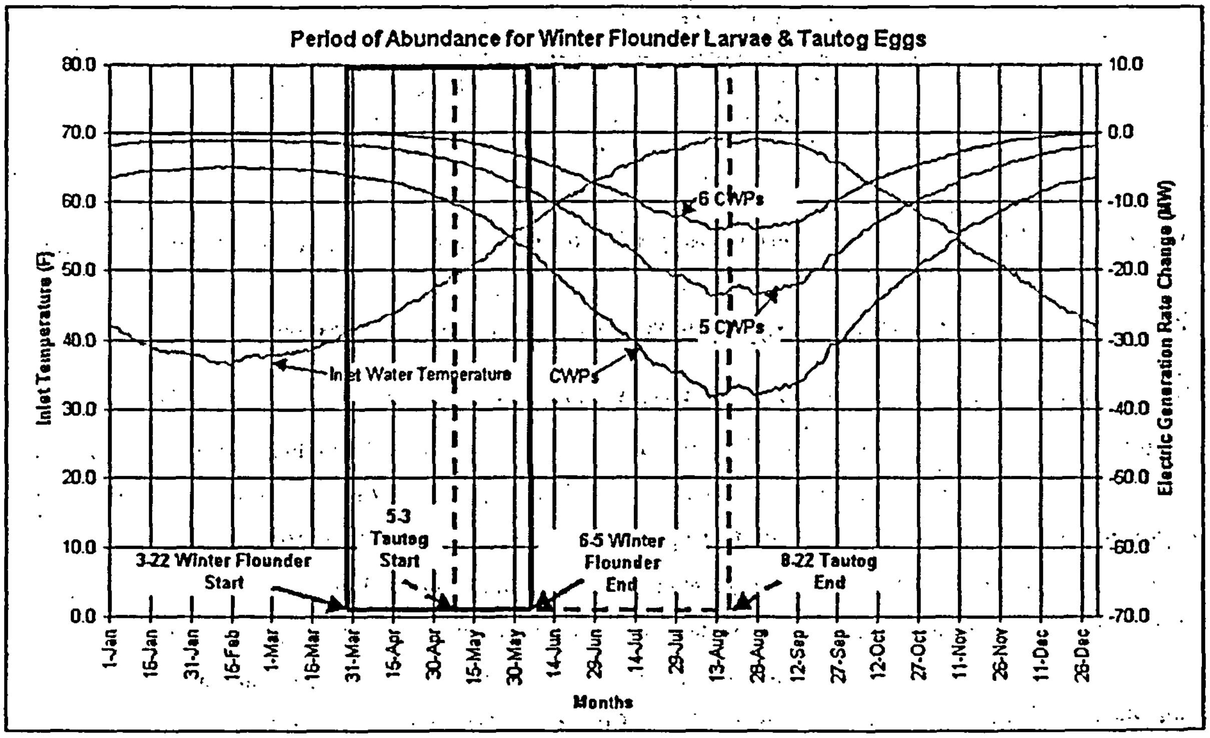

Figure 7.2-2: Millstone Unit 3 – Electrical Generation Rate Change vs Operating CWPs & Inlet Temp

7.2.2.1 Unit Reliability

In order to evaluate the impact on the Unit from operating with a reduced number of CWPs, a review of the Unit 3 Plant Condition Reports (CRs) for the Circulating Water System was performed. This review identified adverse plant conditions (through summer 2000) that involved a risk to generation. A total of 156 CRs were identified on the CWS system since commercial operation commenced in 1986. Thirty of the 156 CRs were identified as having a high impact on plant operation, they involved conditions such as plant trip, downpower, or system degradation that significantly challenged operation of the plant. Each of these conditions would have been more severe (e.g., additional plant trips or extended downpower) if the Unit had been operating with reduced Circulating Water System flows with one or more pumps isolated at the time of the event. These additional plant trips and downpower transients could have caused unnecessary challenges to plant equipment, and substantially reduced plant electrical generation factors.

An additional 20 of the 156 CRs were identified as having a smaller increase in the possibility of an impact on plant operation, if the Unit had been operating at reduced Circulating Water System flows. They involve an increased likelihood of a plant downpower or degradation of plant systems that would have required additional corrective action or more maintenance costs. An example includes degraded condensate oxygen chemistry resulting from decreased circulating water flow, which could result in a long-term degradation of the steam generators and require very expensive chemical cleaning with significant chemical waste generated. This condensate dissolved oxygen (DO) condition has been resolved, and since August 2001, Unit 3 no longer requires a downpower for this issue.

7.2.2.2 Performance

Operating in this configuration results in reduced flow through the condenser tubes, which increases maintenance requirements (e.g., waterbox cleaning). In addition, this configuration results in an increased backpressure in the condenser shells with reduced circulating water flow rates and electric generation. Increased operator action may be required in order to maintain the condenser backpressure below the 4.5 inch Hg limit as well as maintaining the differential pressure between the condenser shells below 2 inch Hg. This alternative also reduces the reliability of the Unit to respond to transients because of the reduced number of operating pumps and the high turbine backpressure that reduces the time available for the operator to respond. In addition, higher temperatures in the condenser increases plating out of materials on the tubes further reducing efficiency. Moreover, this option only reduces cooling water flow by 8 to 16%.

7.2.3 Operation with Reduced Number of CWPs and New Cross-Connects

As discussed previously, reducing the number of operating CWPs has a potential for reducing the reliability of the Units. Installation of cross-connect valves on the circulating water piping down stream of the CWPs

could increase reliability of the system. The cross-connect arrangement for Unit 2 would consist of installation of one 66-inch diameter line between the 84-inch B and C circulating water system trains. For Unit 3, two 66-inch diameter cross-connect lines would be installed between the CWS 84-inch pipes of trains B and C and between trains D and E. Each cross connect line would contain a 66-inch butterfly valve. Operating with these new cross-connect valves open as well as the condenser waterbox cross-connect valves open would allow the operating CWPs to supply flow to all of the waterboxes. This arrangement would tend to reduce the flow disparity between condenser waterboxes, which would reduce the differential pressure between the shells of the condensers. In addition, since each CWP can provide flow to all of the waterboxes, the loss of another CWP would result in a less severe plant transient since cooling water would still be supplied to all six waterboxes. Table 7.2-1 shows the CWS flow rates through each condenser waterbox when operating either five CWPs or four CWPs with all cross-connect valves open.

Table 7.2-1: Unit 3 CWS Flow Rates Through Condenser Waterboxes

No. of Operating CWPs	Waterbox A Flow Rate (gpm)	Waterbox B Flow Rate (gpm)	Waterbox C Flow Rate (gpm)	Waterbox D Flow Rate (gpm)	Waterbox E Flow Rate (gpm)	Waterbox F Flow Rate (gpm)
5 (CWP 1A off)	90,100	112,500	137,900	139,500	145,000	146,300
4 (CWPs 1A & 1F off)	87,900	109,800	129,800	130,000	110,000	88,000

Figure 7.2-3 provides a sketch of the Unit 3 Circulating Water System with the proposed cross-connect arrangement. Unit 2 would be similar except that only one cross-connect line would be required. The cross-connect lines for Units 2 and 3 would be installed in the area located between the intake structures and the turbine buildings. It has been estimated that the capital costs for installation of the cross-connect are approximately $559,000 for Unit 2 and $1,070,000 for Unit 3.

The percent flow rate reduction and the change in performance of each unit with the installation of the CWS cross-connect arrangement would be approximately the same as discussed previously for reduced number of operating CWPs. Moreover, this option only reduces cooling water flow by 7 to 16%.

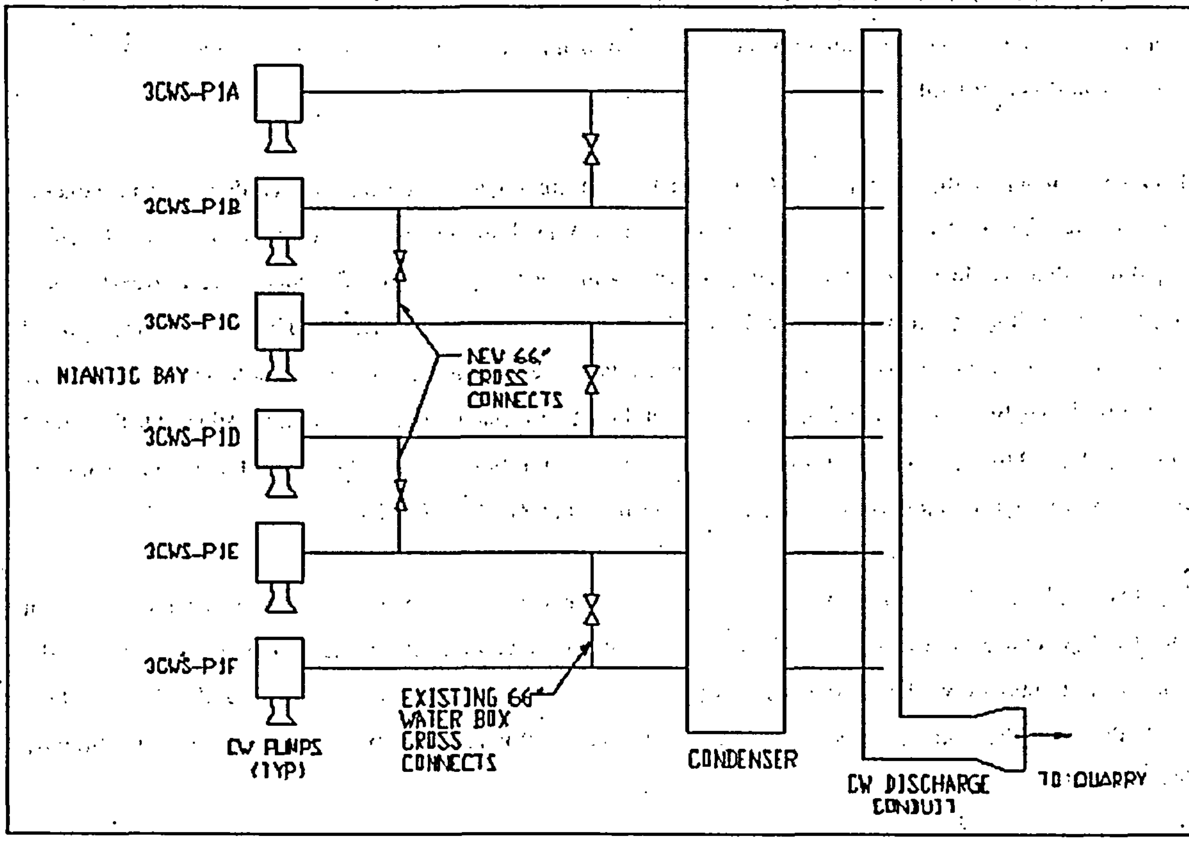

Figure 7.2-3: Millstone Unit 3 – Circulating Water System Cross-Connect Schematic

7.3 THROTTLING CIRCULATOR DISCHARGE FLOW

Circulating water pump flow could be reduced by throttling the motor operated butterfly valves located downstream of the condenser. The total reduction in the cooling water flow that is estimated to be achieved is similar to the alternative with the reduced number of operating CWPs (see Section 7.2). The butterfly valves for both Units 2 and 3 were not originally purchased for throttling applications. Therefore, using these valves in a throttling mode would result in the valves being damaged in a short-time period due to the increased velocity and resulting cavitation from operating the valves partially open. Physical modification to the circulating water systems would be required for this alternative to be feasible. The physical modification would include: 1) changing the butterfly valves (i.e., four valves Unit 2 and six valves Unit 3) to butterfly valves that are designed for throttling, and 2) changing the valve control scheme for each of the valves from an on/off control to an on/off control with throttle capability. Review of the Units 2 and 3 manufacturer's pump curves shows that throttling of the circulating water pumps to 75% of design point would be acceptable. This would result in CWP flow rate of approximately 103,000 gpm for Unit 2 and approximately 115,000 gpm for Unit 3. Throttling pump flow beyond 75% would put the pump operating point close to the unstable region on the pump curve, which could cause the pump to oscillate/vibrate. Operating below the 75% of design point could quickly result in pump damage or even failure. This

arrangement would result in a reduction in flow rate for Unit 2 and Unit 3 of approximately 6 and 15%, respectively. These percent reductions are compared against the maximum flow rates without taking credit for the shutdown of Unit 1.

Butterfly valves of this size (i.e., 84-inch) that are designed for throttling are available. One vendor, Trouvay & Cauvin has provided an estimate for a Vanadour Type T butterfly valve with throttling capability that would replace the existing valves. Vanadour Type T butterfly valves are currently being used for throttling applications in the Port Kelang Power Plant in Malaysia. This is the same type of application as would be used at the Millstone Units. The cost for each valve would be approximately $80,000. It has been estimated that the total capital costs for this alternative would be $948,000 for Unit 2 and $1,393,000 for Unit 3. If this alternative is selected, vibration levels at the top motor bearing would be monitored for significant change to ensure long-term reliability of the CWPs.

Figures 7.3-1 and 7.3-2 shows the relationship, for Units 2 and 3, respectively, between the change in electrical generation rates for all CWPs operating with the CWS throttling alternative as a function of the inlet water temperature. The impact on unit performance for this alternative is summarized in Table 7.11-2 for both winter flounder larvae and tautog eggs. Moreover, this option only reduces cooling water flow by 6% for Unit 2 and 15% for Unit 3.

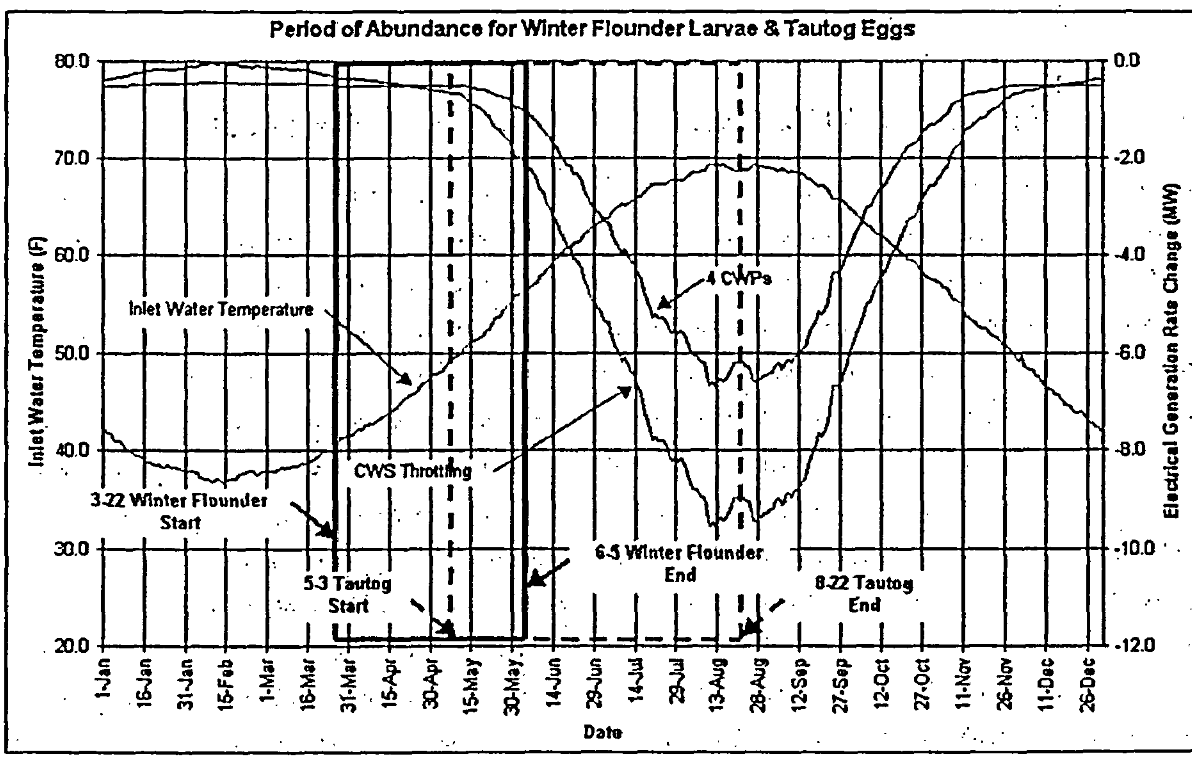

Figure 7.3-1: Millstone Unit 2 – Electrical Generation Rate Change with CWS Throttling Option

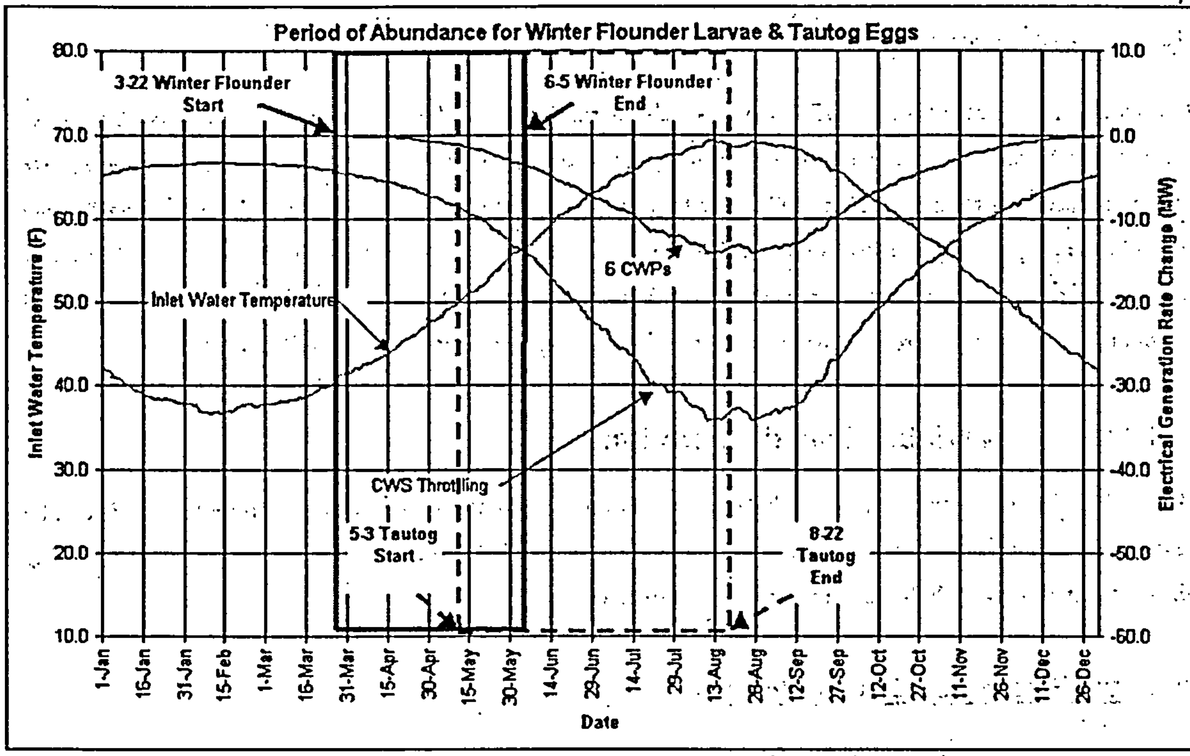

Figure 7.3-2: Millstone Unit 3 – Electrical Generation Rate Change with CWS Throttling Option

7.4 VARIABLE SPEED CIRCULATORS

7.4.1 Variable-Speed Drive Pumps – Unit 3

Variable-speed drives for the circulating water pumps would allow reduction in circulating water flow during periods of interest. A variable speed and a two-speed drive, which would operate the circulating water pumps either at rated flow or at a reduced flow rate, were evaluated in this Section.

7.4.1.1 Hydraulic and Pumping Energy Requirements

<u>Variable Speed Operation</u>

Installation of variable frequency drive (VFD) controls for each existing circulator would allow the pumps to be operated at a reduced flow during periods of high entrainment. The lower pumping capacity would also allow for a lower approach velocity at the traveling screens. With this technology it would be possible to vary the speed of the motor from 10 to 100%. For this evaluation, the speed of the motor was limited to produce a flow rate of approximately 75% of the manufacturer's specified design point for flow. This results in a flow rate of approximately 115,000 gpm for each pump.

Two-Speed Operation

Reduction in the pump speed to 75% would result in transposition of the pump performance curve to flows equal to 75% of the existing curve and total dynamic heads of 9/16 of the existing curve, according to pump affinity laws (Karassik et al. 1976). Reducing six circulating water pumps to 75% speed would result in each pump operating at a flow of 115,000 gpm at a total dynamic head of 15.2 feet. This would result in a reduced power requirement for each pump from the existing 1,225 to 520 horsepower. This total reduction in pumping energy requirements for 75% speed operation would be 2,889 kW.

7.4.1.2 Variable Speed Operation

A variable circulating water flow can be achieved by controlling the speed of the pump motors. This can be accomplished either by installing variable frequency drives (VFDs) for the existing motors or by replacing the existing motors with 2-speed motors and controllers.

Variable Frequency Drives (VFDs)

Medium voltage variable frequency drives that can run the circulating water pump motors in the range of 10 to 100% of the rated speed are available. ABB and Robicon, two of the several manufacturers of these VFDs in the US, were contacted to discuss the application and requested to provide quotes for the VFDs. 12-pulse and 24-pulse pulse width modulated (PWM) type VFDs are manufactured by these two companies.

According to the manufacturers, the VFDs produce a near-sinusoidal current in the motor. The VFDs will be equipped with input isolation transformers and output filters. The output filters absorb voltage spikes created by the VFDs to protect the motors. Therefore, it may not be necessary to replace the existing motors. However, based upon the maintenance history and the age of the motors, the need to replace the existing motors with new motors must be evaluated. The cost of the new motors is included in this report, although the replacement may not be required until further evaluation is performed.

The six VFDs would be supplied from the 4160-V switchgear 34A and 34B, three from each switchgear. The existing 4160-V circuit breakers in the switchgear can be used. Preliminary estimates indicate that harmonic distortion produced by the VFDs is not significant and would likely to be well within the limits recommended by IEEE Std. 519-1992. Consequently, harmonic filters would not be required. If this alternative is selected, a complete harmonic analysis would be required to confirm the preliminary estimates.

The VFDs would require a metal enclosure or a building with dimensions of approximately 50 feet long by 40 feet wide by 12 feet high complete with lighting and HVAC to dissipate the heat generated by the VFD components.

Based upon a quote from Robicon, each VFD would cost approximately $200,000. In addition, the cost of each new motor would be approximately $500,000. The capital cost for installation of the VFDs is estimated to be $7,580,000.

Two-Speed Motors

The existing pump motors would be replaced with 2-speed motors of the same horsepower and voltage ratings and each new motor would require a controller. The motors can run either at 100% or at 75% of the rated speed. TECO-Westinghouse Motor Company was contacted to provide a quote. Based upon a quote from TECO-WMC, each motor and controller would cost approximately $590,000. The capital cost for installation of the two-speed motor alternative is estimated to be $6,900,000.

Power would still be provided to the motors from the six breakers located on buses 34A and B. However, a two-speed motor starter would be required for each motor to reconnect the windings to change the motor speed. The motor starters would be controlled from control switches mounted on the main control board. The screenwell structure is neither a suitable environment nor does it have adequate space to locate this equipment. Therefore, the cost of a heated and ventilated building, 30 feet long x 25 feet wide x 12 feet high, was included to house the starters. It was assumed that the existing circulating and service water pumphouse would provide power for the new building HVAC and lighting. The building would be located behind (i.e., between the intake structure and the turbine building) the circulating and service water pumphouse.

As part of the estimate, it was also assumed that existing motor feeder cables would be pulled back to the manhole nearest the circulating and service water pumphouse. This is approximately 300 feet from that structure. A new ductline from the existing manhole to the new starter building would be included. The existing cables would then be pulled and connected to the two-speed motor starters. Finally, new ducts from the motor starter building to the existing circulating and service water building with new motor feeder cables would be included. A cursory check of the existing installation indicated that the foundations were adequate. However, if this alternative were pursued, an extensive investigation of the foundations would be required.

A comparison between the above two options shows that the VFDs would preferable to the two-speed motors because of the lower cost (assuming that the existing motors need not be replaced) and greater flexibility. In addition, since the temperature of the water in the LIS varies over the course of the year,

finding and operating at an effective single lower pump speed could potentially reduce the Unit's output when the reduction in flow is not matched to the intake water temperature and operating conditions.

7.4.2 Variable-Speed Pumps – Unit 2

The conclusions reached above for Unit 3 would also be applicable for Unit 2. Utilizing a VFD to vary the circulating water pump's flow rate would be a better alternative than using a two-speed pump. The flow rate for this alternative could be reduced to approximately 75% of the design point of the pump (i.e., 103,000 gpm per pump). The capital cost for this alternative was estimated at two-thirds the cost for Unit 3 since Unit 2 has four pumps compared to six pumps for Unit 3. The capital cost for this alternative would be approximately $5,050,000.

7.4.3 Impact on Unit Performance

Use of variable-speed pumps would result in reductions of cooling water flow at Unit 2 of 6% and at Unit 3 of 15%.

Reduction in circulating water flow rate to each condenser would also result in a reduction in performance of each unit. This reduction in unit performance would be due to the reduced flow in the condenser tubes and reduction in the heat transfer efficiency of the condenser tubes due to reduced tube flow velocities. A 90% cleanliness factor could only be maintained with on-line ball cleaning at reduced tube flow velocities. Currently, neither unit has an on-line tube cleaning system. Capital cost of this cleaning system would be approximately $1,000,000.

Without on-line tube cleaning, the condenser tubes would foul. The load for each unit would have to be reduced as the condenser become fouled in order to avoid turbine trip. Because of the fouling buildup of slime in the tubes during reduced flow operation, condenser tube cleanup would be required to be performed more frequently.

Figures 7.4-1 and 7.4-2 shows the relationship, for Units 2 and 3 respectively, between the change in electrical generation rates for all CWPs operating and the CWP variable speed alternative as a function of the inlet water temperature. The impact on unit performance for this alternative is summarized in Table 7.11-2 for both winter flounder larvae and tautog eggs. The variable speed CWP alternative would result in a net decrease in Units 2 and 3 pumping energy consumption of approximately 1,757 and 2,889 kW, respectively.

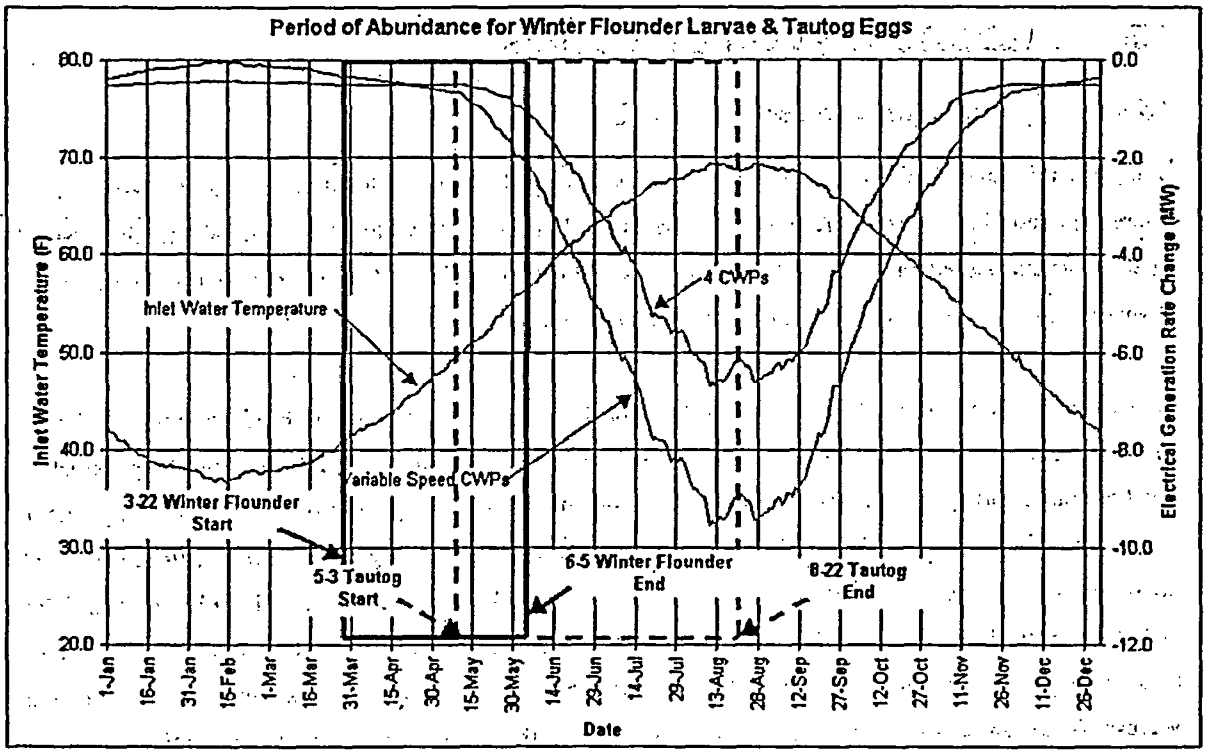

Figure 7.4-1: Millstone Unit 2 – Electrical Generation Rate Change with Variable Speed CWPs

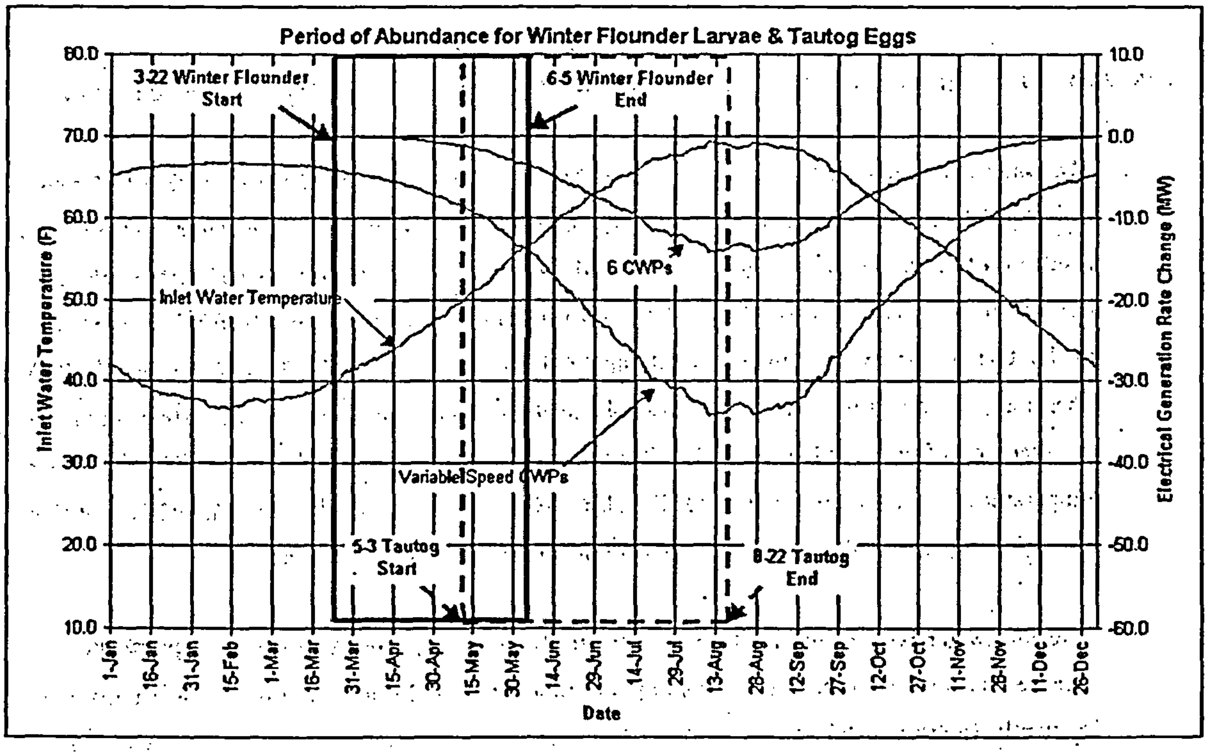

Figure 7.4-2: Millstone Unit 3 – Electrical Generation Rate Change with Variable Speed CWPs

7.5 RECIRCULATION CONCEPTS

7.5.1 Tempering Line – Unit 2

Unit 2 has a 78-inch tempering line which redirects flow back to the intake structure and discharges into a concrete plenum in front of the trash racks. The original purpose of the tempering line was to allow heated water to be discharged in front of the trash racks for ice prevention. The tempering line takes suction downstream of the condenser in the common discharge header.

The use of this line to divert a portion of the flow back to the intake structure in order to reduce the intake flow for Unit 2 was evaluated. It has been estimated that with four CWPs operating, approximately 108,400 gpm could be diverted back to the intake structure. This alternative would allow all four CWPs to remaining operating and would therefore not affect the reliability of the CWS. In addition, since the flow is not diverted until after the condenser, the water velocity through the condenser would not be affected. Note that it is desirable to maintain the design velocity through the condenser tubes. If the water velocity through the condenser was reduced it could impact the performance and increase maintenance requirements because of the increased amount of debris that could settle out and the increased potential for marine fouling. This alternative would reduce the inflow by approximately 7%. Figures 7.5-1 and 7.5-2 provide sketches of this alternative.

There is one major and one minor disadvantage associated with this alternative that are discussed below:

1. The water that is diverted back to the intake structure would increase the inlet water temperature from the LIS by approximately 6.5°F. The increased circulating water inlet temperature would result in a loss in electrical generation rate and the circulating water discharge temperature from the condenser would increase. Unit 2 has a maximum temperature value that limits the operation of the Unit if the average inlet water temperature is above 75°F (Tech Spec Section 3/4.7.5). Therefore, given that this alternative raises the average inlet temperature by approximately 6.5°F, the reactor power would have to be decreased by approximately 28% when the inlet water temperature reached approximately 68°F. This power reduction would occur after May 5, during the period of greatest abundance for winter flounder larvae and tautog eggs.

2. Diverting water back to the intake structure via the tempering line violates the NPDES Permit, because this is not an approved discharge path. In addition, chlorination of the CWS is performed frequently (approximately twice a week) in order to control fouling in the condenser. When chlorinating the CWS, the tempering line would be required to be isolated. In addition, there is the potential for contaminating the secondary service water with wastes that are currently released to the discharge. Waste tanks for the Unit are drained into the CWS conduit for discharging into

the quarry and ultimately into Long Island Sound. Diverting this discharge back to the intake structure would also be in violation of the NPDES Permit. Therefore, when the tempering line is in use, the discharge from the waste tanks would not be allowed unless the NPDES permit was altered by allowing a different point of discharge.

In order to use this alternative, the following system changes would be required:

- The controls for the butterfly valve on the de-icing line would have to be changed to allow automatic closure upon loss of an operating CWP. This control scheme change, although not mandated, would allow cooler water to be pumped through the condenser and, therefore, would reduce the rate that the backpressure increases following a loss of a CWP.

- Four discharge ports, approximately 3 ft diameter each with a sluice gate, would have to be added to the concrete plenum in order to allow the redirected water to be discharged directly into the intake structure.

It has been estimated that the capital cost for this alternative is approximately $201,000.

Since this alternative could not be used when chlorinating the CWS, during discharge of waste tanks, and could impact the operation of the Unit as the inlet water temperature approached the Technical Specification limit, this concept is not identified as a feasible alternative. Therefore, further evaluation of this alternative was not performed.

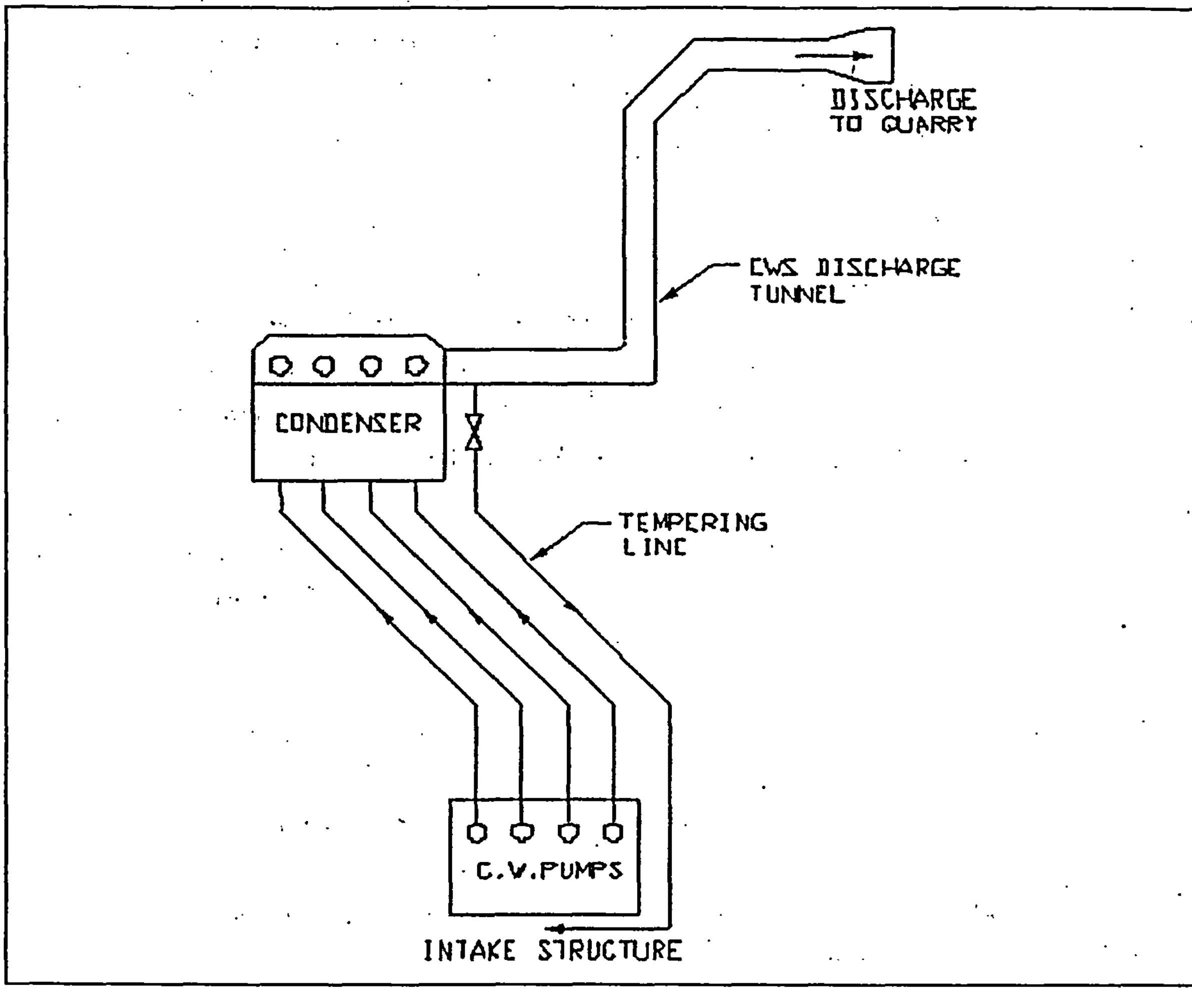

Figure 7.5-1: Millstone Unit 2 – Circulating Water System Schematic

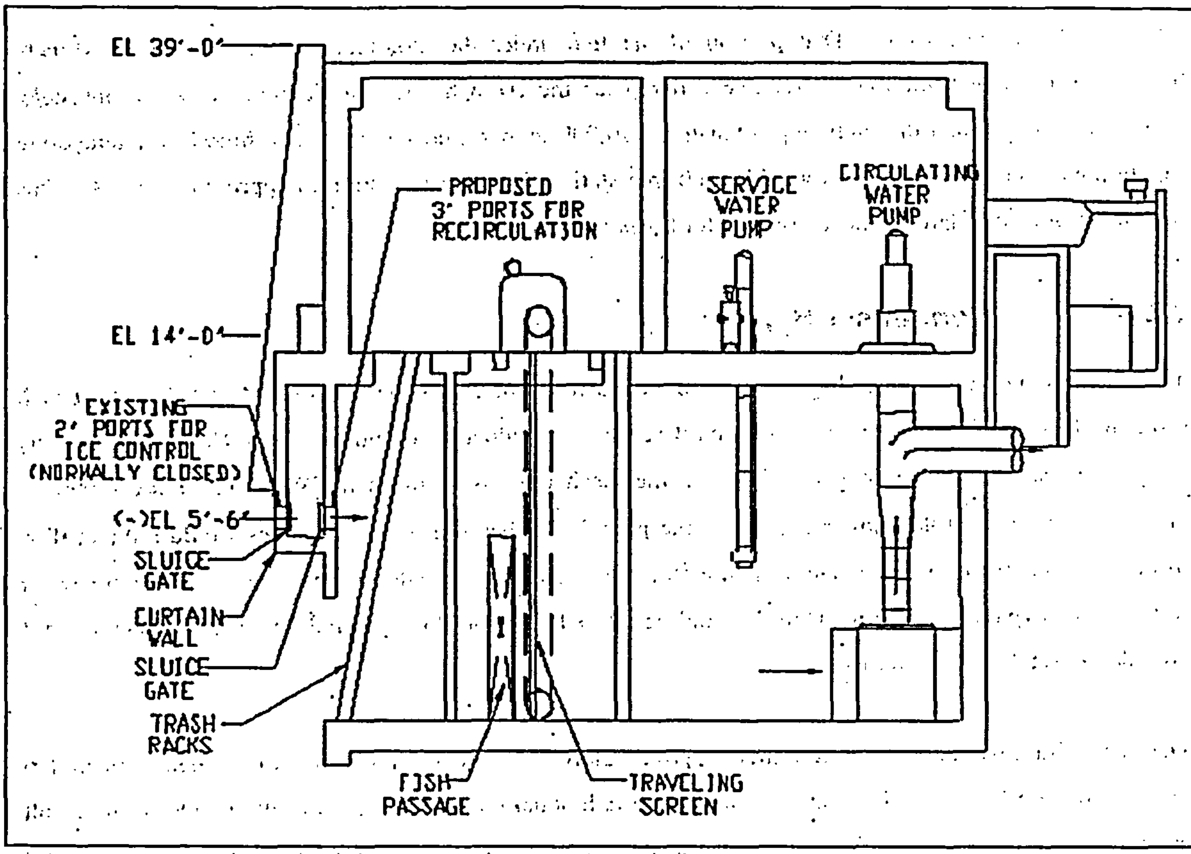

Figure 7.5-2: Millstone Unit 2 – Circulating Water Intake Structure With Recirculation Alternative

7.5.2 Tempering Line – Unit 3

Unit 3 has a 60-inch tempering line which redirects flow back to the intake structure and discharges into a concrete plenum in front of the trash racks. The original purpose of the tempering line was to allow heated water to be discharged in front of the trash racks for ice prevention. The tempering line takes a suction downstream of the condenser in the common discharge header. The tempering line is capable of circulating approximately 57,000 to 90,000 gpm of CWS discharge flow back to the Unit 3 intake structure. The diverted flow reduces the inflow by approximately 4 to 6%. This option was not considered to be a viable alternative because of the low reduction in flow and for the same disadvantages described above for Unit 2.

The installation of an additional Unit 3 60-inch tempering line with variable-speed pumps was considered. However, based on the uncertainty of the impact this option may have on the Unit's CWS hydraulics, it was not considered as an acceptable alternative for future consideration.

The removal of the existing Unit 3 60-inch tempering line and replacement with an 84-inch pipe without pumps was also considered. The 84-inch pipe would only replace the portion of the existing 60-inch tempering line that is accessible and is not routed under the Main and Normal Station Transformers and the

Auxiliary Boiler enclosure. That portion of the line under the structures would remain as 60-inch. Tunneling under the buildings to remove and replace the 60-inch line was determined to be infeasible. Calculations concluded that only approximately 126,000 gpm would be circulated through the tempering line to the Intake Structure. This would result in a station flow rate reduction of approximately 6%. This option was not considered as an alternative for further evaluation.

7.5.3 Condenser Bypass

The installation of a condenser bypass lines on the discharge of each CWP would re-divert flow from each CWP back to the intake structure and would result in a reduction of inflow from Niantic Bay. This alternative consists of installing two lines on the discharge casing of each CWP. The lines would be installed 180° apart at the same elevation as the pump's discharge nozzle. The lines would redirect flow from the CWP back to the intake structure through a diffuser pipe downstream of the traveling water screen. The bypass-line size for Unit 2 would be 20 inch and for Unit 3 would be 24 inch. Figure 7.5-3 provides a sketch of this alternative.

The bypass lines would be sized to redirect approximately 25% of the pump's flow rate, when compared to the manufacturer's specified operating point on the individual pump curves. This alternative would result in very modest reductions in flow from Niantic Bay of approximately 6% for Unit 2 and 15% for Unit 3 when compared to the maximum flow rates. A detailed evaluation and model test of this alternative would be required to substantiate the CWP operation if this alternative was selected.

The capital costs for this alternative would be $813,000 for Unit 2 and $1,390,000 for Unit 3. These costs do not include the detailed evaluation or the model test. The change in Unit performance for this alternative would be approximately the same as specified for the throttling alternative (refer to Section 7.4).

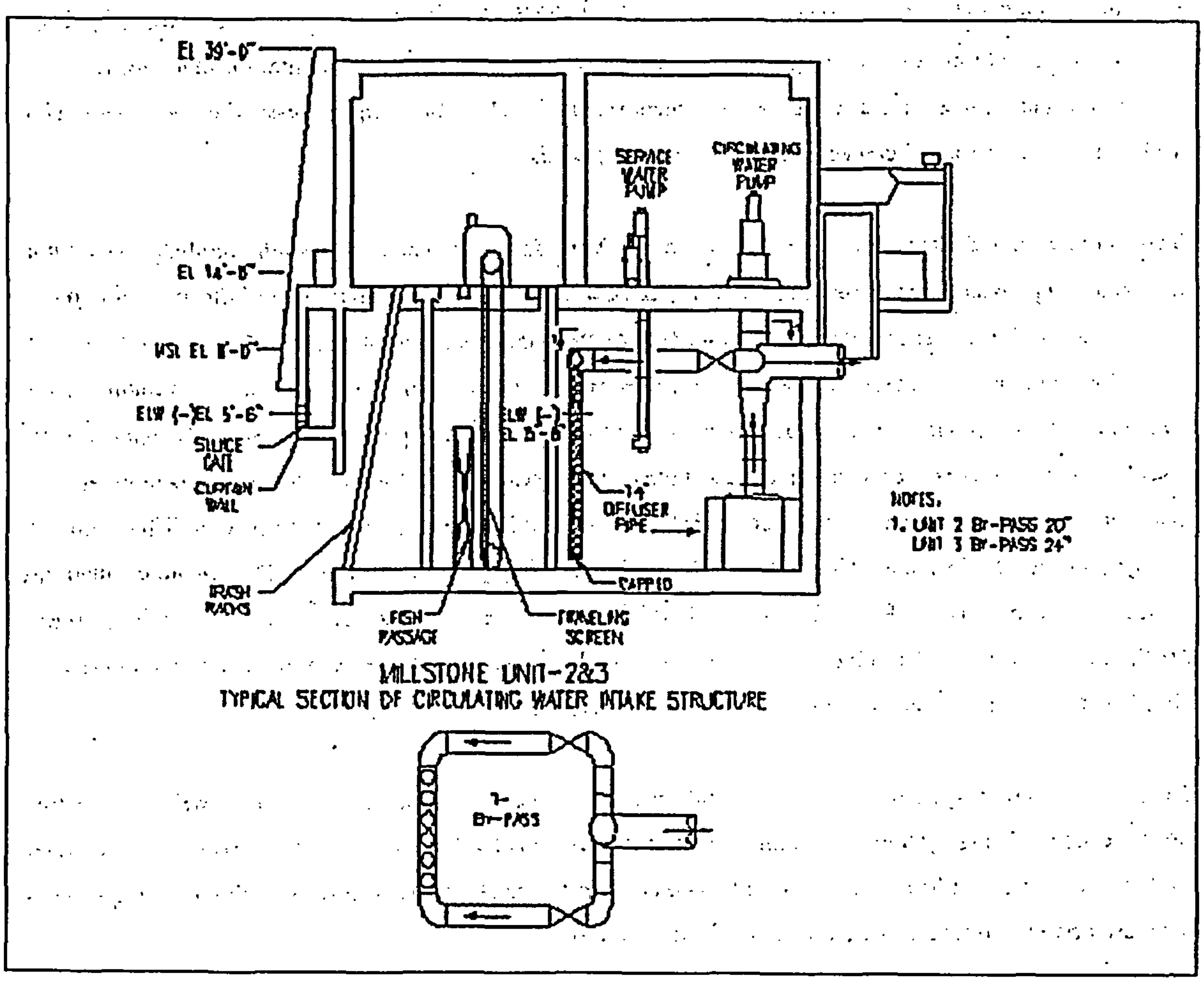

Figure 7.5-3: Condenser By-Pass Alternative

7.6 NATURAL-DRAFT COOLING TOWER – UNIT 3

In an electric generation station the main cooling water system is one of the first systems to be designed and installed. Careful consideration is given to the availability of a reliable source of cooling water for condensing the exhaust steam from the steam turbine(s) and removing heat from other equipment. The designs of many major capital cost components and the system capacity are related to the characteristics of the heat sink (i.e., the cooling water supply). Therefore, any subsequent change to the cooling water system would have a significant impact on the plant's ability to operate effectively at expected design conditions. Even minor changes to the cooling water supply (for example a temperature increase of a few degrees above design or a reduction in flow) can result in a large decrease in the plant's ability to achieve its rated electric generating capacity. In addition, because cooling water systems are one of the first systems to be installed during plant construction, many other plant systems, structures and components are built around and over the system, making retrofitting complicated and expensive.

This alternative for Unit 3 was originally evaluated in the NUSCO (1993) feasibility study. The technology for design of natural-draft cooling towers has not changed since the submittal of that study. The description and engineering evaluation have been repeated below for completeness. The costs associated with this alternative have been updated to the current period.

Two cooling tower alternatives are addressed for Unit 3; a full-size natural-draft cooling tower with accompanying closed-loop circulating water systems, and a similar, but smaller, natural-draft cooling tower system designed to reject 2/3 of the unit waste heat to the atmosphere and the other 1/3 of the waste heat to LIS. The objective of these cooling tower alternatives was to reduce egg and larval entrainment by reducing station saltwater withdrawal rate from Niantic Bay. These two cooling tower alternatives were selected to provide representative current capital cost estimates, unit performance impacts, and construction duration for converting Unit 3 wholly or partially to a closed-loop circulating water system. The results of studies prepared for Millstone Unit 3 during the initial licensing process (Millstone, FSAR) and evaluations conducted during the 1980s addressing closed-loop cooling systems using various cooling tower configurations were used as a basis for this updated study. However, new arrangement and quantities were developed in order to evaluate the cooling tower alternatives.

Both cooling tower system designs would allow either full-time or part-time operation with the existing once-through cooling systems remaining intact and operational. The nuclear safety-related service water system for Unit 3 would remain as is with both cooling tower alternatives; however, regulatory approvals for these cooling tower alternative would still be required.

As seen below these two cooling tower alternatives have very high capital and operational costs.

7.6.1 Full-Size Cooling Tower

This alternative would consist of conversion of the existing once-through circulating water system for Unit 3 to a closed-loop system utilizing a natural-draft saltwater cooling tower. The heat from the condensed steam would be rejected to the atmosphere, primarily by evaporation of the saltwater in the cooling tower. The service water system would remain on a once-through cycle.

The net effect, without considering the shutdown of Unit 1, of this alternative, would be to reduce total station (Units 2 and 3) intake flow from Niantic Bay to approximately 60% of its maximum value. The current total withdrawal rate of saltwater from Niantic Bay is approximately 1,500,000 gpm. The cooling tower would reduce the required Unit 3 circulating water flow withdrawal from 918,000 to 36,000 gpm for cooling tower makeup would result in a total station withdrawal of about 594,000 gpm. Refer to Table 7.11-1 for a summary of the flow reduction.

The natural-draft saltwater cooling tower alternative would consist of the tower located in the wooded area to the east of the switchyard as shown on Figure 7.6-1. This location was selected to locate the cooling tower downwind (the prevailing wind direction is the west) of the switchyard. The cooling tower would have a new circulating water system with the new pump station at the tower location. The existing condenser operation would be changed from the current single-pass configuration to a two-pass configuration. This change would be necessary to maintain high condenser tube velocities for efficient heat transfer with the reduced circulating water flow rate in the closed-loop system. The existing condenser has adequate pressure rating (80 psi) and valving to allow operation in a two-pass mode with no modifications. The proposed circulating water piping from and to the cooling tower would be routed to the north and west of the station and would be manifolded into the existing circulating water piping on the west side of the station as shown on Figure 7.6-1. Two 14-foot diameter pipes (i.e., one supply and one return) would be installed in a common cut and cover trench. The trench would be approximately 46 feet wide. Valving would be provided at the tie-in point of the new closed-loop circulating water system piping and existing circulating water piping to allow operation of Unit 3 either on the cooling tower or once-through. Figure 7.6-1 shows the initial engineering concept for the tie into the existing circulating water system piping. The new piping to and from the cooling tower would have to pass over the existing safety-related service water piping. If this alternative were selected, detailed engineering of this cross and tie-in would be required to ensure that the non-safety-related circulating water piping would not impact the safety-related service water system.

New makeup water pumps would be required in the existing Unit 3 intake structure. The cooling tower blowdown would be discharged to the quarry at the existing Unit 3 outfall.

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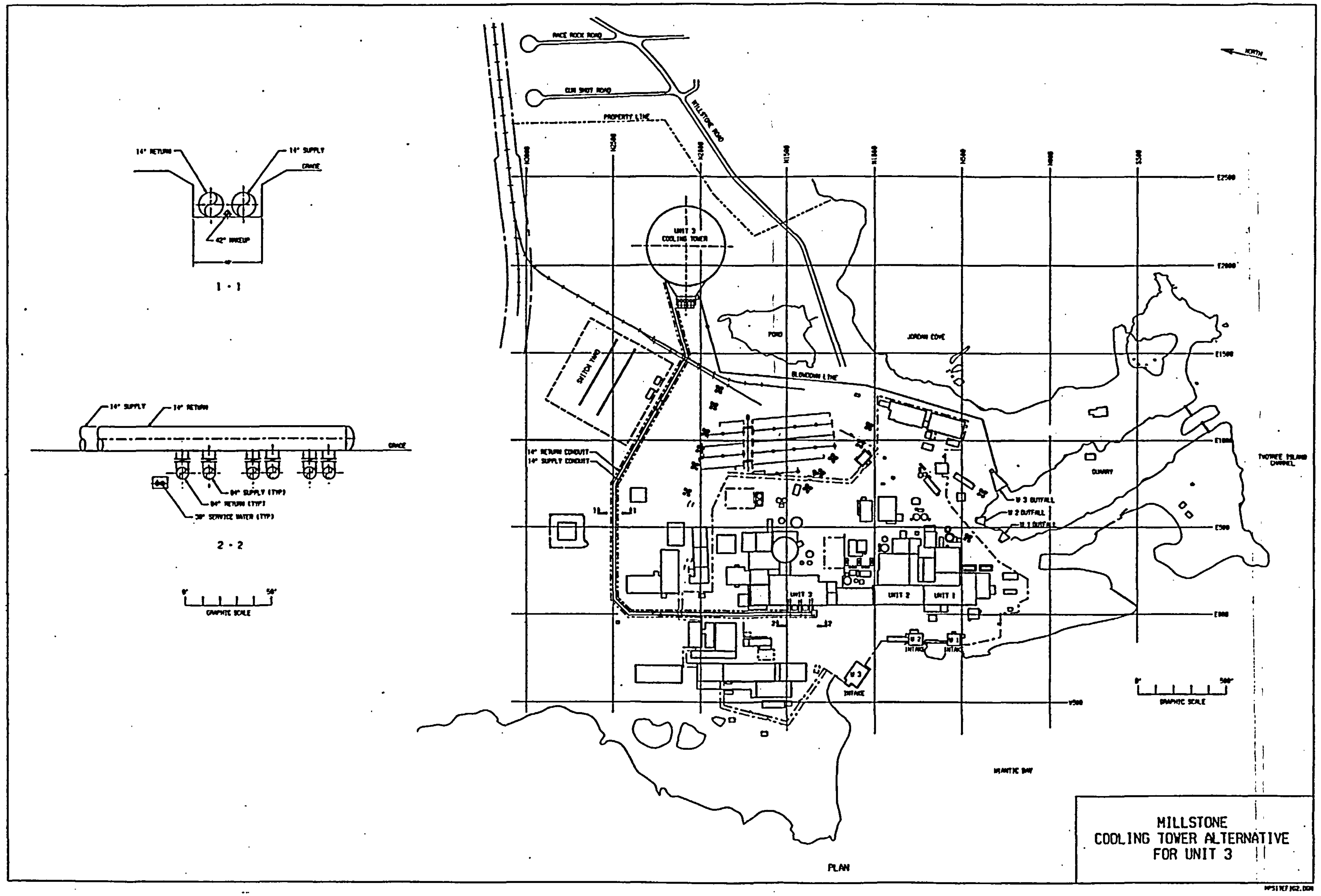

Figure 7.6-1: Unit 3 - Natural-Draft Cooling Tower Arrangement (Full Size)

7.6.1.1 Cooling Tower Design – Unit 3

The natural-draft saltwater cooling tower for Unit 3 would be designed to operate year round including the summer period. However, the system is designed to allow the unit to switch from closed-cycle to once-through design with a short outage period between each change over. The tower would be a large structure, 442 feet in diameter at the base and 550 feet tall from the basin curb to the top. The tower design would be the of counterflow configuration with the fill located within the tower shell just above the air inlet. The fill mass would be disc-shaped covering the full plan area of the tower and would be approximately 4 feet in thickness. A system of channels, pipes, and spray headers would distribute the circulating water evenly over the fill area. Provisions for ice control, such as a spray curtain ring covering the circumference of the air inlet and fill zoning, could be incorporated into the design. Special material provisions for salt water would include use of galvanized or epoxy-coated rebar and Type II Portland cement. The polyvinylchloride (PVC) fill is unaffected by salt water.

Specific design parameters for the cooling tower are as follows:

- Circulating Water Flow 630,000 gpm
- Cooling Range 25°F
- Approach Temperature 14°F
- Wet Bulb Temperature 77°F
- Dry Bulb Temperature 89°F
- Evaporation Rate 2.1%
- Drift Rate 0.0005%
- Concentration Factor 1.5

Drift elimination technology has improved since the early 1970s when cooling towers were originally evaluated for Unit 3. At that time, a drift rate of 0.00375% of the circulating water flow was used for evaluation. Current drift eliminator designs may be able to reduce the drift rate to 0.0005% of the circulating water flow (approximately 3.2 gpm).

A chlorination system to control biofouling in the cooling tower fill and the condenser tubes would be required and a dechlorination system would probably also be required for the blowdown. Costs for these systems were not addressed in the report.

The required makeup water flow to the cooling tower to maintain the concentration factor in the closed-loop circulating water system at 1.5 or less at all times would be approximately 36,000 gpm. Makeup flow would be pumped into the circulating water return line near the condenser discharge manifold

as shown on Figure 7.6-1. Approximately 55 feet of pumping head would be required to pump the makeup water into the system. Required pump motor horsepower for the makeup water pump would be 720 horsepower. Two full-size makeup water pumps would be provided. A 42-inch diameter line would be required for makeup water.

Blowdown would be discharged from the cooling tower basin at an overflow weir structure that would be located on the cooling tower discharge flume. The discharged blowdown would be carried by gravity to the quarry by a 60-inch line buried in a cut and cover trench. Blowdown piping would be routed to the existing discharge flume at the quarry. Blowdown flow would range from 24,000 to 36,000 gpm.

7.6.1.2 Closed-Loop Circulating Water System

The circulating water system for the cooling tower would consist of a pump station containing six circulating water pumps and motors located at the cooling tower basin, a buried circulating water conduit which would convey cooled circulating water from the cooling tower to the condenser and would return heated water from the condenser back to the cooling tower, valves, electric power, and control equipment. The proposed pipe routing is to the north of the station and then south and to the west side of the condenser as shown on Figure 7.6-1.

Flow rate for the closed-loop circulating water system would be 630,000 gpm. Total system head loss and static lift to pump circulating water to the cooling tower fill distribution system would be approximately 100 feet. The head includes friction losses in conduit; losses in the two-pass condenser; form losses at bends, fittings, and junctions; and an estimated 45-foot static lift to the cooling tower fill distribution system. To meet these flow and head requirements, six circulating water pumps would be required, rated at 105,000 gpm at 100 feet total dynamic head. This would require 3,300 horsepower per pump for a total pumping energy requirement of approximately 19,800 horsepower.

The six circulating water pump discharges would be manifolded into a single 14-foot diameter inlet conduit which would convey the circulating water to the west side of the Unit 3 condenser. This piping would be manifolded to join three of the six 84-inch inlets to the condenser. Valving at the manifolded junction would consist of three 84-inch motor-operated butterfly valves in the three inlet lines from the cooling tower. These valves, in conjunction with the existing pump discharge valves and condenser valves, would allow operation of the system either on the cooling tower or once-through. Water would make two passes through the reconfigured condenser and exit the condenser from the alternate three 84-inch lines on the west side of the condenser. These existing 84-inch lines would be cut and manifolded into a single 14-foot diameter return line which would convey heated circulating water back to the cooling tower. Pipe materials selected for the circulating water pipe for this study would be reinforced concrete cylinder pipe (RCP) for the main 14-foot supply and return pipes and fiberglass-reinforced plastic (FRP) for the manifolded pipe at

the pump discharge and the above ground pipe and connections to the existing circulating water lines. Carbon steel pipe would not be considered suitable in saltwater service due to high corrosion rates.

Electric power for the new circulating water pumps at the cooling tower, the makeup water pumps to be located in the existing Unit 3 intake structure, HVAC for the cooling tower pumphouse, and cooling tower lighting would be taken from buses 34A and B in the existing Unit 3 pump structure. Ten new breakers would be required on buses 34A and B presently feeding the existing circulating water pumps. The breakers would feed the six new 3,300 horsepower circulating water pumps located in the cooling tower pumphouse, the two new 720 horsepower makeup pumps which would be located in the existing circulating and service water pumphouse, and a new double-ended 480-V load center would be located in the cooling tower pumphouse. The addition of the breakers to bus 34B would impede access to the switchgear room. It has been assumed that buses 34A and B have adequate capacity to power the increased load. Because air blast breakers are no longer manufactured, vacuum breakers would be used instead.

A 2,800-foot ductline would be required for power cables running from the existing intake structure to the cooling tower. The ductline would follow the same route as the proposed new cooling tower circulating water inlet and discharge lines.

The capital cost for the full-size natural-draft cooling tower has been estimated to be $126,300,000.

7.6.1.3 Impact on Unit 3 Performance

The natural-draft cooling tower would result in added power demand for operation of the higher horsepower circulating water pumps and added cooling tower makeup water pumps. Also, the average circulating water temperature would be higher in the closed-loop cooling tower system, resulting in higher average turbine backpressure and reduced turbine performance, particularly during the summer months.

The existing circulating water pumps are 1,500 horsepower pumps, which draw a total of 6,700 kW of electric energy. The closed-loop circulating water system would require six new circulating water pumps, each rated at 3,300 horsepower, and two makeup water pumps, each rated at 720 horsepower. Normally, all six circulating water pumps and one of the two makeup water pumps would operate continuously. This would result in a net increase in pumping energy consumption of 8,600 kW.

There would be annual Unit 3 performance losses (in MW-hr) resulting from the higher circulating water temperatures in the closed-loop system and the accompanying higher turbine backpressure as shown in Table 7.11-2. The reduction in the electrical generation rate results from higher inlet water temperatures.

Each switching of plant operation from cooling tower to once-through or back to cooling tower operation would require an outage. The performance penalty associated with this outage was not included in the unit performance loss.

7.6.1.4 Licensing and Permitting

The major environmental factors that would influence the permitting cycle and approvals required to convert Millstone Unit 3 to a cooling tower are:

- The height and visual obtrusion of the towers;
- The impacts of the makeup and blowdown systems on marine biota and populations;
- The tower vapor plume effects due to size, frequency, or trajectory, including icing and fogging effects;
- The local weather pattern influences resulting from the tower plume;
- The impact of noise on neighbors;

Although previous impact assessment on egg and larval entrainment has assumed 100% mortality on passage through the once through cooling system, some entrained eggs and larvae may have been viable. With entrainment in the makeup for the closed-loop cooling tower system, entrainment survival is a much less likely expectation. Passage through the pumps, air exposure, a cascade through the cooling tower fill, and exposure to cooling tower biocides are likely to result in total mortality to entrained eggs or larvae.

Licensing the operation of Millstone with a cooling tower would require a number of local, state, and federal approvals. In addition, the Updated Final Safety Analysis Report (UFSAR) would have to be revised and submitted to the Nuclear Regulatory Commission (NRC) for their review and approval.

Licensing and permitting requirements pose a major source of uncertainty. It has been assumed that the regulatory authorities would approve the design used as a basis for the cost estimate and schedule provided herein. If not, there would be an additional incremental cost impact, which has not been included in this estimate. In addition, depending upon the particular permit and schedule, there is the potential for very significant schedule impacts due to delays in obtaining permits.

7.6.2 Two-Thirds Size Cooling Tower – Unit 3

This alternative is similar to the full-size cooling tower except that four of the six condenser paths would be converted to a closed-loop system integrated with the natural-draft cooling tower, and the remaining two condenser paths would remain once-through. The objective of this alternative would be to provide a

reduction to station intake flow from Niantic Bay, at a reduced capital cost and reduced performance penalty, as compared to the full-size cooling tower.

The 2/3-size cooling tower would reduce Unit 3 withdrawal rate from Niantic Bay from 918,000 to 306,000 gpm plus 27,000 gpm cooling tower makeup. This would result in a net reduction in total station withdrawal from Niantic Bay from approximately 1,500,000 to 891,000 gpm. This would be an approximate 40% reduction without taking credit for the shutdown of Unit 1.

The proposed cooling tower location and circulating water pipe routing for the 2/3-size system would be similar to that proposed for the full-size system which is shown in Figure 7.6-1. The four condenser paths requiring conversion to closed-loop would be changed to a two-pass type flow, using existing condenser valving and waterbox cross connections. In this case, as with the full-size system, circulating water would enter and exit the condenser on the west side. Valves would be required at the manifolded junction to allow operation of the system with 2/3 cooling derived from the cooling tower or fully once-through. The two full-size (27,000 gpm) makeup water pumps would be installed in the circulating water pump bays in the existing Unit 3 pump structure.

7.6.2.1 Design of a Two-Thirds Size Cooling Tower – Unit 3

A natural-draft cooling tower sized to reject 2/3 of the Unit 3 heat load would be approximately 400 feet in diameter at the base and approximately 460 feet high. Specific design parameters for the 2/3-size cooling tower are as follows:

• Circulating Water Flow	422,000 gpm
• Cooling Range	25°F
• Approach Temperature	14°F
• Wet Bulb Temperature	77°F
• Dry Bulb Temperature	89°F
• Evaporation Rate	2.1%
• Drift Rate	0.0005%
• Concentration Factor	1.5

The drift for the 2/3-size tower would be anticipated to be about 2/3 of that resulting from the full-size tower. (Refer to the discussion of salt drift in Section 7.6.1.1). Required makeup flow to the 2/3-size cooling tower to maintain a concentration factor in the closed-loop circulating water system at 1.5 or less would be 27,000 gpm. Makeup water pumps would be rated at 27,000 gpm at 55-foot head. Horsepower

requirements for the makeup pump would be 480 horsepower. Two full-size pumps would be required. A 36-inch diameter makeup water line would be required.

Blowdown would be discharged from the cooling tower basin at an overflow weir structure located on the cooling tower discharge flume. The discharged blowdown would be discharged by gravity to the quarry by a 48-inch line buried in a cut and cover trench. Blowdown piping would be routed to the existing Unit 3 discharge flume at the quarry. Blowdown flow would range from 18,000 to 27,000 gpm.

7.6.2.2 Closed-Loop Circulating Water System

The closed-loop circulating water system for the 2/3-size cooling tower would be similar in design and layout to that proposed for the full-size cooling tower. The circulating water pump station would be located at the cooling tower and would contain four 1/4-size pumps, each rated at 105,000 gpm for a total circulating water flow rate of 420,000 gpm. These four circulating water pumps would discharge to a single 12-foot diameter pipe. Both supply and return circulating water lines would be routed to the north and to the west of Unit 3 in a common cut and cover trench similar to that shown on Figure 7.6-1. Each circulating water pump would have a motor-operated discharge valve. Existing 84-inch lines and valves at the condenser would be utilized by the new closed-loop system. Two 12-foot x 7-foot two-pipe manifolds would be required on the west side of the condenser to make the connection between the new 12-foot diameter cooling tower supply, return lines, and the existing piping. The two northerly condenser waterboxes would be converted to the closed-loop system. The two manifolded 84-inch inlet lines from the cooling tower would have motor-operated valves installed. These valves, in conjunction with the existing pump discharge valves and condenser valves, would allow operation of the system either on the cooling tower or once-through. The southerly waterbox would remain once-through. The system head losses for the 2/3-size circulating water system would be essentially the same as that for the full-size system. The four circulating water pumps would be rated for 105,000 gpm at 100-foot total dynamic head. Pump motors rated at 3,300 horsepower would be required.

Eight new breakers would be required on buses 34A and B feeding the existing circulating water pumps. The breakers would feed the four new 3,300 horsepower circulating water pumps located in the cooling tower pumphouse, the two new 480 horsepower makeup pumps which would be located in the existing circulating and service water pumphouse, and a new double-ended 480-V load center located in the cooling tower pumphouse. The addition of breakers to bus 34B would impair access to the switchgear room. It also was assumed that buses 34A and B have adequate capacity to provide power for the increased load. When obtaining estimating prices for new 4,160-V air circuit breakers and switchgear to match existing design, GE stated that they no longer manufacture such equipment and they proposed using vacuum breakers instead.

A 2,800-foot ductline would be required for power cables running from the existing intake structure to the cooling tower. The ductline would follow the same route as the new cooling tower circulating water inlet and discharge lines.

The capital cost for the two-thirds size cooling towers has been estimated to be $101,400,000. Licensing and permitting requirements pose a major source of uncertainty (see Section 7.6.1.4). It has been assumed that the regulatory authorities would approve the design used as a basis for the cost estimate and schedule provided here in. If not, there would be a cost impact which has not been included in this estimate. In addition, depending upon the particular permit and schedule, there is the potential for schedule impacts due to delays in obtaining permits.

7.6.2.3 Impact on Unit 3 Performance

Four 3,300-horse power pumps would also be required for closed-loop circulating water flow. These pumps would operate continuously if the cooling tower were operating. In addition to the higher horsepower circulating water pumps, two 480-horsepower cooling tower makeup pumps would also be required. These pump changes would result in a net power increase for pumping of 5,700 kW.

The loss in electrical generation would occur primarily during the warm weather months of May through September. The reduction in the electrical generation rate results from a higher inlet water temperature. Refer to Table 7.11-2 for a summary of the annual change in unit performance during operation of the 2/3 size cooling tower.

As with the full-sized tower, each switching of plant operation from cooling tower to once-through or back to cooling tower operation would require an outage. The performance penalty associated with this outage was not included in the estimated unit performance loss.

7.6.3 Geotechnical Considerations

The topography in the proposed cooling tower area is characterized by a wooded easterly sloping ground surface with elevations ranging between 15 and 25 feet. No geotechnical explorations have been performed in the vicinity of the proposed cooling tower area to characterize the subsurface in that area. Some rock exposures are noted near the proposed cooling tower structure location on the U.S. Geological Survey map, suggesting the top of rock surface may be near the ground surface. The overburden in that area is considered to be thin (10 feet or less) glacial deposits of outwash and till.

The ground surface in the area of the proposed cooling tower discharge and inlet lines is largely flat due to modifications by construction activities and generally ranges from elevation 24 feet in the plant area to about elevation 30 feet north of the main plant. The proposed locations of these structures are in areas

where subsurface data are absent, except where boring was completed in support of the Temporary Radwaste Facility and Interim Storage Facility for the Steam Generator Replacement Project. These borings suggest that top of rock elevation is variable, ranging from 15 to 24 feet above mean sea level in that area. A few feet of fill material was found at the surface and denser glacial till overlies the rock which was described as granite gneiss.

Since the overburden is presumed to be thin in the cooling tower area and the foundation grade may consist of both rock and soil, it would be recommended that the overburden materials be removed and the structure be founded entirely on bedrock to limit differential settlements. The average maximum bearing capacity of the rock based upon Unit 3 field investigations is 200 ksf. The soil overburden's bearing capacity is considerably less and more variable. Thus, the overburden properties may not be sufficient to limit differential settlements for a structure of this type.

The proposed conduits for the discharge and inlet lines would be constructed through a cut and cover procedure. It was estimated that 50 to 60% of the excavation would be in rock; therefore, conduit construction would require controlled blasting methods to limit vibrations near existing structures. Some local rock support, such as rock bolts, may be necessary depending on excavation height and rock geometry. Soils would require 2H:1V slopes and bracing where slopes are not feasible.

There could be considerable difficulty in coordinating the required activities in excavating areas adjacent to the condenser/turbine building. There are numerous buried utilities in this area, including some that are nuclear safety-related. Numerous plant outages would be required. This has not been addressed in the study and could add significantly to the cost estimate.

7.6.4 Unit 3 Cooling Tower Alternative-Conclusions

The cooling tower alternatives discussed offer a benefit for reduction of ichthyoplankton entrainment. However, such alternatives are very costly because they would have to be backfitted to functional generating units that were designed for once-though cooling operation. As a result, there are significant construction, infrastructure, and siting issues associated with this alternative. These would also result in reduced power generation especially during the summer months. Additional impacts, such as aesthetics, increased chlorination, and air emissions are discussed in Part II.

Estimated capital costs range from $101,400,000 to $126,300,000. Licensing and permitting requirements pose a major source of feasibility and schedule uncertainty. It has been assumed that the regulatory authorities would approve the design used as a basis for the cost estimate and schedule provided herein. If not approved, there would be a cost impact which has not been included in this estimate. In addition,

depending upon the particular permit and schedule, there is the potential for schedule impacts due to delays in obtaining permits.

7.7 NATURAL-DRAFT COOLING TOWER – UNIT 2

This alternative consists of conversion of the existing once-through circulating water system for Unit 2 to a closed-loop system utilizing a natural-draft cooling tower. This alternative is similar in design concept to the full-size cooling tower alternative for Unit 3 with some significant differences. The Unit 2 design temperature rise across the condenser of 24°F does not allow flow reduction for the cooling tower. The condenser design would have to remain as a single pass. Diversion of the heated condenser discharge to the cooling tower would be made by a new pumping facility at the Unit 2 discharge at the quarry. A second new pumping facility will also be required at the cooling tower basin to pump cooled water back through the condenser. The service water system would remain the same.

Unit 2 service water flow rate would remain the same at 24,000 gpm. This alternative would result in a station flow reduction of approximately 32% without credit for the shutdown of Unit 1.

The natural-draft saltwater cooling tower alternative would consist of the tower located in the wooded area to the east of the switchyard adjacent to the proposed Unit 3 cooling tower as shown on Figure 7.7-1. This figure shows the arrangement assuming that both Units 2 and 3 cooling tower options would be installed. The Unit 2 cooling tower would have a new circulating water system with two new pumping stations. One pumping station would be located at the existing Unit 2 discharge structure at the quarry. This pump station would pump the heated Unit 2 discharge to the cooling tower fill distribution system. The second pump station would be located at the cooling tower basin. This pump station would pump the cooled water from the cooling tower through the condenser to the discharge. The proposed circulating water piping from the cooling tower would be routed in a 65-foot wide trench to the north and west side of the station, adjacent to the piping from the proposed Unit 3 cooling tower. Connections to the existing Unit 2 intake lines would be made by routing the new conduit from the cooling tower over the existing 78-inch lines from the intake and making vertical connections down into the existing lines. New motor operated butterfly valves would be located in the vertical connections. The existing pump discharge valves in the intake structure would serve as isolation valves for the intake lines.

A new pumping station would be constructed near the existing discharge at the quarry to pump heated discharge to the cooling tower. A diversion system would be constructed in the discharge conduit to divert the flow to the new pumping station. This diversion system would be capable of diverting all of the Unit 2 heated circulating water discharge to the return pump station and also allow return to once-through operation, if desired. The new return pump station would be a standard, open channel intake structure with four ¼ size cooling tower pumps. A gradually expanding flume is provided between the diversion structure

and the pump structure to meet Hydraulic Institute Standards recommendations. Piping from the pumping station to the cooling tower would be routed to the east of the station. This piping has to cross the existing Unit 3 discharge conduit. It was assumed that the pipe would pass under the existing Unit 3, 14 foot by 14 foot discharge conduit to avoid construction of having above ground pipe. This would require rock excavation under the exiting conduit.

A separate, new makeup water pump system consisting of two full-size pumps with associated controls and electrical equipment would be installed in the existing Unit 2 intake structure. Makeup water pipe to the cooling tower would be routed in the same trench as the cold water conduit from the tower to the Unit 2 condenser. The blowdown discharge line from the tower basin to the quarry would be routed to the east of the station adjacent to the blowdown line from the proposed Unit 3 tower. Discharge to the quarry would be through the Unit 3 discharge structure.

Service water piping would remain the same. The new diversion system in the discharge conduit at the quarry would allow for direct discharge of service water to the quarry while configured for either closed-loop or once-through circulating water system operation. Radioactive waste discharges, currently routed to the Unit 2 discharge conduit, would be rerouted to the new cooling tower blowdown discharge line to the Unit 3 outfall.

A second alternative to the new pumping facility at the discharge, discussed above, would be to construct a diversion in the concrete discharge conduit, under the turbine building, upstream of where the service water discharge lines enter the conduit. The cooling tower pumps would have to pump cooled water from the cooling tower basin, through the condenser and up to the cooling tower fill distribution system, which is similar to the proposed Unit 3 cooling tower configuration. Because of the higher pump head required, the design pressure for the closed-loop portion of the system, including the condenser and portions of the existing inlet piping and discharge conduit, up to and including the new connections would have to be increased from the existing 25 psig to approximately 70 psig. This would require replacement of the condenser water boxes and possibly the tube sheets. It is probable that all of the existing circulating water pipe, valves and the portion of the discharge conduit under the turbine building would have to be replaced with this alternative. This alternative would create a massive disruption during construction and require an extended shutdown of Unit 2. Also, it is likely that many buried facilities would have to be relocated in order to allow construction of the return conduit from the condenser to the cooling tower. For these reasons, this second alternative to the new pumping facility is not considered feasible.

As discussed in Section 7.6 for the Unit 3 cooling tower alternatives, the Unit 2 cooling tower alternative also has very high capital and operational costs.

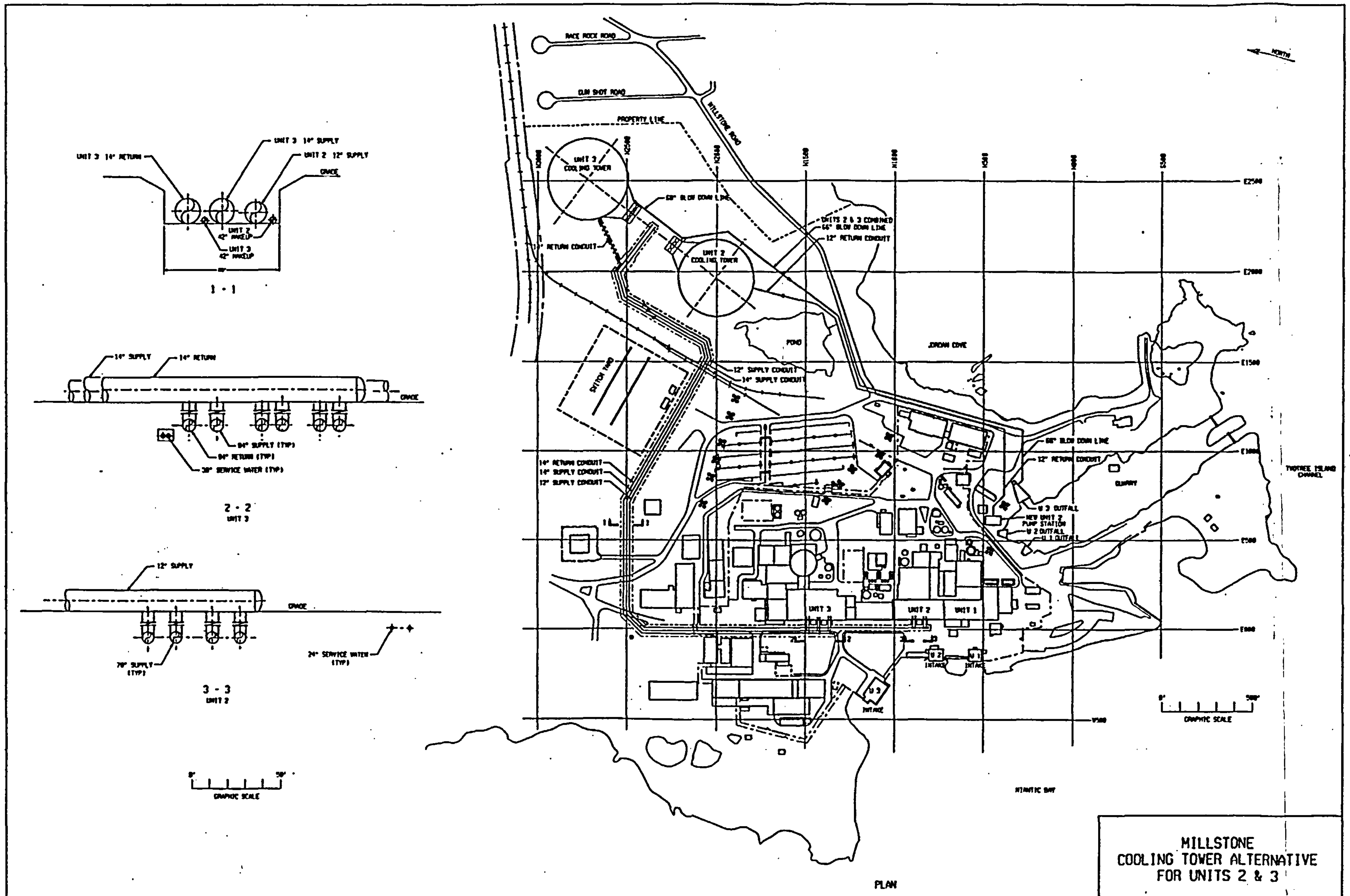

Figure 7.7-1: Units 2 and 3 - Natural-Draft Cooling Tower Arrangements

7.7.1 Cooling Tower Design – Unit 2

The natural-draft saltwater cooling tower for Unit 2 would be designed to operate year round including summer conditions. The Unit 2 tower would be only slightly smaller than the Unit 3 tower, being 425 feet in diameter at the base and 500 feet tall. The tower design would be of the counter-flow configuration with the fill located within the tower shell, just above the air inlet. The fill mass would be disc-shaped covering the full plan area of the tower and would be approximately 4 feet in thickness. A system of channels, pipes and spray headers would distribute the circulating water evenly over the fill area. Provisions for ice control, such as a spray curtain ring covering the circumference of the air inlet and fill zoning, could be incorporated into the design. Special material provisions for salt water would include galvanized or epoxy-coated rebar and Type II Portland cement. The fill would be made of polyvinylchloride (PVC) which is unaffected by salt water.

Specific design parameters for the cooling tower are as follows:

Circulating Water Flow	522,500 gpm
Cooling Range	23°F
Approach Temperature	14°F
Wet Bulb Temperature	77°F
Dry Bulb Temperature	89°F
Evaporation Rate	2.1%
Drift Rate	0.0005%
Concentration Factor	1.5

Refer to the discussion of salt drift in Section 7.6.1.1. Cooling tower drift would be approximately 2.6 gpm.

A chlorination system to control biofouling in the cooling tower fill and the condenser tubes would be required and dechlorination system would probably also be required for the blowdown.

The required makeup water flow to the cooling tower to maintain the concentration factor in the closed-loop circulating water system at 1.5 or less at all times would range from 18,000 to 26,000 gpm. Makeup flow would be pumped directly to the cooling tower basin. Approximately, 25 feet of pumping head would be required to pump makeup water from the intake structure to the cooling tower basin. Required pump motor horsepower for the makeup water pump would be 260 horsepower. Two full-size make-up water pumps would be provided. A 42-inch diameter line would be required for makeup water.

Blowdown would be discharged from the cooling tower basin at an overflow weir structure, located on the cooling tower discharge flume. The discharged blowdown would be carried by gravity to the quarry by a 60-inch line buried in a cut and cover trench routed along the east side of the site adjacent to the Unit 3 cooling tower blowdown line. Unit 2 radioactive waste discharge would be rerouted to the blowdown line. The discharge point at the quarry would be south of the existing Unit 3 discharge on the east side of the quarry.

7.7.2 Closed-Loop Circulating Water System

The circulating water system for the Unit 2 cooling tower would include two pumping stations. One station at the cooling tower basin would pump cooled circulating water through the condenser (supply pumps). The other pump station located near the quarry would pump the heated water back to the cooling tower fill distribution system (return pumps). Each pump station would include four ¼ size circulating water pumps. A buried water conduit, which would convey cooled circulating water from the cooling tower to the condenser, would be routed along the north and west sides of the station, adjacent to the Unit 3 cooling tower supply conduit. Existing inlet and discharge piping at the condenser and the existing discharge conduit would be utilized to convey heated water to the diversion facility and pump station at the quarry. A new conduit, which will carry the diverted heated water from the return pump station to the cooling tower distribution system would be routed along the east side of the station as shown on Figure 7.7-1.

Flow rate for the system from the cooling tower basin through the condenser would be 522,500 gpm. The flow rate for the return pump station and conduit would be set slightly higher than that for the supply side with excess flow discharged to the cooling tower blowdown system. This is to alleviate operational problems associated with pump stations operated in series. A design flow of 530,000 gpm is assumed for the return system. An engineering analysis would be required (not included in this report) to determine the appropriate design flow for the return system and how best to draw the excess flow into the pump station from the quarry. The supply pumps at the cooling tower would require approximately 30 feet total dynamic head. The return pumps at the quarry would require approximately 70 feet total dynamic head. Pump power requirements for the cooling tower system are as follows:

Pump	hp	kW
Make-up Supply	260	194
Supply	5,280	3,934
Return	12,300	9,181

This equates to a total of approximately 13,000 kW of electric power.

At both the supply and return pump stations, the four pump discharges will be manifolded into single 12-foot diameter conduits. The supply piping would be manifolded into the four existing 78-inch inlet lines

from the intake structure in the yard to the west of the turbine building. Each of the four manifold branches would contain a 78-inch motor-operated butterfly valve. The diversion structure at the downstream end of the discharge conduit would consist of a full-size 45 degree branch bifurcation in the 17.5 ft by 6 ft rectangular discharge conduit upstream of the Unit 2 discharge structure at the quarry. The diversion bifurcation would lead to a trasition flume and then a standard open channel pump structure. The new valves and diversion structure would allow operation of the system in either once-through or closed-loop cooling tower operation. Pipe material selected for this study would be reinforced concrete cylinder pipe (RCP) for the main supply and return pipe and fiberglass-reinforced plastic pipe (FRP) for the manfolded sections at the pumps and connections to the existing pipe and the cooling tower supply piping.

The power supply system for each pump station would be similar in scope to that outlined for the Unit 3 cooling tower pump station.

7.7.3 Impact on Unit 2 Performance

The natural-draft cooling tower would result in added power demand for operation of the additional set of return pumps and the makeup water pump. The supply pumps would draw approximately the same power as the existing circulating water pumps. Also, the average circulating water temperature would be higher in the closed-loop cooling mode, resulting in higher turbine backpressure and reduced turbine performance, particularly during the summer months.

In addition, converting the circulating water system to a natural-draft cooling system complicates operation of the unit. Since this arrangement would require pumps to be operated in series. Operation of the two pump stations in series would be a balancing act. A failure of a pump in either the supply or return pump stations would require the immediate shut down of a pump in the other pump station to maintain flow balance. The probability of a pump failure would be increased by the addition of the second pump station. This increased probability of pump failure, combined with the higher water temperatures and resulting higher operating turbine back pressures would lead to more frequent station trips which would place added stress on the reactor, thereby compromising safety.

The existing circulating water pumps require 1,100 hp per pump, which amounts to a total draw of 3,300 kW for the four pumps. The closed-loop circulating water system would require eight new circulating water pumps and two makeup water pumps. All eight of the circulating water pumps and one of the makeup water pumps would normally operate in the closed-loop mode. The existing circulating water pumps would not operate in the closed-loop mode. This would result in a net increase in pumping energy consumption of 10,200 kW. The annual loss to Unit 2 performance from closed-loop operation is shown in Table 7.11-2 for the periods of abundance for winter flounder larvae and tautog eggs.

Each switching of plant operation from once-through to closed-loop or back to cooling tower operation would require an outage. The performance penalty associated with this outage was not included in the estimated unit performance loss.

7.7.4 Unit 2 Cooling Tower Alternative-Conclusions

All of the cooling tower alternatives are very costly because these types of systems would have to be backfit to functional generating units that were designed for once-though cooling operation. As a result, there are significant construction, infrastructure, and siting issues associated with this alternative. The cooling tower alternative offers a benefit for reduction of ichthyoplankton entrainment. However, in the case of Unit 2, conversion to a closed-loop natural-draft cooling tower system would reduce system reliability, which has a direct effect on the safety of the reactor. Also, it would significantly complicate operation of the circulating water system requiring closer operator attention in the closed-loop mode and during change over to and from the closed-loop mode. It would also result in reduced power generation especially during the summer months. Additional impacts, such as aesthetics, increased chlorination, and air emissions are discussed in Part II.

The capital cost for the Unit 2 natural-draft cooling tower system has been estimated to be $123,000,000. Licensing and permitting requirements pose a major source of feasibility and schedule uncertainty. It has been assumed that the regulatory authorities would approve the design used as a basis for the cost estimate and schedule provided herein. If not approved, there would be a cost impact which has not been included in this estimate. In addition, depending upon the particular permit and schedule, there is the potential for schedule impacts due to delays in obtaining permits.

7.8 MECHANICAL-DRAFT COOLING TOWERS

A full-size mechanical-draft cooling tower array for Unit 3 and for Unit 2 are evaluated in this study. This study confirms that the capital cost for implementing mechanical-draft cooling tower systems for each unit would be only slightly less than natural draft cooling tower systems. As with the natural draft designs, the capital and operation costs of the alternatives are very high because the existing generating units are designed to be very effective using once through cooling systems.

7.8.1 Mechanical-Draft Cooling Tower – Unit 3

The full-size mechanical-draft cooling tower alternative for Unit 3 would be similar in configuration and flow capacity to the full-size natural-draft cooling tower alternative presented in Section 7.6.1. An array of multi-cell rectangular cooling towers would be provided in lieu of the single natural-draft cooling tower. All other aspects of the system would be the same. The proposed location for the cooling towers would be in the wooded area to the east of the switchyard, near to the proposed location for the natural-draft cooling

tower. Preliminary sizing and layout of the cooling tower array show that there would be enough space. The service water system would remain the same.

A mechanical-draft cooling tower rejects waste heat by the evaporation of a small percentage of the heated discharge water inside cells which would be supplied with air-flows induced by large fans. The remaining cooled water would be recycled through the condenser again.

Most of the existing mechanical-draft cooling towers are located in the South and West United States. They have been used for many years to supply the closed-cycle cooling requirements of large power plants but only a few have been situated in New England. They are typically between 300 to 500 feet long and 30 to 50 feet wide and may contain between 5 and 30 cells. Since the 1970s, a large number of successful, reliable salt water cooling towers have been installed.

The performance of the closed-cycle mechanical-draft tower, as with the natural-draft tower, would be related only to the wet bulb temperature of the atmosphere during operation. Unlike the natural-draft tower, it has essentially no performance dependence on the dry bulb temperature because the fans produce and control the airflow.

The condenser discharge of the unit would be pumped to multi-cell mechanical-draft, counter-flow towers, cooled with air, and re-circulated back to the condenser. The warm salt water from the condensers would be pumped to an elevation of about 8 feet above the tower air inlet located on the periphery of the cells. The condenser outlet flows would be distributed evenly and dispersed into small droplets over the top of a heat transfer zone in each cell. This heat transfer section of the tower would be covered with water at about the 8-foot level. The water would fall by gravity through that heat transfer section into a basin at ground level where it would be collected and returned to the condensers. In the process, as the heated water droplets fall through the heat transfer section, the water would be cooled by air contact and evaporation of a small portion of the water into the ambient air which would simultaneously be induced by fans to flow upwards in the opposite direction of the falling water.

After passing through the heat transfer section, the air would move through drift eliminators where most of the entrained droplets of circulating water would be removed and returned to the basin. In each cell, the airflow would be produced by the action of a large diameter induced-draft fan situated above the heat transfer section and drift eliminators. Each of the fans would be driven by a large electrical motor. The air would exhaust from the tower generally as a visible plume of 100% relative humidity and would be at a temperature slightly below that of the condenser discharge water. The warm humid exhaust air would be buoyant. Wind and ambient meteorological effects, however, would sometimes produce incidence of ground fog for a moderate distance downwind of the towers and, on rare occasions, icing.

The towers would be constructed from fiberglass. Fiberglass construction often does away with the need for a fire protection system, depending upon the Owner's insurance requirements. The tower would be provided with a grounding system, lightning protection, and area lighting.

The fresh airflow into the tower would be subject to a re-circulation of a small fraction of the warm air exhaust plume that can be drawn back into the tower due to bluff-body wind effects. Re-circulation would reduce some of the tower's thermal performance, but this effect would be compensated for in the design sizing.

Since the cooling effect would mainly be due to evaporation, the warm water the tower returns to the condenser would approach, but would always be warmer than, the local wet bulb temperature. With a mechanical-draft cooling tower, the condenser return temperature would be much warmer than the condenser cooling water for once-through flow currently drawn from Niantic Bay. Accordingly, the turbine backpressure would be elevated, causing an increase in station heat rate and a reduction in generation. Extra plant energy is required to operate the fans of a mechanical-draft tower in addition to increased pump energy to pump the circulating water to the tower and up to the heat transfer section. A mechanical-draft cooling tower would be able to cool the water to a closer approach temperature to the wet bulb temperature (7° vs 14°F) than the natural-draft cooling tower due to the fan generated airflow. The disadvantage of mechanical-draft tower would be the energy required to operate the fans.

The cooling tower would reduce the required Unit 3 circulating water flow withdrawal from 918,000 to 36,000 gpm for cooling tower makeup resulting in a total station withdrawal of about 594,000 gpm. This would be 60% reduction in total station flow.

The mechanical-draft saltwater cooling tower alternative would consist of the tower array located in the wooded area to the east of the switchyard as shown on Figure 7.8-1. This location was selected to locate the cooling towers downwind (the prevailing wind direction is the west) of the switchyard. The cooling tower would have a new circulating water system with the new pump station at the tower location. The existing condenser operation would be changed from the current single-pass configuration to a two-pass configuration. This change would be necessary to maintain high condenser tube velocities for efficient heat transfer with the reduced circulating water flow rate in the closed-loop system. The existing condenser has adequate pressure rating (80 psi) and valving to allow operation in a two-pass mode with no modifications. The proposed circulating water piping from and to the cooling tower would be routed to the north and west of the station and would be manifolded into the existing circulating water piping on the west side of the station as shown on Figure 7.8-1. Two 14-foot diameter pipes (i.e., one supply and one return) would be installed in a common cut and cover trench. The trench would be approximately 46-feet wide. Valving

would be provided at the tie-in point of the new closed-loop circulating water system piping and existing circulating water piping to allow operation of Unit 3 either on the cooling tower or once-through. Figure 7.8-1 shows the initial engineering concept for the tie into the existing circulating water system piping. The new piping to and from the cooling tower would have to pass over the existing safety-related service water piping. If this alternative were selected, detailed engineering of this cross and tie-in would be required to ensure that the non-safety-related circulating water piping would not impact the safety-related service water system.

New makeup water pumps would be required in the existing Unit 3 intake structure. The cooling tower blowdown would be discharged to the quarry.

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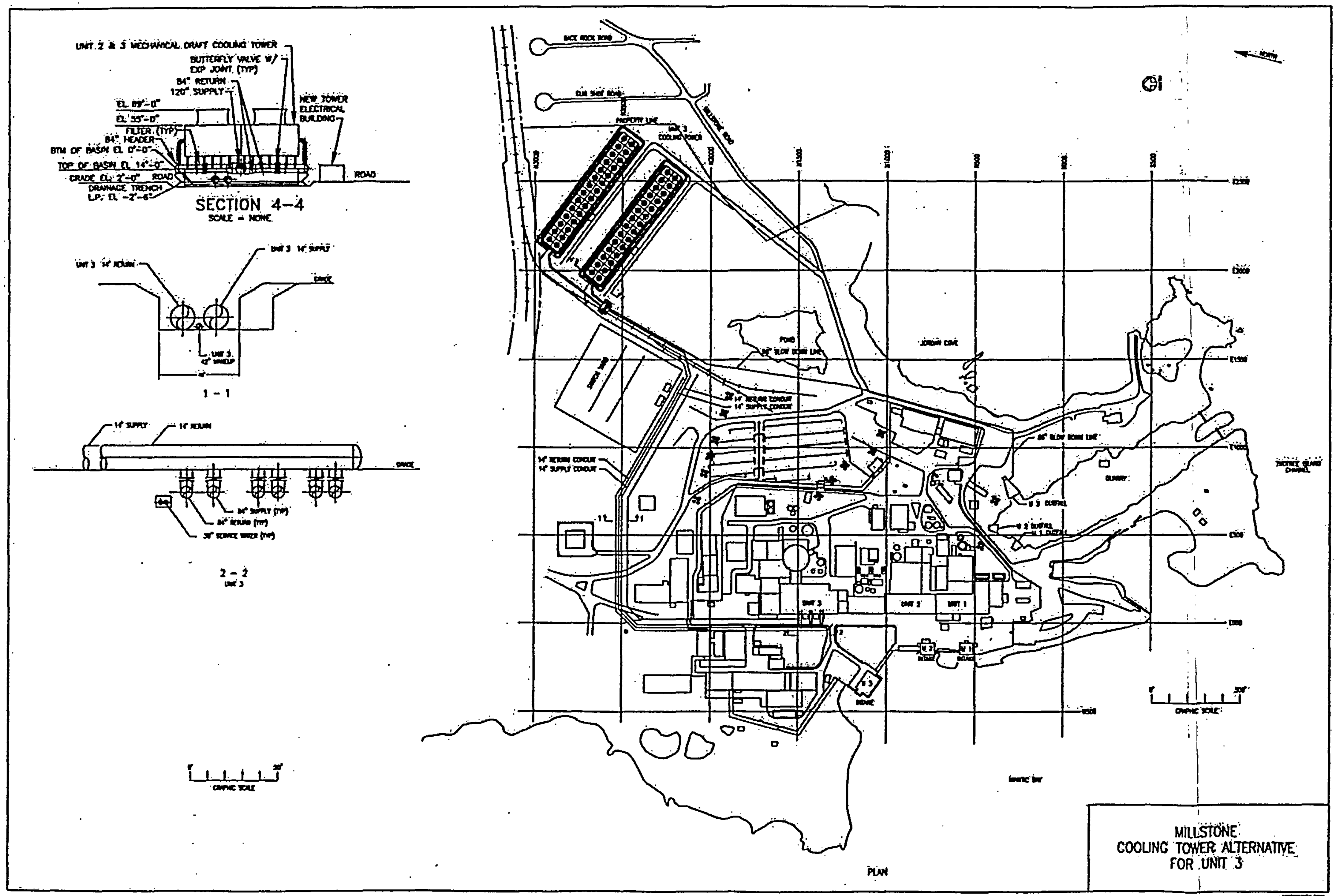

Figure 7.8-1: Mechanical-Draft Cooling Towers for Unit 3

7.8.1.1 Unit 3 Cooling Tower Design

The mechnical-draft saltwater cooling tower for Unit 3 would be designed to operate in summer conditions. The tower would be a multi-cell rectangular array consisting of 56 cells arranged in two back-to-back towers each having 28 cells as shown on Figure 7.8-1. Each of these tower units would be approximately 760 ft long by 110 ft wide. The towers would be spaced 200 ft apart to reduce recirculation. The tower design would be of the counterflow configuration with the fill located within the tower shell just above the air inlet. The fill mass would cover the full plan area of each tower cell and would be approximately 4 feet in thickness. A system of channels, pipes, and spray headers would distribute the circulating water evenly over the fill area. Special material provisions for salt water would include galvanized or epoxy-coated rebar and Type II Portland cement. The polyvinylchloride (PVC) fill is unaffected by salt water.

Specific design parameters for the cooling tower are as follows:

- Circulating Water Flow 630,000 gpm
- Cooling Range 25°F
- Approach Temperature 7°F
- Wet Bulb Temperature 77°F
- Condenser Inlet Temperature 84°F
- Dry Bulb Temperature 89°F
- Evaporation Rate 2.1%
- Drift Rate 0.0005%
- Concentration Factor 1.5

Mechanical-draft cooling towers utilize the same drift elimination technology used in natural-draft cooling towers as discussed previously (Refer to the discussion of salt drift in Section 7.6.1.1).

The drift eliminator would be located above the water distribution system. It would be a layer of PVC louvers, designed to prevent droplets of hot water from being carried out with the air flow. Modern drift eliminators, carefully installed and properly maintained, can reduce drift to 0.0005% of the design flow, or about 3 gpm.

Above the drift eliminators would be the plenum, roofed by the fan deck. The fan deck would be support the fan, fan stack, and driving motor. The fan motor would be located outside of the fan stack on the fan deck and would be mechanically connected to a right-angle gear box at the center of the fan stack on which the fan hub would be mounted. The fan would draw the moist air up from the plenum ("induced-draft") and exhaust it through the stack. Key fan data are as follows:

- Number of fans: 56
- Fan motor rating: 200 hp
- Total fan power: 8,400 kW
- Fan diameter: 28 ft
- Fan stack discharge diameter: 32 ft
- Design fan air flow: 1,365,000 ft^3/min per fan

A chlorination system to control biofouling in the cooling tower fill and the condenser tubes would be required and a dechlorination system would probably be required for the blowdown. Costs for these systems were not addressed in the report.

The required makeup water flow to the cooling tower to maintain the concentration factor in the closed-loop circulating water system at 1.5 or less at all times would be approximately 36,000 gpm. Makeup flow would be pumped into the circulating water return line near the condenser discharge manifold as shown on Figure 7.8-1. Approximately 55 feet of pumping head would be required to pump the makeup water into the system. Required pump motor horsepower for the makeup water pump would be 720 horsepower. Two full-size makeup water pumps would be provided. A 42-inch diameter line would be required for makeup water.

Blowdown would be discharged from the cooling tower basin at an overflow weir structure that would be located on the cooling tower discharge flume. The discharged blowdown would be carried by gravity to the quarry by a 60-inch line buried in a cut and cover trench. Blowdown piping would be routed to the existing discharge flume at the quarry. Blowdown flow would range from 24,000 to 36,000 gpm.

7.8.1.2 Unit 3 Closed-Loop Circulating Water System

The closed-loop cooling water system for the Unit 3 mechanical-draft cooling tower is identical to the closed-loop system for the full-size natural-draft cooling tower presented in Section 7.6.1.2.

7.8.1.3 Impact on Unit 3 Performance

The mechanical-draft cooling tower would result in added power demand for operation of the fans, the higher horsepower circulating water pumps and added cooling tower makeup water pumps compared with current operation of the once-through cooling system. Also, the average circulating water temperature would be higher in the closed-loop cooling tower system, resulting in higher average turbine backpressure and reduced turbine performance, particularly during the summer months.

The existing circulating water pumps are 1,500 horsepower pumps, which draw a total of 6,700 kW of electric energy. The closed-loop circulating water system would require six new circulating water pumps, each rated at 3,300 horsepower, and two makeup water pumps, each rated at 750 horsepower. Normally, all six circulating water pumps and one of the two makeup water pumps would operate continuously. This would result in a net increase in pumping energy consumption of 17,000 kW.

The loss in electrical generation would occur primarily during the warm weather months of May through September. The reduction in the electrical generation rate is the result of higher inlet water temperature. This estimated performance penalty was based on the unit operating on the cooling tower 100% of the time. Refer to Table 7.11-2 for a summary of the change in unit performance.

Each switching of plant operation from cooling tower to once-through or back to cooling tower operation would require an outage. The performance penalty associated with this outage was not included in the estimated performance penalty.

7.8.1.4 Licensing and Permitting

The major environmental factors that would influence the permitting cycle and approvals required to convert Millstone Unit 3 to a cooling tower are:

- Visual impact of the cooling tower;
- The impacts of the makeup and blow-down systems on marine biota and populations;
- The tower vapor plume effects due to size, frequency, or trajectory, including icing and fogging effects;
- The local weather pattern influence on the resulting tower plume; and
- The impact of noise on neighbors.

Licensing the operation of Millstone with a cooling tower would require a number of local, state, and federal approvals. In addition, the Updated Final Safety Analysis Report (UFSAR) would have to be revised and submitted to the Nuclear Regulatory Commission (NRC) for their review and approval.

As with the natural-draft cooling tower alternatives, licensing and permitting requirements for the mechanical-draft cooling towers pose a major source of uncertainty. It has been assumed that the regulatory authorities would approve the design used as a basis for the cost estimate and schedule provided herein. If not, there would be a cost impact which has not been included in this estimate. In addition, depending upon the particular permit and schedule, there is the potential for very significant schedule impacts due to delays in obtaining permits.

7.8.1.5 Capital and O&M Costs

The estimated approximate capital cost for implementing a full-size mechanical-draft cooling tower system to Unit 3 is $125,500,000. This estimated capital cost includes the difference in estimated cost of the mechanical-draft cooling tower and fans as compared with the cost for the natural-draft cooling tower. All other parts of the cost estimate for the closed-loop system with the natural-draft cooling tower are assumed to be the same for the mechanical-draft tower alternative since the piping and pumping systems are the same.

Annual maintenance costs would include fan maintenance, cooling tower basin cleaning, cooling tower fill cleaning and maintenance, and pump maintenance. Pump maintenance would include an estimated normal annual maintenance cost plus a pump overhaul once every 10 years for each pump. These estimated maintenance costs are averaged over a 10-year period to determine an estimate equivalent annual maintenance cost. The estimated annual combined maintenance cost for a mechanical-draft cooling tower system for Unit 3 is $340,000 per year.

7.8.1.6 Unit 3 Cooling Tower Alternative-Conclusions

Mechanical-draft cooling towers also offer a benefit for reduction of ichthyoplankton entrainment. However, like the other cooling tower alternatives, such an option is costly because it would have to be backfitted to functional generating units that were designed for once-though cooling operation. As a result, there are significant construction, infrastructure, and siting issues associated with this alternative. It would also result in reduced power generation especially during the summer months. Additional impacts, such as aesthetics, noise, fogging, increased chlorination, and air emissions are discussed in Part II.

The capital cost for the Unit 3 mechanical-draft cooling tower system has been estimated to be $125,500,000. Licensing and permitting requirements pose a major source of feasibility and schedule uncertainty. It has been assumed that the regulatory authorities would approve the design used as a basis for the cost estimate and schedule provided herein. If not approved, there would be a cost impact which has not been included in this estimate. In addition, depending upon the particular permit and schedule, there is the potential for schedule impacts due to delays in obtaining permits.

7.8.2 Mechanical-Draft Cooling Towers – Unit 2

The mechanical-draft saltwater cooling tower alternative would consist of the tower array located in the wooded area to the east of the switchyard adjacent to the proposed location for the Unit 3 cooling towers as shown on Figure 7.8-2. The Unit 2 cooling tower would have a new circulating water system, identical in design to the system proposed for the natural-draft cooling tower, with two new pumping stations. One pumping station would be located at the existing Unit 2 discharge structure at the quarry. This pump

station would pump the heated Unit 2 discharge to the cooling tower fill distribution system. The second pump station would be located at the cooling tower basin. This pump station would pump the cooled water from the cooling tower through the condenser to the discharge. The proposed circulating water piping from the cooling tower would be routed in a 65-foot wide trench to the north and west side of the station, which would also contain both supply and return piping for the proposed Unit 3 cooling tower. Connections to the existing Unit 2 intake lines would be made by routing the new conduit from the cooling tower over the existing 78-inch lines from the intake and making vertical connections down into the existing lines. New motor operated butterfly valves would be located in the vertical connections. The existing pump discharge valves in the intake structure would serve as isolation valves for the intake lines. Preliminary sizing and layout of the cooling tower array show that there is enough space. The service water system would not be changed.

The total withdrawal rate of saltwater from Niantic Bay is approximately 1,500,000 gpm. The cooling tower would reduce the required Unit 2 circulating water flow withdrawal from 504,000 to 24,000 gpm for cooling tower makeup, resulting in a total station withdrawal of about 998,000 gpm, which corresponds to a 33% reduction attributable to this alternative from maximum station flow.

Since the cooling effect is mainly due to evaporation, the warm water the tower returns to the condenser approaches, but is always higher than, the local wet bulb temperature. With a mechanical-draft cooling tower, the condenser return temperature would be much warmer than the condenser cooling water that is currently drawn from Niantic Bay. Accordingly, the turbine backpressure would be elevated, causing an increase in station heat rate and a reduction in generation. A mechanical-draft cooling tower would be able to cool the water to a closer approach temperature to the wet bulb temperature (7° vs 14°F) than the natural-draft cooling tower due to the fan generated airflow. The disadvantage of the mechanical-draft design would be the energy required to operate the fans. Extra plant energy would be required to operate the fans of a mechanical-draft tower in addition to increased pump energy to pump the circulating water to the tower and up to the heat transfer section.

The fresh airflow into the mechanical-draft cooling tower would be subject to a re-circulation of a small fraction of the warm air exhaust plume that can be drawn back into the tower due to bluff-body wind effects. Re-circulation can reduce some of the tower's thermal performance, but this effect would be compensated for in the design sizing.

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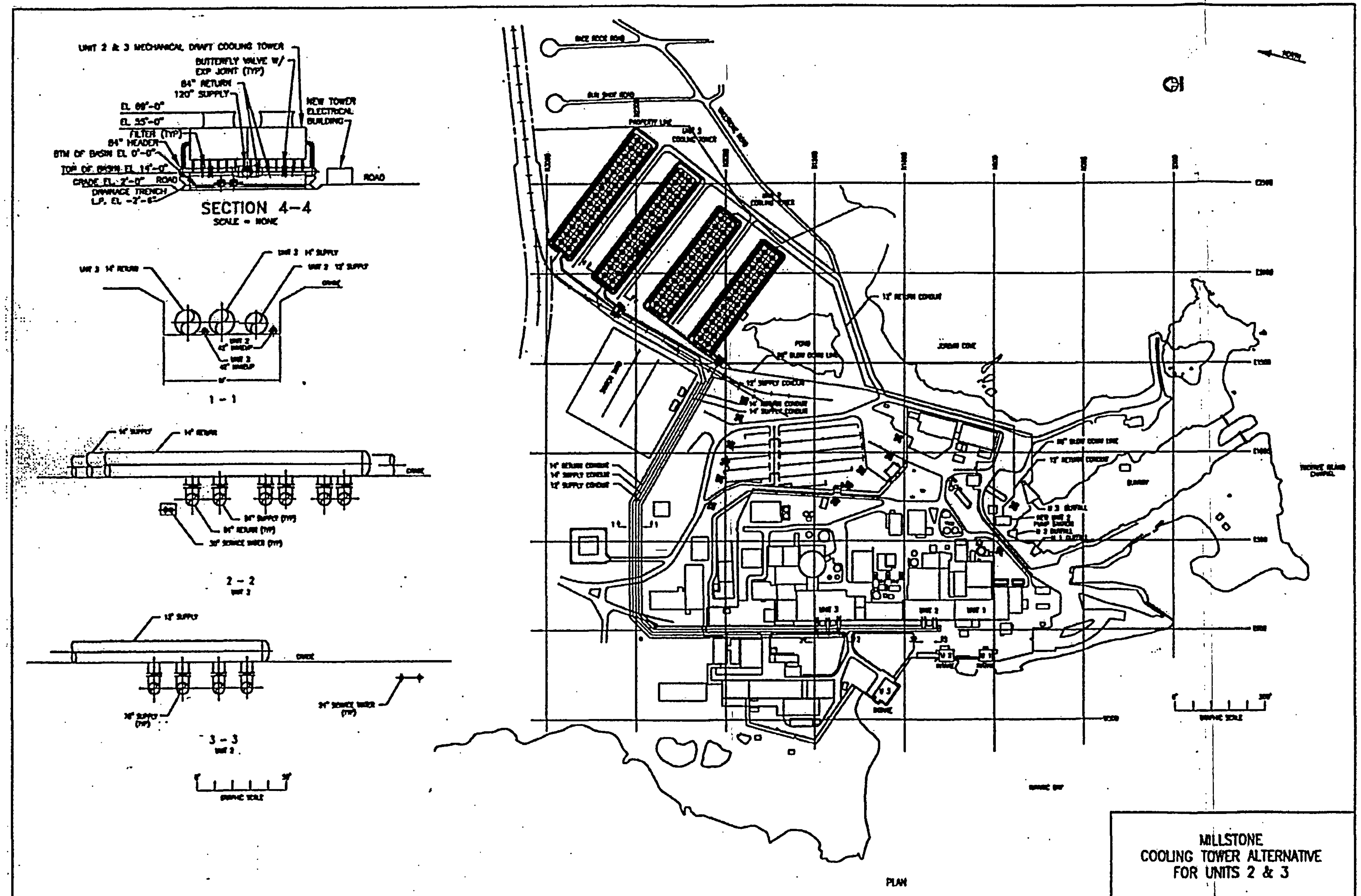

Figure 7.8-2: Mechanical-Draft Cooling Towers for Units 2 & 3

7.8.2.1 Cooling Tower Design – Unit 2

The mechanical-draft saltwater cooling tower for Unit 2 would be designed to operate in summer conditions. The tower would be a multi-cell rectangular array consisting of 48 cells arranged in two back-to-back towers each having 24 cells. Each of these tower units would be approximately 650 ft long by 110 ft wide. The towers are spaced 200 ft apart to reduce recirculation. The tower design would be of the counterflow configuration with the fill located within the tower shell just above the air inlet. The fill mass would cover the full plan area of each tower cell and would be approximately 4 feet in thickness. A system of channels, pipes, and spray headers would distribute the circulating water evenly over the fill area. Special material provisions for salt water would include galvanized or epoxy-coated rebar and Type II Portland cement. The polyvinylchloride (PVC) fill would be unaffected by salt water.

The towers would be constructed from fiberglass. The tower will be provided with a grounding system, lightning protection, and area lighting.

Specific design parameters for the mechanical-draft cooling tower are as follows:

Circulating Water Flow	522,500 gpm
Cooling Range	24°F
Approach Temperature	7°F
Wet Bulb Temperature	77°F
Dry Bulb Temperature	89°F
Evaporation Rate	2.1%
Drift Rate	0.0005%
Concentration Factor	1.5

Refer to the discussion of salt drift in Section 7.6.1.1.

Above the drift eliminators would be the plenum, roofed by the fan deck. The fan deck would support the fan, fan stack, and driving motor. The fan motor would be located outside of the fan stack on the fan deck and would be mechanically connected to a right-angle gear box at the center of the fan stack on which the fan hub is mounted. The fan would draw the moist air up from the plenum ("induced-draft") and would exhaust it through the stack. Key fan data are as follows:

- Number of fans: 48
- Fan motor rating: 200 hp
- Total fan power: 7200 kW
- Fan diameter: 28 ft

- Fan stack discharge diameter: 32 ft
- Design fan air flow: 1,365,000 ft^3/min per fan

A chlorination system to control biofouling in the cooling tower fill and the condenser tubes would be required and dechlorination system would probably be required for the blow-down.

The required makeup water flow to the mechanical-draft cooling tower to maintain the concentration factor in the closed-loop circulating water system at 1.5 or less at all times would be 24,000 gpm. Makeup flow would be pumped directly to the cooling tower basin. Approximately 25 feet of pumping head would be required to pump makeup water from the intake structure to the cooling tower basin. Required pump motor horsepower for the makeup water pump would be 220 horsepower. Two full-size make-up water pumps would be provided. A 42-inch diameter line would be required for makeup water.

Blowdown would be discharged from the cooling tower basin at an overflow weir structure, located on the cooling tower discharge flume. The discharged blowdown would be carried by gravity to the condenser discharge pump basin near the quarry by a 60-inch line buried in a cut and cover trench routed along the east side of the site adjacent to the Unit 3 cooling tower blowdown line. Unit 2 radioactive waste discharge would be rerouted to the Unit 3 discharge. The blowdown would discharge from the condenser discharge pump basin to a point at the quarry south of the existing Unit 3 discharge on the east side of the quarry.

A separate, new makeup water pump system consisting of two full-size pumps with associated controls and electrical equipment would be installed in the existing intake structure. Makeup water piping to the cooling tower would be routed in the same trench as the cold water conduit from the tower. The blow-down discharge line from the tower basin to the quarry to the east of the station adjacent to the blow-down line from the proposed Unit 3 tower. Discharge to the quarry would be through the Unit 3 discharge structure.

7.8.2.2 Closed-Loop Cooling Water System – Unit 2

The closed-loop cooing water system for the mechanical-draft cooling tower would be similar to the closed-loop cooling water system for the natural draft cooling tower discussed in Section 7.7.2. The circulating water system for the Unit 2 cooling tower would include two pumping stations. One station at the cooling tower basin would pump cooled circulating water through the condenser (supply pumps). The other pump station located near the quarry would pump the heated water back to the cooling tower fill distribution system (return pumps). Each pump station would include four ¼ size circulating water pumps. A buried water conduit, which would convey cooled circulating water from the cooling tower to the condenser, would be routed along the north and west sides of the station, adjacent to the Unit 3 cooling tower supply conduit. Existing inlet and discharge piping at the condenser and the existing discharge

conduit would be utilized to convey heated water to the diversion facility and return pump station at the quarry.

A diversion system would be constructed in the discharge conduit to divert the flow to the new return pumping station. This system is identical to that proposed for the natural-draft cooling tower alternative discussed in Section 7.7.2. This diversion system would be capable of diverting all of the Unit 2 heated circulating water discharge to the return pump station and also allow return to once-through operation as desired. The return pump station would be a standard, open channel intake structure for the four ¼ size return pumps. A new conduit, which will carry the diverted heated water from the return pump station to the cooling tower distribution system would be routed along the east side of the station as shown on Figure 7.8-1. This piping would have to cross the existing Unit 3 discharge conduit. Initially, it is assumed that the pipe would pass under the existing Unit 3 14 feet by 14 feet discharge conduit to avoid constructing above ground pipe. This would require rock excavation under the exiting conduit.

Flow rate for the system from the cooling tower basin through the condenser would be 522,500 gpm. The flow rate for the return pump station and conduit would be set slightly higher than that for the supply side with the excess flow drawn to the pump station from the cooling tower overflow being discharged by the blowdown system. This would be to alleviate operational problems associated with pump stations in series. A design flow of 525,000 gpm would be assumed for the return system. An engineering analysis would be required (not included in this report) to determine the appropriate design flow for the return system and how best to route the cooling tower flow into the pump station and to design the blowdown discharge to the quarry. The supply pumps at the cooling tower would require approximately 30 ft total dynamic head. The return pumps at the quarry would require approximately 70 ft total dynamic head. Pump power requirements for the cooling tower system would be as follows:

Pump	No. Pumps	hp/Pump	Total kW
Make-up Supply	2 @ 100%	220	165
C.W. Supply	4 @ 25%	1,350	4,000
C.W. Return	4 @ 25%	3,100	9,200

This would equate to a total of approximately 13,500 kW of electric power.

At both the supply and return pump stations, the four pump discharges would be manifolded into single 12-foot diameter conduits. The supply piping would be manifolded into the four 78-inch inlet lines from the intake structure in the yard to the west of the turbine building. Each of the four manifold branches would contain a 78-inch motor-operated butterfly valve. Refer to Section 7.7.2 for a discussion of the diversion system, pump structure, and pipe materials.

An evaluation of electric power supply for this system has not been performed for this study. The power supply system for each pump station would be similar in scope to that outlined for the Unit 3 cooling tower pump station.

Service water piping would remain unchanged. The new diversion system in the discharge conduit at the quarry will allow for direct discharge of service water to the quarry while configured for either closed-loop or once-through circulating water system operation.

Radioactive waste discharges, currently routed to the Unit 2 discharge conduit, would be rerouted to the new cooling tower blowdown discharge line to be released from the return pump basin as overflow.

7.8.2.3 Impact on Unit 2 Performance

The mechanical-draft cooling towers would result in added power demand for operation of the cooling tower fans plus the additional set of return pumps and the makeup water pump. The supply pumps would draw approximately the same power as the existing circulating water pumps. Also, the average circulating water temperature would be higher in the closed-loop cooling mode, resulting in higher turbine backpressure and reduced turbine performance, particularly during the summer months.

The existing circulating water pumps require 1,100 hp per pump, which amounts to a total draw of 3,300 kW for the four pumps. The cooling tower fans would draw a total of 7,200 kW of additional power. The closed-loop circulating water system would require eight new circulating water pumps and two makeup water pumps. All eight of the circulating water pumps and one of the makeup water pumps would normally operate in the closed-loop mode. The existing circulating water pumps would not operate in the closed-loop mode. This would result in a net increase in pumping energy consumption of 17,400 kW. Table 7.11-2 is a summary of annual unit performance loss the periods of abundance for winter flounder larvae and tautog eggs.

Each switching of plant operation from once-through to closed-loop or back to once-through would require an outage. The performance penalty associated with this outage was not included in the estimated unit performance losses.

7.8.2.4 Licensing and Permitting

The major environmental factors that would influence the permitting cycle and approvals required to convert Millstone Unit 2 to a mechanical-draft cooling tower would be the same as for Unit 3 and include the following:

- The visual obtrusion of the towers;
- The impacts of the makeup and blowdown systems on marine biota and populations;
- The tower vapor plume effects due to size, frequency, or trajectory, including icing and fogging effects;
- The local weather pattern influences resulting from the tower plume; and
- The impact of noise on neighbors.

Licensing the operation of Millstone with a cooling tower would require a number of local, state, and federal approvals. In addition, the Updated Final Safety Analysis Report (UFSAR) would have to be revised and submitted to the Nuclear Regulatory Commission (NRC) for their review and approval. Licensing and permitting requirements pose a major source of uncertainty. It has been assumed that the regulatory authorities would approve the design used as a basis for the cost estimate and schedule provided herein. If not, there would be a cost impact which has not been included in this estimate. In addition, depending upon the particular permit and schedule, there would be the potential for very significant schedule impacts due to delays in obtaining permits.

7.8.2.5 Capital and O&M Costs

The estimated approximate capital cost for implementing a full size mechanical-draft cooling tower system to Unit 2 would be $120,000,000. This estimated capital cost reflects the difference in estimated cost of the mechanical-draft cooling tower and fans as compared with the cost for the natural-draft cooling tower. All other parts of the cost estimate for the closed-loop system with the natural-draft cooling tower are assumed to be the same for the mechanical-draft tower alternative since the piping and pumping systems are the same.

Annual maintenance costs would include fan maintenance, cooling tower basin cleaning, cooling tower fill cleaning and maintenance, and pump maintenance. Pump maintenance would include an estimated normal annual maintenance cost plus a pump overhaul once every 10 years for each pump. These estimated maintenance costs are averaged over a 10-year period to determine an estimated equivalent annual maintenance cost. The estimated annual combined maintenance cost for a mechanical-draft cooling tower system for Unit 2 would be $310,000 per year.

7.8.2.6 Unit 2 Cooling Tower Alternative-Conclusions

As stated above, mechanical-draft cooling towers offer a benefit for reduction of ichthyoplankton entrainment. However, in the case of Unit 2, conversion to a closed-loop mechanical-draft cooling tower system would reduce system reliability, which has a direct effect on the safety of the reactor. Also, it would significantly complicate operation of the circulating water system requiring closer operator attention in the closed-loop mode and during change over to and from the closed-loop mode. It would also result in reduced power generation especially during the summer months. Additional impacts, such as aesthetics, noise, fogging, increased chlorination, and air emissions are discussed in Part II. However, such an option is very costly because it would have to be backfitted to functional generating units that were designed for once-though cooling operation. As a result, there are significant construction, infrastructure, and siting issues associated with this alternative.

The capital cost for the Unit 2 mechanical-draft cooling tower system has been estimated to be $120,000,000. Licensing and permitting requirements pose a major source of feasibility and schedule uncertainty. It has been assumed that the regulatory authorities would approve the design used as a basis for the cost estimate and schedule provided herein. If not approved, there would be a cost impact which has not been included in this estimate. In addition, depending upon the particular permit and schedule, there is the potential for schedule impacts due to delays in obtaining permits.

7.9 DRY COOLING

Dry cooling is being considered more frequently as an option by the United States power industry since it can be applied to certain types of new generating stations presently being constructed, e.g., combined-cycle units. Dry cooling systems reject waste heat from a station's steam cycle either directly or indirectly to ambient air.

Two commercially available options for dry cooling are available. These include the direct acting, air-cooled condenser (ACC) and the indirect acting dry cooling tower (DCT). Both of these technologies are available in either a natural-draft or mechanical-draft configuration. Very few natural-draft ACCs or DCTs have ever been constructed and none have been constructed in the U.S. Mechanical-draft dry cooling systems, particularly ACCs, are now commonly being provided for the new combined-cycle power stations being constructed in the U.S. Only mechanical-draft dry cooling alternatives are considered in this evaluation for possible back-fit to the Millstone Station.

The objective of dry cooling is to completely eliminate station/unit withdrawal from and discharge to the Niantic Bay. Either the ACC or DCT alternative would achieve the zero withdrawal objective, if the entire

station/unit is converted to dry cooling. However, because of space limitations, use of DCTs at Millstone Station are not considered technically feasible.

7.9.1 Air Cooled Condensers (ACC)

In an ACC system, the steam from the turbine is conveyed directly to bundles of fin-covered metal tubes, and condenses inside them. Air is blown across the tube-bundles by large fans to remove the heat. The condensate is collected and pumped back to the power plant. There is no evaporation, so no seawater is used for makeup. The waste heat is transferred directly from the steam to the atmosphere.

Most recent applications of ACCs are with new combined-cycle generating plants. A typical large modern combined-cycle plant of 230 MW total rating, for example, would generate 80 MW in the steam turbine cycle. The ACC would condense the steam from the 80 MW steam turbine. The ACC for the 80 MW steam turbine at a recently developed mid-Atlantic site is about 235 x 113 feet. It is a steel-framed structure about 100 feet high, with the lower 65 feet clear to allow air into the ACC and the upper 35 feet blocked by a "wind-wall" to protect the fans and direct the air across the tube-bundles. The ACC is modular, so the plot area and air space required are proportional to the Unit size. An ACC large enough for Unit 3 at Millstone would be about 235 x 1,600 feet, or 8.6 acres. If the ACC were split into several sections, to allow adequate air space under the wind-walls for all the cells, the total plot area required would be about 17 acres. The ACC for Unit 2 would be proportionally smaller, about 13 acres.

The steam ducts for an ACC must be vacuum-tight and would typically be made of welded steel. They also must be very large to minimize resistance as the steam is conveyed from the LP turbine to the ACC. For Millstone 3, the existing LP turbine exhausts are of a 6-flow design connecting into 3 condenser necks. A possible steam duct arrangement to backfit an ACC would remove the entire surface condenser and allot one ACC steam duct in place of each condenser neck.

The ACC steam ducts would be brought out through the ground floor of the Unit, requiring that the feed water pumps and almost all other equipment on that floor be removed and relocated. The steam ducts would have to be run thousands of feet to reach any site of adequate area for the ACCs.

Retrofit of ACCs to either active Millstone unit was not considered a credible option because of limited space to place the ACCs. In addition, construction of the large steam ducts would require complete removal of virtually all equipment on the turbine building ground floor of the Units. The large steam ducts would have to be either routed above ground or buried in mostly rock excavated trenches, which would have to extend thousands of feet to a site with adequate space for the condensing units.

7.9.2 Dry Cooling Towers (DCT)

In a DCT system, the steam is condensed in a traditional condenser. The circulating water from the condenser is pumped to bundles of fin-covered metal tubes, where it is cooled, and then recirculated back to the condenser. Air is blown across the tube-bundles by large fans to remove the heat. There is no evaporation, so after the system is filled with circulating water (which can be fresh water or seawater), there is no more water used. The waste heat is transferred indirectly from the steam to the circulating water to the atmosphere, so the system is referred to as an "indirect-acting" system or more commonly as a "dry cooling tower" or DCT. The DCT operates to the ambient dry bulb temperature, unlike the evaporative cooling tower alternatives, which operate to the ambient wet bulb temperature.

Dry cooling towers are very similar to wet cooling towers in overall cooling system design concept, so many of the assumptions used in evaluation of wet towers for the Millstone units would apply to dry towers, such as converting the Unit 3 condenser to 2-pass and the 2-pump station arrangement for Unit 2.

There is no reliable design data for a mechanical-draft dry cooling tower sized to discharge the condenser duty of either active Millstone unit (Burns, 1994). Water-to-air cooling duty, such as for turbine components, is now often handled by modular dry-cooling devices called "air-cooled heat exchangers" or "Fin-Fans"[1]. Therefore, a mechanical-draft dry cooling tower would be expected to have a plot area scalable from modern Fin-Fans.

In order to estimate plot area for the mechanical-draft DCT, a bid for a Fin-Fan system was obtained for Millstone 2 (Millstone Project 2001) and scaled for Unit 3. Unit 2 requires approximately 1,100 Fin-Fan units, each 13.5 x 44 feet; Unit 3 requires over 1,300 Fin-Fan units. The plot area required for the Fin-Fans to meet a duty of 6.0 x 10^9 Btu/hr in Unit 2 would be about 15 acres. Scaling this to the duty of 7.9 x 10^9 Btu/hr for Millstone 3 results in a plot area of 20 acres for the equipment alone.

In addition to the Fin-Fan equipment, the mechanical-draft DCT would require a substantial area for circulating water headers, maintenance access, and cool-air access. It was assumed that the Fin-Fans are "ganged" in groups of 20, each 270 feet long and served by a 24-inch supply subheader and a 24-inch return subheader. Each "gang" would be lined up with the prevailing summer wind (southwesterly) and would be separated by about one width (44 feet) from its neighboring "gang," to allow cool air can enter below the fan deck. Unit 2 would require three, 96-inch supply headers, each of which would serve 18 "gangs." Unit 3 would require three, 108-inch supply headers, each of which would serve 22 "gangs". Of course, each supply header has a corresponding return header. The 12 headers would be arranged across the wind for efficient construction and to fit the site area. However, each header must be separated from its

neighbors by approximately two "gang-lengths" or 540 feet, so that the plume of hot air from the upwind Fin-Fans is not recirculated into the downwind Fin-Fans. These design features could easily increase the necessary site area required to 70 acres for both Units. There would not be enough room on the site property for these cooling tower arrays.

7.9.2.1 DCT – Unit 3

From Section 7.6.1.1, the design dry-bulb temperature of the ambient air for the wet cooling towers is 89°F and the cooling range for Unit 3 is 25°F. To evaluate this DCT alternative, an approach of 7°F has been used for a state-of-the-art wet mechanical-draft cooling tower or the modern Fin-Fan (Hudson Products Quotation; 2001). The condenser inlet and outlet temperatures would be 96° and 212°F, respectively. Another reasonable assumption is that the condenser TTD is 6°F which would yield steam saturation temperature (T_S) of 127°F, resulting in a condenser backpressure (P_S) of 4.18 inch HgA (Heat Exchange Institute Standards; 1995).

7.9.2.2 DCT – Unit 2

By similar logic described above for a DCT on Unit 3, Unit 2 which has a 24°F temperature rise would result in a turbine backpressure at the 89°F design ambient dry bulb temperature and 4.07 inch HgA. The backpressure of Unit 2 is limited to 4.5 inch HgA, so a mechanical-draft dry cooling tower for Unit 2 would be less restrictive to unit operation during the summer months than Unit 3. However, the Unit 2 capacity and heat rate would still be penalized. Approximately 33,000 kW would be required to operate all of the DCT fans. Added electric energy would also be required for the new dry cooling tower pumps plus the return pumps. Pumping energy requirements can not be estimated until a site for the cooling towers is determined. Pump energy requirements are anticipated to exceed those for either the natural-draft or mechanical-draft wet towers because the towers would almost certainly be located at a greater distance from the turbine buildings plus distribution of the heated return water to the many tower units would require more pump head.

7.9.2.3 Capital Costs for DCT

It is difficult to estimate an overall cost for a dry cooling tower system for either operating unit until a location is identified with adequate space for the large dry cooling tower arrays. Based on preliminary costs provided by a dry cooling tower supplier, the estimated cost for the Unit 2 dry tower equipment alone would be $104,000,000. From cost estimates for the wet mechanical-draft cooling tower alternative for Unit 2 developed in Section 7.8, the estimated capital cost for the circulating water system and cooling

[1] Fin-Fan is a trademark of the Hudson Products Corporation, Houston, Texas, a leading vendor of air-cooled heat exchangers.

tower basin (not including the cooling tower) would be an approximate additional $103,000,000. The cost for a similar circulating water system for the dry cooling tower array would be substantially more due to the longer pipe runs for the main supply and return headers; more extensive cooling tower basin system and much more extensive supply pipe system for the numerous dry cooling tower units.

7.9.2.4 Conclusions Regarding DCTs for Millstone Station

Notwithstanding the high costs associated with DCTs, there would not be sufficient available space on the station property for the large array of dry cooling towers. Because of this, backfit of DCTs on Unit 2 or 3 would not be technically feasible.

7.10 LICENSING AND PERMITTING ISSUES

The traveling water screen modifications, cooling tower options, and flow reduction concepts considered in this report would all require some license or permitting approval from Federal and Connecticut agencies responsible for environmental resources and nuclear safety-related aspects of the design and operation of Millstone Station. Several examples are noted below.

Each of these alternatives would require Nuclear Regulatory Commission (NRC) approval of both the design and operating conditions of any proposed modifications to the cooling system. Before the well-characterized and field proven cooling water systems at Millstone could be replaced or supplemented with any of the alternatives discussed in the report, the NRC would require submittal of detailed design information and a safety analysis report. That report must contain sufficient detail and description of operation procedures under a variety of plant and environmental conditions to demonstrate that the cooling water alternative would not compromise the safety standards of the project.

Also, the alternative cooling systems would require review and approval from other federal and some state environmental agencies including the Connecticut DEP and the Connecticut Siting Council. The visual effects of both the cooling towers and the vapor plume on the coastal zone would require state review and approval. The Office of Long Island Sound Programs (OLISP) approval would also be required for any extension to the front of the existing intake structure to accommodate a wider screen bay, or for any possible change to the conditions in the quarry that may accompany a change in the discharge temperature as a result of a higher degree of recirculation. This agency also administers permits related to the dredging or filling of coastal wetlands which would be required for modifications in or near the intake or discharge structures.

The discharge operating permit (National Pollutant Discharge Elimination System or NPDES) as issued by the state DEP under delegated authority from Region I EPA would also need to be modified for the cooling

tower or recirculation options. Even though the cooling tower would reduce the quantity of waste heat discharged at the quarry, the actual discharge temperature and characteristics of the discharge at the monitoring point would be altered. Likewise, the flow reduction options would reduce the volume of discharge, but would still change the discharge characteristics and require a modification of the discharge permit. Since the NPDES is a permit for the cooling system, including the intake structure, any modification of the intake would also require a modification of the NPDES permit. Therefore, even the installation of fine-mesh traveling water screens would require NPDES approval authority from DEP.

Licensing and permitting requirements pose a major source of uncertainty in the public and regulatory agency approval of the designs and in the implementation schedule for either the cooling tower and flow reduction alternatives. In deriving the cost estimates, it has been assumed that the regulatory authorities would approve the designs used as a basis for each flow reduction alternative. If not, there could be cost impact. In addition, depending upon the alternative and particular permit, there is the potential for very significant schedule impacts due to delays in obtaining permits and licensing approvals.

7.11 FLOW REDUCTION ALTERNATIVES SUMMARY

Table 7.11-1 summarizes the various flow reduction alternatives that have been discussed previously. The table provides the CWS and SWS flow rates for each of the alternatives as well as the percent flow reduction compared to the maximum flow rates presented in the 1998 letter to DEP (NUSCO 1998). In addition, similar flow reduction alternatives for Units 2 and 3 have been combined in order that a total percent flow reduction can be provided. Table 7.11-2 summarizes the effect on Unit performance for each alternative for the winter flounder larvae and tautog egg periods. The change in Unit performance includes the effect of the pump power changes (i.e., increased or decreased).

Table 7.11-1: Flow Reduction Alternatives Summary

Description	Unit 1		Unit 2		Unit 3		Station	% Flow Reduction
	CWS (gpm)	SWS (gpm)	Tot CWS (gpm)	SWS (gpm)	Tot CWS (gpm)	SWS (gpm)	Total (gpm)	Permit (%)
Permit	420,000	24,000	548,800	24,000	918,000	30,000	1,964,800	N/A
Unit 1 S/D	0	0	548,000	24,000	918,000	30,000	1,476,000	23%
Single Unit Changes - Reduced Number of Operating CWPs								
U3 - 5 CWPs	0	0	504,000	24,000	803,600	30,000	1,361,600	8%
U3 - 4 CWPs	0	0	504,000	24,000	677,200	30,000	1,235,200	16%
U2 - 3 CWPs	0	0	403,200	24,000	918,000	30,000	1,375,200	7%
Single Unit Changes - Condenser By-pass, Throttling, or Variable Speed CWPs								
U3	0	0	504,000	24,000	690,000	30,000	1,248,000	15%
U2	0	0	412,000	24,000	918,000	30,000	1,384,000	6%
Combined Unit Changes - Reduced Number of Operating CWPs								
U3 - 5 CWPs & U2 - 3 CWPs	0	0	403,200	24,000	803,600	30,000	1,260,800	15%
U3 - 4 CWPs & U2 - 3 CWPs	0	0	403,200	24,000	677,200	30,000	1,134,400	23%
Combined Unit Changes - Condenser By-pass, Throttling, or Variable Speed CWPs								
U3 & U2	0	0	412,000	24,000	690,000	30,000	1,156,000	22%
Natural Draft Cooling Towers								
Full Flow - U3	0	0	504,000	24,000	36,000	30,000	594,000	60%
2/3 Full - U3	0	0	504,000	24,000	333,000	30,000	891,000	40%
Full - U2	0	0	26,000	24,000	918,000	30,000	998,000	32%
Full - U2 & U3	0	0	26,000	24,000	36,000	30,000	116,000	92%
Mechanical Draft Cooling Towers								
Full - U2	0	0	24,000	24,000	918,000	30,000	996,000	33%
Full - U3	0	0	504,000	24,000	36,000	30,000	594,000	60%
Full - U2 & U3	0	0	24,000	24,000	36,000	30,000	114,000	92%

Table 7.11-2: Flow Reduction Alternatives – Annual Loss in Unit Performance

Description	Unit No.	Annual Loss in Electric Output (MW-hr) (note)				
		Winter Flounder		Tautog		Flounder & Tautog
		3/22 – 6/5	4/4 – 5/14	5/3 – 8/22	5/29 – 7/12	3/22 – 8/22
Reduced Flow Rate						
Reduced Number of Operating CWPs • 5 CWPs	3	3,132	1,392	14,452	5,329	15,366
Reduced Number of Operating CWPs • 4 CWPs	3	12,466	5,927	41,719	15,953	46,716
Reduced Number of Operating CWPs with Cross Connect • 5 CWPs	3	3,098	1,375	14,404	5,310	15,300
Reduced Number of Operating CWPs with Cross Connect • 4 CWPs	3	12,181	5,775	41,298	15,786	46,135
Reduced Number of Operating CWPs • 3 CWPs	2	3,334	0	184,863	83,900	184,532
Reduced Number of Operating CWPs with Cross Connect • 3 CWPs	2	3,334	0	184,863	83,900	184,532
Throttling of Condenser Discharge Valves	3	12,732	6,276	38,660	14,636	44,224
Throttling of Condenser Discharge Valves	2	915	298	5,185	1,994	5,492
Recirculation						
Installation of Condenser By-pass Lines	3	12,208	5,997	37,884	14,329	43,156
Installation of Condenser By-pass Lines	2	539	98	4,628	1,773	4,724
Variable Speed						
Variable Speed CWPs	3	7,008	3,223	30,188	11,278	32,547
Variable Speed CWPs	2	-2,624	-1,589	-52	-82	-1,727
Cooling Towers						
Natural-Draft – 100% Capacity	3	401,715 (Annual)				
Natural-Draft – 2/3 Capacity	3	134,067 (Annual)				
Mechanical-Draft – 100% Capacity	3	240,925 (Annual)				
Natural-Draft – 100% Capacity	2	109,982 (Annual)				
Mechanical-Draft – 100% Capacity	2	153,811 (Annual)				
Offshore Intake						
Unit 3 Only	3	14,000 (Annual)				
Units 2 and 3 Combined	2 & 3	22,300 (Annual)				
Physical Barriers						
Fine-Mesh Screens	3	0	0	0	0	0
Fine-Mesh Screens	2	0	0	0	0	0

Note: Change in Unit performance includes the increase or decrease in pump and/or fan power, as well as, station generating capacity.

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8 OFFSHORE INTAKE

8.1 UNIT 3

The offshore intake Unit 3 alternative would consist of extending the intake approximately 1 mile south into Long Island Sound utilizing a submerged offshore intake, a rock tunnel, and a booster pump station that would be located in front of the existing intake structures. The proposed design for Unit 3 is shown on Figure 8.1-1. The objective of the offshore intake would be to place effective point of water withdrawal for the intake south into Long Island Sound, past the confines of Niantic Bay, such that smaller numbers of Niantic River winter flounder larvae would be entrained in the Unit 3 intake. Those flounder larvae that would be entrained by the proposed new Unit 3 offshore intake would come from the Long Island Sound population as a whole.

As discussed below, this is very costly alternative in terms of schedule, and capital cost with considerable uncertainties that could not be resolved until more site specific geotechnical data is available to refine the design. Due to the difficulty, magnitude, and cost for a retorfit of this type, this alternative is not recommended for further consideration. In addition, as discussed in Part II, there are several other potential environmental impacts, including increased chlorination and impingement.

8.1.1 Design Basis

The offshore intake system for Unit 3 would be designed for a flow rate of 958,000 gpm, which is 4% greater than the present design flow of the Unit 3 circulating water system (918,000 gpm). The inlet velocity cap structure would be sized for an inlet velocity of 0.5 fps to minimize fish entrainment. The inlet velocity assumption was chosen only because that is a value commonly accepted by the resource agencies. A higher inlet velocity would only slightly reduce the overall cost of this alternative. The offshore conduit would be sized for a flow velocity of 5 fps to minimize head losses. These criteria result in an offshore conduit I.D. (inside diameter) of 24 feet. The head loss in the offshore intake system, assuming biofouling in the tunnel and risers, would be approximately 5 feet. The onshore booster pump facility would be designed to provide pumping head to compensate for head losses in the offshore intake. The booster pumps would be sized to pump a minimum of 5% excess flow into a new forebay that would lead to the existing Unit 3 intake. An excess flow would be provided to prevent surging between the two in-line pumping systems. The forebay walls would be designed to spill the excess flow into Niantic Bay.

Biofouling of the offshore intake, shafts, and tunnel in the form of mussels and other marine organisms could become severe and difficult to control. A chlorination system, which introduces chlorine at the inlet and possibly at multiple locations along the tunnel, would be required. Continuous chlorination during the fouling season may be required to control biofouling of the tunnel, shafts and offshore inlet. This

chlorination would likely kill most fouling organisms and any organisms entrained into the offshore inlet structure. A dechlorination system would also be required for the circulating water discharge. The cost of these systems was not included in the estimates.

8.1.2 Geotechnical Considerations

In the absence of borings along the proposed tunnel alignment and offshore intake, the geology was inferred from the nearshore boring, seismic refraction surveys, and bathymetric surveys. The seafloor bottom along the proposed intake generally slopes seaward from the coast to a depth of approximately 40 feet at the proposed offshore intake. According to seismic refraction surveys, which cover approximately 4,000 feet of the initial proposed 5,000-foot tunnel, the top of rock surface along the alignment is irregular with top of rock elevations ranging from -40 to -120 feet (FSAR Appendix 2.5 K). Thus, the overburden along the alignment would be expected to be between 0 and 80 feet thick.

The nature of the overburden cannot be determined from the seismic velocity data. It was assumed that a dense basal till of varying thickness overlies the bedrock and looser silty sands overlie the till.

The type and quality of bedrock along the alignment was assumed to be similar to the bedrock mapped at the Unit 3 intake structure. The rock types are gneiss and granite with the fractures oriented north-south and dipping near vertical. A conservative range for hydraulic conductivity of a rock mass of this type was assumed to be between 10^{-1} to 10^{-6} cm/s.

Both cut and cover and deep rock tunnel schemes were evaluated for conveyance of water from the offshore intake. The deep rock tunnel would have a much larger range of static water pressure between the offshore intake and the circulating water pumps. Some species and lifestages of fish entrained through the tunnel may not accommodate this change in pressure as well as the smaller range of pressure change associated with the more shallow cut and cover design.

8.1.2.1 Cut and Cover Offshore Twin Pipelines

The cut and cover scheme for a Unit 3 tunnel, would involve the fabrication of two parallel pipes, approximately 12 feet I.D. each, that would be placed in a single common trench. A 5,000-foot long trench would be dredged at a constant elevation from the intake structure to the offshore intake port. The trench would be excavated to a depth of approximately 15 feet (3 feet deeper than the pipe diameter), 26 feet wide (at the bottom), and covered with protective armor stone after the pipes were placed. Due to the thin nature of overburden in some areas, it was estimated that 10 to 15% of the trench would require underwater blasting. Based upon current offshore data, it would be expected that nearly 90% of the trench would be dredged in relatively dense overburden. Major technical concerns of such an operation would be:

1. Disturbance of potentially contaminated sediments during dredging operations and their disposal.
2. Disturbance of marine life which may become a major environmental and permitting concern.
3. Limited available construction period (late spring to early fall).
4. Impact of underwater blasting on marine life and project cost.
5. Numerous regulatory reviews and approvals would be required by both state and Federal agencies.

Soil tests and surveys would be necessary to verify adequate thickness of the overburden, suitability for direct pipe support, and need for structural backfill and armor stone scour protection. While a cut and cover tunnel would appear less challenging from a technical point of view than subsurface tunneling, the environmental impact during construction must be weighed in considering this scheme.

The cut and cover conduit approach would be given further evaluation to include geotechnical investigations of sea floor subsurface conditions along the proposed route prior to refine the design, construction methods, and cost of the alternative.

8.1.2.2 Deep Bedrock Tunnel

The tunnel scheme would require a vertical shaft near the Unit 3 intake structure, sunk to a depth of approximately 300 feet below low mean sea level. The shaft would be sunk 30 to 50 feet deeper than the bottom of the tunnel to provide space for loading and storage of muck. A circular tunnel approximately 225 to 250 feet below low mean sea level (minimum rock cover of 125 to 150 feet), and 26 feet in drilled diameter (24 feet inside lined diameter) would be initiated from the shaft and excavated entirely in rock. The tunnel would be sloped down from the offshore intake structure 1% towards the pumphouse at a descending grade to assure adequate flow and minimize ponding during scheduled shutdown. The offshore intake shaft could employ either a single or multiple "dry tap" construction scheme to intersect the tunnel. The dry tap scheme would use a circular steel caisson grouted in-place on the sea floor bottom. Water would be pumped out of the caisson, and the shaft sinking operation initiated. Similar operations have been performed at the Oswego Steam Plant and at the Seabrook Nuclear Power Plant. The major geotechnical constraints for the tunnel scheme were determined to be:

1. Control of water seepage into the tunnel during construction. (exploratory borings in the rock may indicate that this may not be a concern).
2. High costs of offshore shaft construction.
3. Development of an on-shore access shaft for muck transfer to the surface and a subsurface lay down area for equipment. At the surface, a temporary hoist system would be necessary to lift muck from the shaft and lower excavation equipment.
4. Muck transfer facilities from the access shaft would be necessary, as well as a lay down area at the surface for under-ground equipment, ventilation, etc.

The criteria for 125 to 150 feet of depth of bedrock were based primarily upon estimated rock permeability, rock structure, and manageability of water inflows during construction. Based upon the above assumptions, overall tunnel seepage rates could be expected to range from less than 300 to 3,000 gpm. Groundwater inflows of several hundred gpm in a short tunnel section could adversely impact tunnel advance rates, even when ground support would not be affected.

During shaft excavation, water inflows could be expected at the rock/soil interface and from open joints in weathered rock below the interface. Therefore, pre-grouting would probably be necessary to reduce inflow rates at the interface and in areas of high permeability.

Both drill and blast and tunnel boring machine (TBM) excavation methods were evaluated. Although the TBM advancement rates are faster, this method would require a TBM erection chamber. Additionally, drill and blast would be more versatile and less risky in excavations of poor or variable ground and potentially high water inflows. Never the less, the TBM method would be recommended until a more detailed analysis of other factors including equipment capital costs, labor costs and availability, machine delivery lead times, site considerations, geological considerations, and geometry/space constraints was performed.

Based on available rock elevation data, the proposed tunnel elevation at the near shore access shaft would be 270 feet. The tunnel would slope upward at a 1% grade towards the offshore intake structure to elevation 220 feet. Preliminary layout of the offshore tunnel scheme indicates that the long axis of the tunnel would parallel the regional geological structure. Thus the formation of unstable wedges as the tunnel face advances, prior to liner installation, would be likely. To prevent eccentric loading of the final tunnel liner due to unstable rock wedges and to provide for worker safety, temporary ground support would be necessary. As a preliminary estimate, patterned rock bolting may be necessary along most of the tunnel's length. The rock bolts would be relatively light in size (No. 8) and would be used primarily above the tunnel springline (60% utilization). Additional rock bolts would be used as necessary, as dictated by field conditions, below the springline.

Because of potential environmental problems and uncertain geological conditions associated with the cut and cover offshore twin pipelines, the subsurface rock tunnel alternative was selected to develop preliminary cost and schedule estimates for the offshore intake alternative. The proposed tunnel design for Unit 3 is shown on Figure 8.1-1.

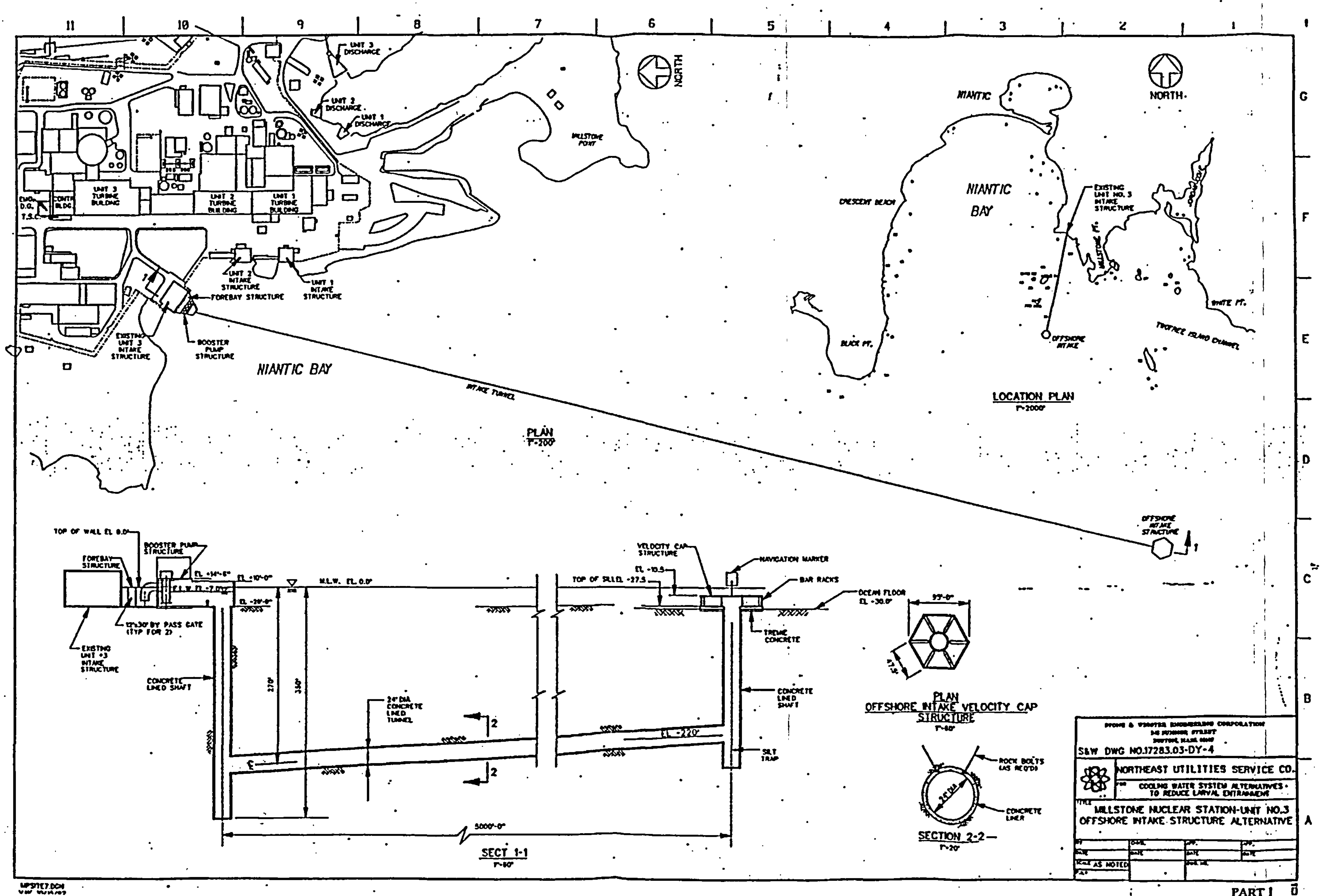

Figure 8.1-1: Millstone Unit 3 – Offshore Intake Structure Alternative

8.1.3 Offshore Inlet

For preliminary design, a single riser shaft and velocity cap would be proposed. The large velocity cap could be constructed and placed in sections. An alternate approach would be to use multiple smaller riser shafts each having a smaller velocity cap. The single large riser could have cost advantages over multiple smaller shafts. A detailed evaluation of cost and construction issues would be required prior to detailed design.

The offshore inlet would consist of a hexagonal velocity cap structure supported on the sea floor by a tremie concrete mat centered over the vertical inlet shaft as shown in Figure 8-1.1. The inlet would be 95 feet wide from point to point. The hexagon and the inlet would be 15 feet high beginning at a sill located 3 feet off the sea floor to minimize entrainment of sand and silt. The inlet entrances would be protected by bar racks. The rack spacing would be 4 inches on center. These bar racks would protect the inlet from the coarsest forms of debris. Inlet approach velocity would be 0.5 fps.

The offshore intake would extend up 19.5 feet from the sea floor in 30-feet deep water and would create a hazard to navigation. The proper warning buoy would have to be provided with the design.

8.1.4 Booster Pump Station

The 24-foot I.D. concrete-lined intake tunnel including riser shafts on either end would be 5,500 feet in length. It is anticipated that a tunnel would become significantly fouled with mussels and barnacles, causing significant hydraulic resistance. Head losses were estimated at 5.0 feet. The existing circulating water pumps, based on the model test report, have very little margin for degraded suction conditions. For this reason, it was considered necessary to include a booster pump station at the onshore end of the-offshore intake system.

The booster pump station would require four low head, high flow pumps each rated at 240,000 gpm at 7.0 feet total dynamic head. Each pump would require 525 horsepower. The total pumping energy requirement for the booster pump station would be 2,100 horsepower. The pumps would be vertical wet pit type. Each would be located in its own pump bay. The pump bays would be 24 feet wide by 52 feet long with an invert elevation of -28 feet. The pumps were sized to draw water from an elevation of -7 feet. The overall plan dimensions of the pump structure would be 106 feet wide by 54 feet long. The pump structure would be constructed of reinforced concrete, and would include a protective building, which would enclose the pumps, motors, electrical equipment and controls. The pump structure would be joined upstream by a transition structure constructed over the 24-foot diameter riser shaft from the tunnel. This transition structure would contain a submerged weir to spread inflowing water evenly to the four pump bays. The pump and transition structures are shown on Figure 8.1-1.

The transition structure connecting the vertical tunnel riser shaft to the booster pump station would also serve as a surge chamber. The chamber would not be covered and the top of the walls would serve as an emergency spillway in the event of surge.

The existing Unit 3 intake structure would be joined to the offshore intake system by sheet pile walls forming a forebay between the two structures and isolating the Unit 3 intake from Niantic Bay. A section of the top of these sheet pile walls would be designed to function as overflow weirs to discharge the excess flow pumped by the booster pumps into Niantic Bay. A 12 foot x 30 foot gate would be required in each of the forebay walls designed to pass 1/2 of the circulating water flow in the event of failure of the offshore intake system.

A separate Category I flow passage (not shown) would be provided for the service water pumps. The system would consist of flow passages constructed in the forebay walls with flow controlled by automatic motor-operated gates or valves. Separate openings with collapsible panels would also be required as a backup. Because the service water system is nuclear safety-related, the design would be nuclear safety-related Category I and would be subject to Nuclear Regulatory Commission review and approval. This area was not addressed in detail.

Four additional 4,160 V breakers would be required for the four new pumps. The new booster pumps would be located in a new intake structure that would be located in front of the existing circulating and service water pumphouse. It was assumed that buses 34A and B have adequate capacity to provide power for the four new pump motors.

When obtaining estimating prices for new 4,160 V air circuit breakers and switchgear, GE stated that they no longer manufacture such equipment and they proposed vacuum breakers instead with a transition section to the existing switchgear. Finally, an 800-foot ductline would be required. The ductline would follow the same route as the ductline to the existing circulating service water pumphouse. A detailed electrical design was not performed and the information developed for this study is considered preliminary and only conceptual in nature. Existing electrical loads and location of utilities could have a significant impact on the conceptual design. The booster pumps also provide an additional source of potential mortality to a variety of lifestages of entrained fish as a result of passage through the pumps and the associated pressure changes within the tunnel and pumps.

8.2 OFFSHORE INTAKE – UNITS 2 AND 3

The inflow for Unit 3 is approximately twice the inflow for Unit 2. The cost associated with a Unit 2 only offshore intake would be approximately equal to the cost for a Unit 3 offshore intake, but since the benefit

on reduced fish entrainment would be less than half that of the Unit 3 offshore intake, this alternative would not be realistic to conduct alone. However, this alternative was considered since some of the construction effort would be common to both Units, therefore the cost would not be twice the cost for Unit 3.

The offshore intake alternative would consist of extending the Unit 2 and 3 intake approximately 1 mile south into Long Island Sound utilizing separate submerged offshore Intakes, a common rock tunnel for Unit 2 and Unit 3, and a booster pump station that would be located in front of the existing Unit 2 and Unit 3 Intake Structures.

The objective of the offshore intake would be to place the Unit 2 and 3 intake south into Long Island Sound past the confines of Niantic Bay such that smaller numbers of Niantic River winter flounder larvae would be entrained by the proposed Unit 2 and 3 offshore intake and would come from the LIS population as a whole.

The Unit 3 Offshore Intake system would be designed for a flow rate of 958,000 gpm which is 4% greater than the present design flow of the Unit 3 Circulating Water System (918,000 gpm). The Unit 2 offshore intake system would be designed for a flow rate of 576,500 gpm, which is also 5% greater than the present design flow of the Unit 2 circulating water system of 548,800 gpm. The velocity cap structure would be sized for an inlet velocity of 0.5 fps to minimize entrainment of fish into the intake tunnel. The offshore conduit would be sized for a flow velocity of 5 fps to minimize head losses. These criteria would result in an offshore conduit with cross-sectional area equivalent to inside diameter of 18 ft for Unit 2 and 24 ft for Unit 3. This would result in a common tunnel with an inside diameter of approximately 30 ft. The tunnel will be separated into a Unit 2 and Unit 3 portion with an internal wall.

The offshore intake system estimated cost for Unit 3 would be approximately $98,130,000. The Units 2 and 3 rock tunnel as stated above would be a common excavation and all other system activities for the Unit 2 offshore intake would be similar to those of Unit 3. The estimated cost for Units 2 and 3 would be approximately $163,300,000. Due to the difficulty, magnitude, and cost for a retrofit of this type, the alternative is not recommended for future consideration.

As discussed in Section 8.1, this is very costly alternative in terms of schedule, and capital cost with considerable uncertainties that could not be resolved until more site specific geotechnical data is available to refine the design, construction methods, and cost of the alternative. In addition, as discussed in Part II, there are several environmental concerns, including increased chlorination and impingement.

8.3 OFFSHORE INTAKE EXPERIENCE AT SEABROOK NUCLEAR POWER STATION

Two deep bedrock tunnels, extending into the Atlantic Ocean to provide cooling water requirements, were constructed for the Seabrook Nuclear Power Station located in Seabrook, New Hampshire. These tunnels are similar in design to the rock tunnel alternative described in previous parts of Section 8. Both an intake and a separate discharge tunnel were constructed, each over 3 miles in length (17,156-foot intake, 16,500-foot discharge) (Hulchizer et al. 1979). The design flow rate for the Seabrook tunnels is 850,000 gpm at a flow velocity of 6 fps. One of the primary reasons for choosing the offshore intake and discharge with deep rock tunnels at Seabrook was to minimize any damage to the coastal environment (Hulchizer et al. 1979).

Geological conditions at Seabrook, necessitated construction of deep rock tunnels in lieu of cut and cover tunnels. Vertical shafts were used on both ends of the tunnels to connect the offshore water ports and the plant cooling-water systems. At land's end, the tunnels are 260 feet below sea level and 180 feet below sea level at the seaward ends. The tunnel shafts are concrete lined. The bore diameter is 22 feet and the liner thickness is 1.5 feet with a tunnel I.D. of 19 feet. Rock bolts were used as necessary along the top of each tunnel.

The Seabrook intake tunnel terminates on the seaward end with three, 9-foot 5-inch diameter shafts located approximately 7,000 feet off the Hampton Beach shoreline at a water depth of 60 feet. Mounted on each shaft at the sea floor are 30.5 feet in diameter velocity cap structures of similar design to that proposed for Unit 3. The velocity caps are clad over their entire exterior surfaces with copper nickel sheeting to minimize marine growth. On the shoreward end the vertical shaft terminates with a surge chamber. The circulating water pump station is located in an excavated chamber adjacent to the surge chamber.

The Seabrook discharge tunnel connects to the ocean by means of eleven, 4-foot 11-inch diameter vertical shafts located approximately 5,000 feet off the Seabrook Beach shoreline.

The Seabrook tunnel construction was accomplished by means of two tunnel boring machines operating concurrently. Offshore construction was done using a jack-up barge. Offshore vertical shafts were drilled and prefabricated steel shaft liners installed from the jack-up barge (Hulchizer and Rossereau 1981). Work began in the summer of 1978. Tunnel and vertical shaft excavation was completed in the spring of 1981. Concrete lining of the tunnels was completed by the end of 1982.

The total project cost for the Seabrook tunnel was approximately $125,000,000 in 1982 dollars.

9 CONVERSION TO NATURAL GAS

In the letter of November 15, 1999, the Connecticut Department of Environmental Protection requested, as part of the feasibility studies on alternate measures to minimize entrainment of aquatic organisms, an evaluation of conversion of the nuclear facility to the latest state-of-the-art natural gas generating technology.

The following two alternatives are available for converting the Millstone Station to natural gas: repowering the site using the existing Balance-of-Plant (BOP) equipment or replacing the existing plant with a new combined-cycle plant. Either alternative is extremely capital intensive since much of the existing and well functioning generating unit equipment would be scrapped in the conversion to natural gas. Also, a new and additional fuel cost would be added to the operational cost of the station.

The first alternative under consideration for the repowering of the Millstone Station is gas-fired combined-cycle power generation. The capacities (i.e., name-plate gross output) of Units 2 and 3, which are currently operating at Millstone, are 909 and 1,253 MW, respectively. One possible combined-cycle plant that would produce about the same total output would comprise seven GE Frame 7 FA gas turbines with fired heat recovery steam generators, producing sufficient steam for Unit 2's existing steam turbine. The existing Unit 3 would be retired or maintained as a backup for the Unit 2 steam turbine. The power generated by the gas turbines would be about 1,100 MW, and the existing Unit 2 steam turbine would generate 650-750 MW, depending on the extent it is modified for the new conditions. The result would be the elimination of the circulating water heat rejection from Unit 3. It is important to note that in this concept, which keeps the total electric capacity about the same, the entire Unit 3 is essentially unutilized. Its capacity is replaced by the new gas turbine capacity. (An alternative would be to add more gas turbines and heat recovery steam generators to make additional steam for the Unit 3 steam turbine. However, that would leave the circulating water flows and heat rejection to Niantic Bay at essentially their current values.)

Since the existing HP steam turbine in Unit 2 is designed for throttle conditions of about 870 psia, at saturation temperature, it is not well suited for efficient combined-cycle operation. Modern steam bottoming cycles in large combined-cycle plants are designed for turbine throttle conditions of 1,500 to 2,400 psia, and superheated temperatures of up to 1,050°F. Moreover, they are designed for reheat temperatures of up to 1,050°F as well. This is significantly different from the reheat temperature of the existing Unit 2 nuclear power cycle, which is only about 500°F. Consequently, the repowered combined-cycle will be considerably less efficient than is customary for a new combined-cycle plant. Therefore, the fuel costs will be correspondingly higher for the same gross electrical output.

A more costly concept involves the addition of a new topping steam turbine generator. In this concept, steam would be generated at somewhat higher pressure and temperature and then partially expanded through the topping turbine for additional power generation. This topping turbine would be designed so that its exhaust conditions reasonably match the design throttle conditions of the existing HP turbine.

Because of the lower efficiency, the levelized cost of electricity from the repowered plant would probably not be appreciably better than it would be from a new combined-cycle plant. Moreover there would be significant capital cost for the gas turbines which is associated with replacement power (replacing the idled Unit 3) rather that new capacity. Therefore this alternative was not evaluated further.

The second alternative considered was the repowering the Millstone Station with a new combined-cycle plant.

Combined-cycle plants represents the latest technology for natural gas facilities. A combined-cycle plant has a thermal conversion efficiency of between 50 to 58%, depending on the type of equipment selected. Typical size for a large "two on one" configured (two combustion turbine trains and a single steam turbine) combined-cycle plant are 500 to 750 Mwe, based on a 2 x 2 x 1 configuration (2 combustion turbines, 2 heat recovery steam generators, and 1 steam turbine).

Millstone Units 2 and 3 have a combined generation capacity of approximately 2000 MWe. To replace this electrical generation capacity would require a three or four "block" (two on one) combined-cycle plants. The following Section provides discussion on the following major topics related to conversion to natural gas:

- Gas Supply
- Cooling Requirements
- Decommissioning and Licensing
- Cost

9.1 GAS SUPPLY

Gas supply issues are an important factor with any conversion to a combined-cycle gas-fired generation at the site of the Millstone Nuclear Power Station. The output would be rated at approximately 2,000 MWe and the plant would require approximately 300 MMscf/d of high-pressure natural gas on a firm basis. Higher pressure gas (up to 700 psig) allows for lower operating costs by reducing the cost of fuel gas compression.

It is important to keep in mind that the gas supply and the transportation of that gas are ultimately provided by two separate entities. For illustration purposes, high volume gas for generation purposes typically has a delivered cost in New England of about $4.50 per million Btu on a firm basis. The cost of the gas from the gas producer is from $1.80 to $2.10 and the balance is the cost of transportation to the project. The price at the producer was approximately $5.20/Mscf. This transportation charge will be the source of revenue to support the pipeline company's financing of the pipeline system improvements to support an uninterrupted gas supply to the site. The delivered cost of natural gas is subject to fluctuations in the market and use sources of energy, such as oil and/or coal. In early 2001, the delivered cost of natural gas as listed in the U.S. Energy Information Administration's Natural Gas Monthly Report of May 2001, was on the order of $10.50/Mscf. These prices have come down slightly in recent months. Although difficult to predict, the estimated average price from the producer over the next 20 years is on the order of $4.00/Mscf.

While physical access to either of the two pipelines in the area will provide access to a diversity of suppliers (improving project economics), the transportation routes will be limited to just a few.

9.1.1 Concepts

The two closest pipeline operators in the area are the Algonquin Gas Transmission Company (a unit of Duke Energy of Charlotte, NC) and the Iroquois Gas Pipeline System. Neither pipeline system is immediately adjacent to the project site and each system would require extensive capital investment to provide the required volumes. Serving the plant through Algonquin would be accomplished through onshore pipeline extensions and looping as well as upstream compressor additions. The Iroquois service would best be accomplished through an offshore route from the existing Iroquois facilities west of the project site. Figure 9.1-1 shows the location of the proposed pipelines.

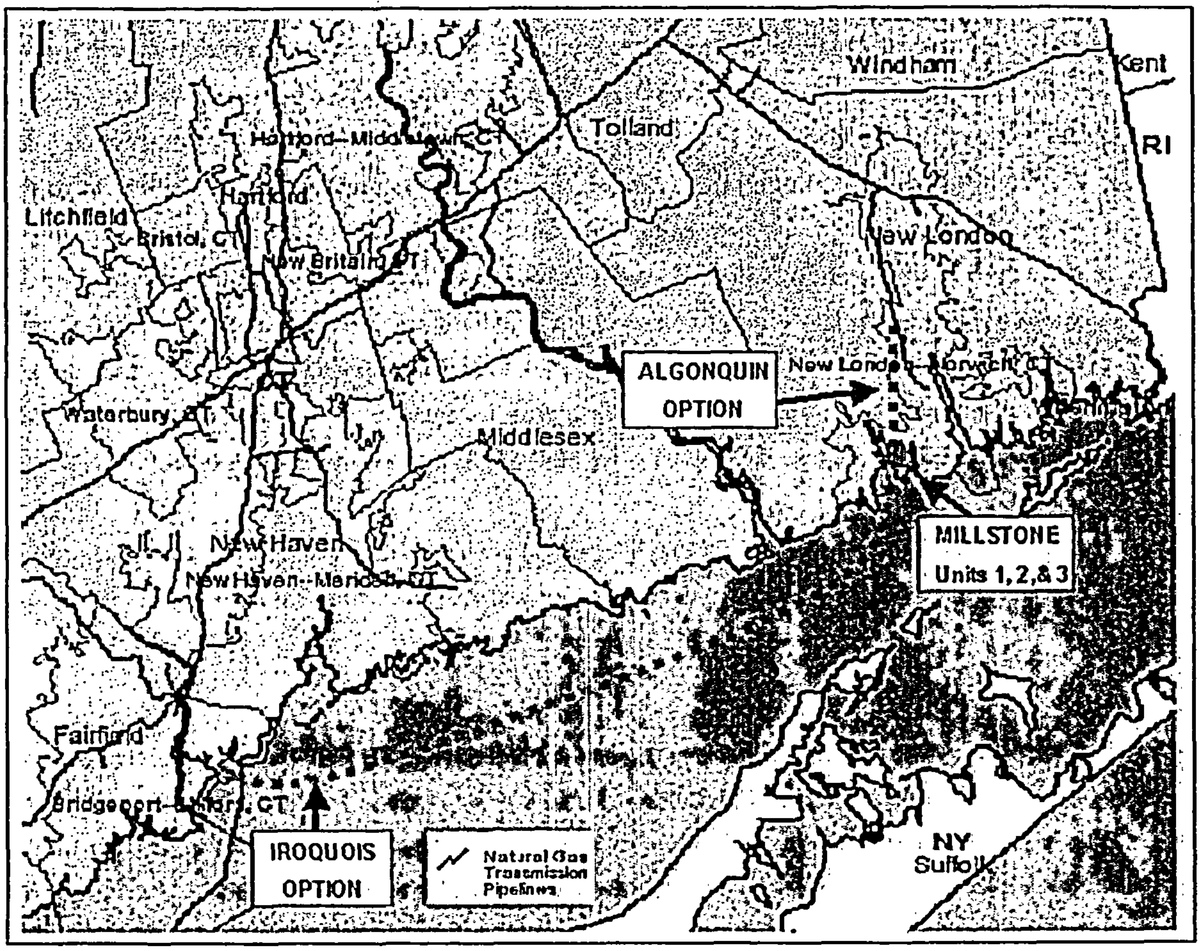

Figure 9.1-1: Proposed Additional Pipelines

9.1.2 The Algonquin Option

Algonquin has an existing 6-inchdiameter pipeline serving the New London Area. This pipeline is parallelled by a 10-inch / 12-inch pipeline that terminates in Montville, CT. The two pipelines can operate at pressures up to 750 psig, although in normal operation the pressures somewhat less due to loads on the Algonquin system. The capacity of Algonquin's entire system is approximately 1.6 Bcf/D.

To meet the required deliveries of 400 MMscf/d at around 700 psig, a pipeline of 20 to 24 inches in diameter would be required to serve the plant.

It is anticipated that the following system upgrades may include:

- An extension of the existing Algonquin lateral feeding the Groton/New London area of approximately 12 miles to the Power Station site. Estimated cost would be $22 to $26 million.

- Replacement of approximately 20 miles of one of the two existing Algonquin pipelines with larger diameter pipe. Estimated cost would be $28 to $34 million.
- Upstream compressor station additions and/or upgrades at several locations on the Algonquin and the Texas Eastern or Iroquois systems. Estimated cost would be a minimum of $150 million.

The cost estimates above can vary widely based on population density in the proposed pipeline route, local opposition and other factors. The costs provided only cover capital expenditures. Additional costs would be incurred in operating and maintaining the added facilities. For a base load plant, utilizing firm supply and firm transportation, the cost of the capital expansion may be financed completely through an appropriate transportation charge. Note that gas transportation charges are subject to strict Federal regulation through the FERC. Gas commodity costs are largely market based.

The gas supply for this project, would consist of an arrangement through Texas Eastern Transmission Company, and could be derived from several supply areas, including the Gulf Coast and the mid-continent areas. Through a northern route from Maritimes & Northeast Pipeline, the project could access supplies from the Sable Island area (offshore Nova Scotia). Algonquin also has a high volume interconnect with Iroquois at Brookfield, CT, allowing access to Alberta area supplies.

9.1.3 The Iroquois Option

Although a less conventional approach, an offshore route from the Iroquois Gas Transmission System may be possible. The route would originate at the Iroquois facilities near Milford, CT and proceed easterly following an offshore route to the project site. The length would be about 50 miles. Upstream compressor upgrades and/or pipeline looping would be required on either the Iroquois or Algonquin/Texas Eastern systems, depending on the source of gas supply.

Costs of the marine pipeline portion of this option could range between $140 to $180 million. The total option cost, including upstream facilities, is not easy to estimate, since the existing Iroquois single pipeline system is near its ultimate capacity. An addition of this magnitude could trigger extensive looping requirements on the pipeline. This cost does not include any upgrades to Iroquois' existing pipeline system to handle the additional volumes.

9.1.4 Pipeline Schedule

In the Iroquois case the offshore pipeline may take 12 to 14 months for FERC environmental review, yielding a longer development time frame, typically 2.5 to 3 years.

In the Algonquin case, the more conventional expansion projects could require less time for FERC approval, yielding a slightly shorter development window, typically 2 to 2.5 years.

9.1.5 Gas Supply Conclusion

The size of this project represents a substantial fraction of the current capacity of the pipelines involved, roughly 25% of Algonquin's peak day and 30% of Iroquois' peak day. As such, this expansion would be a major undertaking by either company with substantial risk stemming from environmental regulation, Federal rate regulation and financing concerns.

9.2 COOLING REQUIREMENTS

A multiple "block" combined-cycle plant still requires cooling water to condense the steam. However, the heat load is approximately 1/3 of present operation at Units 2 and 3 because of the reduction in electric generation using stream turbines. The heat load can be removed from the natural gas units by either installation of cooling towers or using direct cooling from Long Island Sound. The present design of Units 2 and 3 require approximately 1,500,000 gpm of cooling water flow. Designed as a combined cycle plant, the station would require approximately 500,000 gpm cooling water flow from Long Island Sound, if the units were designed with once-through cooling. Utilizing once-through cooling design would have the same fish entrainment concerns as the existing Millstone units.

The other option for heat removal is to use cooling towers (either mechanical or natural draft). The size of the cooling towers required for the combined cycle plants is approximately equal to the one described for the full flow alternative for Unit 3. A detailed engineering evaluation would have to be performed in order select the appropriate cooling system design.

9.3 DECOMMISSIONING AND LICENSING

There are several scenarios available for conversion of the facility to natural gas at the existing site:

- The complete decommissioning and fuel removal of the existing units before construction of the new natural gas facility begins,
- The construction of the new natural gas facility while the existing nuclear units continue to operate,
- The simultaneous decommissioning and construction of the units.

If this alternative was selected (i.e., conversion to natural gas), a detailed engineering and cost study would have to be performed to select the appropriate alternative or combination of alternatives. Scheduling and phasing are particularly important to cost since these alternatives require long and interconnected

permitting and construction schedules. In addition to an engineering and cost study, there are additional issues related to obtaining the appropriate permits and well as the NRC licensing revisions and financing for a new project sited with a site undergoing decommissioning activity. The purpose of this study was not to select the appropriate scenario, but to identify the issues that would have to be addressed.

9.4 COST

Typical capital costs for 500 to 750 MWe combined cycle plants are on the order of $400 to $500/kW. In order to replace the electrical generation rate of the existing units, it is estimated that the costs would be approximately $900,000,000 to $1,000,000,000. This cost does not include the costs associated with the decommissioning of Millstone Units 2 and 3 or the cost for replacement power. If gas units were installed at the current site, there could be some structures and site infrastructure that may be able to be reused. This includes some of the buildings, switchyard, transmission lines, etc. However, a detailed evaluation would have to be performed which considered both the timing for decommission of the existing units as well as the construction of the gas units in order to determine the cost benefit for using the existing structures.

9.5 CONCLUSIONS

There are many issues associated with the conversion of the Millstone nuclear units to natural gas units as discussed above and in Part II as well. In addition, these issues, combined with the estimated cost ($1 billion), makes this option impractical.

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10 CAPITAL COST AND SCHEDULE INFORMATION

Approximate costs and estimated construction schedules were developed for each of the alternatives discussed previously in this report.

10.1 APPROXIMATE COSTS

The estimated costs for each of the alternatives are summarized in Tables 10.1-1 through 10.1-8. The estimated costs represent present-day capital costs consisting of March 2001 direct, distributable, and engineering costs, and allowance for indeterminates/contingencies. In addition, the estimates were based on the following assumptions:

- Present day prices and fully sub-contracted labor rates as of February 2000.
- Dredged material can be disposed of locally (i.e., material assumed not to be contaminated)
- Required construction utilities will be supplied by Owner
- Land required for construction trailers, parking, and lay down provided by Owner
- Allowance for interferences along pipeline trench; electrical ductbank included within trench
- Construction management included at 7% of direct construction cost
- Detailed engineering/design included at 10% of direct construction cost
- Allowance for indeterminates (AFI) /contingency included at 20% of the total direct, construction, and engineering costs for the follow:
  - Cooling Towers
  - Variable Speed CWPs
  - Condenser Bypass
- AFI/contingency included at 25% of the total direct, construction, and engineering costs for the follow:
  - Offshore Intake
  - Fine-mesh Screens
  - CWS Cross Connect
  - CWS Throttling Valves

The costs associated with the following were not included in the estimate:

- Escalation
- Abandonment
- Demolition/relocations
- Sales, use, service or other taxes

- Insurance (building all risk and other marine insurances)
- Severe contingency costs (e.g., those associated with adverse weather, craft strikes)
- Startup
- Permits (including environmental)
- Employee training, certifications, security work
- Operating and maintenance
- Category 1 structures
- Owner's cost

The approximate cost estimates were developed for each of the alternatives, by either updating NUSCO (1993) for those design alternatives that have not changed, or by developing new information for the new design alternatives.

For major equipment pricing, vendors were contacted to verify/update pricing for major equipment and components (i.e., cooling tower, fine-mesh screens, valves, pumps, etc.). In other cases, material costs were reviewed and either updated based on current price tends or escalated based on the Construction Cost index standards (published by the Engineering News Record) to reflect current pricing. In addition, a local labor survey was taken to update the craft wage rates for the construction components. Historical performance data was used to update the construction labor hours (with special attention being paid to the site-specific conditions). *Timberline's Precision Estimating for Windows*, a leading commercially available software package, was used for this effort. This estimating tool made organizing, editing/updating, summarizing and documenting information efficient and simple.

Stone & Webster's Corporate Estimating Database was used as the basis for all cost information. This managed database is a library of construction activities and contains historical Stone & Webster construction costs and installation rates. It also draws from other commercially published resources material (e.g., Means, Richardsons, MCAA, etc.)

Table 10.1-1: Fine-Mesh Screens - Summary of Approximate Cost Estimate

Item	Unit 2	Unit 3
Forcbay, Cofferdam, Temp Dock	2,360,000	4,250,000
Dredging/Concrete	3,480,000	6,250,000
Structure	550,000	980,000
Electrical	310,000	550,000
Pipe & Valves	580,000	1,050,000
Equipment	4,560,000	8,200,000
Tie-in Operating Plant	24,000	44,000
TOTAL DIRECT COST:	**11,864,000**	**21,324,000**
Construction Management	830,000	1,500,000
Engineering	1,190,000	2,130,000
AFI/Contingency	3,500,000	6,240,000
TOTAL CAPITAL COST:	**17,384,000**	**31,194,000**

Note: Costs were developed for relative comparison purposes and due to their conceptual nature may be considerably lower than actual.

Table 10.1-2: CWS Throttling Valves – Summary of Approximate Cost Estimate

Item	Unit 2	Unit 3
Instruments & Controls	1,000	2,000
Valves	310,000	460,000
Removal/Replacement	339,000	488,000
TOTAL DIRECT COST:	**650,000**	**950,000**
Construction Management	44,000	67,000
Engineering	64,000	96,000
AFI/Contingency	190,000	280,000
TOTAL CAPITAL COST:	**948,000**	**1,393,000**

Note: Costs were developed for relative comparison purposes and due to their conceptual nature may be considerably lower than actual.

Table 10.1-3: Variable Speed Pumps - Summary of Approximate Cost Estimate

Item	Unit 2	Unit 3
Site Work (General)	90,000	136,000
Concrete	104,000	156,000
Structures	36,000	54,000
Electrical	310,000	460,000
Instruments & Controls	1,000	1,000
Pipe & Valves	22,000	33,000
Equipment	2,900,000	4,340,000
TOTAL DIRECT COST:	**3,463000**	**5,180,000**
Construction Management	242,000	360,000
Engineering	350,000	520,000
AFI/Contingency	1,000,000	1,520,000
TOTAL CAPITAL COST:	**5,055,000**	**7,580,000**

Note: Costs were developed for relative comparison purposes and due to their conceptual nature may be considerably lower than actual.

Table 10.1-4: Unit 3 - Two-Speed CW Pumps - Summary of Approximate Cost Estimate

Item	Cost
Site Work (General)	134,000
Concrete	130,000
Structure	40,000
Electrical	700,000
Instruments & Controls	1,000
Pipe & Valves	35,000
Equipment	3,680,000
TOTAL DIRECT COST:	**4,720,000**
Construction Management	330,000
Engineering	470,000
AFI/Contingency	1,380,000
TOTAL CAPITAL COST:	**6,900,000**

Note: Costs were developed for relative comparison purposes and due to their conceptual nature may be considerably lower than actual.

Table 10.1-5: Circulating Water System Cross - Connect-Summary of Approximate Cost Estimate

Item	Unit 2	Unit 3
Site Work (General)	113,000	217,000
Concrete	29,000	57,000
Valve Housings	8,000	15,000
Electrical	29,000	56,000
Instruments & Controls	17,000	32,000
Pipe & Valves	183,000	349,000
Equipment	3,000	6,000
TOTAL DIRECT COST:	382,000	732,000
Construction Management	27,000	51,000
Engineering	38,000	73,000
AFI/Contingency	112,000	214,000
TOTAL CAPITAL COST:	559,000	1,070,000

Note: Costs were developed for relative comparison purposes and due to their conceptual nature may be considerably lower than actual.

Table 10.1-6: Condenser Bypass - Summary of Approximate Cost Estimate

Item	Unit 2	Unit 3
Concrete	16,000	24,000
Pipe	309,000	500,000
Valves	166,000	300,000
Supports	24,000	46,000
Removing/Replacing Pump Internals	64,000	120,000
TOTAL DIRECT COST:	**579,000**	**990,000**
Construction Management	41,000	69,000
Engineering	58,000	99,000
AFI/Contingency	135,000	232,000
TOTAL CAPITAL COST:	**813,000**	**1,390,000**

Note: Costs were developed for relative comparison purposes and due to their conceptual nature may be considerably lower than actual.

Table 10.1-7: Units 2 & 3 Natural- and Mechnical-Draft Cooling Towers - Summary of Approximate Cost Estimate

Item	Full Natural Draft Tower Unit 2	Full Natural Draft Tower Unit 3	2/3 Natural Draft Tower Unit 3	Mechanical Draft Towers Unit 2	Mechanical Draft Towers Unit 3
Site Development	210,000	230,000	230,000	210,000	230,000
Plant Electrical	5,040,000	5,070,000	4,050,000	6,240,000	6,240,000
Yard Electrical	1,400,000	1,410,000	1,130,000	2,120,000	2,120,000
Plant I&C	320,000	330,000	260,000	330,000	330,000
CW Pumps	42,170,000	47,260,000	37,760,000	42,750,000	47,660,000
Cooling Towers	31,300,000	32,570,000	26,030,000	25,410,000	28,070,000
CT Pump Str & Fl.	2,240,000	2,970,000	2,370,000	2,270,000	2,990,000
Return Pump St & Fl	4,750,000	N/A	N/A	4,810,000	N/A
CT Electrical Bldg	220,000	220,000	170,000	220,000	220,000
SWGR Bldg. CT	210,000	210,000	170,000	210,000	210,000
Load Ctr. Bldg.	170,000	170,000	130,000	170,000	170,000
CT Pump Bldg.	120,000	130,000	100,000	130,000	130,000
Access Roads	30,000	30,000	20,000	30,000	30,000
Sound Wall	N/A	N/A	N/A	1,100,000	1,610,000
Transportation	1,600,000	1,600,000	1,600,000	1,600,000	1,600,000
Total Directs Costs:	**89,780,000**	**92,200,000**	**74,020,000**	**87,600,000**	**91,610,000**
Construction Management	6,290,000	6,450,000	5,180,000	6,130,000	6,410,000
Engineering	8,980,000	9,220,000	7,400,000	8,760,000	9,160,000
AFI/Contingency	17,950,000	18,430,000	14,800,000	17,510,000	18,320,000
Total Capital Costs:	**123,000,000**	**126,300,000**	**101,400,000**	**120,000,000**	**125,500,000**

Note: Costs were developed for relative comparison purposes and due to their conceptual nature may be considerably lower than actual.

Table 10.1-8: Offshore Intakes - Summary of Approximate Cost Estimate

Item	Unit 3	Units 2 & 3
Forebay, Cofferdam, Temp Dock	4,290,000	5,950,000
Dredging/Concrete	8,580,000	21,750,000
Shaft	12,000,000	24,500,000
Tunnel	35,500,000	46,600,000
Pre-Engineered Building	280,000	370,000
Electrical	760,000	1,170,000
Instruments & Controls	2,000	3,000
Pipe & Valves	120,000	200,000
Equipment (i.e., pumps, etc.)	4,750,000	9,590,000
Tie-in Operating Plant	800,000	1,590,000
TOTAL DIRECT COST:	**67,082,000**	**111,723,000**
Construction Management	4,800,000	7,800,000
Engineering	6,700,000	11,160,000
AFI/Contingency	19,700,000	32,650,000
TOTAL CAPITAL COST:	**98,282,000**	**163,333,000**

Note: Costs were developed for relative comparison purposes and due to their conceptual nature may be considerably lower than actual.

10.2 SPECIAL EXCAVATION COST CONSIDERATIONS

Relative and approximate cost estimates for excavation were based on preliminary excavation quantities, available site conditions and similar case histories.

10.2.1 Natural-Draft Cooling Tower Excavation Costs

Typical rock excavation costs, utilizing pre-split blasting in rock range from $10.00 to $20.00 per cubic yard. This assumed that average haulage would be less than 5 miles, and easy site access would be available.

10.2.2 Offshore Intake Costs

10.2.2.1 Unit 3 - Tunnel Excavation Assumptions/Costs

A relative and approximate of tunneling costs for a 24-foot I.D., 5,000-foot long intake tunnel, for Unit 3 only, has been made. The following assumptions were made:

1 The tunnel would be excavated using a tunnel boring machine (TBM) along its entire 5,000-foot length.
2 A single intake structure would be built offshore, requiring an offshore shaft to be constructed from the tunnel up to the submerged structure elevation.
3 The tunnel liner would be cast in place, reinforced concrete, and 1-foot average thickness.
4 Tunnel cross-sectional shape would be near circular/modified horseshoe.
5 The access shaft would also be located offshore, approximately 150 to 200 feet from the front of the current pump house structure.
6 One working face was assumed to be available starting from the access shaft, and that the tunnel would be driven towards the offshore intake structure.
7 The tunnel was assumed wet, yet with controllable water inflow rates; and the rock assumed competent. If the heading were to be driven under wet conditions with crushed rock or unconsolidated conditions, the tunnel excavation cost contingency could be as high as 50%.

Table 10.2-1 describes the breakdown of the tunneling costs. In general, tunnel costs are approximately $7,000/linear foot. Total cost of the tunnel excavation and construction is estimated at $35,500,000 for 5,000 feet of cast in place concrete lined tunnel.

Table 10.2-1: Relative and Approximate Costs for Tunneling – Unit 3

Description	Quantity	Unit Cost ($)	Total Cost ($)
Mobilization	N/A	5,400,000	5,400,000
Shaft Station Development	2	189,000	378,000
Tunnel Excavation & Temp. Support (Rock Bolts)	5,000 LF	3,460	17,300,000
Concrete Lining (Slip Form)	5,000 LF	2,300	11,500,000
Drilling in Advance of Face	5,000 LF	45	225,000
Pressure Grouting at Tunnel Face	5,000 LF	108	324,000
Muck Disposal	106,000 cu-yd	-	146,000
Final Cleanup	5,000 LF	45	227,000
GRAND TOTAL			$35,500,000 or $7,100 / LF of Tunnel

10.2.2.2 Unit 3 - Shaft Excavation Assumptions/Costs

1 The circular access shaft would be sunk through conventional drill and blast full face methods.

2 The intake shaft would be drilled by raised boring/slashing/reaming methods to 26 feet in diameter.

3 Only conventional surface preparation costs and equipment were considered. Underwater preparation, offshore shaft servicing and operations were not considered and are likely to raise this estimate.

4 Access shaft diameter would be 27 feet O.D. (outside diameter), 24 feet I.D. with cast in place concrete liner. It would be drilled overburden and through rock.

5 The rock was assumed to be competent and groundwater inflows to be at a rate as only requiring standard grouting techniques during shaft sinking.

The costs for a full-faced excavated shaft were estimated based upon 1982 Army Corps of Engineers' estimates for a shaft of this diameter. The final costs were adjusted to 2000 prices through the Construction Cost Index published by the Engineering News Record. The average cost per linear foot of shaft depth is $8,265/foot.

These costs compare with other proposed shafts in high strength granite of similar diameter in North New Jersey. The New Jersey project cost estimate for a 24-foot shaft was $6883/foot. The New Jersey costs reflect dryer conditions (little or no grouting), and little or no ground support prior to liner installation. Excavation techniques are similar. Collar development in rock for a 24-foot diameter shaft typically costs $1 to $1.5 million.

The shaft for the outfall tunnel of the MWRA Deer Island Project was similar to the proposed shaft of MNPS. Slurry wall construction was necessary, as was a larger diameter (35 feet) to accommodate a TBM. The unit costs associated with constructing 4 TBM-mined, concrete-lined bedrock tunnels for the MWRA

in the Boston area ranged from $4,000/ft for a 5.5 mile x 14-ft diameter tunnel to $7,000/ft for a 9.5 mile x 28-ft diameter tunnel. These costs included any shafts associated with the end points of the tunnels.

10.2.2.3 Unit 3 – Schedule Assumptions and Considerations

The schedule was based upon onsite construction requirements. It does not include engineering design, site investigation work, or other prerequisite work. The schedule also does not include the Unit 3 intake structure modifications. Both the access shaft caisson structure and the intake shaft structures would be prefabricated and floated to final location. The schedule was based upon similar facility experience. Variations in rock types or ground conditions could significantly impact the schedule. Excavation techniques for the access shaft and the tunnel would utilize tunnel boring methods. The offshore intake shaft would be excavated using raised boring/slashing/reaming techniques, which would reduce shaft excavation time and create a safer working environment. Excavation rates for the tunnel and access shaft were assumed at 30 feet/day and 8 feet/day, respectively. The excavation for the raised boring machine was assumed at 30 feet/day. It was assumed that the liner would be upon completion of the tunnel mining.

10.2.2.4 Unit 3 –Total Offshore Intake Excavation Costs

Two offshore shafts would be necessary, one main access shaft and one intake shaft. The main access shaft would be close to shore, 350 feet deep. The offshore shaft would be 225 feet deep, yet constructed approximately 1 mile offshore in slightly deeper water by raise bore techniques. While the raised boring schedule would be shorter than conventional shaft construction techniques, capital equipment costs were assumed to be higher. For estimation purposes, both shafts have equivalent costs of $4,515,000. The total cost for this scheme would be:

Tunnel	$35,500,000
Shafts (2) - $4,515,000 x 2	$9,030,000
Access Costs for Shafts	$2,970,000
Total	**$47,500,000**

10.2.2.5 Units 2 and 3 –Total Offshore Intake

In addition to an offshore intake for only Unit 3, an offshore intake for both Units 2 and 3 was evaluated. As discussed in Section 9.0 of the report, the arrangement would be similar except the inside diameter of the tunnel would be approximately 30 ft. The tunnel would be separated, by an internal wall, into a Unit 2 and 3 portion. The arrangement would consist of four offshore shafts, two for each unit. Table 10.2-2 provides a breakdown of the tunneling costs.

Table 10.2-2: Relative and Approximate Costs for Tunneling – Units 2 and 3

Description	Quantity	Unit Cost ($)	Total Cost ($)
Mobilization	N/A	7,100,000	7,100,000
Shaft Station Development	4	189,000	756,000
Tunnel Excavation & Temp. Support (Rock Bolts)	5,000 LF	4,530	22,650,000
Concrete Lining (Slip Form)	5,000 LF	3,020	15,100,000
Drilling in Advance of Face	5,000 LF	45	225,000
Pressure Grouting at Tunnel Face	5,000 LF	108	325,000
Muck Disposal	150,000 cu-yd	-	146,000
Final Cleanup	5,000 LF	45	227,000
GRAND TOTAL			**$46,600,000** or $9,300 / LF of Tunnel

The total cost for the combined Units 2 and 3 offshore intake would be:

Tunnel	$46,500,000
Shafts (4) - $4,515,000 x 4	$18,060,000
Access Costs for Shafts	$6,440,000
Total	**$71,100,000**

10.3 CONSTRUCTION PERIOD ESTIMATES

Construction periods, construction start dates, and estimated outage periods for each of the alternatives are presented in Table 10.3-1. The construction period estimates were developed assuming standard construction methods and workweeks. Estimated outage periods are total durations. The construction periods do not include the engineering design, site investigation work, or other prerequisite work that may be required. For scheduling purposes, it was assumed that any necessary permit application would be approved in December 2002. In addition, it was assumed that the following time would elapse before construction begins in order to perform the planning, permitting, engineering, and selection of constructor:

- CWS Cross-Connect 12 months
- CWS Throttling Valves 12 months
- Condenser Bypass 12 months
- Variable Speed Pumps 12 months
- Natural-Draft Cooling Towers 18 months
- Offshore Intake 18 months
- Fine-mesh Screens 18 months

It is recognized that these may be very optimistic schedules for the permitting efforts. This is especially true for the cooling tower alternatives and offshore intake alternative with their greater environmental impacts and public interest and sensitivity to the visual effects in this coastal community.

Table 10.3-1: Construction Periods, Start Dates, and Outage Periods

Alternative Description	Construction Start	Construction Period (Months)	Outage Period (Months)
CWS Cross-Connect	12/03	3	3
CWS Throttling			
• Unit 2	12/03	2	1
• Unit 3	12/03	2.5	1.5
Condenser Bypass			
• Unit 2	12/03	4	Note 1
• Unit 3	12/03	6	
Variable Speed CWPs			
• Unit 2	12/03	3	Note 1
• Unit 3	12/03	4	
Cooling Towers			
• Natural	06/04	24	6
• Mechanical	06/04	24	6
Offshore Intake			
• Unit 3 only	06/04	36	6
• Units 2 & 3	06/04	36	6
Fine-mesh Screens	06/04	24	6

Note 1: It was assumed that the work would be performed during Unit operation with the shutdown of one bay at a time.

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11 USE OF REFUELING OUTAGES TO REDUCE ENTRAINMENT

11.1 OUTAGE HISTORY

As part of its NPDES permit reissuance in December 1992, Northeast Nuclear Energy Company (NNECO) was required to submit a report relative to the feasibility of reducing entrainment of winter flounder larvae. This report, entitled "Feasibility Study of Cooling Water Alternatives to Reduce Winter Flounder Entrainment at Millstone Units 1, 2, and 3 (NUSCO 1993), was submitted to the DEP on January 27, 1993 and concluded that "open-cycle cooling using the existing intake structures and equipment at MNPS remains the best available technology at a reasonable economic cost with respect to larval winter flounder entrainment" (NUSCO 1993, p. ES-11). With respect to planned refueling outages, the 1993 feasibility study observed that "refueling outages are generally targeted for periods of low electrical demand and hence, most refueling outages are generally scheduled for the spring and fall" (NUSCO 1993, p. ES-7). Upon review, the DEP approved this study in a letter dated January 14, 1994 (DEP 1994) and included several conditions: 1) that NNECO "continue efforts to schedule refueling outages to coincide with the period of high winter flounder larval abundance at the intake (typically April 1st through June 15)", and 2) following each outage, "submit a report to the Commissioner which identifies important factors which contributed to the timing of the outage". These outage reports have been submitted to DEP as required.

As Table 11.1-1 illustrates, there have been seven refueling outages at MNPS since 1993. Of these, three were planned to occur during the spring, while three others extended through to spring. In addition, all three units, due to unplanned, extended outages to respond to and resolve matters before the U.S. Nuclear Regulatory Commission (NRC), did not operate during the 1996, 1997, and 1998 winter flounder larval abundance periods. Additionally, Unit 1 has not operated since fall 1995 and is now being decommissioned.

As discussed in NUSCO (1993), numerous factors have played a major role in the actual timing of refueling outages. Since approval of the study in January 1994, reductions in larval winter flounder entrainment ranging from 21 up to 48% have been achieved during refueling outages. From 1996 to 1998, during the extended, unplanned site-wide outage, annual larval winter flounder entrainment was reduced between 71 and 84%. Due to the voluntary shutdown of Unit 1, an approximate 23% reduction will be achieved every year, realizing the 1993 DEP-requested goal of a 25% reduction in winter flounder entrainment. Furthermore, even though MNPS was not in operation during the 1996-98 winter flounder larval abundance periods and Unit 1 has not operated since the fall of 1995, the adult Niantic River winter flounder population remains at relatively low levels of abundance and, as is demonstrated in Section 4 of Part II, it is likely that factors other than MNPS operation are affecting this population.

Table 11.1-1: Millstone Nuclear Power Station Refueling/Extended Outage History, 1994 to Present

Date	Unit	Type	Reduction in Cooling Water Flow *	Reduction in Larval Winter Flounder Entrainment **
January 15 - May 23, 1994	1	Refueling	94%; 27%	21%
October 1, 1994 - August 4, 1995	2	Refueling	34%; 18%	44%
April 14 - June 7, 1995	3	Refueling	65%; 36%	44%
November 4, 1995 to Present	1	Refueling/ Extended Outage/ Decommissioning ***	-	23%
February 20, 1996 - May 11, 1999	2	Extended Outage	-	1996 - 72% 1997 - 84% 1998 - 71% 1999 - 48%
March 30, 1996 - July 5, 1998	3	Extended Outage	-	1996 - 72% 1997 - 84% 1998 - 71%
April 30 - June 29, 1999	3	Refueling	63%; 57%	48%
April 22 - June 1, 2000	2	Refueling	67%; 42%	35%
February 3 - March 30, 2001	3	Refueling	66% 54%	<1%

Notes:

* For each refueling outage, the first percentage given is the percent reduction in water volume for the particular unit shut down and the second value is for MNPS as a whole.

** Reduction in larval winter flounder entrainment as a result of an outage(s) was calculated on a whole-station basis (i.e., full three-unit operation for MNPS). Reductions were calculated from actual entrainment data (except for 2000, which is an estimate) and is an aggregated total if more than one unit was shut down during a particular period.

*** As a result of the Unit 1 decommissioning, MNPS water use and entrainment has been permanently reduced by approximately 23%.

11.2 FREQUENCY OF REFUELING

11.2.1 General Outage Planning Considerations

In NNECO (1993), it was assumed that, subject to many factors, the interval between refueling outages would be approximately 2 years. This projection was the basis for the alternating spring and fall outages for Units 1 and 3. It appears that the 2-year interval forecast assumed both a cycle capacity factor of approximately 85% and lengthier refueling outage periods than presently forecast. These assumptions reflected the MNPS operating and refueling history at the time. In addition, the 2-year projections were not

based on 2-year fuel core loads at high capacity factors. Rather, the schedules assumed that the units would be out of service approximately 15% of the time for unplanned events, thereby preserving fuel and also enabling any NRC-required surveillances that might arise between refuelings to be performed.

Due to the unplanned outages starting in 1996, among other factors, these assumptions did not hold. Since Unit 3 returned to service July 1998, it has had a capacity much greater than 85%. For example, upon returning from its previous refueling outage in June 1999, Unit 3 operated with a capacity factor of approximately 98.7% up until its most recent refueling, which commenced February 3, 2001. Similarly, once Unit 2 returned to service in June 1999, it also has run at a capacity factor greater than 85%. Since June 2000, Unit 2 has run at a capacity factor of approximately 96%. The higher the capacity factor, the faster the fuel in the core is burned.

As a result of the above, NNECO, previous owner and operator of MNPS, and now DNC have continued to evaluate outage cycles. It has been determined that approximately 18 months between refuelings is the preferred cycle length. A wide range of factors was considered, including electrical capacity and Independent System Operator - New England (ISO-NE) considerations, plant operating capacity, environmental considerations, reactor core design constraints, regulatory requirements, and economic considerations. A brief discussion of each interval follows.

11.2.2 12-Month Cycle

While a 12-month cycle may assist in the effort to plan for yearly spring and fall outages, refueling cycle intervals for nuclear power plants in the United States are clearly trending towards 18- to 24-month intervals. An annual outage raises significant logistical and resource issues if both Units 2 and 3 were to be refueled each spring. Given the resources required to accomplish an outage, it would be impractical to overlap refueling outages or to schedule one immediately after the other. As a result, a 12-month cycle would not accommodate two refuelings each spring; one would be scheduled in the spring and one would be scheduled in the fall. Finally, a 12-month cycle substantially increases plant operating costs which must be considered.

11.2.3 18-Month Cycle

An 18-month cycle supports the effort to attain alternating outage schedules for Unit 2 and 3, as well as alternating spring and fall outages at each unit. An 18-month cycle reduces core design concerns with respect to longer cycles, maintains both units within their NRC-approved operating basis, and provides greater operating flexibility than a 24-month cycle. Such a cycle can be designed to avoid refueling outages during the summer months, where there is the potential for significant ISO-NE penalties if a plant is planned out of service during periods of peak demand. Once the units are on a nominal 18-month

baseline schedule, current planning forecasts, subject to significant change based on a variety of factors, indicate the potential for an outage sometime in the spring two out of every three years.

11.2.4 24-Month Cycle

One advantage of a 24-month operating cycle would be the potential to schedule spring only outages in alternating years for Units 2 and 3. However, a core design based on a full 2 years of operation presents significant core design issues at both units. Licensing surveillance issues and Technical Specification changes would likely require approval from NRC. These issues are expanded upon in the following section.

11.3 24- MONTH CORE DESIGN ISSUES

As stated previously, there are significant operational and core design issues for both MNPS Units 2 and 3 that would result from implementation of a 24-month operating cycle. A 24-month fuel cycle operating at an assumed capacity factor of 95% between refueling outages, and assuming a 30-day refueling outage, would require 665 full power days of energy to be loaded into the reactor core. All operating units have a finite amount of margin available to the design limits which must be met to operate the plant. Attempting to increase the operating fuel cycle length to 24 months would utilize a significant portion of this operating margin. This would impact plant reliability and reduce operating flexibility. For example, the ability of each unit to run in a power coast-down mode at the end of the cycle would be compromised. The consequence of not being able to perform coast-down is that the unit would be less likely to shutdown for refueling at a specific date, which is counter-productive. Issues specific to each unit are discussed below.

11.3.1 Unit 3 Issues

Unit 3 core design concerns include lack of core loading flexibility, lack of boric acid tank capacity, fuel design limit restrictions and NRC Technical Specification changes. Each is discussed below.

With respect to fuel core loading flexibility, a minimum of one half of the core (about 97 fuel assemblies) would have to be replaced during each cycle to achieve 665 days of full power energy, thereby reducing the margin to design limits necessary to operate the unit. For example, the Unit 3 spent fuel pool heat load analyses limit the number of fuel assemblies discharged (that is removed from the core and placed in spent fuel storage) in a fuel cycle to 97 fuel assemblies out of 193. If one-half of the core is already being replaced, then there would be no flexibility to account for a situation in which fuel inspections performed during the outage dictates the replacement of additional fuel assemblies. The present 18-month cycle requires replacing of between 35 and 40% of the core, allowing for the replacement of additional fuel assemblies if warranted.

Regarding the capacity of the boron storage tanks, the soluble boron concentration requirements in the reactor coolant system would increase under a 24-month cycle. To reach a 24-month fuel cycle, the minimum required Technical Specification boric acid storage tank volumes and boron concentrations are expected to exceed existing tank volumes. As a result, other nuclear fuel designs not currently in use at Unit 3 would need to be evaluated.

As to the ability of the fuel to support a 24-month refueling schedule, the fuel power distribution across the reactor core and fuel rod design limits would also be challenged if the operating fuel cycle is extended to 24 months. Specifically, this refers to the design requirements for the amount of power or energy produced within either a fuel rod or fuel assembly. The maximum fuel pin burn-up limit is expected to have no margin to the design limit, precluding coast-down operation on a 24-month cycle. The allowed fuel peaking factor in a given rod versus fuel assembly burn-up limits assumed in the Unit 3 safety analysis would be challenged on a 24-month cycle. As a result, it is likely that fuel design limit restrictions would have a significant impact upon the ability to design and operate a 24-month cycle with operating margins.

Finally, there are numerous NRC Technical Specification surveillances that must be performed at a frequency that would be impacted by lengthening the fuel cycle to 24 months. Several Technical Specification change requests, along with supporting analyses, would be required to be processed and approved by the NRC to support the longer cycle, since the present Technical Specifications do not currently allow a 24-month refueling interval. These requests are in addition to the technical challenges identified above.

11.3.2 Unit 2 Issues

Unit 2 reactor core design concerns include lack of fuel loading flexibility, increases in soluble boron concentrations, in-core instrumentation replacements, and NRC Technical Specification changes.

With respect to the core loading flexibility, Unit 2 criticality safety analyses limit the fuel uranium enrichment that may be loaded into a fuel assembly for any given cycle. The Unit 2 spent fuel pool heat load analyses limit the number of fuel assemblies discharged (removed and placed in spent fuel storage) in a fuel cycle to approximately 80 fuel assemblies out of total of 217. These limits preclude the unit from loading enough fuel to achieve 665 days of full power energy, with existing equipment.

Regarding boron, the soluble concentration requirements in the reactor coolant system would increase, resulting in a challenge to a number of design requirements. Specifically, the Refueling Water Storage Tank and Safety Injection Tank minimum NRC Technical Specification boron concentration requirement of 1,720 ppm would have to be increased.

A larger number of in-core instruments would also have to be replaced each fuel cycle if a 24-month cycle is used. This would increase the refueling outage length, the amount of radioactive waste generated and stored in the spent fuel pool, and would increase potential personnel radiation exposure.

Finally, there are NRC-required Technical Specification surveillances that must be performed at a frequency that will be impacted by lengthening the fuel cycle to 24 months. Several Technical Specification change requests requiring NRC approval, along with supporting analyses, would be required to support the longer cycle since the present Technical Specifications do not allow a 24-month refueling interval.

11.4 COOLING-WATER FLOW REDUCTIONS

The environmental benefit of the timing of outages coincident with the winter flounder larval abundance period in particular is the reduction of cooling water flow and the potential for lessening entrainment. As discussed below, however, it is not always possible or prudent to shut all circulating pumps during an outage. The following provides technical engineering information with respect to the operation of circulating water pumps during refueling outages.

While the goal of the station is to keep the minimum number of circulating water pumps in operation during a refueling outage, two operating circulating water pumps are required to run during a refueling outage, as per the NPDES permit, to provide adequate flow for certain discharges. Consequently, two circulating water pumps are typically kept running for a part of a refueling outage at both Units 2 and 3. Although discharges which require the pumps to be running are not continuous, certain conditions make it necessary to run two pumps even when not discharging.

At various times during a refueling outage, due to supporting equipment outages, starting circulating water pumps is not permitted by procedure or design. Also, it is not good operational practice to frequently start circulating water pumps. The following technical information describes these conditions for starting prerequisite, starting transients, discharges, and heat load:

11.4.1 Starting Prerequisites

Initial conditions that are required for pump starts may not be available during a refueling outage. Therefore, once a pump is stopped, it may not always be permitted by procedure or system design to be restarted. Consequently, these considerations often dictate operability of pumps to support discharges.

11.4.1.1 Pump Start Interlocks

The circulating water pumps have several supporting systems which must be operational to allow a pump start. These support systems include station compressed air, circulating water pump eductor, domestic water, service water, waterbox priming, traveling screens, turbine building closed cooling water, and electrical busses. During a refueling outage, some support systems may be taken out of service for maintenance, necessitating continual operation of circulating water pumps, or prohibiting restart if the pumps are off.

One specific example of such a support system is the waterbox priming system. During the recent Unit 3 outage, the entire waterbox priming system was removed from service for extensive maintenance and major component replacement. There is a logic interlock between this system and the circulating water pumps on Unit 3. Logic interlocks consist of electronic circuitry which control the flow of power to various components that are dependent upon one another. Without the waterbox priming system in service, the system logic at Unit 3 will not allow the pump to start. The purpose of the waterbox priming system is to partially pre-fill the waterboxes and tubes to minimize the hydraulic shock that occurs when a circulating water pump is started. Therefore, a physical bypass of the start permissive logic interlock is not recommended nor allowed by procedure due to potential significant equipment damage. In this specific example, two circulating water pumps were left running prior to the waterbox priming system being taken out of service. Until the waterbox priming system was restored, these two pumps remained operating because system design would not allow any circulating water pump restarts by procedure and design. The work on the waterbox priming system lasted 3 weeks. If the circulating water pumps had been shut off, they would not have been able to restart until the water priming system was restored to service.

Support systems such as the station compressed air, turbine building closed-loop cooling water, or waterbox priming are commonly out of service for required maintenance for extended periods of time during a refuel outage. These systems typically can only be taken out of service during a refueling outage. Outages of these support systems prohibit circulating water pump starts but have no damaging effect on continuous operation of circulating water pumps.

11.4.1.2 Manual Preparations

The start of a circulating water pump requires many manual preparations. These include alignment of large valves in the system and ensuring that all the support systems are aligned and functional. Alignment, preparation, and operation of these support systems for the circulating water pump restart may take several personnel up to a few hours. Eduction of a bay (analogous to priming the pump) itself may take up to 45 minutes, depending upon tide level and load demands upon the air compressors. The manpower resources which support pump starts are tightly scheduled during refueling outages.

11.4.2 Starting Transients

Starting circulating water pumps can place additional stresses on various systems. Such starts should be limited to protect components of the circulating water system and to maximize equipment reliability and longevity. Examples are given in the following three sections for motor current, pump stress, and hydraulic shock.

11.4.2.1 Motor Current

The circulating water pumps at both units have large, 4160-volt motors that draw high starting currents, which can be in excess of 250 amps. This current heats the motor to a level beyond normal operating temperatures, causing additional wear. If a pump fails to start, it must remain idle for 45 minutes for another start attempt. This is required so that the motor will have adequate cooling time between starts. Frequent starts of motors of this size lead to significant damage to the components. Accordingly, motor reliability dictates that, to the extent possible, motors remain in service.

11.4.2.2 Pump Stress

Each circulating water pump start produces vibrations along the pump shaft that are greater than the normal operating vibrations. The additional vibrations produce stresses upon the mechanical components of the pump which cause wear. Pump starts also produce greater torque forces along the shaft due to the resistance of the standing water. These forces add to the wear of the mechanical components. The rubber bearings require continuous lubrication from a supplied water source. The bearings are not visible and flow meters are used to verify flow. There is greater chance that a bearing will become damaged upon a pump start than during normal operation. This is because it cannot be visually verified that the bearing surfaces are fully wetted, and because the increased vibrations and torsion forces on the shaft could cause damage to the bearings.

11.4.2.3 Hydraulic Shock

The high-flow, circulating water pumps produce a hydraulic shock to system components. The shock is minimized by the waterbox priming system but it still exists. The circulating water pumps at Unit 2s and 3 are approximately 137,200 and 153,000 gallons per minute, respectively. Upon initial startup, a massive force of water is introduced rapidly to the system. This makes piping, valves, waterboxes, tubesheets, and condenser tubes subject to an initial force greater than their normal operating forces. This produces wear on the system components. Also, the rapid change in temperature from ambient system air temperature to ambient intake water temperature can cause sharp expansion and contraction forces that the system does

not experience during normal operation. Repeated application of these forces can lead to condenser tube-sheet damage, condenser tube leaks, or leakage at mechanical joints.

11.4.3 Discharges

During a refueling outage, it is desirable to keep the holding tanks for the various unit discharge systems at low levels to ensure capacity for additional water processing which may result from numerous refueling outage evolutions. Therefore, discharges are often made to keep up with the volume and to ensure adequate holding tank capacity. Because of this, it is difficult to plan and achieve a complete circulating water pump outage. Typically, all circulating water pumps can be out of service for a maximum of 2 to 4 days, consecutively, before discharges are required due to full holding tanks. Any total circulating water pump outage must be planned for a time when minimal refueling activity inputs are filling the holding tanks and when the holding tank levels are very low. If the holding tanks were to fill, many refueling evolutions would have to cease until circulating water pumps could be restored. Similarly, if pump support systems were out of service preventing pump restart, the ability to deal with increasing tank volumes would be jeopardized.

11.4.4 Heat Load

At the beginning and end of a refueling outage, there are various heat loads on the steam-side of the plant that are drained into the main condenser. For quenching purposes, circulating water is required to cool the main condenser and protect the equipment. Once the plant is no longer producing electricity, it can take several days to cool the plant from an operating state. It also requires several days to heat the plant back up from cold shutdown. Without this cooling water from the circulating water pumps, there would be catastrophic failure of main condenser components and subsystems.

Regarding circulating pump operation during refueling outages, DNC has concluded that while minimizing pump operation remains a goal, there are technical issues such as pump starting prerequisites, resources, pump stress, and heat load considerations which dictate that pump(s) be available and on-line as plant discharges and other outage requirements dictate.

11.5 OUTAGE DATE SELECTION

As discussed above, both Units 2 and 3 have been out of phase for alternating outages to occur in the spring and fall. DNC is in the process of adjusting fuel purchases based on projected operating performance and outage lengths to realign the operating cycles of both units. Nuclear fuel is usually ordered about 1 year ahead of delivery (i.e., approximately 2.5 years ahead of the end of its cycle). As a result, the need for such advanced long-term planning limits some of the flexibility available to achieve desired schedules. The fuel ordered for the next operating cycle for Unit 2, based upon the current schedule, will take Unit 2 to a fall

2003 outage, after which the unit is projected to be "in phase" to implement the long-term strategy of alternating spring and fall outages. At present, the next spring outage for Unit 3 is projected to occur in 2004 and the next spring outage for Unit 2 is projected for 2005. Any unplanned deviation from this refuel schedule will represent a substantial burden on MNPS as well as the electrical capacity of New England.

11.6 CONCLUSION

Based on the above discussion of refuel outage planning issues, it is not prudent to pursue further consideration of moving Units 2 and 3 to 12- or 24-month fuel cycles at this time for purposes of entrainment reduction, particularly of winter flounder in spring. Core design margins, spent fuel capacity limitations, and NRC Technical Specifications preclude this as an option for achieving annual spring outages. Fuel purchases now underway will allow Unit 2 and Unit 3 to support alternating spring and fall outages. Again, it is important to point out that the timing of outages is often imprecise due to unplanned outages, changing regional capacity requirements, and available outage resources.

12 ECONOMIC EVALUATION

The total cost of various cooling-water intake alternatives previously described in Part I, Sections 5 through 10, were modeled to determine the Net Present Value (NPV) of each option. The NPV analysis was performed to determine the financial cost or benefit of each option in equivalent terms (i.e., 2001 dollars).

The options were divided into six categories:

1. Reduced Flow
2. Recirculation
3. Variable Speed Pumps
4. Cooling Towers
5. Offshore Intake
6. Physical Barriers.

All options were analyzed using a common financial model, described below. The capital costs, maintenance costs, lost generation quantities (MWH), outage duration, and construction start dates and duration were derived from the engineering evaluations. The outage or downpower time frames were evaluated for the larval or egg entrainment seasons of two important species affected by station operation, the winter flounder and tautog (Table 12-1). A combined winter flounder and tautog season was also evaluated. For each species, the primary season encompasses nearly all entrainment and an optimal season avoids the tail ends of larval or egg distributions and allows some options (e.g., Reduced Flow) to be more economic. A description of how these seasons were quantified is given in Part II, Chapter 3 of this report.

Table 12-1: Seasonality of Winter Flounder and Tautog Entrainment

Species	Affected Time Period
Winter flounder (primary season)	March 22 through June 5
Winter flounder (optimal season)	April 4 through May 14
Tautog (primary season)	May 3 through August 22
Tautog (optimal season)	May 29 through July 12
Combined winter flounder and tautog	March 22 through August 22

12.1 FINANCIAL PARAMETERS COMMON TO ALL CASES

Amounts were input in 2001 dollars and subsequently escalated by 2.75% per year. The analysis was performed including plant life extension to 2045.

The after-tax cash flow is comprised of:

- Capital costs
- Incremental maintenance expense
- Lost revenues due to continued operation at reduced capacity during the spawning season
- Lost revenue during tie-in of modifications to existing systems
- For the Cooling Tower and the Offshore Intake options, lost revenue for all the months after the modifications have been completed
- Tax depreciation on the capital investments
- State and federal income taxes changes due to the above items

Construction Costs assumed necessary permits were issued at the end of December 2002 and the designs were completed during the subsequent 12 months.

Incremental maintenance expenses were escalated by the projected average annual increase in inflation.

Lost revenues due to reduced generation during spawning seasons were calculated for each of the five time periods identified in Table 12-1. The lost generation was spread evenly over the period, then the monthly total MWH were multiplied by the $ per MWH projected on the spot energy market by the NorthBridge Group, an independent consulting firm (see Appendix A).

NorthBridge provided five price curves. The first assumed both units were available and operating 100% of the time, or 100% station operating capacity. The second curve assumed that station operating capacity was 75%. The other three curves assumed the station operating capacity was reduced to 50%, 25%, and finally to 0%. The New England Power Pool (NEPOOL) price was predicted to increase as station operating capacity decreased, and this was due to the higher marginal cost units that would replace the lost generation from Millstone Station.

Lost revenue due to outages required to tie the modifications to the plants existing systems were calculated using the net capacity for Unit 2 and Unit 3, 875 MWH and 1,154 MWH, respectively, times the number of hours in the month times the expected station operating capacity. For this calculation, the station operating capacity was assumed to be 96%, which reflects an assumed forced outage rate of 4%.

Lost revenue for the Cooling Tower and the Offshore Intake options were calculated by multiplying the monthly reduction in generation (MWH) times the monthly spot energy prices provided by NorthBridge. The price curve that assumed the units were operating 100% of the time was used. For the Offshore Intake option, the assumed reduction was spread evenly throughout the year. The reduction due to the Cooling Tower option varies due to varying temperature of the water.

Tax depreciation was calculated as the annual amount of tax depreciation, using 15-year MACRS (Modified Accelerated Cost Recovery System), starting the year the modification was assumed to be completed. The rates assume a mid-year convention.

Income tax effect was calculated by adding:

- The incremental maintenance expense
- The tax depreciation
- The lost revenue during the modification tie in, during the spawning seasons, and, for the Cooling Tower and
- Offshore Intake options, for all years once the tie-in was completed

The resultant value was then multiplied by the composite income tax rate to derive the reduction in income taxes to be paid. The assumed composite tax rate 39.88% incorporates a marginal federal income tax rate of 35% and a Connecticut State income tax rate of 7.5%.

An annual change in cash flow was calculated using the XNPV function of Microsoft Excel. The function was chosen as it allows using the mid-point of each year in the actual NPV calculation, which more accurately models our cases.

Weighted Average Cost of Capital (WACC) assumed 55% debt and an interest rate of 7.5% with a 15% return on equity. The debt to equity ratio is the target ratio for Dominion Energy. The 7.5% interest rate represents an expected average incremental cost of debt to Dominion Energy, and also represents the expected mix of short-, medium-, and long-term debt that Dominion Energy would experience. The return on equity represents Dominion Energy's view of the risk adjusted return required for an investment in a nuclear facility.

12.2 FINANCIAL MODEL RESULTS

The results of analyses are summarized in Table 12-2 and show that none of the cases has a positive NPV, indicating that Millstone Station would lose money on each of the options from a strict financial perspective. More detailed information on the financial analyses are given in Appendix B. The cost data provided in Table 12-2 for the tautog primary season period for each option, except Plant Shutdown, have larger negative NPVs than the combined winter flounder and tautog period, even though the lost MWHs shown in Table 7.11-2 are larger for the combined winter flounder and tautog period. This is because the methodology used for determining an NPV is based on an average $ per MWH for the period and assumes that the lost MWHs are evenly distributed over the period. This methodology results in a conservative (i.e., underestimated) NPV for the combined winter flounder and tautog period.

In the Reduced Flow, Recirculation, Variable Speed Pumps, Cooling Towers, and Physical Barriers categories, the cases shown in Table 2-12 were created independently of one another. Thus, some cases may be combined by simply adding the resultant individual cases. For example, the NPV for Unit 3 Variable Speed Pumps = $8,187,000 and for Unit 2 Variable Speed Pumps = $3,169,000. Therefore, Variable Speed Pumps at both Units 2 and 3 = $8,187,000 + $3,169,000 = $11,356,000. Attributes not modeled in this approach are the expected higher market price of electricity due both plants being off line, if the installations are done in parallel, or the extended outage if they are completed in series. The effect would increase the lost revenues for the station and subsequently further decrease the NPV associated with the option.

Table 12-2: Cooling-Water Intake Alternatives Costs (45-year Net Present Value) for Primary and Optimal Entrainment Seasons for Winter Flounder, Tautog, and Combined Winter Flounder-Tautog Season

Summary	Unit	NPV (000s)				
		Winter Flounder (WF)		Tautog (T)		WF & T
Reduced Flow Rate		3/22 - 6/5	4/4 - 5/14	5/3 - 8/22	5/29 - 7/12	3/22 - 8/22
Reduced Number of Operating CWPs 5	3	($63,226)	($62,652)	($68,351)	($64,605)	($68,278)
Reduced Number of Operating CWPs 4	3	($66,254)	($64,088)	($79,954)	($69,395)	($80,673)
Reduced Number of Operating CWPs with Cross Connect 5	3	($64,015)	($63,446)	($69,131)	($65,396)	($69,052)
Reduced Number of Operating CWPs with Cross Connect 4	3	($66,963)	($64,841)	($80,576)	($70,120)	($81,244)
Reduced Number of Operating CWPs 3	2	($48,212)	($47,235)	($119,009)	($81,562)	($113,811)
Reduced number of Operating CWPs with Cross Connect 3	2	($48,630)	($47,653)	($119,427)	($81,980)	($114,228)
Throttling of Condenser Discharge Valves	3	($32,735)	($30,590)	($45,028)	($35,202)	($46,087)
Throttling of Condenser Discharge Valves	2	($20,338)	($20,154)	($22,083)	($20,886)	($22,051)
Recirculation						
Installation of Condenser By-Pass Lines	3	($5,039)	($2,977)	($17,197)	($7,537)	($18,139)
Installation of Condenser By-Pass Lines	2	($848)	($717)	($2,487)	($1,415)	($2,394)
Use of Tempering Line for Recirculation	2	($307)	($177)	($1,946)	($875)	($1,854)
Variable Speed Pumps						
Variable Speed CWPs	3	($8,187)	($6,936)	($18,744)	($10,985)	($18,769)
Variable Speed CWPs	2	($3,169)	($3,491)	($3,918)	($3,904)	($3,315)
Plant Shutdown						
Unit 2 Shutdown	2	($477,395)	($247,797)	($949,010)	($396,422)	($1,207,588)
Unit 3 Shutdown	3	($629,156)	($326,544)	($1,251,198)	($522,630)	($1,592,259)
Unit 2 & 3 Shutdown	2&3	($1,066,210)	($553,402)	($2,120,015)	($885,554)	($2,697,804)
		Annual (000s)				
Cooling Towers						
Natural Draft - 100 Capacity	3	($418,000)				
Natural Draft - 2/3 Capacity	3	($269,392)				
Mechanical Draft - 100% Capacity	3	($334,495)				
Natural Draft - 100% Capacity	2	($241,246)				
Mechanical Draft - 100% Capacity	2	($253,354)				
Offshore Intake						
Unit 3 Only	3	($219,876)				
Unit 2 & 3 Combined	2&3	($377,363)				
Physical Barriers						
Fine Mesh Screens	3	($154,176)				
Fine Mesh Screens	2	($113,506)				

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13 REFERENCES

ASA (Applied Science Associates, Inc.). 1999. Ichthyoplankton monitoring study deployment of a Gunderboom system at Lovett Generating Station Unit 3 1998. Prepared for Orange and Rockland Utilities, Inc.

Brown, R. E. and K. Bernier. 1997. The Use of Aquatic Guidance Strobe Lighting System to Enhance the Safe Passage of Atlantic Salmon Smolts. Presented at the American Fisheries Society Annual Meeting, Monterey, CA, August 25, 1997.

Brueggemeyer, V., D. Cowdrick, K. Durrell, S. Mahadevan, and D. Bruzek. 1988. Full-Scale Operational Demonstration of Fine-Mesh Screens at Power Plant Intakes. Pages 2-51-2-65 in W.C. Micheletti, ed. Proceedings: Fish Protection at Steam and Hydroelectric Power Plants. EPRI CS/EA/AP-5663-SR. Electric Power Research Institute, Palo Alto, CA.

DEP (Connecticut Department of Environmental Protection). 1994. Letter C05513 dated January 14, 1994 from E. Parker, DEP, to D. Miller, NNECO. Approval letter.

Dunning, D. 1997. Ultrasound Deterrence: Alewife at a Nuclear Generating Station in New York. *In*: T. J. Carlson and A. N Popper (eds.): Using Sound to Modify Fish Behavior at Power-Production and Water-Control Facilities: A Workshop. Prepared for U.S. Department of Energy and Bonneville Power Administration, DOE-BP-62611-11.

EPRI (Electric Power Research Institute). 1986. Assessment of Downstream Migrant Fish Protection Technologies for Hydroelectric Application. EPRI Report No. 2694-1.

EPRI (Electric Power Research Institute). 1994a. Research Update on Fish Protection Technologies for Water Intakes. EPRI Report No. TR-104122.

EPRI (Electric Power Research Institute). 1994b. Fish Protection/Passage Technologies Evaluated by EPRI and Guidelines for Their Application. EPRI Report No. TR-104120.

EPRI (Electric Power Research Institute). 1996a. Evaluation of the Modular Inclined Screen (MIS) at the Green Island Hydroelectric Project. 1995 Test Results. EPRI Report Npo. TR-106498.

EPRI (Electric Power Research Institute). 1996b. PWR Secondary Water Chemistry Guidelines. EPRI TR-102134-R4, Revision 4, November 1996.

EPRI (Electric Power Research Institute). 1998. Evaluation of Fish Behavioral Barriers. EPRI Report No. TR-109483.

Elarbash, M.M., R. Cheesman, and Y.G. Mussalli. 1994. New Infiltration Intake System for Zebra Mussel Control and Larval Exclusion. Proceedings of the Fourth International Zebra Mussel Conference, Wisconsin, March 1994 pages 179 to 184.

Hanson, C.H., D. Hayes, and K.A. F. Urquhart. 1997. Biological Evaluations of the Georgiana Slough Experimental Acoustic Fish Barrier, Phases I-IV during 1993-1996. *In*: Fish Passage Workshop, Milwaukee, Wisconsin, May 6-8, 1997.

Harza and RMC. 1993. Response of Juvenile Clupeids to Louvers in the Holyoke Canal, Fall 1992. Prepared for Northeast Utilities Service Company, Berlin Connecticut.

Heat Exchange Institute Standards. 1995. Standards for Steam Surface Condensers, Ninth Edition.

Hudson Products Quotation - Millstone Project. 2001. Air-Cooled Heat Exchanger – Millstone 2 Dry Cooling Tower, dated February 6, 2001.

Hulchizer, A. J., and J. P. Rossereau. 1981. Design and Installation of Large Diameter Sub Sea Connecting Shafts for the Seabrook Station Cooling System. RETC, San Francisco, CA.

Hulchizer, A. J., J. C. Struart, R. L. Obradovic, and A. J. Struart. 1979. Land Shaft Construction and Initial Station Development for Seabrook Station Cooling Water Tunnels. RETC Proceedings, Vol. 2.

Karassik, I. J., W. C. Krutzsch, W. H. Fraser, and J. P. Messina. 1976. Pump Handbook, McGraw-Hill Book Co.

Klinect, D.A., P.H. Loeffelman, and J.H. Van Hassel. 1992. A New Signal Development Process and Sound System for Diverting Fish from Water Intakes. *In*: Proceedings of the American Power Conference, Chicago, IL 1992, 54:427-432.

Knudsen, F.R., C.B. Schreck, S.M. Knapp, P.S.Enger, and O. Sand. 1997. Infrasound Produces Flight and Avoidance Responses in Pacific Juvenile Salmonids. Journal of Fish Biology 51:824-829.

Kuhl, G.M., and K.N. Mueller. 1988. Prairie Island Nuclear Engineering Plant Environmental Monitoring Program 1988 Annual Report: Fine-mesh Vertical Traveling Screens Impingement Survival Study. Prepared for Northern States Power Company.

LMS (Lawler, Matusky, & Skelly Engineers). 1994. Effectiveness Evaluation of a Fine-Mesh Barrier Net Located at the Cooling Water Intake of the Bowline Point Generating Station. Prepared for Orange and Rockland Utilities, Inc.

LMS (Lawler, Matusky & Skelly Engineers). 1996a. Lovett Generating Station Gunderboom System Evaluation Program 1995. Prepared for Orange and Rockland Utilities, Inc.

LMS (Lawler, Matusky & Skelly Engineers). 1996b. Effectiveness Evaluation of a Fine-mesh Barrier Located at the Cooling Water Intake of the Bowline Point Generating Station. Prepared for Orange and Rockland Utilities, Inc.

LMS (Lawler, Matusky & Skelly Engineers). 1997. Lovett Generating Station Gunderboom System Evaluation Program 1996. Prepared for Orange and Rockland Utilities, Inc.

Loeffelman, P.H., D.A. Klinect, and J.H. Van Hassel. 1991. Fish Protection at Water Intakes Using New Signal Development Process and Sound System. *In*: Waterpower '91, Proceedings of the International Conference on Hydropower. American Society of Civil Engineers, New York, NY.

Millstone Nuclear Power Station Unit 3, Final Safety Analysis Report (FSAR), Docket No. 50-423.

MNPS (Millstone Nuclear Power Station). 1999a. Millstone Procedure NGP 2.17, Secondary Water Chemistry Program, Revision 10, January 8, 1999.

MNPS (Millstone Nuclear Power Station). 1999b. Technical Evaluation M3-EV-99-0093 Revision 0, Millstone 3 Condensate Dissolved Oxygen, September 27, 1999.

Millstone Project. 2001. Hudson Products Quotation: Air-Cooled Heat Exchanger – Millstone 2 Dry Cooling Tower, dated February 6, 2001.

Nestler, J.M., G.R. Ploskey, J. Pickens, J. Menezes, and C. Schilt. 1992. Responses of Blueback Herring to High-Frequency Sound with Implications for Reducing Entrainment at Hydropower Dams. North American Journal of Fisheries Management 12:667-683.

NUSCO (Northeast Utilities Service Company). 1993. Feasibility study of cooling Water system alternatives to reduce winter flounder larval entrainment at Millstone Units 1, 2, and 3. Submitted by letter D06112 dated January 27, 1993 from C.F. Sears, NUSCO, to T. Keeny, Commissioner, DEP.

NUSCO (Northeast Utilities Service Company). 1998. Millstone Nuclear Power Station, Additional Information on Millstone Waste Streams and LCS-1000, conquer 3585, LCS-1200 and carbohydrazide. Submitted by letter D 12000 dated January 28, 1998, from F.C. Rothen, NUSCO to D. Cherieo, DEP.

Ploskey, G.R., P.N. Johnson, M.G. Burczynski, J.M. Nestler, and T.J. Carlson. 1998. Effectiveness of Strobe Lights, Infrasound Devices, and a Sound Transducer for Eliciting Avoidance by Juvenile Salmonids. Technical Report EL-98, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Ross, Q.E., D.J. Dunning, R. Thorne, J.K. Menezes, G.W. Tiller, and J.K. Watson. 1993. Response of Alewives to High Frequency Sound at a Power Plant Intake on Lake Ontario. North American Journal of Fisheries Management 13:291-303.

Schilt, C.,. and G. Ploskey. 1997. Ultrasound Deterrence: Blueback Herring at a Pumped Storage Facility in Georgia. *In*: T. J. Carlson and A. N Popper (eds.): Using Sound to Modify Fish Behavior at Power-Production and Water-Control Facilities: A Workshop. Prepared for U.S. Department of Energy and Bonneville Power Administration, DOE-BP-62611-11.

Scientech (Scientech, Inc.). 1998. Performance Evaluations of Power System Efficiencies (PEPSE), Version 64 and 64a.

S&W (Stone & Webster). 1982. Calculation 12179-HYD-H33, Hydraulic Grade Line – Circulating Water System, Revision 0, October 25, 1982.

S&W (Stone & Webster). 2000. Calculation 08560-M-001, Unit 2 Circulating Water System Flow, Revision 0, March 6, 2000.

Veneziale, E.J. 1991. Fish Protection with Wedge-Wire Screens at Eddystone Station. *In*: Proceedings of the American Power Conference.

APPENDIX A TO SECTION 12 OF PART I

LONG-TERM NEPOOL PRICE FORECAST: INPUTS AND ASSUMPTIONS

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LONG-TERM NEPOOL PRICE FORECAST: INPUTS AND ASSUMPTIONS

In order to compare the financial impact of various operating and refueling schedules for the Millstone nuclear units, long-term electric price forecasts for the New England region are required. These forecasts should include not only expected market prices over the forecast period, but also uncertainty estimates about these projections. Additionally, forecasts must cover a range of available power from Millstone at any given time, from both units fully on to fully off, in order to assess the revenue impact of full or partial outages at either plant.

Dominion has worked with The NorthBridge Group, an economic consulting firm specializing in electric power markets, to develop these forecasts. The forecasts predict prices over the 45-year span from August 1, 2001 to July 31, 2046 utilizing a methodology developed over the last several years by NorthBridge in conjunction with EPRI (the Electric Power Research Institute). The forecasting approach and methodology are briefly reviewed below, followed by a discussion of key price drivers for the New England market. Model inputs and assumptions are summarized, and key outputs including both forward prices and their corresponding volatilities are discussed.

FORECAST METHODOLOGY

Central to the EPRI/NorthBridge Forecasting System (the Model) is the generation of an ensemble of possible scenarios of future fuel commodity prices and system loads, both of which are key drivers for market electric prices. These stochastic scenarios are generated so as to preserve, on average, the expected forward or spot prices or load levels at each point in time. At the same time, they also span a distribution of possible values consistent with the volatility characteristics of each commodity, and preserving expected levels of correlation between commodities and/or load. While the model can generate spot price and load scenarios, the preferred approach is to work in a risk-neutral framework tied to forward prices (and loads), which are directly observable in the market for such commodities as oil and natural gas. In this framework the output electric prices are benchmarked by comparison to observable market forwards for electricity, an advantage that is difficult to replicate using expected spot prices.

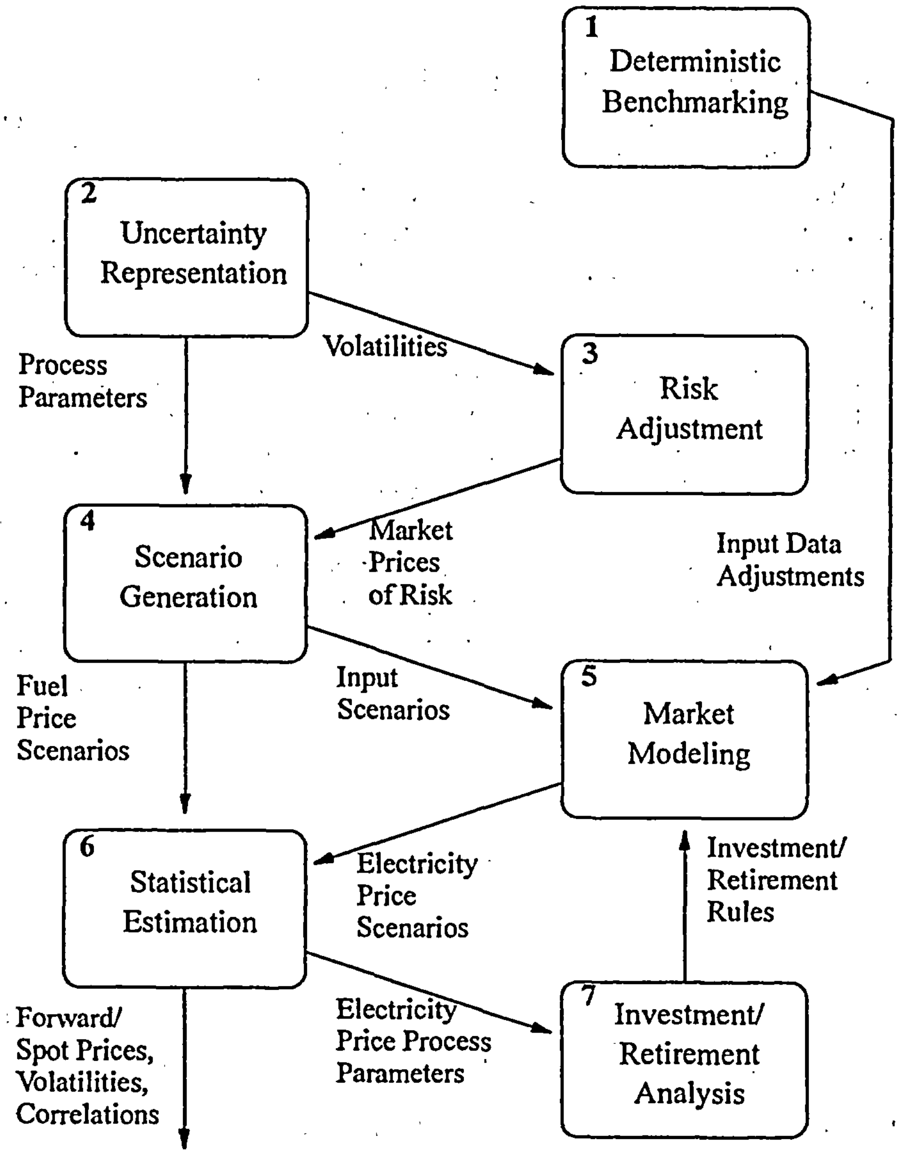
Using modern sampling techniques, the Model is able to efficiently represent the universe of possible price and load paths by a manageable number of scenarios, typically 30 – 100. Coupled with stochastic forced outages for generation units, the fuel price and load scenarios are transformed into hourly market clearing prices for electricity using a structural market model containing a fairly detailed description of the generation assets in a particular region. This market model utilizes a simple unit stacking algorithm to produce hourly price outputs for each scenario. Averaging across scenarios and hours yields the monthly forward or expected spot prices (depending on user selection) for power, while the standard deviation of the log of prices

provides a volatility measure appropriate for many valuation techniques derived from modern options theory.

For long forecasts, a new investment module adds capacity to each scenario to keep up with load growth. The Model utilizes an algorithm based on a Planning Reserve Margin algorithm.

This forecasting approach is described in much greater detail in several EPRI reports, principally the 1998 report "Forward Price Forecasting" (portions of which are available to non-EPRI members). A graphical depiction of the process is shown in Figure 1 below.

Figure 1 – Price Forecasting Process



PRICE DRIVERS FOR ELECTRICITY

In terms of price dynamics, electricity is the most complex energy commodity. Because it is expensive to store (or because the available storage is limited), excess generation capability cannot typically be used to meet shortages at other times. Similarly, due to transmission limitations, localized shortages cannot always be alleviated by importing power from neighboring regions. As a result, electricity prices can vary substantially over time and between regions. This temporal and regional variation makes the behavior of electricity prices complex and difficult to analyze.

The dynamics of electricity prices depend on the time frame of interest. Figure 2 establishes three separate time frames, based on somewhat arbitrary break points at one month, one year, and ten years. In each time frame, key price drivers are identified. Note that the notion of a price driver has a very specific definition. In order to be a price driver, a particular source of uncertainty must have a significant effect on the electricity price. In addition, information obtained today must resolve uncertainty that affects the electricity forecast. Accordingly, weather is a key price driver in the short term. When the weather forecast for tomorrow changes, that information will alter the electricity price forecast for tomorrow. But we receive little or no information today that will alter a weather forecast one year in the future. Hence, weather is not a medium-term or long-term price driver.

Figure 2
Time Frames in Electricity Price Forecasting

Time Scale	Short (current – 1 month)	Medium (1 month – 1 year)	Long (1 year – 10 years)
Price Drivers	Weather Unit outages Interregional flows	Load growth Fuel prices Hydro availability	Load growth Fuel prices New technology cost/performance
Sources of Price Information	Current and projected state of system Deterministic system modeling Historical spot price data	Futures and options prices Probabilistic system modeling	Probabilistic system modeling Investment/retirement analysis

Short-term behavior covers the next month. Over this period, weather and unit outages are the primary sources of uncertainty that drive price dynamics. Another key driver is the extent to which the transmission system can damp price swings by allowing interregional flows. Over this period, fuel prices are rarely a key driver. There is typically enough storage in the fuel system to smooth out supply and demand imbalances. The notable exception here concerns the effect of gas pipeline constraints on peak winter days in the midwest and northeast. Similarly, there is relatively little variation in hydro availability on a day-to-day basis (except as limited by environmental constraints). Even most run-of-river hydro systems have enough inherent storage to provide a relatively consistent capability within the month.

In the medium term — from one month to one year — key drivers are load growth, fuel prices, and hydro availability. Relatively minor changes in peak load expectations can have a dramatic impact on peak period electricity prices. Changes in fuel price expectations ripple through to affect the electricity forward curve. Current rainfall and snowpack conditions will affect hydro availability over the coming months. Weather and unit outages will still affect prices in this time frame, but one cannot predict today what those affects might be. With the possible exception of "El Nino" conditions, we cannot reliably forecast weather conditions beyond a week or so. Similarly, for most generating units, the current operating status tells us relatively little about their possible operating status months from now. Nuclear units are the exception here, in that units that are currently unavailable are more likely to be unavailable months into the future than those that are currently operating. New technology costs have an insignificant effect, because lead times are such that the underlying capacity stock is essentially fixed over this time frame.

Some of these drivers also affect long-term prices. Current economic conditions can produce sustained load growth over a period of years. Regulatory policy and technological innovation can affect the long-run cost of new fuel supplies. Associated shifts in the long-term forward curve for natural gas will affect the long-term forward curve for electricity. Beyond the one-year horizon, investment in electricity generation and transmission will change the capacity stock over time. Accordingly, cost and performance improvements in electricity generation and transmission technology can dramatically affect long-term prices.

The nature and availability of price information also differ by time frame. In the short term, the most important information is the current and projected state of the electricity system. An up-to-date understanding of the weather forecast, unit availabilities, and loading conditions on major transmission interfaces is absolutely critical to projecting short-term prices.

Forward and futures markets are most active in the medium term — at least for very standardized monthly products. Where these futures and option prices exist, they are probably the best source of price information (at least if the markets are relatively liquid and bid/ask spreads are small). The range of possible outcomes in this time frame is sufficiently large that one cannot understand the nature of price uncertainty simply by running a few sensitivity cases of a deterministic price forecasting model. In order to augment the market information, probabilistic system modeling is really needed.

Beyond a year or so, the quality of market price quotes deteriorates rapidly. Markets are thin, and bid/ask margins wide. Understanding long-term prices really requires a fundamental understanding of long-term supply and demand conditions and the implication for price levels and volatility. Probabilistic system modeling is essential. In addition, as the regulatory umbrella unfolds and markets tighten with load growth, some generating units will be retired and new investments built. These changes in the capacity stock will affect market prices; therefore, understanding investment and retirement dynamics is a critical component of price forecasting.

FASTFORWARD

The major components of the EPRI/NorthBridge Forecasting System are implemented in a software package developed by NorthBridge entitled *FastForward,* which is distributed through EPRI to members of the PM&RM target area. A synopsis of *FastForward* is provided as Appendix A to this memo. This software was used to generate the NEPool forecasts discussed herein. In the remainder of this section, we will discuss the assumptions, inputs and results from this model.

NEPOOL FORECAST – INPUTS AND ASSUMPTIONS

Because this study is primarily concerned with the prices into which Millstone can sell power, and because the coastal Connecticut region is typically not constrained in transmission capability, the forecast treats NEPool as a single region with no transmission constraints or zones. While the Boston market typically experiences tight supplies and higher prices due to congestion, treating NEPool as a single region provides prices applicable to most of the region and in particular to the Waterford area.

A bid price equal to the marginal cost of generation is assumed for each generating unit, tied to the appropriate fuel prices for that day and scenario. No bidding strategies are assumed, which if anything leads to conservative (understated) prices and revenues. The forecast uses generator heat rates equal to 110% of the full load rating, believed to be a fair estimate of average heat rates during typical operation.

Forward market prices for Henry Hub natural gas, No. 2 heating oil, crude oil and eastern coal are the basis for the near-term forecast for natural gas, distillate oil, residual oil and coal, respectively. Beyond the last market quotes, a fitted curve adjusted to closely match the seasonal behavior and long term trends of the current forwards is utilized. For gas, a 10-year strip contract was also used in the fitting process. Long-term price growth rates were fitted to forecast data from 2004 through 2020 contained in the Energy Information Administration's "Annual Energy Outlook 2001" report, which contains a 20-year forecast of fuel prices in 1999 dollars. Annual inflation of 2.2%, deduced from the difference in yields between regular and inflation-linked long-term Treasury bonds, was added to these growth rates to yield growth rates in real-time (shrinking) dollars. Finally, a risk premium consistent with each fuel was subtracted to convert the growth in spot prices to the smaller growth rate of the corresponding forward contract prices:

Fuel Costs: Long Term Growth Rates (%/year)

	Nat gas	FO2	FO6	Coal
Basis	Wellhead	World Oil	World Oil	Delivered
EIA Rate of increase in 1999 dollars (2004 - 2020)	1.39	0.49	0.49	-0.94
Implied Rate of increase in real dollars (spot)	3.57	2.67	2.67	1.24
Risk Premium	1	0.8	0.6	0.2
Implied Rate of increase in real dollars (forwards)	2.57	1.87	2.07	1.04

For gas, no tightness was assumed in the supply over the forecast period – but some scenarios will naturally trend to extremely high prices due to their random walks above the expected level. Also, seasonal transportation costs are added to natural gas to capture the typical $2 - $4 difference between Henry Hub market and New England city-gate prices in winter. Fuel forwards, representing the observed or extrapolated market forwards, are shown for these four fuels in Figure 3 below. Market prices for oil, coal and gas futures are from NYMEX quotes from the last week of July, 2001.

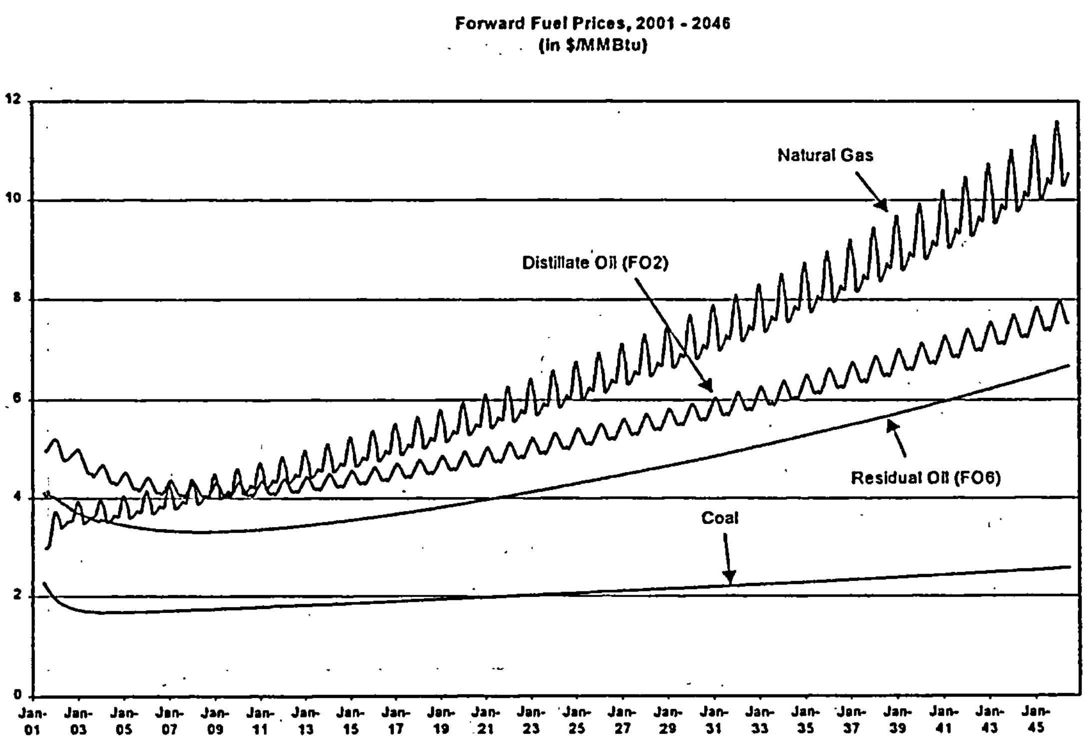


Figure 3 – Fuel Price forwards (from July 25 market quotes)

Electricity forwards for NEPool are available from a variety of sources. For this study, quotes were obtained from NatSource, a broker covering the New England and New York power markets, for July 27, 2001. These quotes are typically expressed as Jan-Feb peak, July-Aug peak, and peak for some individual months for the coming year, as on-peak for a quarter or a calendar year, and as off-peak for a month or calendar year. Bid and ask prices were quoted for peak power through calendar 2003, and for off-peak forwards through calendar year 2003. This market is thinly traded, particularly in comparison to oil and gas forwards, and quotes typically extend only for a few years – often no more than two or three. This mix of near-term specific months quotes, full year quotes and the shape of the forward curve was used to infer average forward prices for the unquoted months.

Note that forward prices for electricity are not inputs for the model, but rather serve as target prices to benchmark the model outputs in the early years of a forecast. Adjusting model parameters and assumptions to match market forwards is an important step in developing a new forecast, yielding confidence in the forecast forward or spot prices in years beyond the available market data. The forward quotes obtained for NEPool in this manner, along with the corresponding forecast results after tuning, are shown in Figure 4 below.

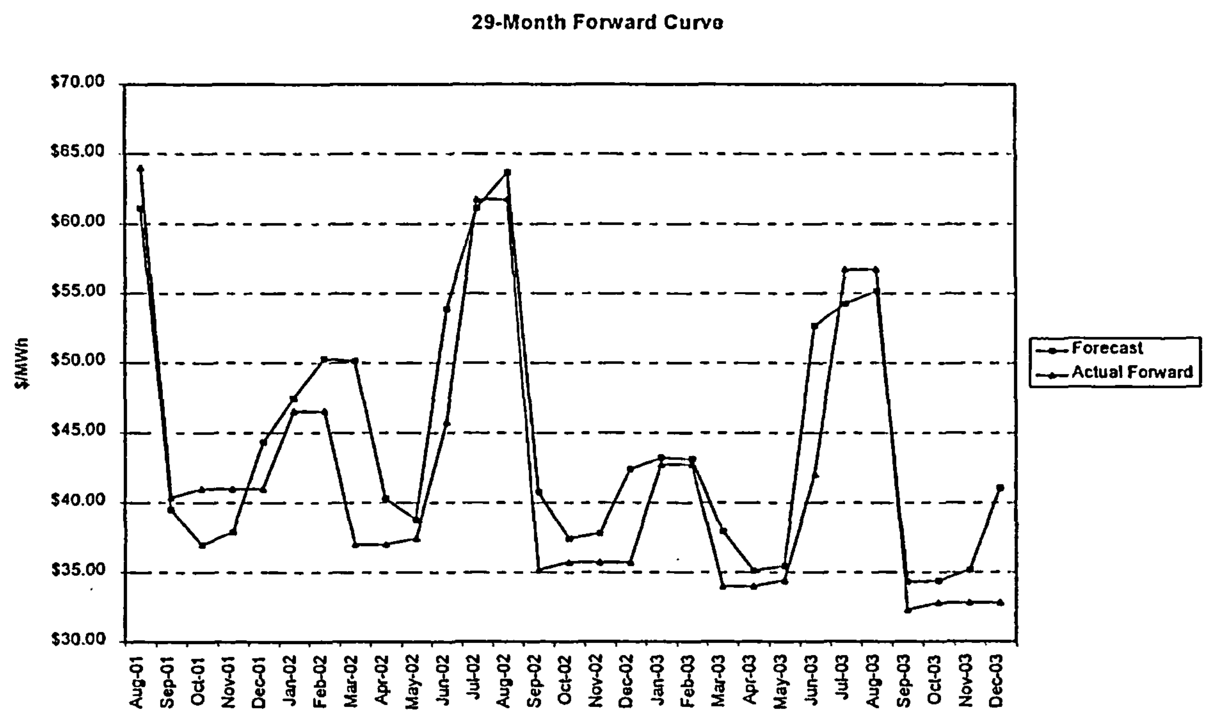


Figure 4 – Forward prices for on-peak power deduced from market quotes

The expected average load for each month of the first portion of the forecast window (Aug. 2001 through Dec. 2010) was taken from ISO- New England's 2001 CELT report. Load projections were taken from the 2001 NEPool CELT report for 2001-2002. After 2010, monthly loads were inflated at 2% per year. These loads represent actual expected (spot) loads, not adjusted for risk (i.e. not the risk-neutral or "forward" load expectation). Hourly load shape profiles based on several years of historical data are then applied to the monthly averages to produce hourly expected load values for each hour of the forecast window.

For loads and fuel prices, the expected value is only half the story. The other half is the volatility representation, which governs how far from the expected value scenarios will stray at any given time. For each fuel commodity and for load, NorthBridge has estimated parameters describing the evolution of uncertainty over time based on available historical data, options and forwards prices, and other sources. The Model represents each commodity as a three-factor mean-reverting process, which means that the stochastic meanderings of each scenario are governed by three hidden factors: A short term factor for day-scale effects, a medium-term factor for month-scale effects, and a long-term factor for permanent (no mean reversion) effects. Each factor for each commodity is parameterized by volatility, mean reversion rate, and market price of risk, which represents the risk premium between expected spots and forward prices. Finally, a correlation matrix establishes the expected level of coupling between price movements (or lack thereof). For example, distillate and residual oil often move in tandem, so this characteristic we should be preserved in the scenarios.

NorthBridge has spent considerable effort over the last few years estimating these parameters for NEPool, and therefore has some confidence in the values used during these runs. The volatility term structure for each commodity is governed by these parameters, and can be compared to that inferred from the commodities options markets and from historical price movements.

The forward price curves for fuels and the forecast load profile form the expected path for all scenarios, that is, the average across scenarios at any time equals the input forecast. The volatility parameters govern the distribution of scenarios about these averages, including correlations between commodities and marginal (short time scale) volatility behavior. All of these features are incorporated into the Scenario Generator module of FastForward. For this forecast, 50 scenarios were generated.

THE MARKET MODEL

The market model embedded in FastForward is based on a simple unit-stacking market clearing mechanism. A table of generating units and their characteristics is utilized for each region to determine the current supply stack of available power versus price, from lowest price to highest. Given the current price of the fuels and unit parameters such as heat rate, variable O&M, SOx and NOx emission rates and prices, and fuel transportation costs, the marginal cost of generation for each unit is determined for each time period (hour or day). The current capacity of each unit is governed by a seasonal capacity curve to reflect differences between summer and

winter capacities. This base capacity is modified by a planned maintenance derating factor applied across groups of units, or in the case of large nuclear units, by known maintenance outage plans. Finally, each unit is then assigned to be available or unavailable due to a forced outage, by means of a stochastic outage table generated internally from unit outage parameters (forced outage rate and typical outage durations).

Included in the NEPool model are special entries corresponding to imported power from Hydro Quebec, New Brunswick, and New York. In addition, pseudo-units corresponding to interruptible load are included at prices well above the usual marginal dispatch levels. These prices rise almost exponentially with load at extreme load conditions, consistent with a fairly inelastic supply curve. Special treatment is given to pumped storage units to simulate their cycle of adding to load offpeak and discharging power on peak.

Detailed characteristics of the generating units in the NEPool model include summer and winter capacities, maintenance and availability factors, heat rates, fuel types and costs, variable operating costs, and emission content for NOx and SOx pollutants. Emission allowance prices for SOx and NOx (during the summer ozone season) are added to the marginal costs.

In NEPool there are currently about 25 large-scale new power projects either under construction, recently completed or well advanced through the permitting process. Almost all of the new projects are efficient gas-fueled combined cycle (CC) units that will tend to reduce the average cost of power in the region by displacing older steam units. A few gas-fueled combustion turbines (CT's) are also in the mix. Barring any shortages of gas supply, the expectation is that this new capacity will lower power costs in the region. For units still under construction, estimated total capacity additions are built into the Model at six-month intervals.

Beyond the near term capacity additions, the Model adds new capacity to each scenario automatically as load grows over the 45-year forecast. The quantity of new capacity is tied to the growth of the expected peak loads through the Planning Reserve Margin, and is therefore scenario-dependent. A fixed-ratio bundle of CCs and CT's is added to the pool to keep up with the load growth. Reflecting technological advances, the heat rate for this fleet of new units decreases somewhat over time. The planning reserve margin and the ratio of CC's to CT's are set through a tuning process in which the average payback on these new investment units is tuned to be commensurate with a 25-year capital recovery schedule, including depreciation and tax effects.

The results of this tuning process, coupled with the long-term growth rate of fuel costs, are the critical drivers for long-term electricity prices. By tuning the economic returns of new investment units to appropriate levels, the Model bounds the long-range prices to a reasonable range relative to the fuel prices. Ultimately, for markets in long-term equilibrium, the price for electricity will be tied to these fuel costs.

For nuclear units with known refueling schedules, these planned outages are incorporated in the near-term forecast to tune to market forward prices. Beyond the near term, average

availabilities are assumed (except for the Millstone units, discussed below). All other units are assigned an average maintenance schedule derived from ISO-NE's published annual maintenance report. Forced outage rates and durations for different categories of generating units are tied to data used in ISO-NE reliability reports.

ECONOMIC IMPACT STUDY

Once the reference case model was tuned to match both short-term market forward prices for electricity and long-term economic payback for new investment units, five special runs were done for the current study. Keeping everything else constant, the available power from Millstone 2 and 3 were set to the five percentages of full power: 0, 25, 50, 75 and 100%, with no deviations for planned or unplanned outages. These runs provide the expected price on any given day in the forecast period as a function of how much power is available from Millstone Station. New investment units are unaffected by this modification and are the same for all five runs. The price increase as power drops from 100% to 0% is linear enough in available Millstone power that simple interpolation between the five values is sufficient for most purposes.

The code was run in "Spot" mode to yield expected spot prices in the forecast period, with the exception of the runs to tune to near-term Nepool forwards and long-term economic payback for new units. Those runs were done in a risk-neutral mode that models "Forward" prices.

For each run, the forecast results are summarized in terms of the average all-hours monthly prices, and the volatility associated with each result. This volatility is a measure of the price uncertainty expressed in a standard financial manner: volatility equals the standard deviation of the log of prices, divided by the square root of the time (in years) since August 1, 2001 (the forecast date). To show that result in a more useful form, the prices corresponding to plus or minus one standard deviation in the log price distribution are also presented. If the distribution of prices is perfectly log-normal (often a good approximation), this corresponds to a one-sigma delta in price as well. These resulting High and Low prices are usually a reasonable representation of the level of uncertainty in the prices.

Appendix A: FastForward – A Synopsis

Until recently, U.S. power companies enjoyed the relative security of a regulated industry in which investors were promised a fair rate of return and the costs of doing business were routinely passed on to consumers. Those days are rapidly coming to a close. The current evolution of power markets to competition and open access is creating opportunities for those companies savvy enough to adapt quickly, and potentially fatal pitfalls and hazards for those who don't. Companies facing a complex array of new issues and increased exposure to risk require new analytic tools in order to survive and prosper.

One essential element for success in this competitive market environment is the ability to correctly gauge the present value of power contracts and generating assets. This information is crucial for a number of decisions facing today's power companies: How to price power at the wholesale and retail levels, when to make and when to buy power; whether to keep, sell or retire generating assets, whether to invest in new plants or plant upgrades; how to manage risk through the use of forward power contracts and options.

Modern finance and options theory provides the necessary framework to evaluate quantities such as the net present value of a power plant facing uncertain future loads, fuel prices, outages, and market prices for electricity. By treating fuel costs and electric prices as volatile commodities, one can express the expected value of running a given generating unit over a specific hour or over a lifetime. But in order to accurately capture the dynamics of wholesale electric prices, one must first have an electric market model incorporating the uncertainties of loads, outages, fuel and possibly emission costs, all relevant fuel prices, and future additions to and retirements from the generating unit pool.

To meet these modeling needs, The NorthBridge Group is developing *FastForward*, an EPRI-sponsored, PC-based application designed to rapidly generate forward price curves for electricity. *FastForward* captures the probabilistic price forecasting methodology of the EPRI-NorthBridge Forward Price Forecasting System in an efficient, flexible and user-friendly package. *FastForward* features a Scenario Generation module, a multi-region market model for estimating hourly electricity market clearing prices, and a Statistical Estimation module to summarize and graphically display the forecast results. An Investment/Retirement module based on economic decision rules is currently under development, as are tools to estimate volatility parameters from historical or forecast data.

FastForward provides an essential capability for survival in a competitive market environment - the crucial price forecasting and volatility data required for accurate valuation of power contracts, generating assets, and investment options. In addition, intermediate results may prove useful for planning purposes. Outputs of the *FastForward* modules include:

- Forecasts of expected electric price and associated uncertainty (volatility) for each region,
- Estimates of volatility parameters and correlation factors for commodity prices and loads,
- Scenarios of loads and commodity prices that efficiently span the range of possibilities,
- Transmission flows between regions,
- Power generated by specific plants over a period of time,
- Supply curves (cost vs. load) for specific hours and scenarios,
- Net revenues for specific plants over a period of time,
- Conditional expectations of capacity reserve margin, commodity prices or net revenues,
- Capacity additions or retirements based on the above conditional expectations.

PART II

EVALUATION OF BIOLOGICAL AND ENVIRONMENTAL CONSIDERATIONS OF SELECTED COOLING-WATER SYSTEM ALTERNATIVES AT MILLSTONE NUCLEAR POWER STATION

August 31, 2001

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PART II - CHAPTER 1

INTRODUCTION TO THE EVALUATION OF BIOLOGICAL AND ENVIRONMENTAL CONSIDERATIONS FOR SELECTED COOLING-WATER SYSTEM ALTERNATIVES AT MILLSTONE NUCLEAR POWER STATION

1.1 INTRODUCTION

Part II of this report assesses the potential effects of implementing various intake system technologies at Millstone Nuclear Power Station (MNPS) on populations of seven fishes: the Atlantic menhaden, anchovies, grubby, tautog, cunner, American sand lance, and winter flounder (see Table 1-1 for a list of common and scientific names of all vertebrates and shellfish found in this report). An evaluation of these species was specifically requested by the Connecticut Department of Environmental Protection (DEP 2000) and they were chosen primarily because they have early life history stages numerically dominating entrainment estimates (Table 1-2). In addition, silversides, although not entrained, were examined for potential thermal effects due to changes in plant operation. Plant effects reviewed include impingement of juvenile and adult fish and entrainment of pelagic early life stages (eggs and larvae, collectively known as ichthyoplankton) through the condenser cooling-water systems of each unit. As noted in Section 1 of the Introduction to this report, the effect of impingement was largely reduced by the operation of fish return systems at the intakes of MNPS units and is not a focus of this report. Rather, the emphasis is on entrained eggs and larvae, which are subjected to various mechanical, thermal, and occasional chemical (biocide application) effects before being discharged. The effects of entrainment are evaluated using data from long-term entrainment monitoring at the MNPS discharges, field ichthyoplankton sampling, and year-round or specifically directed monitoring programs. The basis for the MNPS monitoring studies providing these data is presented in Section 2 of the Introduction.

Alternative cooling-water system technologies examined for MNPS are evaluated generically in Chapter 2 of Part II for their feasibility in reducing entrainment mortality and for additional environmental impacts. Additional details concerning the entrainment of designated fishes and the monitoring programs providing specific data for assessments are given in Chapter 3 and its appendices. Species-specific life history data and other information, such as entrainment survival rates, are also given in Chapter 3. Using information presented in the previous two chapters, species-specific quantitative assessments are found in Chapter 4 and appendices. A non-technological entrainment mitigation methodology is presented in Chapter 5, stock enhancement of winter flounder by hatchery production and stocking. For all chapters and most appendices of Part II, the tables and figures are found following the text.

The biological and economic analyses presented herein were completed conservatively in regards to period of MNPS operation as DNC is investigating the possibility of a 20-year license renewal for Units 2 and 3, which would extend

their lifetime to 2035 and 2045, respectively, as opposed to the present dates for retirement of 2015 and 2025. This means that there is an additional 20-year period of entrainment effect on fish populations, but also an additional 20-year period to recover costs.

Throughout Part II, English units of measure (e.g., gallons, feet, miles, °F) are used whenever possible to describe flows, volumes, and physical measurements, as these are the units used in the NPDES permit. Exceptions include measurements of fish, their eggs, or densities of ichthyoplankton that are typically given in metric units and some screen mesh sizes, which appeared to have been specifically manufactured in metric units of measure. Also, some plotted temperatures relating to larval winter flounder growth and development remain in °C, although °F equivalents were given in accompanying text.

1.2 REFERENCES

Cooper, J.A., and F. Chapleau. 1998. Monophyly and intrarelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. Fish. Bull., U.S. 96:686-726.

DEP (Connecticut Department of Environmental Protection). 2000. Letter C09872 dated February 16, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Comments on proposed cooling water alternatives scope of study.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea, and W.B. Scott. 1991. Common and scientific names of fishes from the United States and Canada. Fifth ed. Am. Fish. Soc. Spec. Pub. 20. 183 pp.

TABLE 1-1. Common and scientific names of vascular plant, shellfish, and vertebrate[a] taxa found in this report.

Common name	Scientific name	Common name	Scientific name
alewife	*Alosa pseudoharengus*	menhaden	*Brevoortia* spp.
American lobster	*Homarus americanus*	mullet	*Mugil* spp.
American sand lance	*Ammodytes americanus*	mummichog	*Fundulus heteroclitus*
American shad	*Alosa sapidissima*	naked goby	*Gobiosoma bosc*
anchovies	*Anchoa* spp.	northern anchovy	*Engraulis mordax*
Atlantic cod	*Gadus morhua*	northern pipefish	*Syngnathus fuscus*
Atlantic croaker	*Micropogonias undulatus*	northern sand lance	*Ammodytes dubius*
Atlantic halibut	*Hippoglossus hippoglossus*	paralichtyid flounder	*Paralichthys* spp.
Atlantic herring	*Clupea harengus*	penaeid shrimp	*Penaeus* spp.
Atlantic mackerel	*Scomber scombrus*	pink salmon	*Oncorhynchus gorbuscha*
Atlantic menhaden	*Brevoortia tyrannus*	pleuronectid flounder	Pleuronectidae
Atlantic silverside	*Menidia menidia*	pollock	*Pollachius virens*
Atlantic tomcod	*Microgadus tomcod*	radiated shanny	*Ulvaria subbifurcata*
bay anchovy	*Anchoa mitchilli*	rainbow smelt	*Osmerus mordax*
bay scallop	*Argopectin irradians*	river herrings	*Alosa* spp.
black sea bass	*Centropristis striata*	rock gunnel	*Pholis gunnellus*
blennies	Blenniidae	sculpins	Cottidae
blue crab	*Callinectes sapidus*	scup	*Stenotomus chrysops*
blue mussel	*Mytilus edulis*	seaboard goby	*Gobiosoma ginsburgi*
blueback herring	*Alosa aestivalis*	seals	Phocidae
brown shrimp	*Crangon crangon*	searobins	*Prionotus* spp.
brown sole	*Pleuronectes herzensteini*	sevenspine bay shrimp	*Crangon septemspinosa*
butterfish	*Peprilus triacanthus*	shadow goby	*Quietula y-cauda*
caridean shrimp	*Crangon* spp.	silversides	*Menidia* spp.
capelin	*Mallotus villosus*	skates	*Raja* spp.
common flounder	*Pseudopleuronectes yokohamae*	snailfishes	*Liparis* spp.
cunner	*Tautogolabrus adspersus*	southern flounder	*Paralichthys lethostigma*
double-crested cormorant	*Phalacrocorax auritus*	spot	*Leiostomus xanthurus*
drums	Sciaenidae	sticklebacks	*Gasterosteus* spp.
eelgrass	*Zostera marina*	stone flounder	*Platichthys bicoloratus*
European flounder	*Platichthys flesus*	striped anchovy	*Anchoa hepsetus*
European plaice	*Pleuronectes platessa*	striped bass	*Morone saxatilus*
flounders	Bothidae; Pleuronectidae	striped searobin	*Prionotus evolans*
fourbeard rockling	*Enchelyopus cimbrius*	summer flounder	*Paralichthys dentatus*
freshwater drum	*Aplodinotus grunniens*	tautog	*Tautoga onitis*
giant kelpfish	*Heterostichus rostratus*	trouts and salmon	Salmonidae
gizzard shad	*Dorosoma cepedianum*	vireos	Vironidae
gobies	Gobiidae	warblers	Parulidae
green crab	*Carcinus maenus*	white bass	*Morone chrysops*
grubby	*Myoxocephalus aenaeus*	white croaker	*Genyonemus lineatus*
haddock	*Melanogrammus aeglefinus*	white perch	*Morone americana*
hakes	*Urophycis* spp.; *Merluccius bilineatus*	white seabass	*Atractoscion nobilis*
harbor seal	*Phoca vitulina concolor*	windowpane	*Scophthalmus aquosus*
hard clam	*Mercenaria mercenaria*	winter flounder	*Pseudopleuronectes americanus*
herrings	Clupeidae	wrasse	Labridae
inland silverside	*Menidia beryllina*	yellow perch	*Perca flavescens*
Japanese flounder	*Paralichthys olivaceous*	yellowtail flounder	*Pleuronectes ferruginea*
kinglets	Sylviidae		

[a] North American fish names from Robins et al. (1991). However, flatfish names are as given by Cooper and Chapleau (1998).

TABLE 1-2. Taxonomic composition of fish larvae and eggs collected at the MNPS discharges (as a percentage of the total) from June 1976 through May 2000 (for larvae) and May 1979 through September 1999 for eggs.

Taxon	Larvae	Eggs
Anchovies	47.2	5.3
Winter flounder	14.4	-[a]
American sand lance	7.5	-
Atlantic menhaden	7.4	-
Grubby	5.4	-
Rock gunnel	2.8	-
Cunner	2.2	54.0
Tautog	2.0	27.6
Fourbeard rockling	1.5	-
Radiated shanny	1.2	-
Snailfishes	1.1	-
Atlantic herring	1.0	-
Northern pipefish	0.7	-
Windowpane	0.7	-
Butterfish	0.7	-
Others	4.2	13.1

[a] Little or no entrainment of eggs.

PART II - CHAPTER 2

ENVIRONMENTAL AND BIOLOGICAL EVALUATION OF SELECTED COOLING-WATER SYSTEM ALTERNATIVES

2.1 INTRODUCTION

The purpose of this chapter is to examine specific technologies or operating strategies selected for evaluation to reduce entrainment at MNPS that were presented in Part I. They are evaluated below under the same general categories of behavioral barriers, physical barriers, diversion systems, flow reduction concepts, alternate intake location, revised operational schedules, and conversion of the plant to natural gas fueled units. Parts of this review update information first presented in the 1993 Feasibility Study (NUSCO 1993a). The effectiveness of various methods in reducing entrainment mortality as reported in industry and scientific literature is summarized where appropriate, focusing on marine or estuarine species whenever possible as these are the forms affected at MNPS. Similarly, most attention was paid to experiences at larger power plants with greater cooling-water flow requirements than small stations that may have used some technologies unsuitable for a nuclear power plant. Additional environmental impacts resulting from a change in plant design or operation are also discussed. Since nearly all of these options result in increased air emissions from fossil-fueled generation to make up for lost generation at MNPS or from the conversion of the station to natural gas, this environmental impact is presented in an appendix to this chapter. Conclusions on the relative merits and applicability of various alternatives at MNPS with notes on additional environmental considerations related to plant operations and safety that would be imposed by each are given. Also summarized are the applicability of each alternative at MNPS, estimates of the effectiveness of each alternative in reducing entrainment mortality of species analyzed at MNPS, which include the Atlantic menhaden, anchovies, American sand lance, grubby, cunner, tautog, and winter flounder and other costs or benefits to the local environment and plant operation. These data, found in Table 2-1, are used in quantitative analyses and helped form the conclusions made in this report.

2.2 BEHAVIORAL BARRIERS

Behavioral barriers are designed to either elicit an avoidance or attraction response in fish to reduce their presence in a cooling water intake or facilitate their removal. Behavioral barriers include various acoustic devices, infrasound, strobe and mercury lights, electric screens, air bubble curtains, water jet curtains, and various hybrid systems. These systems are environmentally benign, generally do not affect plant operation or personnel safety, and can reduce impingement of fish at power plants or control movements of migrating fish near hydroelectric facilities. Examples of behavioral barrier systems at power plants were given in EPRI (1999), but all of them were directed towards reducing impacts to juvenile and adult fish. By definition, planktonic organisms such as fish larvae, although able to undertake some vertical movements, maintain little control over horizontal position in the water column. Obviously, fish eggs have no

means of locomotion nor exhibit any behavior. Many eggs are also demersal and adhesive, such as winter flounder and grubby. Thus, behavioral barriers are ineffective in reducing entrainment of ichthyoplankton at cooling water intakes. Even if a fish larva has some ability to respond to a stimulus, its sensory field is much more limited in scope than that of larger, fully transformed juvenile or adult fish, further limiting its ability to avoid a cooling-water intake. Based on the above, behavioral barriers are not considered as a viable alternative to reduce ichthyoplankton entrainment at MNPS.

2.3 PHYSICAL BARRIERS

2.3.1 Traveling Water Screens

Conventional 0.375-in traveling water screens are the present, baseline operating condition for MNPS. Unless modified to include fine-mesh screening and collection systems (discussed in the following section), conventional traveling water screens typically found at many power plants have relatively large mesh openings which allow most ichthyoplankton and other planktonic organisms to pass through the screens and become entrained through the cooling-water system. These conventional cooling-water systems, however, are often modified to improve the survival of larger organisms that become impinged on the traveling screens. As noted in Chapter 1 of Part II, effects of impingement at MNPS have been largely mitigated by the installation of fish return sluiceways. Survival of entrained organisms, particularly for the fishes of interest at MNPS, at power plants with conventional once-through cooling and standard traveling screens is discussed in Chapter 3 of Part II and Appendix A to Chapter 3.

2.3.2 Fine-Mesh Screens

The objective of fitting intake screen panels with fine mesh is to remove eggs and larvae large enough to become impinged on the fine-mesh screens before they become entrained through the condenser cooling-water system of a power plant. Fine-mesh screens may be fitted to conventional through-flow traveling screens, dual-flow screens, rotary drum screens, or angled screens, which may offer additional benefits and are discussed in greater detail in following sections. Available data from laboratory studies, field evaluations at test facilities, and plant operating experience which evaluate fine-mesh screens in reducing entrainment mortality of larval fish are summarized below. For most systems, survival is dependent upon the species and life stage affected (EPRI 1999; Taft 2000). In some instances, fine-mesh screens may increase mortality and plant impact if the survival of larvae impinged on the small mesh is less than that of organisms passing through coarser mesh screens, entrained through the cooling-water system, and discharged back into the receiving water body. Fine-mesh screens used at marine sites may also be subject to increased debris loading that could jeopardize plant operations and safety. Additional studies of fine-mesh screens are also discussed below in Section 2.4 in conjunction with diversion systems, which often incorporate fine-mesh screens with a removal system to facilitate the return of impinged ichthyoplankton.

Edwards et al. (1981) tested six Pacific marine fishes in a laboratory flume with fine-mesh screens of several types (Nytex and carbon steel) that ranged in mesh size from 0.5 to 3.3 mm. Retention and survival varied widely among the species tested and were related to the size, age, and behavior of the test organisms. Two species (shadow goby and white croaker) were particularly hardy, whereas few northern anchovy or giant kelpfish survived impingement on these screens. They concluded that survival of impinged larvae may be limited to the most hardy species, with the survival of less hardy species only improving somewhat with age and size of individuals.

Laboratory evaluations of fine-mesh screening, which included tests on alewife, striped bass, and winter flounder larvae, were reported by ARL and SWEC (1981) and Taft et al. (1981a). Various test velocities (0.5, 1, 1.5, and 2 $ft \cdot s^{-1}$) and durations (2, 4, 8, and 16 min) were employed, and initial, 96-h latent, and total mortality values were determined for 0.5-mm synthetic fine-mesh screens. For small larval alewife (5.2-5.5 mm), mortality increased with increasing velocity and duration of impingement. With a test duration of 8 min, mean mortality ranged between 4 and 70% at the test velocities. Post-larval alewife (6.6-14.7 mm) had high (76%) mortality under all test conditions (control mortality was 43%). Yolk-sac striped bass (6.4-6.4 mm) also had relatively high mortality under all test conditions, although control mortality was also high. Striped bass post-larvae (6.5-17.1 mm) had low (<10%) mortality when velocities and test duration were low (<2 $ft \cdot s^{-1}$, 4 min, respectively). Stage 1 (yolk-sac) winter flounder larvae had mean mortality rates between 7 and 36% over the given range of velocities. Winter flounder larvae equivalent to Stage 2 of development (4.4 mm) had high test mortality under all conditions; control mortality was 43%. Older larvae (6.1 mm; likely in Stage 3 of development) had better survival, with mortality equal to 16-36% in six of the nine velocity-duration combinations tested.

Several studies (EA 1977, 1979) were completed at the Indian Point Generating Station Unit 1, a nuclear-powered unit located on the Hudson River that was retired in 1974 (Hutchison 1988). A continuously operated fine-mesh (2.5 mm) screen was used as a replacement for conventional traveling screen panels. In 1977, larval and juvenile fish impinged on this screen were collected from the bypass sluiceway. Collection efficiency and impingement survival were measured using larval striped bass. This screen was not effective in preventing the entrainment of post-yolk-sac larvae (7-9 mm in length). The minimum size of larvae effectively collected by this screen mesh was in the 10 to 18 mm size range. Initial survival of these larger larvae was 69% and survival after a 96-h holding period was 47%. Survival of larger (17-23 mm) juvenile striped bass was higher (88%), indicating that this fine-mesh screen had the potential to reduce the entrainment mortality of this life stage. Follow-up studies in 1978 were designed to improve estimates of screen collection efficiency. Only 835 (2.2%) of the 38,700 yolk-sac larvae released were recovered. Additional work was completed with small juvenile striped bass. It was concluded that this size screen would retain nearly all of the young striped bass 19 mm and larger and that their survival would likely exceed 75%.

Fine-mesh screens have been operated since 1985 at the Big Bend Station Units 3 and 4 (about 400 MWe each), located on an arm of Tampa Bay in North Ruskin, FL. Studies of prototype fine-mesh (0.5 mm) screens were conducted between 1979 and 1981 (Taft et al. 1981b; Brueggemeyer et al. 1988). Tests were conducted using various combinations of approach velocities and screen rotational speeds. Results of pilot studies showed that temperature and approach velocity significantly affected initial survival, hatchability, and latent survival of eggs and larvae of various species of drums. However, the differences were not large and explained little of the observed variability in survival. Invertebrate (various crabs and shrimps) larvae showed 96-h latent survival of about 43 to 80% (controls, 28-93%), depending upon the species. Fish eggs, including those of various drums, herrings, and anchovies, had relatively good survival rates, ranging between 46 and 98% (controls, 28-98%); drums had better survival than herrings and anchovies. However, initial survival among fish larvae in both the test and control samples was relatively low (0-43%) and latent test sample sizes were too small to be conclusive.

Six continuously operating fine-mesh (0.5-mm) screens were eventually retrofitted to Big Bend Units 3 and 4, as were Hidrostal pumps to transport collected organisms, specially designed return troughs, and new spraywash systems. A full-scale operational demonstration of this system was reported in Brueggemeyer et al. (1988). Initially, a number of operating and maintenance problems were encountered, including frequent screen outages because of mechanical problems. This led to higher approach velocities at the screens remaining in operation and subsequent decreased efficiencies in larval fish removal. Mortality of fish eggs and larvae were initially high (78% and 94%, respectively) at this station. Biofouling, particularly by barnacles and oysters, caused screen mesh and seal failures, and spray line and screenwash nozzle clogging. Gaps and tears in seals and screens also allowed increased entrainment of ichthyoplankton. A daily surveillance and preventative maintenance plan was put into effect to reduce these problems. On the basis of a brief follow-up study, preliminary results indicated that efficiency in screening of fish eggs (primarily drums and bay anchovy) exceeded 95% and fish larvae (primarily drums, bay anchovy, blennies, and gobies) was about 86%. Other studies indicated latent (48-h) survival of fish eggs and larvae of about 80% and 65%, respectively, for drums, and 93% and 66% for bay anchovy.

Fine-mesh (0.5 mm) screens were used on Passavant center-flow traveling screens at the Barney M. Davis Power Station (two units, 650 MWe), located on the upper Laguna Madre near Corpus Christi, TX. This type of intake system uses a single-entry, double-exit flow design with water flowing from the inside to the outside of the screens. Sampling took place in 1977 to examine the initial survival of impinged organisms; no latent survival studies were conducted (Murray and Jinnette 1978). More than 12,000 individuals (15 invertebrate species and 37 fishes) were examined. Overall initial survival was 86%, but rates varied by species and date. Menhaden collected in February had the lowest (5%) mortality. Bay anchovy in June (98%) had the highest mortality, which was attributed to the coincidental impingement of large masses of jellyfish. Higher mortality was associated with heavy loading of marine grasses, which entangled organisms. Periods of high algal loading, however, did not increase mortality.

The Brunswick Steam Electric Plant, a facility with two nuclear-fueled units producing a total of 1,642 MWe, is located about 5.7 mi upstream of the mouth of the Cape Fear, NC estuary and draws cooling water through a 3-mi long intake canal (Hogarth and Nichols 1981; Thompson 2000). Despite intensive long-term monitoring programs showing insignificant plant effects to the Cape Fear estuary (Thompson 2000), to alleviate environmental impact due to loss of organisms through entrainment and impingement and in lieu of installation of cooling towers, the station initiated three modifications. These included a flow reduction scheme (discussed below in Section 2.5.1), installation of a 9.5-mm mesh diversion fence at the head of the intake canal reducing entry of larger organisms into the canal to lessen impingement, and use of 1-mm fine-mesh screens in the intake structure with a return flume to reduce entrainment mortality. Two of the four intake traveling screens at each unit had standard 0.375-inch screens that were replaced with 1-mm fine-mesh polyester screens in 1983; a third screen at each unit was modified in the same way during 1987. Leaving one set of screens unmodified with larger mesh increased plant reliability (Hogarth and Nichols 1981). The screens were operated continuously, but only when ambient water temperature was less than 64.5°F (EPRI 1999). Initial evaluations were conducted to determine if the fine-mesh screens could reduce entrainment and increase survival of impinged organisms without jeopardizing plant safety (Hogarth and Nichols 1981). Tests showed that the plant could be operated with fine-mesh screens to reduce entrainment, even though they were not installed on all of the traveling screens. Entrainment rates of seven important species were projected to be reduced by 44 to 70%, due to a combination of proposed flow reductions and use of the fine-mesh screens. The preliminary work showed some important taxa (e.g., post-larval shrimp) could be returned with high (>82%) survival, whereas others (e.g., anchovy and goby larvae) had poor (<17%) survival due to fine-mesh screen impingement losses. Once fine-mesh screens and associated equipment, particularly modifications enabling continuous screen rotation, were permanently installed at Brunswick, studies were conducted during the winter of 1984-85 to determine the resulting reduction in entrainment (Carolina Power & Light 1985). Gobies made up about one-quarter of the mean density of all organisms collected, followed by Atlantic croaker, spot, and anchovies (15-16% each). Daily entrainment ranged between 22,000 and 6.6 million fish per day. Use of the fine-mesh screens reduced entrainment by 84%, but an estimated 570 million larval organisms of 99 taxa were impinged on the fine-mesh screens during 1984. Thompson (2000) noted that the survival (initial and 96-h latent) of specimens impinged on small-mesh screens in 1987 was particularly high (76-96%) for macroinvertebrates (blue crab megalops and penaeid shrimp post-larvae) and was also relatively good for mullet (70%) and paralichthyid flounders (93%) at fast screen rotation. However, survival of other fish larvae (drums and goby) was less than 34% at fast screen rotation and even lower (<15%) for the same species at slow screen rotation speed. Survival was relatively poor (<1-3%) for bay anchovy and Atlantic menhaden, regardless of screen rotation velocity. In general, mean survival rates depended upon species, size, and speed of screen rotation.

Fine-mesh screens have the capability of improving survival of fish eggs and larvae at power plant intakes, but survival rates are highly specific to species, life stage or size of the organism, screen design and type, and amount of debris impinged concurrently. Some fish species and life stages are too delicate to survive the impingement and removal

process and most incidental materials impinged (e.g., marine grasses, seaweeds, jellyfish) exacerbate mortality. This makes fine-mesh screens an unlikely solution at MNPS due to existing debris loading problems. A further evaluation of fine-mesh screening coupled with a diversion system is given below in Section 2.4.1.

2.3.3 Rotary Drum Screens

In the United States, rotary drum screens are primarily used at western irrigation and hydroelectric facilities to prevent passage of juvenile salmon (EPRI 1999). Many of these screens were found to be ineffective because of the poor orientation fish demonstrate to the screens, a lack of a suitable bypass or return system, and screen seals that are inadequate to prevent entry into the system. As a consequence, rates of impingement on these screens are high. Angled drum screens appear to work better in diverting fish and have been particularly effective in guiding downstream passage of juvenile salmon at hydroelectric and irrigation facilities in the western United States. However, they have never been applied at a thermal electric power plant (EPRI 1999) and would not increase survival of fish eggs and larvae. Rotary drum screens with fish pumps are discussed in more detail in Section 2.4.2.

2.3.4 Gunderboom

The Gunderboom is a relatively new technology that could be applied at some power plant sites to reduce impingement and entrainment of fish (EPRI 1999). This technology should be considered experimental at this time with questions regarding debris loading and anchoring needed to be resolved (Taft 2000). In information supplied by its manufacturer (Gunderboom® Marine Life Exclusion System™; Gunderboom, Inc., Anchorage, AK), the Gunderboom was described as a treated polypropylene/polyester fabric suspended from flotation billets on the surface and secured to the bottom with anchors or piles. The curtain boom is composed of a fabric matting of minute fibers with an apparent opening size of ≤20 μm. A Gunderboom should be installed at a location such that it is sealed against the bottom and shoreline and should be designed to have a large enough surface area that would allow water to pass through to the intake structure at a low velocity. The material can filter out particulates as small as 0.2 mm, which would include much of the plankton, although the fabric may have to be modified to achieve optimum flow rates at a particular facility. The manufacturer notes that for fish protection, target filtration rates are approximately 3 to 5 $gal{\cdot}min^{-1}{\cdot}ft^2$, having a through-flow velocity of about 0.02 $ft{\cdot}s^{-1}$, although 0.5-mm holes could be punched into the fabric to increase infiltration rate. Flow rates greater than 10 to 12 $gal{\cdot}min^{-1}{\cdot}ft^2$ exceed the optimum performance range of the material, which was designed to be operated and maintained at lower flows. An automated pressurized air system can be installed along with the boom and is used to clean the fabric curtain whenever necessary. A manufacturer's representative claims that two Gunderbooms constructed of the same type of material used for filtration barriers and used for beach protection were deployed in western Long Island Sound (LIS) for several years without a build-up of fouling organisms (McCusker 1999).

To date, the Gunderboom has only been tested at one power plant, the Lovett Generating Station, located on the Hudson River and described in Hutchison (1988). This station currently has three operating units generating a total of 449 MWe (Puder and Veil 1999). Preliminary tests at Lovett Station in 1995 showed a reduction in entrainment after the Gunderboom was employed (LMS 1996b). The initial Gunderboom used at this site was about 400 ft long and nearly 20 ft deep and was designed to filter the entire intake flow of Lovett Unit 3, a 69 MWe unit drawing approximately 42,600 gal·min^{-1} of water at an average velocity of 0.05 ft·s^{-1}. However, within hours of its initial installation, the surface support straps failed and water began passing over the top of the boom. As additional time elapsed, siltation caused further submersion of the barrier and at the end of the study it was estimated that all the water used at the station was spilling over the top of the Gunderboom. Nevertheless, in a comparison of entrainment rates between Units 3 and 4 (intake outside of the Gunderboom), the overall effectiveness of the Gunderboom in reducing entrainment was 82% for this deployment (LMS 1996b). In 1996, a two-layer Gunderboom approximately 800 ft in length was set in place around the intakes of Lovett Units 3-5. Additional flotation and anchoring was used in this deployment and an air purging system was installed between the fabric layers to clean off silt. Similar to the experience the previous year, the boom quickly showed excessive strain from fabric tears and attachment failures and was removed after only 22 h of operation, when the air purging system did not improve flotation (LMS 1997). In 1997, further testing showed that the Gunderboom effectively filtered the flow for Unit 3, but only over a 4.5-day period. The cleaning system worked effectively and the anchoring system maintained the boom in its correct position. However, on the fifth day a tear was noted in the fabric and the deployment was ended. Further experiments in 1998 were made to examine the feasibility of the Gunderboom to decrease entrainment of ichthyoplankton (LMS 1998; ASA 1999). Set again only at Unit 3, the barrier was about 500 ft long, 20-35 ft deep, and, according to a figure prepared by ASA (1999), was deployed in a roughly oval shape extending about 100 ft offshore from the shoreline intake of Unit 3. Additional 0.5-mm perforations were made in the material to enable water passage while maintaining the filtering capacity of the fabric. A pressurized air system was again used to clean the Gunderboom of sediment and algae. Entrainment samples were taken simultaneously at Units 3 and 4 (outside of the barrier). Bay anchovy comprised about two-thirds of the larvae collected; river herrings, striped bass, and naked goby were also relatively abundant. At the beginning of the deployment in June, a significant reduction in entrainment densities was found after the Gunderboom placement. However, by mid-July, the magnitude of the reduction decreased and similar entrainment densities were found at both units. In early August, densities of bay anchovy and naked goby were actually higher at Unit 3 (inside the boom) than at Unit 4 (outside). Thus, the effectiveness of the boom in reducing entrainment was questionable.

Based on an infiltration rate supplied by the manufacturer of 10 gal·min^{-1}·ft^{-2} (with 0.5-mm holes punched into the fabric to increase flow rate), an average depth of 30 ft in Niantic Bay off the MNPS intakes, and a present nominal cooling-water requirement of about 1.6 million gal·min^{-1} at MNPS, the minimum size of a Gunderboom needed to provide necessary cooling-water volume would be about 5,000 feet in length. To achieve this distance, the barrier would have to encompass an area extending from northwest of the plant intakes at Bay Point to southeast of the intakes

at Millstone Point (Fig. 2-1). At lower filtering rates (as for the Gunderboom used at Lovett Station), a barrier approximately 2 miles in length would be necessary, which would enclose a substantially larger area. This is a considerable area that would be closed off to public access and navigation and would likely encounter considerable opposition and permitting difficulties. The large size required for a Gunderboom deployment at MNPS and potential clogging and operational problems make it an unlikely choice at MNPS. With limited success at only one other power plant, a Gunderboom must remain considered as an unproven technology with respect to large marine power plants.

2.3.5 Barrier Nets

Barrier nets have been installed to exclude fish from intakes and decrease impingement. However, according to EPRI (1999), only one station (Bowline Generating Station on the Hudson River) used a mesh small enough to possibly reduce ichthyoplankton entrainment. Described in Hutchison (1988), this two-unit, 1,200 MWe station can withdraw up to 768 thousand gal·min^{-1} of cooling water from a 121-acre embayment located just off the mainstem river. An experimental fine-mesh (3 mm) nylon net was set in a V-shape around the intake structure of the plant during 1993 and 1994 (LMS 1994). Little river current is found in the area of this station and intake velocities were below 0.05 ft·s^{-1}. In 1993, the net sank because it became clogged with fine silt. The net was finally cleaned by divers using high pressure sprays, but in 1994 even this cleaning was not effective as the net became so fouled with algae that two of the support piles snapped and the net had to be removed to land for cleaning (LMS 1996a). During both of these years, too few bay anchovy were present to determine the effectiveness of the net in reducing entrainment. Although a fine-mesh net could possibly have reduced entrainment at this site, barrier nets were considered by the investigators and by Taft (2000) to remain as an experimental fish protection technology and, thus, would be unsuitable for MNPS.

2.3.6 Infiltration Intakes

Infiltration intakes, such as wells or filter beds, require highly specific hydrological and geological conditions to operate correctly. Even though this type of intake would greatly reduce intake effects to aquatic organisms, it has not been used at any power plants because of low flow capacities (EPRI 1999; Taft 2000). Although such technology has been applied to small-scale water intakes, artificial filter beds are generally unreliable because of clogging of the media (USEPA 1976). Little work or applicability of infiltration intakes to power plants was anticipated by EPRI (1999).

2.3.7 Porous Dikes

Porous dikes that allow water but not organisms to pass into an intake were shown to be effective in some laboratory and small-scale field experiments involving juvenile and adult fish. However, in other instances entrainable organisms often either became entrapped in the porous medium used or continued in the water flow to become entrained in the cooling-water flow. Ketschke (1981a) performed field and laboratory studies using a porous gabion dike as a barrier that was composed of 8-inch diameter rocks. He studied swimming orientation and avoidance responses of five larval

marine fishes in a laboratory test flume. The threshold response was the ability of a larvae to detect and swim against a current of 0.1 $ft \cdot s^{-1}$, although the response did not have to result in the avoidance of entrainment. Windowpane were the only larvae that did not exhibit an upstream orientation. Both Atlantic menhaden and sticklebacks showed strong avoidance responses as early stage larvae and had improved swimming ability as they grew older. Winter flounder and northern pipefish drifted passively as early stage larvae and showed little swimming response even when further developed. When older winter flounder larvae were tested, they often oriented to the flume bottom in response to currents. Of note, during tests with juvenile and adult fishes, both mummichog and cunner were strongly attracted to the gabion and took up residence within the rock, although none became entrained.

In field tests at the Brayton Point Station (see Section 2.4.1 below, for a description), a reinforced 21-X 60-X 20-ft concrete and steel dike was constructed. The dike had three cells holding the gabions, two of which were tested for infiltration that used rocks of about 3 and 8 inches in diameter, respectively. Water was drawn through the dike by a pump having a capacity of 46,600 $gal \cdot min^{-1}$. Ichthyoplankton were sampled using pump samplers located both upstream and downstream of the dike. If downstream densities were lower, it was assumed that avoidance, filtration, or cropping had occurred. Significant differences in larval densities were found for bay anchovy and winter flounder. With gabions having 8-inch rock, densities of bay anchovy larvae decreased from upstream to downstream by 94-99% and winter flounder larvae by 23-87%. Except for winter flounder, no larval exclusion data were available for the smaller 3-inch rock gabions. The differences in winter flounder densities inside and outside of the dike became greater as the larval season progressed. The observed density differences for winter flounder larvae were similar among the two rock sizes, except that it did not occur until later in the season for the smaller-sized rock tested. Ketschke (1981b) also reported a hydraulic head loss of 68% of this experimental porous dike over the 17-month period of testing, which he attributed to surface fouling and clogging. Head loss did stabilize, but periodic backflushing was necessary. Void space within the dike decreased approximately 25% after 6 months; about half the fouling or clogging material was silt and organic debris and the other half was comprised of living organisms. Although tested onsite, Anderson et al. (1988) noted that a full-scale porous dike was never used to filter cooling water at the Brayton Point Station as most larval organisms appeared to be consumed or killed during passage, maintenance requirements were uncertain, and a large (1,200-1,500 ft) amount of shoreline property would have been required for its construction. In summary, a porous dike has not been used as a viable intake technology at power plants (EPRI 1999; Taft 2000).

2.3.8 Cylindrical Wedge-Wire Screen Intakes

Wedge-wire screens with small (0.5-1.0 mm) mesh (i.e., slot openings) can be effective in providing protection against the entrainment of ichthyoplankton because they operate with low (ca. 0.05 $ft \cdot s^{-1}$) intake velocities in relation to the water around them, although cross-currents of sufficiently high velocity are necessary to remove organisms and debris away from each screen element (SWEC 1984; EPRI 1999; Taft 2000). Key and Miller (1978) and Hanson et al. (1978) first reported on the potential for this type of screening to reduce fish impingement and entrainment at power plants.

Using scaled-down screens for testing, Hanson (1981) in a laboratory test with yellow perch and striped bass, Browne et al. (1981) in a field marine study, and Otto et al. (1981) in a field freshwater study each indicated that wedge-wire screens may be useful in some instances in reducing ichthyoplankton entrainment. Their results, however, were often dependent upon the species, size of larvae encountered, and time of day.

Exclusion efficiency of cylindrical wedge-wire screens in estuarine waters was investigated at the Chalk Point Steam Electric Station, located on the Patuxent River in Aquasco, MD (Weisberg et al. 1987). Entrainment of larval bay anchovy and naked goby was studied on a barge-mounted intake test facility with wedge-wire screen slot sizes of 1, 2, and 3 mm. No fish smaller than 5 mm were excluded, but exclusion increased as larval size increased. About 80% of large larvae were excluded from entrainment, including 100% of larvae longer than 10 mm when the 1-mm screen was used. The 2- and 3-mm screens were not as effective, but slot width was determined to be less important than fish size. Wedge-wire screens have been successfully applied to reduce larval entrainment at closed-cycle power plants with minimal water withdrawn (e.g., Ehrler and Raifsnider 2000). However, only two relatively large power plants in the United States presently use wedge-wire screening in their intakes (EPRI 1999; Taft 2000). In preliminary studies, Zeitoun et al. (1981) reported that ambient larval fish densities were about eleven times greater in waters near a Lake Michigan power plant intake equipped with wedge-wire screens than in entrainment samples at the station. They estimated that 90% of the larvae (mostly rainbow smelt, alewife, and yellow perch) avoided entrainment through the screens tested (2.0 and 9.5-mm slot openings), mainly by behavioral mechanisms, and, to a lesser extent, by screen exclusion. The flow rate during the test was 500 $gal \cdot min^{-1}$ at an intake velocity of 0.5 $ft \cdot s^{-1}$. This experimental work was done at the J.H. Campbell Plant, at which the 770 MWe Unit 3 has a summer peak cooling-water demand of 340,800 $gal \cdot min^{-1}$. Twenty-eight cylindrical wedge-wire screens (9.5-mm slot openings) arrayed in a manifold were ultimately installed at an offshore location in southeastern Lake Michigan where water was drawn for this unit. Because the larger slot size of the two used in the experiments was chosen had less ability to exclude ichthyoplankton, the realized reduction in entrainment observed at Unit 3 relative to Campbell Units 1 and 2, both of which draw water from a smaller, productive lake connected to Lake Michigan, was believed to have been mostly due to the deep offshore location of the intake (EPRI 1999). The only operational problem to date has been one shutdown due to anchor ice. However, debris loading in the deeper waters of Lake Michigan was noted to be inconsequential and not a problem for this particular wedge-wire screen system to handle.

The second operating wedge-wire screen application at a relatively large power plant intake is found at the Eddystone Generating Station, located on the tidal Delaware River near Philadelphia, PA. This station, which draws a combined flow of about 440,685 $gal \cdot min^{-1}$, had impinged over 3 million fish during a 20-month period. To meet resource agency concerns, the owners chose to replace the conventional traveling screens with wedge-wire screens (6.4-mm slot) at the intakes of Units 1 and 2 (EPRI 1999). An air-burst cleaning system was installed to keep the sixteen cylindrical screens

free of debris and appears to have worked effectively. EPRI (1999) noted that the station has apparently eliminated its impingement problem, but no mention was given of any entrainment studies, either before or after this retrofit.

McGroddy et al. (1981a) concluded that fine-mesh cylindrical wedge-wire screens may not be feasible for offshore marine installations because of excessive fouling and debris (e.g., macroalgae, detritus) loading. Their study results indicated that this type of screen could become clogged daily or even more frequently during high ambient debris concentrations and that this could compromise plant operation and safety. Also, within a few weeks biofouling could reduce water flow enough to degrade effective operation. Frequent cleaning and the need for reliable systems to accomplish this in marine waters makes the retrofit of fine-mesh wedge-wire screens an inadequate option for once-through cooling-water systems. In contrast, Browne et al. (1981) concluded that wedge-wire screens of 1- and 2-mm slot width were a feasible alternative in an estuarine environment when used with an air backwash system and manufactured with screening material more resistant to biofouling. Their work showed that entrainment densities of some larval fishes and zooplankton species were lower than in ambient waters. Weisberg et al. (1986) also suggested back-flushing the screens with air and using toxic coatings to reduce or control biofouling in marine applications. Nonetheless, no wedge-wire screens have been installed at any large marine or estuarine power plants since these studies were concluded and any consideration of wedge-wire screen use should include small-scale prototype studies to determine effectiveness in reducing entrainment mortality and identify problems with clogging and fouling (Taft 2000). A wedge-wire screen intake is therefore not a viable option for a large coastal marine power plant such as MNPS.

2.3.9 Sills and Curtain Walls

Intake skimmer walls at Marshall Steam Station (four units, 1,900 MWe capacity) and Oconee Nuclear Station (three units, 2,580 MWe), both located on freshwater reservoirs in the Piedmont region of North Carolina, have been successfully used to reduce ichthyoplankton entrainment at these two locations (Olmsted and Adair 1981). However, the skimmer walls at each of the stations extend from the surface to depths of approximately 60 to 65 ft, allowing only deep, bottom waters of the source water bodies, which are largely devoid of fish larvae, to enter intake coves. It is unlikely that bottom sills, curtain or skimmer walls could effectively reduce the entrainment of ichthyoplankton at MNPS. Water depths of only about 25 ft are present in front of the MNPS intakes and with a tidally and wind-driven, well-mixed, non-stratified system in this area, deep skimmer walls are not a viable option to reduce entrainment. Bottom sills would not be appropriate for reducing entrainment either. For example, although there is a tendency for older winter larvae to be found closer to the bottom, particularly during daylight hours, they remain essentially planktonic. Much of the entrainment of late stage winter flounder larvae occurs at night, when they tend to disperse throughout the water column. As long as water volume drawn into the station is not reduced, ichthyoplankton would be entrained in proportion to their relative densities in the water. Structures such as sills placed in the water near the intake would also likely act as an attractant to older fish, including tautog and cunner, thereby increasing their availability to

impingement and any eggs spawned in the vicinity would become entrained. It is unlikely that a sill or curtain wall would decrease ichthyoplankton entrainment mortality at MNPS.

2.4 DIVERSION SYSTEMS

2.4.1 Angled Screens

Diversion systems in general include various systems of pivoting, fixed, or traveling screens, louvers, and other bypasses coupled with conventional or angled bar racks (EPRI 1999). Fine-mesh angled screens with a diversion system have been proposed as a way of reducing power plant impact by diverting ichthyoplankton, as well as juvenile and adult fish, through a bypass pump so that a majority of specimens are neither entrained nor impinged. This type of system should reduce overall mortality because organisms have reduced contact with screens as opposed to conventional traveling screens simply fitted with fine mesh. The latter design reduces entrainment, but increases impingement of small organisms and has more typical screenwash removal systems (e.g., conventional spraywash) than the specialized pumps or other removal devices of a diversion system.

Experiments were conducted by McGroddy et al. (1981b) on five Pacific marine larval fishes to determine if they could be guided into a bypass collection zone using angled louvers, both with and without fine-mesh overlays. Guidance increased with increasing larval length and use of fine-mesh screening resulted in more smaller larvae diverted. With fine-mesh screens, removal efficiencies for three species ranged from 64 to 95%, but these larvae were over 20 mm in length. Survival estimates were confounded by high control mortality of the more fragile species and small (<20 mm) larvae generally had low diversion and high mortality. They concluded that smaller and more sensitive species show a lower capacity for survival in an angled fine-mesh diversion system.

In laboratory evaluations during 1978-80 (ARL and SWEC 1981; Taft et al. 1981a), the effectiveness of angled fine-mesh diversion systems in returning larval fish was examined. The work included experiments on alewife, striped bass, and winter flounder. Mesh (both metallic and synthetic organic manufacture) sizes of 1.5 and 2.5 mm were used, but smaller (0.355 and 0.5 mm) mesh screens were needed for some tests because of the small size of winter flounder larvae; nearly all of these fish passed through 1.0-mm mesh screens. In 1978, tests were conducted at velocities ranging between 0.5 and 3 $ft \cdot s^{-1}$ and at durations of 2, 4, 8, and 16 min. Total system efficiency (TSE) in diverting striped bass larvae (fish of approximately 8 to 20 mm in length were tested) increased with increasing larval length, and was greater for the 1.5-mm mesh and the synthetic mesh. TSE exceeded 80% for the most optimum test conditions. During 1979, only synthetic meshes were used and larger (4, 5, and 9.5 mm) mesh sizes were added. Striped bass of about 10 to 41 mm were used. With a 1-mm mesh, 50% TSE was achieved at a larval striped bass length of 8.2 mm and 100% at 16.1 mm; TSE was observed to increase as did length, which was attributed to increased swimming ability. During 1980, alewife and winter flounder were examined. Neither the yolk-sac (mean length of 5.5 mm) nor post-yolk-sac (9.5 mm)

larval alewife showed any ability to guide along the 1.0-mm mesh angled screen at a test velocity of 0.5 $ft \cdot s^{-1}$. Older larvae (11-15 mm), however, had relatively good (60-84%) diversion rates, but in all tests the 96-h delayed mortalities were high, resulting in low (<27%) TSE. Because most of these larvae spent various times impinged on the fine-mesh screens prior to diversion and control mortalities were low, Taft et al. (1981a) believed that impingement stress contributed to the high mortality. No successful diversion of larval winter flounder was observed in four tests. The authors concluded that small (3.6-4.4 mm, which include the sizes of larvae in Stages 1 and 2 of development) winter flounder larvae were not effectively removed by the spraywash system evaluated. Larger larvae (mean of 6.1 mm, approximate size of Stage 3 larvae) were removed to a greater extent, but suffered high latent mortality. However, this finding was confounded by high control mortality. Air exposure (to simulate a screenwash) caused little (0-8%) mortality for larvae in sizes corresponding to Stages 1 and 3, but mortality was 32-64% for Stage 2-sized larvae exposed to air for 1-5 min. Winter flounder larvae were also particularly difficult to wash out of the test screen buckets because the fish were so small. A tentative conclusion of ARL and SWEC (1981) was that winter flounder larvae would not be successfully diverted by a fine-mesh angled screen.

Several studies at Hudson River sites evaluated the diversion efficiency and survival of larval fish at a full-scale angled screen demonstration facility located on the river. Matousek et al. (1988) found the angled screen system efficiency for ichthyoplankton removal was about 16% and was inversely related to angled screen approach velocity and directly related to the size of the larvae. Overall, the efficiency in removing fish larvae was only 1.7%. They concluded that the 1-mm fine-mesh angled screen investigated was ineffective in mitigating ichthyoplankton entrainment mortality. LMS (1985) also reported on a 3-year study of a fine-mesh angled screen diversion system at a testing facility at the Danskammer Point Generating Station, located on the Hudson River near Newburgh, NY. This test facility was described in detail by Holsapple et al. (1981). The full-size screen was used with 1-mm mesh screen panels to examine the impingement and removal of ichthyoplankton. The species examined were larvae of river herrings, white perch, striped bass, and Atlantic tomcod; larvae of all but the latter are generally larger than those of the winter flounder. Although survival of Atlantic tomcod larvae was good (ca. 85%), diversion efficiency was very low. Calculated total survival of Atlantic tomcod larvae after subtracting for larvae not returned by the fish removal system was 3.9% for yolk-sac larvae and 5.3% for post-yolk-sac larvae.

In a study most pertinent to the MNPS entrainment feasibility evaluation, angled fine-mesh screens with fish diversion pumps were extensively evaluated at the Brayton Point Generating Station. This station, located at the head of Mount Hope Bay (MA-RI) in Somerset, MA on a peninsula between the Lee and Taunton Rivers, has four fossil-fueled units with a total net generating capacity of 1,610 MWe, making it the second largest electrical generating station in New England after MNPS. The station and biological studies conducted at the intakes were described in detail by LMS (1987), Anderson et al. (1988), Davis et al. (1988), and PG&E Generating and MRI (1999). Unit 4, a 460 MWe unit, has an intake with six traveling screens set in a canal at an angle of 25° to the intake flow of approximately 260,000

gal·min^{-1}. The screens were originally fitted with panels of 1.0-mm fine-mesh screen. Organisms that passed along the front of the traveling screens could enter a fish bypass by moving through a 0.5 ft wide by 17 ft high slot located at the apex of each screenwell. These organisms were returned to the Lee River through a Hidrostal screw impeller pump and an 18-inch diameter pipe. Other organisms that encountered the screens were either entrained through the cooling-water system or impinged on the fine-mesh screens and periodically washed off into a fish trough for return to the river.

A 1984-86 study on the effectiveness of the Brayton Point angled fine-mesh screen system in reducing entrainment mortality, 52,847 larval winter flounder were examined. Of these, about 20% of the larvae were diverted through the fish diversion pumps, 28% were impinged on the fine-mesh screens, and 52% were entrained. Some 11,426 specimens were examined for survival, which was determined upon initial collection and after 72 h. Survival estimates were adjusted for control (collection and handling) mortality. For larvae entering the fish diversion system, 44% were alive initially. Of these, 57% were alive after 72 h, for a total bypass system survival of about 25%. Only 11% of the larvae were alive after impingement on the fine-mesh traveling screens and only about half of these survived after 72 h, for a total impingement survival of 5.5%. Entrained winter flounder larvae were not examined for survival, but other species had an overall survival of approximately 20%. TSE in this study was defined as the probability that a larva would be alive after 72 h, whether it had been entrained, impinged on the fine-mesh screens and returned, or entered the fish diversion pumps. For winter flounder, the TSE was 6.5%. Thus, based on operating experience at Brayton Point, fine-mesh screens did not substantially alleviate entrainment mortality of larval winter flounder. Further, TSE for other larval fishes, including herrings, bay anchovy, seaboard goby, and tautog, was even less (<0.6%) than for winter flounder. At nearly 19%, only northern pipefish showed some minor capability of survival with this system. LMS (1987) concluded that when the angled screen system was equipped with the 1.0-mm fine-mesh panels, it was not effective at mitigating larval entrainment. The station subsequently removed the fine-mesh screen panels and replaced them with conventional 0.375-inch mesh panels (M. Anderson, New England Power Service Company, Westborough, MA, pers. comm.).

Based on the experience at Brayton Point Station, an angled fine-mesh screen with a diversion system would not result in increased survival of most fish eggs and larvae entering the MNPS intake structures. Thus, it is not an appropriate technology for implementation.

2.4.2 Rotary Drum Screens With Fish Pump

No North American applications of rotary drum screens with fish pumps to remove impinged organisms were identified during a comprehensive review of intake technologies performed by EPRI (1999). Rotary drum screens have been used in France, including installation at the intakes of large (ca. 1,300 MWe) nuclear power plants. According to information presented by the French screen manufacturer, E. Beaudrey & Co. at a 1985 conference sponsored by the New York State Public Service Commission, the standard drum screen mesh used in France is 3.2 mm, but screens as

small as 0.4 to 1 mm can be found at suitable sites (e.g., areas with low debris loading). With tight seals and efficient cleaning sprays, these particular rotary drum screens are easily cleaned and keep most materials out of the plant cooling water system. The fine-mesh screens can be used with a fish pump to remove impinged organisms of most sizes. E. Beaudrey representatives indicated that preliminary work in France showed fish eggs and larvae and macrozooplankton could be removed from the rotary drum screens with good survival. However, no other supporting data were found to verify the claims of the manufacturer's representatives. This technology remains unproven in North America and cannot be advocated for use at MNPS.

2.5 FLOW REDUCTION CONCEPTS

2.5.1 Reduced Pump Flow

Reduction in cooling-water flow should reduce entrainment rates in proportion to the flow reduction achieved at an existing intake. Reduced flow can be attained by several engineering alternatives, such as by operating fewer circulating water pumps or installing variable speed pumps. Flow reduction has been used to reduce entrainment and impingement at several estuarine power plant sites. As noted above under Fine-mesh Screens (Section 2.3.2), flow reduction was used in concert with an intake canal barrier and fine-mesh traveling screens to lessen impingement and entrainment losses at the Brunswick Steam Electric Plant (BSEP) in North Carolina. The flow reduction scheme, based on seasonal trends in water temperature, was described in Hogarth and Nichols (1981) as operational modifications which reduced cooling water by 45% from December 1 through April 15, 17% during both April 16-30 and November 1-30, and 24% from May 1 through October 31. Total station cooling-water use was reduced about 31% on an annual basis and entrainment was expected to be reduced commensurately. This was accomplished by reducing the number of circulating water pumps in use and throttling pumps to reduce flow rate. Based on the scheduled flow reductions and the seasonality of entrained larvae, flow minimization was expected to reduce entrainment losses of seven important taxa by 24 to 45% (34% overall), regardless of other physical changes made at the station (i.e., fine-mesh screen installation) that were also designed to reduce mortalities. Hogarth and Nichols (1981) noted that the proposed flow reductions at BSEP were expected to result in some energy loss and to impact station generating capacity, efficiency, and reliability, and, particularly, the ability of the plant to deal with aberrations in the circulating water system, such as what would occur if one of the circulating water pumps tripped or failed. Similarly, effects of flow reduction methods at MNPS in these regards (i.e., operations and engineering) were evaluated in Part I of this report.

Flow reduction was one of the methodologies used to settle the litigation over open-cycle cooling at power plants on the Hudson River (Barnthouse et al. 1988). For this settlement, the river was viewed as an ecological system affected by the operation of many power plants in concert. In lieu of building cooling towers at the Indian Point, Bowline Point, and Roseton generating stations (each described by Hutchison 1988), the utilities operating these facilities agreed to operational changes designed to reduce impingement and entrainment of five key species: striped bass, white perch,

Atlantic tomcod, American shad, and bay anchovy. During times of the year when river water temperatures were low, less cooling water could be pumped and fewer organisms entrained. Although the resultant ΔT (i.e., difference between intake and discharge temperatures) at the station discharges would increase, this was not considered to be a problem during most of the year. However, in summer, when increased water temperatures would have resulted in greater entrainment mortality, maintenance outages at some of the plants would be scheduled to coincide with expected peak abundance of key species in the vicinity of each plant. The large amounts of data and assessment models amassed during Hudson River power plant ecological studies were used to estimate the effectiveness of modified operating schedules. A mathematical model described in Englert et al. (1988) was developed and included the spatiotemporal distribution of ichthyoplankton to evaluate the effectiveness of alternative schedules in meeting the terms of the settlement agreement. The model enabled desired entrainment reductions to be achieved at acceptable costs to the utilities and in providing electric power reliability to customers. By properly scheduling reductions in cooling-water use at the three plants, expected entrainment could be greatly reduced. All three stations reduced cooling-water flow during winter and spring, but not in summer, when thermally-related mortalities of entrained organisms would have more than offset reductions in entrainment numbers. To meet the reduced flow objective, the two operating Indian Point Nuclear Power Plant units installed variable speed circulating water pumps. Annual maintenance outages at the Roseton and Bowline Point facilities (both having two fossil-fueled units) were scheduled to occur during peak entrainment seasons at each station. Both of these stations were to have 30 unit-days of outages scheduled each year between May 15 and June 30. An additional 31 unit-days of outages were to be scheduled at Bowline Point during July. As a nuclear-fueled facility, Indian Point is refueled at approximately 16 to 18-month intervals and routine maintenance is usually completed during this period. This cycle made scheduling shutdowns during peak entrainment season difficult, but the settlement agreement specified an average of 42 unit-days of outages at Indian Point Units 2 and 3 to occur between May 10 and August 10 of each year. Curiously, the Indian Point summer outages contributed relatively little to overall entrainment mitigation, but did reflect the history of both scheduled and non-scheduled operations at this station (Barnthouse et al. 1988). Other schemes to increase the effectiveness of Indian Point outages were developed (Englert et al. 1988), but were rejected because they were too costly and imposed system reliability problems. The utilities involved chose to trade reduced summer operation of the fossil-fueled stations in order to operate Indian Point most economically. However, to maintain electrical system reliability and for unanticipated contingencies, especially during the June-July period of peak demand, a system of outage credits was established among these plants. This agreement permitted deviations from the specified outage schedules without changing the level of desired reductions in entrainment and enabled the Bowline Point or Roseton units to operate should a shutdown occur at an Indian Point unit that would have eventually exceeded the outage requirements.

Reductions in conditional entrainment mortality rates at the Hudson River plants resulting from the above operational changes were estimated as 15% for bay anchovy, 24% for American shad, 25% for white perch, 27% for striped bass, and 43% for Atlantic tomcod (Barnthouse et al. 1988). For striped bass and white perch, about half the savings came

from cooling-water flow reductions during winter and spring and half from fossil plant summer outages. All savings of Atlantic tomcod came from flow reductions, whereas most reductions in bay anchovy and American shad came from reduced summer operation. Costs to the utilities for implementing the entrainment mitigation settlement, including capital and one-time costs, carrying costs, inflation, and purchases of replacement power during outages, were $104 million (all costs given here are in 1980 dollars). The total for the entire settlement agreement, which also included impingement reduction schemes, a striped bass hatchery, and funding of further monitoring and research, was $180 million, with an associated annual cost to customers of about $17.7 million levelized over a 20-year recovery period. In contrast, estimated costs of cooling towers for all six of the generating units were estimated at $1.8 billion, with annual costs to customers of $175.3 million over 20 years. The 15 to 43% reduction in entrainment mortality by flow reduction and scheduling of forced outages was therefore achieved at 10% of the cost of cooling towers.

The Hudson River settlement involved a multi-plant scheme to reduce effects of entrainment and impingement to several key species. The percent reductions in conditional entrainment mortality rates for most of these species were 24-27%. Note that cooling-water flow at MNPS has already been reduced by 23% by the retirement of Unit 1.
A number of options were presented in Part I that could be implemented to reduce cooling-water use at MNPS Units 2 and 3. Although lower ichthyoplankton entrainment would occur under reduced pump flow, less flow would also result in an increased ΔT and this could increase mortality of entrained organisms. In conjunction with reduced flow, a higher ΔT would also result in an altered thermal plume distribution. The MNPS three-unit plume was described in detail in NUSCO (1988b) and plots of selected isotherms at four tidal stages are shown in Figure 2-2. With Unit 1 retired, MNPS under two-unit operation now has a slightly lower ΔT (about 20°F) and the geographic extent of the thermal plume at full two-unit operation is smaller. Environmental impacts associated with the MNPS thermal plume to date have been mostly limited to near-field effects to the rocky shore community adjacent to the MNPS Quarry discharge, where approximately 165 yards of rocky shoreline has been impacted (NUSCO 2000d). No changes have been observed in the eelgrass beds of Jordan Cove that could be attributed to the MNPS thermal plume (NUSCO 2000e). Local benthic infaunal communities have been disturbed by activities associated with MNPS operation, but they appear to be from dredging and scour rather than the thermal plume (NUSCO 2000f). Also, no evidence has been found for any measurable thermal impacts to fish or the American lobster (NUSCO 2000a, 2000b, 2000c).

The ecological impacts associated with alternatives to the present MNPS cooling water systems depend on the particular alternative considered. However, general conclusions may be drawn from past experience and extensive knowledge of the local marine communities. Since any proposed technology rejecting heat to the atmosphere (e.g., cooling towers) would decrease both cooling water flow and ΔT, impacts to the marine environment could only be decreased. Therefore, the discussion below is restricted to alternatives that reduce cooling water flow at the expense of increasing ΔT. From present calculated ΔT values of 18.9°F for a combination of four circulating water pumps at Unit 2 and six pumps at Unit 3, flow reduction alternatives proposed for MNPS would result in a ΔT of 20.5°F for three

pumps at Unit 2 and six at Unit 3, a ΔT of 22.1°F for three pumps at Unit 2 and five pumps at Unit 3, and a ΔT of 24.5°F for three pumps at Unit 2 and four pumps at Unit 3.

The direction and characteristics of a thermal plume discharged into LIS vary with the time of year, velocity and temperature of the discharge, ambient tidal currents, wind, and many other environmental factors. A description of the two-unit MNPS thermal plume is given in Appendix A to this chapter. However, it is obvious that reducing cooling-water flow using the present configuration of two fixed-sized openings from the Millstone Quarry would produce a slower discharge plume having lower momentum to carry it offshore into Twotree Island Channel. This would reduce any potential impact to the biota of Jordan Cove (e.g., eelgrass, shore-zone fish), but may increase impact in the area adjacent to the discharge, specifically the rocky shore between the Quarry cuts and the southern tip of Fox Island, located just to the east of the cuts (Fig. 2-3).

Changes to the rocky shore community observed in the past (e.g., following the second quarry cut opening in 1983; start-up of Unit 3 in 1986; station shutdown in 1996 and restarts of Units 3 and 2 in 1998 and 1999, respectively) were documented in NUSCO (2000d) and previous annual reports. Many component species of local undisturbed communities have arctic-boreal distributions, which approach the southern limit of their geographical ranges in LIS. Therefore, the thermal incursion resulting from a lower flow, higher ΔT discharge when added to maximum ambient water temperatures would likely exceed the upper physiological temperature tolerance limit for *Ascophyllum nodosum, Fucus vesiculosus, Chondrus crispus, Mytilus edulis, Semibalanus balanoides, Littorina littorea,* and many other common intertidal species. The thermal plume should produce indirect effects on other species as well, such as changes to growth rate, metabolic activity, reproduction, and season of occurrence.

Although similar changes were noted at Fox Island in the past, following the initial start-up of Unit 3, water temperatures, even though elevated above ambient levels, were consistent enough to permit development of a relatively stable community (NUSCO 1987a). Warm water-tolerant macroalgae were present, such as perennial, habitat-forming species *Codium fragile, Sargassum filipendula, Gracilaria tikvahiae,* and *Agardhiella subulata.* Under further altered conditions that would likely result from changing water flow and ΔT, the present complex community would likely exhibit notable changes. Species such as barnacles, mussels and *Fucus* could settle and grow in the spring, but would be eliminated by high water temperatures in summer. The resulting community would be dominated by ephemeral, tolerant species, such as *Polysiphonia, Enteromorpha,* and diatoms. However, the small geographic extent of the affected region near the MNPS Quarry cut discharges (ca. 165 yards of shoreline) would result in minimal environmental impact on local sessile communities from the MNPS thermal plume.

As found in continuing monitoring studies, eelgrass beds in Jordan Cove and resident fishes (in particular, Atlantic and inland silversides) have not been affected by the former three-unit or present two-unit thermal discharge of

MNPS. Eelgrass beds in the cove have had fluctuating shoot densities and biomass over the past 15 years, but populations have remained healthy (NUSCO 2000e). Temperature monitoring showed that most variability in water temperature was a result of natural solar warming and hydrodynamic conditions within the cove. Further, no relation was found between MNPS discharge flows and thermal output and the eelgrass population fluctuations observed at two Jordan Cove study sites. Therefore, a reduced two-unit plume is not expected to have any effect on eelgrass. The predicted and measured increase in temperature of approximately 1.5°F at the Jordan Cove seine station, where silversides are collected, has not resulted in measurable impacts to these fishes (NUSCO 2000b). Again, observed elevated temperatures appeared to be more directly related to solar heating of the shallow sand flats favored by these species than as a result of MNPS operation. An altered thermal plume with smaller volume is neither likely to reach the shallow beaches favored by these fishes nor appreciably affect their distribution, growth, or reproduction.

The quantitative effect of flow reductions by various means on the species selected for evaluation in this report is given in Chapter 4 of Part II. Increases in fish number or biomass are then compared to the expense of implementing technologically feasible options, which is done in Part III, to enable a consideration of both the costs and benefits of this methodology in reducing entrainment.

2.5.2 Re-circulation Concepts

Similar to reduced circulating water pump flows, smaller volumes of intake cooling water flow can be achieved by re-circulating discharge water. Again, entrainment would be reduced in proportion to intake flow reductions, which for this evaluation focuses on the re-circulation of approximately 25% of the flow. Re-circulation can be achieved by several engineering alternatives, such as a tempering line from one of the MNPS discharge tunnels or by a direct line from the MNPS Quarry (see Part I). As with reduced pump flows, re-circulation would result in an increased ΔT from the station and an altered thermal plume, the expected effects of which were evaluated in the previous section.

A re-circulation flow concept was instituted at Brayton Point Station, which was described above in Section 2.3.2 (Fine-mesh Screens). This plant modified its operation by re-circulating cooling water from Units 1, 2, and 3 (combined 1,125 MWe; 618,500 gal·min^{-1}) for use at Unit 4 (475 MWe; 260,000 gal·min^{-1}), a method referred to as "piggyback" mode (PG&E Generating and MRI 1999). Originally designed with an appropriately-sized condenser for closed-cycle cooling, Unit 4 commenced operation in 1974. However, the saltwater spray modules used for cooling proved to pose problems, including short-circuiting transmission lines and creating a salt-spray plume that was carried beyond the plant boundary (Anderson et al. 1988). Fresh water was purchased to provide safer and more environmentally benign cooling, but the water contract was terminated in 1981 because of an increasing need for potable water by the municipal supplier. The first piggyback operation then began and a flow of about 259,500 gal·min^{-1} of cooling water discharged from Units 1-3 was pumped through the Unit 4 condenser and then back into the Units 1-3 discharge canal. However, this mode of operation constrained plant operation because of NPDES Permit

limits for discharge temperature, so other solutions (see sections on Angled Screens, 2.4.1, and Porous Dikes, 2.3.7, above) were then advocated to reduce entrainment, enabling Unit 4 to resume once-through cooling in 1984. The inadequacies of a porous dike, the failure of the angled fine-mesh screen system to reduce entrainment mortality, and concerns over thermal loading to Mount Hope Bay led to renewed interest in the piggyback mode of operation. Operation of the station was subsequently modified under several Memoranda of Agreement (MOA) among the owner and various regulatory agencies, which limit water flow for entrainment reduction, total heat load into Mount Hope Bay, and ΔT during 8 months (October-May) of the year (PG&E Generating and MRI 1999). Under once-through cooling, the station ΔT is 22°F, but under piggyback operation the upper limit allowed is 30°F; total thermal loading is about the same as once-through operation because of reduced flow rate. A piggyback demonstration was made in March 1993 and Unit 4 operated in this mode during early to late February through the end of April in both 1994 and 1996 and through May of 1997 (PG&E Generating and MRI 1999). Because of an outage at the relatively large Unit 3 (642 MWe) from mid-February through April of 1995 and during the first 2 weeks of April in 1997, Unit 4 used once-through cooling during those periods, but plant operation was considered to be equivalent to piggyback mode in terms of station flow and entrainment impact. Under the second MOA, beginning in the fall of 1997, piggyback operation of Unit 4 was to run from October through May and did so in 1997-98. Based on nominal flow rates, the use of the piggyback mode of operation reduced overall station flow and entrainment by about 29%.

2.5.3 Natural and Mechanical Draft Cooling Towers

Full- and two-thirds-size hyperbolic natural draft cooling towers and mechanical draft cooling waters were evaluated for MNPS. Their use would lessen many environmental impacts associated with the present intake structures because of reduced cooling-water flow, but there are other environmental effects associated with cooling tower use and this technology is very costly. For a full-sized cooling tower at either unit, condenser cooling-water use would decrease by approximately 95% at that unit. For a two-thirds-size tower, the engineering scope for which was developed for only Unit 3 (see Part I), four of the six circulating water pumps would be served by the tower with flow reduced proportionately. Any unit with a cooling tower would maintain service water flow, which would continue to be withdrawn from the intake structure. Total entrainment at the two MNPS units would be reduced in proportion to flow reductions, the calculations for which include the use of nominal flow rates at each unit and do not take into consideration the retirement of Unit 1: 32% for the full-size Unit 2 tower, 39% for the two-thirds-size Unit 3 tower, 59% for the full-size Unit 3 tower, and 91-92% for full-sized natural and mechanical draft towers for both units. Smaller intake volumes in comparison to once-through cooling should also considerably reduce impingement.

A blowdown of approximately 24-36,000 gal·min^{-1} containing salt concentrations about 1.5 times that of natural seawater would be discharged into the Millstone Quarry by a full-sized natural draft cooling tower for Unit 3. This blowdown discharge, described in Part I of this report, would empty into the Quarry at the present discharge area. However, the blowdown may require a waste treatment facility as a new point source discharge. Similarly, chemicals

would likely be required to control biofouling and scaling, and perhaps pathogenic organisms (see below). The cost of a treatment facility was not included with other price estimates for the full-size and the two-thirds-size cooling tower alternatives that were presented and, if required, would represent an additional expense. The small volume of a waste treatment facility should be rapidly diluted by the discharge of once-through cooling water from the other unit in operation (if not shut down) before entering LIS. This should not result in any adverse environmental effects. Because of the reduction in cooling-water flow, the MNPS thermal discharge would be entirely from the unit without a tower, a ΔT from Unit 2 operation of approximately 23°F and from Unit 3 of 17°F. Also due to the reduced volume, however, is that the area of LIS subjected to thermal addition should decrease and no further thermal impacts would be expected.

Increased frequency of fogging and icing may result from a cooling tower vapor plume, depending upon ambient meteorological conditions (temperature, humidity, and wind). Ground level fog rarely occurs because of the height of a natural draft cooling tower and the initially high temperature and exit velocity of the plume. An analysis presented in NUSCO (undated) showed that a plume from a natural draft cooling tower at MNPS would not hamper air, ground, or water transportation because its range would be limited. Some increased icing was indicated in winter, but its effects would be local and not severe. Although drift eliminators have reduced the production of larger airborne water droplets, they do not affect the production and drift of very small (≤10 μm) aerosols, which can include various pathogenic microbes (Adams and Lewis 1978). All types of cooling towers have been found to harbor Legionnaires' Disease bacteria (LDB; Tyndall 1982). Although LDB can be controlled by some chemical treatments and biocides, including chlorine, the effective concentrations necessary may not meet present discharge standards. Being much lower in height, mechanical draft cooling towers may present increased risks of fogging, icing, and aerosol drift. These potential problems should be evaluated in depth before such a tower is fully designed and constructed.

The construction of any cooling tower would affect land that is now undeveloped at the site and designated for use as a wildlife refuge. This land use would be even greater if two full-sized natural or mechanical draft towers were to be constructed, which would require considerable space. Along with the clearing of nearly all vegetation from this mostly wooded area, a long-occupied osprey nesting platform would be disturbed. The Millstone Nature Trail, a public recreational use area, would also be disrupted. Native wildlife throughout this area would necessarily be displaced through loss of habitat. Two mechanical draft towers, in particular, would require so much land area that they would encroach upon the site boundary. The potential effects of salts or other particulates discharged from a natural draft cooling tower were discussed in NUSCO (undated). In the original analysis, salt deposition rates much greater than found under natural conditions were predicted. A continuous daily deposition of salts could harm or eliminate local vegetation by direct contact or soil contamination, even though coastal vegetative forms, in general, are tolerant of increased concentrations of salts. Wildlife habitat would therefore be altered. Salt deposition could also lead to increased corrosion and necessary maintenance for exposed metal structures that would be affected (e.g., the nearby switchyard), although drift elimination technology can largely reduce salt drift as a potential significant environmental

impact. However, any salt drift from a mechanical draft tower would likely have consequences to vegetation and nearby structures as this type of tower discharges a vapor plume much lower to the ground than a natural draft tower.

As with other tall structures, cooling towers can cause mortalities of migrating birds through collisions, particularly at night or during other periods of low visibility (e.g., fog, rain) or under conditions of low cloud cover (Jaroslow 1979). In addition, birds may be attracted or orient to lights that would likely be required to mark the structure. Continuous illumination of tall structures at night attracts and disorients birds and many eventually collide with it (Jaroslow 1979). Although not as hazardous to birds as tall television broadcasting towers, power plant cooling towers have been found to cause bird mortalities. An 8-year study of avian mortalities was conducted at the Davis-Besse Nuclear Power Plant, located near Port Clinton, OH on the shore of Lake Erie and with a 495-foot high, 410-foot wide (base) natural draft cooling tower (Ryback et al. 1973; Temme and Jackson 1981). A total of 1,561 bird carcasses were collected at this station, with about 79% of them having collided with the cooling tower (Temme and Jackson 1981). Most were of nocturnally migrating songbirds, such as warblers, vireos, and kinglets, and most mortalities were associated with the spring and fall migration period. Incidents decreased after construction lights were removed from the tower and it became relatively dark and as other site buildings became more strongly illuminated. Because many passerine birds migrate at night and follow the coast, cooling towers sited along shorelines may be particularly hazardous to these birds unless proper lighting controls are undertaken. This could include the manipulation of lighting regimes (Ryback et al. 1973) or installation of the proper warning lights and ground illumination (Temme and Jackson 1981).

Other impacts associated with cooling towers include aesthetics and noise. The size (e.g., 535 ft tall, 450 ft in diameter at its base for Unit 3) of a full-size natural draft cooling tower is significant impact in itself. A tower would be a dominating visual intrusion on the coastal landscape near Millstone Point (Fig. 2-4). Natural draft cooling towers and their vapor plumes can be visible for many miles. An estimate of visibility for a similarly sized natural draft cooling tower proposed for the Salem (New Jersey) Nuclear Generating Station was 20 miles (PSE&G 1984). A tower would be highly visible in local residential areas, from nearby transportation corridors, and from LIS. In addition, noise from the cascading water within the tower may exceed prevailing standards in nearby residential areas and should be evaluated fully before a cooling tower is considered for MNPS. Although various sound attenuation methodologies are available, they may only achieve modest results unless significant costs are incurred (Mirsky 1995). The noise problem with a mechanical draft tower would be even greater and cannot be understated as the fans would operate continuously. These aesthetic impacts are exacerbated as the proposed locations for cooling towers at MNPS are near site boundaries and nearby residences. Receiving state and local approvals for the construction of such structures on the LIS shoreline would likely be problematic for many of the reasons given above.

The considerable technical and engineering difficulties in backfitting a large structure such as a natural or mechanical draft cooling tower to a MNPS unit were detailed in Part I of this report. Unless further detailed engineering studies are

completed, it is not known for certain if a cooling tower is even a viable alternative at MNPS. The considerable cost of these structures must also be considered in light of any potential benefits from reduced cooling-water use.

2.5.4 Dry Cooling Towers

Dry cooling towers would almost entirely eliminate the need for cooling water and any effects from its withdrawal and would have more benign environmental effects than wet cooling towers. However, this type of tower was shown in Part I of this report to be unsuitable for use at MNPS and is not considered further.

2.6 ALTERNATE INTAKE LOCATION

Insights to potential impingement and entrainment effects associated with an offshore intake may be provided by the experience of Seabrook Station, an 1,150 MWe nuclear generating plant located in Seabrook, NH. Described in Jacobson et al. (1999), this station has three intake structures that are spaced about 100 ft apart and located in the Atlantic Ocean approximately 1.3 mi offshore of the coastline. The intakes draw water into the plant through a 19-ft diameter tunnel. The mid-water intakes are about 15 ft off the bottom in 60 ft of water. Each has a velocity cap 30 ft in diameter with a 7-ft opening that allows water to be withdrawn at relatively low (0.5 $ft{\cdot}s^{-1}$) velocity into the structure, although the rate increases to about 6 $ft{\cdot}s^{-1}$ in the riser shaft. The station utilizes about 496,000 $gal{\cdot}min^{-1}$ and discharges water back to the ocean with an average ΔT of 39°F. Fish drawn into the offshore intakes are impinged on 0.375-inch traveling screens at the plant and there is no return system. Annual impingement estimates from 1994 through 1997 ranged between about 10 and 27 thousand (Jacobson et al. 1999), whereas annual totals at MNPS Unit 2 from 1976 through 1987 ranged from about 9 to 60 thousand, if one large (nearly one-half million) impingement event of Atlantic sand lance in 1984 is disregarded (NUSCO 1988a). Despite having a midwater intake, some of the fishes most frequently impinged at Seabrook included demersal species, such as sculpins, hakes, and flounders. Pelagic fishes, including alewife, rainbow smelt, and pollock were also impinged, but did not dominate the samples. It was thought that some fish were attracted to the structure and sought cover, which increased their likelihood of being drawn into the intake tunnel, especially during storm events, when impingement of both organisms and debris mostly occurred. The midwater intakes with velocity caps, nevertheless, appeared to be performing as expected in minimizing impingement at Seabrook Station. Of note, the species composition of the ichthyoplankton entrained at Seabrook differed in some respects from fish larvae sampled in the ocean near the intakes. These differences were attributed to lack of entrainment samples at various times due to plant shutdowns, behavior of fish larvae (e.g., diel differences, depth preferences, swim speeds) that made some species more or less susceptible to entrainment at the midwater intakes, and because the field ichthyoplankton sampling gear was deployed throughout the water column, whereas plant water withdrawal took place in a narrower depth stratum (Jacobson et al. 1999). Bar rack spacing at the offshore intakes was also reduced in 1999 to 4 to 4.9 inches to eliminate the impingement of harbor seals and other seal species.

The location for an alternate intake location offshore of MNPS was selected and evaluated in NUSCO (1993a) on the basis of hydrodynamics of Niantic Bay in relation to the distribution of Niantic River winter flounder larvae in the bay (NUSCO 1992a, 1992c). The same location was selected for this report and is found just outside a line extending from Black Point to Millstone Point. This is an area of the bay that exchanges a considerable amount of water with LIS, and because water in this area is well-mixed and flushes with each tidal cycle, it is not a good retention area for Niantic River winter flounder larvae. For example, the approximate volume of Niantic Bay is about 13.2 billion gallons (E. Adams, Massachusetts Institute of Technology, pers. comm.), while the average tidal prism of the Niantic river is 713 million gallons (Kollmeyer 1972). With 1.9 tidal cycles per day, this tidal prism would dilute Niantic River water by about 1:10. Nevertheless, waters near the offshore site may still contain relatively high densities of winter flounder larvae flushed from inshore spawning sites, particularly during April and May, and of other ichthyoplankton seasonally. Based on hydrodynamic conditions, most of the winter flounder larvae in the area of the present plant intakes originate from spawning stocks found to both the east and west of Niantic Bay and are transported by tidal currents into this area. Entrainment of Niantic River winter flounder larvae would likely be reduced by an estimated 31 to 50% by placing an offshore intake at the designated location. This assumed that an offshore intake location would be removed far enough from the mouth of the Niantic River to have diluted larvae flushing from the river by about one-half and would either provide cooling water for only Unit 3 or for both units, respectively.

Although the fraction of entrained winter flounder larvae attributed to the Niantic River stock may decrease by using an offshore intake, overall entrainment totals of winter flounder larvae could increase rather than decrease. Based on special bay-wide sampling conducted in 1991 (NUSCO 1992a), entrainment of winter flounder larvae, particularly those in Stage 3 of development, may increase during flood tides. However, as inferred from the densities of larvae found in water masses entering Niantic Bay (NUSCO 1992a), many of these larvae would likely have drifted in from other areas. This would proportionately shift more of the MNPS-imposed entrainment mortalities to stocks other than the one spawning in the Niantic River. The ultimate contribution of larvae flushed away from spawning and nursery grounds to future adult stocks is not known, but has been thought to be relatively small because of higher mortality in offshore waters (Pearcy 1962). A reduction in the number of winter flounder larvae coming from any one particular source with an increasing fraction of entrained larvae arriving from increasing distances from the plant should lessen the compensatory responses necessary to stabilize the abundances of these various spawning populations.

Impact of an offshore intake may also depend, in part, upon the depth from which water is drawn. Data collected during initial ichthyoplankton studies at MNPS in April and May of 1974 and 1975 from offshore waters of LIS were analyzed. During these years, bongo sampler collections were taken just below the surface, near the bottom, and obliquely throughout most of the water column during both day and night. A non-parametric Wilcoxon's signed rank test was used to compare densities by tow type within time of day. During daylight, densities of winter flounder larvae collected near the bottom were significantly higher than densities near the surface and in oblique tows. Significantly

more larvae were found in oblique tows, which integrates most of the water column, than in surface tows. During the night, bottom and oblique tows again had significantly more larvae collected than in surface tows, but no significant difference was found between bottom and oblique tows. This implied that, in general, concentrations of winter flounder larvae were highest closer to the bottom, but at night most dispersed throughout the water column. Thus, an offshore intake situated closer to the bottom would likely entrain more larvae than one constructed closer to the surface. However, the densities of winter flounder by depth were only measured at two discrete locations: very near the surface and very near the bottom. The physical size of an offshore intake structure with a velocity cap may result in relatively small differences in total entrainment of winter flounder larvae, whether it is located closer to the bottom or the surface.

A change from the present intake located on the shoreline at MNPS to one offshore may detrimentally affect other species through increased entrainment. Of the most abundant fishes collected as larvae, in most years the grubby was taken in higher densities in entrainment samples at the MNPS discharges than in 60-cm bongo sampler collections at a station in mid-Niantic Bay (NUSCO 1993b). More grubby spawn in the Niantic River and in inner areas of Niantic Bay, with less spawning likely taking place in more offshore waters. Conversely, larvae of the American sand lance and anchovies in some years were considerably more abundant in mid-Niantic Bay than at the MNPS discharge, so more adults of these species probably spawn either in deeper waters of the bay or offshore in LIS. Anchovy eggs and larvae of both species are advected into the bay to join those produced from fish spawning closer to MNPS. Based on the relatively large sizes of most entrained Atlantic menhaden larvae and the lack of any menhaden eggs in entrainment samples, this species likely spawns at some distance from MNPS. An offshore intake may therefore increase entrainment estimates of these three species. Spatial distribution studies of tautog eggs completed in 1996 and 1997 (NUSCO 1997, 1998, 1999) revealed that they were more concentrated in nearshore stations than those farther offshore, although the "inshore" station for this study was located in the vicinity of the proposed offshore intake for MNPS. In an earlier 1994 study summarized in NUSCO (1997), no statistical differences in tautog egg densities were found among four stations within and adjacent to Niantic Bay and at the MNPS discharge, indicating a relatively homogeneous distribution of eggs in the area of the plant. Also, tautog eggs were found to be fairly homogeneous throughout the water column, except close to the bottom, where they are less abundant. Thus, an offshore intake, at least at the proposed location, may not result in a reduction in tautog egg entrainment. Most older tautog collected in the MNPS trawl monitoring program were taken at two deeper offshore stations (NUSCO 1993b), but spawning adults are also known to be found in rocky inshore areas, as are many of the related cunner. Cunner eggs and larvae may have a similar pattern of abundance and distribution as tautog and more of them could be entrained at an offshore intake. Like an artificial reef, an offshore intake structure may attract these two species and local spawning of resident fish near the intake would result in increased egg and larval entrainment. Although these species may be habitat-limited and a new structure would afford additional shelter for recruiting juveniles, most of the reproductive effort of resident adults that could have spawned elsewhere would probably be lost to the population.

Increased impingement mortality of juvenile and adult fish is another consideration for an offshore intake. It is possible that impingement of some species would increase, particularly for those likely to be attracted to the structure (e.g., cunner, tautog, black sea bass) or those more common offshore (e.g., skates, searobins, windowpane). Impingement of fish more commonly found inshore (e.g., silversides, sticklebacks, northern pipefish), however, would likely decrease. Impingement to a large degree is a far less passive phenomenon than entrainment and behavior of larger fish, as well as their distribution, largely influences the availability of individuals to entrapment. This process may vary diurnally, seasonally, or in response to variable environmental conditions, such as storms as seen at Seabrook Station, or periods of rapidly changing water temperature, as noted at MNPS (NUSCO 1987b). For example, scup (mostly young-of-the-year) have ranked second only to winter flounder in trawl catches at the stations just off the MNPS intake and in mid-Niantic Bay (NUSCO 1992b), yet relatively few of them were impinged from 1976 through 1987 (NUSCO 1987c, 1988a). Conversely, Atlantic tomcod were much more common in impingement samples than in trawl collections during the same years. A winter estuarine spawner, Atlantic tomcod may be attracted to water flows in inshore areas.

An offshore intake would require a significant increase in the amount of biocide needed to control fouling in the intake structure and within a long intake tunnel. For example, at Seabrook Station, except for January and February, chlorine (ca. 6,000 gal·day^{-1} as sodium hypochlorite) is injected at a concentration of about 0.5-0.7 ppm into the vertical shaft of each intake just below the opening of each offshore intake structure (R. Sher, North Atlantic Energy Service Corporation, Seabrook, NH, pers comm.). This concentration allows a monthly average value of 0.2 ppm to be met at the discharge at the station. The chlorine concentration is further reduced in the long discharge tunnel at the station, but biofouling there is mostly controlled by the high station ΔT of 39°F. The effects of continuous chlorination on fish eggs, larvae, juveniles, and adults entrained within an offshore intake system at MNPS could be considerable. Impinged fish at Seabrook Station are not returned and no data are available on their survival, but it is likely that most specimens are killed due to the pressure changes induced by passage through the deep intake tunnel. Further, although detailed engineering was not presented in Part I, a long intake tunnel of this type may require booster pumps which would further exacerbate mortality of entrained and impinged organisms. Because of a potential increase in the use of chlorine, the condenser cooling water from an offshore intake at MNPS may require a dechlorination unit so that NPDES permit limits for discharged chlorine are not exceeded. This would also be true of other alternatives, such as wedge-wire screens, which would require additional biofouling control. The costs of a dechlorination unit were not included in estimates presented in Part I. Biofouling control for an offshore intake would also result in additional resources (personnel, materials, and labor costs) required to maintain desired reliability. For example, divers must periodically inspect and clean exterior portions of the offshore intakes at Seabrook Station (R. Sher, North Atlantic Energy Service Corporation, Seabrook, NH, pers comm.). The environmental impacts from construction of an offshore intake would also have to be evaluated in further detail and would require significant permitting from a number of state and federal agencies. Impacts would include, at minimum, a displacement of benthic flora and fauna due to dredging

and other activities associated with construction, increased turbidity during the period of work, and limits to navigation in the area of construction.

In summary, an offshore intake would likely have a range of intake structure effects, with some reductions in entrainment and some increases, depending upon the species. In particular, the effect of impingement would increase as presently many impinged fish and invertebrates are returned alive in the Units 2 and 3 fish return sluiceways, whereas passage through a deep tunnel and booster pumps would likely cause high if not complete mortality. Significant construction and operational and maintenance expenses would also be incurred from this option.

2.7 REVISED OPERATIONAL SCHEDULES

An operational schedule (i.e., forced outage) could be implemented to reduce MNPS cooling-water flow and entrainment during critical periods of ichthyoplankton occurrence. Effects would be contingent upon the overlap in flow reduction and the occurrence of each species of concern. No additional environmental effects would occur at MNPS due to a shutdown. However, if there is a demand for electric generation during a forced MNPS outage, it would likely be made up by fossil-fueled sources and estimates of environmental impact from additional air emissions because of lost generation at MNPS are given in Appendix B to this chapter. No evaluation has been made of additional entrainment or impingement that would occur if this generation is made up by increased operation of other coastal or river-sited power plants in Connecticut, some of which (e.g., New Haven Harbor, Bridgeport Harbor, Montville, AES Thames) affect species similar to those found near MNPS, including the winter flounder (Crecco 1994). As noted in Section 12 of Part I, forced outages are prohibitively expensive for the station.

2.8 CONVERSION OF MNPS TO A NATURAL GAS-FUELED FACILITY

The conversion of MNPS to natural gas would have both positive and negative environmental effects. Because this option is so costly and has many other associated issues (e.g., engineering, licensing), making it an unlikely viable alternative, the following discussion is not intended to be comprehensive or detailed. Depending upon the specific type of cooling chosen, a gas plant can use considerably less cooling-water than the present once-through system at MNPS that would alleviate many of the entrainment issues. Cooling requirements for gas units noted in Part I of this report were given as 660,000 gal·min^{-1} for once-through cooling to much less if cooling towers were constructed for the converted station. Because gas units would require a pipeline to be constructed to the plant site, considerable effects to both terrestrial and aquatic habitats would likely occur in building this line, the extent of which would be dependent upon the route chosen. This prospect also raises many probable licensing issues. Additional environmental impacts onsite may occur, depending upon the plant design. Effects of new plant construction and decommissioning of the nuclear units would need further evaluation after a detailed design and decommissioning plan were formulated. Gas-fueled units would also result in increased air emissions, which are evaluated in Appendix B of Chapter 2.

2.9 SUMMARY

A summary of the alternative cooling-water technologies evaluated in this chapter, their status as a proven or unproven intake technology at large thermal power plants, reductions in flow that could be realized with some of the alternatives, estimated reduction in entrainment mortality at MNPS that would occur with the use of each, and a brief listing of pertinent factors (e.g., plant reliability issues, other environmental impacts) associated with each alternative are given in Table 2-1. A number of the alternatives were shown to represent unproven or unworkable technologies in reducing entrainment or entrainment mortality, such as behavioral barriers, rotary drum screens, barrier nets, infiltration intakes, and porous dikes. Other technologies that may be effective at smaller power plants cannot be implemented at large coastal marine stations, including the Gunderboom and wedge-wire screens. An examination of fine-mesh screens at another power plant in Southern New England indicated that this device would not likely result in improved survival of fish eggs and larvae. An offshore intake may also not be effective in reducing entrainment mortality and may actually increase impingement effects. Flow reduction schemes encompass a variety of options, from taking offline a circulating water pump to the installation of a cooling tower or conversion of the station to natural gas-fueled units. These latter two options are extremely expensive and upon further examination may be technically infeasible at MNPS. The information presented in this chapter regarding the likelihood of entrainment survival by these various methodologies is further used in quantitative analyses, particularly for winter flounder, that are found in Chapter 4.

2.10 REFERENCES

Adams, A.P., and B.G. Lewis. 1978. Bacterial aerosols generated by cooling towers of electrical generating plants. Presented at the 1978 Cooling Tower Institute (CTI) Annual Meeting, Houston, TX. Reprinted by CTI, Houston, TX. 13 pp.

Anderson, M.R., J.A. DiVito, and Y.G. Mussalli. 1988. Design and operation of angled-screen intake. J. Hyd. Eng. 114 (b):598-615.

ARL and SWEC (Alden Research Laboratory and Stone & Webster Engineering Corporation). 1981. Laboratory evaluation of fine-mesh screening for the protection of fish larvae at intakes. Prepared for Empire State Electric Energy Research Corporation.

ASA (Applied Science Associates, Inc.). 1999. Ichthyoplankton monitoring study deployment of a Gunderboom system at Lovett Generating Station Unit 3 1998. Prepared for Orange and Rockland Utilities, Inc. (Not seen, cited *in* EPRI 1999).

Barnthouse, L.W., J. Boreman, T.J. Englert, W.L. Kirk, and E.G. Horn. 1988. Hudson River settlement agreement: technical rationale and cost considerations. Pages 267-373 *in* L.W. Barnthouse, R.J. Klauda, D.S. Vaughan, and R.L. Kendall, eds. Science, law, and Hudson River power plants: a case study in environmental impact assessment. Am. Fish. Soc. Monogr. 4.

Browne, M.E., L.B. Glover, D.W. Moore, and D.W. Ballangee. 1981. In-situ biological and engineering evaluation of fine-mesh profile-wire cylinders as power plant intake screens. Pages 36-46 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

Brueggemeyer, V., D. Cowdrick, K. Durrell, S. Mahadevan, and D. Bruzek. 1988. Full-scale operational demonstration of fine mesh screens at power plant intakes. Pages 2-51-2-65 *in* W.C. Micheletti, ed. Proceedings: fish protection at steam and hydroelectric power plants. EPRI CS/EA/AP-5663-SR. Electric Power Research Institute, Palo Alto, CA.

Carolina Power & Light. 1985. Brunswick Steam Electric Plant Cape Fear studies interpretive report. Biology Unit, Environmental Services Section. (Not seen, cited *in* EPRI 1999).

Crecco, V.A. 1994. Cumulative effects of impingement and entrainment from coastal power plants on winter flounder in Connecticut waters. CT DEP, Div. Mar. Fish. 19 pp. + app.

Davis, R.W., J.A. Matousek, M.J. Skelly, and M.R. Anderson. 1988. Biological evaluation of Brayton Point Station Unit 4 angled screen intake. Pages 3-23-3-42 *in* EPRI conference on fish protection at steam and hydro plants, San Francisco, CA. EPRI CS/EA/AP-5663-SR. Electric Power Research Institute, Palo Alto, CA.

EA (Ecological Analysts, Inc.). 1977. Preliminary investigations into the use of a continuously operating fine mesh traveling screen to reduce ichthyoplankton entrainment at Indian Point Generating Station. Prepared for Consolidated Edison Company of New York, Inc. (Not seen, cited *in* EPRI 1999).

EA (Ecological Analysts, Inc.). 1979. Evaluation of the effectiveness of a continuously operating fine mesh traveling screen to reduce ichthyoplankton entrainment at Indian Point Generating Station. Prepared for Consolidated Edison Company of New York, Inc. (Not seen, cited *in* EPRI 1999).

Edwards, S.J., P.M. McGroddy, D. Lispi, and P. Dorn. 1981. Fine-mesh screens as impingement-release system for marine fish larvae. Pages 128-137 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

Ehrler, C., and C. Raifsnider. 2000. Evaluation of the effectiveness of intake wedgewire screens. Env. Sci. Pol. 3:S361-S368.

Englert, T.L., J. Boreman, and H.Y. Chen. 1988. Pages 274-279 *in* L.W. Barnthouse, R.J. Klauda, D.S. Vaughan, and R.L. Kendall, eds. Science, law, and Hudson River power plants: a case study in environmental impact assessment. Am. Fish. Soc. Monogr. 4.

Electric Power Research Institute (EPRI). 1999. Status report on fish protection at cooling water intakes. EPRI Rep. No. TR-114013. Palo Alto, CA. Prepared by Alden Research Laboratory, Inc.

Hanson, B.N. 1981. Studies of larval striped bass (*Morone saxatilis*) and yellow perch (*Perca flavescens*) exposed to a 1 mm slot profile-wire screen model intake. Pages 22-35 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

Hanson, B., W.H. Bason, B. E. Beitz, and K. E. Charles. 1978. A practical intake screen which substantially reduces the entrainment and impingement of early life stages of fish. Pages 393-408 *in* L.D. Jensen, ed. Fourth national workshop on entrainment and impingement. EA Communications, Melville, NY.

Holsapple, J.G., R.C. Roberts, and Y.G. Mussalli. 1981. Development of an angled fine/coarse mesh traveling screen demonstration facility. Pages 184-192 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

Hogarth, W.T., and K.L. Nichols. 1981. Brunswick steam electric plant intake modifications to reduce entrainment and impingement losses. Pages 272-282 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

Hutchison, J.B., Jr. 1988. Technical descriptions of Hudson River electricity generating stations. Pages 113-117 *in* L.W. Barnthouse, R.J. Klauda, D.S. Vaughan, and R.L. Kendall, eds. Science, law, and Hudson River power plants: a case study in environmental impact assessment. Am. Fish. Soc. Monogr. 4.

Jacobson, P.J., E. Lorda, D.J. Danila, J.D. Miller, C.A. Tomichek, and R.A. Sher. 1999. Studies of cooling water intake effects at two large coastal nuclear power stations in New England. Pages 9-1-9-25 *in* D. Dixon and K. Zammit, eds. Proceedings: 1998 EPRI Clean Water Act Section 316(b) Technical Workshop, Coolfont Conference Center, Berkeley Springs, WV. TR-112613. Electric Power Research Institute, Palo Alto, CA.

Jaroslow, B.N. 1979. A review of factors involved in bird-tower kills, and mitigative procedures. Pages 469-473 *in* G.A. Swanson, tech. coord. The mitigation symposium: a national workshop on mitigating losses of fish and wildlife habitats. Gen. Tech. Rep. RM-65. Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Dept. Agriculture, Fort Collins, CO.

Ketschke, B.A. 1981a. Field and laboratory evaluation of the screening ability of a porous dike. Pages 84-90 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

Ketschke, B.A. 1981b. Hydraulic performance of a porous dike intake. Pages 91-99 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

Key, T.H., and J.C. Miller. 1978. Preliminary studies on the operating aspects of small slot wedgewire screens with conceptual designs for power station use. Pages 385-392 *in* L.D. Jensen, ed. Fourth national workshop on entrainment and impingement. EA Communications, Melville, NY.

Kollmeyer, R.C. 1972. A study of the Niantic River estuary, Niantic, Connecticut. Final report phases I and II, physical aspects of the Niantic River estuary. Rep. No. RDCGA 18. U.S. Coast Guard Academy, New London, CT.

LMS (Lawler, Matusky & Skelly Engineers). 1985. Fish protective intake test facility: angled screen diversion study. Prepared for Empire State Electric Energy Research Corporation.

LMS. 1987. Brayton Point Station Unit No. 4 angled screen intake biological evaluation program. Prepared for New England Power Company.

LMS. 1994. Effectiveness evaluation of a fine mesh barrier net located at the cooling water intake of the Bowline Point Generating Station. Prepared for Orange and Rockland Utilities, Inc. (Not seen, cited *in* EPRI 1999).

LMS. 1996a. Effectiveness evaluation of a fine mesh barrier net located at the cooling water intake of the Bowline Point Generating Station. 1994 barrier net evaluation program report. Prepared for Orange and Rockland Utilities, Inc. (Not seen, cited *in* EPRI 1999).

LMS. 1996b. Lovett Station Gunderboom evaluation program 1995. Prepared for Orange and Rockland Utilities, Inc. (Not seen, cited *in* EPRI 1999).

LMS. 1997. Lovett Station Gunderboom evaluation program 1996. Prepared for Orange and Rockland Utilities, Inc. (Not seen, cited *in* EPRI 1999).

LMS. 1998. Lovett Station Gunderboom evaluation program 1998. Prepared for Orange and Rockland Utilities, Inc. (Not seen, cited *in* EPRI 1999).

Matousek, J.A., T.E. Pease, J. Holsapple, and R.C. Roberts. 1988. Biological evaluation of angles screen test facility. J. Hyd. Eng. 114(b):641-650.

McCusker, A.J. 1999. Letter dated June 18, 1999 to M. Keser, Manager, Millstone Environmental Laboratory, Waterford, CT.

McGroddy, P.M., S. Petrich, and L.E. Larson. 1981a. Fouling and clogging evaluation of fine-mesh screens for offshore intakes in the marine environment. Pages 5-21 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

McGroddy, P.M., S.J. Edwards, and P. Dorn. 1981b. Diversion of marine fish larvae with angled louvers and fine-mesh screens. Pages 225-234 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

Mirsky, G.R. 1995. Cooling tower noise. Presented at the 1995 Cooling Tower Institute (CTI) Annual Meeting, Fort Worth, TX. Reprinted by CTI, Houston, TX. 5 pp. + figs.

Murray, L.S., and T.S. Jinnette. 1978. Survival of dominant estuarine organisms impinged on fine mesh traveling screens at the Barney M. Davis Power Station. Central Power and Light Co., Corpus Christi, TX. (Not seen, cited *in* EPRI 1999).

NUSCO (Northeast Utilities Service Company). Undated. Millstone Nuclear Power Station Unit 3. Environmental report - construction permit stage. Vol. 1. Sections 7.2 and 10. Waterford, CT.

NUSCO. 1987a. Ecological significance of community changes at Fox Island. 24 pp. + 15 fog. + 1 tab. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1987b. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Summary of studies prior to Unit 3 operation. 151 pp. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1987c. Fish ecology. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Summary of studies prior to Unit 3 operation. 102 pp. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1988a. Fish ecology studies. Pages 255-307 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Three-unit operational studies, 1986-1987. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1988b. Hydrothermal studies. Pages 323-355 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Three-unit operational studies, 1986-1987. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1992a. Winter flounder studies. Pages 7-110 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1991. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1992b. Fish ecology studies. Pages 7-110 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1991. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1992c. Niantic Bay current studies. Pages 111-156 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1991. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1993a. Feasibility study of cooling water system alternatives to reduce winter flounder larval entrainment at Millstone Units 1, 2, and 3. Parts I and II. Berlin, CT. Submitted by Letter D06112 dated January 27, 1993 from C.F. Sears, NUSCO, to T. Keeney, Commissioner, DEP.

NUSCO. 1993b. Fish ecology studies. Pages 151-187 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1992. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1997. Fish ecology studies. Pages 9-58 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1996. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1998. Fish ecology studies. Pages 1-8 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1997. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1999. Fish ecology studies. Pages 113-160 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1998. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 2000a. Winter flounder studies. Pages 9-112 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1999. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 2000b. Fish ecology studies. Pages 113-158 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1999. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 2000c. Lobster studies. Pages 159-188 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1999. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 2000d. Rocky intertidal studies. Pages 189-218 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1999. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 2000e. Eelgrass. Pages 219-234 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1999. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 2000f. Benthic infauna studies. Pages 235-265 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1999. Northeast Utilities Environmental Laboratory, Waterford, CT.

Olmsted, L.L., and W.D. Adair. 1981. Protection of fish larvae at two southeastern power plants using skimmer walls. Pages 290-295 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

Otto, R.G., T.I. Hiebert, and V.R. Kranz. 1981. The effectiveness of a remote, profile-wire screen intake module in reducing the entrainment of fish eggs and larvae. Pages 47-56 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

PG&E Generating and MRI (Marine Research, Inc.). 1999. 1998 annual report Brayton Point Station, Somerset, MA.

PSE&G (Public Service Electric and Gas). 1984. Salem Generating Station 316 (b) demonstration. Public Service Electric and Gas Company, Newark, NJ. (Not seen, cited *in* MMES 1986).

Pearcy, W.G. 1962. Ecology of an estuarine population of winter flounder *Pseudopleuronectes americanus* (Walbaum). Bull. Bingham Oceanogr. Coll. 18(1):1-78.

Puder, M.G., and J.A. Veil. 1999. Summary data on cooling water use at utilities and nonutilities. Prepared for U.S. Dept. Of Energy, Office of Fossil Energy and Office of Policy and International Affairs. Contract W-31-109-ENG-38. Argonne National Laboratory, Argonne, IL.

Rybak, E.J., W.B. Jackson, and S.H. Vessey. 1973. Impact of cooling towers on bird migration. Pages 187-194 *in* Sixth Bird Control Seminar, Bowling Green Univ., Bowling Green, OH.

SWEC (Stone and Webster Engineering Corporation). 1984. Advance intake technologies study. EPRI CS-3644. Project 2214-2 final report. Electric Power Research Institute, Palo Alto, CA.

Taft, E.P. III, R. Berger, L. Larsen, J.G. Holsapple, and L.W. Eberley. 1981a. Laboratory evaluation of larval fish impingement and diversion systems. Pages 138-158 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

Taft, E.P. III, T.J. Horst, and J.K. Downing. 1981b. Biological evaluation of a fine-mesh traveling screen for protecting organisms. Pages 159-168 *in* P.B. Dorn and J.T. Johnson, eds. Advanced intake technology for power plant cooling water systems.

Taft, E.P. 2000. Fish protection technologies: a status report. Env. Sci. Pol. 3:S349-S359.

Temme, M., and W.B. Jackson. 1981. Cooling towers as obstacles in bird migrations. Proc. Bird Control Sem. 8:111-118.

Thompson, T. 2000. Intake modifications to reduce entrainment and impingement at Carolina Power & Light Company's Brunswick Steam Electric Plant, Southport, North Carolina. Env. Sci. Pol. 3:S417-S424.

Tyndall, R.L. 1982. Concentration, serotypic, profiles and infectivity of Legionnaires' Disease bacteria populations in cooling towers. Presented at the 1982 Cooling Tower Institute (CTI) Annual Meeting, Houston, TX. Reprinted by CTI, Houston, TX. 21 pp.

USEPA (United States Environmental Protection Agency). 1976. Development document for the best technology available for the location, design, construction, and capacity of cooling water intake structure for minimizing adverse environmental impact. EPA 440/1-76/015a. Washington, DC.

Weisberg, S.B., F.S. Stoup, and A.F. Holland. 1986. Tests of biofouling control technologies for use with fine-mesh screens in an estuarine environment. Mar. Tech. Soc. J. 20:37-43. (Not seen, cited *in* Weisberg et al. 1987).

Weisberg, S.B., W.H. Burton, F. Jacobs, and E.A. Ross. 1987. Reductions in ichthyoplankton entrainment with fine-mesh, wedge-wire screens. N. Am. J. Fish. Man. 7:386-393.

Zeitoun, I.H., J. A. Gulvas, and D.B. Roarabaugh. 1981. Effectiveness of fine mesh cylindrical wedge-wire screens in reducing entrainment of Lake Michigan ichthyoplankton. Can. J. Fish. Aquat. Sci. 38:120-125.

TABLE 2-1. Summary of cooling-water alternatives evaluated for MNPS with their status as proven technology in reducing egg and larval entrainment mortality at large thermal power plants, estimated reductions in cooling-water flow and entrainment mortality rates if implemented at MNPS, and pertinent remarks about each technology.

Alternative	Technology proven to reduce entrainment mortality?[a]	Could reduce entrainment mortality at MNPS?[b]	Estimated % reduction in cooling-water flow[c]	Estimated % reduction in entrainment mortality[d]	Remarks[e]
Behavioral barriers	No	No	0	0	Larvae cannot react to behavioral devices
Conventional traveling screen	No	No	0	0	Current system employed at MNPS; relatively large mesh allows for larval entrainment
Fine-mesh screen	Yes	Unlikely to be significant	0	Variable depending upon species[f]	Poor survival found for many marine fishes, but some potential for invertebrate larvae; debris loading, biofouling, reliability issues
Rotary drum screen	No	No	0	0	Not applicable to thermal power plants or for larval entrainment reduction
Gunderboom	Yes	Possibly	0	?	Poor performance and uneven entrainment reduction at one plant; debris loading, reliability issues; large area would need to be cordoned off
Barrier net	No	No	0	?	Poor performance at one plant; debris loading, reliability issues; large area would need to be cordoned off
Infiltration intake	Yes	No	0	100	Not applicable to large power plants; requires specific geology, hydrology; reliability issues
Porous dike	No	Unlikely to be significant	0	?	High larval mortality may still result from entrapment in dike; debris loading, biofouling, reliability issues; requires large shoreline area
Wedge-wire screen	Yes	Likely, depending upon mesh	0	?	Never applied at a plant as large as MNPS; mortality reductions are screen-size dependent; debris loading, biofouling, reliability issues
Angled screens (fine-mesh)	Yes	Unlikely	0	Variable depending upon species[f]	Poor survival seen for many marine fishes, but some potential for invertebrate larvae; debris loading, biofouling, reliability issues
Rotary drum screen with fish pump	No (in North America)	Unknown	0	?	Unproven in North America; uncertain performance in reducing entrainment mortality
Flow reduction	Yes	Yes	Variable by how, when implemented	Variable by how much flow reduced	Effects to various species would vary by how implemented (addressed in Chapter 3); results in increased ΔT; possible plant reliability issues; increased air emissions as generation reduced
Re-circulation	Yes	Yes	Variable by how, when implemented	Variable by how much flow reduced	Effects to various species would vary by how implemented (addressed in Chapter 3); results in increased ΔT; increased air emissions as generation reduced

TABLE 2-1 (continued).

Alternative	Proven Technology?[a]	Could reduce entrainment mortality at MNPS?[b]	Estimated % reduction in cooling-water flow[c]	Estimated % reduction in entrainment mortality[d]	Remarks[e]
Cooling tower	Yes	Yes	U2 (full) - 34 U3 (full) - 58 U3 (2/3) - 36 U2&3 (full) - 91	U2 (full) - 34 U3 (full) - 58 U3 (2/3) - 36 U2&3 (full) - 91	Associated environmental impacts from land use, blowdown, chlorination, noise, aesthetics; possible impacts to bird migration
Alternate intake location (offshore)	Yes	Yes / No (species-specific)	0	Variable by species[g]	Increased chlorination; possible changes to impingement; some construction effects, such as dredging
Revised operating schedule (forced outages)	Yes	Yes	Would vary according to schedule	Would vary according to schedule	Effects to various species would vary by how implemented; impossible to reduce entrainment for all species due to lengthy seasons of occurrence; increased air emissions
Conversion of MNPS to gas fuel	Yes	Yes	≥55	Variable by how much flow reduced	Likely considerable effects due to construction of gas pipeline; possibly some construction and decommissioning effects; increased air emissions

[a] Yes, if shown to be a proven technology in reducing larval entrainment mortality at large thermal power plants, and No, if not.
[b] On the basis of demonstrated biological, engineering, and operational characteristics associated with the technology.
[c] Reduction from present MNPS two-unit operation with once-through cooling. The retirement of Unit 1 has already reduced the total (i.e., former three-unit) station flow by 23%.
[d] Reduction in entrainment mortality achieved directly because of reduced flow (assumed to be proportional) or because of actions associated with the technology.
[e] See text for a full discussion of each alternative.
[f] Based on other plant operating experience and experimental work, estimated to be <10% for winter flounder, Atlantic menhaden, anchovy, cunner, and tautog larvae (possibly greater for larger menhaden and anchovy larvae); possibly 25-50% for sand lance and grubby larvae; and possibly 60-90% for anchovy, cunner, and tautog eggs.
[g] Estimated to be a 31-50% decrease for Niantic River winter flounder larvae, but possibly an increase for larvae from other winter flounder stocks; probably no net change for tautog and cunner eggs; probable decrease for grubby larvae; and probable increases for anchovy eggs and Atlantic menhaden, anchovy, and sand lance larvae. Mortality could be total for all impinged and entrained fish because of pressure changes in intake tunnel (needs further evaluation).

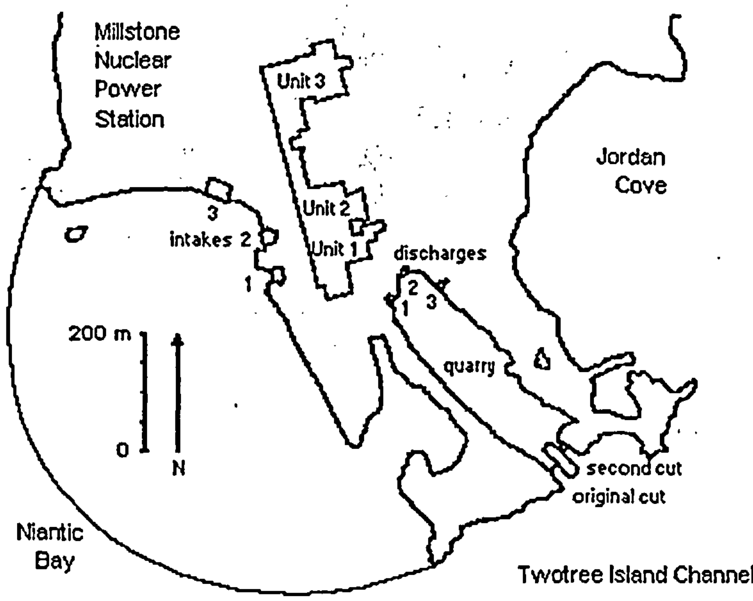


Fig. 2-1. Approximate area that would be contained within a 5,000-foot Gunderboom deployed off the MNPS intakes.

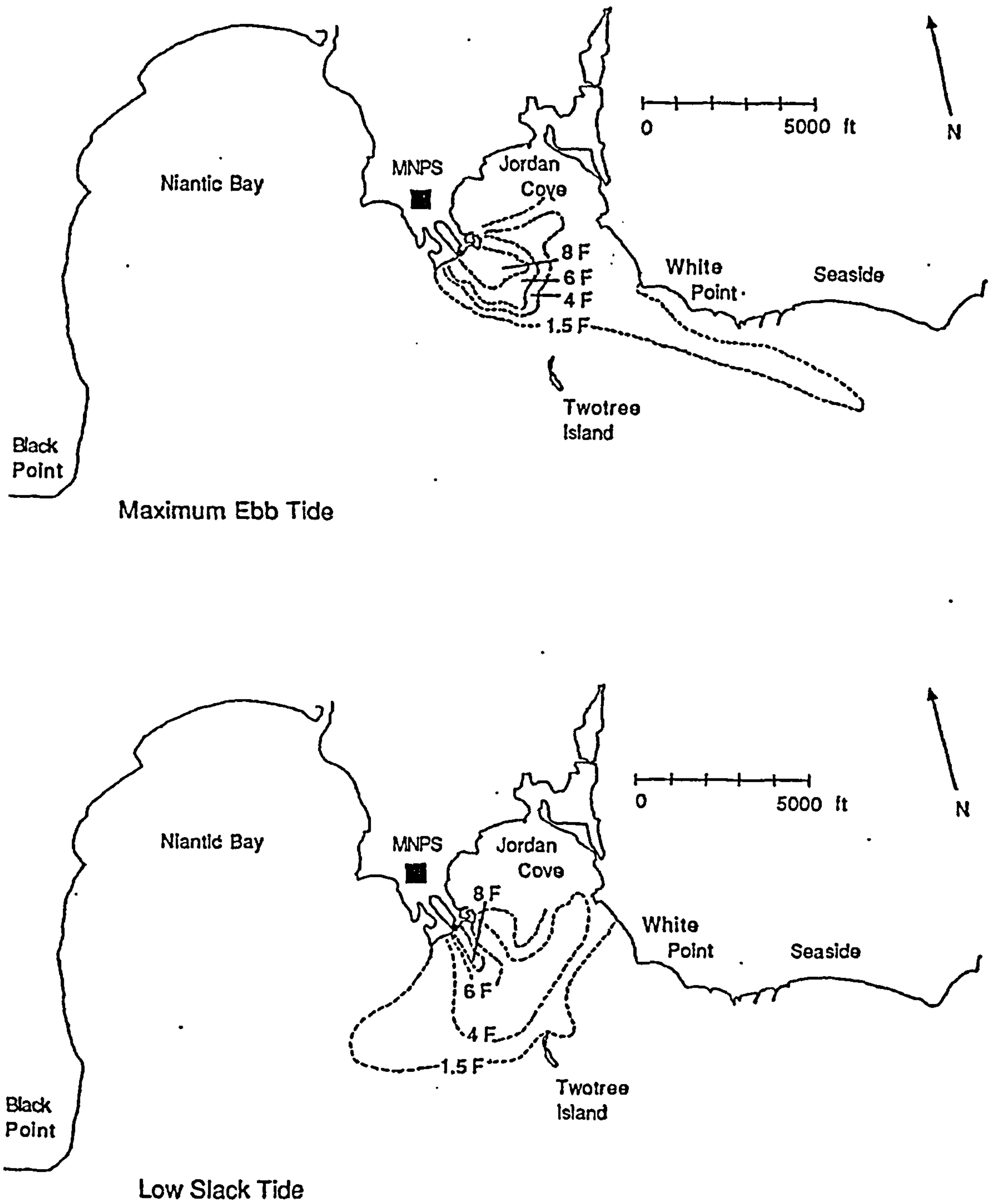
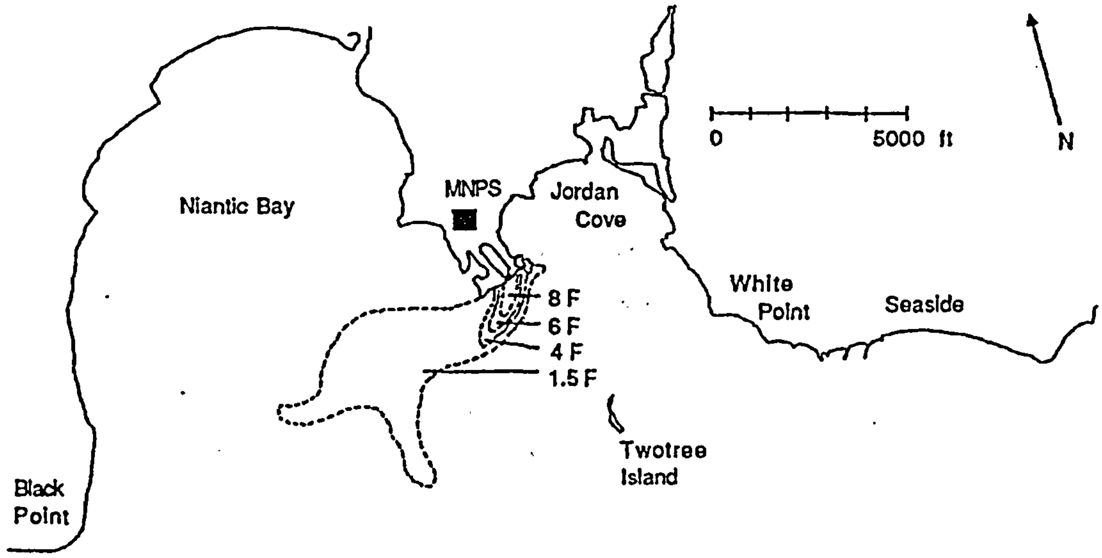
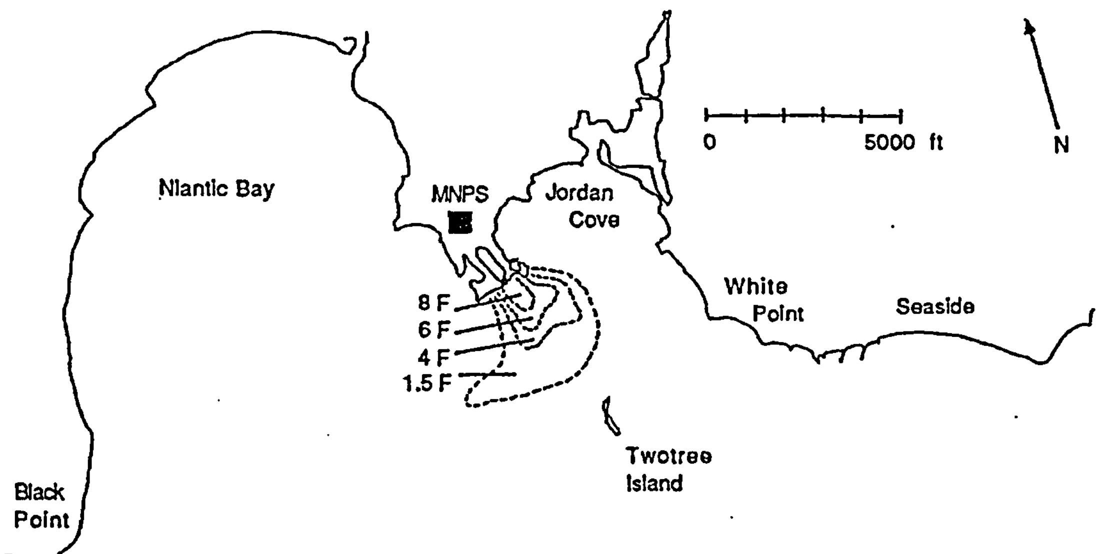


Fig. 2-2. Locations of selected three-unit thermal plume isotherms (1.5°F, 4°F, 6°F, and 8°F) under various tidal conditions.



Maximum Flood Tide



High Slack Tide

Fig. 2-2. (continued).

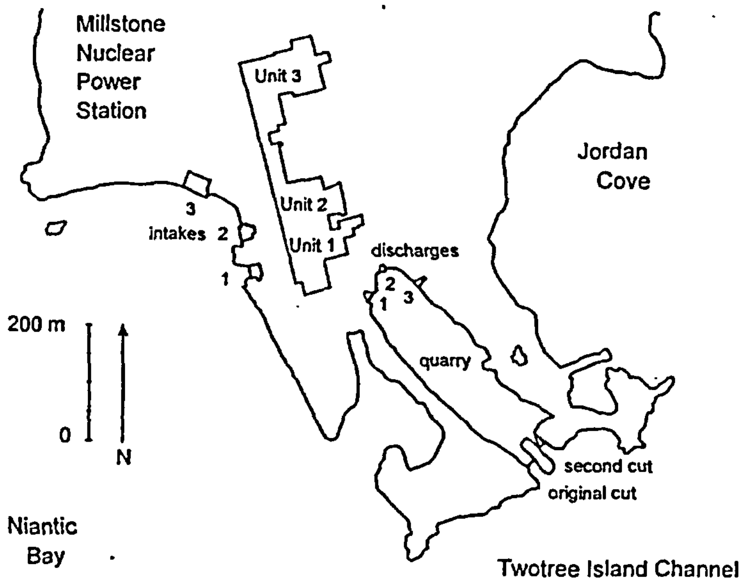


Fig. 2-3. The MNPS site, showing the intake and discharge of each unit, the Quarry, and the two Quarry discharge cuts. Fox Island is located immediately to the east of the second cut.

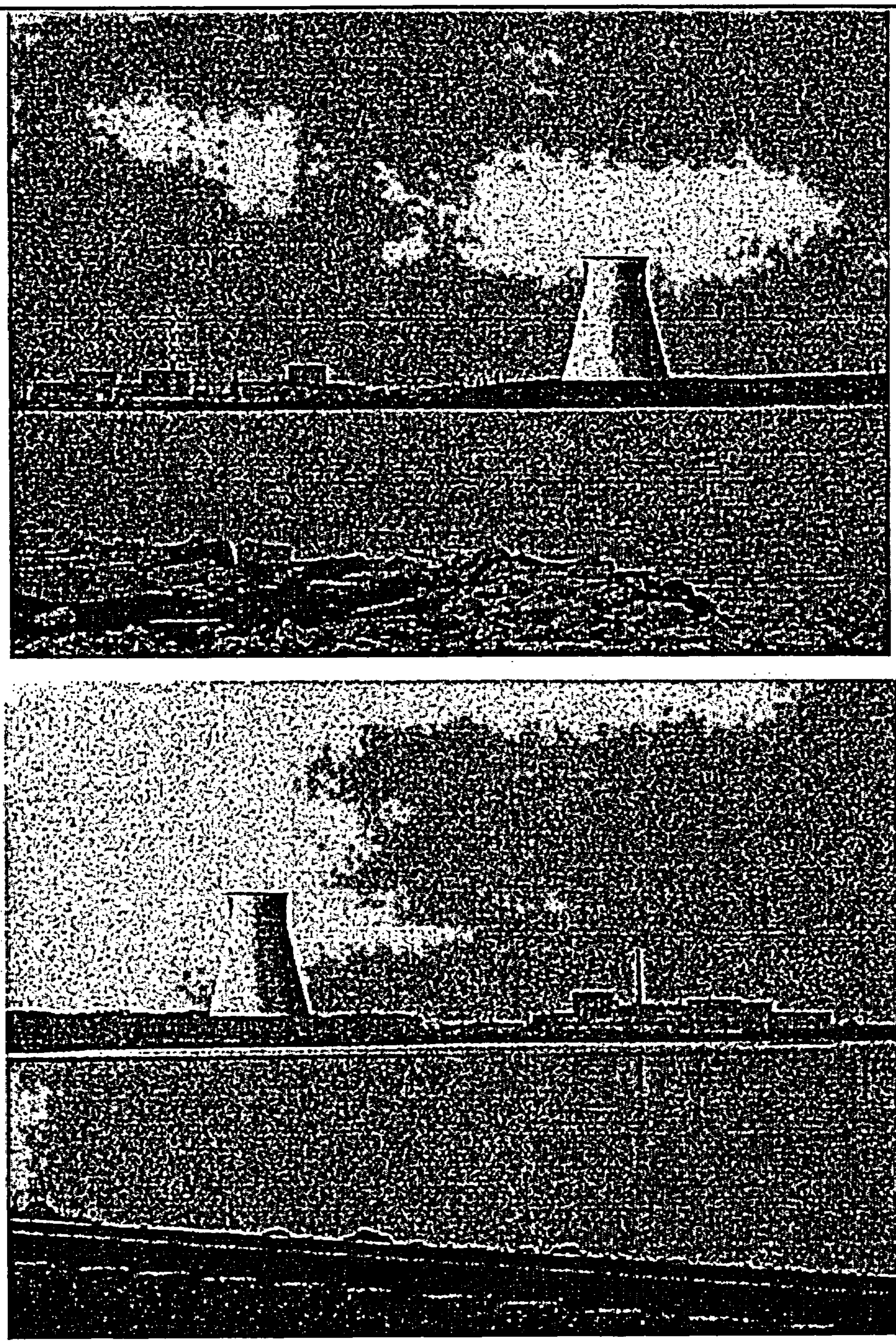


Fig. 2-4. Engineering conception to scale of a 520-foot natural draft cooling tower at MNPS as viewed (upper) from the DEP boat launch site at Pleasure Beach, Waterford (east location looking west) and (lower) at a shoreline point near the intersection of CT Routes 156 and 161 in Niantic (northwest location looking southeast).

APPENDIX A TO CHAPTER 2 OF PART II

THERMAL PLUME ANALYSIS FOR MILLSTONE POWER STATION, UNITS 2-3

Independent review performed for Dominion Nuclear Connecticut, Inc. by:

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THERMAL PLUME ANALYSIS FOR MILLSTONE POWER STATION, UNITS 2-3

by

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July 2001

Introduction

The purpose of this report is to analyze thermal plume characteristics of the Millstone Power Station under a range of operating conditions assuming its present configuration with Units 2 and 3. The analysis addresses two related objectives. The first is to determine the effects on near field mixing of reduction in heat rejection (from earlier Units 1-3 to current Units 2-3), proposed seasonal reductions in pumping (to reduce intake entrainment) and potential deliberate restrictions in cross-sectional area of the quarry cuts (to increase velocity and hence mixing). The second objective is to summarize the expected dimensions of the thermal plume in Niantic Bay for operation with Units 2-3.

Background

Millstone Power Station operates with once through cooling, discharging condenser cooling water into a quarry which then empties through a pair of openings (quarry cuts) into Niantic Bay. See Figure 1. An abbreviated history of station operation and quarry cuts is shown in Table 1.

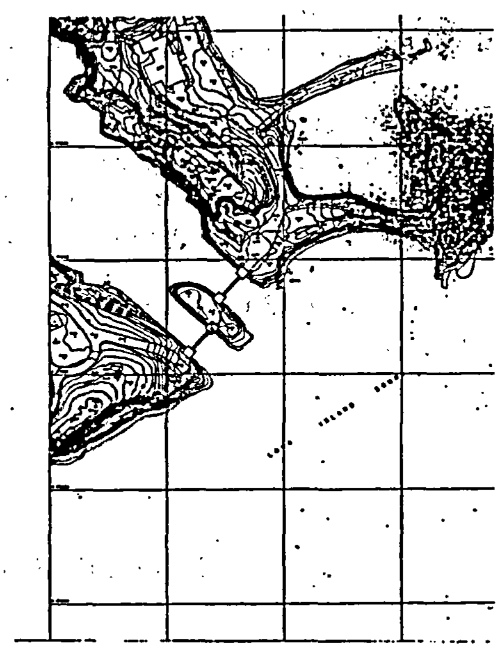

Figure 1 Sketch of discharge with two quarry cuts

Table 1 Abbreviated history of Millstone Power Station		
Pre-1983	Units 1 and 2	1 quarry cut
1983-1986	Units 1 and 2	2 quarry cuts
1986-1995	Units 1, 2 and 3	2 quarry cuts
1999-present	Units 2 and 3	2 quarry cuts

Each of the two cuts is 55 feet wide and has 11 louvres (each 5' wide) designed to prevent fish passage upstream. The cuts were sized to provide a reasonable range in discharge velocity to accommodate three-unit operation. However, since 1999 the station has been operating with only Units 2-3. The reduction in condenser flow rate, and hence discharge velocity, leads to reduced mixing of the heated water with ambient water in Niantic Bay. There is concern that the reduced mixing could cause the thermal plume to intrude into the adjacent cove to the east of the discharge, reminiscent of conditions during 1983-86 when the second quarry cut had been made but the station was operating with only Units 1-2.

In addition, to reduce intake entrainment during certain times of the year, there are possible plans to turn off one or more of the condenser pumps. This would further reduce flow rate and velocity as well as increase discharge temperature rise, leading to generally higher near field temperatures.

The 11 louvres at each cut are removable. By replacing one or more of the louvres with "blanks", the effective flow area would be reduced, promoting increased velocity and mixing. The first main objective of this report is to analyze the competing effects on near field mixing of reducing the number of units and pumps, on the one hand, and reducing the area of flow passage, on the other. A specific objective is to determine the number of blank louvres needed to effect conditions similar to those that have occurred historically, either with three units and two cuts, or earlier with two units and one cut. In this analysis it is assumed that only louvres in the east cut would be replaced with blanks and that the replacement would start from the east side of the cut.

Another main objective is to update the 3-unit thermal plume analysis of Stolzenbach and Adams (1979) to apply to Units 2-3.

Near Field Mixing

Analysis

Near field mixing is governed by a modified densimetric Froude number, F_o', defined by

$$F_o' = \frac{u_o}{\sqrt{g\beta\Delta T_o \ell_o}} \qquad (1)$$

and the discharge length scale, given by

$$\ell_o = \sqrt{A_o/2} \qquad (2)$$

where u_o is the discharge velocity, ΔT_o is the discharge temperature rise, A_o is the area of discharge opening, β is the coefficient of thermal expansion and g is gravity. In particular, Jirka et al (1981) show that the centerline dilution at the end of the near field mixing region is given by

$$S = \frac{\Delta T_o}{\Delta T_{NF}} = \left(1 + F_o'^2\right)^{1/2} \qquad (3a)$$

or, for $F_o' > 3$,

$$S \cong F_o' \qquad (3b)$$

In Eq. 3, ΔT_{NF} is the centerline excess temperature at the end of the near field mixing regions, whose length is given by

$$X_{NF} \cong 15 F_o' \ell_o \qquad (4)$$

The widths and maximum depths of the near field mixing region are also proportional to $F_o' \ell_o$.

Eqs. 1, 2 and 3 can be used to express the dilution S as

$$S = \left[1 + \frac{2^{1/2} \rho c Q_o^{\,3}}{g \beta J_o A^{5/2}}\right]^{1/2} \qquad (5a)$$

or, for $F_o' > 3$,

$$S \cong \frac{2^{1/4} (\rho c)^{1/2} Q_o^{\,3/2}}{g^{1/2} \beta^{1/2} J_o^{\,1/2} A_o^{\,5/4}} \qquad (5b)$$

In Eq. 5, Q_o is the condenser flow rate, and J_o is the heat rejection

$$J_o = \rho c Q_o \Delta T_o \qquad (6)$$

where ρc is the heat capacity of water per unit volume. The discharge area is related to the tidally varying quarry cut water depth h_o and the number of blank louvres n. For conditions after 1983 (two cuts),

$$A_o = 5(22-n)h_o \tag{7a}$$

while prior to 1983 (one cut)

$$A_o = 5(11-n)h_o \tag{7b}$$

Similarly, Eqs. 1, 2 and 4 can be used to express the near field length

$$X_{NF} \cong \frac{15(\rho c)^{1/2} Q_o^{\ 3/2}}{2^{1/4} g^{1/2} \beta^{1/2} J_o^{\ 1/2} A_o^{\ 3/4}} \tag{8}$$

and Eqs. 3, 5 and 6 can be combined to yield

$$\Delta T_{NF} = \frac{J_o}{\rho c Q_o S} = \frac{J_o}{\rho c Q_o \left(1 + \frac{2^{1/2} \rho c Q_o^{\ 3}}{g \beta J_o A^{5/2}}\right)^{1/2}} \tag{9a}$$

or, for $F_o' > 3$,

$$\Delta T_{NF} \cong \frac{g^{1/2} \beta^{1/2} J_o^{\ 3/2} A_o^{\ 5/4}}{2^{1/4} (\rho c)^{3/2} Q_o^{\ 5/2}} \tag{9b}$$

It can be seen that the near field plume characteristics depend on the number of units (J_o), the number of pumps (Q_o), the number of blank louvres (A_o or n), and the season (β).

Illustrations

A spread sheet was developed to compute sensitivity of the near field parameters given in Eqs 1-9 to variation in Q_o, J_o, n, tidal stage (h_o) and season (β). Some of these calculations are shown below.

Table 2 shows the sensitivity to the number of units, the number of quarry cuts and the number of pumps assuming no blank louvres. The first three rows are for historical conditions with two units and one cut, two units and two cuts, and three units and two cuts, respectively. The next four rows show the current configuration with Units 2 and 3 with two cuts using all ten pumps (row 4), nine pumps (row 5), eight pumps (row 6) and seven pumps (row 7). Values of flow rate per pump, discharge channel depth h_o (to compute A_o) and monthly water temperatures (to compute β) were provided by J. Foertch (personal communication).

As anticipated from Eq. 6, the condenser temperature rise (ΔT_o, column 4) increases as the number of pumps goes down. The last three columns in the table give a range of centerline dilutions (Eq. 5), centerline excess temperatures at the end of the near field (Eq. 9), and length of the near field (Eq. 8). The ranges reflect the variation due to tidal stage and season with the greatest dilutions, lowest excess temperatures, and longest lengths occurring during low tide in winter and the lowest dilutions, greatest excess temperatures and shortest lengths occurring at high tide in the summer. The table clearly indicates that, as the number of pumps is reduced, the dilution is reduced, with a corresponding increase in near field temperature and decrease in near field distance.

Table 3 shows what happens as some of the louvres are replaced with blanks, assuming Units 2 and 3 are in operation with ten pumps. Column headings remain the same as for Table 4. As the number of blank louvres increases, the effective cross-sectional area of the quarry cuts is decreased, which increases the discharge velocity. The result is an increase in dilution, a decrease in near field temperature and an increase in the length of the near field.

Table 2 Sensitivity of near field mixing to number of units, number of cuts and number of pumps

Units	Cuts	Pumps	ΔT_o	Blanks	Dilution	ΔT_{NF}	X_{NF}
1+2	1	4+4	24.0	0	2.3-3.8	6.3-10.4	570-920
1+2	2	4+4	24.0	0	1.3-1.8	13.0-18.1	340-550
1+2+3	2	4+4+6	20.2	0	2.2-3.6	6.6-9.4	740-1220
2+3	2	4+6	18.9	0	1.8-3.0	6.3-10.3	590-990
2+3	2	4+5	20.3	0	1.7-2.7	7.5-11.9	530-880
2+3	2	3+5	22.1	0	1.6-2.4	9.2-14.1	460-760
2+3	2	3+4	24.5	0	1.4-2.1	11.8-17.2	390-640

Table 3 Sensitivity of near field mixing to number of louvre blanks for Units 2-3 and 10 pumps

Units	Cuts	Pumps	ΔT_o	Blanks	Dilution	ΔT_{NF}	X_{NF}
2+3	2	4+6	18.9	0	1.8-3.0	6.3-10.3	590-990
2+3	2	4+6	18.9	1	1.9-3.2	6.0-9.8	620-1030
2+3	2	4+6	18.9	2	2.0-3.3	5.7-9.4	640-1060
2+3	2	4+6	18.9	3	2.1-3.5	5.4-9.0	660-1110
2+3	2	4+6	18.9	4	2.2-3.1	5.0-8.5	690-1150
2+3	2	4+6	18.9	5	2.4-4.0	4.7-8.0	720-1200
2+3	2	4+6	18.9	6	2.5-4.3	4.4-7.5	750-1260
2+3	2	4+6	18.9	7	2.7-4.6	4.1-7.0	790-1320
2+3	2	4+6	18.9	8	2.9-5.0	3.7-6.5	830-1390
2+3	2	4+6	18.9	9	3.1-5.5	3.4-6.1	880-1470
2+3	2	4+6	18.9	10	3.4-6.1	3.1-5.5	940-1560
2+3	2	4+6	18.9	11	3.8-6.8	2.8-5.0	1000-1660

Table 4 shows how the number of blank louvres can be chosen to create near field mixing conditions with Units 2 and 3 that approximate historical conditions with Units 1-3. The first four columns are again similar to those in Tables 2 and 3. The last three columns show the number of blank louvres needed to approximately match the dilution, the centerline excess temperature at the end of the near field, and the near field length as a function of the number of pumps. Because a reduction in the number of pumps causes a reduction in velocity and an increase in condenser excess temperature, more blanks are needed as the number of pumps is reduced. (The exact number required for a given number of pumps depends on the condition being matched. The greatest number is required to match the near field length, because that depends, from Eq. 4, on the product $F_o'\ell_o$. As blank louvres are added to increase F_o', the cross-sectional area, and hence ℓ_o, decreases, requiring a further increase in the number of blanks.) While these results were chosen to match three unit conditions with two cuts, similar results would be obtained by matching historical conditions with two units and one cut.

Table 4 Number of blank louvres to approximate historical conditions with Units 1-3

Units	Cuts	Pumps	ΔT_o	Blanks needed to match		
				Dilution	ΔT_{NF}	X_{NF}
2+3	2	4+6	18.9	3	2	5
2+3	2	4+5	20.3	5	5	8
2+3	2	3+5	22.1	7	8	10
2+3	2	3+4	24.5	9	11	11

Thermal Plume Calculations

Stolzenbach and Adams (1979) presented thermal plume contours for Units 1-3 based on a near field analysis (using similar methodology as underlies Eqs. 1-9 above) and the 2-D depth-averaged numerical model developed for the site by Liang and Tsai (1979). The methodology was calibrated to field measurements collected under station operation with Units 1-2. Figures A1a-A1d in the appendix reproduce these figures, showing temperature contours for four tidal stages under average environmental conditions and Figures A2a-A2d show similar figures for extreme conditions. Figures A3a-A3d show centerline excess temperatures for both average and extreme conditions. Based on these figures, the dimensions of various isotherms are summarized in Tables 5a-5d for different tidal conditions. The indicated range in plume dimensions reflects differences between average and extreme environmental conditions. Below, we scale these dimensions for application to the current conditions with Units 2-3 with different numbers of pumps, *assuming no blank louvres.* The scaling is somewhat different for near, intermediate and far fields.

Table 5a Lengths, widths and depths in feet of isotherms for Units 1-3 under conditions of maximum flood

Isotherm (°F)	Length	Width	Depth
12	460-720		
10	540-960		
8	700-1300		
6	1020-1820	1250	18
4	1620-2500	2050	19
1.5	11000*	6800	21

* extrapolated

Table 5b Lengths, widths and depths in feet of isotherms for Units 1-3 under conditions of slack after flood

Isotherm (°F)	Length	Width	Depth
12	400-480		
10	560-640		
8	780-1000		
6	1360-2400	1360-2400	18
4	2100-3000	1480-3000	19
1.5	4000	7410	21

Table 5c Lengths, widths and depths in feet of isotherms for Units 1-3 under conditions of maximum ebb

Isotherm (°F)	Length	Width	Depth
12	720-920		
10	920-1320		
8	1320-2120		
6	2080-4230	860-1940	17-19
4	4200-7200	1830-3400	20-22
1.5	14000*	5700	22-24

* extrapolated

Table 5d Lengths, widths and depths in feet of isotherms for Units 1-3 under conditions of slack after ebb

Isotherm (°F)	Length	Width	Depth
12	480-560		
10	720-1000		
8	1260-2000		
6	2500-4700	1420-4050	19-22
4	4800-5470	4000-5130	21-24
1.5	10830	6270	23-26

Far field scaling

In the far field, we expect passive diffusion. Because the heat transport equation is linear, excess temperatures at a given location (x, y, z) are directly proportional to the heat loading or

$$\Delta T(x,y,z) \sim J_o \tag{10}$$

Since the heat loading with Units 2-3 is approximately 73% of the three-unit loading, the predicted far field excess temperatures in Stolzenbach and Adams (1979) can be scaled proportionally. That is, at a given position (x, y, z), the three-unit excess temperature would simply be multiplied by 0.73.

As an approximation, the length and width of a given far field excess isotherm would scale as

$$length_2(\Delta T) = length_3(\Delta T) J_{oratio}^{1/2} \tag{11a}$$

$$width_2(\Delta T) = width_3(\Delta T) J_{oratio}^{1/2} \tag{11b}$$

where J_{oratio} is the ratio of heat rejection for Units 2-3 to that for Units 1-3 (0.73). Eqs. 11a and b imply that the lengths and widths of given excess isotherms with Units 2-3 would each be about $0.73^{1/2} = 0.85$ times their lengths and widths for three units. The maximum depth of any given isotherm will always occur in the near field, so there is no corresponding depth scale.

Near field scaling

Scaling in the near field is slightly more complicated and involves several steps. These steps involve computing the ratios--for conditions with Units 2-3 compared with Units 1-3--of centerline dilution at the end of the near field mixing region (S given by Eq. 5b), centerline excess temperature at the end of the near field mixing (ΔT_{NF} given by Eq. 9b), and near field length (represented by X_{NF} in Eq. 8). The ratios, in turn, depend on the ratios of Q_o, J_o, A_o (or n). Table 6 summarizes these ratios.

For each of the 3 unit near field excess temperatures in Table 5, the ΔT_{NF} ratio is used to estimate the equivalent excess temperature with Units 2-3 according to

$$\Delta T^* = \Delta T / \Delta T_{NFratio} \tag{12}$$

Because $\Delta T_{NFratio}$ is larger than one, ΔT^* will be less than ΔT. Next, results in Stolzenbach and Adams (1979) are used to compute the distances to ΔT^*. Finally, these distances are scaled by the length ratio yielding

$$length_2(\Delta T) = length_3(\Delta T^*) X_{NFratio} \quad (13a)$$

$$width_2(\Delta T) = width_3(\Delta T^*) X_{NFratio} \quad (13b)$$

$$depth_2(\Delta T) = depth_3(\Delta T^*) X_{NFratio} \quad (13c)$$

Table 6 Ratio of plume parameters between Units 2-3 and Units 1-3

Pumps	J_{oratio}	S_{ratio}	$\Delta T_{NFratio}$	$X_{NFratio}$
10	0.73	0.84	1.11	0.81
9	0.73	0.77	1.31	0.72
8	0.73	0.69	1.58	0.63
7	0.73	0.62	1.97	0.53

Intermediate field scaling

Eqs. 13 and 12 give procedures for scaling dimensions in the near and far fields, respectively. In practice, there is also a substantial transition region that we refer to as the intermediate field (Stolzenbach and Adams, 1979). Here we use the near field scaling if the predicted isotherm length given by Eq. 13 is less than X_{NF} and the far field scaling if the predicted isotherm length given by Eq. 13 is greater than 2 X_{NF}. For intermediate values of plume length, linear interpolation is used.

Results

Tables 7a-7d shows predicted lengths of the various isotherms for Units 2-3 corresponding to the lengths shown in Table 5 for Units 1-3. Results are shown for 7, 8, 9 and 10 pumps representing approximate reductions in flow rate (compared with full Unit 2-3 operation) of 23, 14, 7 and 0 percent. Again, any range in lengths reflects the difference between average and extreme environmental conditions.

The lower temperature isotherms (6, 4 and 1.5 °F) for Units 2-3 are all shorter than their three-unit counterparts, because these isotherms fall in the far field and there is less heat being rejected. The higher temperature isotherms (12, 10 and 8 °F) are more comparable with some being a bit longer, but most being shorter than their three-unit counterparts. In general, as the number of pumps decreases, a given isotherm length first increases (because of the reduced mixing and increased ΔT_o), but then decreases (due to the shorter near field length). Although not indicated, similar behavior would be expected for isotherm widths and depths—i.e., generally shorter dimensions for conditions of Units 2-3 versus conditions of Units 1-3.

References

Jirka, G.H., Stolzenbach, K.D. and Adams, E.E., 1981. "Buoyant surface jets", *J. Hydraulics Div*, ASCE 107(HY11):1467-1487.

Liang, H.X. and Tsai, C.E., 1979. "Far-field thermal plume predictions for Units 1, 2 and 3, Millstone Nuclear Power Station" NERM – 49, Stone & Webster Engineering Corporation, Boston, MA.

Stolzenbach, K. D and Adams, E.E., 1979. "Thermal plume modeling of the Millstone Nuclear Power Station", report presented to Northeast Utilities Service Company.

Table 7a Lengths of isotherms in feet for Units 1-3 and for Units 2-3 with varying numbers of pumps under conditions of maximum flood

Isotherm (°F)	Units 1-3	Units 2-3 (10 pumps)	Units 2-3 (9 pumps)	Units 2-3 (8 pumps)	Units 2-3 (7 pumps)
X_{NF}		630	570	500	420
12	460-720	390-660	420-710	480-680	490-610
10	540-960	500-860	550-860	570-820	550-820
8	700-1300	650-1100	670-1100	680-1100	610-1100
6	1020-1820	870-1550	870-1550	870-1550	870-1550
4	1620-2500	1380-2120	1380-2120	1380-2120	1380-2120
1.5	11000*	9350	9350	9350	9350

Table 7b Lengths of isotherms in feet for Units 1-3 and for Units 2-3 with varying numbers of pumps under conditions of slack after flood

Isotherm (°F)	Units 1-3	Units 2-3 (10 pumps)	Units 2-3 (9 pumps)	Units 2-3 (8 pumps)	Units 2-3 (7 pumps)
X_{NF}		590	530	460	390
12	400-480	390-450	460-550	510-550	430
10	560-640	530-620	600-670	580-540	480-540
8	780-1000	730-900	730-850	660-850	660-850
6	1360-2400	1160-2040	1160-2040	1160-2040	1160-2040
4	2100-3000	1780-2550	1780-2550	1780-2550	1780-2550
1.5	4000	3400	3400	3400	3400

Table 7c Lengths of isotherms in feet for Units 1-3 and for Units 2-3 with varying numbers of pumps under conditions of maximum ebb

Isotherm (°F)	Units 1-3	Units 2-3 (10 pumps)	Units 2-3 (9 pumps)	Units 2-3 (8 pumps)	Units 2-3 (7 pumps)
X_{NF}		630	570	500	420
12	720-920	670-840	690-780	610-780	610-780
10	920-1320	830-1120	780-1120	780-1120	780-1120
8	1320-2120	1120-1800	1120-1800	1120-1800	1120-1800
6	2080-4230	1770-3600	1770-3600	1770-3600	1770-3600
4	4200-7200	3570-6120	3570-6120	3570-6120	3570-6120
1.5	14000	11900	11900	11900	11900

Table 7d Lengths of isotherms in feet for Units 1-3 and for Units 2-3 with varying numbers of pumps under conditions of slack after ebb

Isotherm (°F)	Units 1-3	Units 2-3 (10 pumps)	Units 2-3 (9 pumps)	Units 2-3 (8 pumps)	Units 2-3 (7 pumps)
X_{NF}		590	530	460	390
12	480-560	490-650	640-690	540	410-480
10	720-1000	760-950	720-850	610-850	610-850
8	1260-2000	1100-1700	1070-1700	1070-1700	1070-1700
6	2500-4700	2120-4000	2120-4000	2120-4000	2120-4000
4	4800-5470	4080-4650	4080-4650	4080-4650	4080-4650
1.5	10830	9210	9210	9210	9210

Appendix

3-Unit Thermal Plume Predictions from Stolzenbach and Adams (1979)

Figure A1a Surface temperature rises for Units 1-3 under maximum flood conditions—average case

Figure A1b Surface temperature rises for Units 1-3 under slack after flood conditions—average case

Figure A1c Surface temperature rises for Units 1-3 under maximum ebb conditions—average case

Figure A1d Surface temperature rises for Units 1-3 under slack after ebb conditions—average case

Figure A2a Surface temperature rises for Units 1-3 under maximum flood conditions—extreme case

Figure A2b Surface temperature rises for Units 1-3 under slack after flood conditions—extreme case

Figure A2c Surface temperature rises for Units 1-3 under maximum ebb condition—extreme case

Figure A2d Surface temperature rises for Units 1-3 under slack after ebb conditions—extreme case

Figure A3a Centerline temperature rise vs distance under maximum flood conditions for average and extreme cases

Figure A3b Centerline temperature rise vs distance under slack after flood conditions for average and extreme cases

Figure A3c Centerline temperature rise vs distance under maximum ebb conditions for average and extreme cases

Figure A3d Centerline temperature rise vs distance under slack after ebb conditions for average and extreme cases

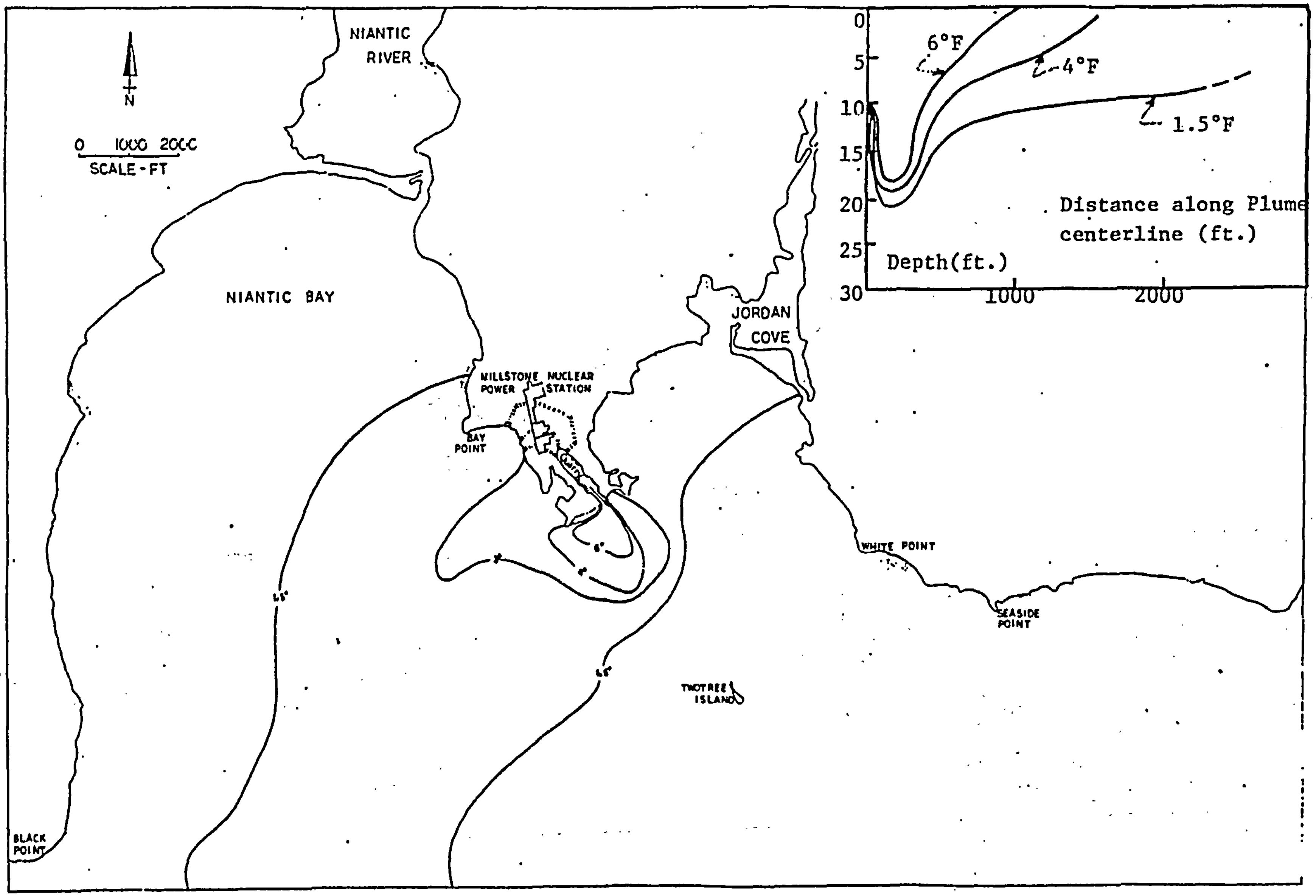

Figure A1a : Predicted Surface Temperature Rise: Maximum Flood Conditions - 3 unit operation - Average Case

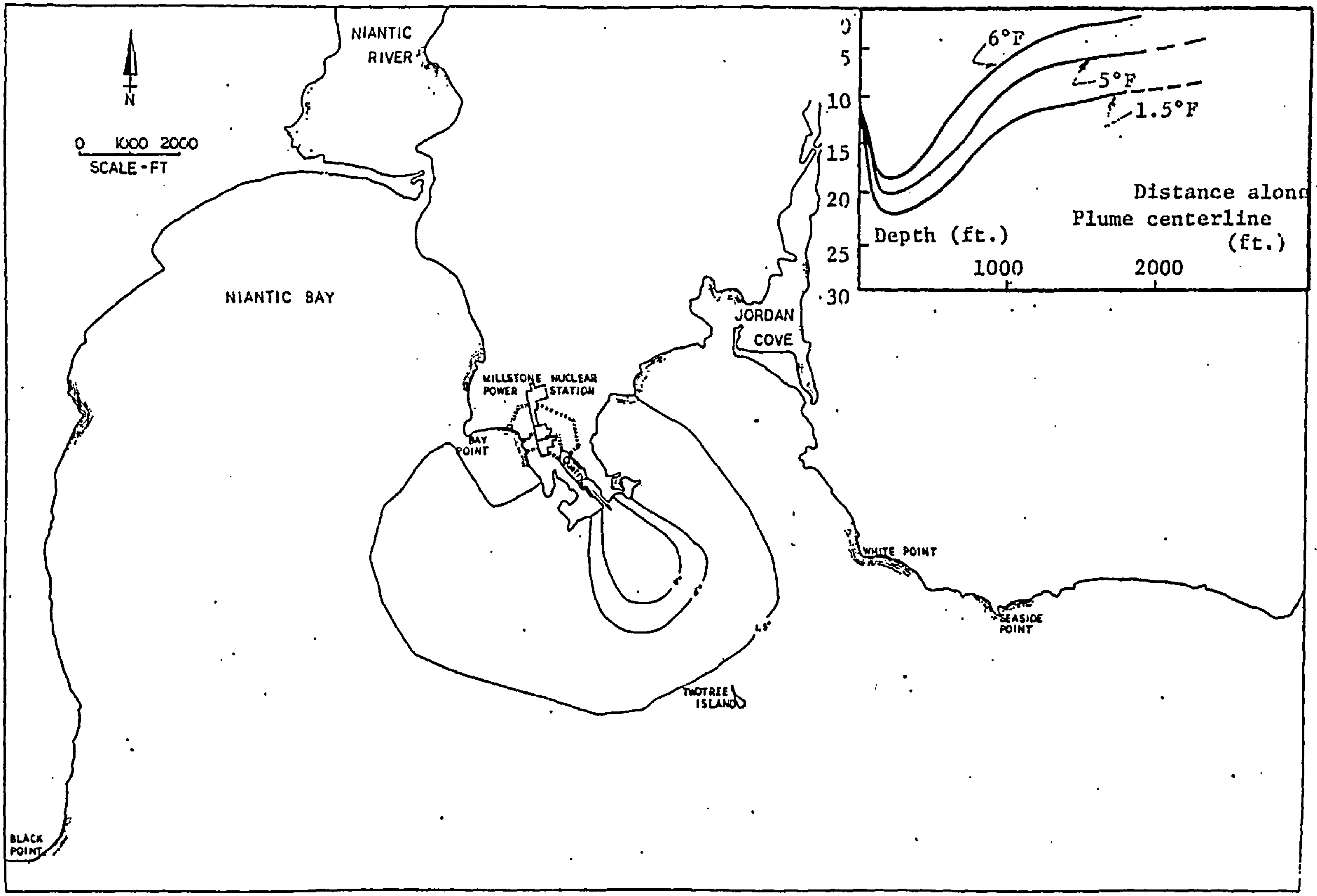

Figure A1b : Predicted Surface Temperature Rise: Slack after Flood Conditions - 3 unit operation - Average Case

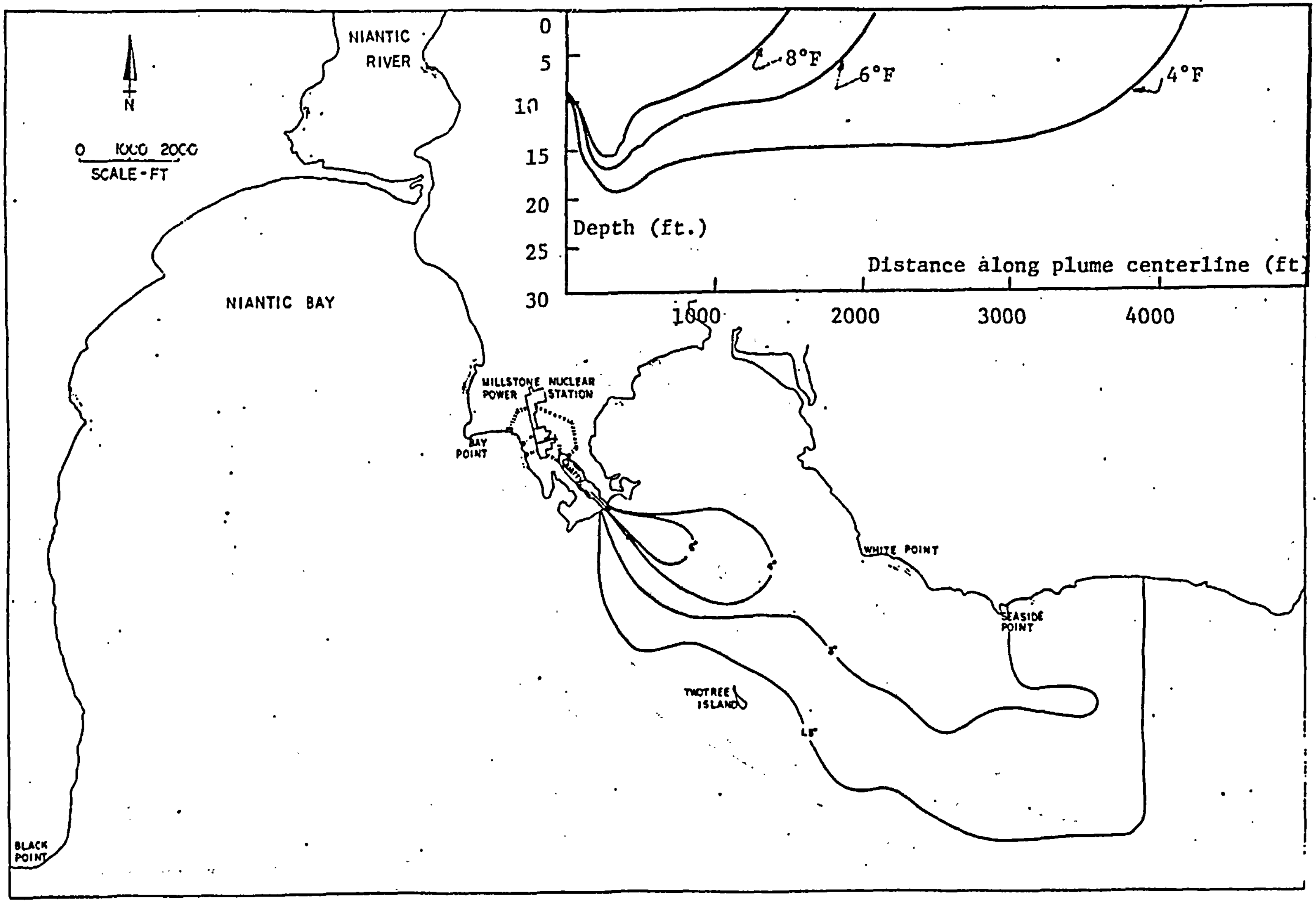

Figure A1c : Predicted Surface Temperature Rise: Maximum Ebb Conditions - 3 unit operation - Average Case

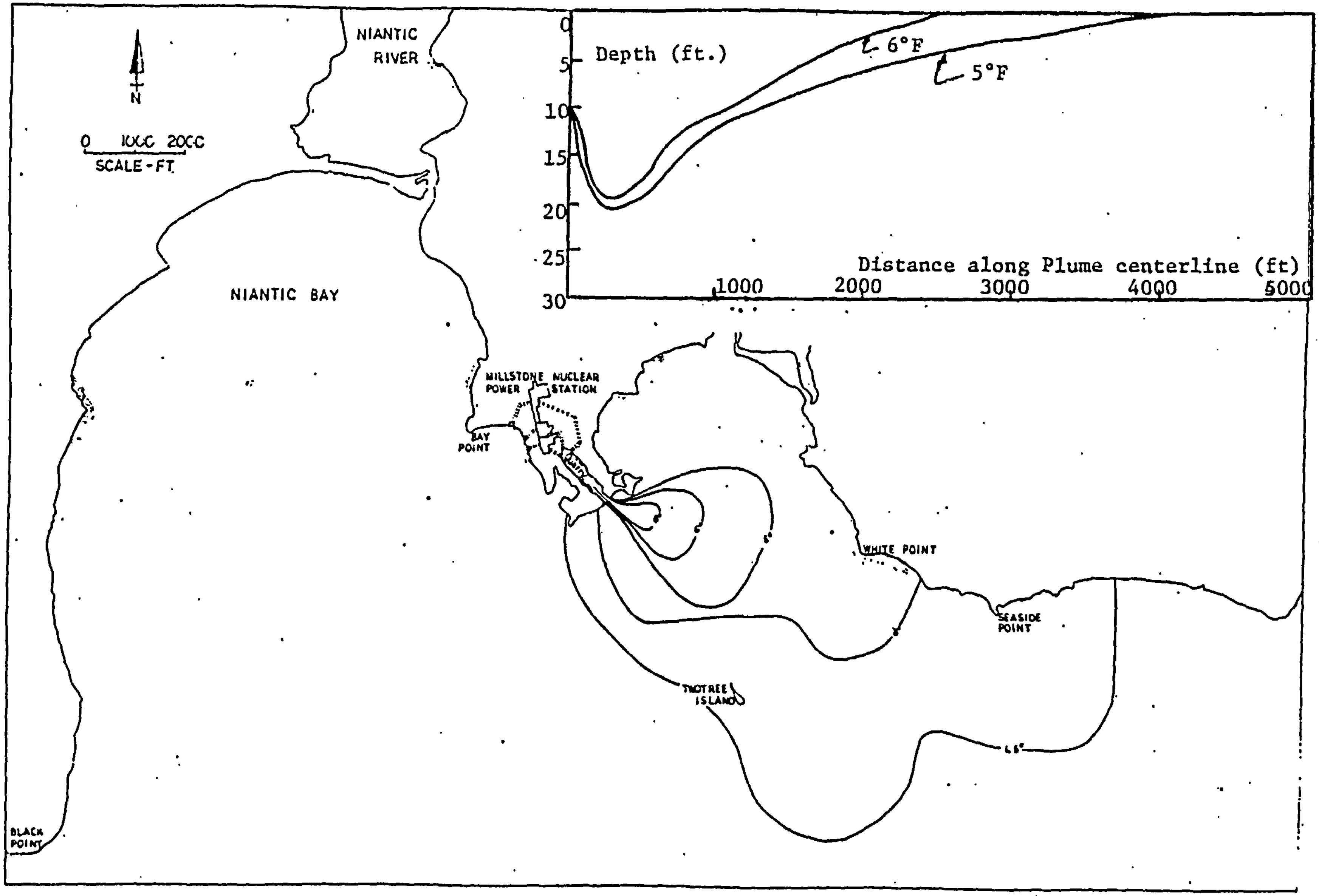

Figure A1d : Predicted Surface Temperature Rise: Slack after Ebb Conditions - 3 unit operation - Average Case

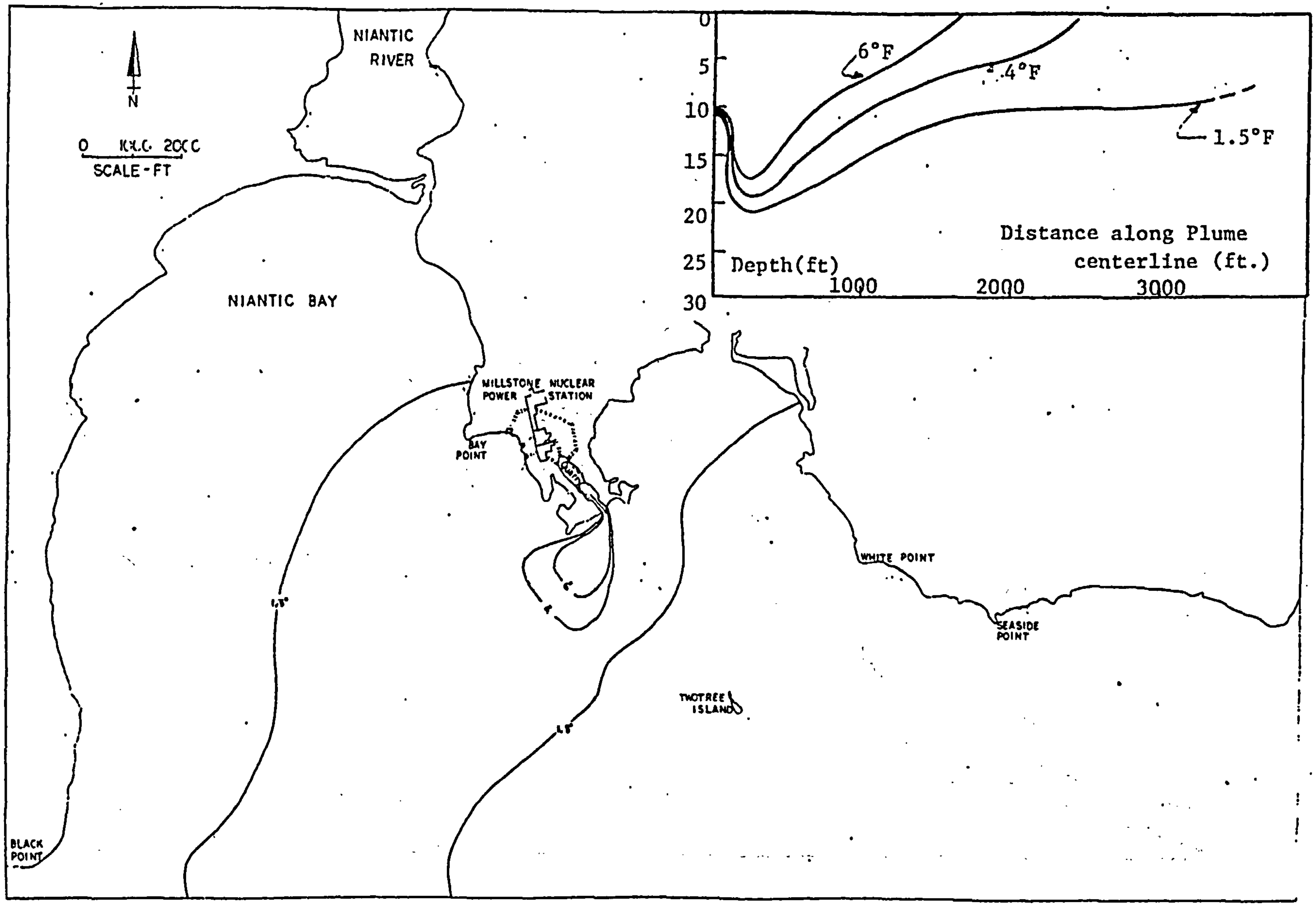

Figure A2a: Predicted Surface Temperature Rise: Maximum Flood Condition - 3 unit operation - Extreme Case

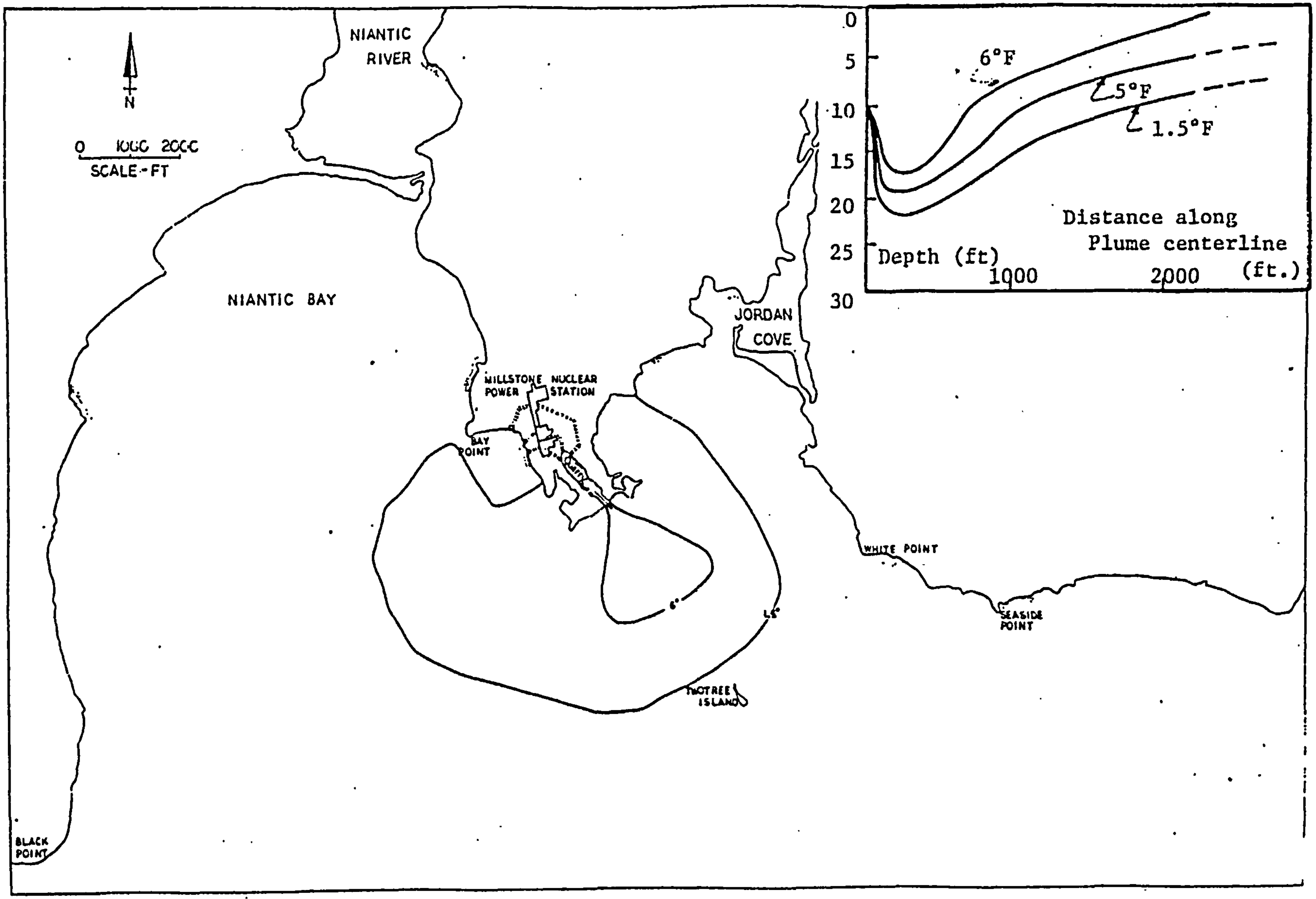

Figure A2b : Predicted Surface Temperature Rise: Slack after Flood Conditions - 3 unit operation - Extreme Case

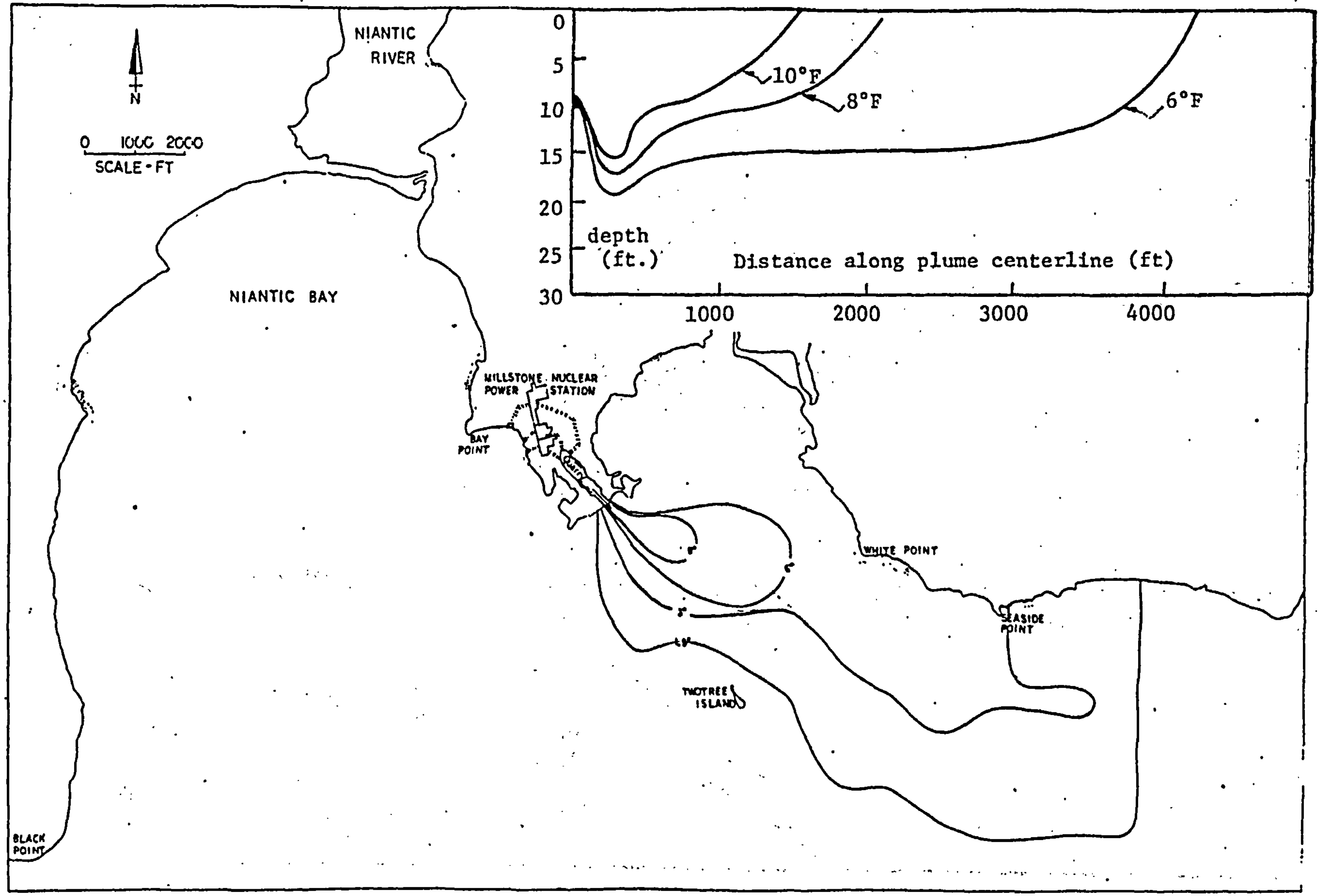

Figure A2c : Predicted Surface Temperature Rise: Maximum Ebb Conditions - 3 unit operation - Extreme Case

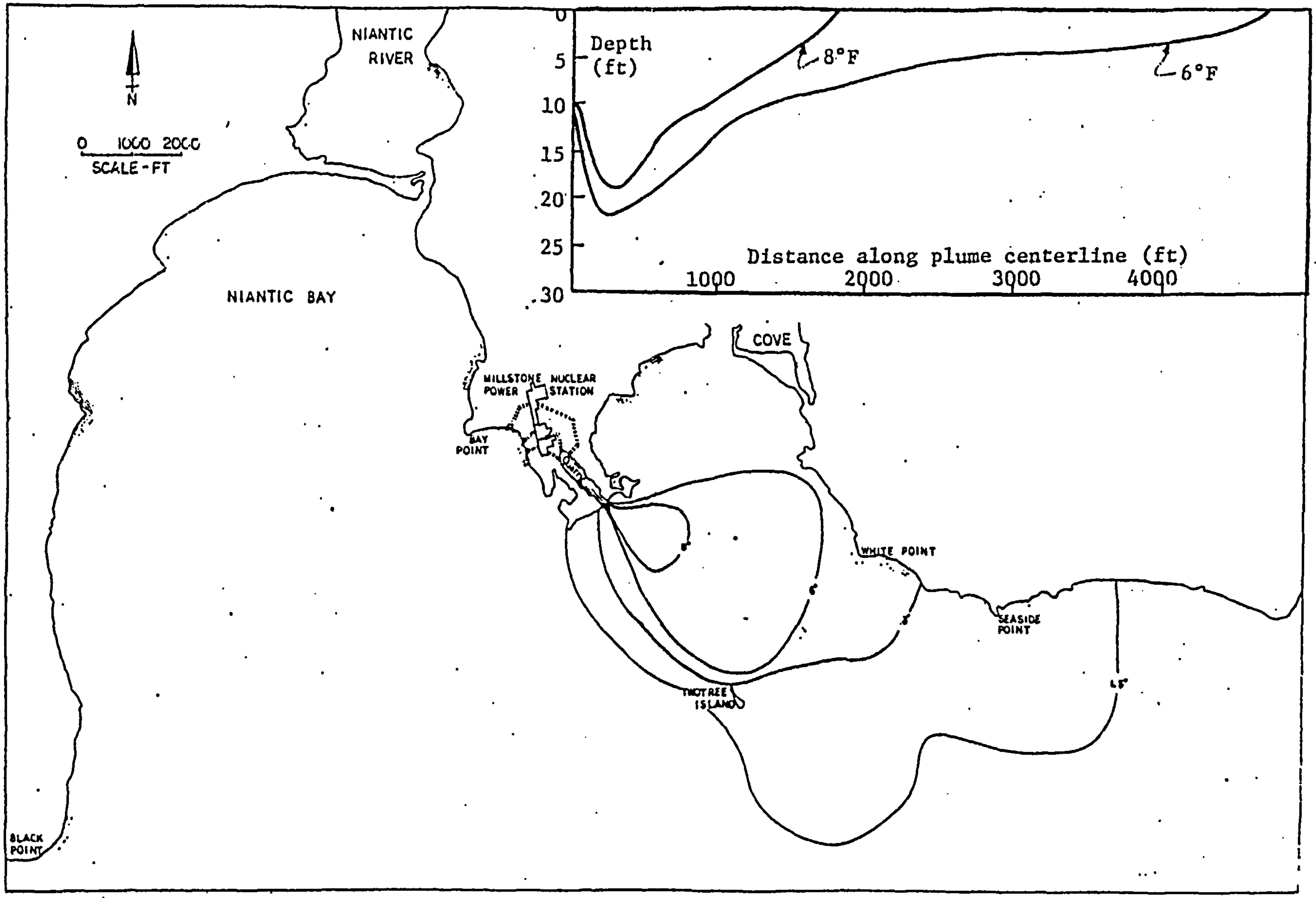

Figure A2d : Predicted Surface Temperature Rise: Slack after Ebb Condition - 3 unit operation - Extreme Case

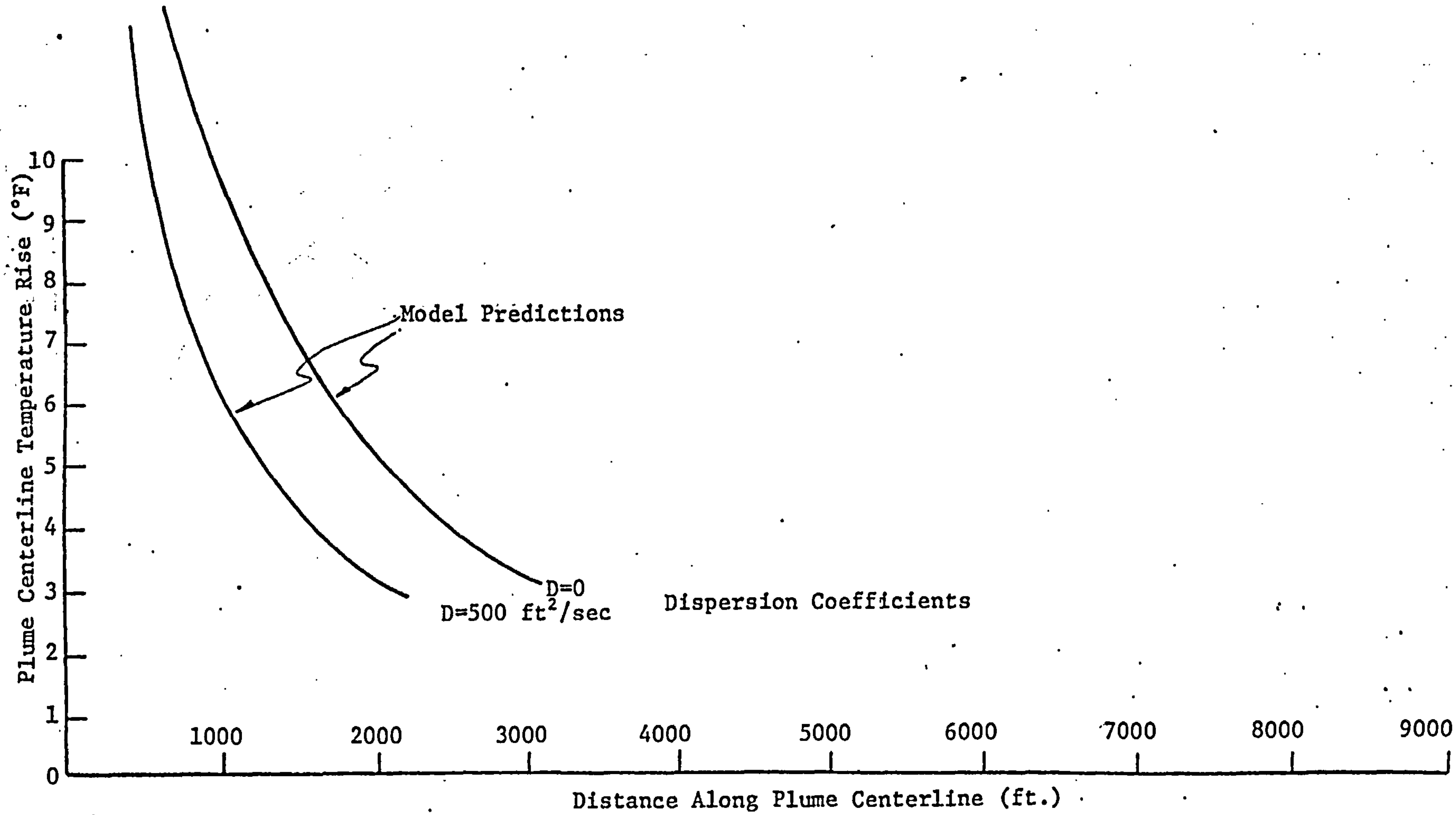

Figure A3a : Centerline temperature rise vs distance under maximum flood conditions for average and extreme cases

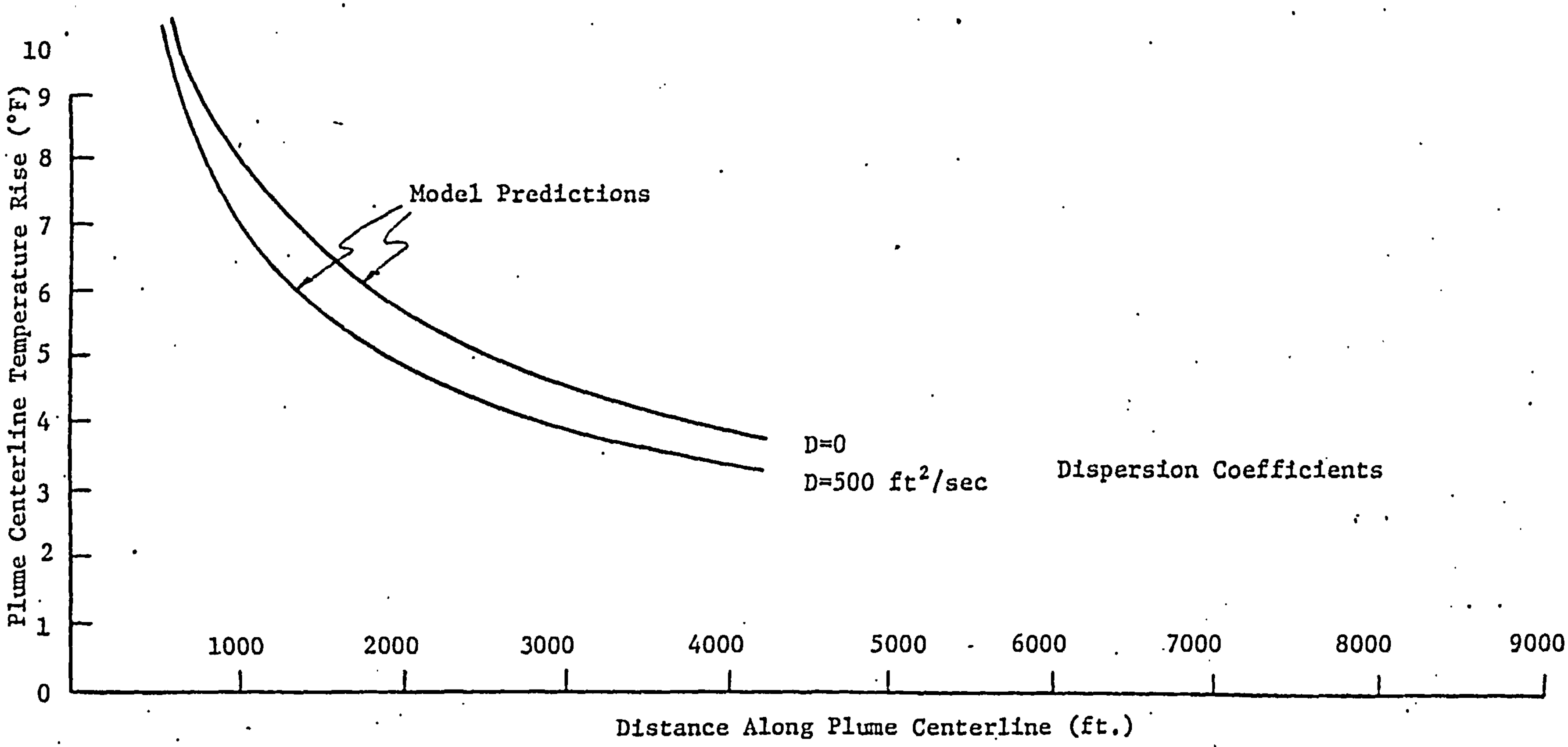

Figure A3b Centerline temperature rise vs distance under slack after flood conditions for average and extreme cases

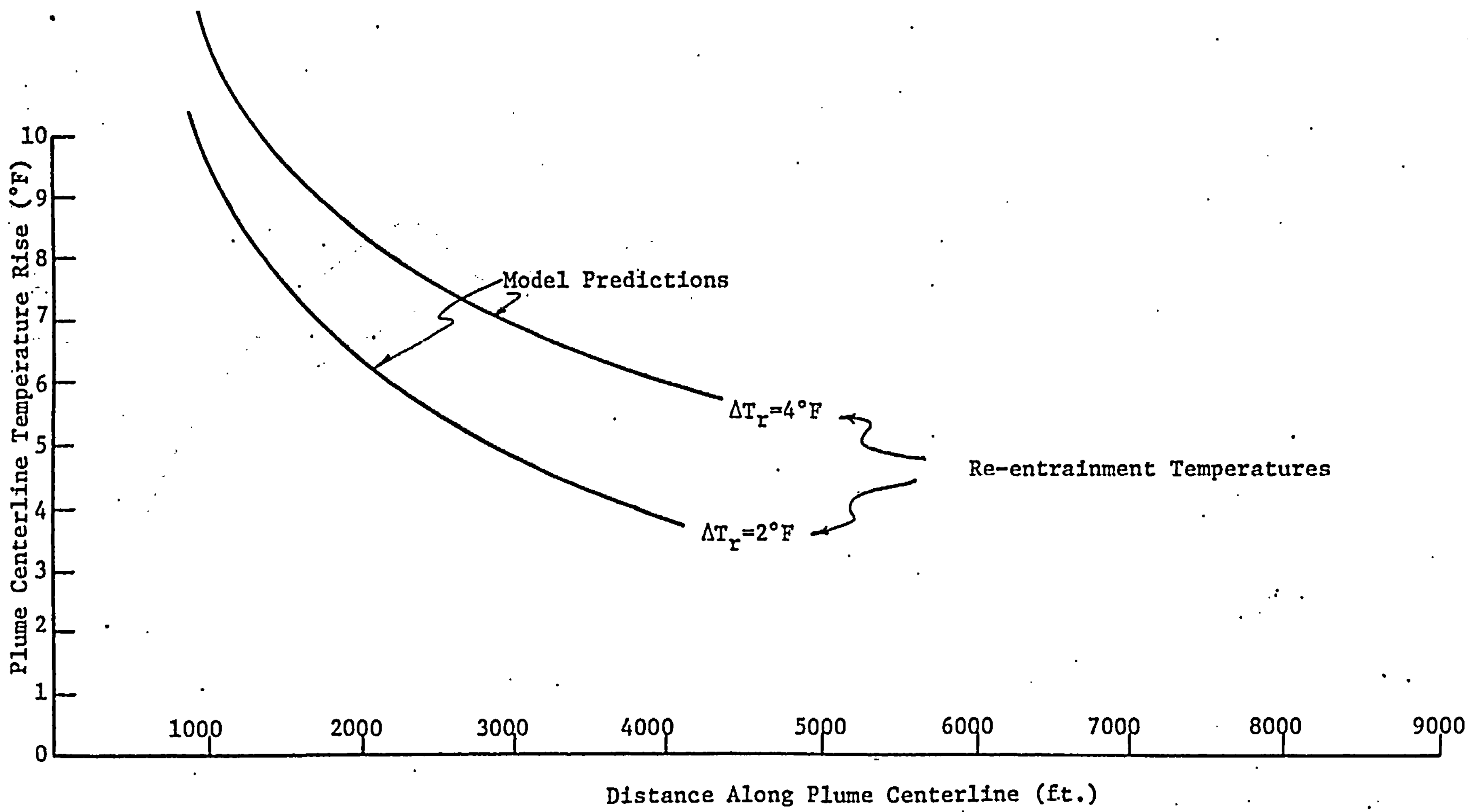

Figure A3c Centerline temperature rise vs distance under maximum ebb conditions for average and extreme cases

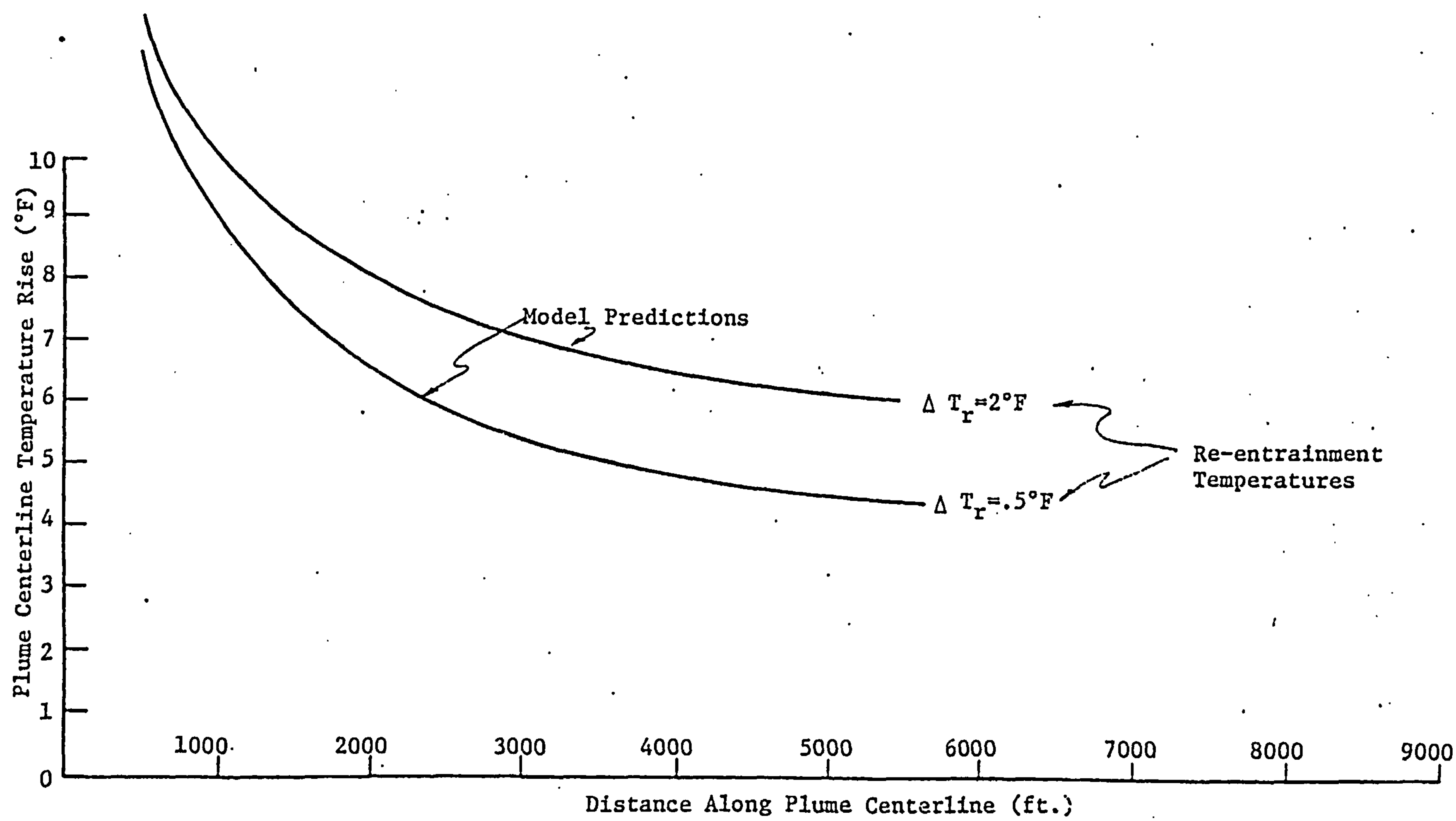

Figure A3d Centerline temperature rise vs distance under slack after ebb conditions for average and extreme cases

APPENDIX B TO CHAPTER 2 OF PART II

ADDITIONAL AIR EMISSION PROJECTIONS FOR SELECTED COOLING-WATER SYSTEM ALTERNATIVES AT MILLSTONE NUCLEAR POWER STATION

B2.1 INTRODUCTION

As a nuclear electric generating facility, Millstone Nuclear Power Station (MNPS) spares the emissions of a significant amount of air pollution and other emissions over the available alternatives. For instance, at ISO New England 1999 Marginal Emission Rates, for a single year in which MNPS Units 2 and 3 operate at an 80% capacity factor, the station would avoid the emissions of:

- approximately 14,000 tons of nitrogen oxides (NO_X);
- 58,000 tons of sulfur dioxide (SO_2); and
- more than 10,000,000 tons of carbon dioxide (CO_2).

In addition, the station spares further emissions of particulates and ash, carbon monoxide, and other hazardous air pollutants resulting from fossil-fueled generation.

Intake technology system alternatives given in Part I of this report would result in additional emissions from replacement power requirements. These replacement power requirements would result from lost electrical generation due to:

- reduced electrical output;
- extended refueling outages required by construction;
- additional internal electrical requirements due to either new pump configurations or additional pump requirements.

For each alternative scenario, total emissions are calculated for SO_2, NO_X, and CO_2. These pollutants were selected due to their roles in acid rain (SO_2 and NO_X), ground level ozone (NO_X), and global warming (CO_2).

In addition to the alternative condenser cooling-water scenarios, at the request of the Connecticut Department of Environmental Protection (DEP 2000), a scenario was included in which MNPS Units 2 and 3 are replaced by combined cycle natural gas plants. In all scenarios, including that discussed above, the assumption is made that natural gas remains sufficiently available throughout the scenario. However, because of considerable uncertainties associated with natural gas supplies three decades from now, as well as uncertainties about what form replacement power will take in the future, each scenario is carried out only to 2026. No assumptions about replacement power are made beyond that year, even though Dominion Nuclear Connecticut, Inc. is currently pursuing the possibility of 20-year license renewal for Units 2 and 3, which would enable operation until 2035 and 2045, respectively.

B2.2 ASSUMPTIONS USED IN SCENARIOS

B2.2.1 SCENARIO 1- MNPS REPLACED BY COMBINED CYCLE NATURAL GAS PLANTS

In Scenario 1, a sufficient number of new, combined-cycle gas plants would be constructed to replace power from Units 2 and 3. These gas units would be comparable to those currently in existence, and result in emissions of the following:

- SO_2: 0.005 pounds per megawatt-hour ($lbs{\cdot}MW\text{-}Hr^{-1}$)
- NO_X: 0.263 $lbs{\cdot}MW\text{-}Hr^{1}$
- CO_2: 885.0 $lbs{\cdot}MW\text{-}Hr^{1}$

In this scenario an assumption was made that both Units 2 and 3 would have operated at an annual 80% capacity factor, resulting in an annual total of 14,156,160 MWe-hours. Total emissions for the replacement gas-fueled power plants were based on this annual production of electricity, carried through to 2026 (Table B2-1).

B2.2.2 ALL OTHER SCENARIOS

A total of 22 other scenarios was developed as a means of minimizing potential entrainment impacts to fish populations. These scenarios range from changes in operations, such as turning off circulating water pumps, to significant modifications to MNPS, such as cooling towers or an offshore intake, and finally shutting the units down completely during the larval entrainment seasons at issue (discussed below; see Part II, Chapter 3 for a discussion of these seasons). Specifics of each scenario are provided in Table B2-1.

For Scenarios 2 through 13 and Scenario 23, two different seasons are considered. For the first part of each scenario, the time frame under consideration is from March 22 to June 5 each year, concurrent with the primary winter flounder larval season (see Part II, Chapter 3, Section 3.2.4). For the second part of these scenarios, the time frame under consideration is from March 22 to August 22 each year, to accommodate both the entire winter flounder and tautog entrainment seasons. Additionally, some of these scenarios entail outage extensions required for construction or equipment installation. Replacement power during these extensions is included in the emission calculations. Note that, for scenario 13, the pump electricity savings exceed the lost power output, resulting in an actual savings of emissions due to decreased station power requirements. For Scenarios 19 and 20 (installation of an offshore intake), two factors are considered:

- additional pump energy requirements, and
- construction time that results in an additional five months of outage time in 2007

For Scenarios 21 and 22, (installation of fine-mesh screens), only the construction time is considered.

A significant amount of uncertainty is associated with projections of replacement power emissions several years into the future. Numerous factors add to this uncertainty, including:

- future availability of fossil fuel supplies;
- projected growth in demand for electricity;
- future economics of the various alternatives;
- role of future technologies in power supply.

Because of the uncertainties, as discussed in the Introduction to this appendix, replacement power scenarios were carried out only to the year 2026 and any replacement power requirements after that year were not included, although with a license extension Unit 2 would operate until 2035 and Unit 3 until 2045.

Two methodologies were selected in determining the emissions from alternative power supplies. The result of the methodologies is a range of emissions for each scenario. The two methodologies used to determine the range of possible emissions are:

- Method 1: From the year 2000 to 2026, Marginal Emission Rates (emission rates for those plants that would be used to replace the next power plant to go off-line) would transition from actual 1999 Marginal Emission Rates as determined by ISO-New England (Hodgdon and Tsikirayi 2001) to a complete change-over by 2026 to Conceptual Natural Gas-fired Combined Cycle Plants with Best Available Control Technology.
- Method 2: Year 2000 rates (taken from the U.S. Environmental Protection Agency, Acid Rain Program, Clean Air Markets Division website, Year 2000 Scorecard for State of Connecticut) are based on a mix of emission rates from existing Connecticut fossil plants that are listed in the U.S. EPA's Acid Rain Program Emission Tracking System (selected as being representative of regional replacement power). Future projected growth of 2% per year in electricity demand (through 2026) is accomplished by building Natural Gas-fired Combined Cycle Plants with emissions equal to identical existing plants. Beginning in 2003 (RCSA Section 22a-174-19a), existing Connecticut coal and oil fossil plants achieve a statewide limit on SO_2 emissions of 0.3 $lbs \cdot mmbtu^{-1}$ (millions of British thermal units). Beginning in 2004 (RCSA Section 22a-174-22b), existing Connecticut coal and oil fossil plants achieve statewide limit on NO_X emissions of 0.15 $lbs \cdot mmbtu^{-1}$. Total emissions associated with each scenario to 2026 are summarized in Table B2-1.

Note that in Part I of this report, the analyses applied only engineering considerations in the calculations for flow reduction alternatives. In these analyses, the MWe-hours lost were calculated disregarding station procedures and practices that limit generation when flow is reduced so as to not exceed present NPDES Permit ΔT limitations. Thus, in this appendix the MWe-hours lost and resulting air emissions totals are conservative because they do not take this downpowering into consideration. However, exemption from present ΔT limits would make the calculations more applicable to the particular alternative modeled.

B2.3 CONCLUSIONS

Most alternative reduced-flow options result in additional air pollutant emissions, due to the combination of factors discussed above. For perspective on the air emissions presented in Table B2-1, the NO_X Budget Program's 2000 ozone season NO_X emissions for the entire State of Connecticut was a total of 4,697 tons. By comparison, at the ISO New England 1999 Marginal Emission Rate, MNPS Units 2 and 3 would annually spare the emission of more than 14,000 tons of NO_X, nearly 6,000 tons of which would be saved during each ozone season.

Also for perspective on the total emissions in Table B2-1, total Greenhouse Gas emissions in 1995 for the entire State of Connecticut, all sectors, were 43,015,970 tons of CO_2 Equivalent (TCDE). Note that TDCE is an index which takes into consideration the heat-trapping characteristics of the individual greenhouse gases. All of the greenhouse gas emissions are converted to a CO_2 Equivalent.

Shutting down MNPS Units 2 and 3 for the primary winter flounder larval season (March 22-June 5) or the entire combined larval winter flounder and tautog seasons (March 22-August 22) would result in the greatest amount of emissions over the course of the scenario (from 2003 to 2026), including:

- for the 76 days of the primary larval winter flounder entrainment season:
  - from 95,210 to 162,309 tons of SO_2;
  - from 42,235 to 54,945 tons of NO_X; and
  - from 48,665,349 to 73,418,442 tons of CO_2.
- for the 154 days of the combined winter flounder and tautog entrainment seasons:
  - from 192,925 to 328,889 tons of SO_2;
  - from 85,582 to 111,336 tons of NO_X; and
  - from 98,611,365 to 148,768,948 tons of CO_2.

Replacement of MNPS Units 2 and 3 with Combined Cycle Natural Gas plants would result in the next-greatest amount of emissions over the course of the scenario (from 2005 to 2026), including 40,954 tons of NO_X, and 137,810,218 tons of CO_2. This would include more than 1,800 tons of NO_X annually, approximately 750 tons of which would occur during the ozone season.

B2.4 REFERENCES

DEP (Connecticut Department of Environmental Protection). 2000. Letter C09872 dated February 16, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Comments on proposed cooling water alternatives scope of study.

Environmental Research Institute and Department of Natural Resources Management and Engineering, University of Connecticut. 1999. Connecticut's 1990 and 1995 greenhouse gas emission inventory.

Hodgdon, S. S., and Tsikirayi, E. K. 2001. 1999 NEPOOL Marginal Emission Rate Analysis. ISO New England, Inc., Holyoke, MA.

Nelson, C. 2001. NOx Budget Program 2000 Recap. Connecticut Department of Environmental Protection.

RCSA 22a-174. Air pollution abatement regulations.

U.S. Environmental Protection Agency, Acid Rain Program, Clean Air Markets Division website, Year 2000 Scorecard for State of Connecticut.

TABLE B2-1. Additional air emissions resulting from replacement power requirements associated with the imposition of various intake cooling-water technology alternatives at MNPS.

Scenario number and description	Season	SO_2 (tons)	NO_X (tons)	CO_2 (tons)
1—MNPS Units 2 and 3 are replaced with Combined Cycle Natural Gas Units. Scenario begins in 2005.	All Year	779	40,954	137,810,218
2—Unit 3 operates with 5 circulating water pumps. Scenario begins in 2003.	3/22-6/5	81 to 138	36 to 47	41,368 to 62,410
	3/22-8/22	397 to 677	176 to 229	202,957 to 306,189
3—Unit 3 operates with 4 circulating water pumps. Scenario begins in 2003.	3/22-6/5	322 to 549	143 to 186	164,653 to 248,403
	3/22-8/22	1,207 to 2,058	536 to 697	617,034 to 930,882
4—Unit 3 operates with 5 circulating water pumps, with condenser cross-connect to reduce risk of shutdown. Two-month outage extension in 2004. Scenario begins in 2004.	3/22-6/5	2,249 to 5,922	1,223 to 1,440	1,220,328 to 1,508,364
	3/22-8/22	2,532 to 6,372	1,383 to 1,559	1,363,893 to 1,730,088
5—Unit 3 operates with 4 circulating water pumps, with condenser cross-connect to reduce risk of shutdown limits. Two-month outage extension in 2004. Scenario begins in 2004.	3/22-6/5	2,460 to 6,257	1,342 to 1,529	1,327,196 to 1,673,412
	3/22-8/22	3,247 to 7,510	1,789 to 1,858	1,726,688 to 2,290,396
6—Unit 2 operates with 3 circulating water pumps. Scenario begins in 2003.	3/22-6/5	86 to 147	38 to 50	44,036 to 66,435
	3/22-8/22	4,768 to 8,129	2,115 to 2,752	2,437,336 to 3,677,059
7—Unit 2 operates with 3 circulating water pumps, with condenser cross-connect. Scenario begins in 2005. Two-month outage extension in 2005.	3/22-6/5	1,685 to 4,309	920 to 1,032	911,426 to 1,148,019
	3/22-8/22	5,654 to 10,389	2,647 to 3,177	2,916,871 to 4,282,908
8—Unit 3 reduces flow by throttling Condenser Discharge Valves. One half-month outage extension in 2004 for modifications. Scenario begins in 2004.	3/22-6/5	723 to 1,611	400 to 401	382,353 to 516,589
	3/22-8/22	1,453 to 2,773	707 to 814	752,879 to 1,088,835

TABLE B2-1 (continued).

Scenario number and description	Season	SO_2 (tons)	NO_X (tons)	CO_2 (tons)
9—Unit 2 reduces flow by throttling Condenser Discharge Valves. Scenario begins in 2005.	3/22-6/5	21 to 34	9 to 12	10,766 to 16,627
	3/22-8/22	127 to 203	53 to 72	64,617 to 99,796
10—Unit 3 operates with condenser bypass lines. Scenario begins in 2004.	3/22-6/5	299 to 493	129 to 169	152,346 to 232,517
	3/22-8/22	1,057 to 1,744	456 to 599	538,552 to 821,962
11—Unit 2 operates with condenser bypass lines. Scenario begins in 2005	3/22-6/5	12 to 20	5 to 7	6,342 to 9,794
	3/22-8/22	110 to 174	46 to 62	55,581 to 85,841
12—Unit 3 installs variable speed circulating water pumps. Scenario begins in 2004.	3/22-6/5	172 to 283	74 to 97	87,454 to 133,476
	3/22-8/22	797 to 1,315	344 to 452	406,161 to 619,900
13—Unit 2 installs variable speed circulating water pumps. Scenario begins in 2005.	3/22-6/5	(61) to (97)	(25) to (35)	(30,873) to (47,681)
	3/22-8/22	(40) to (64)	(17) to (23)	(20,319) to (31,382)
14—Unit 3 installs 100% capacity, Natural Draft Cooling Towers. Scenario begins in 2007. Five-month outage extension in 2007.	All Year	12,916 to 23,595	6,063 to 7,266	6,665,327 to 9,820,148

TABLE B2-1 (continued).

Scenario number and description	Season	SO_2 (tons)	NO_X (tons)	CO_2 (tons)
15—Unit 3 installs 67% capacity, Natural Draft Cooling Towers. Scenario begins in 2007. Five-month outage extension in 2007.	All Year	7,722 to 16,287	4,092 to 4,298	4,064,270 to 5,651,616
16—Unit 3 installs 100% capacity, Mechanical Draft Cooling Towers. Scenario begins in 2007. Five-month outage extension in 2007.	All Year	9,796 to 19,205	4,879 to 5,483	5,102,737 to 7,315,895
17—Unit 2 installs 100% capacity, Natural Draft Cooling Towers. Scenario begins in 2006. Five-month outage extension in 2006-2007.	All Year	6,313 to 13,431	3,392 to 3,510	3,325,710 to 4,604,585
18—Unit 2 installs 100% capacity, Mechanical Draft Cooling Towers. Scenario begins in 2006. Five-month outage extension in 2006-2007.	All Year	7,273 to 14,901	3,783 to 4,057	3,810,796 to 5,362,866
19—Offshore Intake Structure constructed for Unit 3. Five-month outage extension in 2007. Scenario begins in 2007.	All Year	5,392 to 13,009	2,966 to 3,208	2,897,435 to 3,781,610
20—Offshore Intake Structure constructed for Units 2 and 3. Five-month MP3 outage extension in 2007. Five-month MP2 outage extension in 2008. Scenario begins in 2007.	All Year	9,324 to 22,098	5,136 to 5,446	5,004,065 to 6,573,285
21—Fine-Mesh Screens for Unit 3. Five-month outage extension in 2007 for construction. Scenario involves 2007 Unit 3 replacement power emissions only.	5-Month Construction Period	5,120 to 12,627	2,811 to 3,105	2,761,380 to 3,563,565
22—Fine-Mesh Screens for Unit 2. Five-month outage extension in 2006-2007. Scenario involves Unit 2 replacement power emissions only.	5-Month Construction Period	3,904 to 9,741	2,140 to 2,412	2,108,462 to 2,701,797
23—Shut down both units for entire season. Scenario begins in 2003.	3/22-6/5	95,210 to 162,309	42,235 to 54,945	48,665,349 to 73,418,442
	3/22-8/22	192,925 to 328,889	85,582 to 111,336	98,611,365 to 148,768,948

PART II - CHAPTER 3

THE ENTRAINMENT OF FISH EGGS AND LARVAE AT MILLSTONE NUCLEAR POWER STATION

3.1 INTRODUCTION

The purpose of this chapter is to provide information on seven selected species having early life history stages entrained at Millstone Nuclear Power Station (MNPS). These data are used in quantitative analyses and for inferences made about entrainment impact found in Chapter 4. For each species, information is provided on MNPS studies and regulatory interest; spawning and early life history; natural mortality of early life history stages; annual entrainment at MNPS, including a quantification of the entrainment season; entrainment survival, and sources of entrained larvae. By far, most information is available for winter flounder, which is the first species addressed below in Section 3.2 and in Appendices A-C to Chapter 3. In more recent years, additional work beyond routine monitoring has also been completed for tautog and this species is the focus of Section 3.3. The remaining five species (Atlantic menhaden, anchovies, grubby, cunner, and American sand lance) are discussed together in Section 3.4.

3.2 WINTER FLOUNDER

3.2.1 Background

Since 1973, the winter flounder has been the focus of detailed environmental impact studies by Northeast Utilities Service Company (NUSCO) because of the importance of this species to the sport and commercial fisheries of Connecticut (Smith et al. 1989) and its abundance in the local demersal fish community. The population of winter flounder spawning in the nearby Niantic River has been studied primarily to assess the long-term effect of MNPS operation on the size of this stock; details of ongoing work may be found in NUSCO (2000a) and DNC (2001a). The mortality of entrained winter flounder larvae potentially has greater significance than for many other local species because many winter flounder larvae are products of local spawning in the Niantic River. Because winter flounder have geographically isolated stocks associated with individual estuaries or specific coastal areas (Lobell 1939; Perlmutter 1947; Saila 1961), losses may be disproportionately represented by a local spawning stock. Winter flounder larvae have been collected regularly at a station in Niantic Bay since 1979 and in the Niantic River at three stations since 1983 (Fig. 3-1). The long-term sampling programs at MNPS have provided information on the abundance, distribution, development, growth, and mortality of larval winter flounder. Larval sampling for specific purposes also has been undertaken periodically (Table 3-1). A complete history and evolution of various sampling programs of NUSCO winter flounder studies up to that time was given in NUSCO (1987a). Current descriptions of MNPS winter flounder studies, including the sampling programs, methodologies of data analyses, and detailed results, have been

given in the series of Annual Reports of the monitoring programs (e.g., DNC 2001a). Also, relatively complete synopses of information on winter flounder life history may be found in Klein-MacPhee (1978) and Pereira et al. (1999). Distribution of winter flounder taken by the CT DEP trawl survey in LIS by depth and bottom type was given in Gottschall et al. (2000).

Estimates of the long-term effect of MNPS operation were made several times since 1976 using various impact assessment models as part of licensing requirements of the Connecticut Department of Environmental Protection (DEP) and other state and federal agencies. Initially, effects of entrainment and impingement were considered together in the initial MNPS 316(b) demonstration (NUSCO 1976). The larval entrainment portion of the deterministic model used to assess impact in NUSCO (1976) was based on work completed by the University of Rhode Island (URI), which was summarized by Hess et al. (1975) and Saila (1976). Based on the few years of information available at that time, impingement was considered to be the most detrimental impact. An 18% reduction was predicted for the Niantic River winter flounder population after 35 years of three-unit operation, with one-third of this effect attributed to larval entrainment and the rest to impingement. The next formal application of an assessment model was for the Unit 3 Environmental Report-Operating License Stage (NUSCO 1983b), which was prepared for the U.S. Nuclear Regulatory Commission and was also reviewed by other federal and state agencies. As data from additional years of operating experience were then available and because of the actual or planned operation of fish return sluiceways at Units 1 and 3, impingement was determined to have little long-term significance in this particular analysis. Larval entrainment was the primary focus for impact assessment and a potential 5 to 6% reduction in the Niantic River winter flounder population was predicted after 35 years of three-unit operation using the URI model with the updated information.

After 1982, adult winter flounder abundance began to decline in Connecticut and elsewhere in the northeastern United States, even though juvenile winter flounder of some year-classes were apparently abundant (Howell et al. 1992; Simpson et al. 1996; Desfosse et al. 1998; NUSCO 2000a; DNC 2001a). During the late 1980s, as abundance decreased further, winter flounder studies at MNPS were the subject of increased review by DEP. This resulted in several meetings among DEP and NUSCO personnel to discuss the situation and the potential relation between MNPS operation and decreasing winter flounder abundance. In addition to Annual Reports regularly submitted in April (e.g., DNC 2001a for winter flounder), annual updates of winter flounder abundance were presented to the DEP each October, beginning in 1988 and continuing through 1993. Furthermore, also beginning in 1988 was a series of special reports and model impact assessment simulations sent to the DEP (Table 3-2). Along with the increased emphasis on winter flounder studies during this period was the development of the NUSCO stochastic population dynamics model (SPDM), which has been used for assessment of long-term impacts. The SPDM assesses effects of MNPS operation on the Niantic River population by simulating the long-term effects of historical and projected rates of fishing mortality and simultaneous annual production losses due to larval entrainment. The rate of production loss was determined indirectly from mass-balance calculations used to estimate annual fractions of larvae from the Niantic River population

that were entrained. The SPDM also includes the relatively minor effect of impingement of juvenile and adult winter flounder, which is implemented as additional fishing mortality. A complete description of the model and its use in assessing the effectiveness of potential reduction in entrainment rates as a result of various cooling-water alternatives is given in Chapter 4.

3.2.2 Spawning and Early Life History

Most adult winter flounder enter inshore waters in late fall and early winter and spawn nocturnally in upper portions of estuaries during late winter and early spring at temperatures between 34 and 50°F (peaking at 35.5-41°F) and at salinities of 10 to 35‰ (Bigelow and Schroeder 1953; Pearcy 1962; Scarlett and Allen 1992; Stoner et al. 1999). Three years are required for oocyte maturation and one batch of eggs matures each year (Dunn and Tyler 1969; Dunn 1970; Burton and Idler 1984). Spawning behavior in a large experimental laboratory aquarium was described by Stoner et al. (1999). In eastern Long Island Sound (LIS), females begin to mature at age-3 and 4 and males at age-2 (NUSCO 1987a), although Johnson et al. (1998) reported that a small percentage of both age-2 females and age-1 males in LIS were mature. Adult winter flounder spawn in this area from January through April and information on winter flounder spawning in LIS was given in Howell and Molnar (1996, 1998). Local spawning takes place in the mid to upper Niantic River with little or no reproduction in Niantic Bay. At present, average fecundity of Niantic River females was calculated as approximately 583,000 eggs per female (DNC 2001a). In an earlier (1978-79) study in the Shoreham area of central LIS, mean fecundity was reported as 715,407 (GEOMET Technologies, Inc. 1980). Winter flounder population size was shown by Howell (1993) to be related to the area of the habitat producing them. Of the fourteen areas shown in Howell (1993), the Niantic River was third smallest in area and with a commensurately relatively small abundance.

Following spawning, larval development proceeds through several distinct early life history stages, which are briefly summarized in Table 3-3. The demersal eggs hatch from 5 to 31 days with greatest viable hatch at 37.4°F and salinities of 15 to 35‰ and decreases at increasing temperature (Rogers 1976). Keller and Klein-MacPhee (2000) reported hatching on 20 days at about 39°F and 30 days at about 35°F. Development of larvae through metamorphosis takes about 6 to 8 weeks, depending upon water temperature (Laurence et al. 1979). Small larvae are planktonic and although many remain near the estuarine spawning grounds, others are carried into coastal waters by tidal currents. Some of the displaced larvae are returned to the estuary on subsequent incoming tides, but many of them are swept away from the area into deeper coastal waters, where their survival may be reduced (Smith et al. 1975; NUSCO 1989; Crawford 1990). Following fin ray development, older and larger larvae maintain some control over their position by vertical movements and also may spend considerable time on the bottom. At metamorphosis, young-of-the-year winter flounder become wholly demersal and many move into shallow inshore waters. Survival is greatest in appropriate nursery areas (e.g., shallow waters of estuaries), such as within the Niantic River. Locally, sampling during a 5-year period (1988-93) showed that survival of settled juveniles was very poor outside of the river

in Niantic Bay (NUSCO 1994b) and Steves et al. (1999) found only one winter flounder juvenile out of more than 15 thousand age-0 fish of many species collected on the New York Bight continental shelf. Further detailed information on the habitat requirements of larvae and demersal juvenile winter flounder may be found in Howell et al. (1999), Meng and Powell (1999), and Pereira et al. (1999).

3.2.3 Natural Mortality of Eggs, Larvae, and Juveniles

The rate of natural mortality during the early life history of a fish is an important factor in any life-stage-based assessment model. Furthermore, large changes in mortality rate or changes in mortality associated with density may be an indication of biological compensation occurring during a particular period of development, which may be a significant factor in assessing the effects of power-plant-related mortality.

Annual abundance of newly hatched winter flounder larvae should be related to adult spawner egg production and the number of eggs that hatch, many of which are lost to predation or other sources of natural mortality. To examine this relationship, annual egg production estimates calculated from Niantic River adult winter flounder abundance surveys (Table 3-4) were compared to an annual abundance index of Stage 1 larvae in the river (Fig. 3-2). Testing with functional regression showed a significant ($p \leq 0.05$) positive relationship through 1996, but with the addition of data from 1997-99 the slope was no longer significantly different from zero. Review of the results from analyses completed since 1994 showed that the probability of rejection of the null hypothesis (H_0: slope = 0) decreased with the addition of data from 1995 and continuing through 1999. It appeared that the abundance of newly hatched larvae was directly related to the adult egg production through 1994, suggesting that egg survival was similar among these years. The greater than expected Stage 1 abundance for 1995-99 may have resulted from egg survival increasing as egg production decreased, which is indicative of a compensatory response. However, a decrease occurred in the abundance of Stage 1 larvae in the Niantic River during 2000. Larval abundance in 2000 was the magnitude expected from the relatively low estimated egg production. This suggested a somewhat reduced compensatory response that year.

To examine egg survival, a relative annual survival rate index was determined by computing the ratio of the Stage 1 abundance index (in thousands) to annual egg production estimates (in billions), followed by grouping years as either 1984-94 and 2000 or 1995-99. The mean ratio (relative survival rate index) for the first yearly group was 0.34 (SE = 0.06) and for the later group was 1.55 (SE = 0.213), indicating that average egg survival appeared to be greater by more than four times during the these 5 years in comparison to the previous 11-year period combined with 2000. In addition, there was a significant ($p = 0.002$) difference between ratios for the two yearly groups (Wilcoxon two-sample test; Sokal and Rohlf 1969). Egg survival is a possible compensatory mechanism, where fewer eggs produced resulted in greater egg survival to newly hatched larvae, although the 2000 result indicated that this mechanism may not be well-established or may be related to variable predator abundance. Increased egg

survival could be an important factor in maintaining winter flounder populations under low adult spawning stock abundance. The exact mechanisms responsible for greater egg survival are not known, but may include less predation pressure because of fewer cues for predators when egg abundance is low, better egg quality because of greater food resources shared among fewer adult female spawners, or, as suggested by Buckley et al. (1991b), greater relative fecundity and viability of eggs produced by a spawning stock dominated by larger individuals. Alternatively, adult spawner abundance may have been systematically underestimated in recent years due to subtle habitat changes or factors affecting their location within the Niantic River relative to locations sampled. This implies that there could have been greater egg production rather than greater egg survival.

High rates of mortality during early life stages are relatively common among marine fishes. Percent survival (S) of Niantic River winter flounder larvae was calculated using the ratio of the abundance of Niantic River winter flounder larvae in larger (7-mm; Stage 4) to smaller (≤3 mm; Stage 1) size-classes (i.e., hatching to metamorphosis). Percent mortality rate (A) was the complement of S and instantaneous mortality rate (Z) was determined from $-\log_e(S)$ (Ricker 1975). Percent mortality for 1984-99 ranged between 82.4 and 97.9% and Z from 1.73 to 3.88 (Table 3-5). The 16-year mean percent mortality rate was 92.4%, equivalent to a Z of 2.58 and a daily mortality rate of about 5%. A mortality rate could not be computed for 2000 as the abundance of small winter flounder larvae was much less than in previous years, while larger size-classes were atypically abundant (DNC 2001a). This implied that survival was high in 2000. In other studies of winter flounder larvae, Pearcy (1962) observed a mortality rate of 98.6% during the first 2.4 months of life of Mystic River winter flounder larvae. Smaller larvae had higher mortality (20.7%·day^{-1}) than larger larvae (9.1%·day^{-1}). Black et al. (1988) reported a daily mortality rate of about 4.5%, Laurence (1977) 7-9%·day^{-1}, and Buckley et al. (1991a) 13%·day^{-1}. Keller and Klein-MacPhee (2000) reported larval winter flounder mortality rates of 5.6 to 8.9%·day^{-1} in warmer mesocosms and 3.6 to 4.0%·day^{-1} in colder tanks, although predators in these experimental systems were relatively low in comparison to natural systems. Mortality rates for Niantic River larvae appear to be intermediate in comparison to these values.

Examination of Niantic River winter flounder larval length-frequency distributions from 1983 through 1999 suggests that most mortality occurred between the 3.0- to 4.0-mm size-classes. The decline in frequency between these two size-classes, which includes yolk-sac (Stage 1) and first-feeding (Stage 2) larvae, has been about 90% each year. In larger size-classes, smaller reductions were found from one size-class to the next, suggesting that mortality rates declined with increasing size and age. Pearcy (1962) also reported a greater mortality for young winter flounder larvae (20.7% per day) compared to older individuals (9.1% per day). In a laboratory study, Chambers et al. (1988) found that winter flounder larval mortality was concentrated during the first 2 weeks after hatching. Laurence (1977) noted that winter flounder larvae had a low energy conversion efficiency at first feeding (i.e., Stage 2) compared to later development, and that this stage of development was probably a critical period for mortality. Hjorleifsson (1992) showed that the ratio between RNA and DNA, an index of condition and growth rate, was lowest at the time of first feeding of winter

flounder (about 4 mm in length) and that these ratios were affected by food availability. Thus, relative strength of a year-class may be determined, in part, by the availability of sufficient food after completion of yolk absorption.

Annual instantaneous mortality rates of larvae were compared to annual egg production estimates from adult spawning surveys (methods and results described in NUSCO 2000a) to determine if density-dependent compensatory mortality could be identified in the larval stage of Niantic River winter flounder. In addition, the effect of water temperature (as recorded at the MNPS intakes) on larval mortality was examined. A multiple regression model ($R^2 = 0.572$; $p = 0.004$) indicated that larval mortality decreased as egg production decreased ($p = 0.012$) and April water temperature ($p = 0.008$) increased (Fig. 3-3). This suggested that density-dependent larval mortality occurred in the Niantic River, which was further moderated by April water temperatures. Warmer temperatures positively influenced larval growth and development, likely affecting mortality rate. For example, the low mortality rate seen in 1998 (83.0%; $Z = 1.77$) corresponded with one of the lowest annual egg production estimates and the warmest April water temperatures, whereas the high rate observed in 1989 (97.9%; $Z = 3.88$) corresponded with relatively good egg production and cool spring temperatures found that year. In an analysis completed recently specifically for this report, a back-propagation neural network was used to examine the relationship among egg production, water temperature, and mortality (S. Saila, Hope Valley, RI, pers. comm.). February, March, and April water temperatures were used in this model, which explained about 83% of the variation, as opposed to 54% for the regression model discussed above. This finding makes a stronger case for density-dependent compensatory mortality with a strong temperature effect.

After larvae metamorphose to become demersal juveniles, events occurring during the first summer of life, a period during which MNPS has minimal effect on winter flounder, can also profoundly influence year-class strength. This is discussed in greater detail in Chapter 4, Section 4.2.6. As noted previously, despite initially high densities of settling larvae in Niantic Bay, few or no larger juveniles are produced due to apparent high rates of mortality in this area (NUSCO 1994b). Within the Niantic River nursery grounds, where age-0 juveniles remain common, unlike the bay, survival of these fish has been variable at two stations sampled since the mid-1980s (Fig. 3-4; Table 3-6). High rates of mortality were seen in some years between early and late summer, particularly when young were found in high densities. However, this was not always consistent and the relationship between density and mortality rate is apparently subject to considerable variability and the exact regulatory mechanisms are not well-established. The result has been the production of young winter flounder, as measured by the median catch-per-unit-effort (CPUE) in the 1-m beam trawl used for sampling, which has varied by more than eleven-fold in late summer (Fig. 3-5). These juvenile fish eventually become the recruits to both the spawning population and to the fisheries.

3.2.4 Entrainment at MNPS

Since 1976, winter flounder larvae entrained through the MNPS cooling-water system have been collected at the discharges into the Millstone Quarry. Details of entrainment sampling at MNPS may be found in DNC (2001a, b).

Winter flounder larvae are collected from February through June, with most (>90%) taken in April and May. A more detailed description of entrainment temporal distribution of winter flounder larvae is given below. Annual dates of peak abundance in entrainment samples were highly correlated with mean water temperature in March and April, which reflected varying rates of development (Fig. 3-6). Peak abundance occurs earlier in warmer years and varied by 41 days over 25 years of sampling. A 3.6°C (6.5°F) difference in the March-April water temperature occurred between the earliest (April 13, 1991) and latest (May 23, 1978) dates of peak abundance. This agreed with the results of Laurence (1975), who found that winter flounder larvae in the laboratory metamorphosed 31 days earlier at 46.5°F than at 41°F.

The estimated number of larvae entrained in the MNPS condenser cooling-water system each year is a more direct measure of impact on winter flounder than volume of cooling-water withdrawn. However, a better measure is the fraction of the annual production of Niantic River larvae removed by plant operation, which is used as an input to the computer population dynamics model found in Chapter 4. To determine production loss, accurate annual estimates of entrainment and egg production of spawning females are required. The former is described in Section 3.2.3 and methodology for entrainment estimation at MNPS follows.

Because the distribution of larval abundance data over time is usually skewed, densities increase rapidly to a maximum and decline slowly. A cumulative density over time from this type of distribution results in a sigmoid-shaped curve, where the time of peak abundance coincides with the inflection point. Therefore, the Gompertz function (Draper and Smith 1981) was used to describe cumulative abundance distributions of winter flounder larvae because the inflection point of this function is not constrained to the mid-point of the sigmoid curve. This form of the Gompertz function is described in detail in DNC (2001a). Entrainment estimates were obtained from larval densities (termed *A*) at the MNPS discharge and the actual volume of cooling water used by MNPS units during the larval season. The Gompertz density function (Eq. 3 of DNC 2001a) was fit to larval data and daily densities (number per 500 m^3) were calculated. Daily entrainment estimates were determined after adjusting for the daily condenser cooling-water volume. An annual estimate was determined by summing all daily estimates during the larval season. An evaluation of this method for determining entrainment estimates was given in NUSCO (1991c). The Gompertz-based estimates were judged superior to those previously generated using a seasonal median density estimate because they accounted better for fluctuations in condenser cooling-water flow. This method also provides daily entrainment estimates, which is not possible from a median-based method. The entrainment estimation methodology using a sample median had previously replaced the use of an arithmetic mean density from weekly samples, which likely overestimated entrainment because of a skewed sampling data density distribution (NUSCO 1983a).

The largest annual entrainment estimate since 1976 was about 493 million winter flounder larvae, which occurred in 1992 because relatively high cooling-water volume use at MNPS coincided with the highest annual density of larvae in Niantic Bay (Table 3-7). Entrainment and cooling-water use were relatively low during 1996-98, even though larval

densities in 1997 were the second highest observed, but all three MNPS units were in extended shutdowns during these years. The 1999 estimate of 146 million larvae represented an increase attributable to increased cooling-water volume from plant startup and moderately high larval densities. The 2000 entrainment estimate of 332.7 million was the second largest of the 25-year period and reflected the second highest annual larval density found at the intakes and relatively high volume of cooling water used that year. Although no confidence intervals (CI) are available for annual entrainment estimates derived from the Gompertz model, the 95% CI for the total cumulative density indicated good precision for these estimates. Standard errors of entrainment density estimates, expressed as a percentage of the parameter estimates, were 7% or less with most values 3% or smaller, except for 1978 (18%).

Of all the winter flounder larvae taken in entrainment collections from 1983 through 1999, nearly two-thirds (63.7%) were in Stage 3 of development. Stage 1 larvae comprised 3.7% of the total, 19.0% were in Stage 2 of development, and 13.2% were Stage 4. Despite the relatively high (ca. 0.8-10·m^2) abundance of newly metamorphosed young (Stage 5) taken in 1-m beam trawl samples near the intakes from 1988 through 1992 (NUSCO 1994b), very few (0.4%) of these fish have been found in entrainment samples throughout all years of sampling. Settlement and residence of metamorphosed individuals on the bottom likely limits their vulnerability to being drawn into the MNPS intakes and limits to a large degree the impact of the plant to winter flounder once they have metamorphosed.

Densities of winter flounder larvae and other ichthyoplankton entrained at MNPS varies throughout their seasons of occurrence. As noted previously, the Gompertz function was used to describe the cumulative daily abundance distribution of winter flounder larvae. Entrainment mitigation methodologies which rely on a seasonal reduction of cooling-water flow (see Chapter 2 of Part II) have varying effectiveness, depending upon when they are scheduled. Cooling-water use can be reduced throughout the season of occurrence for a species or to a portion of a season that would optimize reductions in entrainment with less restrictions to plant operation and economics. To determine the feasibility of flow reduction methods, the costs of implementing them, and the resultant benefits to winter flounder (and for the other species discussed below) over the greater part of their season of occurrence or during an optimal time frame, the seasonal patterns of entrainment were examined quantitatively. The average seasonal occurrence of ichthyoplankton at the MNPS intakes and dates of peak abundance were first determined using entrainment density data from 1976 through 1999 for larvae and 1979-99 for eggs (Table 3-8). By sequentially adding the fraction of larvae found on successive days on either side of the peak (April 24 for winter flounder), a cumulative percent distribution was constructed (Fig. 3-7A). The cumulative percent curve initially increased at a relatively high rate until the tails of the season were reached, after which the rate of larval occurrence decreased substantially, but over an extended number of days. Thus, the "primary" season of occurrence was defined as that portion of the density distribution available for entrainment that encompassed 95% of the cumulative percentage. For winter flounder, the primary entrainment period at MNPS was March 22 through June 5. An "optimal" season was next determined objectively by summing incrementally the computed percentages found on each day both before and after the peak until the sum of the

percentages on the tail ends comprised less than 2%. Although this point represented, on average, about 1% of the daily larval distribution, in reality the daily fractions of larvae at these points in time ranged between approximately 0.5 and 1.5% for winter flounder and the other species similarly analyzed. This non-symmetry occurred because when tails of the ichthyoplankton distributions were approached, daily percentages became unequal due to the skewed data distributions. The number of days both before and after the peak that encompassed an optimal season for larval winter flounder entrainment is shown on Figure 3-7B. The optimal larval winter flounder entrainment season extended from April 4 to May 14 and included 76% of the available larvae. Note that because the Gompertz data distribution was based on many years of entrainment samples, the seasonal calculations ignored any effects of temperature on the temporal distribution and abundance of winter flounder larvae, which can result in annual dates of peak abundance that vary by as much as 35 days (April 10 through May 15).

Of note, for practical future application of a flow reduction scheme, it may be possible to refine annual estimates of the entrainment season by constructing an effective model with good predictive capabilities that accounts for anticipated variation (e.g., a neural network). This would allow for annual differences in entrainment as a result of varying environmental conditions, such as water temperature, which can affect the timing of maximum entrainment and the effectiveness of entrainment mitigation.

3.2.5 Entrainment Survival

An intensive entrainment survival study targeting several important species, including winter flounder, was performed at the Oyster Creek Nuclear Generating Station (OCNGS), located off Barnegat Bay in Forked River, NJ (EA 1986). This single-unit 550 MWe plant has conventional traveling water screens and a once-through condenser cooling-water system. Initial survival (corrected for handling and collection mortality), 96-hour latent survival, and overall total survival were measured. Nearly 4,000 winter flounder larvae of various sizes and stages of development were examined from the plant intake and 3,000 from the discharge. Thermal output from the station varied throughout the course of this study. Initial survival at the intake ranged from about 77 to 96% (arithmetic mean of 84%). Initial discharge survival was 36 to 96% (mean of 77%). Initial entrainment survival was characterized as high (93%) and stable at a ΔT of 16.75°F or less. Sampling at a ΔT of 19°F or higher produced lower (mean of 54%) and more variable survival estimates. Some 5,000 larvae were held for periods of 72-96 h to examine for latent survival. The holding regime did not account for the decay in heat that an organism would have experienced while passing down the OCNGS discharge canal and, thus, was conservative. Mean latent survival of larvae collected at the intake was 62% (range of 57-68%) and for those from the discharge was 28% (6-66%). In comparison to intake survival rates, the discharge samples had highly variable survival. Latent survival in tests with a ΔT of 6.3°F was 100% after 96 h, 84% at a ΔT of about 10.5°F, and 20-30% for a ΔT ranging between 16.75 and 20°F. Most mortality occurred during the first 12 h, with other smaller, delayed effects observed between 72 and 96 h. Overall total entrainment survival ranged between 4 and 94% for the tests conducted. Survival was highly correlated with ΔT. Based on the relationship found, survival

was predicted to be 0% at a ΔT of 21.5°F, 50% at a ΔT of 13.7°F, and 100% at a ΔT of 5.75°F or less. Applying these findings to 6 years of previous entrainment estimates, EA (1986) estimated that 12 to 79% of winter flounder larvae survived annually following passage through the condenser cooling-water system of OCNGS.

Entrainment survival studies were also conducted at two power plants sited in New York waters of LIS (EA 1978; EPRI 2000), although sample sizes for winter flounder larvae were low. The fossil-fueled Port Jefferson Generating Station has four units totaling 490 MWe and a study was done during a relatively brief period in April 1978, when water temperatures ranged between approximately 44.6 and 48.2°F and plant ΔT from 9 to 20°F. Initial and 96-h latent survival was measured, but most latent mortality was thought due to collection and handling stress (EA 1978). All 23 post-yolk-sac winter flounder larvae (mean length of 4.6 mm; range of 3-6 mm) survived through-plant entrainment. However, at the 1,500 MWe Northport Generating Station, extended survival of 17 post-yolk-sac winter flounder larvae entrained in April 1980 was only about 10% (EPRI 2000).

For assessment purposes at MNPS, all winter flounder larvae are presumed to die during passage through the condenser cooling-water system. This conservative assumption is also applied to eggs and larvae of the other fishes discussed in this report. For winter flounder, laboratory thermal tolerance studies were conducted during 1973 and 1974 to estimate the effect of increased temperature on larvae during entrainment (NUSCO 1975, 1987a). Larvae were grouped as pre-metamorphosed (< 5 mm) and metamorphosing (> 5 mm) and were exposed to water at about 70°F after acclimation at 46.5°F (i.e., a ΔT of 23.5°F). Pre-metamorphosed larvae died as exposure time increased. At 1 hour, 29% died, 48% died at 2 hours, 53% at 3 hours, and 89% at 6 hours. Metamorphosing larvae exposed to elevated temperature for up to 9 hours suffered no mortality. Because most entrained larvae are 5 mm or larger and during two- or three-unit operation would be exposed to elevated temperatures for considerable less than 9 hours, most larvae would be expected to survive the thermal increase associated with entrainment. In a laboratory study, Itzkowitz and Schubel (1983) characterized larval winter flounder as resistant to acute thermal shock. They cited a study done for the proposed Shoreham Nuclear Power Station in which the highest mortality was of larvae acclimated to 37.5°F and exposed to a ΔT of 25°F for 13 minutes. Their own study showed that 5-day old winter flounder larvae suffered little mortality when exposed to a ΔT of 40°F for up to 32 minutes. Mortality increased at higher temperatures and longer exposure times. They concluded that resistance to thermal shock was age-dependent with the younger, newly hatched larvae more tolerant to thermal stress than older larvae. Note that this is contrary to the early MNPS study. Regardless, neither the effects due to mechanical damage nor any interactions between mechanical and thermal effects were examined in these studies.

A preliminary field study of entrainment survival was conducted in 1983 (NUSCO 1984). Winter flounder larvae (n = 135) were collected in the quarry following passage through the condenser cooling-water system when water temperatures were about 70 to 72.5°F; ΔT ranged between 14.5 to 20.7°F. Larvae were collected by slowly hauling a

0.5-m net from near the bottom to the surface (ca. 50 feet) by hand. Specimens were held at elevated temperatures for 2 to 4 hours (approximating estimated retention time in the quarry for three- and two-unit operation, respectively). Following this period, they were held at ambient water temperature without feeding to observe latent mortality for a total of 96 hours. All Stage 4 larvae collected were initially alive and 79% survived the holding period. Although some of both Stage 2 and 3 larvae were alive at time of collection (33 and 79%, respectively), all of these larvae died during the 96-hour holding period. Because of the relatively small (12%) proportion of entrained larvae that are in Stage 4 and 5 of development, the overall survival of entrained larvae may be less than 10%, if these estimates are indicative of actual entrainment survival at MNPS.

Further evidence of entrainment survival is important to evaluate entrainment impact to winter flounder. A more comprehensive entrainment survival study was completed at MNPS in spring of both 2000 and 2001 using a specially designed pump sampler. The study, summarized in Appendix A to this chapter, was designed to estimate survival of larvae immediately following entrainment through the cooling-water system and survival over a period of 96 h to account for latent effects of plant passage. Although this work was limited in scope and there were problems in estimating control mortality, the sampling indicated that some Stage 4 larvae and likely all of the relatively few Stage 5 juvenile winter flounder entrained could survive through-plant passage. Conservatively, as many as 5% of entrained larvae likely survive through-plant passage. This is particularly important as older and larger winter flounder larvae, which have greater potential for survival, suffer less entrainment mortality. Thus, based on preliminary studies done at MNPS and other power plants, there is good likelihood that a portion of winter flounder larvae survive entrainment, even though impact assessments made to date (and including this report) have assumed 100% mortality.

3.2.6 Sources of Entrained Larvae

The number of winter flounder larvae entrained at MNPS depends upon larval densities in Niantic Bay. The magnitude of the impact to the Niantic River stock due to larval entrainment should be related to the proportion of larvae in Niantic Bay originating from the river. However, many winter flounder larvae enter the bay from LIS as progeny from the other spawning stocks located to the east and west of MNPS and also become entrained (NUSCO 2000a). Knowledge of the sources of larvae entrained at MNPS and the proportion of larvae entrained from the Niantic River population are important factors for impact assessment. Depending upon the relative proportions, entrained larvae originating from two or more sources would lessen the impact on any particular stock. Effects on the Niantic River population are of primary concern, however, because of its relatively small size and close proximity to MNPS. Spawning grounds in proximity to LIS other than the Niantic River include the upper Mystic River (Pearcy 1962), and, as identified in special NUSCO sampling of larvae for genetic stock identification studies, the middle reach of the Thames River north of the Coast Guard Academy and an area just west of the Connecticut River mouth (Fig. 3-8). Both the latter areas were also sampled by Howell and Molnar (1996). Other potential larval source areas were identified to the west of the Connecticut River (e.g., Clinton Harbor) from sampling by NUSCO and Howell and Molnar (1998).

Differentiating the origin of entrained larvae could be accomplished, for example, by elucidating the genetic composition (e.g., DNA-based methods) or the chemical elemental composition of larvae from stocks most likely to be entrained at MNPS. If Stage 1 larvae collected on known spawning grounds could be characterized by either of these techniques, older larvae from entrainment samples may be examined to determine the relative contribution of these sources to the sample. A study to assign winter flounder larvae to natal populations by characterizing the mitochondrial DNA of individual larvae was completed in the early 1990s, but due to technical problems this approach was not entirely successful (Goddard 1992). Thus, indirect methods (discussed in the following paragraph) were used in subsequent years to ascertain and quantify sources of larvae entrained at MNPS. However, with rapid and continuing advances in genetic and multi-elemental analytical techniques, NNECO sponsored studies of both techniques that were initiated in winter and spring of 2000. More comprehensive sampling was undertaken during winter and spring of 2001. Results of both these studies will be submitted to DEP as soon as possible following their receipt from the contracted researchers at the Universities of Connecticut and Rhode Island.

Without a direct method as yet to assign entrained larvae to a spawning stock, an indirect method termed a "mass-balance calculation" has been used to quantify the sources of entrained larvae at MNPS (NUSCO 2000a). The calculation indicates whether the number of winter flounder larvae entering Niantic Bay from Niantic River can sustain the number of larvae observed in the bay during the winter flounder larval season. This method is based on hydrodynamic investigations in LIS near MNPS (Kollmeyer 1972; Dimou 1989; Dimou and Adams 1989; Dimou et al. 1990; NUSCO 1992c), special larval winter flounder sampling in this area (NUSCO 1984, 1985, 1986, 1989, 1992a, 1993, 1994b), and routine monitoring data (e.g., NUSCO 2000a). Due to the importance and complexity of this information, detailed discussions of larval source area and the basis for the mass-balance calculation are given in Appendix B to this chapter. A more detailed summary of data, derivation of equations, and other methods for calculating terms of the model is found in NUSCO (2000a). A sensitivity analysis of mass-balance model input parameters, first presented in NUSCO (1991a), is included in Appendix B along with a new analysis completed for this report. Also, reviews and a sensitivity analysis completed by independent experts at the behest of DEP (DEP 2000) are given in Appendices C and D.

Three potential sources of larvae to Niantic Bay (and the MNPS intakes) include those from eggs hatching within the bay, those flushed from the Niantic River, and those produced by other spawning stocks that enter the bay from LIS across its boundary between Millstone Point and Black Point. The few yolk-sac larvae collected annually in Niantic Bay suggests that minimal spawning and subsequent hatching occurs in the bay and this area was considered to be a negligible source of larvae. Larvae were known to be flushed from the river into the bay and, thus, this input to the bay was estimated from available data. However, the number of larvae exiting or entering Niantic Bay to or from LIS was unknown. Four ways in which larvae may leave Niantic Bay include natural mortality, by entering the Niantic River during a flood tide, through entrainment at MNPS, and by flushing from the bay into LIS. Estimates are available for

the number of larvae lost through natural mortality, entering the Niantic River, and entrained at MNPS, but little is known about the number of larvae flushed from Niantic Bay into LIS or vice versa. Therefore, the numbers of larvae flushed to and from LIS were combined as the unknown in the mass-balance equations.

Mass-balance calculations have been made using data from 1984 through 1999; 11 of these years (1986-95 and 1999) coincided with MNPS three-unit operation and 3 years (1996-98) with limited plant operation. Detailed results of these calculations were presented in NUSCO (2000a) and the patterns found were generally consistent for all years examined. No mass-balance calculation was made for 2001 as a reliable larval mortality estimate was not available for this year (DNC 2001a). In general, a net loss of larvae was indicated from Niantic Bay during the first part of the larval season. However, beginning in about late March or early April, larvae from other source areas in LIS were required to support changes observed in larval abundance. The timing of this change agreed with results from independent hydrodynamic studies. These studies indicated that much of the condenser cooling-water enters Niantic Bay from LIS. This was confirmed by special sampling conducted in the bay during 1991, which showed a net import of larvae from LIS in late March or early April (see Appendix B to Chapter 3 for details). During the period of peak entrainment (mid-April), fewer larvae were entrained at MNPS than were imported into Niantic Bay from LIS, indicating that other stocks were likely sources of larvae found in the bay, particularly for larvae in Stages 3 and 4 of development.

The mass-balance model allows calculations to be made that allocate larvae to either the Niantic River or to all other sources combined. The proportion of entrained larvae coming from the Niantic River was estimated from the ratio of larvae entering the bay from the river to the total input from all sources. This proportion was applied to the total number entrained to estimate the number entrained from the Niantic River. When mass-balance calculations indicated that a sufficient number of larvae entered Niantic Bay from the river to support the observed change in abundance over 5 days, all entrained larvae were assumed to have originated from the river. This is conservative because dye studies indicated that only 20% of the discharge volume of the Niantic River passed through MNPS during three-unit operation (Dimou and Adams 1989). In most years, Stage 3 was the predominant stage entrained, with the largest source identified as the Niantic River. However, Stage 2 larvae predominated as the larvae attributable to the Niantic River in 1984 and 1985 and Stages 1 and 2 larvae in 1996. Consistent in these calculations was that most entrained Stage 3 and 4 larvae were determined to have originated from other sources.

Based on mass-balance calculations for data collected in 1984-99, about 12 to 59% of winter flounder larvae entrained at MNPS originated from the Niantic River (Table 3-9). These subdivided entrainment estimates, along with developmental stage data, were further used to calculate production loss from the Niantic River stock of winter flounder, a key input to the winter flounder impact assessment model, and which is discussed in Chapter 4.

3.3 TAUTOG

3.3.1 Background

Among the important sport and commercial fishes of LIS (Smith et al. 1989) and with eggs ranked second in entrainment abundance (Table 3-10), the tautog, like the winter flounder, began to receive more attention in MNPS studies as adult stocks began to decline in recent years (Simpson et al. 1989; ASMFC 1996). This species is slow-growing and long-lived and may be susceptible to overfishing. In 1995, discussions were held between DEP and NUSCO (on behalf of NNECO) after the latter proposed the deletion of three trawl monitoring program stations, which was to take place in January 1996. The DEP concurred with this change in the sampling as long as NNECO agreed to put an equivalent amount of effort into tautog studies (NNECO 1995). Since then, several special studies that concentrated on the egg stage of development were completed in compliance with this requirement. Results of these studies were provided in the annual monitoring reports and are briefly summarized below. Also, NUSCO and NNECO co-sponsored along with the National Marine Fisheries Service, the University of Connecticut, and DEP, a workshop on the biology of tautog and cunner, which was held in fall 1999. This conference provided an opportunity for American and Canadian scientists to exchange information on both of these species. Detailed biological data on tautog were also recently summarized by Steimle and Shaheen (1999). Distribution of tautog taken by the CT DEP trawl survey in LIS by depth and bottom type was given in Gottschall et al. (2000).

3.3.2 Spawning and Early Life History

Male tautog mature when 2 to 3 years old and females at age-3 to 4. This species is particularly long-lived and is capable of reaching an age of 34 years (Cooper 1964). Adults return to nearshore waters in spring prior to spawning. According to Cooper (1964), a high proportion of fish return to the same spawning area each year, but Olla and Samet (1977) and Olla et al. (1980) believed that mixing of spawning fish from different localities was common. Orbacz and Gaffney (2000) examined genetic population structure of tautog from Rhode Island to Virginia. They found that mean nucleotide diversity of this species was among the lowest of any reported for a marine fish, which suggested the absence of population structuring along the Atlantic coast. As a result of the low level of genetic diversity, they tentatively concluded that tautog form a single genetic stock.

Tautog spawn during afternoon or early evening hours from mid-May until mid-August in Southern New England and New York waters (Wheatland 1956; Chenoweth 1963; Olla and Samet 1977, 1978; Ferraro 1980b; Monteleone 1992). Fecundities at specific sizes and ages were reported by Chenoweth (1963), GEOMET Technologies, Inc. (1980), and White (1996). The first two studies only described a single length-fecundity relationship, but the last one noted that the tautog is a multiple spawner. White (1996) determined that an individual female tautog spawned, on average, every 1.14 days and, based on this spawning frequency, estimated the total reproductive output for age-

3 through 9 female tautog to range between 168,000 and 11,053,00 eggs. Chenoweth (1963) reported maximum egg production per unit of ovary weight for fish 7 to 9 years old with production declining in fish age-16 and older.

NNECO (2000, 2001) committed to verify seasonal fecundity estimates for tautog in Connecticut waters by sponsoring a study that was initiated during the summer of 2000 and was continued in 2001. This research at the newly renovated Avery Point campus of the University of Connecticut includes long-term observations of spawning male and female tautog in a laboratory holding facility as well as histological examination of gonads of field-collected fish. Results of this tautog reproductive biology study will be submitted to DEP as soon as possible following their receipt from the contracted researchers at the University of Connecticut.

Periodicity of tautog spawning was examined by field sampling, including 24-h studies conducted at the MNPS discharges in 1993 (NUSCO 1997), and laboratory observations made in 1997 and 1998 (NUSCO 1998, 1999). These studies corroborated one another and showed that daily spawning activity began at about 1600 h, rapidly reached a peak at about 1800 h, and declined to a low level after 2100 h (Figs. 3-9 and 3-10). These findings also confirmed observations of Olla and Samet (1977) and Ferraro (1980b). As the tautog spawning season is influenced by water temperature, a significant negative relationship was found between mean water temperature in May and the estimated date of peak spawning near MNPS (Fig. 3-11). Thus, cool springs result in peak spawning that occurs in early July, whereas warmer springs are reflected by peak spawning as early as mid-June.

Berrien and Sibunka (1999) reported tautog eggs from coastal and mid-shelf waters off the northeastern United States. Highest abundances of eggs and larvae are generally found off Southern New England and Long Island (Colton et al. 1979; Sogard et al. 1992). The pelagic eggs, about 0.7 to 1.2 mm in diameter, hatch in 42 to 45 hours at 71.5°F, but require 81 hours at 57.5-62.3°F (Richards 1959; Williams 1967; Fritzsche 1978; Perry 1994). Egg size decreases over the season as water temperatures increase (Williams 1967). Although lacking oil globules, the eggs are buoyant and may be found in highest concentrations at the surface (Fritzsche 1978; Bourne and Govoni 1988). This pattern of egg distribution was found in Niantic Bay in early evening after spawning, but by the following morning egg densities were similar at the surface and near bottom (NUSCO 1997). Based on observed developmental anomalies and increased mortalities, the upper temperature limit for normal early life stage development is about 74.3 to 75.2°F (Olla and Samet 1978).

Newly hatched larvae are relatively small, about 2.2 mm in length (Steimle and Shaheen 1999). Larvae are capable of feeding by 52 hours post-hatching (Schoedinger and Epifanio 1997). In laboratory experiments, Laurence (1973) found that larval tautog may encounter potential energy deficits at temperatures greater than 71.5°F and Schoedinger and Epifanio (1997) found that prey densities strongly affected larval growth and development. The pelagic larval stage lasts about 2.5 to 3 weeks and individuals settle on the bottom when they reach a size of about

17 mm (Sogard et al. 1992; Dorf 1994; Schoedinger and Epifanio 1997). Estimated growth rate during pre-settlement is about 0.75 mm per day and during post-settlement is about 0.5 mm per day (Sogard et al. 1992; Dorf 1994), although growth of young in experimental cages set in various habitats varied from –0.1 to 0.6 mm per day (Phelan et al. 2000). Eelgrass and macroalgae beds located in coves and estuaries were reported as preferred habitats of juveniles by Sogard and Able (1991), Hostetter and Munroe (1993), and Dorf and Powell (1997), but Phelan et al. (2000) found habitat quality as defined by growth rate difficult to evaluate.

3.3.3 Natural Mortality of Eggs and Larvae

The proportion of normally developing eggs and larvae appears to decrease during summer, suggesting possible effects of increasing water temperature (Olla and Samet 1978; Perry 1994). The occurrence of tautog eggs over time during the 1993 entrainment field study was used to estimate daily egg mortality (NUSCO 1998). The rapid decline in observed egg densities was attributed to high natural mortality rather than hatching, as egg incubation would have taken longer than the 24-h period of this particular study. Williams et al. (1973) noted similar high daily egg mortality for cunner, a sympatric species also of concern at MNPS, the losses of which were attributed to predation. In a study at MNPS, a daily (1800 h to 1700 h) estimate of total instantaneous mortality (Z) was calculated using the hazard function of the Weibull distribution, a methodology suggested by Pinder et al. (1978) and Saila and Lough (1981). Z was estimated as 2.06, which is equivalent to a daily mortality rate of 87.3% (Figs. 3-12 and 3-13). Egg mortality exhibited a diel pattern, with a decline following completion of daily spawning at around midnight. No definitive estimates of larval tautog mortality are available in the literature or from studies conducted at MNPS. Schoedinger and Epifanio (1997) found highly variable mortality rates of larval tautog in laboratory rearing experiments and attributed the low estimated daily mortality rates of about 14-15% to the lack of predators and ample available food densities in their study.

To validate egg mortality estimates based on the temporal decline of egg abundances in field collections, developmental stages of tautog eggs collected near the time of peak spawning were examined in a 1997 study using archived samples (NUSCO 1998). Microscopic examination of histologically stained eggs allowed them to be classified in various stages of development. In addition, an approximate age in hours was associated with the various developmental stages. Results indicated that the daily survival rate during the first 24 h was 0.366 during the first day and 0.348 during the second day, although considerable variability was found among samples. The average hourly Z was 0.043, about half that estimated from 24-hour field sampling (0.090) and routine entrainment monitoring data (0.086). The reason for this discrepancy was not known and suggests further investigation.

3.3.4 Entrainment at MNPS

Annual entrainment estimates for tautog eggs from 1979 through 1999 ranged between 111 million and 3.75 billion, with highest numbers during the mid-1980s (Table 3-10). Particularly low entrainment estimates in recent years

were associated with reduced cooling-water flow at MNPS and historically low densities of eggs that occurred during 1997 and 1998 (Fig. 3-14). A significant declining trend ($p = 0.003$) was found for tautog egg densities from 1979 through the present. Despite the pronounced daily cycle of tautog (and also for the sympatric cunner) spawning, egg entrainment estimates were not found to be biased due to time of sampling (NUSCO 1994a).

Tautog larvae are much less abundant than eggs in MNPS entrainment samples, ranking eighth among entrained ichthyoplankton since 1976. However, larvae may be more numerous at the MNPS discharges than indicated by the sampling. As part of an egg mortality study in 1990, newly hatched larvae were observed to pass through a 202-µm mesh net used in the egg hatching chambers, whereas 333-µm mesh nets are used to sample entrainment. A follow-up net extrusion study was conducted in 1991, which indicated that 88 of 100 newly hatched larvae were extruded through the 333-µm mesh nets of a bongo sampler towed through the water with a through-net velocity less than that found at the MNPS discharges (NUSCO 1992b). Since 1976, larval abundance appeared to have increased and decreased rapidly in relation to peaks observed in 1981, 1991, and 1999 (Fig. 3-14). No significant temporal trends in abundance were found. Through 1999, annual densities of tautog and cunner eggs were highly correlated (Spearman's rank-order correlation coefficient $r = 0.86$; $p < 0.040$; Figs. 3-14 and 3-15).

The primary and optimal entrainment seasons for tautog eggs were determined in a manner similar to winter flounder, which was outlined in Section 3.2.4. On average, peak tautog egg abundance occurred on June 20, with the primary season of occurrence extending from May 3 through August 22 (Table 3-8; Fig. 3-16). The optimal season, encompassing 64% of total egg entrainment, was from May 29 through July 12.

3.3.5 Entrainment Survival

Smith et al. (1980) examined water temperature effects on mortality and suggested that tautog eggs entrained at a once-through cooling-water system at a power plant having a ΔT of 18°F and a 15-minute transit time would result in a mortality ranging between 10 and 50%. Collings et al. (1981) reported on the survival of wrasse (likely more cunner than tautog and perhaps also a few yellowtail flounder) eggs at the Canal Electric Company Station, a fossil-fueled plant having twin 560 MWe units located near the eastern entrance to the Cape Cod Canal in Sandwich, MA. Station ΔT varied between 12.6 and 31.5°F over the course of this 2-year study. Some 11,662 eggs were examined at the intake and 6,172 at the discharge. Estimated total entrainment survival of these eggs was 32% using one method of calculation and 13% using another. Nearly all the mortality was attributed to initial entrainment effects with little delayed mortality found. Studies at MNPS were conducted in 1990, 1991, and 1993 to determine the entrainment mortality of wrasse eggs (NUSCO 1991b, 1992b, 1994a). A comparison was made between hatching rates of wrasse eggs collected in Niantic Bay near the MNPS intakes and those taken at the MNPS Quarry cuts. The 1990 study indicated that survival of entrained eggs was higher than expected, ranging from 27 to 69% on the three dates sampled (mean of 43%). Eggs collected in the bay, considered to reflect natural rates of hatching and

mortality, hatched at rates of 81 to 98% and had an average survival of 91%. This study also confirmed that cunner and tautog eggs had similar mortality rates and validated the bimodal egg diameter technique of Williams (1967) for differentiating eggs of these two related species. Similar survival (45%) of entrained eggs was noted in a study conducted at the Pilgrim Nuclear Power Station in Massachusetts (MRI 1990). The 1991 study at MNPS produced results similar to the previous year, although an observation was made that 56% fewer eggs were collected at the Quarry cuts than at the discharges. This finding suggested that some of the wrasse eggs may have died and settled out of the water column or hatched within the Quarry before reaching the cuts. If eggs had died within the Quarry, the corrected estimated average entrainment survival rate would have been 23% in this study. The 1993 study was designed to assess the disproportionately high entrainment survival estimate, which was based on the eggs collected at the Quarry cuts. A Pitot tube sampler was designed and constructed for use at the MNPS discharges. Average egg hatching rates based on this sampling technique was 4%, a considerable decrease from the rate of 41% found in the 1990-91 studies. Some of the decrease may have been an artifact of the sampling, as 59% of eggs that were collected using the same gear in Niantic Bay near the MNPS intakes hatched as did an average of 91% of eggs collected by bongo sampler in the bay. Because of these discrepancies, NUSCO (1994a) concluded that the entrainment mortality of wrasse eggs should be assumed as 100% until more reliable estimates can be obtained. The special collecting device used for the entrainment survival study initiated in spring 2000 for larval winter flounder may also be used in summer 2001 and subsequent years to ascertain survival of entrained tautog and cunner eggs.

3.3.6 Sources of Entrained Eggs and Larvae

Cooper (1966) believed that adult tautog form discrete spawning groups with a high proportion of fish returning to the same area to spawn each year. However, Hostetter and Munroe (1993) observed that movements of tautog in Virginia were not as well-defined and Orbacz and Gaffney (2000) tentatively concluded that tautog made up a single genetic stock along the Atlantic coast. The widespread distribution of eggs in LIS suggests that considerable mixing occurs.

Spatial distribution studies completed in recent years and summarized in NUSCO (1997, 1998) showed that tautog spawn throughout many areas of LIS. The pelagic eggs are dispersed rapidly and widely from specific spawning sites by tidal transport. Based on average tidal current velocities and egg incubation times, the potential source of tautog eggs entering Niantic Bay encompasses an area with a radius of about 5 nautical miles, as measured from a point in mid-bay midway between Black and Millstone Points. This includes an area extending along the shoreline from about 2 nautical miles east of the Connecticut River to the Thames River. Field sampling showed that eggs tended to be widely distributed in the area around MNPS, including areas outside of Niantic Bay. Eggs were significantly more abundant at stations located to the east of MNPS than to the west and densities were higher in inshore than offshore waters (NUSCO 1998). This may have been related to preferred spawning habitat. However,

when depth was considered, the number of eggs was similar per unit of surface area, suggesting that egg densities became diluted in deeper waters as they dispersed and became distributed homogeneously. These studies also confirmed that tautog eggs were uniformly distributed throughout the water column, except very close to the bottom, where fewer were present. Thus, tautog eggs appear to be relatively ubiquitous in LIS near the plant.

3.4 OTHER SELECTED FISHES

3.4.1 Background

Since the mid-1970s, assessments at MNPS have been made for various fish taxa based on their susceptibility to entrainment (Table 1-3 of Chapter 1 of Part II), impingement, or potential effects of the MNPS thermal plume. The fishes evaluated changed somewhat throughout the years of study, but in most years included anchovies, silversides, grubby, cunner, and American sand lance, in addition to the winter flounder and tautog discussed previously in this chapter. Examples of species no longer analyzed for impact assessment include Atlantic tomcod and sticklebacks, which were once examined because they were numerous in impingement collections, although not in entrainment samples. Once fish returns were installed and operated at Units 1 and 3 and impingement at Unit 2 was re-evaluated and found to have decreased after Unit 3 went online (NUSCO 1987b), impact assessments of these species were terminated because they demonstrated good survival in the MNPS fish return systems. Conversely, the Atlantic menhaden was once the subject of detailed impact assessments (NUSCO 1976, 1983b) because of several high impingement and entrainment episodes that occurred during the early 1970s at Unit 1. Beginning in the mid-1970s, numbers of Atlantic menhaden entrained or impinged at MNPS decreased considerably and less concern was expressed about impact to this fish, particularly after modeling showed that even extremely high rates of impingement and entrainment occurring year after year would have little effect on its population (NUSCO 1983b). However, after increases were again observed in annual larval entrainment estimates, particularly during the early and mid-1990s, beginning in 1997 the Atlantic menhaden was once again evaluated (NUSCO 1998). In the present examination of intake technologies, silversides are not be assessed for entrainment effects because so few of their larvae are entrained, due to the reproductive characteristics of the two local species. However, because silversides are common in the shore zone of Jordan Cove, an assessment was given in Chapter 2 for potential effects of an altered thermal plume resulting from several of the proposed cooling-water flow reduction methodologies.

Because the other potentially impacted species have been the subject of less intense studies at MNPS than winter flounder or tautog, they are discussed in aggregate below. Additional details of the life history and ecology of these other selected species are summarized in NUSCO (2000b) and DNC (2001b). Of note, the grubby and cunner, in particular, have less information published in the scientific literature than the heavily exploited Atlantic menhaden or the bay anchovy, which is ubiquitous in inshore estuarine waters and has been the subject of many ecological studies. Although dated, general summaries of life history information are available for the Atlantic menhaden (Ahrenholz

1991), cunner (Gleason and Recksiek 1988), and American sand lance (Reay 1970). Many aspects of bay anchovy life history were summarized in Rose et al. (1999). Distribution of Atlantic menhaden, grubby, and cunner taken by the CT DEP trawl survey in LIS was reported by depth and bottom type in Gottschall et al. (2000).

3.4.2 Spawning and Early Life History

The Atlantic menhaden is a coastal, migratory species considered to be estuarine-dependent, with young-of-the-year found in coastal bays, rivers, and sounds, often penetrating to upstream limits of saline water (Reintjes and Pacheco 1966). It has a life span of about 10 to 12 years, with most females maturing during the second year of life at about 180 mm in length (Lewis et al. 1987). Based on its movements and distribution, the Atlantic menhaden is treated as a single stock for management, although Epperly (1989) found some evidence for northern and southern sub-populations, based on meristic and biochemical differences. Atlantic menhaden are multiple spawners, releasing eggs in a series of batches (Higham and Nicholson 1964). Combining data from several studies, Lewis et al. (1987) estimated fecundity to range between about 38 thousand for a 180 mm female to 488 thousand for a 350 mm fish. Spawning, which mostly takes place at night in the ocean or in major estuaries, can occur during nearly any month of the year (Ferraro 1980b; Ahrenholz 1991). However, the presence of larvae and juveniles in particular oceanic or estuarine waters is largely associated with a highly regular annual cycle of adult movements and reproduction along the Atlantic coastline, which was described by Nicholson (1971, 1978), Dryfoos et al. (1973), and Kroger and Guthrie (1973). Spawning was reported to occur within LIS and adjacent waters from late spring through early fall (Dietrich 1979; Ferraro 1981; Powell and Phonlor 1986). Ferraro (1981) noted spawning in the Peconic Bays, NY, which occurred at water temperatures between about 54°F and 77°F, with peak spawning at 59-64.5°F.

Atlantic menhaden eggs (ranging from 1.3 to nearly 2.0 mm in diameter; Jones et al. 1978) hatch in about 8.5 days at 50°F, 3 days at 59°F, 1.6 days at 68°F, and about 1 day at 77°F (Ferraro 1980a). In LIS, larvae exhibit a bimodal distribution, which suggests two distinct spawning periods, with most spawning occurring during summer and a lesser spawning event in fall. Similar annual bimodal spawning periodicity was reported in the Peconic Bays, NY (Ferraro 1981) and for New England and Middle Atlantic coastal waters in general (Berrien and Sibunka 1999). Atlantic menhaden eggs and larvae are tolerant of a wide range of salinities and temperatures (Ferraro 1980a). Size of larvae at hatch varies from 2.6 to 3.7 mm and is probably related to egg size (Powell and Phonlor 1986). A description of larval development was given by Lewis et al. (1972) and Jones et al. (1978). Young larvae are relatively undeveloped, but their growth is rapid. Atlantic menhaden have a lengthy developmental period, including a prejuvenile stage, and do not metamorphose until reaching a length between 30 and 40 mm. Most early larval growth and development occurs throughout large areas of the continental shelf. The landward movement of small larvae occurs particularly by Ekman transport and from active movements of older larvae and juveniles (Nelson et al. 1977). Larvae between 14 and 34 mm enter estuarine or inshore coastal nursery areas at about 45 to 60 days old (Reintjes and Pacheco 1966). Larval and juvenile movements (including diel vertical migration) have

been found to be affected by environmental cues, such as light (Forward et al. 1993, 1996) and temperature (Friedland and Haas 1988; De Vries et al. 1995), with increased swimming activity and movement towards surface waters occurring at night.

Both bay anchovy and striped anchovy have been collected in MNPS monitoring programs. These species have similar geographic ranges, but the occurrence of the latter species north of the Chesapeake Bay is variable and it is also usually found farther offshore than the former (Hoese and Moore 1977; Smith 1985). The eggs of the two species can be readily distinguished and, since 1979, when eggs were first identified to species in MNPS entrainment samples, about 96% of the anchovy eggs collected were those of the bay anchovy. Olney (1983) similarly found the striped anchovy to be much less abundant in Chesapeake Bay than the bay anchovy and Berrien and Sibunka (1999) noted that striped anchovy eggs were less common than bay anchovy in coast-wide sampling. Although they are referred to collectively as anchovies throughout much of this report, information presented herein focuses on the bay anchovy because of its predominance in the local area.

The bay anchovy, one of the most abundant of the inshore fishes found along the Atlantic coast and in many large estuarine systems (McHugh 1967; Houde and Zastrow 1991), is a short-lived (ca. 3 years), early-maturing (2.5 months to 1 year), serial-spawning fish (Stevenson 1958; Luo and Musick 1991; Zastrow et al. 1991; Newberger and Houde 1995; Wang et al. 1997). In a study of genetic differences, little population substructuring was found for bay anchovies found within Chesapeake Bay (Morgan et al. 1995), likely because of significant mixing during seasonal movements, which take place over hundreds of miles (Jones et al. 1978; Vouglitois et al. 1987). Throughout much of its range, bay anchovy eggs and larvae usually dominate summer ichthyoplankton samples (e.g., Wheatland 1956; Olney 1983; Leak and Houde 1987; Vouglitois et al. 1987; Monteleone 1992; Berrien and Sibunka 1999). In LIS, spawning takes place at depths of 65 feet or less from May through September, with a peak during June and July (Wheatland 1956; Richards 1959); duration of the spawning season decreases with increasing latitude (Castro and Cowen 1991). The bay anchovy matures at about 40 to 45 mm in length and individuals spawn repeatedly during a relatively short period at night (typically between 2100 and 2400 h) from May through mid-September (Luo and Musick 1991; Zastrow et al. 1991). Luo and Musick (1991) also reported that adults in Chesapeake Bay spawn about every 4 days in June and every 1.3-1.9 days in other months with an average number of spawning events of 54. Total egg production for a 55-mm fish was 45,110, with batch fecundity varying from month to month. A pooled mean batch fecundity estimate of 775 eggs was given by Zastrow et al. (1991) for Chesapeake Bay and 852 eggs by GEOMET Technologies, Inc. (1980) for the Shoreham region of central LIS. Size-specific fecundity, however, may be affected by prey availability (Peebles et al. 1996). In Chesapeake Bay, spawning was more common offshore than inshore (MacGregor and Houde 1996) and in the deeper lower bay than the upper bay (Rilling and Houde 1999b), but in LIS, most spawning reportedly occurs at depths of 65 feet or less

(Wheatland 1956; Richards 1959). Spawning appears to be correlated with high zooplankton abundances (Castro and Cowen 1991; Peebles et al. 1996) and warm water temperatures (Zastrow et al. 1991).

The slightly elongated bay anchovy eggs are pelagic and at 71.5°F hatch in about 24 hours (Kuntz 1914). Like those of the tautog, anchovy eggs decrease in size as the spawning season progresses (Wheatland 1956; Richards 1959) and are larger (mean major axis length of 1.05-1.12 mm) in lower (5-10 ‰) salinity than in higher salinity (0.95-0.97 mm; 15-20‰; Dovel 1971). Bay anchovy larvae were described in Jones et al. (1978). Newly hatched larvae are 1.8 to 2.7 mm in length and metamorphosis occurs at about 22.5 mm (Kuntz 1914). MacGregor and Houde (1996) found that larvae in Chesapeake Bay were not concentrated in tidal fronts, but abundance followed an inshore-offshore gradient with most larvae found offshore. Although some larvae could have been transported from offshore to inshore regions, they hypothesized that anchovy recruitment was dependent upon physical and biological processes occurring in each of these areas. Upon entering tidal rivers, anchovy larvae were found to move upstream as they grew (Loos and Perry 1991).

Female grubby reach maturity within 1 year and their fecundity is relatively low, ranging between 672 and 1,554 eggs for four females (67-95 mm in length) examined by Lazzari et al. (1989). Range of egg sizes was given as 1.5 to 1.7 mm by Lund and Marcy (1975) and 1.4 to 2.0 mm by Lazzari et al. (1989). Female grubby spawn once in winter and have demersal, adhesive eggs, which are attached to a variety of substrates; incubation time is 40 to 44 days at water temperatures of about 40 to 43°F (Lund and Marcy 1975; Lazzari et al. 1989). Richards (1959) reported larvae present in LIS from February through April and Laroche (1982) noted that they are more abundant near the bottom than in surface waters. Early larval development was described by Lund and Marcy (1975).

Cunner commonly occur in the area near MNPS, particularly in rocky habitat. Most cunner live only 5 to 6 years, with maximum age about 10 years, less than one-third of the life span of the closely-related tautog (Dew 1976; Regan et al. 1982). Cunner mature at age-1 to 2 and, similar to tautog, spawn from May through September during late afternoon into early evening (Johansen 1925; Dew 1976; Pottle and Green 1979a; Green et al. 1985). Lawton et al. (1996) and Nitschke et al. (2001) reported all cunner larger than 65 mm observed in western Cape Cod Bay to be mature. Larger (>200 mm) males may spawn with individual females, whereas smaller (80-180 mm) males and females spawn in groups of 30 to 150 or more individuals (Pottle et al. 1981). Nitschke et al. (2001) calculated a nonlinear quadratic length-fecundity relationship with egg production ranging from about 1.2 thousand for a 77-mm fish to 84.4 thousand for a 171-mm female. Cunner can spawn more than once a day and on multiple days (Pottle and Green 1979a). Spawning commences at about 52 to 54°F (Bigelow and Schroeder 1953). The pelagic cunner eggs are very similar to those of the tautog, although slightly smaller at 0.75-0.85 mm (Bigelow and Schroeder 1953). Williams (1967) noted that decreasing egg size over the summer occurs in parallel for both of these wrasse species and this bimodal size distribution has been successfully used to differentiate eggs of these species in MNPS

entrainment samples since 1979. Besides being present in coastal embayments and estuaries, cunner eggs are also common in inshore areas of the northeastern continental shelf (Berrien and Sibunka 1999). Cunner eggs hatch in 2 to 6 days, depending upon water temperature (Williams 1967; Dew 1976). Egg and larval development was described in detail by Johansen (1925). Newly-hatched larvae are 2 to 3 mm in length, metamorphose at 6 to 10 mm, and settle into preferred habitats, such as near rock or other hard structures, eelgrass, or macroalgal beds (Miller 1958; Levin 1991, 1996). Larval cunner undertake vertical migrations with greater densities found higher in the water column during night (Malchoff 1993). At the MNPS discharges, abundances of tautog and cunner larvae from 1976 through 1999 were highly correlated (Spearman's rank-order correlation coefficient $r = 0.86$; $p < 0.001$), likely indicating similar reproductive processes.

The American sand lance is a widely distributed forage fish in the North Atlantic. Sexual maturation occurs at age-1 or 2 with adults spawning once a year, mostly between November and March (Richards 1963, 1982; Westin et al. 1979; Grosslein and Azarovitch 1982; Scott and Scott 1988). Richards (1982) and GEOMET Technologies, Inc. (1980) reported that the smallest mature female sand lance examined from LIS was 89 mm and 73 mm, respectively. Based on examination of 30 ripe females from Block Island Sound, Westin et al. (1979) calculated a length-fecundity relationship that gave estimates ranging between 2,184 eggs for a 98 mm female to 17,459 eggs for a fish 168 mm in length. GEOMET Technologies, Inc. (1980) reported a mean fecundity of 5,276 (range 424-16,302) in central LIS. Richards (1982) gave a range of 1,855 to 5,196 eggs for eight females (89-141 mm). A range of mean diameters was given for the demersal and adhesive eggs: 0.34 mm (Westin et al. 1979), 0.67-1.1 mm (Richards 1982), and 1.0 mm (Smigielski et al. 1984). Embryonic and larval development can be protracted, with minimum egg hatching times ranging from 61 days at water temperatures of about 30 to 37.5°F to 25 days at 50°F (Smigielski et al. 1984). Newly hatched larvae are from 5.7 to 6.3 mm in length and the average larval period is about 102 days to metamorphosis at about 30 to 40 mm (Smigielski et al. 1984). Larvae were found to be abundant from outer portions of estuaries to throughout the continental shelf (Norcross et al. 1961; Richards and Kendall 1973: Meyer et al. 1979; Monteleone et al. 1987). Post-larvae up to 8 mm in length are phytophagous, so early life history characteristics may be related to the spring phytoplankton bloom (Monteleone and Peterson 1986). Recently hatched (<5 mm) sand lance larvae are found throughout the water column, but older (>10 mm) larvae exhibit behavior similar to adults, with most staying near bottom during the day and moving up into the water column at night (Potter and Lough 1987). Pre- (20-30 mm) and post-metamorphic (50-80 mm) young presumably stay near bottom or burrow into sediments during the day as they were only caught at night. Potter and Lough (1987) also found highest densities at depths between 33 and 66 feet.

3.4.3 Natural Mortality of Eggs and Larvae

In a laboratory study, Ferraro (1980a) reported that Atlantic menhaden egg mortality through hatching was 98% at 50°F, 58% at 59°F, and about 67% at both 68°F and 77°F. Survival and normal development were not affected at

salinities between 10 and 30‰. In field studies, Ferraro (1981) estimated daily mortality and total mortality during embryogenesis that ranged from 3.4 to 94.6% and 11.1 to 99.8%, respectively. Mortality was generally lowest earlier in the spawning season. Through the egg and early larval stage, mortality was 99.96% during the first 13 days of life in 1972 and between 99.97 and 99.99% for the first 7 days in 1973 (Ferraro 1981). Late-spawned larvae may be killed during periods of extreme cold, particularly when water temperatures fall below 37.5°F (Lewis 1965; Reintjes and Pacheco 1966; Kendall and Reintjes 1975).

Data on mortality rates of eggs and larvae of the bay anchovy are summarized in Table 3-11. In general, daily mortality rates during the early life history of bay anchovy are relatively high, even when compared to estimates for other anchovy species (Leak and Houde 1987; Castro and Cowen 1991; Dorsey et al. 1996). For example, Dorsey et al. (1996) noted that 73% of all eggs spawned in Chesapeake Bay died before hatching; of those that survived, 72% of the yolk-sac larvae hatching died during the following day. Predation, particularly by ctenophores and jellyfish, was indicated as an important cause of mortality of anchovy eggs and larvae (Govoni and Olney 1991; Cowan and Houde 1992, 1993; Purcell et al. 1994; Dorsey et al. 1996; Rilling and Houde 1999a, 199b). Modeling studies by Cowan et al. (1999) indicated that the bay anchovy has a compensatory capacity to regulate its abundance through density-dependent processes throughout its lifetime.

Information on mortality rates for early life history stages of grubby is limited. This winter-spawning species has a large demersal egg, which probably confers some survival advantages, as does the time of its spawning. Grubby females also produce relatively few eggs, also a likely indicator of greater survival than would occur for eggs of more fecund fishes. Larval mortality rates may also be lower on a daily basis than for summer-spawned fish, even though they have a longer developmental season, because predation rates tend to be less in winter.

Williams et al. (1973) noted that only about 5% of cunner eggs survive to hatching. Mortality rates of cunner larvae have not been reported, but it is quite likely that both cunner eggs and larvae have mortality rates very similar to those of the tautog, which were given in Section 3.3.3. Using data from MNPS entrainment samples from 1979 through 1999, relative annual egg survival indices for both tautog and cunner were calculated by dividing Δ-mean (see Table 3-10) sample densities of larvae by those of eggs. The survival indices for tautog and cunner were highly correlated (Spearman's rank-order correlation coefficient $r = 0.862$; $p < 0.001$), indicating common processes that affected the recruitment of larvae for both of these related fishes. Post-settlement survival of young cunner over a 3-month period was reported to range between 0 and 4.5%, with highest survival found in more complex substrates (reef, cobble) and lowest in grass beds and on open sand (Tupper and Boutilier 1997).

The winter-spawned demersal eggs of the sand lance likely have higher survival than those of pelagic summer spawners. Mortality of sand lance larvae in laboratory experiments was unaffected by temperature (Buckley et al.

1984). Mean daily instantaneous total mortality rate (Z) for newly hatched larvae through day 16 was 0.01 (99% survival), independent of food ration level. Calculated Z for older larvae ranged between 0.02 (98% survival) and 0.2 (82%) and decreased with increasing food. Monteleone et al. (1987) reported that sand lance larvae can withstand several weeks without food, depending upon water temperature, surviving up to 60 days at 32°F and 19 days at 50°F. Buckley et al. (1984) calculated a range of larval survival rates to metamorphosis (102-day period) of 0.12%, 5.75%, and 11.74%, based on three daily levels of feeding (200, 500, and 1,000 rotifers·L^{-1}, respectively). They characterized these survival rates as being comparable to those for larval haddock, winter flounder, northern anchovy, and bay anchovy, but noted that American sand lance were better adapted for survival at low food densities. Noting extreme historical fluctuations in sand lance abundance were observed in LIS, including three distinct periods of alternating very high and very low abundance from the 1950s through the 1980s, Monteleone et al. (1987) suggested that annual mortality rates of sand lance larvae may vary considerably. They also found that larval sand lance densities were not correlated with environmental factors or with spring phytoplankton blooms, although 4 of the 6 years of lowest larval densities were associated with the warmest December water temperatures. They suggested that, similar to findings of Sherman et al. (1981), the boom and bust cycles of American sand lance abundance may be the result of predation on larvae by Atlantic herring and Atlantic mackerel. These predators may be particularly important in regulating sand lance abundance, as mackerel migration into LIS coincides with peak sand lance larval densities and they apparently eat sand lance larvae almost exclusively at this time. Monteleone et al. (1987) also suggested that American sand lance exhibit a density-dependent stock and recruitment relationship.

3.4.4 Entrainment at MNPS

Entrainment estimates of eggs and larvae of the other selected species assessed at MNPS are given in Tables 3-10 and 3-12 and Δ-mean densities at the plant discharges are shown in Figures 3-15 and 3-17 through 3-20. Entrainment volumes were largest from 1986 through 1995, the years of three-unit operation, and were smallest in 1996 and 1997, when MNPS units were mostly shut down. Entrainment estimates reflected both the volume of cooling water used and the annual abundance of eggs or larvae present at the intakes. To examine whether a direction of change of an entrainment density time-series of a species represented a significant ($p \leq 0.05$) trend, a nonparametric, distribution-free Mann-Kendall test (Hollander and Wolfe 1973) was used. Sen's (1968) nonparametric estimator of the slope was used to describe the rate of change of significant trends. This approach to trend analysis was suggested by Gilbert (1989) as particularly well-suited for analysis of environmental monitoring data because no assumptions regarding data distribution are required and small sample sizes are acceptable.

Atlantic menhaden larvae have become increasingly common at MNPS in recent years (Fig. 3-17) and this species now ranks fourth in abundance in MNPS entrainment samples. However, despite a significant ($p = 0.001$) trend of increasing abundance, larval menhaden densities and entrainment estimates have fluctuated considerably over the 24-year period, ranging from less than 1 million in 1979 to 208 million in 1989 (Table 3-12). Although larvae were

sometimes numerous at the intakes, very few eggs were entrained, which suggests that spawning takes place at some distance from the plant. Also, unlike the other important entrainment species, a bimodal periodicity of occurrence was found for Atlantic menhaden, indicating two distinct spawning periods. This is consistent with regional life history information given above (e.g., Ferraro 1981). Most spawning occurs during summer, with an estimated date of peak larval abundance on July 14 (Table 3-8). A smaller spawning event takes place in fall, peaking in early November, although and it may not be found in some years. During the summer reproductive period, nearly all larval entrainment occurs in July, with the primary and optimal entrainment seasons approximately the same (Table 3-8; Fig. 3-21). Besides being smaller in extent, the fall season is less well-defined, and can extend over about a 2-month period from October into early December. The optimal entrainment season in fall includes about 81% of the total larvae present and occurs from mid-October to mid-November (Fig. 3-22).

Besides tautog, the eggs of anchovies (mostly those of the bay anchovy) and cunner dominated collections at the MNPS discharges (Table 3-10). Although anchovy eggs ranked third behind the two wrasse species, numbers entrained (<1 to 883 million) have decreased significantly ($p = 0.001$) since the mid-1980s. Anchovy egg densities and entrainment estimates fluctuated erratically throughout the 1990s, with notably low entrainment estimates in 1996 (4 million) and 1997 (<1 million), when the station had low cooling-water use, and again in 1999 (<1 million). Nearly one-half of all larvae entrained at MNPS since 1976 have been anchovies, with greatest abundance observed in the late 1970s and early 1980s (Table 3-12). From 1976 through 1995, entrainment estimates ranged from 117 million to 1.4 billion. However, abundance of both anchovy eggs and larvae decreased significantly ($p = 0.001$) in recent years. Particularly low larval entrainment estimates were recorded in 1996 and 1997 (24 and 17 million, respectively). Throughout the years, anchovy egg and larval densities were significantly correlated (Spearman's rank-order correlation coefficient $r = 0.67$; $p = 0.001$). On average, peak egg entrainment occurred on July 19, about 11 days before peak larval entrainment (Table 3-8). The anchovy larval season is also more extended than that of eggs, so that the optimal entrainment season for eggs (July 8-30) encompassed 91% of the total (Fig. 3-23), but only 78% (July 11-August 18) for larvae (Fig. 3-24).

As indicated by MNPS entrainment samples, the grubby reproductive season peaks about 1 month before that of winter flounder, with larvae occurring primarily from February through mid-May and reaching a maximum on March 18 (Table 3-8). However, because the larval grubby season tails off relatively slowly, the optimal season includes only about two-thirds of the total entrainment (Table 3-8; Fig. 3-25). Densities of larval grubby and entrainment estimates have remained consistent since 1977. Most entrainment estimates ranged between 11 and 73 million, with one high value of 112 million found in 1988 (Table 3-12). Annual larval densities also remained relatively similar, with an occasional high value found, but no particularly low ones (Fig. 3-19). No significant trend in abundance was found for larval grubby abundance over the past 23 years.

Cunner eggs were always the most numerous of the eggs entrained each year, with annual estimates since 1979 ranging from 569 million to 6.1 billion (Table 3-10). Egg densities also varied considerably over this period (Fig. 3-15). The smallest entrainment estimates occurred from 1996 through 1998, when MNPS used appreciably less cooling water. No significant temporal trends were detected for cunner egg densities at MNPS. Peak cunner egg entrainment was estimated to occur on June 12, about 1 week earlier than that of tautog eggs. Both the primary and optimal entrainment seasons were shorter than that for tautog, indicating that the cunner likely has less protracted spawning (Table 3-8; Fig. 3-26). About 78% of the cunner egg entrainment occurs between May 24 and July 1.

Relative to other species, American sand lance larvae have a lengthy season of occurrence (December through June) at the MNPS discharges and their entrainment temporal distribution has lengthy tails. The primary season extends from January 17 through June 23 with the peak occurring on March 25 (Table 3-8). This lengthy season with small incremental daily changes resulted in an calculated optimal season that would protect only 39% of sand lance larvae (Table 3-8; Fig. 3-27). Sand lance were extremely abundant in the MNPS area from 1977 through 1981, with relatively high densities (Fig. 3-20) resulting in high entrainment estimates of 80 to 176 million for those years (Table 3-12). However, numbers decreased precipitously in 1982 and, in general, densities and entrainment estimates remained low, except for 1995 and 2000 (88-89 million entrained). There was no significant ($p = 0.12$) declining trend found over the entire 24-year period. However, an obvious decrease occurred after 1981 and abundance remained relatively stable only afterwards.

3.4.5 Entrainment Survival

With the exception of cunner eggs, little information on entrainment survival at MNPS exists for species other than winter flounder. Survival of cunner eggs in the MNPS discharge is most likely the same as that of tautog eggs; wrasse egg survival was discussed previously in Section 3.3.5. At the Canal Electric Company station, survival of entrained anchovy eggs ($n = 156$) ranged between 12 and 40%, depending upon the method of calcualtion, with about half of the mortality due to initial entrainment effects and half from delayed mortality (Collings et al. 1981). This study also provided some of the only information on entrainment survival of sand lance larvae. A total of 2,977 larvae was examined from the plant intakes and discharges and entrainment survival was calculated as 83% with nearly all mortality occurring immediately. However, high control mortality led Collings et al. (1981) to conclude that the true survival rate was likely less than 10% (as shown by a second method of calculation) due to the susceptibility of sand lance larvae to mechanical damage.

As part of a study summarized in Section 3.2.5 for larval winter flounder, survival of entrained bay anchovy eggs and larvae was also examined at the Oyster Creek Nuclear Generating Station (OCNGS) by EA (1986). Egg survival was noted by holding 46,520 bay anchovy eggs through hatch. Initial survival ranged between 21 and 83%, and had a weighted mean of about 50%. Lowest survival rates in these experiments were correlated with

higher discharge temperatures. More than 23,000 eggs were held to examine for latent survival. From 45 to 100% of the eggs collected at the intake survived through hatching, whereas the range for eggs collected at the plant discharge was 0 to 96%. Survival of eggs from the intake was correlated with water temperature, with an optimum temperature for survival ranging between about 79°F and 80.5°F. Survival at the discharge was also highly correlated with maximum temperature exposure encountered during the collection and holding period. Latent survival was relatively high (mean of 96%) when the maximum temperature was between 79°F and 80.5°F, declined when temperatures ranged between about 88°F and 98.5°F, and was zero at 100°F and higher. Total entrainment survival was highly variable and ranged between 0 and 93%. A regression analysis predicted 100% survival at a discharge temperature of 75°F, 50% at 88°F, and no survival at 100°F. Mortality due to physical effects of condenser passage was estimated at about 19%, with the remainder attributed to thermal effects. During a period of variable plant operations from 1976 through 1981, from 11 to 45% of bay anchovy eggs were estimated to have suffered entrainment mortality. Annual differences were largely due to variable plant thermal output in relation to prevailing ambient water temperatures. Initial entrainment survival of bay anchovy larvae at OCNGS was examined using 6,870 larvae (EA 1986). At a discharge temperature of 96°F or greater, no larvae survived, but at lower temperatures survival ranged between 53 and nearly 100%; a weighted mean survival rate of 71% was determined for the station. An immediate mortality of about 30% was estimated for pump and condenser passage with the remainder from thermal effects, but the estimate could have ranged between 20 and 67%, depending upon assumptions chosen during data analysis. About 3,600 specimens were held during latent survival studies. This work was not successfully completed because nearly all larvae, including controls, died during the 96-hour holding period. Since survival was similar between intake- and discharge-collected specimens, most of the mortality was probably a result of holding effects. EA (1986) noted that, unlike bay anchovy eggs, larvae of this species appeared to be very fragile and were difficult to maintain in the experimental holding facility.

Another study examining the survival of bay anchovy at a power plant with conventional traveling screens and a once-through cooling-water system was completed at the P.H. Robinson Generating Station, a 2,215 MWe plant located on Galveston Bay in Texas (Chung and Strawn 1982). This station has an approximately 2-mile long discharge canal with five helper cooling towers positioned halfway between the plant discharge and the end of the canal. The cooling towers were only operated during summer to reduce the thermal discharge from 104°F to 95°F or less. Bay anchovy were held in laboratory tanks at experimental temperatures for up to 3 hours, the maximum time estimated for a fish to pass from the plant to the area of the cooling towers in the discharge canal. Fish examined ranged between 20 and 70 mm, which would have included larger larvae, juveniles, and likely smaller adults. Almost all bay anchovy survived the holding period when discharge canal water temperature was about 89.5°F (intake temperature of 68°F or greater). Few fish survived at temperatures of 97°F or greater.

The Calvert Cliffs Nuclear Power Plant, described by (Sellner and Peters 1987), has twin 880 MWe units that withdraw about 1.2 million gal·min^{-1} from Chesapeake Bay and produces a maximum ΔT of 12°F. From 3 to 5% of bay anchovy larvae survived entrainment in comparison to 88 to 98% for the more robust naked goby larvae (EA 1981).

Information on entrainment survival of larval Atlantic menhaden and other herrings (mostly alewife and blueback herring) and anchovies was compiled in EPRI (2000). As expected from the many different power plants and water temperatures sampled in these studies and the differing sampling techniques used, results were quite variable. Even so, some entrainment survival (mean of about 25%) of these generally fragile fishes was indicated. However, anchovies and herrings demonstrate higher mortality than most other marine or estuarine fishes, such as striped bass and drums. Some data were also available for sand lance larvae (EA 1978; EPRI 2000). At the Port Jefferson power plant (see section 3.2.5), sand lance had a survival of 27% (n = 166) using one type of pump sampler and 93% (n = 25) with another type of pump. Sculpin larvae, which includes the grubby, had a survival of 75% (n = 17) in this study. Considerably more (n = 782) larval sand lance were collected in a 1980 study at the Northport Generating Station on LIS (EPRI 2000). Initial survival was 25.3%, but only 1.8% of these larvae survived a 48-h period following entrainment.

In summarizing general results of power plant entrainment survival studies, EPRI (2000) concluded that the probability of a larva surviving plant passage was related to the species entrained, the size of the larva, whether or not a biocide was in use, effects due to mechanical action, and the discharge temperature. With the exception of herrings and anchovies, survival of various larval fishes at many power plants averaged in excess of 50%. In general, survival usually increased with larval length. Although mortality increased with biocide treatments, the short duration of chlorine application at MNPS would greatly limit this effect on survival. Mechanical effects (e.g., shear, abrasion, pressure changes) were once believed to be an important source of entrainment mortality. However, studies completed at power plants pumping water but without any thermal discharge indicated that mortality due to mechanical effects is likely negligible in some cases and low in others. Probably the greatest effects on larval survival are due to discharge temperature. It appears that survival is related to species-specific upper thermal tolerances, which for some estuarine species such as striped bass and anchovies, tends to fall between 86 and 89.6°F. At temperatures above 91°F survival decreases markedly.

3.4.6 Sources of Entrained Eggs and Larvae

Based on their biology and literature reports, the early life history stages of Atlantic menhaden and American sand lance found in LIS are produced by large and widely distributed Atlantic coastal populations, the spawning of which occurs throughout large areas of the continental shelf (Richards and Kendall 1973; Nizinski et al. 1990; Ahrenholz 1991). However, Epperly (1989) found some evidence for northern and southern subpopulations of Atlantic

menhaden based on meristic and biochemical differences and Richards (1982) speculated that there is some population differentiation within the total range of American sand lance. The American sand lance has a demersal egg, which does not lend itself to transport. However, the larval stage of sand lance is very lengthy, which allows larvae to become widely distributed. Based on the general absence of its pelagic eggs in MNPS entrainment samples, apparently few adult Atlantic menhaden spawn near the plant and larvae must therefore be transported to Niantic Bay from offshore areas. Similarly, the bay anchovy does not appear to form distinctive subpopulations associated with discrete geographical areas and it is unclear whether adults return to natal estuaries. However, based on their migratory patterns to offshore waters in fall and winter, population abundance may be limited as much by overwintering mortality as by successful summertime reproduction in natal estuaries (Vouglitois et al. 1987). The extensive offshore winter migration of bay anchovy likely facilitates considerable mixing, with Morgan et al. (1995) finding little genetic variation over large geographic areas and suggesting a panmictic population for the bay anchovy in Chesapeake Bay.

Unlike the species discussed above, the grubby may form more discretely localized populations as it has a relatively large, demersal egg not subject to transport. However, since it is a winter spawner, larvae may have a relatively lengthy development, enabling them to become widely distributed. The grubby, like the winter flounder, is one of the few species having larvae in higher densities in more inshore areas, such as the Niantic River, than in more offshore waters, which also suggests a localized source population. As adults, cunner may also form localized populations as they appear to establish very small home ranges and do not undertake extensive movements throughout their lifetime (Green and Farwell 1971; Green 1975; Olla et al. 1975; Pottle and Green 1979b; Lawton et al. 1996). However, the sources of settling juveniles that form these relatively sedentary adult groups is unknown. Like the tautog, cunner eggs are widely distributed in LIS and can be transported 5 miles or more between spawning and hatching. Larvae may move even further before final transformation and settlement as young juveniles. Thus, with the exception of grubby and possibly cunner, individuals of these other species most likely belong to widely distributed coastal populations spawning throughout large areas of LIS and Atlantic Ocean continental shelf waters, which would lessen any potential power plant impact to their populations.

3.5 SUMMARY

Information presented in this chapter, particularly the calculation of species-specific entrainment seasons given in Table 3-8 for winter flounder and tautog, are used in the assessments found in Chapter 4. Further, winter flounder larvae were allocated to either the Niantic River or non-Niantic River populations. Despite some evidence for through-plant survival of entrained eggs or larvae, 100% mortality is conservatively assumed and no correction factor was applied to reduce entrainment estimates prior to the assessments. Life history data presented herein allowed inferences to be made regarding population-level effects that might be expected as a result of entrainment of fish eggs and larvae at MNPS, which are given in the following chapter.

3.6 REFERENCES

Ahrenholz, D.W. 1991. Population biology and life history of the North American menhadens, *Brevoortia* spp. Mar. Fish. Rev. 53:3-19.

ASMFC (Atlantic States Marine Fisheries Commission). 1996. Draft fisheries management plan for tautog. Public hearing summary. Washington, DC. 10 pp.

Berrien, P., and J. Sibunka. 1999. Distribution patterns of fish eggs in the U.S. northeast continental shelf ecosystem, 1977-1987. NOAA Tech. Rep. NMFS 145. 310 pp.

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish Wildl. Serv. Bull. 53:1-577.

Black, D.E., D.K. Phelps, and R.L. Lapan. 1988. The effects of inherited contamination on egg and larval winter flounder, *Pseudopleuronectes americanus*. Mar. Envir. Res. 25:45-62.

Bourne, D.W., and J.J. Govoni. 1988. Distribution of fish eggs and larvae and patterns of water circulation in Narragansett Bay, 1972-73. Am. Fish. Soc. Symp. 3:132-148.

Buckley, L.J., A.S. Smigielski, T.A. Halavik, E.M. Caldarone, B.R. Burns, and G.C. Laurence. 1991a. Winter flounder *Pseudopleuronectes americanus* reproductive success. I. Among-location variability in size and survival of larvae reared in the laboratory. Mar. Ecol. Prog. Ser. 74:117-124.

Buckley, L.J., A.S. Smigielski, T.A. Halavik, E.M. Caldarone, B.R. Burns, and G.C. Laurence. 1991b. Winter flounder *Pseudopleuronectes americanus* reproductive success. II. Effects of spawning time and female size on size, composition and viability of eggs and larvae. Mar. Ecol. Prog. Ser. 74:125-135.

Buckley, L.J., S.I. Turner, T.A. Halavik, A.S. Smigielski, S.M. Drew, and G.C. Laurence. 1984. Effects of temperature and food availability on growth, survival, and RNA-DNA ratio of larval sand lance (*Ammodytes americanus*). Mar. Ecol. Prog. Ser. 15:91-97.

Burton, M.P., and D.R. Idler. 1984. The reproductive cycle in winter flounder *Pseudopleuronectes americanus* (Walbaum). Can. J. Zool. 62:2563-2567.

Castro, L.R., and R.K. Cowen. 1991. Environmental factors affecting the early life history of bay anchovy *Anchoa mitchilli* in Great South Bay, New York. Mar. Ecol. Prog. Ser. 76:235-247.

Chambers, R.C., W.C. Leggett, and J.A. Brown. 1988. Variation in and among early life history traits of laboratory-reared winter flounder *Pseudopleuronectes americanus*. Mar. Ecol. Prog. Ser. 47:1-15.

Chenoweth, S.B. 1963. Spawning and fecundity of the tautog, *Tautoga onitis* (Linnaeus). M.S. Thesis. University of Rhode Island, Narragansett, RI. 60 pp.

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. Env. Biol. Fish. 7:57-62.

Collings, W.S., C. Cooper-Sheehan, S.C. Hughes, and J.L. Buckley. The effects of power generation on some of the living marine resources of the Cape Cod Canal and approaches. Mass. Dept. Fish., Wildl., and Rec. Vehicles, Div. Mar. Fish. 212 pp. + app.

Colton, J.B., Jr., W.G. Smith, A.W. Kendall, Jr., P.L. Berrien, and M. Fahay. 1979. Principle spawning areas and times of marine fishes, Cape Sable to Cape Hatteras. Fish. Bull., U.S. 76:911-915.

Cooper, R.A. 1964. Some vital statistics of the tautog, *Tautoga onitis* (Linnaeus) from Rhode Island. Ph.D. Thesis, University of Rhode Island, Narragansett, RI. 153 pp.

Cowan, J.H., Jr., and E.D. Houde. 1992. Size-dependent predation on marine fish larvae by ctenophores, scyphomedusae and planktivorous fishes. Fish. Oceanogr. 1:113-126.

Cowan, J.H., Jr., and E.D. Houde. 1993. The relative predation potential of scyphomedusae, ctenophores, and planktivorous fish on ichthyoplankton in Chesapeake Bay. Mar. Ecol. Prog. Ser. 95:55-65.

Cowan, J.H., Jr., K.A. Rose, E.D. Houde, S-B. Wang, and J. Young. 1999. Modeling effects of increased larval mortality on bay anchovy population dynamics in the mesohaline Chesapeake Bay: evidence for compensatory reserve. Mar. Ecol. Prog. Ser. 185:133-146.

Crawford, R.E. 1990. Winter flounder in Rhode Island coastal ponds. Rhode Island Sea Grant, University of Rhode Island, Narragansett, RI. RIU-G-90-001. 24 pp.

Crecco V.A., and P. Howell. 1990. Potential effects of current larval entrainment mortality from the Millstone Nuclear Power Station on the winter flounder, *Pseudopleuronectes americanus*, spawning population in the Niantic River. CT Dept. Envir. Prot., Bu. Fish., Spec Pub. 37 pp.

DEP (Connecticut Department of Environmental Protection). 2000. Letter C09872 dated February 16, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Comments on proposed cooling water alternatives scope of study.

Desfosse, J.C., M. Gibson, and D. Simpson. 1998. 1998 review of interstate fishery management plan for inshore stocks of winter flounder (*Pseudopleuronectes americanus*). Pages 130-138 *in* R.E. Beal, J.C. Desfosse, J.D. Field, A.M. Shick, and T.L. Berger. Atlantic States Marine Fisheries Commission 1998 review of interstate fishery management plans. ASMFC Spec. Rep. No. 66.

De Vries, M.C., R.B. Forward, Jr., and W.F. Hettler. 1995. Behavioural response of larval Atlantic menhaden to different rates of temperature change. J. Fish Biol. 47:1081-1095.

Dew, C.B. 1976. A contribution of the life history of the cunner, *Tautogolabrus adspersus*, in Fishers Island Sound, Connecticut. Chesapeake Sci. 14:101-113.

Dietrich, C.S., Jr. 1979. Fecundity of the Atlantic menhaden, *Brevoortia tyrannus*. Fish. Bull., U.S. 77:308-311.

Dimou, K. 1989. Simulation of estuary mixing using a 2-D random walk model. M.S. Thesis, Massachusetts Institute of Technology, Cambridge, MA. 138 pp.

Dimou, N.K., and E.E. Adams. 1989. Application of a 2-D particle tracking model to simulate entrainment of winter flounder larvae at the Millstone Nuclear Power Station. Energy Laboratory Report No. MIT-EL 89-002. Massachusetts Institute of Technology, Cambridge, MA. 73 pp.

Dimou, N.K., A.T. Obst, J. Moeller, and E.E. Adams. 1990. Numerical simulation of fish larvae entrainment at the Millstone Nuclear Power Station. Summary report covering the period December 1989 - August 1990. Energy Laboratory Report No. MIT-EL 90-003. Massachusetts Institute of Technology, Cambridge, MA. 11 pp. + app.

DNC (Dominion Nuclear Connecticut, Inc.). 2001a. Winter flounder studies. Pages 9-94 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 2000. Millstone Environmental Laboratory, Waterford, CT.

DNC. 2001b. Fish ecology studies. Pages 95-137 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 2000. Millstone Environmental Laboratory, Waterford, CT.

Dorf, B.A. 1994. Ecology of juvenile tautog (*Tautoga onitis*, Family Labridae) in Narragansett Bay, Rhode Island. Ph.D. Thesis, University of Rhode Island, Narragansett, RI. 213 pp.

Dorf, B.A., and J.C. Powell. 1997. Distribution, abundance, and habitat characteristics of juvenile tautog (*Tautoga onitis*, Family Labridae) in Narragansett Bay, Rhode Island, 1988-1992. Estuaries 20:589-600.

Dorsey, S.E., E.D. Houde, and J.C. Gamble. 1996. Cohort abundances and daily variability in mortality of eggs and yolk-sac larvae of bay anchovy, *Anchoa mitchilli*, in Chesapeake Bay. Fish. Bull., U.S. 94:257-267.

Dovel, W.L. 1971. Fish eggs and larvae of the upper Chesapeake Bay. Univ. Maryland Nat. Res. Inst., Spec. Rep 4. 71 pp. (Not seen, cited *in* Jones et al. 1978).

Dryfoos, R.L., R.P. Cheek, and R.L. Kroger. 1973. Preliminary analyses of Atlantic menhaden, *Brevoortia tyrannus*, migrations, population structure, survival, and exploitation rates, and availability as indicated from tag returns. Fish. Bull., U.S. 71:719-734.

Dunn, R.S. 1970. Further evidence for a three-year oocyte maturation time in the winter flounder (*Pseudopleuronectes americanus*). J. Fish. Res. Board Can. 27:957-960.

Dunn, R.S., and A.V. Tyler. 1969. Aspects of the anatomy of the winter flounder ovary with hypotheses on oocyte maturation time. J. Fish. Res. Board Can. 26:1943-1947.

Draper, N., and H. Smith. 1981. Applied regression analysis. John Wiley and Sons, New York. 709 pp.

Durbin, A., and E. Durbin. 1990. Analysis of otolith microstructure in larval winter flounder from the Niantic River, Connecticut. Report to Electric Power Research Institute. University of Rhode Island, Graduate School of Oceanography, Narragansett, RI. 26 pp. + 5 tab. + 2 app. tab. + 12 fig. + 1 app. fig.

EA (EA Engineering, Science, and Technology, Inc.). 1978. Port Jefferson Generating Station entrainment survival study. Prepared for Long Island Lighting Company, Hicksville, NY. EA Rep. LIL81.

EA. 1981. Entrainment abundance and viability studies, Calvert Cliffs nuclear Power Plant. Final report 1978-1980. Prepared for Baltimore Gas & Electric Company. (Not seen, cited *in* Mayhew et al. 2000).

EA. 1986. Entrainment and impingement studies at Oyster Creek Nuclear Generating Station 1984-1985. Prepared for GPU Nuclear Corporation, Morristown, NJ. EA Rep. GPU44G.

Epperly, S.P. 1989. A meristic and biochemical investigation of Atlantic menhaden, *Brevoortia tyrannus* (Latrobe). J. Fish Biol. 35:139-152.

EPRI (Electric Power Research Institute). 2000. Review of entrainment survival studies: 1970-2000. Palo Alto, CA. EPRI Tech. Rep. 1000757. Prepared by EA Engineering, Science, and Technology, Inc.

Ferraro, S.P. 1980a. Embryonic development of Atlantic menhaden, *Brevoortia tyrannus*, and a fish embryo age estimation method. Fish. Bull., U.S. 77:943-949.

Ferraro, S.P. 1980b. Daily time of spawning of 12 fishes in the Peconic Bays, New York. Fish. Bull., U.S. 78:455-464.

Ferraro, S.P. 1981. Eggs and larvae of Atlantic menhaden (*Brevoortia tyrannus*) in the Peconic Bays, New York in 1972-74. Rapp. P.-v. Réun. Cons. int. Explor. Mer 178:181-182.

Forward, R.B., L.M. McKelvey, W.F. Hettler, and D.E. Hoss. 1993. Swimbladder inflation of the Atlantic menhaden *Brevoortia tyrannus*. Fish. Bull., U.S. 91:254-259.

Forward, R.B., Jr., R.A. Tankersley, and J.S. Burke. 1996. Endogenous swimming rhythms of larval Atlantic menhaden, *Brevoortia tyrannus* Latrobe: implications for vertical migration. J. Exp. Mar. Biol. Ecol. 204:195-207.

Friedland, K.D., and L.W. Haas. 1988. Emigration of juvenile Atlantic menhaden, *Brevoortia tyrannus* (Pisces: Clupeidae), from the York River Estuary. Estuaries 11:45-50.

Fritzsche, R.A. 1978. Development of fishes of the Mid-Atlantic Bight. An atlas of egg, larval and juvenile stages. Vol. V. Chaetodontidae through Ophidiidae. Power Plant Project, Off. Biol. Serv., U.S. Fish Wildl. Serv., U.S. Dept. of the Interior, FWS/OBS-78/12. 340 pp.

GEOMET Technologies, Inc. 1980. Fecundity of selected fish species from Shoreham, New York 1978-1979. Prepared for Long Island Lighting Company, Hicksville, NY. 93 pp.

Gilbert, R.O. 1989. Statistical methods for environmental pollution monitoring. Van Nostrand-Reinhold Co., New York. 320 pp.

Gleason, T., and C. Recksiek. 1988. Synopsis of biological data for the cunner *Tautogolabrus adspersus* (Walbaum). University of Rhode Island. Contrib. 240 of the RI Exp. Sta. Unpublished ms.

Goddard, K. 1992. Final report to Northeast Utilities on the project entitled: assignment of winter flounder larvae to natal populations. The American University, Washington, DC. 27 pp + 2 tab. + 5 fig.

Gottschall, K.F., M.W. Johnson, and D.G. Simpson. 2000. The distribution and size composition of finfish, American lobster, and long-finned squid in Long Island Sound based on the Connecticut Fisheries bottom trawl survey, 1984-1994. NOAA Tech. Rep. NMFS 148. 195 pp.

Govoni, J.J., and J.E. Olney. 1991. Potential predation on fish eggs by the lobate ctenophore *Mnemiopsis leidyi* within and outside the Chesapeake Bay plume. Fish. Bull., U.S. 89:181-186.

Green, J.M. 1975. Restricted movements and homing of the cunner *Tautogolabrus adspersus*. Can. J. Zool. 53:1427-1431.

Green, J.M., and M. Farwell. 1971. Winter habits of the cunner, *Tautogolabrus adspersus* (Walbaum 1792), in Newfoundland. Can. J. Zool. 49:1497-1499.

Green, J.M., G. Martel, and E.A. Kingsland. 1985. Foraging time allocation in a territorial fish: influence of reproductive activities. Mar. Ecol. Prog. Ser. 24:23-26.

Grosslein, M.D., and T.R. Azarovitch. 1982. Fish distribution. MESA New York Bight Atlas Monogr. 15. New York Sea Grant Institute, Albany, NY. 182 pp.

Hess, K.W., M.P. Sissenwine, and S.B. Saila. 1975. Simulating the impact of entrainment of winter flounder larvae. Pages 1-30 *in* S.B. Saila, ed. Fisheries and energy production: a symposium. D.C. Heath and Co., Lexington, MA.

Higham, J.R., and W.R. Nicholson. 1964. Sexual maturation and spawning of Atlantic menhaden. Fish. Bull., U.S. 63:255-271.

Hjorleifsson, E. 1992. Abundance, condition, growth and mortality of winter flounder (*Pleuronectes americanus,* Walbaum) larvae in Narragansett Bay during spring of 1988. Ph.D. Dissertation. University of Rhode Island, Narragansett, RI. 259 pp.

Hoese, H.D., and R.H. Moore. 1977. Fishes of the Gulf of Mexico. Texas A&M University Press, College Station, TX. 327 pp.

Hollander, M., and D.A. Wolfe. 1973. Nonparametric statistical methods. John Wiley and Sons, New York. 503 pp.

Hostetter, E.B., and T.A. Munroe. 1993. Age, growth, and reproduction of tautog, *Tautoga onitis* (Labridae: Perciformes) from coastal waters of Virginia. Fish. Bull., U.S. 91:45-64.

Houde, E.D., J.C. Gamble, S.E. Dorsey, and J.H. Cowan, Jr. 1994. Drifting mesocosms: the influence of gelatinous zooplankton on mortality of bay anchovy, *Anchoa mitchilli,* eggs and yolk-sac larvae. ICES J. Mar. Sci. 51:383-394.

Houde, E.D., and C.E. Zastrow. 1991. Bay anchovy. Pages 8-1 -8-14 *in* S.L. Funderburk, J.A. Mihursky, S.J. Jordan, and D. Riley, eds. Habitat requirements for Chesapeake Bay living resources (2nd ed.). Living Resources subcommittee, Chesapeake Bay Program, Annapolis, MD. (Not seen, cited *in* Rilling and Houde 1999b).

Howell, P., A. 1993. Certain decisions with uncertain data: early life-history data and resource management. Am. Fish. Soc. Symposium 14:159-165.

Howell, P., A. Howe, M. Gibson, and S. Ayvazian. 1992. Fishery management plan for inshore stocks of winter flounder. Fisheries management rep. no. 21 of the Atlantic States Marine Fisheries Commission. 138 pp.

Howell, P.T., and D.R. Molnar. 1996. Job 3: a study of inshore finfish habitat. Pages 71-89 *in* A study of recreational fisheries in Connecticut. CT Dept. Envir. Prot., Bur. Nat. Res., Fish. Div.

Howell, P.T., and D.R. Molnar. 1998. Job 3: a study of inshore finfish habitat. Pages 105-127 *in* A study of recreational fisheries in Connecticut. CT Dept. Envir. Prot., Bur. Nat. Res., Fish. Div.

Howell, P.T., D.R. Molnar, and R.B. Harris. 1999. Juvenile winter flounder distribution by habitat type. Estuaries 22:1090-1095.

Itzkowitz, N., and J.R. Schubel. 1983. Tolerance of five-day-old winter flounder, *Pseudopleuronectes americanus,* larvae to thermal shock. Fish. Bull., U.S. 81:913-916.

Johansen, F. 1925. Natural history of the cunner (*Tautogolabrus adspersus* Walbaum). Contrib. Can. Biol. 2:423-468.

Johnson, M.W., K. Gottschall, and D.G. Simpson. 1998. Job 2: marine finfish survey. Part 1: Long Island Sound trawl survey. Pages 37-94 *in* A study of recreational fisheries in Connecticut. CT Dept. Envir. Prot., Bur. Nat. Res., Fish. Div.

Jones, P.W., FD. Martin, and J.D. Hardy, Jr. 1978. Development of fishes of the Mid-Atlantic Bight. An atlas of egg, larval and juvenile stages. Vol. I. Acipenseridae through Ictaluridae. Power Plant Project, Off. Biol. Serv., U.S. Fish Wildl. Serv., U.S. Dept. Interior, FWS/OBS-78/12. 314 pp.

Keller, A.A., and G. Klein-MacPhee. 2000. Impact of elevated temperature on the growth, survival, and trophic dynamics of winter flounder larvae: a mesocosm study. Can. J. Fish. Aquat. Sci. 57:2382-2392.

Kendall, A.W., Jr, and J.W. Reintjes. 1975. Geographic and hydrographic distribution of Atlantic menhaden eggs and larvae along the middle Atlantic coast from RV *Dolphin* cruises, 1965-66. Fish. Bull., U.S. 73:317-335.

Klein-MacPhee, G. 1978. Synopsis of biological data for the winter flounder, *Pseudopleuronectes americanus* (Walbaum). NOAA Tech. Rep. NMFS Circ. 414. 43 pp.

Kollmeyer, R.C. 1972. A study of the Niantic River estuary, Niantic, Connecticut. Final report phases I and II, physical aspects of the Niantic River estuary. Rep. No. RDCGA 18. U.S. Coast Guard Academy, New London, CT. 78 pp.

Kroger, R.L., and J.F. Guthrie. 1973. Migrations of tagged juvenile Atlantic menhaden. Trans. Am. Fish. Soc. 102:417-422.

Kuntz, A. 1914. The embryology and larval development of *Bairdiella chrysura* and *Anchovia mitchilli*. U.S. Bur. Fish., Bull. (1913) 33:1-19.

Laroche, J.L. 1982. Trophic patterns among larvae of five species of sculpins (Family: Cottidae) in a Maine estuary. Fish. Bull., U.S. 80:827-840.

Laurence, G.C. 1973. Influence of temperature on energy utilization of embryonic and prolarval tautog, *Tautoga onitis*. J. Fish. Res. Board Can. 30:435-442.

Laurence, G.C. 1975. Laboratory growth and metabolism of the winter flounder *Pseudopleuronectes americanus* from hatching through metamorphosis at three temperatures. Mar. Biol. (Berl.) 32:223-229.

Laurence, G.C. 1977. A bioenergetic model for the analysis of feeding and survival potential of winter flounder, *Pseudopleuronectes americanus*, larvae during the period from hatching through metamorphosis. Fish. Bull., U.S. 75:529-546.

Laurence, G.C., T.A. Halavik, B. Burns, and A.S. Smigielski. 1979. An environmental chamber for monitoring "in situ" growth and survival of larval fishes. Trans. Am. Fish. Soc. 108:197-203.

Lawton, R., B. Kelly, V. Malkoski, J. Chisholm, P. Nitschke, and J. Boardman. 1996. Annual report on assessment and mitigation of impact of the Pilgrim Nuclear Power Station on finfish populations in Western Cape Cod Bay *in* Marine Ecology studies related to the operation of Pilgrim Station. Semi-annual Rep. No. 47. Boston Edison Company. 86 pp.

Lazzari, M.A., K.W. Able, and M.P. Fahay. 1989. Life history and food habits of the grubby, *Myoxocephalus aenaeus* (Cottidae), in a Cape Cod estuary. Copeia 1989:7-12.

Leak, J.C., and E.D. Houde. 1987. Cohort growth and survival of bay anchovy, *Anchoa mitchilli*, larvae in Biscayne Bay, Florida. Mar. Ecol. Prog. Ser. 37:109-122.

Levin, P.S. 1991. Effects of microhabitat on recruitment variation in a Gulf of Maine reef fish. Mar. Ecol. Prog. Ser. 75:183-189.

Levin, P.S. 1996. Recruitment in a temperate demersal fish: does larval supply matter? Limnol. Oceanogr. 41:672-679.

Lewis, R.M. 1965. The effect of minimum temperature on the survival of larval Atlantic menhaden, *Brevoortia tyrannus*. Trans. Am. Fish. Soc. 94:409-412.

Lewis, R.M., D.W. Ahrenholz, and S.P. Epperly. 1987. Fecundity of Atlantic menhaden, *Brevoortia tyrannus*. Estuaries 10:347-350.

Lewis, R.M., E.P. Wilkins, and H.R. Grody. 1972. A description of young Atlantic menhaden, *Brevoortia tyrannus*, in the White Oak River estuary, North Carolina. Fish. Bull., U.S. 70:115-118.

Lobell, M.J. 1939. A biological survey of the salt waters of Long Island, 1938. Report on certain fishes. Winter flounder (*Pseudopleuronectes americanus*). Suppl. 28th Ann. Rep., N.Y. Cons. Dep., Pt. I:63-96.

Loos, J.J., and E.S. Perry. 1991. Larval migration and mortality rates of bay anchovy in the Patuxent River. Pages 65 to 76 *in* R.D. Hoyt, ed. LarvaL fish recruitment and research in the Americas. Thirteenth annual larval fish conference, Mérida, Mexico, May 1989. NOAA Tech. Rep. NMFS 95.

Luo, J., and J.A. Musick. 1991. Reproductive biology of bay anchovy in Chesapeake Bay. Trans. Am. Fish. Soc. 120:701-710.

MacGregor, J.M., and E.D. Houde. 1996. Onshore-offshore pattern and variability in distribution and abundance of bay anchovy *Anchoa mitchilli* eggs and larvae in Chesapeake Bay. Mar. Ecol. Prog. Ser. 138:15-25.

Malchoff, M.H. 1993. Age, growth, and distribution of cunner (*Tautogolabrus adspersus*) and tautog (*Tautoga onitis*) larvae in the New York Bight: a single season analysis. M.S. Thesis, Bard College, Annadale-on-Hudson, NY. 75 pp. (Not seen, cited *in* Levin 1996).

Mayhew, D.A., L.D. Jensen, D.F. Hanson, and P.H. Muessig. 2000. A comparitive review of entrainment survival studies at power plants in estuarine environments. Env. Sci. Pol. 3:S295-S301.

McHugh, J.L. 1967. Estuarine nekton. Pages 581-620 *in* G.H. Lauff, ed. Estuaries. Amer. Assoc. Advan. Sci. Publ. 83.

Meng, L., and J.C. Powell. 1999. Linking juvenile fish and their habitats: an example from Narragansett Bay, Rhode Island. Estuaries 22:905-916.

Meyer, T.L., R.A. Cooper, and R.W. Langton. 1979. Relative abundance, behavior, and food habits of the American sand lance, *Ammodytes americanus*, from the Gulf of Maine. Fish. Bull., U.S. 77:243-253.

Miller, D. 1958. A key to some of the more common larval fishes of the Gulf of Maine. Woods Hole Lab. Ms. Rep. 58-1. 56 pp.

Monteleone, D.M. 1992. Seasonality and abundance of ichthyoplankton in Great South Bay, New York. Estuaries 12:230-238.

Monteleone, D.M., and W.T. Peterson. 1986. Feeding ecology of American sand lance *Ammodytes americanus* larvae from Long Island Sound. Mar. Ecol. Prog. Ser. 30: 133-143.

Monteleone, D.M.,W.T. Peterson and G.C. Williams. 1987. Interannual fluctuations in the density of sand lance, *Ammodytes americanus*, larvae in Long Island Sound, 1951-1983. Estuaries 10: 246-254.

Morgan, R.P. II, B.M. Baker, and J.H. Howard. 1995. Genetic structure of bay anchovy (*Anchoa mitchilli*) populations in Chesapeake Bay. Estuaries 18:482-493.

MRI (Marine Research, Inc.). 1990. Ichthyoplankton entrainment monitoring at Pilgrim Nuclear Power Station, January-December 1989 *in* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 25, January 1989-December 1989. Boston Edison Co., Braintree, MA.

Nelson, W.R., M.C. Ingham, and W.E. Schaaf. 1977. Larval transport and year-class strength of Atlantic menhaden, *Brevoortia tyrannus*. Fish. Bull., U.S. 75:23-41.

Newberger, T.A., and E.D. Houde. 1995. Population biology of bay anchovy *Anchoa mitchilli* in the mid Chesapeake Bay. Mar. Ecol. Prog. Ser. 116:25-37.

Nicholson, W.R. 1971. Coastal movements of Atlantic menhaden as inferred from changes in age and length distributions. Trans. Am. Fish. Soc. 100:708-716.

Nicholson, W.R. 1978. Movements and population structure of Atlantic menhaden indicated by tag returns. Estuaries 1:141-150.

Nitschke, P., M. Mather, and F. Juanes. 2001. A comparison of length-, weight-, and age-specific fecundity relationships for cunner in Cape Cod Bay. N. Am. J. Fish. Man. 21:86-95.

Nizinski, M.S., B.B. Collette, and B.B. Washington. 1990. Separation of two species of sand lance, *Ammodytes americanus* and *A. dubius*, in the Western North Atlantic. Fish. Bull., U.S. 88:241-255.

NNECO (Northeast Nuclear Energy Company). 1995. Letter D08983 dated November 29, 1995 from D.B. Miller, NNECO, to S.J. Holbrook, Commissioner, CT DEP. Millstone Nuclear Power Station addendum to ecological monitoring program.

NNECO. 2000. Letter D15460 dated January 27, 2000 from P.M. Jacobson, NNECO, to A. Rocque, Commissioner, CT DEP. Addendum to the 2000 Millstone Nuclear Power Station ecological monitoring program.

NNECO. 2001. Letter D16923 dated January 30, 2001 from G.W. Johnson, NNECO, to A. Rocque, Commissioner, CT DEP. Addendum to the 2001 Millstone Nuclear Power Station ecological monitoring program.

Norcross, J.J., W.H. Massmann, and E.B. Joseph. 1961. Investigations of inner continental shelf waters off lower Chesapeake Bay. Part II. Sand lance larvae, *Ammodytes americanus*. Chesapeake Sci. 2:49-59.

NUSCO (Northeast Utilities Service Company). 1975. Summary report ecological and hydrographic studies. May 1966 through December 1974. Millstone Nuclear Power Station, Waterford, CT.

NUSCO. 1976. Environmental assessment of the condenser cooling water intake structures (316b demonstration). Vol. 1 and 2. Millstone Nuclear Power Station, Waterford, CT.

NUSCO. 1983a. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report, 1982. 53 pp. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1983b. Millstone Nuclear Power Station Unit 3 environmental report. Operating license stage. Vol. 1-4.

NUSCO. 1984. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report, 1983. 65 pp. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1985. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report, 1984. 74 pp. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1986. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report, 1985. 69 pp. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1987a. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Summary of studies prior to Unit 3 operation. 151 pp. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1987b. Justification for discontinuing impingement monitoring at Millstone Unit 2. Enclosure 2 to Letter D01595 dated July 31, 1987 from E.J. Mroczka, NUSCO, to L. Carothers, Commissioner, CT DEP. 12 pp.

NUSCO. 1988. The usage and estimation of DELTA means. Pages 311-320 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Three-unit operational studies, 1986-1987.

NUSCO. 1989. Winter flounder studies. Pages 239-316 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1988. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1991a. Winter flounder studies. Pages 9-86 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1990. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1991b. Fish ecology studies. Pages 89-125 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1990. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1991c. Ichthyoplankton entrainment estimation. Pages 261-270 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1990. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1992a. Winter flounder studies. Pages 7-110 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1991. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1992b. Fish ecology studies. Pages 111-156 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1991. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1992c. Niantic Bay current studies. Pages 317-331 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1991. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1993. Winter flounder studies. Pages 189-269 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1992. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1994a. Fish ecology studies. Pages 111-140 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1993. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1994b. Winter flounder studies. Pages 141-228 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1993. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1997. Fish ecology studies. Pages 9-58 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1996. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1998. Fish ecology studies. Pages 107-160 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1997. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 1999. Fish ecology studies. Pages 113-159 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1998. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 2000a. Winter flounder studies. Pages 9-112 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1999. Northeast Utilities Environmental Laboratory, Waterford, CT.

NUSCO. 2000b. Fish ecology studies. Pages 113-158 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1999. Northeast Utilities Environmental Laboratory, Waterford, CT.

Olla, B.L., A.J. Bejda, and A.D. Martin. 1975. Activity, movements, and feeding behavior of the cunner, *Tautogolabrus adspersus*, and comparison of food habits with young tautog, *Tautoga onitis*, off Long Island, New York. Fish. Bull., U.S. 73:895-900.

Olla, B.L., and C. Samet. 1977. Courtship and spawning behavior of the tautog, *Tautoga onitis* (Pisces: Labridae), under laboratory conditions. Fish. Bull., U.S. 75:585-599.

Olla, B.L., and C. Samet. 1978. Effects of elevated temperature on early embryonic development of the tautog, *Tautoga onitis*. Trans. Am. Fish. Soc. 107:820-824.

Olla, B.L., A.L. Studholme, A.J. Bejda, and C. Samet. 1980. Role of temperature in triggering migratory behavior of the adult tautog, *Tautoga onitis*, under laboratory conditions. Mar. Biol. 59:23-30.

Olney, J.E. 1983. Eggs and early larvae of the bay anchovy, *Anchoa mitchilli*, and the weakfish, *Cynoscion regalis*, in lower Chesapeake Bay with notes on associated ichthyoplankton. Estuaries 6:20-35.

Orbacz, E.A., and P.M. Gaffney. 2000. Genetic structure of tautog (*Tautoga onitis*) populations assayed by RFLP and DGGE analysis of mitochondrial and nuclear genes. Fish. Bull., U.S. 98:336-344.

Pearcy, W.G. 1962. Ecology of an estuarine population of winter flounder *Pseudopleuronectes americanus* (Walbaum). Bull. Bingham Oceanogr. Coll. 18(1):1-78.

Peebles, E.B., J.R. Hall, and S.G. Tolley. 1996. Egg production by the bay anchovy *Anchoa mitchilli* in relation to adult and larval prey fields. Mar. Ecol. Prog. Ser. 131:61-73.

Pennington, M. 1983. Efficient estimators of abundance for fish plankton surveys. Biometrics 39:281-286.

Pennington, M. 1986. Some statistical techniques for estimating abundance indices from trawl surveys. Fish. Bull., U.S. 84:519-525.

Pereira, J.J., R. Goldberg, J.J. Ziskowski, P.L. Berrien, W.W. Morse, and D.L. Johnson. 1999. Essential fish habitat source document: winter flounder, *Pseudopleuronectes americanus*, life history and habitat characteristics. NOAA Tech. Mem. NMFS-NE-138. 39 pp.

Perlmutter, A. 1947. The blackback flounder and its fishery in New England and New York. Bull. Bingham Oceanogr. Coll. 11:1-92.

Phelan, B.A., R. Goldberg, A.J. Bejda, J. Pereira, S. Hagan, P. Clark, A.L. Studholme, A. Calabrese, and K.W. Able. 2000. Estuarine and habitat-related differences in growth rates of young-of-the-year winter flounder (*Pseudopleuronectes americanus*) and tautog (*Tautoga onitis*) in three northeastern estuaries. J. Exp. Mar. Biol. Ecol. 247:1-28.

Pinder, J.E., III, J.G. Wiener, and M.H. Smith. 1978. The Weibull distribution: a new method of summarizing survivorship data. Ecology 59:175-179.

Perry, D.M. 1994. Artificial spawning of tautog under laboratory conditions. Prog. Fish. Cult. 56:33-36.

Potter, D.C., and R.G. Lough. 1987. Vertical distribution and sampling variability of larval and juvenile sand lance (*Ammodytes* sp.) on Nantucket Shoals and Georges Bank. J. Northw. Atl. Fish. Sci. 7:107-116.

Pottle, R.A., and J.M. Green. 1979a. Field observations on the reproductive behaviour of the cunner, *Tautogolabrus adspersus* (Walbaum), in Newfoundland. Can. J. Zool. 57:247-256.

Pottle, R.A., and J.M. Green. 1979b. Territorial behaviour of the north temperate labrid, *Tautogolabrus adspersus*. Can. J. Zool. 57:2337-2347.

Pottle, R.A., J.M. Green, and G. Martel. 1981. Dualistic spawning behaviour of the cunner, *Tautogolabrus adspersus* (Pisces: Labridae), in Bonne Bay, Newfoundland. Can. J. Zool. 59:1582-1585.

Powell, A.B., and G. Phonlor. 1986. Early life history of Atlantic menhaden, *Brevoortia tyrannus*, and gulf menhaden, *B. patronus*. Fish. Bull., U.S. 84:991-995.

Purcell, J.E., D.A. Nemazie, S.E. Dorsey, E.D. Houde, and J.C. Gamble. 1994. Predation mortality of bay anchovy *Anchoa mitchilli* eggs and larvae due to scyphomedusae and ctenophores in Chesapeake Bay. Mar. Ecol. Prog. Ser. 114:47-58.

Reay, P.J. 1970. Synopsis of biological data on North Atlantic sand eels of the genus *Ammodytes*. (*A. tobianus*, *A. dubius*, *A. americanus* and *A. marinus*). FAO Fish. Synop. No. 82. 28 pp.

Regan, J.D., W.L. Carrier, C. Samet, and B.L. Olla. 1982. Photoreactivation in two closely related marine fishes having different longevities. Mech. Ageing Devel. 18:59-66.

Reintjes, J.W., and A.L. Pacheco. 1966. The relation of menhaden to estuaries. Am. Fish. Soc. Spec. Pub. 3:50-58.

Richards, S.W. 1959. Pelagic fish eggs and larvae of Long Island Sound. Bull. Bingham Oceanogr. Coll. 17:95-124.

Richards, S.W. 1963. The demersal fish population of Long Island Sound. Bull. Bingham Oceanogr. Coll. 18:1-101.

Richards, S.W. 1982. Aspects of the biology of *Ammodytes americanus* from the St. Lawrence River to Chesapeake Bay, 1972-75, including a comparison of the Long Island Sound postlarvae with *Ammodytes dubius*. J. Northw. Atl. Fish. Sci. 3:93-104.

Richards, S.W., and A.W. Kendall, Jr. 1973. Distribution of sand lance, *Ammodytes* sp., larvae on the continental shelf from Cape Cod to Cape Hatteras from RV *Dolphin* surveys in 1966. Fish. Bull., U.S. 71:371-386.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191. 382 pp.

Rilling, G.C., and E.D. Houde. 1999a. Regional and temporal variability in growth and mortality of bay anchovy, *Anchoa mitchilli*, larvae in Chesapeake Bay. Fish. Bull., U.S. 97:555-569.

Rilling, G.C., and E.D. Houde. 1999b. Regional and temporal variability in distribution and abundance of bay anchovy, (*Anchoa mitchilli*) eggs, larvae, and adult biomass in the Chesapeake Bay. Estuaries 22:1096-1109.

Rogers, C.A. 1976. Effects of temperature and salinity on the survival of winter flounder embryos. Fish. Bull., U.S. 74:52-58.

Rose, K.A., J.H. Cowan, Jr., M.E. Clark, E.D. Houde, and S-B. Wang. 1999. An individual-based model of bay anchovy population dynamics in the mesohaline region of Chesapeake Bay. Mar. Ecol. Prog. Ser. 185:113-132.

Saila, S.B. 1961. A study of winter flounder movements. Limnol. Oceanogr. 6:292-298.

Saila, S.B. 1976. Effects of power plant entrainment of winter flounder populations near Millstone Point, Connecticut. URI-NUSCO Rep. No. 5. 139 pp + 4 app.

Saila, S.B. and R.G. Lough. 1981. Mortality and growth estimation from size data - an application to some Atlantic herring larvae. Rapp. P.-v. Reun. Cons. int. Explor. Mer. 178:7-14.

Scarlett, P.G., and R.L. Allen. 1992. Temporal and spatial distribution of winter flounder (*Pleuronectes americanus*) spawning in Manasquan River, New Jersey. Bull. N.J. Acad. Sci. 37:13-17.

Schoedinger, S.E., and C.E. Epifano. 1997. Growth, development and survival of larval *Tautoga onitis* (Linnaeus) in large laboratory containers. J. Exp. Mar. Biol. Ecol. 210:143-155.

Scott, W.B., and M.G. Scott. 1988. Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731 pp.

Sellner, K.G., and B.A. Peters. 1987. General characteristics of the Chesapeake Bay and study area. Pages 1-10 *in* K.L. Heck, Jr., ed. Ecological studies in the middle reach of Chesapeake Bay. Lecture notes on coastal and estuarine studies 23. Springer-Verlag, New York.

Sherman, K., C. Jones, L. Sullivan, W. Smith, P. Berrien, and L. Ejsymont. 1981. Congruent shifts in sand eel abundance in western and eastern North Atlantic ecosystems. Nature (London) 291:486-489.

Simpson, D.G. 1989. Population dynamics of the tautog, *Tautoga onitis*, in Long Island Sound. M.S. Thesis. Southern Connecticut State Univ., New Haven, CT. 65 pp.

Simpson, D.G., M.W. Johnson, and K. Gottschall. 1996. Job 2: marine finfish survey. Part 1: Long Island Sound trawl survey. Pages 23-59 *in* A study of recreational fisheries in Connecticut. CT Dept. Envir. Prot., Bur. Nat. Res., Fish. Div.

Smigielski, A.S., T.A. Halavik, L.J. Buckley, S.M. Drew, and G.C. Laurence. 1984. Spawning, embryo development and growth of the American sand lance *Ammodytes americanus* in the laboratory. Mar. Ecol. Prog. Ser. 14:287-292.

Smith, C.F., J.R. Schubel, M.P. Greges, N. Itzkowitz, S.J. DiPiero, J. Longo, and M.A. Morgan. 1980. Thermal resistance characteristics of early life history stages of finfish from Long Island waters. SUNY Stony Brook Mar. Sci. Res. Cen. Spec. Pub. 26. 64 pp. (Not seen, cited *in* Steimle and Shaheen 1999).

Smith, C.L. 1985. The inland fishes of New York State. NY State Dept. Envir. Conserv. Albany, NY. 522 pp.

Smith, E.M., E.C. Mariani, A.P. Petrillo, L.A. Gunn, and M.S. Alexander. 1989. Principal fisheries of Long Island Sound, 1961-1985. CT Dept. Envir. Prot., Bu. Fish., Mar. Fish. Program. 47 pp. + app.

Smith, W.G., J.D. Sibunka, and A. Wells. 1975. Seasonal distributions of larval flatfishes (Pleuronectiformes) on the continental shelf between Cape Cod, Massachusetts and Cape Lookout, North Carolina, 1965-1966. NOAA Tech. Rep. NMFS SSRF-691.

Sogard, S.M., and K.W. Able. 1991. A comparison of eelgrass, sea lettuce, and marsh creeks as habitats for epibenthic fishes and decapods. Est. Coast. Shelf Sci. 33:501-519.

Sogard, S.M., K.W. Able, and M.P. Fahay. 1992. Early life history of the tautog *Tautoga onitis* in the Mid-Atlantic Bight. Fish. Bull., U.S. 90:529-539.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Company, San Francisco. 775 pp.

Steimle, F.W., and P.A. Shaheen. 1999. Tautog (*Tautoga onitis*) life history and habitat requirements. NOAA Tech. Mem. NMFS-NE-118. 23 pp.

Stevenson, R.A. 1958. The biology of the anchovies *Anchoa mitchilli* and *Anchoa hepsetus* in Delaware Bay. M.S. Thesis. Univ. Delaware, Newark, DE. 56 pp.

Steves, B.P., R.K. Cowen, and M.H. Malchoff. 1999. Settlement and nursery habitats for demersal fishes on the continental shelf of the New York Bight. Fish. Bull., U.S. 98:167-188.

Stoner, A.W., A.J. Bejda, J.P. Manderson, B.A. Phelan, L.L. Stehlik, and J.P. Pessutti. 1999. Behavior of winter flounder, *Pseudopleuronectes americanus*, during the reproductive season: laboratory and field observations on spawning, feeding, and locomotion. Fish. Bull., U.S. 97:999-1016. Wheatland, S.B. 1956. Oceanography of Long Island Sound. 1952-1954. II. Pelagic fish eggs and larvae. Bull. Bingham Oceanogr. Coll. 15:234-314.

Tupper, M., and R.G. Boutilier. 1997. Effects of habitat on settlement, growth, predation risk and survival of a temperate reef fish. Mar. Ecol. Prog. Ser. 151:225-236.

Vouglitois, J.J., K.W. Able, R.J. Kurtz, and K.A. Tighe. 1987. Life history and population dynamics of the bay anchovy in New Jersey. Trans. Am. Fish. Soc. 116:141-153.

Wang, S.B., J.H. Cowan, K.A. Rose, and E.D. Houde. 1997. Individual-based modeling of recruitment variability and biomass production of bay anchovy in mid-Chesapeake Bay. J. Fish Biol. 51(Suppl. A):101-120.

Westin, D.T., K J. Abernethy, I.E. Meller, and B.A. Rogers. 1979. Some aspects of biology of the American sand lance, *Ammodytes americanus*. Trans. Am. Fish. Soc. 108:328-331.

Wheatland, S.B. 1956. Oceanography of Long Island Sound. 1952-1954. II. Pelagic fish eggs and larvae. Bull. Bingham Oceanogr. Coll. 15:234-314.

White, G.G. 1996. Reproductive biology of tautog, *Tautoga onitis*, in the lower Chesapeake Bay and coastal waters of Virginia. M.S. Thesis, The College of William and Mary, Williamsburg, VA. 100 pp.

Williams, G.C. 1967. Identification and seasonal size changes of eggs of the labrid fishes, *Tautogolabrus adspersus* and *Tautog onitis*, of Long Island Sound. Copeia 1967:452-453.

Williams, G.C., D.C. Williams, and R.J. Miller. 1973. Mortality rates of planktonic eggs of the cunner, *Tautogolabrus adspersus* (Walbaum), in Long Island Sound. Pages 181-195 *in* A. Pacheco, ed. Proceedings of a workshop on egg, larval and juvenile stages of fish in Atlantic coast estuaries. Nat. Mar. Fish. Serv., Mid. Atl. Coast. Fish. Ctr. Tech. Pub. No. 1.

Zastrow, C.E., E.D. Houde, and L.G. Morin. 1991. Spawning, fecundity, hatch-date frequency and young-of-the-year growth of bay anchovy *Anchoa mitchilli* in mid-Chesapeake Bay. Mar. Ecol. Prog. Ser. 73:161-171.

TABLE 3-1. Special field sampling or laboratory studies conducted from 1973 through August 2001 relating to larval winter flounder.

Year[a]	Description	Reference[a]
1973, 1974	Thermal tolerance of entrained larvae	NUSCO (1975)
1983	Limited entrainment survival study in the Millstone Quarry	NUSCO (1984)
1983, 1984	24-hour studies examining diel and tidal effects on sampling densities in the lower Niantic River	NUSCO (1984, 1985)
1983, 1984, 1985, 1988	Import-export studies conducted at the mouth of the Niantic River	NUSCO (1984, 1985, 1986, 1989)
1984, 1985	Attempts to age larvae using daily otolith rings	NUSCO (1985, 1986)
1984, 1985	Mesh size and tow duration effects on net extrusion	NUSCO (1985, 1986)
1986	Predation by *Cyanea* sp. jellyfish	NUSCO (1987)
1988	Two 24-hour studies examining diel and tidal effects on sampling densities in Niantic Bay and Twotree Island Channel	NUSCO (1989)
1988	Analysis of otolith microstructure in Niantic River larvae	Durbin and Durbin (1990)
1988, 1989	Dye study and model of Niantic River water circulation (larval flushing and MIT model)	Dimou (1989); Dimou and Adams (1989); Dimou et al. (1990)
1990, 1991	Mitochondrial DNA stock identification studies of larval winter flounder (Niantic, Connecticut, and Thames River populations)	Goddard (1992)
1991	Drogue studies of tidal currents in Niantic Bay	NUSCO (1992c)
1991	Vertical distribution of yolk-sac larvae in the Niantic River using a pump sampler	NUSCO (1992a)
1991	Three additional stations sampled in Niantic Bay to determine larval winter flounder abundance and spatial distribution relative to tidal currents	NUSCO (1992a)
1983-92	Analysis of larval entrainment densities during ebb and flood tides	NUSCO (1993)
1992, 1993	Special larval sampling at the mouth of the Niantic River	NUSCO (1993, 1994b)
2000, 2001	Larval stock identification using both DNA-based genetics and multi-elemental chemical analyses	Work in progress
2000, 2001	Larval entrainment survival study at MNPS Unit 3 discharge	Work in progress

[a] Studies completed through 1986 are also summarized in NUSCO (1987).

TABLE 3-2. Special submittals made to DEP concerning impact of MNPS on winter flounder from 1987 through the completion of this report. Not included are annual reports of winter flounder abundance that were routinely submitted to DEP from 1988 through 1993 (usually in October) and reports of the effectiveness of MNPS refueling outages on reducing larval winter flounder entrainment, which were cited in Chapter 1 of Part II of this report.

Date	NUSCO correspondence number	Title
October 7, 1987	B12700	Millstone Unit No. 3 equivalent-adult revised calculation (submitted to the U.S. Nuclear Regulatory Commission with copy to DEP)
January 29, 1988	D01830	Overview of NU's winter flounder studies and the effectiveness of the MNPS fish return
October 14, 1988	D02227	Absolute abundance estimates for the Niantic River population of winter flounder
July 20, 1989	D02901	Assessment of population differentiation in winter flounder: a preliminary report (prepared by J.R. Powell and K.A. Goddard, Yale University)
February 7, 1990	D03431	Application of a 2-D particle model tracking model to simulate entrainment of winter flounder larvae at the Millstone Nuclear Power Station (prepared by N.K. Dimou and E.E. Adams, Massachusetts Institute of Technology)
October 30, 1990	D04143	Mass-balance calculations for assessing production losses due to entrainment of winter flounder
January 23, 1991	D04339	Niantic River winter flounder population: simulation of long-term effects of larval entrainment at MNPS
January 23, 1991	D04343	Evaluation of the larval winter flounder sampling program in the Niantic River
June 20, 1991	D04716	Reassessment of impingement effects on winter flounder at MNPS
May 29, 1992	D05565	Scope of work for cooling water alternatives feasibility study to reduce larval reduce larval winter flounder entrainment
October 29, 1992	D05905	Final report on the assignment of winter flounder larvae to natal populations (prepared by K.A. Goddard, The American University)
January 27, 1993	D06112	Feasibility study of cooling-water system alternatives to reduce larval winter flounder. entrainment
October 12, 1993	D06958	Information on winter flounder stock rebuilding time from SPDM output
September 15, 1999	D14915	Review and critique of the report "Estimation of the reduction in recruitment of winter flounder in the Niantic River associated with operations at the Millstone Nuclear Power Station" by Mark Gibson
December 30, 1999	D15309	Scope of study for the evaluation of intake technology alternatives at the Millstone Nuclear Power Station
March 13, 2000	D15614	Revised scope of study for the evaluation of intake technology alternatives at the Millstone Nuclear Power Station
August 30, 2000	D16199	Further revised scope of study for the evaluation of intake technology alternatives at the Millstone Nuclear Power Station

TABLE 3-3. Brief description of winter flounder early life history stages.

Stage	Brief description	Approximate duration of stage in days[a]	Approximate size (mm) of stage[b]
Egg	Demersal and adhesive	15	0.70 - 0.85
1	Yolk-sac present or eyes not pigmented	10	2.5 - 3.5
2	Eyes pigmented, but no yolk-sac present, no fin ray development, and no flexion of notochord	20	3.0 - 4.0
3	Fin rays present and flexion of notochord started, but left eye not yet migrated to the midline	10	4.5 - 7.5
4	Left eye migrated to midline, but typical juvenile characteristics not present	10	7.0 - 9.0
5	Transformation to juvenile complete with intense pigmentation present near the caudal fin base	-	> 9.0

[a] Developmental rates dependent upon water temperature.
[b] To nearest 0.05 mm for eggs and 0.5 mm for larvae. Includes most individuals in life stage, although some may be smaller or larger than the ranges given.

TABLE 3-4. Relative and absolute standardized catch of female winter flounder spawners and corresponding egg production in the Niantic River from 1977 through 2000 (see DNC 2001a for details of sampling and data analyses). The area sampled is shown in Figure 3-4.

Survey year	Relative index of spawning females[a]	% mature females (of all fish)[b]	% mature females (of all females)[c]	Average fecundity[d]	Relative index of total egg production[e]	Total female stock size[f]	Total egg production (X 10^9)[f]
1977	1,145	36	61	450,470	515.7	31,802	14.325
1978	1,762	51	76	503,749	887.4	48,935	24.651
1979	1,283	37	64	472,406	606.1	35,637	16.835
1980	1,076	34	51	466,919	502.3	29,885	13.954
1981	2,583	44	70	519,461	1,342.0	71,763	37.278
1982	2,733	49	77	580,082	1,585.5	75,924	44.042
1983	1,827	47	78	577,885	1,055.9	50,753	29.330
1984	881	40	77	577,774	508.9	24,465	14.135
1985	907	43	75	608,374	551.6	25,187	15.323
1986	647	42	86	666,132	431.2	17,982	11.979
1987	836	39	85	622,995	520.6	23,211	14.465
1988	1,256	53	89	676,469	849.5	34,881	23.596
1989	954	52	90	726,652	693.3	26,504	19.259
1990	534	41	73	631,150	336.8	14,824	9.356
1991	1,032	47	85	600,832	620.1	28,667	17.224
1992	519	53	94	730,945	379.5	14,421	10.541
1993	265	54	93	815,957	215.9	7,352	5.999
1994	491	56	87	648,741	318.6	13,641	8.849
1995	206	63	87	772,187	158.7	5,708	4.408
1996	94	52	82	843,828	79.6	2,620	2.211
1997	177	60	83	796,337	141.2	4,927	3.923
1998	126	55	79	755,316	95.4	3,509	2.650
1999	115	45	65	698,083	80.3	3,196	2.231
2000	179	55	80	737,564	131.8	4,962	3.660

[a] Based on proportion of the relative annual standardized catches of winter flounder that were mature females.
[b] As a proportion of all winter flounder 20 cm or larger.
[c] As a proportion of all female winter flounder 20 cm or larger.
[d] Total egg production divided by the number of spawning females.
[e] A relative index for year-to-year comparisons and not an absolute estimate of production.
[f] Calculated on the assumption that the relative annual standardized catches were approximately 3.6% of absolute values.

TABLE 3-5. Estimated larval winter flounder total instantaneous mortality rate (Z) from hatching to the 7-mm size-class from 1984 through 2000 (see DNC 2001a for details).

Year	Abundance index Newly hatched	Abundance index 7-mm size-class	% mortality rate (A)[a]	Instantaneous mortality rate (Z)[a]
1984	6,500	654	89.9	2.30
1985	13,773	452	96.7	3.42
1986	2,483	438	82.4	1.73
1987	6,480	474	92.7	2.62
1988	24,561	678	97.2	3.59
1989	19,192	394	97.9	3.88
1990	7,915	653	91.7	2.49
1991	3,992	560	86.5	2.00
1992	8,020	609	92.4	2.58
1993	1,874	88	95.3	3.06
1994	7,270	761	89.5	2.26
1995	13,088	1,536	88.3	2.14
1996	11,151	576	94.8	2.96
1997	14,894	1,645	89.0	2.20
1998	9,306	921	90.1	2.31
1999	4,658	791	83.0	1.77
2000	1,725	1,758	-[b]	-[b]
				mean = 2.58

[a] Survival = $1 - A = e^{-Z}$.

[b] Could not be calculated as more larger than smaller larvae were found in 2000.

TABLE 3-6. Monthly instantaneous total mortality rate (Z) estimates as determined from catch curves of age-0 winter flounder taken at two stations (LR and WA) in the Niantic River from 1984 through 2000 (see DNC 2001a for details). Locations of the two sampling stations are shown in Figure 3-4.

Year	Station	n[a]	slope[b]	Standard error	r^2	Station	n[a]	slope[b]	Standard error	r^2
1984	LR	16	-0.129 **	0.017	0.80	WA	-	-	-	-
1985		15	-0.118 **	0.015	0.82		16	-0.084 **	0.023	0.51
1986		15	-0.127 **	0.012	0.89		-[c]	-[c]	-	-
1987		15	-0.108 **	0.021	0.67		16	-0.139 **	0.016	0.84
1988		19	NS	-	-		19	NS	-	-
1989		12	-0.154 **	0.022	0.84		13	-0.145 **	0.028	0.71
1990		13	-0.322 **	0.028	0.92		15	-0.235 **	0.028	0.84
1991		18	-0.140 **	0.016	0.82		18	-0.049 **	0.011	0.54
1992		18	-0.129 **	0.019	0.74		16	-0.112**	0.009	0.91
1993		9	-0.087 *	0.028	0.57		10	NS	-	-
1994		9	-0.110 **	0.008	0.96		9	-0.124 **	0.020	0.84
1995		9	-0.203 **	0.010	0.98		9	-0.138 **	0.018	0.89
1996		9	-0.116 *	0.046	0.47		8	NS	-	-
1997		8	-0.185 **	0.025	0.90		9	-0.187 **	0.020	0.93
1998		8	-0.101 **	0.013	0.91		8	-0.102 **	0.029	0.68
1999		9	-0.111 **	0.024	0.74		9	-0.128 **	0.029	0.73
2000		8	-0.072 **	0.019	0.71		8	NS	-	-

Year	Station	Mortality (Z_{mo})[d]	Survival (S_{mo})	Station	Mortality (Z_{mo})[d]	Survival (S_{mo})
1984	LR	0.560	57.1%	WA	-	-
1985		0.512	59.9%		0.363	69.9%
1986		0.552	57.6%		-[c]	-
1987		0.469	62.6%		0.604	54.7%
1988		-	-		-	-
1989		0.669	51.2%		0.630	53.3%
1990		1.398	24.7%		1.021	36.0%
1991		0.608	54.4%		0.213	80.8%
1992		0.560	57.1%		0.486	61.5%
1993		0.377	68.6%		-	-
1994		0.476	62.1%		0.538	58.4%
1995		0.883	41.4%		0.600	54.9%
1996		0.504	60.4%		-	-
1997		0.802	44.9%		0.811	44.4%
1998		0.437	64.6%		0.443	64.2%
1999		0.480	61.9%		0.556	57.4%
2000		0.312	73.2%		-	-
	Mean	0.619	54.9%	Mean	0.570	56.6%
	Standard error	0.064		Standard error	0.065	
	CV	42%		CV	38%	

[a] Weekly sampling during 1984-92 and biweekly sampling during 1993-2000. WA was not sampled in 1984.

[b] Slope (Z) determined from a catch curve (natural logarithm of density plotted against time in weeks). The probability level that the slope of the catch curve differs from zero is shown:
NS - not significant ($p > 0.05$), * - significant at $p \leq 0.05$, ** - significant at $p \leq 0.01$.

[c] Although having a significant slope, the catch curve for 1986 at station WA did not provide a reliable estimate of Z because of considerable variation in weekly abundance.

[d] Monthly mortality rate (Z_{mo}) = $(-Z)\cdot(30.4 / 7)$ and monthly survival (S_{mo}) = $e^{-Z_{mo}}$.

TABLE 3-7. Annual abundance index (*A* parameter of the Gompertz function) with 95% confidence interval of winter flounder larvae in entrainment samples and total annual entrainment estimates in millions during the larval season of occurrence, and the volume in billions of gallons of seawater entrained at MNPS each year from 1976 through 1999 during an 136-day period from February 15 through June 30 (see DNC 2001a for details).

Year	*A* parameter	Standard error	95% confidence interval	Number entrained (X 10^6)	Volume entrained (gallons X 10^9)
1976	1,656	32	1,588 - 1,724	121.4	168.1
1977	751	47	650 - 852	29.7	148.5
1978	1,947	352	1,186 - 2,706	83.6	124.5
1979	1,296	81	1,121 - 1,470	45.5	120.2
1980	2,553	37	2,475 - 2,632	168.3	160.6
1981	1,163	23	1,113 - 1,213	45.8	115.5
1982	2,259	36	2,184 - 2,334	163.5	171.0
1983	2,966	21	2,921 - 3,012	210.5	164.3
1984	1,840	47	1,741 - 1,939	84.5	145.5
1985	1,585	48	1,483 - 1,686	80.0	133.9
1986	903	31	837 - 968	125.3	343.3
1987	1,194	23	1,145 - 1,242	165.1	335.7
1988	1,404	42	1,315 - 1,493	185.5	350.5
1989	1,677	13	1,650 - 1,704	167.9	265.3
1990	1,073	25	1,021 - 1,125	133.2	330.4
1991	1,149	18	1,110 - 1,189	116.4	237.0
1992	3,974	76	3,812 - 4,136	493.2	303.8
1993	328	23	280 - 377	43.3	358.2
1994	1,709	38	1,626 - 1,790	174.8	297.9
1995	2,571	47	2,470 - 2,671	213.9	287.6
1996	1,388	78	1,222 - 1,554	51.7	137.6
1997	3,241	61	3,112 - 3,371	75.5	46.9
1998	2,039	47	1,939 - 2,139	83.8	95.7
1999	1,928	40	1,844 - 2,011	145.9	201.1
2000	3,688	170	3,330 - 4,046	332.7	269.3

TABLE 3-8. Based on the availability of eggs or larvae for entrainment, dates of peak entrainment abundance at MNPS and the primary (95% of occurrence) and optimal seasons of entrainment of fish taxa examined in this report. The fraction of eggs or larvae included within the optimal season is also given.

Taxon	Date of peak abundance	Primary entrainment season	Optimal entrainment season	Fraction of eggs or larvae included in optimal season
Winter flounder larvae	April 24	March 22 - June 5	April 4 - May 14	76%
Tautog eggs	June 20	May 3 - August 22	May 29 - July 12	64%
Atlantic menhaden larvae:				
summer	July 14	July 3 - July 27	July 3 - July 25	90%
fall	November 3	October 10 - December 4	October 17 - November 20	81%
Anchovy eggs	July 19	July 8 - August 2	July 8 - July 30	91%
Anchovy larvae	July 30	June 30 - September 6	July 11 - August 18	78%
Grubby larvae	March 18	February 2 - May 15	February 25 - April 9	65%
Cunner eggs	June 12	May 14 - July 20	May 24 - July 1	78%
American sand lance larvae	March 25	January 17 - June 23	March 7 - April 12	39%

TABLE 3-9. Estimates of the total number of larval winter flounder entrained, number of larvae entrained from the Niantic River, and the percentage of total entrainment attributed to the Niantic River from 1984 through 1999 (see NUSCO 2000a for details).

Year	Total entrainment ($X 10^6$)	Niantic River larval entrainment ($X 10^6$)	% entrainment attributed to the Niantic River
1984	84.5	32.0	37.9
1985	80.0	27.8	34.8
1986	125.3	28.1	22.4
1987	165.1	41.7	25.3
1988	185.5	39.5	21.3
1989	167.9	33.5	20.0
1990	133.2	38.5	28.9
1991	116.4	35.2	30.2
1992	493.2	80.3	16.3
1993	43.3	6.0	13.9
1994	174.8	50.4	28.8
1995	213.9	77.9	36.4
1996	51.7	30.4	58.8
1997	75.5	9.3	12.3
1998	83.8	25.9	30.9
1999	145.9	32.9	22.5

TABLE 3-10. Estimated annual Δ-mean[a] density ± 95% confidence interval in MNPS entrainment samples, annual entrainment estimate in millions, and the volume in billions of gallons of seawater entrained at MNPS on which the entrainment estimates were based for eggs of tautog, anchovies, and cunner from June 1979 through May 1999 (see DNC 2001b for details).

	Tautog			Anchovies			Cunner		
Year	Δ-mean density at MNPS[a]	Number entrained ($X 10^6$)	Volume entrained[b]	Δ-mean density at MNPS[a]	Number entrained ($X 10^6$)	Volume entrained[b]	Δ-mean density at MNPS[a]	Number entrained ($X 10^6$)	Volume entrained[b]
1979	1,648 ± 566	448	180.7	1,558 ± 807	324	195.5	8,349 ± 4,601	1,053	180.7
1980	3,741 ± 1,482	969	201.3	999 ± 689	87	159.6	8,379 ± 3,788	1,660	201.3
1981	2,501 ± 604	1,398	203.2	769 ± 273	287	177.8	7,326 ± 3,890	1,547	203.2
1982	3,561 ± 1,400	1,253	213.5	499 ± 202	210	179.7	7,874 ± 2,359	2,078	213.5
1983	2,372 ± 994	1,019	198.9	2,415 ± 2,130	371	158.8	7,580 ± 6,106	1,899	198.9
1984	1,817 ± 504	1,323	205.8	3,631 ± 3,528	883	174.1	6,707 ± 4,494	2,135	205.8
1985	4,027 ± 2,424	1,720	208.7	118 ± 72	27	178.3	12,842 ± 6,156	2,814	208.7
1986	2,833 ± 1,212	3,750	468.2	586 ± 366	522	392.1	2,579 ± 1,460	2,855	468.2
1987	2,972 ± 1,232	3,597	445.7	64 ± 19	31	370.4	5,017 ± 3,536	4,090	445.7
1988	2,211 ± 906	2,693	486.9	32 ± 26	15	411.6	5,388 ± 3,608	4,294	486.9
1989	3,373 ± 2,002	3,002	408.7	32 ± 29	5	350.6	6,255 ± 5,302	4,307	408.7
1990	1,942 ± 978	2,101	455.5	89 ± 88	27	387.1	7,269 ± 7,198	3,634	455.5
1991	2,040 ± 1,052	1,521	316.5	317 ± 306	105	258.4	6,987 ± 5,482	4,117	316.5
1992	1,189 ± 462	1,338	392.1	62 ± 70	18	321.3	2,776 ± 1,654	2,648	392.1
1993	1,394 ± 582	2,062	437.3	329 ± 260	228	358.5	4,535 ± 2,612	5,421	437.3
1994	1,350 ± 658	2,069	429.9	234 ± 204	177	367.0	8,722 ± 9,644	6,146	429.9
1995	1,807 ± 798	2,562	405.8	118 ± 154	30	350.6	4,266 ± 3,222	5,527	405.8
1996	2,323 ± 2,032	313	69.7	36 ± 29	4	44.4	8,801 ± 6,043	872	69.7
1997	587 ± 235	111	56.0	5 ± 5	<1	42.5	3,610 ± 3,157	569	56.0
1998	897 ± 423	496	196.8	114 ± 123	53	170.1	1,458 ± 6,313	581	196.8
1999	1,373 ± 636	1,168	317.0	1 ± 1	<1	265.3	3,530 ± 3,044	1,959	317.0

[a] Given in n·500m³. Methodology of calculation described in detail in DNC (2001b). Briefly, a Δ-mean is the best estimator of the mean for abundance data approximating a lognormal distribution and containing numerous zeros (Pennington 1983; 1986; NUSCO 1988). Seasons of occurrence were May through August for tautog and cunner and June through September for anchovies.

[b] Given in billions of gallons. Volume determined from condenser-cooling water flow at MNPS during the annual season of occurrence for each species.

TABLE 3-11. Summary of bay anchovy mortality rates of various life stages given in increments of time or length.

Source	Study location	Mean Z (range)[a]	% mortality (range)[a]
Leak and Houde (1987)[b]	Biscayne Bay, FL	E: 1.94·day^{-1} (0.31-3.54) E+L: 0.40·day^{-1} (0.30-0.45)	E: 85.6%·day^{1} (26.7-97.1) E+L: 33.3%·day^{-1} (25.9-36.2)
Castro and Cowen (1991)[c]	Great South Bay, NY	E+L: 0.594·day^{-1} (0.493-0.758) EY: 2.377·day^{-1} (1.193-3.019) OL: 0.327·day^{-1} (0.177-0.481)	E+L: 44.8%·day^{-1} (38.9-53.1) EY: 90.7%·day^{-1} (69.7-98.2) OL: 27.9%·day^{-1} (16.2-38.2)
Loos and Perry (1991)[d]	Patuxent River, MD	L: 0.161-0.162·mm^{-1} at 10 mm L: 0.064-0.079·mm^{-1} at 20 mm	L: 15%·mm^{-1} at 10 mm L: 6.2-7.6%·mm^{-1} at 20 mm
Houde et al. (1994)[e]	Patuxent River, MD	E: 0.073·hour^{1} (0.031-0.156) YL: 0.051·hour^{1} (0.001-0.126)	E: 78%·21 hours^{-1} YL: 71%·first day post-hatch^{-1}
Purcell et al. (1994)[f]	Chesapeake Bay, MD-VA	E: 1.48·hour^{1} (0.40-3.70) L: 1.23·day^{1} (0.41-4.25)	E: 69.6%·hour^{1} (33-97.5) L: 58.8%·day^{1} (33.5-98.8)
Newberger and Houde (1995)[g]	Chesapeake Bay, MD-VA	JA: 2.19-2.95·year^{1}	JA: 89-95%·year^{1}
MacGregor and Houde (1996)[h]	Chesapeake Bay, MD-VA	L (all): 1.24·mm^{-1} (1.09-1.34) L(2.5-4.5 mm): 1.52·mm^{-1} L(5-8.5 mm): 0.60·mm^{-1} L(8.5-14 mm): 0.29·mm^{-1}	L (all): 71.1%·mm^{-1} (66-74) L(2.5-4.5 mm): 78.1%·mm^{-1} L(5-8.5 mm): 45.1%·mm^{-1} L(8.5-14 mm): 25.2%·mm^{-1}
Dorsey et al. (1996)[i]	Chesapeake Bay, MD-VA	E: 0.066·hour^{1} (0.001-0.185) YL: 1.272·day^{-1} (0.41-4.24)	E: 73.3%·day^{-1} (2-98) YL: 72.0%·day^{1} (33.5-98.5)
Rilling and Houde (1999a)[j]	Chesapeake Bay, MD-VA	L: 0.23-0.41·day^{-1} L(2-5 mm): 0.33-0.45·mm^{-1} L(10-13 mm): 0.05-0.07·mm^{-1}	L: 20.5-33.6%·day^{-1} L(2-5 mm): 28.1-36.2%·mm^{-1} L(10-13 mm): 4.9-6.8%·mm^{-1}

[a] Z = instantaneous total mortality rate; E = eggs; L = unspecified larvae; EY = eggs and yolk-sac larvae; YL: yolk-sac larvae; OL = post-yolk-sac larvae; JA: post-larval juveniles and adults; + = combination of stages considered.
[b] Field study of four egg and larval cohorts over a 20-day period. Calculated losses from predation were 2-3 times higher than from starvation. Survivorship of cohorts after 20 days ranged between 0.012-0.248%. Most mortality occurred in egg and yolk-sac larval stages.
[c] Field study of eight egg and larval cohorts. No differences in survival noted between eelgrass and non-vegetated areas. Starvation may have been important for earliest and latest cohorts, but predation probably most important during middle of spawning season.
[d] Used Pareto function to estimate mortality for field-collected larvae and published growth rates. Likely underestimated mortality of smallest larvae because immigration not taken into account. Estimates similar to those of Leak and Houde (1987).
[e] Drifting mesocosms used in 17 experiments; some variability introduced from initial number of eggs and larvae, complex mixture of predators and prey in enclosed volumes. Larval mortality rates more variable than eggs. Lowest mortality in absence of gelatinous zooplankton predators. Overall loss rate of 80 to 98% indicated for first 2 days of life.
[f] Measured predation by gelatinous zooplankton and field abundance of eggs and larvae at nine stations on four dates. High variation in the nine estimates. Egg stage duration was 20 hours.
[g] From age-0.5 through age-3. Based on trawl surveys from July through December examining abundance and aging. Mortality rates were determined using several methodologies.
[h] Apparent length-specific mortality calculated from field studies on four dates and eight stations. Using an assumed daily growth rate of 0.5 mm·day^{1}, mean percent daily losses for all larvae were 42.0-48.8%. Mortality decreased from offshore to inshore and as larvae increased in size.
[i] Field study at seven sites on 12 days. Egg stage duration was 20 hours. When egg and yolk-sac larvae were considered together, >93% of daily cohorts die within 2 days of spawning, although there was high variability in the daily estimates.
[j] Field study over wide area of bay over 2 months. Mortality rate decreased from June to July as growth rate and larval size increased. Rates also varied by region within the bay.

TABLE 3-12. Estimated annual Δ-mean[a] density ± 95% confidence interval in MNPS entrainment samples, annual entrainment estimate in millions, and the volume in billions of gallons of seawater entrained at MNPS on which the entrainment estimates were based for larvae of Atlantic menhaden, anchovies, grubby and American sand lance from June 1976 through May 2000 (see DNC 2001b for details).

Year	Δ-mean density at MNPS[a]	Number entrained (X 10^6)	Volume entrained (gallons X 10^9)[b]	Δ-mean density at MNPS[a]	Number entrained (X 10^6)	Volume entrained (gallons X 10^9)[b]
	Atlantic menhaden			Anchovies		
1976	5 ± 1	3	235.1	1,152 ± 419	378	156.1
1977	3 ± 1	2	226.4	931 ± 408	414	145.0
1978	3 ± 1	3	273.4	483 ± 206	161	166.7
1979	1 ± 1	<1	236.5	2,168 ± 908	805	140.8
1980	2 ± 1	2	184.9	2,430 ± 1,249	877	128.4
1981	1 ± 0.4	2	263.9	5,768 ± 3,326	1,448	161.2
1982	9 ± 3	14	226.9	816 ± 240	449	138.7
1983	18 ± 10	20	198.9	1,421 ± 530	613	122.3
1984	2 ± 1	4	261.3	302 ± 165	167	153.5
1985	38 ± 22	44	215.6	1,102 ± 453	690	153.0
1986	2 ± 1	5	469.2	1,244 ± 893	1,093	318.6
1987	2 ± 1	2	471.6	126 ± 69	117	294.3
1988	5 ± 4	7	530.8	359 ± 216	383	339.2
1989	47 ± 64	208	498.0	619 ± 416	530	305.9
1990	16 ± 12	37	512.3	1,122 ± 853	978	322.6
1991	81 ± 140	56	286.7	799 ± 801	451	199.2
1992	37 ± 28	52	423.0	178 ± 80	151	258.7
1993	8 ± 4	28	475.6	203 ± 103	197	277.4
1994	44 ± 76	70	508.1	475 ± 410	509	315.2
1995	56 ± 60	91	491.4	181 ± 117	175	316.5
1996	145 ± 431	23	55.7	175 ± 196	24	35.1
1997	23 ± 18	5	56.3	131 ± 90	17	33.0
1998	28 ± 60	35	249.4	106 ± 80	63	150.9
1999	58 ± 63	140	404.8	129 ± 135	136	239.1
	Grubby			American sand lance		
1977	41 ± 9	31	110.4	94 ± 117	80	234.6
1978	38 ± 9	11	126.0	318 ± 117	176	187.6
1979	36 ± 7	20	149.0	119 ± 25	111	214.0
1980	38 ± 7	32	196.0	111 ± 26	112	257.3
1981	107 ± 27	42	110.4	136 ± 32	75	165.7
1982	72 ± 13	48	171.7	21 ± 4	27	244.9
1983	68 ± 19	55	196.8	27 ± 8	30	263.1
1984	50 ± 15	39	177.8	18 ± 4	18	231.7
1985	68 ± 23	35	165.7	9 ± 2	8	237.8
1986	34 ± 10	54	354.3	3 ± 1	4	466.6
1987	29 ± 7	52	383.9	13 ± 4	35	518.4
1988	95 ± 35	112	343.2	41 ± 13	86	479.0
1989	63 ± 18	68	316.5	31 ± 13	44	451.3
1990	30 ± 8	47	373.8	24 ± 7	45	529.5
1991	24 ± 6	31	288.0	7 ± 2	7	415.3
1992	58 ± 17	73	305.7	18 ± 6	22	403.2
1993	34 ± 9	52	377.5	28 ± 10	48	531.3
1994	48 ± 16	56	317.8	43 ± 13	65	480.6
1995	43 ± 15	58	322.6	63 ± 29	89	471.1
1996	85 ± 37	41	210.6	18 ± 7	18	279.0
1997	140 ± 60	28	47.6	11 ± 5	3	60.0
1998	55 ± 19	22	91.9	28 ± 15	11	125.2
1999	39 ± 24	49	223.0	13 ± 11	14	293.8
2000	45 ± 19	47	298.8	53 ± 29	88	426.2

[a] Given in n·500m³. Methodology of calculation described in detail in DNC (2001b). Briefly, a Δ-mean is the best estimator of the mean for abundance data approximating a lognormal distribution and containing numerous zeros (Pennington 1983; 1986; NUSCO 1988). Seasons of occurrence were June through December for Atlantic menhaden, July through September for anchovies, February through May for grubby, and December (of previous year) through May for American sand lance. Years differ among species because of reporting requirements (see DNC 2001b).

[b] Volume determined from condenser-cooling water flow at MNPS during the species annual season of occurrence.

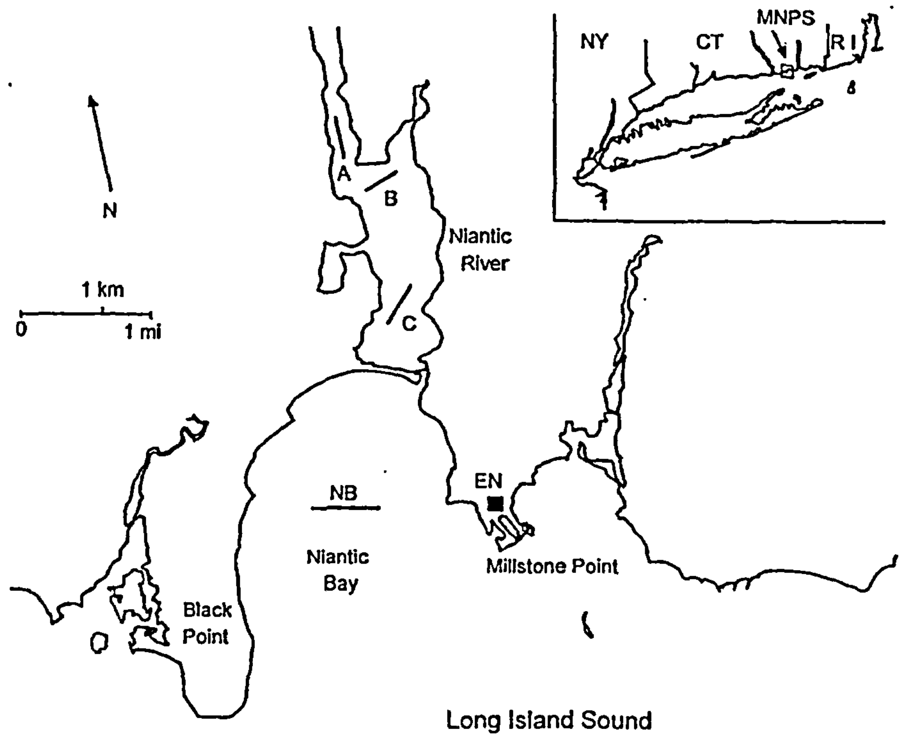

Fig. 3-1. Location of stations (denoted by letters) currently sampled for larval winter flounder at or near MNPS.

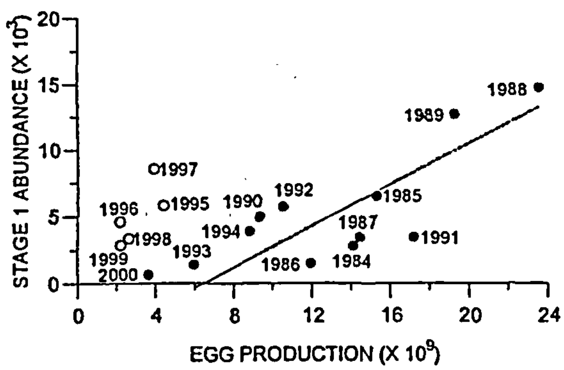

Fig. 3-2. Comparison between an annual abundance index of Stage 1 winter flounder larvae in the Niantic River (*A* parameter of the Gompertz function) and estimated annual adult female winter flounder egg production from 1984 through 2000. A functional regression was fitted to data (filled circles) from 1984 through 1994 and 2000 ($r = 0.793$, $p = 0.002$) and excluded data from 1995-99 (open circles).

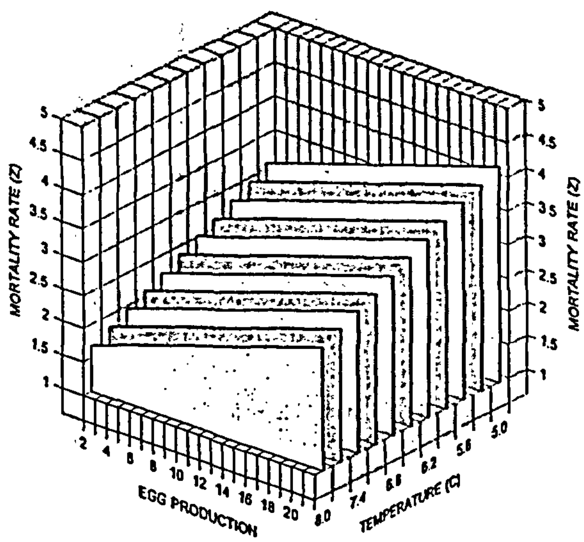

Fig. 3-3. Relationship between the instantaneous larval mortality rate (Z) and annual winter flounder egg production in the Niantic River and April mean water temperature (1°C = 1.8°F) at the MNPS intakes from 1984 through 1999 ($Z = 5.302 + 0.057 \cdot$egg production $- 0.467 \cdot$April water temperature).

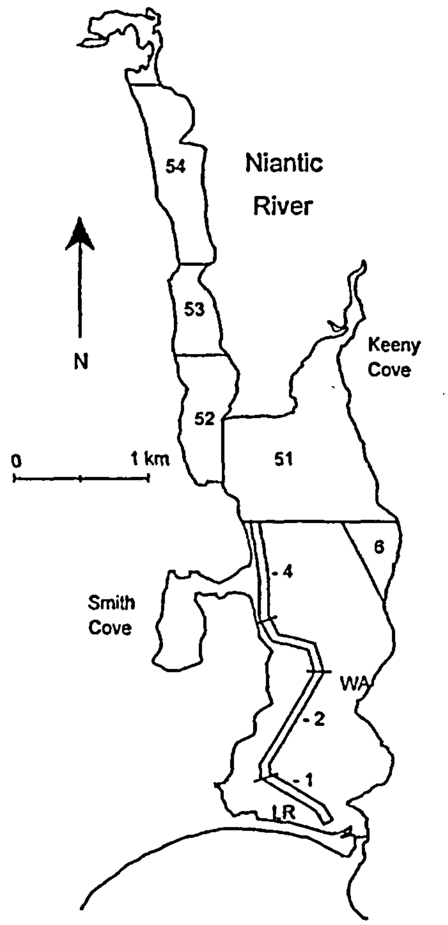

Fig. 3-4. Location of stations sampled in the Niantic River during for adult winter flounder during spawning season surveys from late February through early April (numbers) and age-0 winter flounder from late May through September (letters).

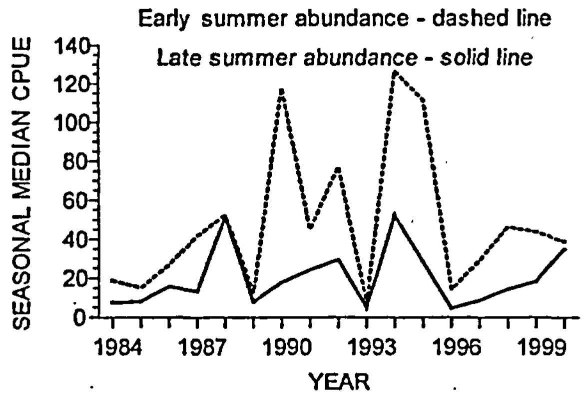

Fig. 3-5. Comparison between the early and late summer seasonal 1-m beam trawl median CPUE at two Niantic River stations combined from 1984 through 2000.

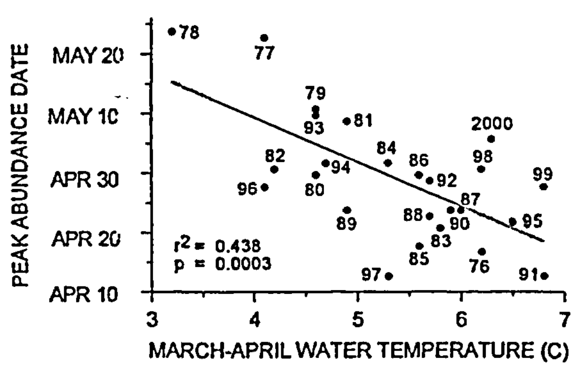

Fig. 3-6. Relationship between March-April mean water temperature (1°C = 1.8°F) and the annual date of peak abundance of winter flounder larvae (estimated from the Gompertz function) that were entrained at MNPS from 1976 through 2000.

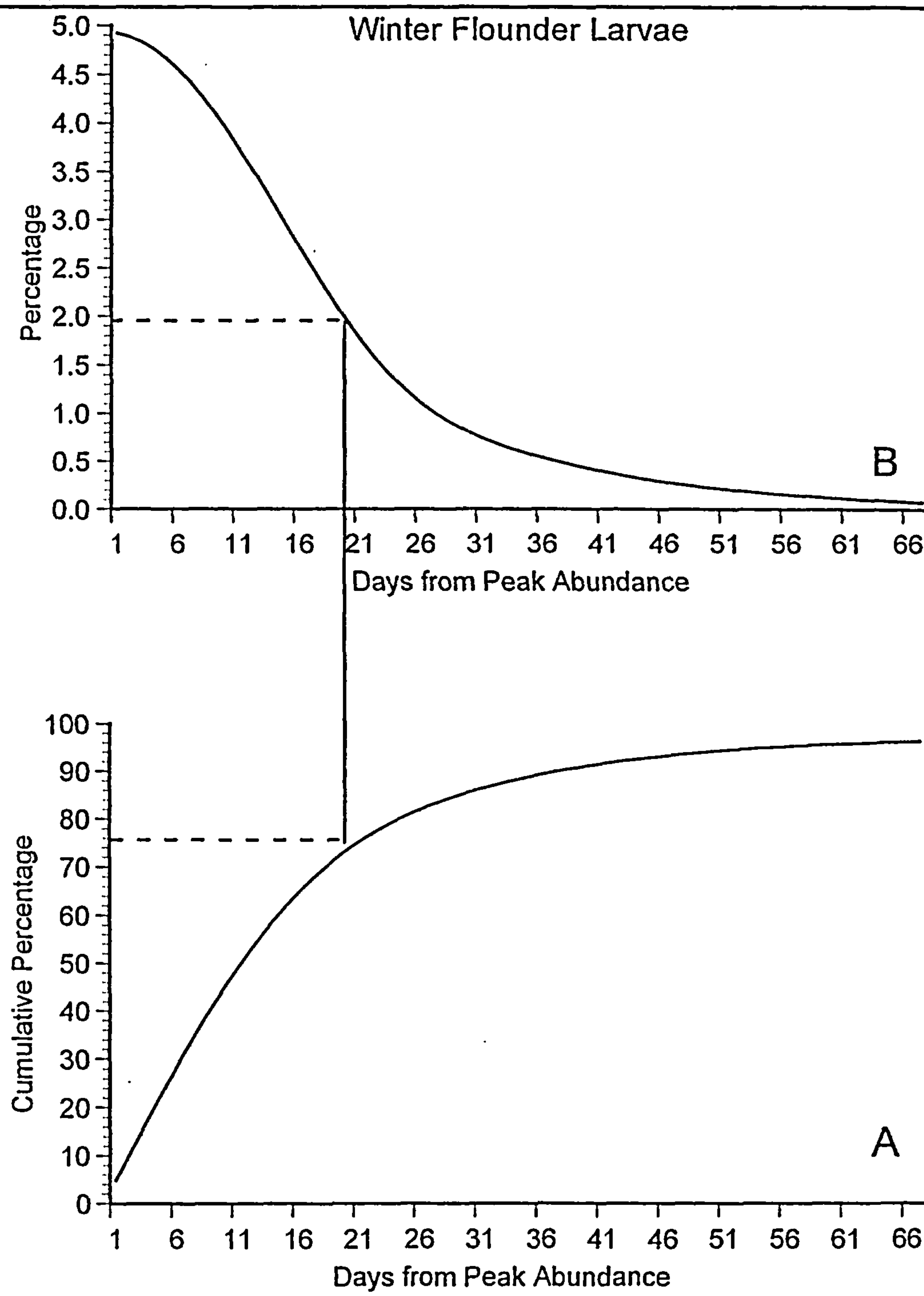

Fig. 3-7. A) The daily cumulative percentage before and after the estimated date of peak abundance of winter flounder larvae at the MNPS intakes, and B) the sum of the daily percentages of larvae proceeding incrementally before and after the peak (sum of 2 days). The solid vertical line connecting A and B represents the number of days before and after estimated peak abundance when the percentage of larvae available for entrainment decreases (on average) to less than 1% per day. The dashed horizontal line on A shows the associated cumulative percentage of available larvae corresponding to the 40-day period encompassed when using this criterion.

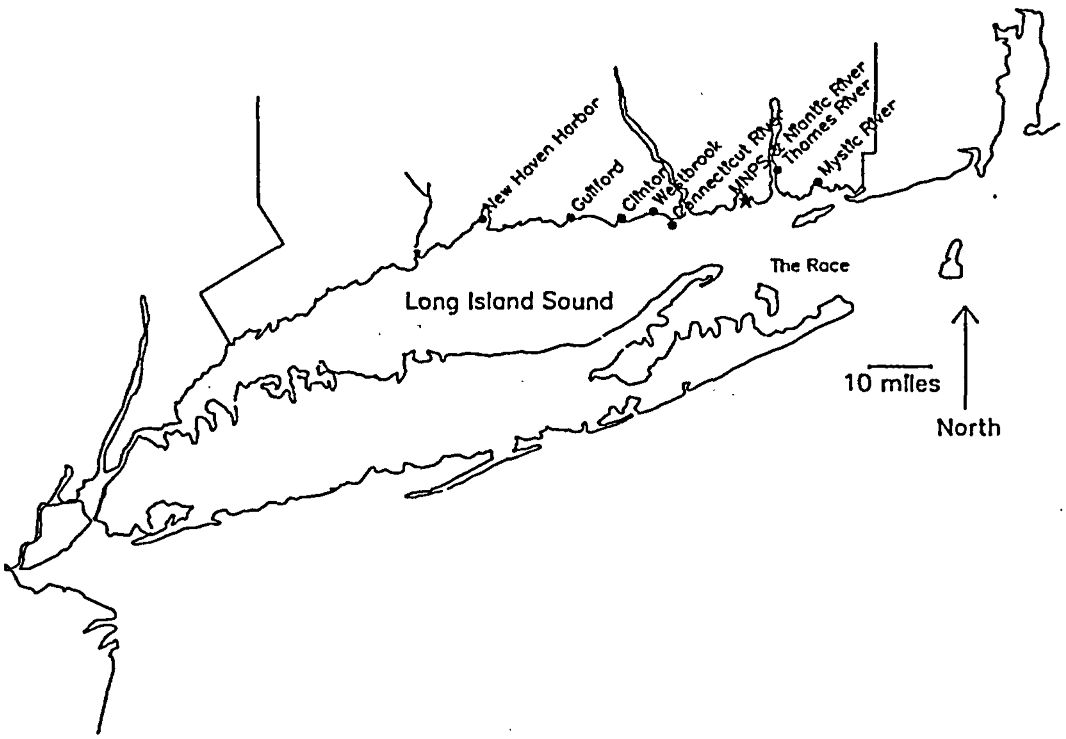

Fig. 3-8. Locations (solid circles) along the Connecticut shoreline of central and eastern Long Island Sound where early stage winter flounder larvae have been collected (i.e., presumed spawning grounds). Based on studies conducted at MNPS (plant location indicated by star) and data presented in Pearcy (1962) and Howell and Molnar (1996, 1998).

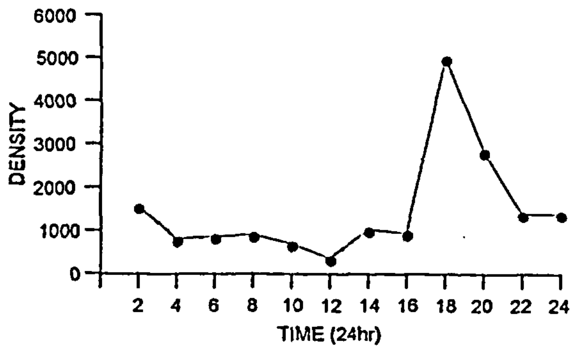

Fig. 3-9. The geometric mean density of tautog eggs collected every 2 h at the MNPS discharges in three 24-h studies conducted on June 8-9, June 15-16, and July 19-20, 1993.

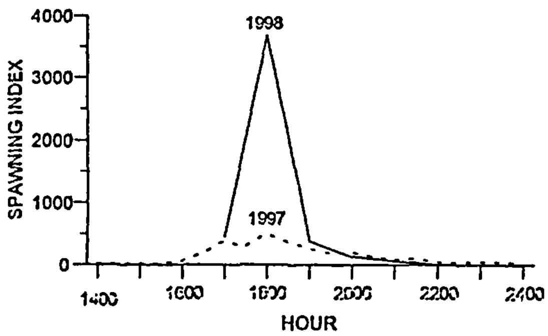

Fig. 3-10. Daily tautog spawning periodicity in a spawning tank at the NMFS Laboratory, Milford, CT on June 28, 1997 and June 29, 1998. The spawning index is the number of eggs collected in 1 minute at 30-minute intervals from 1400 through 2400 h in 1997 and 60-minute intervals from 1700 through 2400 h in 1998.

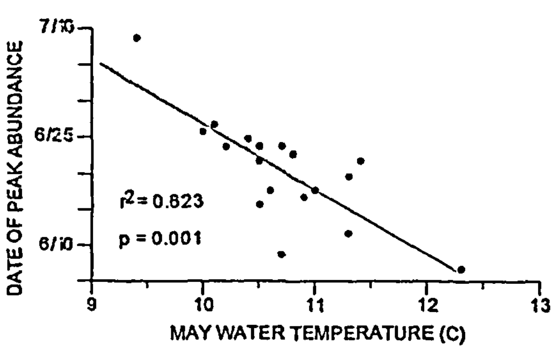

Fig. 3-11. Relationship between annual mean May water temperature (shown in °C; 9.5°C = 49°F; 12.25°C = 54°F) at the MNPS intakes and the date of peak abundance of tautog eggs from 1979 through 1996.

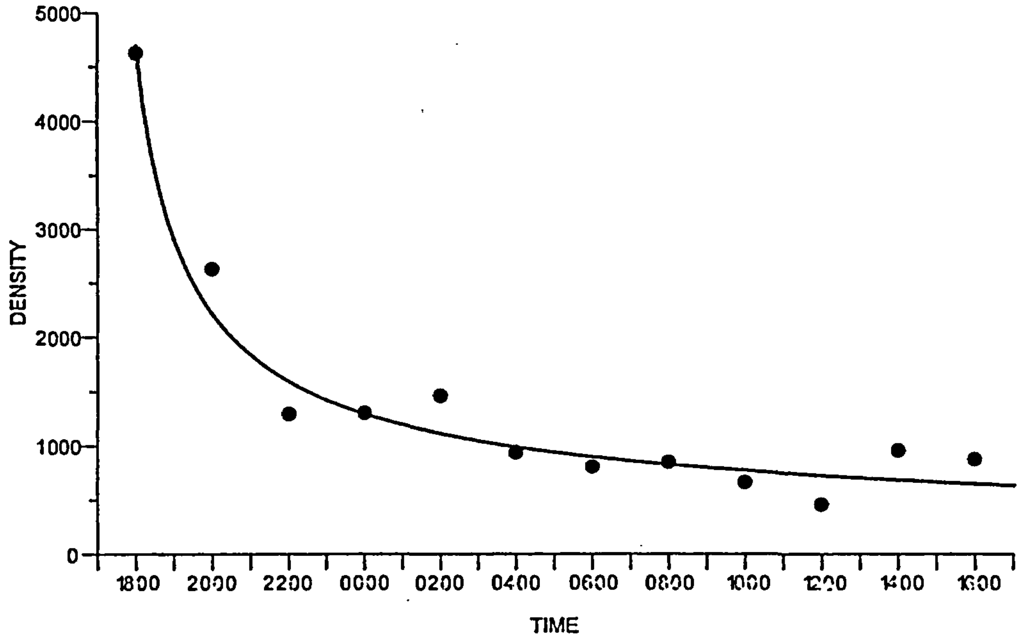

Fig. 3-12. Geometric mean densities (per 500 m^3) of tautog eggs collected at 2-h intervals during 24-h studies conducted on three dates (June 8-9, June 15-16, and July 19-20) at the MNPS discharges in 1993 (NUSCO 1994a). The curve of predicted abundance was fitted from the hazard function of the Weibul distribution (Saila and Lough 1981).

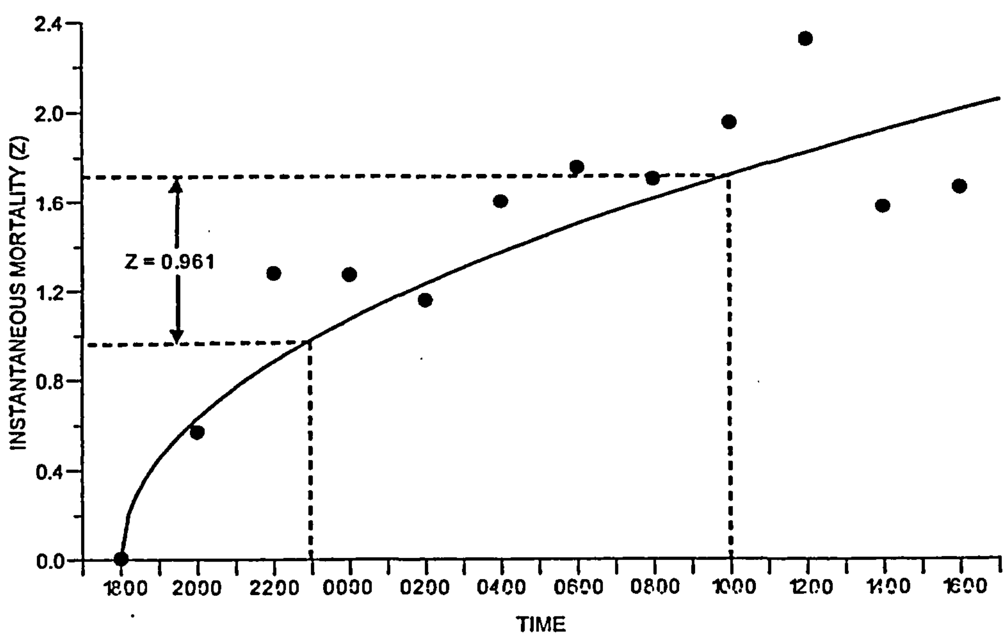

Fig. 3-13. Instantaneous mortality rate (Z) after 1800 h, calculated from geometric mean densities of tautog eggs collected at 2-h intervals during 24-h studies conducted on three dates (June 8-9, June 15-16, and July 19-20) at the MNPS discharges in 1993 (NUSCO 1994a). The curve of predicted Z was fitted from the hazard function of the Weibul distribution (Saila and Lough 1981).

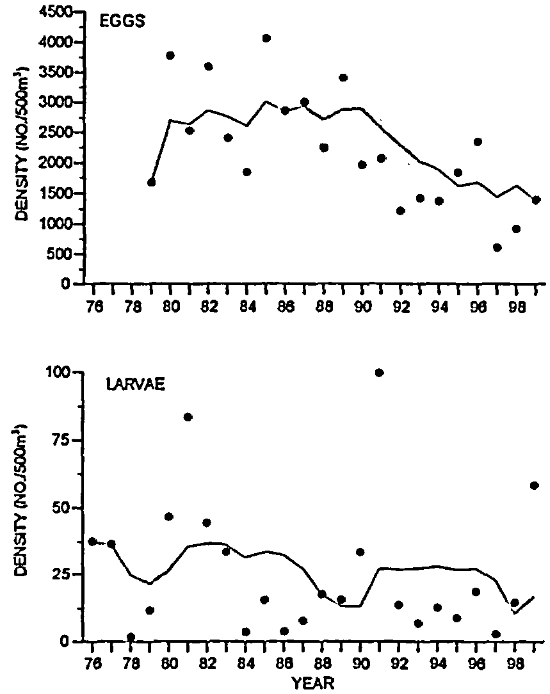

Fig. 3-14. Annual Δ-mean densities (data points) with 4-year moving averages (line) of tautog eggs (1979-99) and 5-year moving averages of tautog larvae (1976-99) at the MNPS discharge. (Note that the vertical scales differ between the graphs).

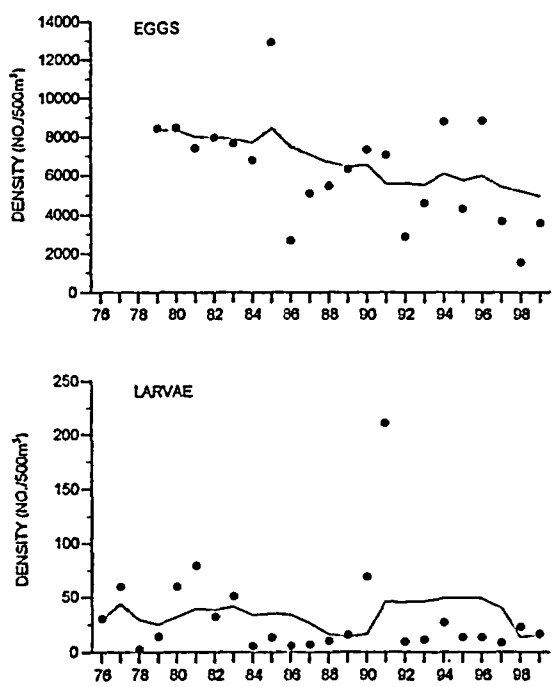

Fig. 3-15. Annual Δ-mean densities (data points) with 4-year moving averages (line) of cunner eggs (1979-99) and 5-year moving averages of cunner larvae (1976-99) at the MNPS discharges. (Note that the vertical scales differ between the graphs).

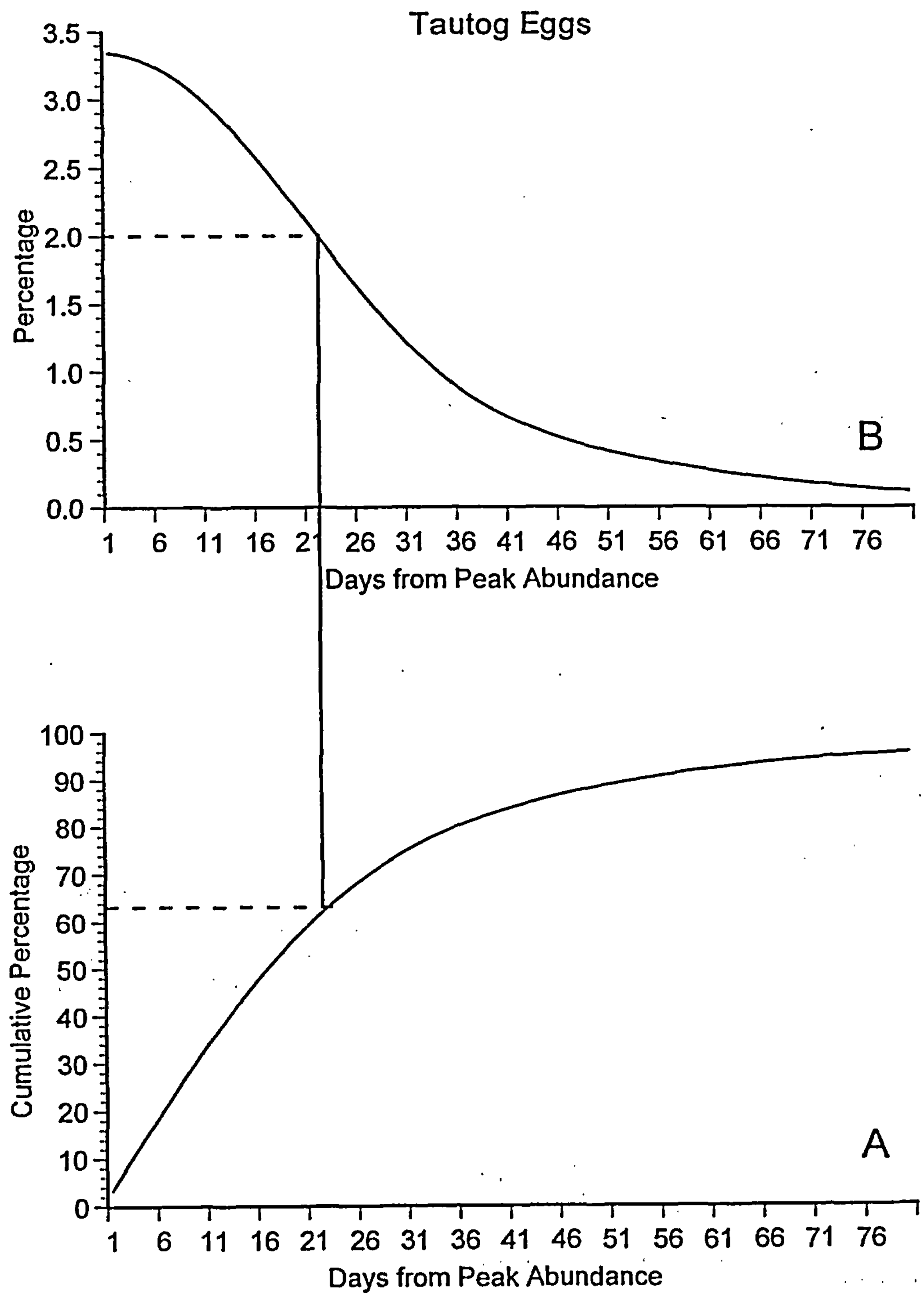

Fig. 3-16. A) The daily cumulative percentage before and after the estimated date of peak abundance of tautog eggs at the MNPS intakes, and B) the sum of the daily percentages of eggs proceeding incrementally before and after the peak (sum of 2 days). The solid vertical line connecting A and B represents the number of days before and after estimated peak abundance when the percentage of eggs available for entrainment decreases (on average) to less than 1% per day. The dashed horizontal line on A shows the associated cumulative percentage of available eggs corresponding to the 44-day period encompassed when using this criterion.

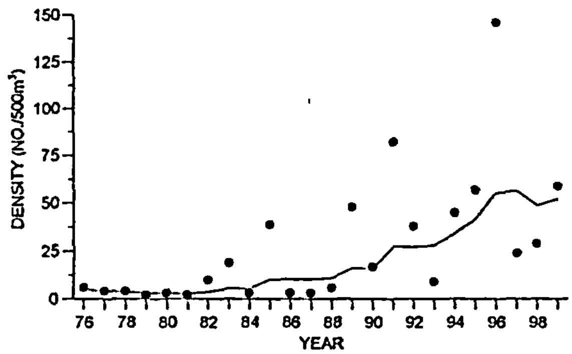

Fig. 3-17. Annual Δ-mean densities (data points) and the 5-year moving average (line) of Atlantic menhaden larvae at the MNPS discharges from 1976 through 1999.

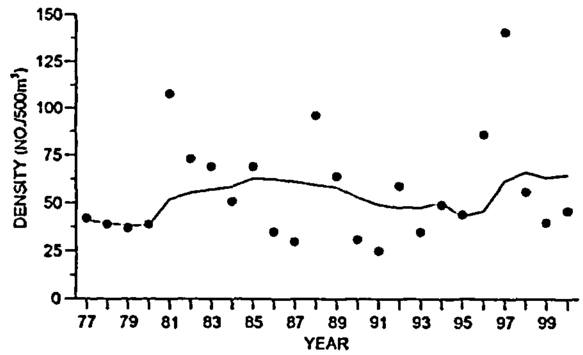

Fig. 3-19. Annual Δ-mean densities (data points) with a 5-year moving average (line) of grubby larvae at the MNPS discharges from 1977 through 2000.

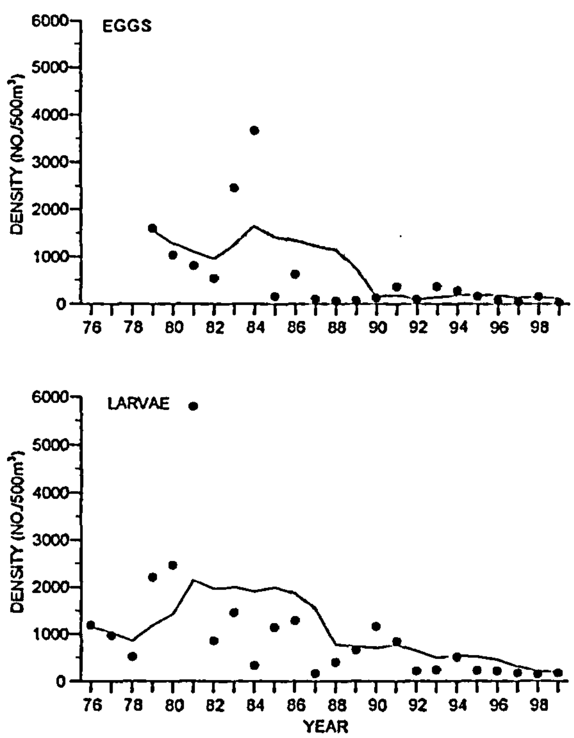

Fig. 3-18. Annual Δ-mean densities (data points) with moving averages (line) of 4 years for anchovy eggs (1979-99) and 5 years for anchovy larvae (1976-99) at the MNPS discharges.

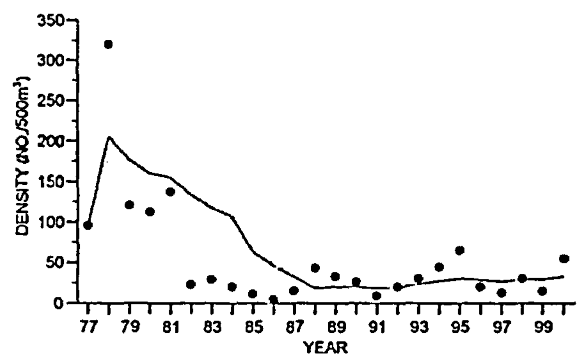

Fig. 3-20. Annual Δ-mean densities (data points) and the 5-year moving average (line) of American sand lance larvae at the MNPS discharges from 1977 through 2000.

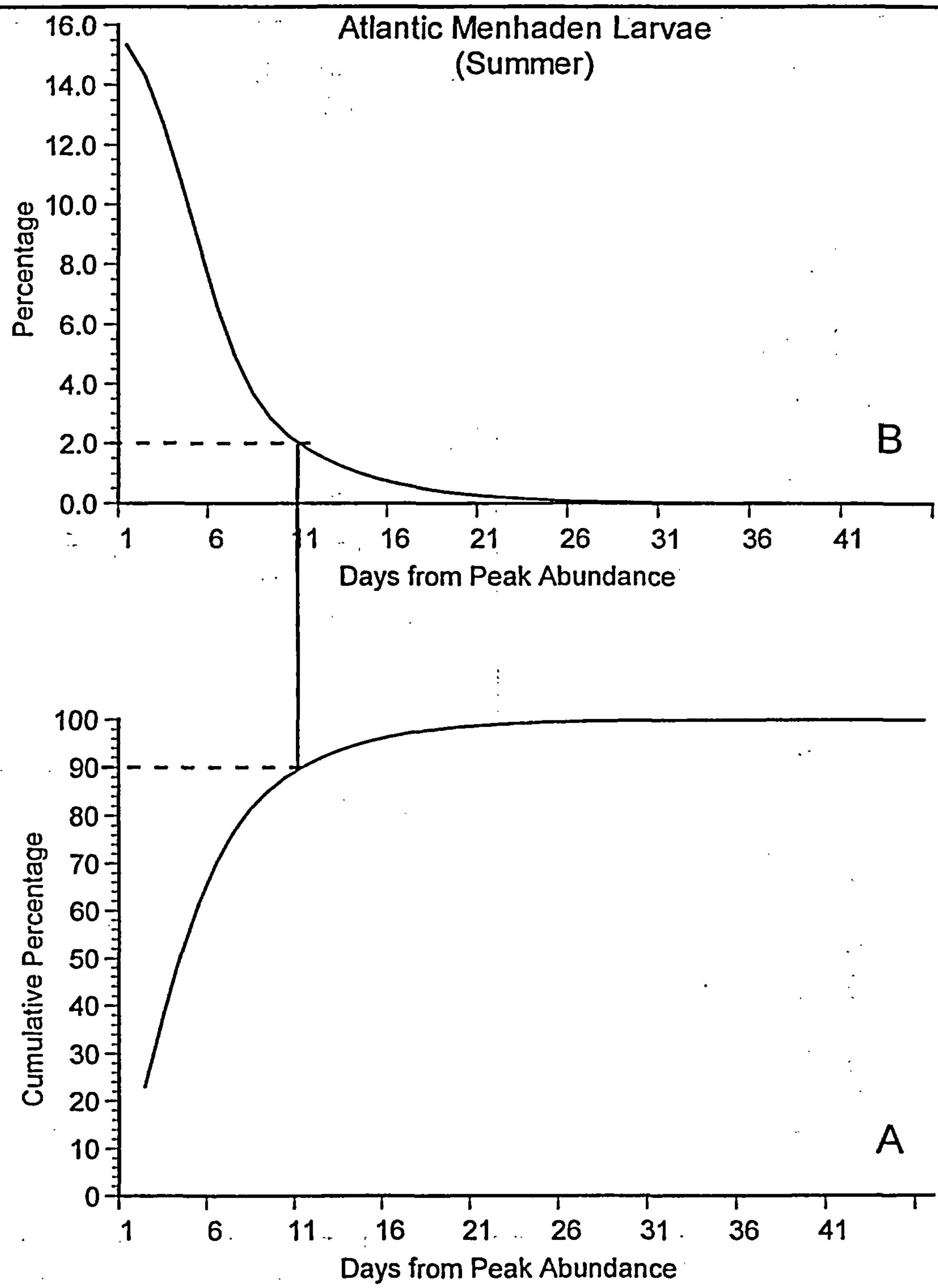

Fig. 3-21. A) The daily cumulative percentage before and after the estimated date of peak abundance of Atlantic menhaden larvae at the MNPS intakes during summer, and B) the sum of the daily percentages of larvae proceeding incrementally before and after the summer peak (sum of 2 days). The solid vertical line connecting A and B represents the number of days before and after estimated peak abundance when the percentage of larvae available for entrainment decreases (on average) to less than 1% per day. The dashed horizontal line on A shows the associated cumulative percentage of available larvae corresponding to the 22-day period encompassed when using this criterion.

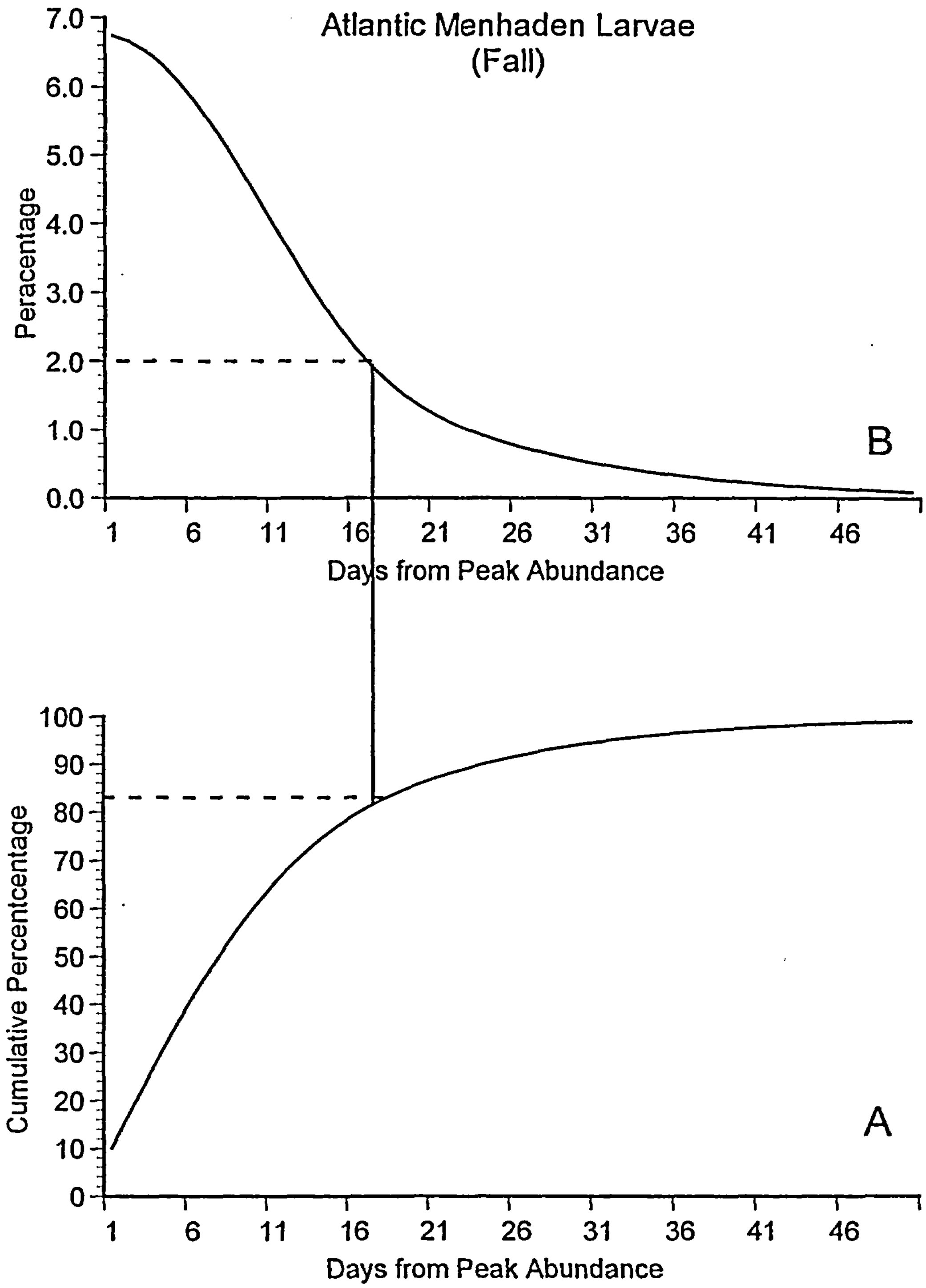

Fig. 3-22. A) The daily cumulative percentage before and after the estimated date of peak abundance of Atlantic menhaden larvae at the MNPS intakes during fall, and B) the sum of the daily percentages of larvae proceeding incrementally before and after the fall peak (sum of 2 days). The solid vertical line connecting A and B represents the number of days before and after estimated peak abundance when the percentage of larvae available for entrainment decreases (on average) to less than 1% per day. The dashed horizontal line on A shows the associated cumulative percentage of available larvae corresponding to the 34-day period encompassed when using this criterion.

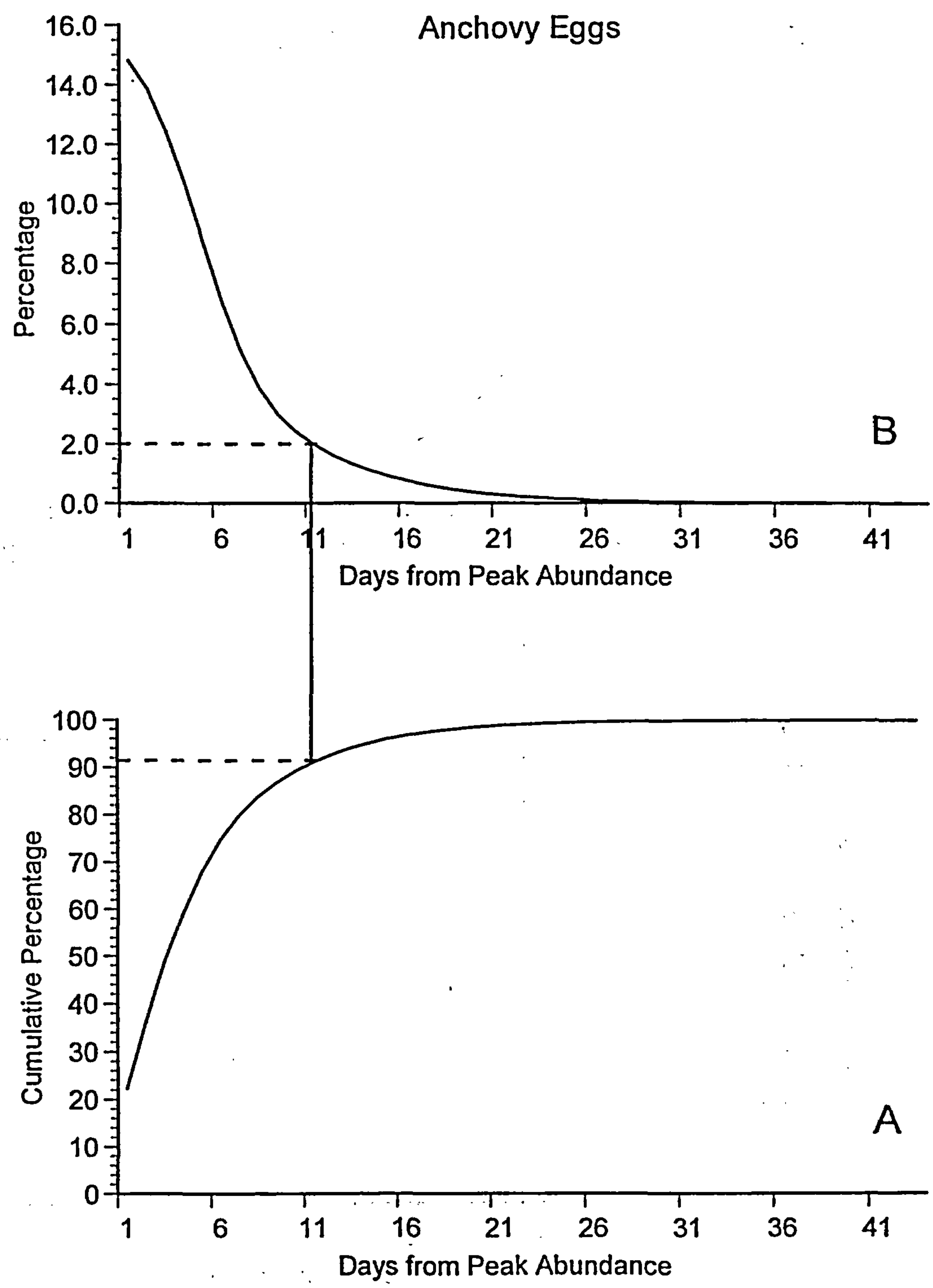

Fig. 3-23. A) The daily cumulative percentage before and after the estimated date of peak abundance of anchovy eggs at the MNPS intakes, and B) the sum of the daily percentages of eggs proceeding incrementally before and after the peak (sum of 2 days). The solid vertical line connecting A and B represents the number of days before and after estimated peak abundance when the percentage of eggs available for entrainment decreases (on average) to less than 1% per day. The dashed horizontal line on A shows the associated cumulative percentage of available eggs corresponding to the 22-day period encompassed when using this criterion.

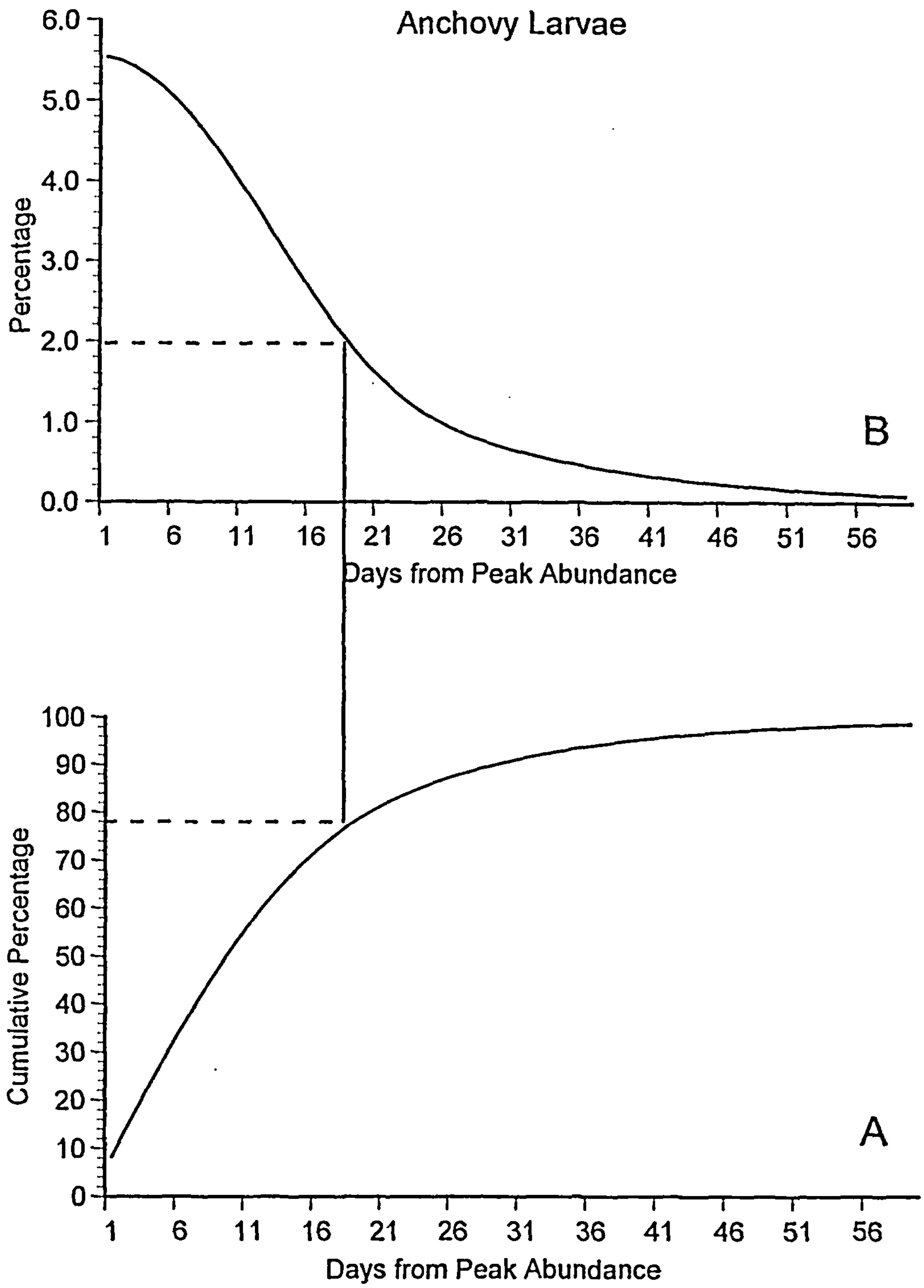

Fig. 3-24. A) The daily cumulative percentage before and after the estimated date of peak abundance of anchovy larvae at the MNPS intakes, and B) the sum of the daily percentages of larvae proceeding incrementally before and after the peak (sum of 2 days). The solid vertical line connecting A and B represents the number of days before and after estimated peak abundance when the percentage of larvae available for entrainment decreases (on average) to less than 1% per day. The dashed horizontal line on A shows the associated cumulative percentage of available larvae corresponding to the 38-day period encompassed when using this criterion.

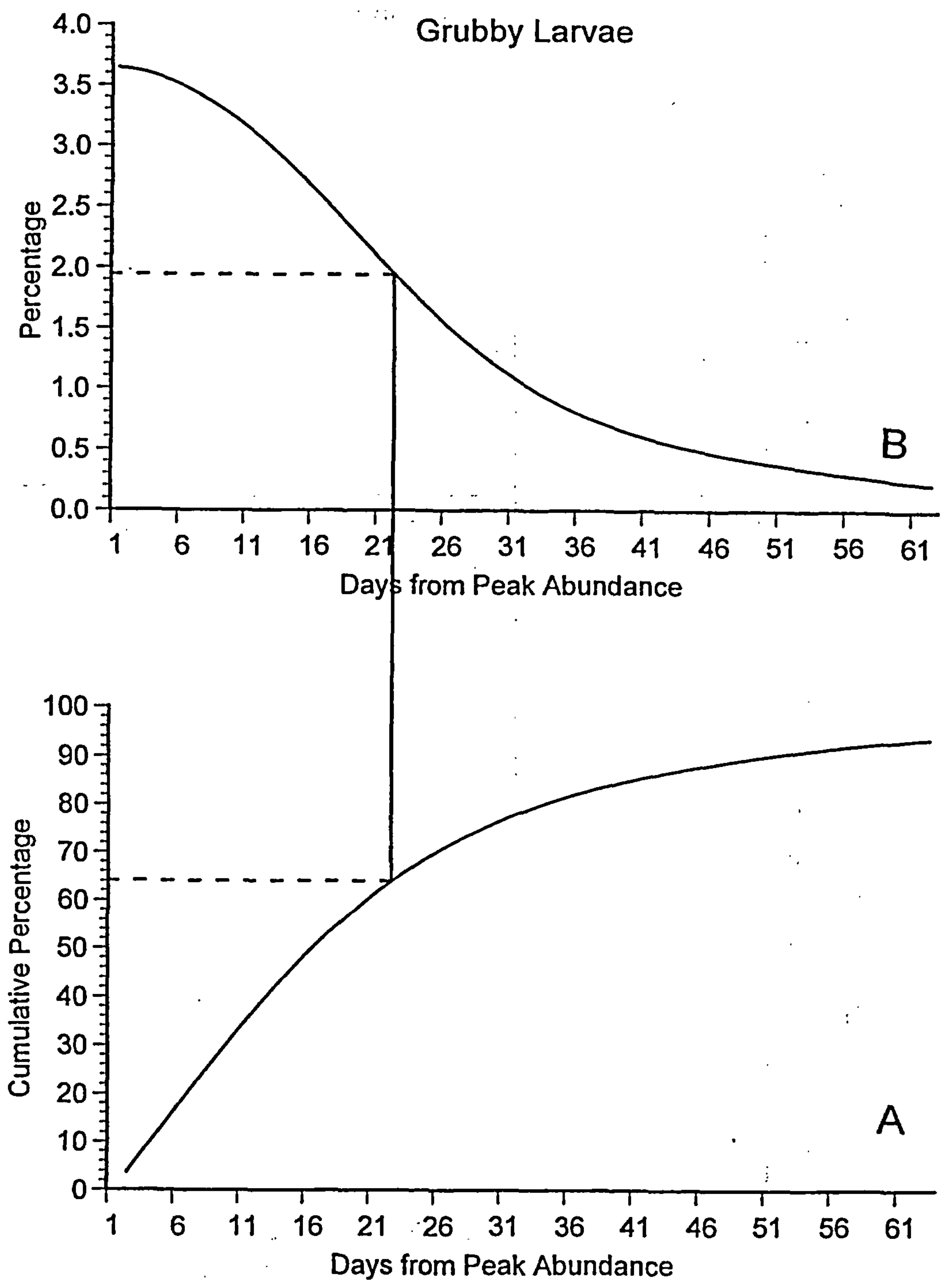

Fig. 3-25. A) The daily cumulative percentage before and after the estimated date of peak abundance of grubby larvae at the MNPS intakes, and B) the sum of the daily percentages of larvae proceeding incrementally before and after the peak (sum of 2 days). The solid vertical line connecting A and B represents the number of days before and after estimated peak abundance when the percentage of larvae available for entrainment decreases (on average) to less than 1% per day. The dashed horizontal line on A shows the associated cumulative percentage of available larvae corresponding to the 44-day period encompassed when using this criterion.

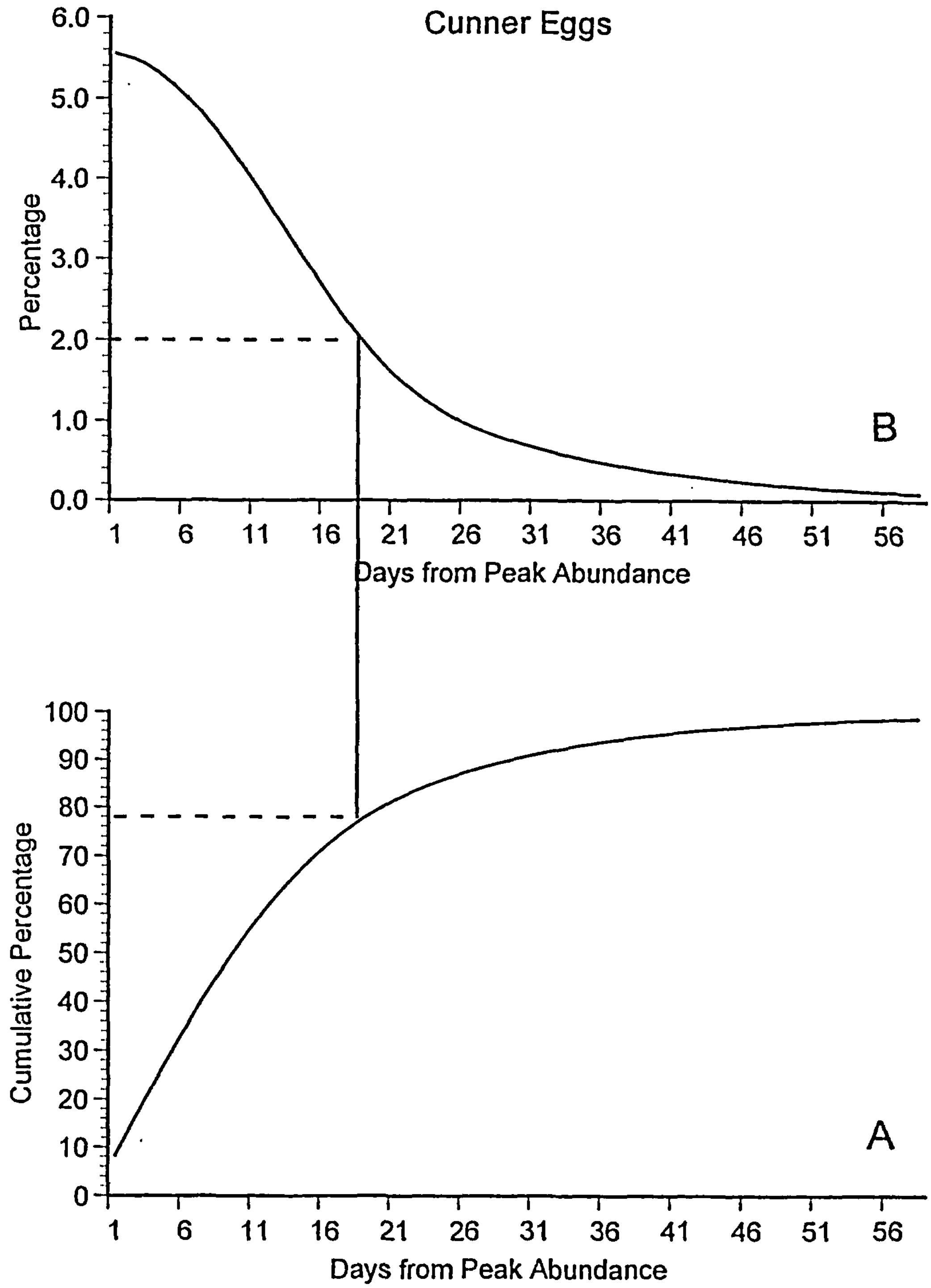

Fig. 3-26. A) The daily cumulative percentage before and after the estimated date of peak abundance of cunner eggs at the MNPS intakes, and B) the sum of the daily percentages of eggs proceeding incrementally before and after the peak (sum of 2 days). The solid vertical line connecting A and B represents the number of days before and after estimated peak abundance when the percentage of eggs available for entrainment decreases (on average) to less than 1% per day. The dashed horizontal line on A shows the associated cumulative percentage of available eggs corresponding to the 38-day period encompassed when using this criterion.

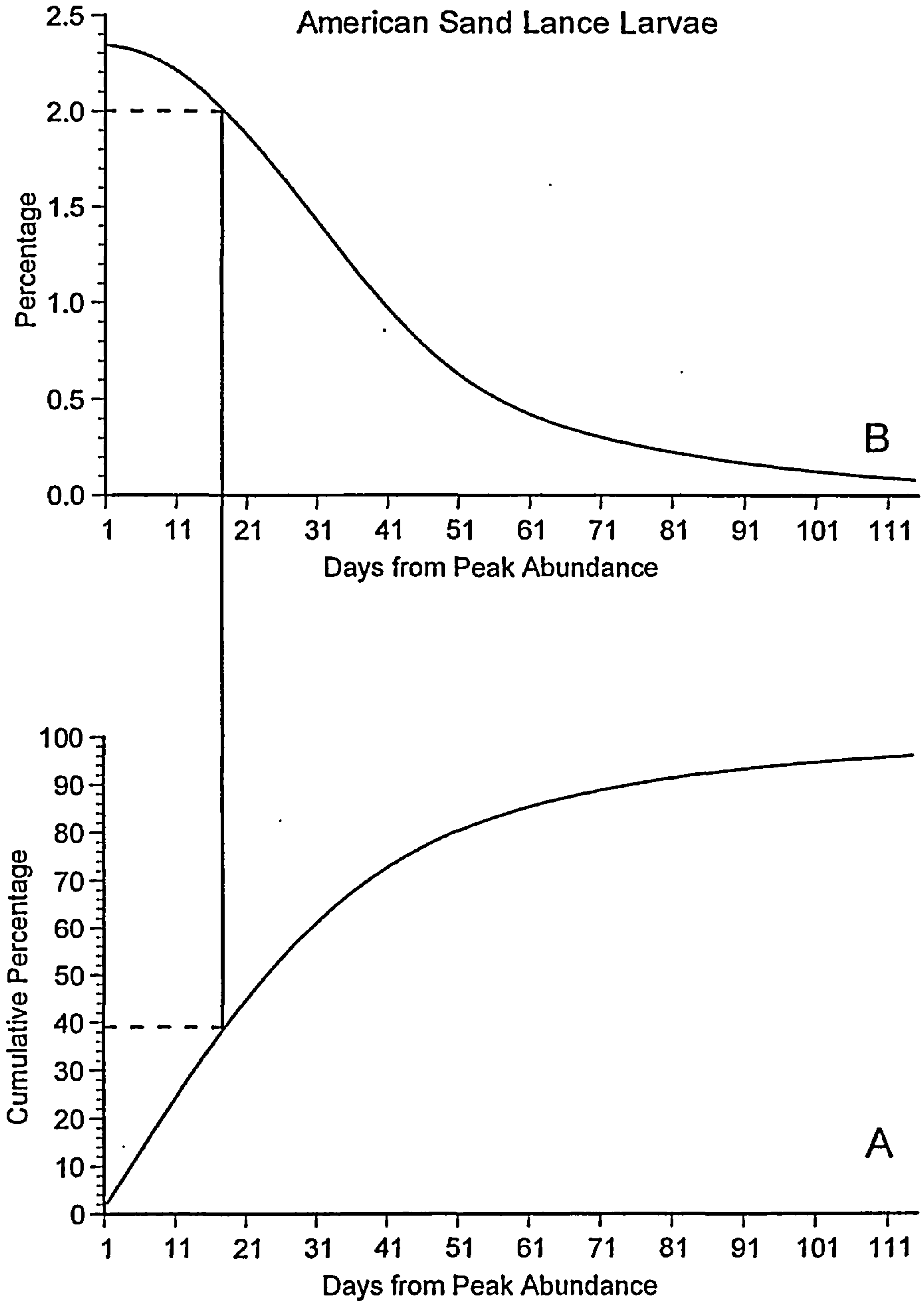

Fig. 3-27. A) The daily cumulative percentage before and after the estimated date of peak abundance of American sand lance larvae at the MNPS intakes, and B) the sum of the daily percentages of larvae proceeding incrementally before and after the peak (sum of 2 days). The solid vertical line connecting A and B represents the number of days before and after estimated peak abundance when the percentage of larvae available for entrainment decreases (on average) to less than 1% per day. The dashed horizontal line on A shows the associated cumulative percentage of available larvae corresponding to the 36-day period encompassed when using this criterion.

APPENDIX A TO CHAPTER 3 OF PART II

LARVAL WINTER FLOUNDER ENTRAINMENT SURVIVAL STUDY CONDUCTED AT MILLSTONE NUCLEAR POWER STATION IN 2000 AND 2001

A3.1 INTRODUCTION AND METHODOLOGY

A pump sampler was employed at the Millstone Nuclear Power Station (MNPS) Unit 3 cooling-water discharge in the Millstone Quarry (Fig. A3-1) to evaluate the survival of entrained winter flounder larvae during spring in 2000 and 2001. Identical pump samplers were used near the MNPS intake structure and the discharge in 2001 to provide an estimate of control mortality. The samplers consisted of a 1.0 wide by 1.0 m deep (2000) or 1.0 wide by 0.5 m deep (2001) conical net of 0.333-mm mesh fitted with a 2-L codend bucket to hold larvae. The net was suspended inside a chamber connected to an intake hose situated in the chamber wall above the net and an outlet hose at the bottom of the chamber (Figs. A3-2 and A3-3). Net length was reduced in 2001 so that the sampler and its chamber could be deployed on a research vessel for control sampling. At the Unit 3 discharge, the entire sampling apparatus was situated on a 3-m^2 floating platform. The intake hose entered the chamber below the water line so that water entered the chamber by gravitational force. The unattached end of the hose on the sampler at the intake site was placed in the water column below the sampler platform and the hose end was moved vertically in the water column during sampling. The unattached end of the intake hose on the sampler at the discharge site was placed in the discharge plume immediately below the Unit 3 discharge structure. Water was pumped out of the bottom of the chamber using a gasoline-powered pump, thereby filtering water through the net. Volume of water sampled was measured using an analog flow meter attached to the outlet line after the pump. Flow was adjusted with a valve at the terminus of the outlet line.

The pump sampler was typically run for 1 h and filtered about 50 m^3 of water. At the end of the hour sampling time, the net was slowly raised from the chamber and gently rinsed to wash all organisms and debris into the codend bucket. The bucket was then removed, sealed, and placed in a bucket of discharge water (or intake area water, depending on the site) to maintain temperature during transport to the laboratory. The sample was examined at the laboratory using a magnifying lens to remove larvae. Larvae were identified and assessed for signs of life. Transport and processing typically took between 20 and 30 min. Live winter flounder larvae were placed in flow-through beakers of salt water of similar temperature to the discharge water. Dead larvae were measured (to nearest 1.0 mm) and developmental stage recorded. Beakers with live larvae were subjected to a 1-h acclimation period, lowering the temperature to ambient Long Island Sound (LIS) water temperature to simulate the movement of water from the discharge into LIS, then placed in a tank having flow-through sea water. During holding, larvae were fed

live rotifers to satiation. Numbers of larvae surviving entrainment were determined at 0, 24, 48, and 96 h after collection. Larvae experiencing latent mortality were measured and the developmental stage of each was recorded.

A3.2 RESULTS AND DISCUSSION

During control sampling, a total of 27 winter flounder larvae was collected with the pump sampler near the MNPS intake structures between April 28 and May 10, 2001. Total sampling effort was 14 hours, filtering approximately 960.8 m^3 of water. The collected larvae consisted of 8 Stage 2 and 13 Stage 3 winter flounder with developmental stages of 6 fish unrecorded. Ten of the 27 larvae collected were alive at the time of capture and no larvae survived to 24 hours (Table A3-1).

During the entrainment survival sampling at the Unit 3 discharge in 2000, 16 Stage 3 and 72 Stage 4 larvae, and 3 Stage 5 metamorphosed juveniles were collected between May 18 and June 7. Volume of discharge water sampled in 2000 was approximately 465.5 m^3 during 10 hours of sampling effort. Of the fish collected, 4 Stage 3, 44 Stage 4, and 3 Stage 5 larvae were alive during initial observations. No Stage 3 larvae survived to 24 hours, while 21% and 100% of Stage 4 and 5 fish, respectively, survived through 96 hours (Table A3-2). Approximately 332.7 million winter flounder were entrained at MNPS in 2000 (see Chapter 3, Table 3-7). About 58.8% of the entrained fish were in Stage 3 of development, 19.8% were Stage 4, and 1% were Stage 5 (DNC 2001). Placing the survival estimates into perspective with the numbers of winter flounder entrained in 2000, approximately 14.4 million Stage 4 larvae and 2.7 million Stage 5 juveniles would have survived entrainment, assuming that survival of entrained winter flounder was similar across both Units 2 and 3 (Table A3-3). Thus, about 5% of the entrained winter flounder in 2000 may have survived through-plant passage.

In 2001, entrainment survival sampling took place from March 18 through June 11, when 9 Stage 2, 292 Stage 3, and 115 Stage 4 winter flounder larvae, and 1 Stage 5 juvenile were collected during 32 hours of sampling effort that filtered approximately 1,551.0 m^3 of discharge water. While 4 of the 9 Stage 2 larvae were alive at time of initial examination, none survived to 24 hours. Initial survival of Stage 3 larvae was good, as 80 of 292 larvae were alive at the time of capture, but only 1% survived to 96 hours. Stage 4 larvae showed slightly less than 50% initial survival and 96-hour latent survival in 2001 was about 17%, slightly lower than the 21% estimated in 2000. The single Stage-5 juvenile collected in 2001 survived through 96 hours (Table A3-4).

Despite the small sample sizes, entrainment survival appeared to increase with developmental stage (Table A3-5). Survival of Stage 2 and 3 larvae was negligible, while Stage 4 survival was between 17% and 21% during this study. All Stage 5 juveniles examined survived, but this was based on only 4 fish captured during the 2-year study.

These results indicated that some winter flounder, particularly older and larger specimens in later developmental stages, can survive through-plant entrainment.

The sampling protocol was designed to collect samples from waters at the intake structure that would provide an estimate of sampler-induced mortality useful to adjust estimates based on samples taken at the discharge site. Unfortunately, few fish were captured at the intake site and those that were collected were of early developmental stages and did not survive. This may be an indication that the sampling gear, particularly the net, may be inducing mortality. This aspect requires further study. The small sample size was probably due to sampler avoidance as Stage 2 and 3 larvae have swimming speeds greater than 2 $cm \cdot sec^{-1}$ and escape speeds in excess of 5 $cm \cdot sec^{-1}$ (Williams and Brown 1992). Further, larger larvae in advanced development have even greater swimming and escape speeds (Yin and Blaxter 1987; Williams and Brown 1992). Also, larvae were likely fully cognizant at the intake site and actively avoided the intake hose, whereas fish coming out of the discharge could not actively avoid the sampler. The high mortality of larvae collected at the intake site may indicate that the sampler was collecting fish in poor physiological condition that were too weak to escape the sampler. These results indicate that some sampler-induced mortality occurs, but was not measurable. Therefore, results from the intake sampler could not be adequately compared to results from the discharge samples due to small sample sizes and a lack of any survival of collected fish. Until further work is completed the survival estimates calculated from sampling at the Unit 3 discharge in 2000 and 2001 should be considered as minimum estimates.

A3.3 REFERENCES

DNC (Dominion Nuclear Connecticut, Inc.). 2001. Winter flounder studies. Pages 9-94 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 2000. Millstone Environmental Laboratory, Waterford, CT.

Williams, J.P., and J.A. Brown. 1992. Development changes in the escape response of larval winter flounder *Pleuronectes americanus* from hatch through metamorphosis. Mar. Ecol. Prog. Ser. 88:185-193.

Yin, M.C., and J.H.S. Blaxter. 1987. Escape speeds of marine fish larvae during early development and starvation. Mar. Biol. 96:459-468.

TABLE A3-1. Summary of larval winter flounder survival from pump samples collected at the MNPS cooling-water intake site.

Date	Volume sampled (m³)	Developmental stage	Total catch	Initial number alive	Alive at 24 h	Alive at 48 h	Alive at 96 h	% survival[a]
28 April	195.9	3	7	4	0			0
30 April	101.5	-	0	-				-
3 May	310.2	2	3	1	0			0
		3	5	2	0			0
8 May	53.2	-	0	-				-
9 May	149.9	2	5	2	0			0
		3	1	0	0			0
10 May	150.1	not recorded	6	1	0			0
Total	960.8		27	10	0			0

[a] Average percent survival through 96 hours.

TABLE A3-2. Larval and juvenile winter flounder survival from pump samples collected at the MNPS Unit 3 cooling-water discharge in 2000.

Date	Volume sampled (m³)	Developmental stage	Total catch	Initial number alive	Alive at 24 h	Alive at 48 h	Alive at 96 h	% survival[a]
18 May	160.8	3	4	1	0	not recorded	not recorded	0
31 May	101.2	3	6	1	0			0
		4	51	34	16	16	11	22
		5	3	3	3	3	3	100
7 June	108.4	3	6	2	0			0
		4	21	10	4	4	4	19
Total	370.4	3	16	4	0			0
		4	72	44	20	20	15	21
		5	3	3	3	3	3	100

[a] Average percent survival through 96 hours.

TABLE A3-3. Number of winter flounder larvae entrained at MNPS, estimated probability of surviving entrainment, and estimated numbers of winter flounder larvae surviving entrainment by developmental stage in 2000.

Stage	Number entrained (millions)	Survival probability	Number of survivors (millions)
1	5.3	no estimate	no estimate
2	62.9	no estimate	no estimate
3	195.6	0.000	0
4	65.9	0.208	14.4
5	2.7	1.000	2.7

TABLE A3-4. Larval and juvenile winter flounder survival from pump samples collected at the MNPS Unit 3 cooling-water discharge in 2001.

Date	Volume sampled (m^3)	Developmental stage	Total catch	Initial number alive	Alive at 24 h	Alive at 48 h	Alive at 96 h	% survival[a]
18 March	96.1	-	0					-
24 March	50.4	-	0					-
18 April	101.2	2	4	4	1	0		0
		3	31	19	1	0		0
		4	2	2	2	2	2	100
21 April	96.8	3	13	5	0			0
		4	1	1	0			0
24 April	143.3	2	3	0				0
		3	66	14	1	1	1	<1
2 May	207.5	2	2	1	0			0
		3	38	18	0			0
		4	8	8	4	4	4	50
10 May	105.0	3	11	2	0			0
		4	6	4	3	3	3	50
16 May	151.9	3	24	5	0			0
		4	11	9	1	1	1	11
21 May	52.6	3	16	0				0
		4	5	0				0
29 May	206.3	3	44	14	0			0
		4	31	11	1	1	1	3
		5	1	1	1	1	1	100
4 June	189.2	3	49	3	0	0	0	0
		4	42	12	4	4	4	10
11 June	150.7	4	11	5	5	5	5	45
Total	1,551.0	2	9	4	1	0	0	0
		3	292	80	2	1	1	<1
		4	115	52	20	20	20	17
		5	1	1	1	1	1	100

[a] Average percent survival through 96 hours.

TABLE A3-5. Summary of winter flounder larvae entrainment survival at the MNPS Unit 3 discharge station during spring of 2000 and 2001.

Year	Volume sampled (m^3)	Developmental stage	Total catch	Number alive at 0 h	% alive at 96 h
2000	465.5				
		3	16	4	0
		4	72	44	21
		5	3	3	100
2001	1,551.0				
		2	9	4	0
		3	292	52	<1
		4	115	80	17
		5	1	1	100

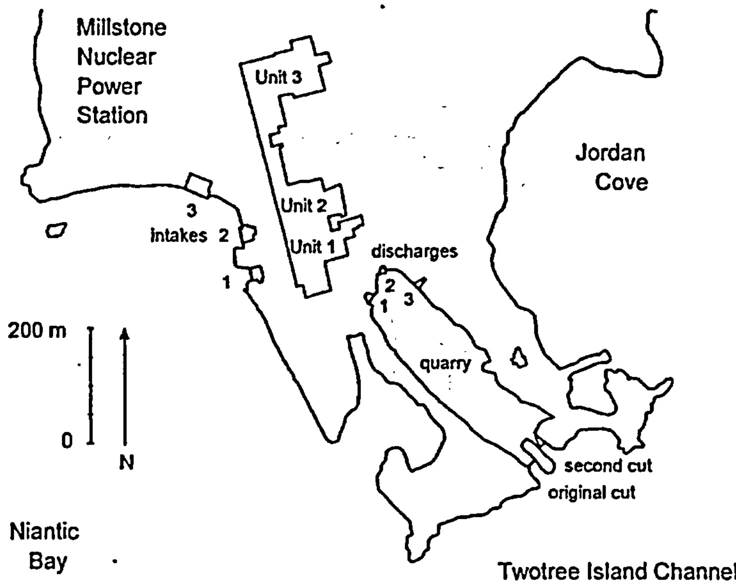

Fig. A3-1. The MNPS site, showing the intake and discharge of each unit, the Quarry, and the two Quarry discharge cuts.

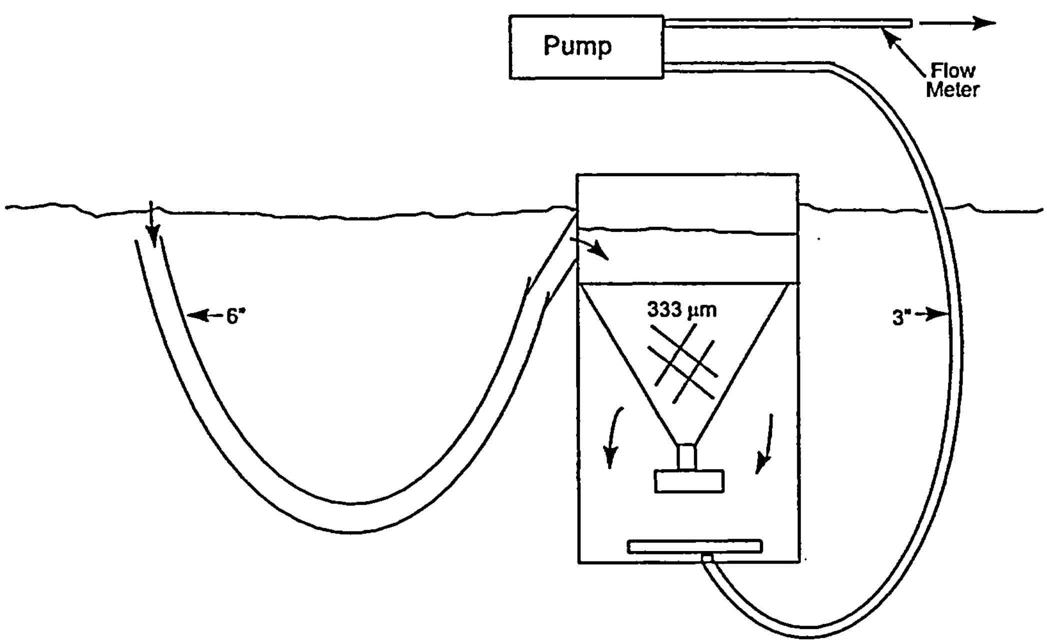

Fig. A3-2. Side view of the MNPS entrainment survival sampler.

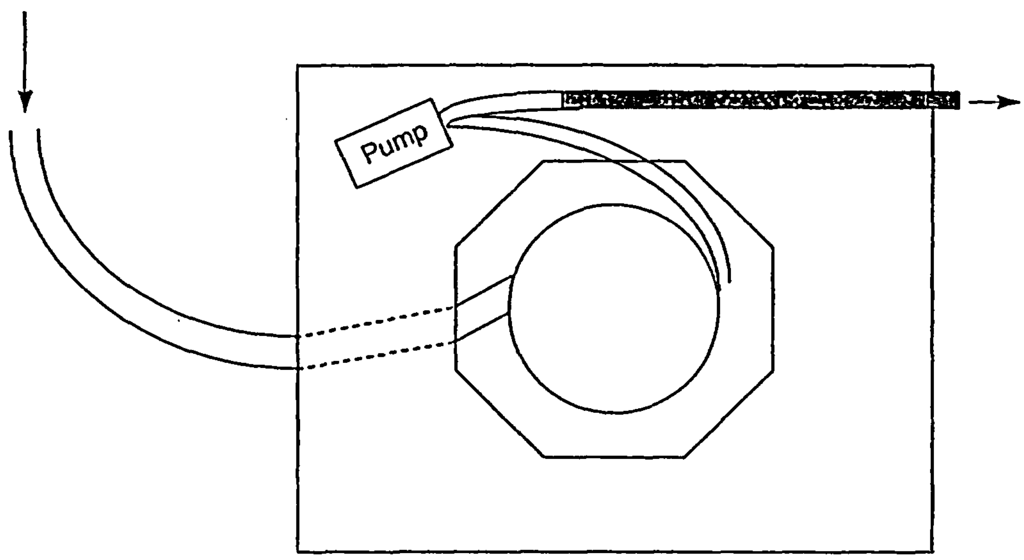

Fig. A3-3. Overhead view of the MNPS entrainment survival sampler.

APPENDIX B TO CHAPTER 3 OF PART II

SOURCES OF LARVAL WINTER FLOUNDER ENTRAINED AT MILLSTONE NUCLEAR POWER STATION

B3.1 INTRODUCTION

The temporal and spatial distribution of larval winter flounder in Niantic Bay and adjacent potential source areas has been examined through special larval abundance studies, hydrodynamic investigations, and evaluation of routine monitoring data. The focus of these studies was to determine the probable sources of winter flounder entrained by Millstone Nuclear Power Station (MNPS) and the effects of tidal currents on larval abundance and distribution. In part, the results of these studies were used to develop and verify mathematical calculations, termed mass-balance calculations, to estimate the annual number of entrained larvae that originated from Niantic River spawning stock. A discussion of the hydrodynamic regime and movements of winter flounder larvae in the vicinity of MNPS (Section B3.2) is followed by a description of the mass-balance model and a sensitivity analysis of parameter estimates (Section B3.3). At the request of the Connecticut Department of Environmental Protection (DEP 2000), independent reviews of the mass-balance model and an independently conducted sensitivity analysis are found in Appendices C and D to Chapter 3.

B3.2 HYDRODYNAMIC FEATURES AND LARVAL WINTER FLOUNDER ABUNDANCE AND DISTRIBUTION

B3.2.1 Niantic Bay Tidal Circulation

Tidal circulation patterns in Niantic Bay and Long Island Sound (LIS) could affect the distribution of ichthyoplankton in the area near Millstone Point and, thus, the source of winter flounder larvae entrained in the condenser cooling-water system of MNPS. Hydrodynamic measurements indicated that there is extensive mixing of Niantic Bay and LIS waters, with an estimated mean tidal exchange for the bay of 44.9 million gal·min^{-1} (NUSCO 1976). In contrast, the average tidal exchange between Niantic River and Bay is relatively small. Kollmeyer (1972) estimated an average tidal prism for the Niantic River of 713.3 million gallons. Assuming about 6 hours for a tidal stage, the tidal exchange would average nearly 2 million gal·min^{-1}. Based on these estimates, the volume of the bay, which was determined as approximately 13.25 billion gallons (derived from estimate of E.E. Adams, Massachusetts Institute of Technology, Cambridge, MA, pers. comm.), is exchanged, on average, in about 5 hours. This rate of exchange indicates that Niantic Bay is well mixed due to vigorous tidal circulation. Hydrodynamic modeling of the Millstone area was developed to examine the dispersal of larval winter flounder. The first model was developed by the University of Rhode Island (NUSCO 1976; Saila 1976) and provided estimates of flow direction and velocity during various tidal stages (Figs. B3-1 and B3-2). A second model was developed by the Massachusetts Institute of

Technology (Dimou and Adams 1989; Dimou et al. 1990) and indicated that about 20% of the Niantic River discharge is utilized as condenser cooling-water under full MNPS three-unit operation. The predicted sources of water utilized for condenser cooling for both hydrodynamic models were verified using dye releases.

During the summer and fall of 1991, five current drogue studies were conducted to examine the tidal circulation patterns in specific areas of Niantic Bay and the results were compared to model predictions (NUSCO 1992b). Current direction and velocity data from these drogue studies were combined to summarize water movements during ebb and flood tidal stages in Niantic Bay (Figs. B3-3 and B3-4). The estimated average current direction and velocities were plotted for each tidal stage during the first hour following slack current and at the time of predicted maximum current velocity. The general flow pattern during an ebbing tide is that water enters the bay from south of Black Point, travels north with the velocity decreasing in mid-bay, passes by the MNPS intakes, and exits the bay south of Millstone Point with an increasing velocity. During a flood tide, water enters the bay from south of Millstone Point. Some of the water mass flows north past the MNPS intakes and continues towards the Niantic River and the remaining water continues westward, until being deflected towards the southwest by Black Point. Current velocities were greatest near Black Point and Millstone Point, but decreased in mid-Niantic Bay. These water movements and current velocity estimates strongly suggested that water in the southern portion of the bay is well-mixed and much of the water available for condenser cooling-water flow at MNPS may come from LIS.

The current directions and velocities for ebb and flood tidal stages were compared to previous model predictions (Figs. B3-1 and B3-2). Good agreement was found between model predictions and drogue measurements, indicating that the predictions were good estimators of the hydrodynamics of Niantic Bay. It was again likely that much of the water utilized for MNPS condenser cooling originates from LIS, because the average tidal exchange in Niantic Bay with LIS is about 20 times greater than the other primary source of exchange, the Niantic River.

B3.2.2 Larval Winter Flounder Abundance and Distribution in Niantic Bay

The estimated annual number of larval winter flounder entrained at MNPS from 1976 through 2000 ranged from 29.7 to 493.2 million (see Table 3-7). Since 1983, when larval developmental staging began, Stage 3 larvae were the dominant (64%) developmental stage collected in entrainment samples with 4% as Stage 1, 19% as Stage 2, 13% as Stage 4, and <1% as Stage 5. The number of larvae entrained is not only related to cooling-water usage, but also their temporal abundance. Based on a long-term average, over 98% of the annual winter flounder larvae were available for entrainment during the period from March 15 through June 30 (Fig. B3-5), with the primary season of occurrence (95% of the distribution) determined as March 22 through June 5 (see Table 3-8 and Fig. 3-6). The estimated date of average peak abundance was April 24, although annually date of peak abundance has ranged from April 10 through May 15. In contrast, since 1984, approximately half the larvae collected in the Niantic River were

Stage 1. This was expected because the river is an area of spawning and larval hatching. In addition, the average date of peak abundance in the river was March 10, 45 days earlier than in entrainment collections. The availability of winter flounder larvae to entrainment is dependent upon their abundance in Niantic Bay, particularly in the vicinity of MNPS intakes. The number and developmental stages entrained is probably strongly related to tidal circulation patterns within and entering Niantic Bay.

During the 1991 larval winter flounder season, three stations in Niantic Bay were sampled to determine larval abundance and spatial distribution relative to tidal current (NUSCO 1992a). Station RM was located south of the mouth of the Niantic River, MP west of Millstone Point, and BP east of Black Point (Fig. B3-6). Stepwise oblique tows were conducted within one hour of the time of maximum ebb and flood tidal currents twice a week from March through May. An additional station (NB), located in mid-Niantic Bay, was sampled twice a week during the same time period but only during a flood tide. A comparison of seasonal abundance indicated large differences between ebb and flood collections at the three stations (Table B3-1). Abundance indices were characterized by the *A* parameter of the Gompertz function (see NUSCO 2000 for details of this index). Two distinct groups were evident on the basis of abundance. Larvae were most abundant for RM-flood, MP-flood, and BP-ebb collections, with *A* values ranging from 4,225 to 5,322. Similarly, lowest abundances were found for RM-ebb, MP-ebb, and BP-flood, with *A* values ranging from 1,865 to 2,124. The NB-flood index also was within this lower abundance range. The 95% confidence intervals indicated good precision of the abundance estimates, except for both ebb and flood collections at station RM. These lower precisions were probably a result of heavy detrital loads collected at RM, particularly during ebb collections, which may have affected the quality of sample processing.

Abundance curves were constructed based on the Gompertz density function to examine temporal abundance at each bay station (Fig. B3-7). Due to the low precision of parameter estimates for station RM, only limited interpretations were made concerning temporal changes at this location. The estimated abundance for RM-flood collections began to exceed RM-ebb in early March and continued throughout the season. MP-flood abundance was greater than MP-ebb starting on March 23. In contrast, BP-ebb exceeded BP-flood beginning on April 5. The shape of the abundance curves and density estimates were similar for MP-ebb, BP-flood, and NB-flood (Fig. B3-8).

The tidal circulation patterns and differences in larval abundance between ebb and flood tides at station MP and BP indicated that as the larval season progressed into April, large numbers of larvae entered Niantic Bay from LIS. Collections with the greatest larval abundance were MP-flood and BP-ebb. In both areas, the primary source of water entering the bay was from LIS. In contrast, the lowest larval densities occurred during MP-ebb and BP-flood collections. For these collections the water sampled had entered from LIS, but had flowed across the bay and most likely mixed with bay water, possibly diluting the greater densities of larvae entering from LIS. Abundances during

NB-flood collections were similar to those for BP-flood and MP-ebb collections (Fig. B3-8), suggesting a similar dilution of LIS water in the bay. In 1988, 24-hour tidal studies at station NB showed no tidally-related differences in larval winter flounder abundance (NUSCO 1989).

Developmental stage-specific abundances were compared at stations RM, MP, and BP, on the basis of cumulative weekly geometric means (Fig. B3-9), an approximation for the *A* parameter of the Gompertz function. Stage 1 larvae were most abundant at station RM, with the Niantic River the most probable source of the early developmental stage. Stage 2 larval abundance was more homogenous in the bay, except for RM-ebb collections. Nevertheless, it is likely that the primary source of this developmental stage was the Niantic River. Stage 3 abundance was much greater than that of Stage 2 and collection by tidal stage indicated that more of these larvae were entering the bay from LIS (MP-flood and BP-ebb) than were being flushed out of the bay to LIS (MP-ebb and BP-flood). A similar pattern at stations MP and BP was evident for Stage 4 larvae.

The abundances of winter flounder larvae by developmental stage that were collected during ebb and flood tidal stages in entrainment samples from 1983 through 1998 (combined) were examined to determine if this lengthy time-series agreed with the results from 1991 at station MP, located near the MNPS intakes. Data were restricted to collections when a developmental stage was present and were tested with the Wilcoxon two-sample test (Sokal and Rohlf 1969). No significant differences were found between ebb and flood tidal collections for Stage 1 larvae ($p = 0.775$; $n = 348$ samples). Stage 2 abundance was slightly ($p = 0.041$; $n = 883$) greater during flood tide, but Stages 3 and 4 larvae had highly significantly ($p < 0.001$; $n = 982$ and 432, respectively) greater abundances during a flood tide. Therefore, results from the 1991 tidal sampling were representative of data collected over a 16-year period in relation to larval winter flounder abundance and tidal stage, where entrainment densities were similar to station MP, which was close to the MNPS intakes.

The relative abundance of winter flounder larvae in LIS near Niantic Bay was compared to the numbers flushed from Niantic River into the bay. In 1988, 24-hour larval winter flounder sampling was conducted in Twotree Island Channel (Fig. B3-6: station TT) on April 25 and May 5 (NUSCO 1989), near the historical time period of peak abundance for larval winter flounder collected in entrainment samples. Stage 3 larvae were the dominant (94%) development stage collected. The geometric mean density of all winter flounder larvae collected in the 26 samples (dates combined) was 149·500 m^{-3} (95% CI of 117-191). Average tidal exchange though Twotree Island Channel was estimated to be 3,398 $m^3 \cdot sec^{-1}$ (NUSCO 1976), so based on the mean density and tidal exchange rate, an estimated 21.9 million winter flounder larvae passed through Twotree Island Channel during a flood tide (about 6 hours) towards Millstone Point. The number of winter flounder larvae flushed annually from the Niantic River was estimated based on the relationship of the estimated larval density in the lower Niantic River (Fig. B3-6: station C)

to the larval density at the mouth of the Niantic River during an ebb tide. An average tidal prism of 2.7 million m^3 was used to estimate the term *FromNR* for mass-balance calculations (NUSCO 2000; discussed in the following section). The estimated number of winter flounder larvae annually (February 15 - June 30; 136 days) flushed from the Niantic River into Niantic Bay during 1984-99 ranged from 84.8 to 728.0 million. For comparison to the results from 24-hour collections in Twotree Island Channel during 1988, the average number of winter flounder larvae entering Niantic Bay from the river during an ebb tide was approximately 0.5 million, for a 10-day period from April 25 through May 4, 1988 (NUSCO 1993: Appendix V) and 1.9 tidal cycles a day. For the same seasonal period, there were about 40 times more larvae passing through Twotree Island Channel towards Millstone Point during a flood tide than entering the bay from the Niantic River during an ebb tide. In summary, results of the special larval sampling studies summarized above indicated that many entrained winter flounder larvae of older stages likely entered Niantic Bay from LIS, particularly from areas to the east of Millstone Point.

B3.3 MASS-BALANCE MODEL

B3.3.1 Model Description

Mass-balance calculations have been used to investigate whether the number of winter flounder larvae entering Niantic Bay from the Niantic River could sustain the number of larvae observed in the bay during the larval winter flounder season each year since 1984. Three potential larval inputs to Niantic Bay include eggs hatching in the bay, larvae flushed from the Niantic River, and larvae entering the bay from LIS across the boundary between Millstone Point and Black Point (Fig. B3-6). The few yolk-sac larvae collected annually in Niantic Bay suggested that minimal spawning and subsequent hatching occurred in the bay, which was therefore considered to be a negligible source of larvae. Larvae were known to be flushed from the river into the bay and this input to the bay was estimated from available data. The number of larvae entering Niantic Bay from LIS was unknown. Four ways in which larvae may leave Niantic Bay include natural mortality, advection into the Niantic River during a flood tide, entrainment at MNPS, and flushing from the bay into LIS. Estimates could be made for the number of larvae lost through natural mortality, advected into the Niantic River, and entrained at MNPS, but little was known about the number of larvae flushed into LIS. The numbers of larvae flushed to and from LIS were combined as an unknown termed *Source or Sink* in the mass-balance calculations. Thus, the form of the mass-balance equation was:

$$NB_{t+5} = NB_t - NumEnt - Mort + FromNR - ToNR \pm (Source\ or\ Sink) \qquad (1)$$

where t = time in days

NB_{t+5} = number of larvae in Niantic Bay 5 days after day t (instantaneous daily estimate)

NB_t = initial number of larvae in Niantic Bay on day t (instantaneous daily estimate)

$NumEnt$ = number of larvae lost from Niantic Bay by entrainment in the condenser cooling-water system (over a 5-day period)

Mort = number of larvae lost from Niantic Bay due to natural mortality (over a 5-day period)

FromNR = number of larvae flushed from the Niantic River (over a 5-day period)

ToNR = number of larvae entering the Niantic River (over a 5-day period)

Source or Sink = unknown number of larvae in Niantic Bay that flush out to LIS or enter the bay from LIS (over a 5-day period).

Solving for the unknown *Source or Sink* term, the equation was rearranged as:

$$Source\ or\ Sink = NB_{t+5} - NB_t + NumEnt + Mort - FromNR + ToNR. \quad (2)$$

Because these mass-balance calculations were based on the change in the number of larvae in Niantic Bay over a 5-day period:

$$5\text{-}day\ change = NB_{t+5} - NB_t. \quad (3)$$

Thus:

$$Source\ or\ Sink = 5\text{-}day\ change + NumEnt + Mort - FromNR + ToNR. \quad (4)$$

Daily abundance estimates were derived from the Gompertz density equation (NUSCO 2000) and the daily densities for Niantic Bay at two points in time (NB_t and NB_{t+5}) for each 5-day period were calculated from data collected at stations NB and EN combined. These densities, adjusted for the volume of Niantic Bay, provided an estimate of the instantaneous daily standing stock. The difference between these two estimates (NB_t and NB_{t+5}) was the term *5-day change*. The selection of 5 days as the period of change was arbitrary, but a cursory examination of results based on 10-day periods showed that the same conclusions were reached with either 5- or 10-day periods.

Daily entrainment estimates were based on data collected at station EN and the actual daily volume of condenser cooling water used at MNPS. The daily entrainment estimates were summed over each 5-day period (*NumEnt*). Annual stage-specific mortality rates for 1984-89 were determined by Crecco and Howell (1990), for 1990 by V. Crecco (CT DEP, Old Lyme, CT, pers. comm.), and for 1991 and thereafter by Millstone Environmental Laboratory staff. Mortality was partitioned among developmental stages by comparing the rates of decline of predominant size-classes of each stage. Each developmental stage was assigned a portion of the total annual instantaneous larval mortality rate (Z) with similar mortality rates assumed for Stages 3 and 4. Although estimating stage-specific mortality in this manner was imprecise, a sensitivity analysis of the mass-balance calculations (NUSCO 1991; also discussed below) indicated that larval mortality was the least sensitive parameter in the final equation given above. These annual rates were modified to daily stage-specific mortality rates by assuming a duration of 10 days each for Stages 1, 3, and 4 larvae, and 20 days for Stage 2 larvae. The proportion of each stage collected at station EN during each 5-day period was applied to the daily standing stock in Niantic Bay (NB_t) to estimate the number of

larvae in each developmental stage for stage-specific mortality calculations. The daily loss due to natural mortality (*Mort*) was summed for each 5-day period.

The 5-day input of larvae to Niantic Bay from the river (*FromNR*) was based on daily density estimates for station C in the lower river after adjusting for the rate of flushing between that station and the river mouth. To determine the relationship between the estimated daily density at station C and the average density of larvae leaving the river on an ebb tide, the geometric mean density of samples collected during an ebb tide for ten import-export studies conducted at the mouth of the Niantic River during 1984, 1985, and 1988 (NUSCO 1985, 1986, 1989) was compared to the estimated daily densities at station C. The average density of larvae flushed from the Niantic River was estimated from the functional regression equation:

$$FromNR = 9.751 + 0.473 \cdot (\text{Daily density at station C}). \quad (5)$$

The 95% CI for the slope ($r = 0.969$; $p = 0.001$; $df = 8$) was 0.387 - 0.579. The estimated average density, the average tidal prism of 2.7×10^6 m^3 (Kollmeyer 1972), and about 1.9 tidal prisms per day were used to estimate the daily flushing of larvae from the river into Niantic Bay. This daily input to the bay was summed for each 5-day period to calculate the term *FromNR* in the mass-balance equation.

Stepwise oblique tows were collected during 1991 in the channel south of the Niantic River railroad bridge (station RM) during a flood tide to estimate an average density to compute *ToNR* (NUSCO 1992a). In 1992 and 1993, sampling was conducted again at RM during a flood tide, but the collections were made by mooring the research vessel to the railroad bridge and taking continuous oblique tows (NUSCO 1994). Comparison of densities from the paired stations of NB and RM showed a poor relationship. Therefore, daily densities at the two stations were estimated using the Gompertz density curve. For station RM in 1992, the equation could only be adequately fit by smoothing the data using a 3-week running average prior to calculating a weekly cumulative density. The Gompertz function could not be fit to data collected at station NB during 1993. Therefore, catches from stations NB and EN were combined to calculate the weekly geometric means prior to fitting the Gompertz function and estimating daily densities for Niantic Bay. Daily density estimates for 1991-93 were combined and functional regression was used to determine the relationship between abundance at stations NB and RM. The average density of larvae flushed from Niantic Bay into the river was estimated by the functional regression equation:

$$ToNR = 128.149 + 2.073 \cdot NB_t. \quad (6)$$

The 95% CI for the slope ($r = 0.705$; $p = 0.001$; $df = 406$) was 1.827 - 2.351. After being adjusted for the average tidal prism and the number of tidal prisms per day, these daily estimates of the number of larvae entering the river during a flood tide were summed over each 5-day period to calculate the term *ToNR* in the mass-balance equation.

Because of the large intercept in the above regression line when no larvae were present in Niantic Bay ($NB_t = 0$), the term *ToNR* was conservatively set to zero. The term *Source or Sink* represents the 5-day net loss or gain of larvae to Niantic Bay from LIS required to balance the calculation. For a net loss of larvae (flushed to LIS), the *Source or Sink* term would be negative and for a net gain of larvae (imported from LIS), the *Source or Sink* term would be positive. Results from mass-balance calculations by developmental stage were used to estimate the number of larvae entrained at MNPS each year from the Niantic River. If *FromNR* can support the number of larvae entrained by MNPS, then the *Source or Sink* term is negative (i.e., no import) to balance the equation. These larval losses were then used to calculate conditional mortality rates for Niantic River larvae for under both actual operating conditions and projected full MNPS three-unit operation. Their derivation is provided in greater detail in Chapter 4.

B3.3.2 Mass-Balance Model Sensitivity Analysis

Three potential larval inputs to Niantic Bay include eggs hatching in the bay, larvae flushed from the Niantic River, and larvae entering the bay from LIS across the boundary between Millstone Point and Black Point. Losses from the Bay could occur through natural mortality, return to the River via tidal exchange, entrainment through MNPS, or export across the boundary into LIS. Estimates could be made for the number of larvae lost through natural mortality, advected into the Niantic River, and entrained at MNPS, but little was known about the number of larvae flushed into or out of LIS. The numbers of larvae flushed to and from LIS were combined as an unknown termed *Source or Sink* in the mass-balance calculations as given in Equation 1 of Section B3.3.1.

Using information available from 1984 through 1990, a sensitivity analysis of the mass-balance model was presented in NUSCO (1991) to determine the relative importance of the accuracy of four input parameters, including the larval mortality rate (*Mort*), the number of larvae entering Niantic Bay from Niantic River (*FromNR*), the number of larvae entering the river from the bay (*ToNR*), and the number of larvae entrained at MNPS (*NumEnt*). The estimated number of winter flounder larvae entrained from the Niantic River was re-computed, as one of the parameter estimates was doubled (X 2) or halved (X 0.5), while the remaining three values were left unchanged. This was done in sequence for all four of the parameters examined. Based on the percent change in entrainment from the initial estimates, *Mort* and *ToNR* were the least sensitive to change (Table B3-2). However, the most sensitive parameters, *FromNR* and *NumEnt*, were also the ones most precisely estimated, a conclusion based on the special sampling conducted at the mouth of the Niantic River (described above) and the relatively high weekly frequency of entrainment sampling. Although parameter estimates of *Mort* and *ToNR* had the least precision, results of the sensitivity analysis indicated that even relatively large errors in their estimates would not have appreciably changed the estimates of larvae entrained specifically from the Niantic River stock.

A more comprehensive sensitivity analysis was completed for this report as requested by the DEP (DEP 2000b). In this new analysis, all 16 years (1984-99) of available data from larval winter flounder studies were used to estimate the sensitivity of the mass-balance model to errors in both larval density estimates and mortality estimates. The larval densities estimated each year as input to the mass balance model are: 1) the number of larvae entering Niantic Bay from Niantic River (*FromNR* in Eq. 1), referred to in this analysis as Station C densities; 2) the number of larvae entering the river from the bay (*ToNR* in Eq. 1), referred to here as derived from Niantic Bay densities; and 3) the number of larvae entrained at MNPS (*NumEnt* in Eq. 1). The mortality estimates (*Mort* in Eq. 1) are the annual estimates of total mortality through the four larval stages of winter flounder. The strategy for the sensitivity analyses carried out specifically for this study was to generate annual estimates of the fraction of larvae entrained that originated in the Niantic River, simulating errors in the larval density estimates and mortality estimates in two separate and independent sets of simulations. The intent in the case of the larval densities was to simulate errors according to a fully factorial design involving all the possible combinations of error levels and locations where the densities were estimated. The three types of error considered were: underestimation by a factor of 1.5, no error (i.e., the actual field estimate was used), and an overestimation by a factor of 1.5. Since there were three different locations at which the densities were estimated, the total number of possible combinations was 27. Therefore, when these combinations of errors and locations were applied to the larval densities estimated in each of the 16 years of available data, the total number of possible simulation outcomes was 432. Thus, the mass-balance model was used to estimate the percentage of larvae entrained attributed to the Niantic River in each of the 16 years with 27 combinations of error types and locations simulated.

The resulting 432 outcomes are listed in Table B3-3 and include a set of 16 outcomes in the first column labeled (0/0/0) that were the actual annual estimates of percent larvae entrained originating in the Niantic River and assuming no errors. These 16 outcomes were the baseline used in the next step to calculate the estimation biases present in the remaining 416 simulation outcomes. Each bias was calculated as the ratio of the outcome containing errors to the corresponding baseline, so that a bias larger than one represented an overestimate of the percentage of larvae entrained attributed to the Niantic River. Conversely, a bias less than one represented an underestimate. For example, the bias associated with the 1984 estimate when an error of +50% is simulated in the entrainment numbers for that year (the 36% under the label 0/0/P in the top row of Table B3-3) was calculated as the ratio of 36 to the baseline value of 38.75, resulting in a bias equal to 0.929 or an underestimate of about 7%. The set of 416 biases was then randomly replicated (using random uniform integers and sampling with replacement) in order to generate 5,000 bootstrap samples to describe and quantify the mass-balance model sensitivity to errors in the three types of larval density that are input to the model.

The second set of simulations carried out consisted of a total of 32 outcomes of the percentages of entrained larvae attributed to the Niantic River when the annual estimates of larval mortality were either over- or underestimated by a factor of 2 (Table B3-4). As before, the resulting biases were calculated as the ratio of outcomes with errors to the corresponding actual annual estimate, which was assumed to be correct. Also as before, the 32 biases were randomly replicated to generate 5,000 bootstrap samples to describe the mass-balance model sensitivity to errors in estimated larval mortality rate that is input to the model. The two independent sensitivity analyses are summarized by the empirical frequency distributions of the bootstrapped samples in Figure B3-10, which shows a much wider range of biases, or greater sensitivity, for errors in the larval density estimates than for errors in the larval mortality estimates. This result is in agreement with the more limited findings of the sensitivity analysis conducted in 1991. In the present study, the frequency distribution of the bootstrapped samples permitted a computation of the quantiles associated with empirical probability confidence intervals that were useful to more realistically evaluate sensitivity of the mass-balance model. These quantiles show that there is an approximate 90% probability that the biases resulting from the simulated errors in the larval density estimates range between overestimates of 69% and underestimates of 46% (Table B3-5). Similarly, approximate confidence interval for biases resulting from errors in mortality rate estimates would range between overestimates of 6% and underestimates of 9%.

B3.4 CONCLUSIONS

Niantic Bay, the source of condenser cooling-water for MNPS, is well-mixed with strong tidal currents, causing a relatively short retention time for winter flounder larvae flushed from the Niantic River to the bay. Based on tidal circulation patterns, most of the seawater drawn through the intakes is from LIS, particularly during a flood tide. The results of winter flounder larval distribution studies and Niantic Bay tidal circulation patterns provided some insight into the sources of winter flounder larvae in Niantic Bay and entrained by MNPS. Early in the larval season the primary source appeared to be the Niantic River, but as the season progressed the major source was LIS. Because a majority of entrained winter flounder larvae are in a later developmental stage, many of these larvae probably originated from spawning stocks both east and west of the Niantic Bay and were transported by tidal currents into the area of Millstone Point. This information was used in the quantitative assessment of the effects of MNPS on Niantic River winter flounder, which is presented in Chapter 4 of Part II. Results of two new sensitivity analyses conducted for this report suggested that the worst biases expected from substantial errors in input parameters (larval densities and mortality rate estimates) of the mass-balance model should be much less than 100% (i.e., twice or half). Further, when using the 10% to 90% quantiles shown in Table B3-5, the biases should be well within ±50%. These two analyses also indicate that the mass-balance model output is far more sensitive to errors in larval density estimates than to errors in larval mortality rates. This was also the finding of the previous sensitivity analysis conducted by NUSCO in 1991 and of the independent analysis conducted for this study by Dr. Eric Adams of The Massachusetts Institute of Technology (see Appendix C to Chapter 3).

B3.5 REFERENCES

Crecco, V.A., and P. Howell. 1990. Potential effects of current larval entrainment mortality from the Millstone Nuclear Power Station on the winter flounder, *Pseudopleuronectes americanus*, spawning population in the Niantic River. CT Dept. Envir. Prot., Bur. Fish., Spec. Pub. 37 pp.

DEP (Connecticut Department of Environmental Protection). 2000. Letter C09872 dated February 16, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Comments on proposed cooling water alternatives scope of study.

Dimou, N.K., and E.E. Adams. 1989. Application of a 2-D particle tracking model to simulate entrainment of winter flounder larvae at the Millstone Nuclear Power Station. Energy Laboratory Rep. No. MIT-EL 89-002. Massachusetts Institute of Technology, Cambridge, MA. 73 pp.

Dimou, N.K., A.T. Obst, J. Moeller, and E.E. Adams. 1990. Numerical simulation of fish larvae entrainment at the Millstone Nuclear Power Station. Summary report covering period December 1989 - August 1990. Energy Laboratory Rep. No. MIT-EL 90-003. Massachusetts Institute of Technology, Cambridge, MA. 11 pp. + app.

Kollmeyer, R.C. 1972. A study of the Niantic River estuary, Niantic, Connecticut. Final report phases I and II, physical aspects of the Niantic River estuary. Rep. No. RDCGA 18. U.S. Coast Guard Academy, New London, CT. 78 pp.

NUSCO (Northeast Utilities Service Company). 1976. Environmental assessment of the condenser cooling water intake structures (316b demonstration). Vol. 1 and 2.

NUSCO. 1985. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1984. 74 pp.

NUSCO. 1986. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1985. 69 pp.

NUSCO. 1989. Winter flounder studies. Pages 239-316 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1988.

NUSCO. 1991. Winter flounder studies. Pages 9-86 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1990.

NUSCO. 1992a. Winter flounder studies. Pages 7-109 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1991.

NUSCO. 1992b. Niantic Bay current studies. Pages 317-331 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1991.

NUSCO. 1993. Winter flounder studies. Pages 191-269 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1992.

NUSCO. 1994. Winter flounder studies. Pages 141-228 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1993.

NUSCO. 2000. Winter flounder studies. Pages 9-112 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1999.

Saila, S.B. 1976. Effects of power plant entrainment on winter flounder population near Millstone Point. Graduate School of Oceanography, Narragansett Marine Laboratory, University of Rhode Island. 133 pp.

TABLE B3-1. Larval winter flounder abundances and 95% confidence interval for ebb and flood tide collections at stations NB, RM, MP, and BP during 1991. Abundance index is the *A* parameter from the Gompertz function. See Figure B3-6 for station locations.

Station	Ebb	Flood
NB	-[a]	2,026 (1,791 - 2,261)
RM	2,124 (948 - 3,299)	5,141 (2,374 - 7,908)
MP	1,865 (1,688 - 2,044)	4,225 (3,464 - 4,986)
BP	5,322 (4,719 - 5,924)	1,962 (1,688 - 2,236)

[a] Ebb tide was not sampled.

TABLE B3-2. As originally reported in NUSCO (1991), the estimated number of larvae (in millions) entrained at MNPS from the Niantic River during 1984-90 based on mass-balance calculations with a comparison to estimates resulting from sensitivity analyses, which were performed by doubling (X 2) or halving (X 0.5) four of the model parameter estimates. The percent increase (+) or decrease (-) from the original mass-balance estimate as a result of the indicated change is given.

Year	1984 (X 10^6)	1985 (X 10^6)	1986 (X 10^6)	1987 (X 10^6)	1988 (X 10^6)	1989 (X 10^6)	1990 (X 10^6)
Estimated number of winter flounder larvae entrained from the Niantic River	59.8	44.7	53.7	70.7	63.6	51.2	72.5
Mort X 0.5	64.2	47.7	56.2	73.9	66.4	54.2	74.7
% change	+7.4	+6.7	+4.7	+4.5	+4.4	+5.9	+3.0
Mort X 2	52.4	40.4	49.3	64.8	58.0	46.6	67.9
% change	-12.4	-9.6	-8.2	-8.3	-8.8	-9.0	-6.3
FromNR X 0.5	32.7	29.3	30.7	37.3	36.4	28.0	39.5
% change	-45.3	-34.5	-42.8	-47.2	-42.8	-45.3	-45.5
FromNR X 2	88.1	63.7	88.6	125.6	104.3	86.9	119.7
% change	+47.3	+42.5	+65.0	+77.7	+64.0	+69.7	+65.1
ToNR X 0.5	73.6	53.5	61.8	82.5	73.1	58.8	86.2
% change	+23.1	+19.7	+15.1	+16.7	+14.9	+10.3	+18.9
ToNR X 2	41.5	35.1	42.4	55.3	50.1	41.7	53.9
% change	-30.6	-21.5	-21.0	-21.8	-21.2	-18.6	-25.7
NumEnt X 0.5	34.2	25.2	34.6	48.9	39.9	31.7	46.9
% change	-42.8	-43.6	-35.6	-30.8	-37.3	-38.1	-35.3
NumEnt X 2	95.1	75.3	74.4	93.8	90.6	74.0	101.0
% change	+59.0	+68.5	+38.5	+32.7	+42.5	+44.5	+39.3

TABLE B3-3. Mass-balance sensitivity analysis data output using data from 1984 through 1999 and showing the calculated percentage of entrained larvae attributed to the Niantic River. The column headers refer to changes made to three variables (Station C numbers / Niantic Bay numbers / Entrainment numbers, respectively) as follows: 0 = no change, P = increase (+) by a factor of 1.5, M (-) = decrease by a factor of 1/1.5.

Year	0/0/0	0/0/P	0/0/M	0/P/0	0/M/0	0/P/P	0/P/M	0/M/P	0/M/M
1984	38.75	36.00	40.86	29.17	49.42	27.60	30.33	44.97	52.95
1985	34.73	33.18	35.92	29.13	40.22	27.99	29.96	38.14	41.68
1986	21.00	18.40	23.23	17.33	24.55	15.56	18.78	21.01	27.75
1987	25.16	21.49	28.51	20.56	29.67	18.06	22.72	24.68	34.34
1988	21.81	19.53	23.77	18.07	25.72	16.60	19.25	22.40	28.72
1989	20.51	17.97	22.70	16.44	24.54	14.84	17.76	21.06	27.11
1990	28.75	25.28	31.75	23.07	34.49	20.78	24.94	29.60	38.91
1991	30.36	26.94	33.25	24.33	36.50	22.11	26.11	31.61	40.84
1992	16.24	13.82	18.45	13.26	19.30	11.60	14.67	15.94	22.56
1993	13.37	12.31	14.19	11.63	14.85	10.83	12.25	13.55	15.90
1994	28.87	25.57	31.65	22.48	35.86	20.43	24.11	30.89	40.26
1995	36.44	32.82	39.39	28.30	44.88	26.06	30.01	39.48	49.55
1996	60.26	59.23	60.82	54.37	65.51	53.67	54.87	64.23	66.46
1997	45.48	43.59	46.60	32.94	58.42	31.98	33.62	55.80	60.35
1998	32.59	30.45	34.22	25.08	40.32	23.85	25.98	37.15	42.83
1999	22.53	20.48	24.18	17.49	28.08	16.26	18.43	24.90	30.74

Year	P/0/0	P/0/P	P/0/M	P/P/0	P/M/0	P/P/P	P/P/M	P/M/P	P/M/M
1984	56.82	52.78	59.91	43.08	71.73	40.77	44.78	65.55	76.66
1985	42.84	41.17	44.13	36.81	48.84	35.50	37.78	46.17	50.36
1986	30.51	26.76	33.75	25.25	35.62	22.66	27.35	30.50	40.26
1987	36.31	31.10	41.08	29.95	42.23	26.26	33.12	35.19	49.05
1988	29.56	26.53	31.85	24.38	33.83	22.26	26.10	30.00	37.32
1989	27.75	24.96	30.19	23.38	32.18	21.01	24.96	28.12	35.95
1990	42.07	37.03	46.42	33.85	50.07	30.48	36.61	42.99	56.50
1991	44.38	39.45	48.49	35.76	53.00	32.51	38.35	46.09	58.97
1992	23.68	20.13	26.85	19.30	28.16	16.89	21.35	23.27	32.80
1993	17.97	16.56	19.09	15.66	19.97	14.59	16.48	18.21	21.37
1994	42.34	37.59	46.34	33.03	51.76	29.99	35.44	44.64	58.09
1995	50.94	46.12	54.89	40.43	62.08	37.39	42.77	54.94	68.22
1996	67.57	66.82	68.11	62.00	72.81	61.35	62.46	71.58	73.42
1997	62.28	60.24	63.51	47.58	77.06	46.52	48.33	74.44	79.01
1998	45.36	42.47	47.56	35.58	55.03	33.93	36.80	51.29	57.98
1999	32.36	29.48	34.67	25.23	39.98	23.43	26.62	35.51	43.76

TABLE B3-3 (continued).

Year	M/0/0	M/0/P	M/0/M	M/P/0	M/M/0	M/P/P	M/P/M	M/M/P	M/M/M
1984	26.32	24.45	27.74	19.81	33.76	18.75	20.60	30.71	36.17
1985	27.33	25.97	28.36	22.47	32.34	21.54	23.09	30.61	33.70
1986	14.56	12.76	16.11	12.02	17.02	10.80	13.03	14.57	19.23
1987	17.45	14.92	19.74	14.17	20.53	12.45	15.65	17.12	23.80
1988	16.21	14.41	17.74	13.03	19.12	11.89	13.95	16.83	21.19
1989	14.60	12.87	16.10	11.82	17.51	10.72	12.72	14.98	19.83
1990	19.72	17.34	21.77	15.80	23.69	14.23	17.08	20.35	26.72
1991	20.72	18.38	22.68	16.60	24.92	15.08	17.81	21.59	27.88
1992	11.14	9.45	12.68	9.03	13.31	7.89	10.01	10.97	15.54
1993	10.20	9.39	10.84	8.88	11.33	8.27	9.36	10.33	12.14
1994	19.78	17.53	21.66	15.35	24.51	13.95	16.46	21.14	27.50
1995	24.89	22.31	26.99	19.19	31.23	17.65	20.39	27.22	34.70
1996	51.84	50.04	53.22	45.41	57.84	43.89	46.21	56.49	58.86
1997	31.23	29.97	32.15	22.72	42.09	22.07	23.19	39.74	43.83
1998	23.01	21.52	24.12	17.57	28.86	16.71	18.21	26.49	30.72
1999	15.68	14.25	16.83	12.11	19.58	11.25	12.76	17.39	21.41

TABLE B3-4. Mass-balance sensitivity analysis data output using data from 1984 through 1999 and showing the calculated percentage of entrained Niantic River larvae when larval mortality rate as used in the model is decreased or increased by 50% of the base value.

Year	-50%	Base (no change)	+50%
1984	40.61	38.75	35.60
1985	35.85	34.73	32.87
1986	21.66	21.00	19.83
1987	25.96	25.16	23.76
1988	22.51	21.81	20.61
1989	21.41	20.51	19.02
1990	29.46	28.75	27.50
1991	31.20	30.36	28.86
1992	16.73	16.24	15.37
1993	13.70	13.37	12.77
1994	29.84	28.87	27.20
1995	38.19	36.44	33.49
1996	61.50	60.26	57.59
1997	48.40	45.48	40.39
1998	34.49	32.59	29.52
1999	23.16	22.53	21.41

TABLE B3-5. Quantiles estimated from the empirical distribution of 5,000 bootstrapped biases resulting from simulating errors in larval winter flounder density estimates and mortality rates.

Simulation of errors[a] in larval density estimates: Quantile	Bias estimate[c]	Simulation of errors[b] in mortality rates: Quantile	Bias estimate[c]
95%	1.69	95%	1.06
90%	1.47	90%	1.05
75% (Q3)	1.23	75% (Q3)	1.03
50% (median)	0.97	50% (median)	1.02
25% (Q1)	0.75	25% (Q1)	0.95
10%	0.61	10%	0.92
5%	0.54	5%	0.91

[a] Errors simulated for larval densities were actual annual estimates multiplied by 1.5 and actual annual estimates divided by 1.5, applied to all possible combinations involving density estimates at three different stations.

[b] Errors simulated for larval mortality rates were actual annual estimates multiplied by 2 and actual annual estimates divided by 2.

[c] Biases are the ratios of the mass-balance model outcome with simulated input errors to the outcome without input errors. Thus a bias greater than unity indicates overestimation and a bias less than unity implies underestimation. In both cases the approximated % error rate is simply calculated as 100 x (Bias - 1.00).

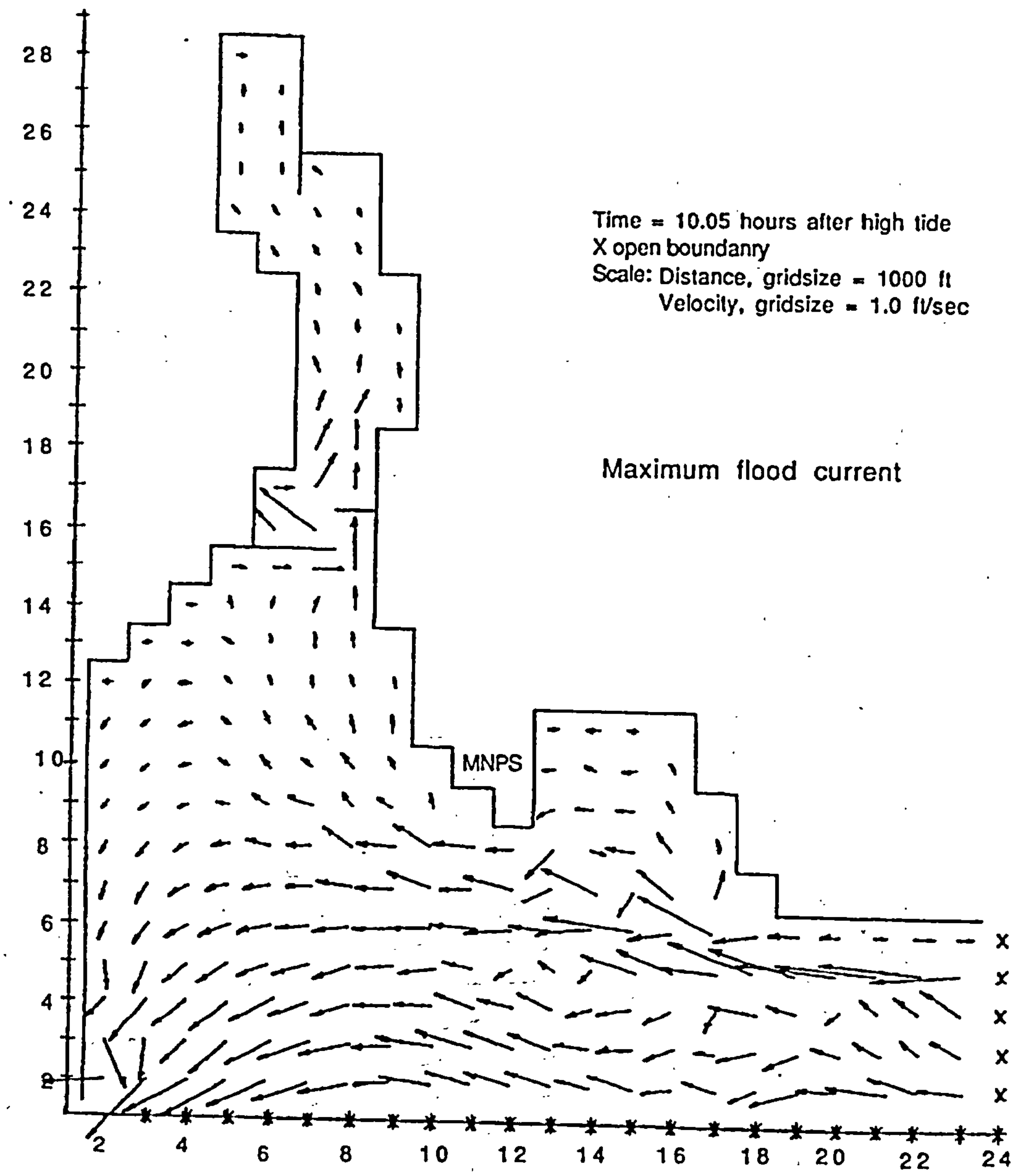

Fig. B3-1. Predicted tidal current direction and velocity in the Niantic Bay at the time of maximum flood current. Adapted from the University of Rhode Island hydrodynamics model (NUSCO 1976; Saila 1976). Numbers on the vertical and horizontal axes only represent grid numbers of the model.

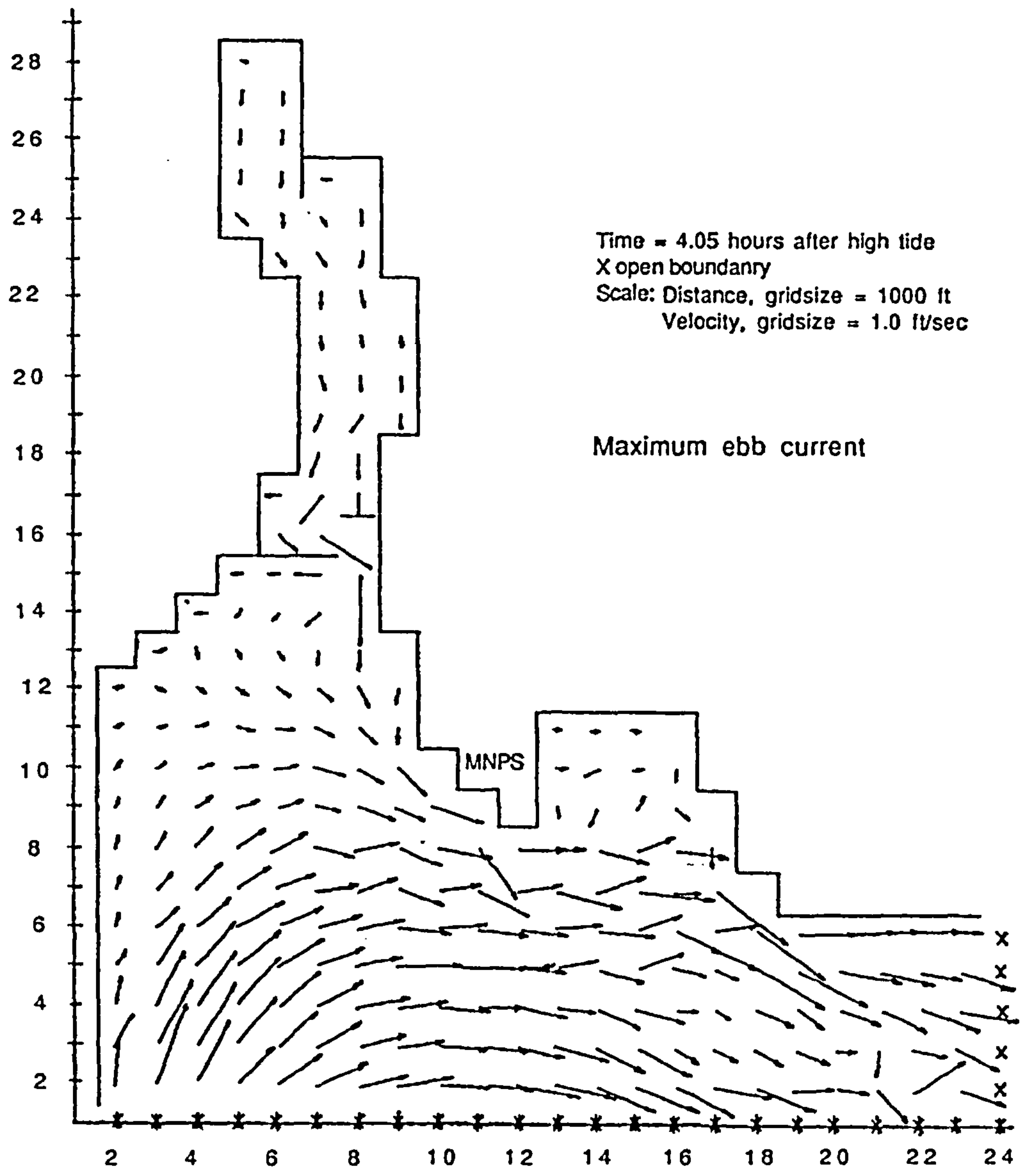

Fig. B3-2. Predicted tidal current direction and velocity in the Niantic Bay at the time of maximum ebb current. Adapted from the University of Rhode Island hydrodynamics model (NUSCO 1976; Saila 1976). Numbers on the vertical and horizontal axes only represent grid numbers of the model.

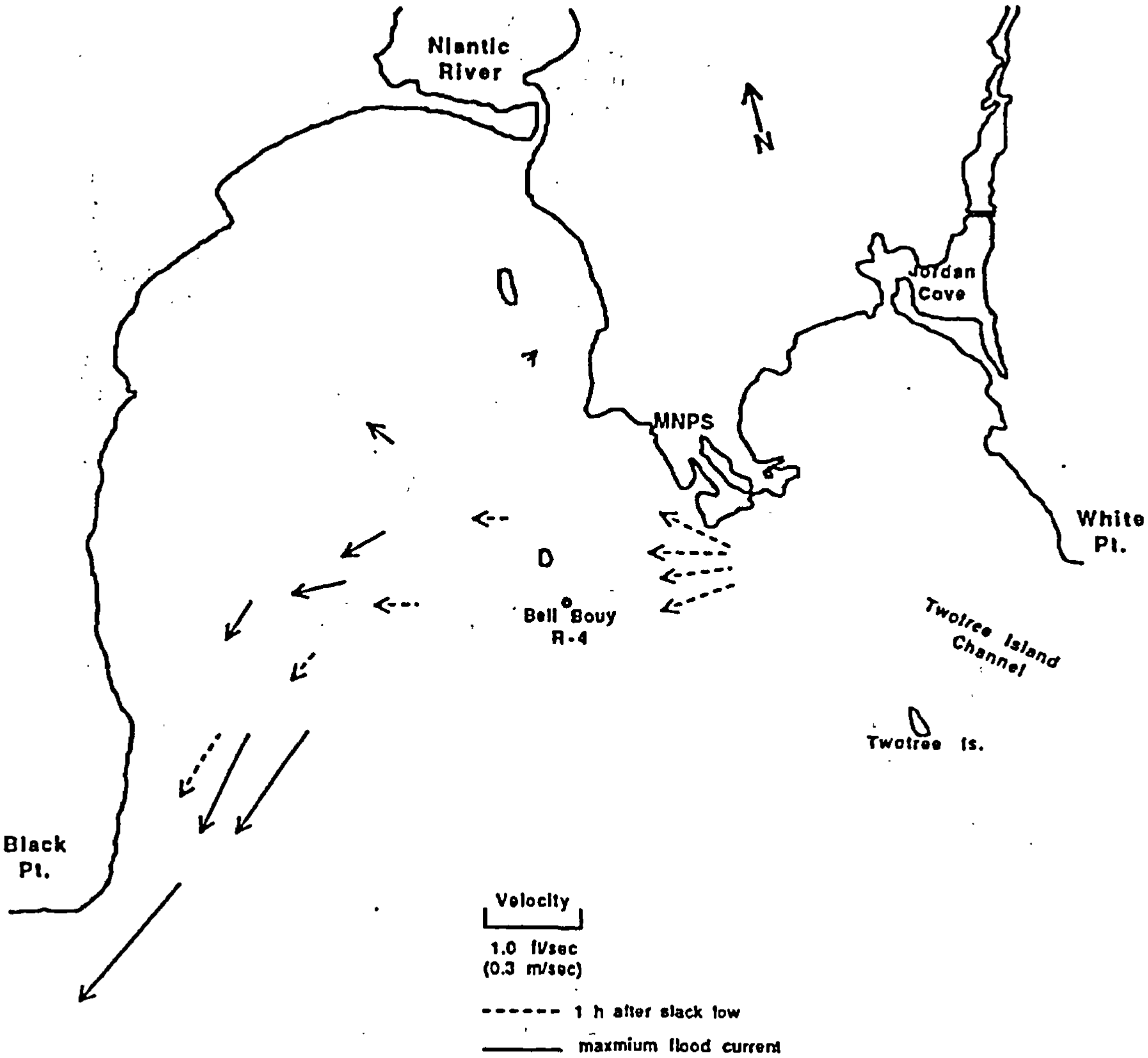

Fig. B3-3. Estimated tidal current direction and velocity in Niantic Bay for a flooding tide during first hour after low slack and at the time of maximum flood current, based on the results of drogue studies conducted in 1991 (NUSCO 1992b). Note that the length of the arrows corresponds to estimated average current velocities.

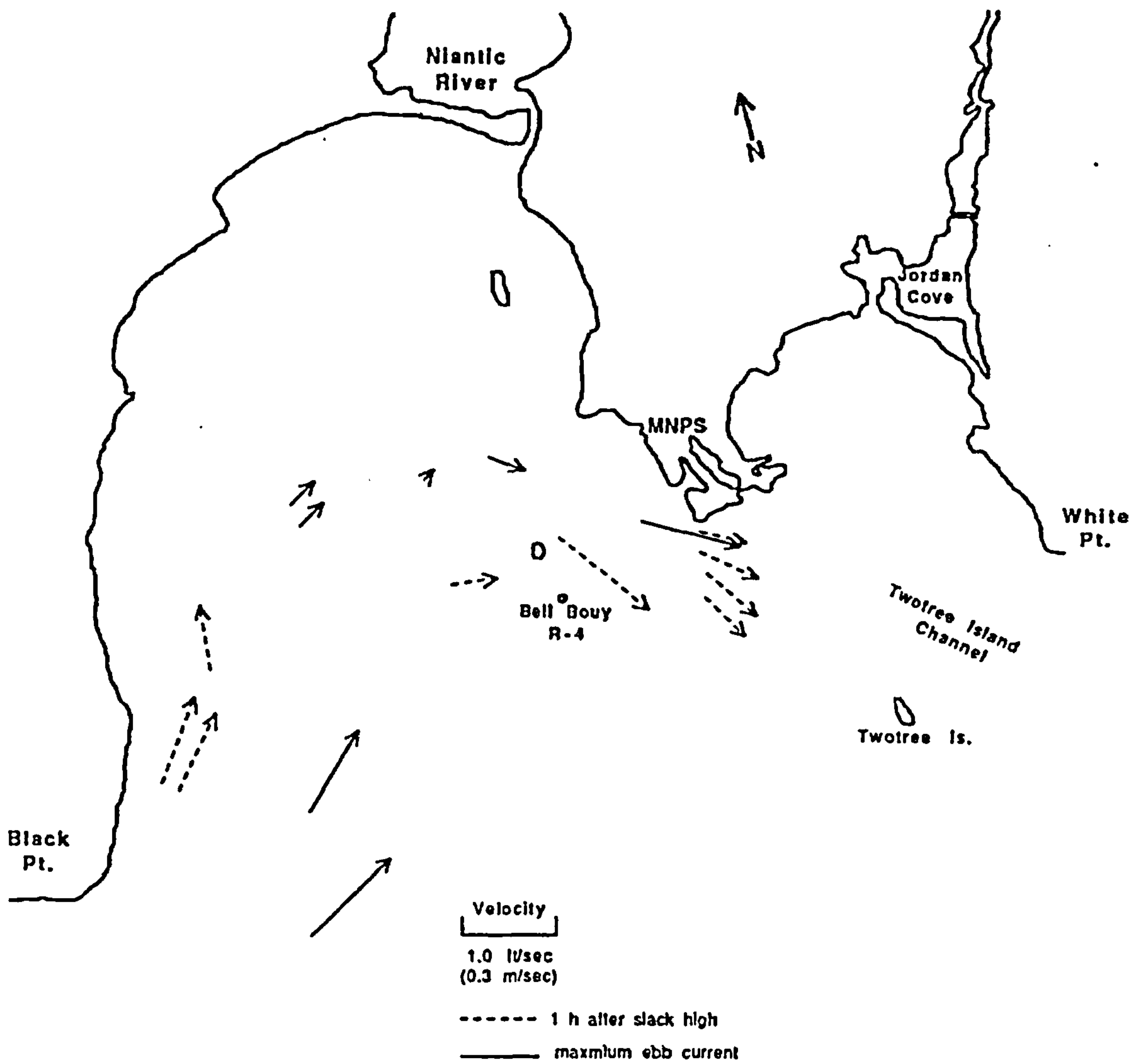

Fig. B3-4. Estimated tidal current direction and velocity in Niantic Bay for an ebbing tide during first hour after high slack and at the time of maximum ebb current, based on the results of drogue studies conducted in 1991 (NUSCO 1992b). Note that the length of the arrows corresponds to estimated average current velocities.

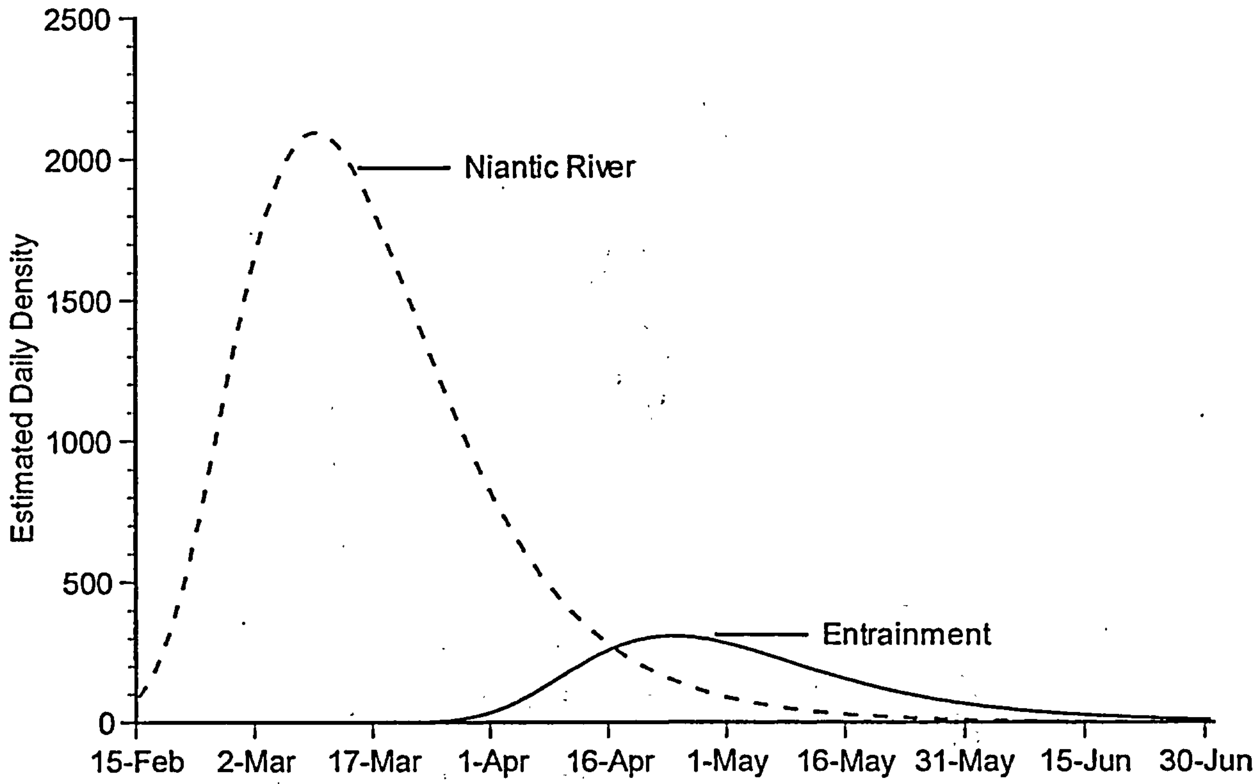

Fig. B3-5. Average annual abundance curves (density per 500 m^3) of winter flounder larvae collected in MNPS entrainment samples at station EN (1976-98) and in the Niantic River (1984-98; stations A, B, and C combined). Daily densities were estimated from the Gompertz density function. See Figure B3-6 for station locations.

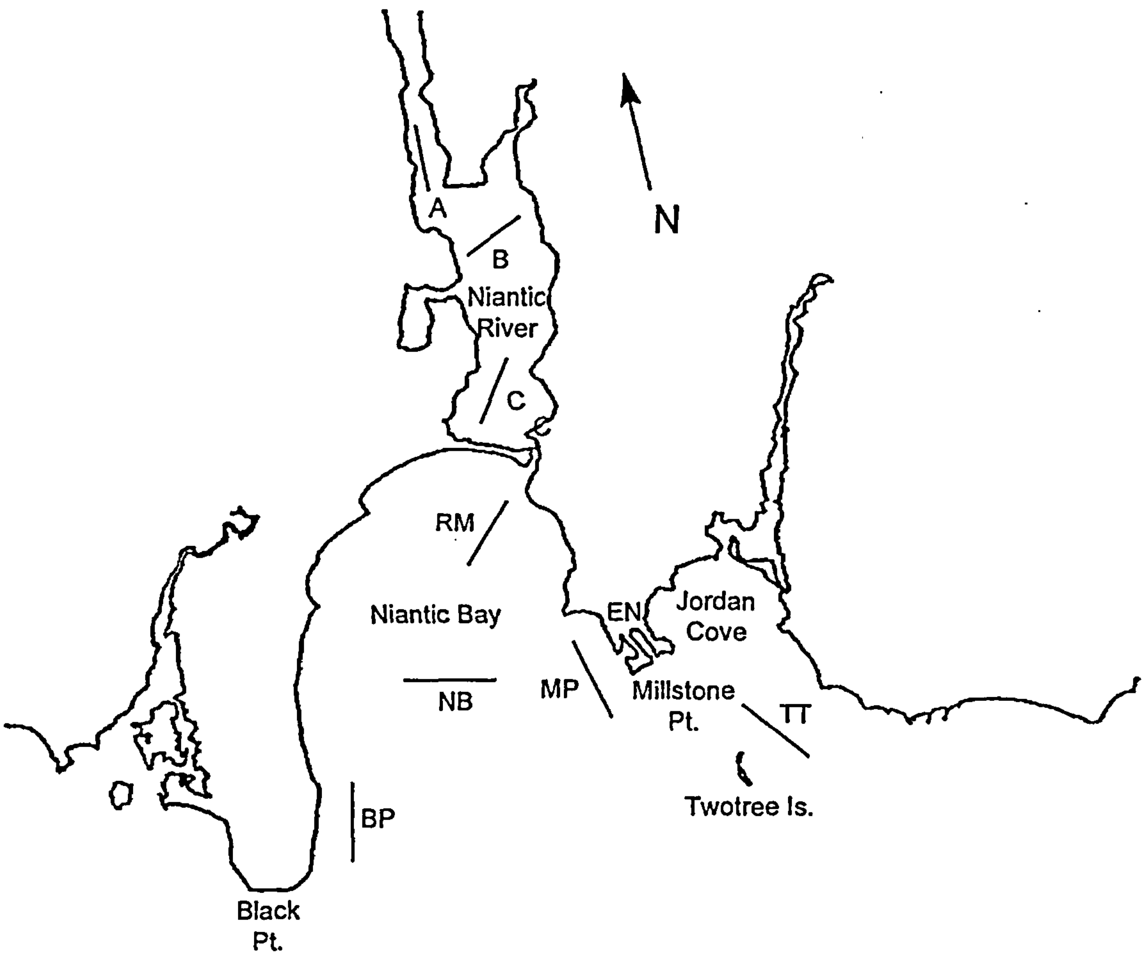

Fig. B3-6. Location of ichthyoplankton stations (A, B, C in the Niantic River; EN at the MNPS discharges; BP, MP, NB, RM, and TT in Niantic Bay or LIS) sampled for winter flounder larvae in the vicinity of MNPS.

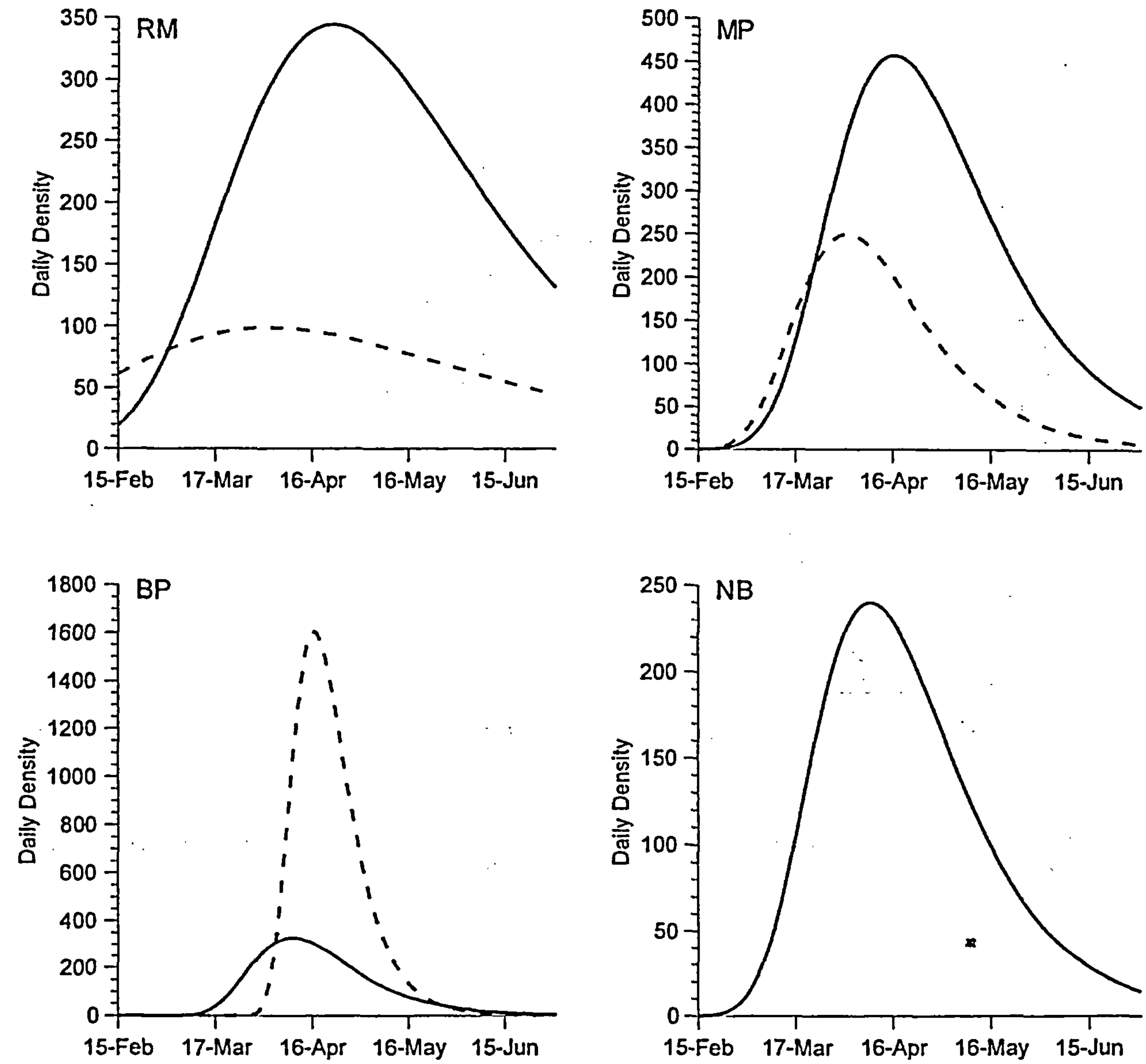

Fig. B3-7. Abundance curves (density per 500 m^3) estimated from the Gompertz density function of larval winter flounder during ebb (dashed lines) and flood (solid lines) tidal stages at stations RM, MP, BP, and NB (flood only) in 1991. Note that the vertical scales differ among the graphs. *See Figure B3-6 for station locations.*

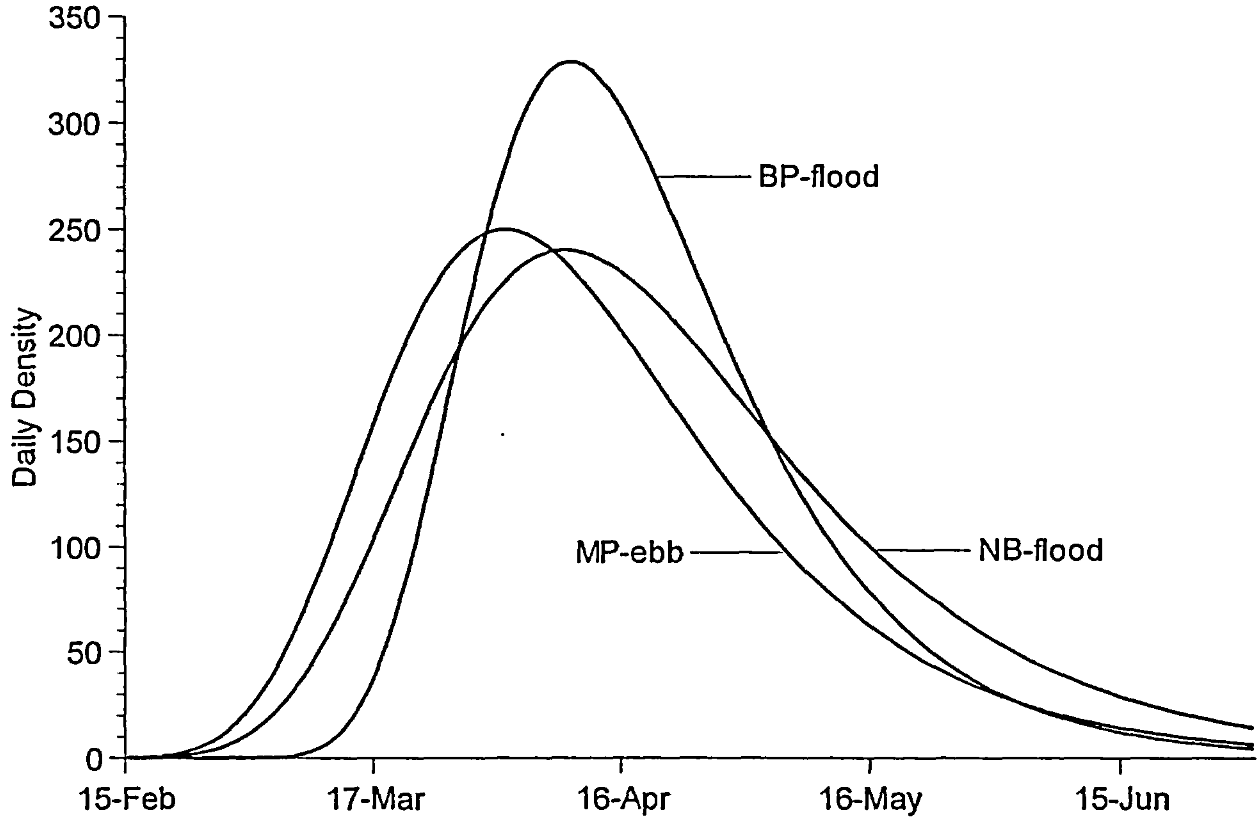

Fig. B3-8. Comparison of abundance curves (density per 500 m^3) estimated from the Gompertz density function of larval winter flounder during selected tidal stages at stations MP, BP, and NB. See Figure B3-6 for station locations.

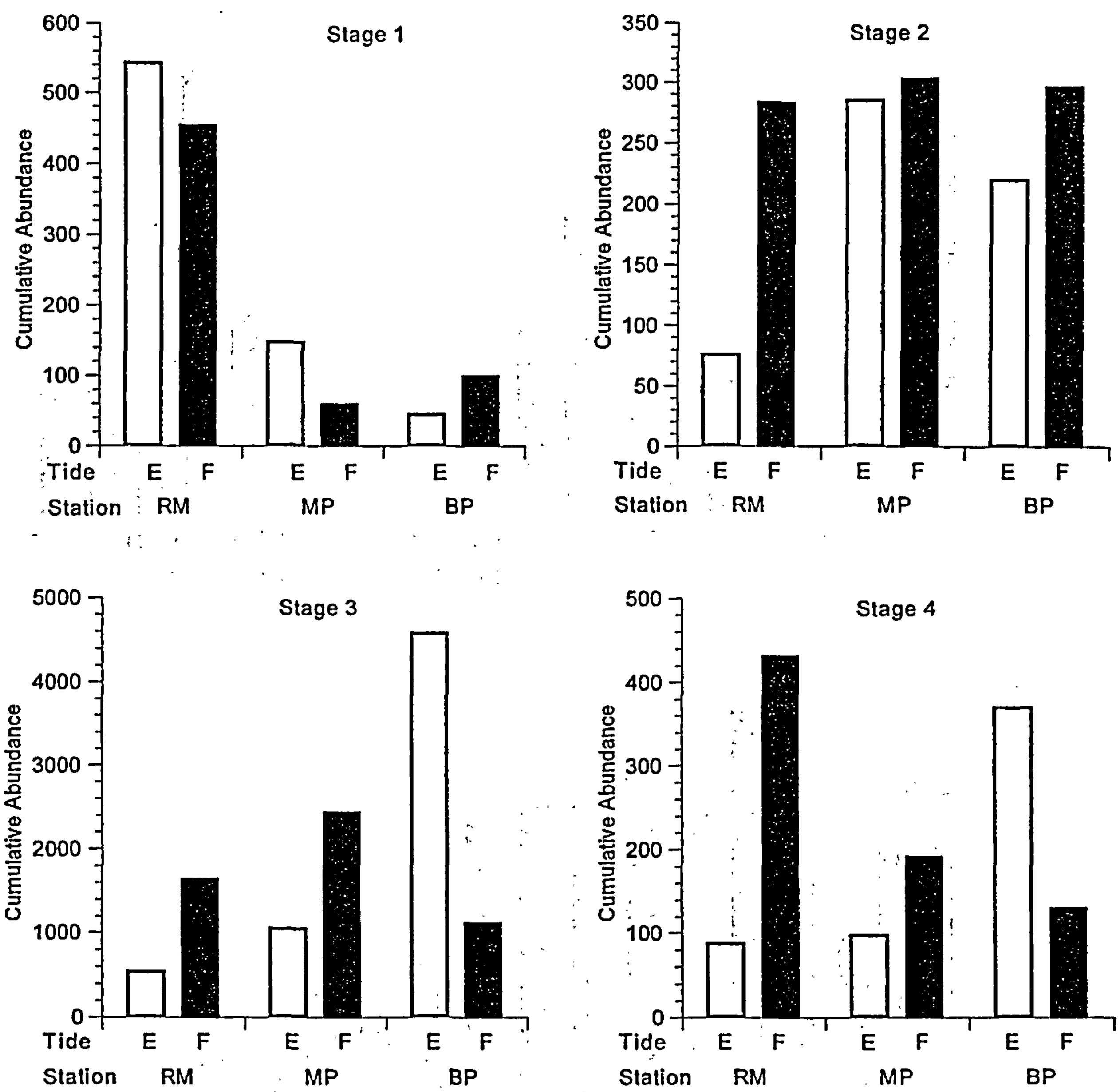

Fig. B3-9. Cumulative density by developmental stage of larval winter flounder collected during ebb (E) and flood (F) tidal stages at stations RM, MP, and BP in 1991. Note that the vertical scales differ among graphs. See Figure B3-6 for station locations.

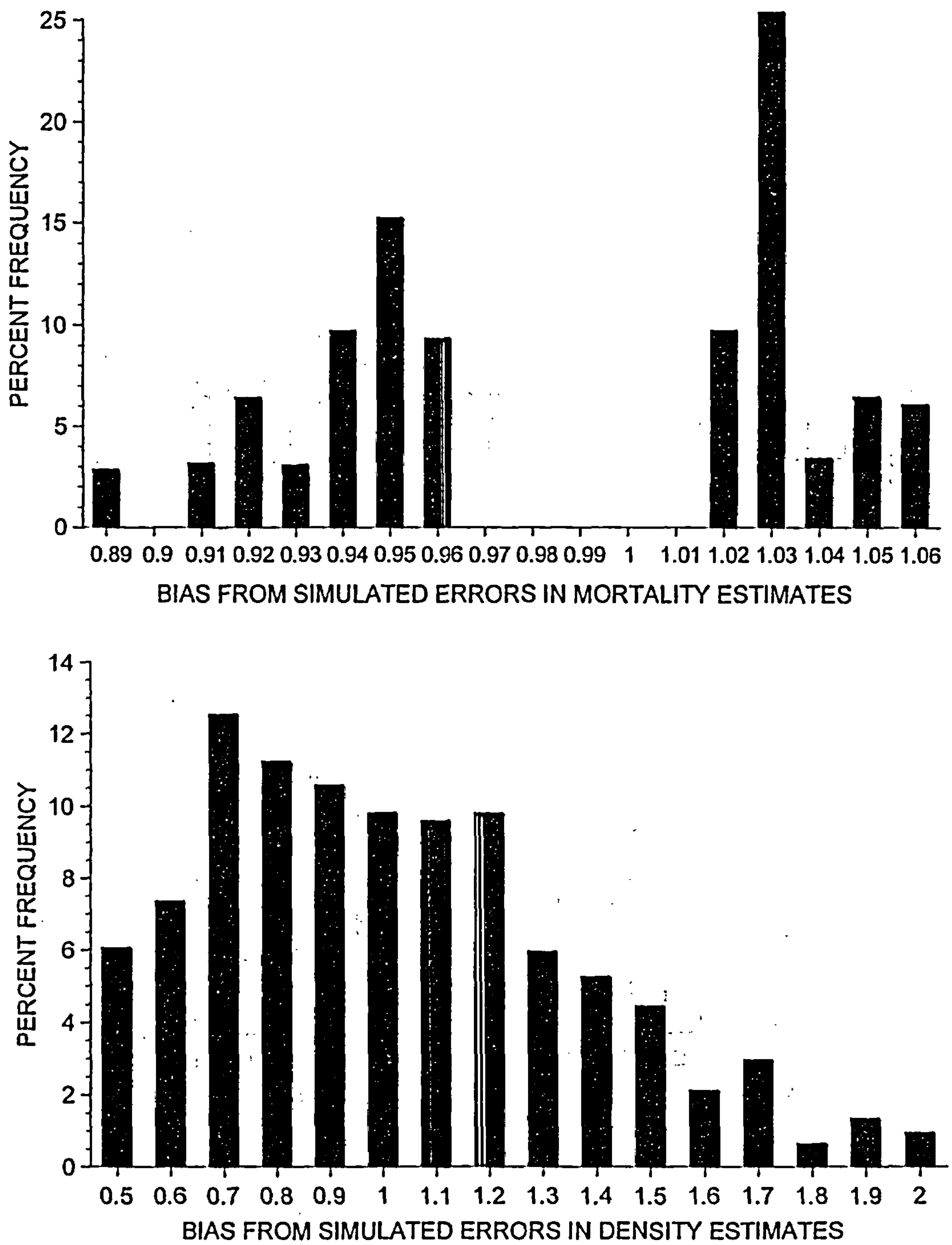

Fig. B3-10. Frequency distributions of 5,000 bootstrapped biases resulting from simulating errors in the annual larval density estimates at three locations and annual mortality rate estimates that are input to the mass-balance model (Eq. 1 of this appendix).

APPENDIX C TO CHAPTER 3 OF PART II

LARVAL MASS BALANCE STUDIES AT MILLSTONE POWER STATION

Independent review performed for Dominion Nuclear Connecticut, Inc. by:

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LARVAL MASS BALANCE STUDIES AT MILLSTONE POWER STATION

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July 2001

I Introduction

Millstone Power Plant draws water from Niantic Bay for condenser cooling. During spring months, winter flounder larvae are entrained with the cooling water and a portion of the larvae are killed during passage through the plant. While it is possible to measure entrainment losses with reasonable accuracy, it is more difficult to determine the source of the entrained larvae. The entrained larvae represent a large fraction of the larvae spawned locally in Niantic River and if most of the entrained larvae actually come from Niantic River, the plant could be having a major impact on the local fishery. On the other hand, to the extent that most of the larvae originate elsewhere (e.g., Connecticut R., Thames R.) and are imported to Niantic Bay, the local impact of larval entrainment would be significantly less.

In the late 1980s MIT conducted several numerical modeling studies to try to explain the fate of winter flounder larvae hatched in Niantic River (Dimou and Adams, 1989; Dimou et al., 1990). A random walk routine based on the modified tidal prism method (Ketchum, 1951) was used to simulate larval dispersion in a two-dimensional (depth-averaged) flow field produced from a finite element circulation model. The number of larvae introduced to the system was computed from the measured abundance of yolk-sac larvae during 1984-87. Larval characteristics included temperature-dependent growth rate and age-dependent mortality and later model versions considered tidal and diel dependent vertical migration.

Table 1 Observed Vs Simulated Larval Length Distribution (annual, in millions, after Dimou and Adams, 1989)

	3-4 mm	4-5 mm	5-6 mm	6-7 mm	7-8 mm
Observed	17.4	18.2	23.8	22.6	16.2
Simulated	1.36	0.052	0.044	0.025	0.0015

Table 1 compares the distribution of entrained larval lengths as observed and as simulated using base case model conditions. It is clear that the distributions do not match. The simulated entrainment is way too small, and the distribution is skewed toward shorter numbers, and does not exhibit the modal distribution seen in the observations. To try to explain the discrepancy, five hypotheses were developed:

1. Simulated larval hatching rates in Niantic River were too small
2. Simulated larvae mortality rates were too low
3. Simulated larval residence times were too short (due either to an overestimate of hydrodynamic flushing or an underestimate of river retention)
4. Simulated bay entrainment rates were too small
5. Simulations ignored the import of larvae into Niantic Bay

Hypotheses 1-4 could account for some of the observed discrepancy, but not all of it. The only hypothesis that could explain the mismatch between observed and simulated entrainment distributions was larval import. If a substantial number of larvae were imported into Niantic Bay, the number of entrained larvae would increase. Because they would have to travel a greater distance, the mean larval age (and hence mean length) would increase. And, because they would arrive through an *advective* process, the distribution of arrival times (hence lengths) would be modal, rather than the declining exponential distribution simulated for larvae essentially *diffusing* from the local Niantic River source. Additional support for the existence of larval import comes from the seasonal patterns of observed larval concentrations. For example: i) late in the season, larval concentrations in the bay can increase even though they already exceed concentrations in the river, ii) averaged over the season, concentrations in the bay can exceed concentrations in the river, and iii) the temporal pattern of larval entrainment matches observed concentrations in the bay better than observed concentrations in the river. These trends can be observed in data for 1991 shown in Figure 2 presented in the following section.

In order to estimate the amount of import, a larval mass balance was proposed. Data to support the mass balance are available from 1984 to present and results from the mass balance have been presented in the annual station reports. (Data discussed here are from 1984-1999.) The purpose of this report is to evaluate the mass balance approach and to suggest possible refinements.

The mass balance approach is described in Section II. In Section III some of the critical assumptions underlying the approach are evaluated and an assessment is made as to which are conservative (tending to overestimate the fraction F of entrainment from local sources) and which are non-conservative. In Section IV, a total of five modifications to the mass balances are considered and evaluated. Section V summarizes the annual mass balance for each of the 16 study years using the original and the five modified balances. Section VI looks at the sensitivity of the mass budget estimates to uncertainty in measured inputs and, finally, Section VII concludes with an assessment of the mass balance approach and suggestions for additional measurements that could reduce the uncertainty.

II Mass Balance Study

As depicted in Figure 1, the mass balance involves the following bookkeeping of winter flounder larvae in Niantic Bay:

$$R/B + S/B = B/R + B/S + E + M + \Delta \qquad (1)$$

where R/B is the flux of larvae from Niantic River to Niantic Bay, S/B is the flux from Long Island Sound to Niantic Bay, B/R is the flux from Niantic Bay to Niantic River, B/S is the flux from Niantic Bay to Long Island Sound, E is the entrainment flux, M is mortality and Δ is the change in larval abundance within Niantic Bay. Measurements are

available to determine (directly or indirectly) five of the seven terms--R/B, B/R, E, M and Δ--using a five day time step.

- R/B is estimated by multiplying the Niantic River tidal prism volume by the number of tidal cycles in five days and by a calculated ebb tide larval concentration at the mouth that is correlated with measured larval concentrations in the river, C_{NR}.
- B/R is estimated by multiplying the Niantic River tidal prism volume by the number of tidal cycles in five days and by a calculated flood tide larval concentration at the mouth that is correlated with measured larval concentrations in the bay, C_{NB}.
- E is calculated from measured entrainment concentrations times the 5-day volume of circulating seawater.
- M is calculated using instantaneous daily mortality rates computed for each of four larval development stages
- Δ is calculated from the 5-day change in C_{NB} multiplied by the bay volume.
- During most years there are no measurements of either S/B or B/S so the model uses Eq. 1 to solve for the *net* import from the sound, $S/B_{net} = S/B - B/S$. (Calling S/B_{net} = S/B essentially assumes B/S = 0).

The annual fraction of entrainment larvae that originate in Niantic River is designated F. The model assumes that Niantic Bay is well-mixed and hence that larvae imported from Long Island Sound (S/B) and from Niantic River (R/B) are equally likely to be entrained. The model also implicitly assumes that R/B represents larvae hatched in Niantic River and being transported to the bay for the first time. Similarly, the model assumes that S/B represents larvae hatched somewhere else in Long Island Sound and being transported for the first time to the bay. (See following discussion of mass balance assumptions.) With these assumptions, for each 5-day interval i

$$F_i = \frac{(R/B)_i}{(R/B)_i + (S/B)_i} \qquad (2)$$

The annual fraction F is obtained by summing the 5-day fractions weighted by the 5-day entrainment, or

$$F = \frac{\sum_i F_i E_i}{\sum_i E_i} \qquad (3)$$

Various terms in the mass balance are illustrated in Figure 2 for the year 1991.

III Mass balance issues

Four major issues have been identified that could affect the mass balance calculations. These are summarized in Table 2 and discussed individually below.

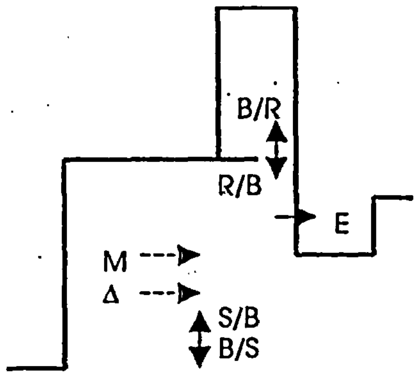


Figure 1 Millstone Mass Balance. See text for definition of terms

Table 2 Summary of Mass Balance Issues

Issue	Conservative/Non-conservative
Model closure	Very Conservative
Interpretation of R/B	Very Conservative
Calculation of B/R	Slightly Conservative
Well-mixed bay	Neutral

1. Model closure. As mentioned above, there are two unknowns, B/S and S/B, for which there are generally no measurements. Since there is only one equation (Eq. 1), the model implicitly sets B/S to zero, so the value of S/B determined by the model is actually a *net* import. Use of a net value (rather than the larger gross value) in the denominator of Eq. 2 is conservative, since it increases the apparent value of F. The model handles this differently early in the season than late in the season. Early in the season, one expects that the gross value of S/B should be zero, so any positive B/S computed by Eq. 1 results in a negative net value of S/B. This would result in $F > 1$. Because this is physically unrealistic, the model rounds the value of F down to one, which seems appropriate. However, later in the season, one expects positive values for both S/B and B/S, as larvae are exchanged back and forth between bay and sound. Setting B/S to zero reduces the net value of S/B, increasing the value of F. As a result, this assumption is very conservative. In Section IV several alternative closure assumptions (rather than assuming B/S = 0) are considered.

Figure 2a 1991 Data for River Import/Export, Entrainment

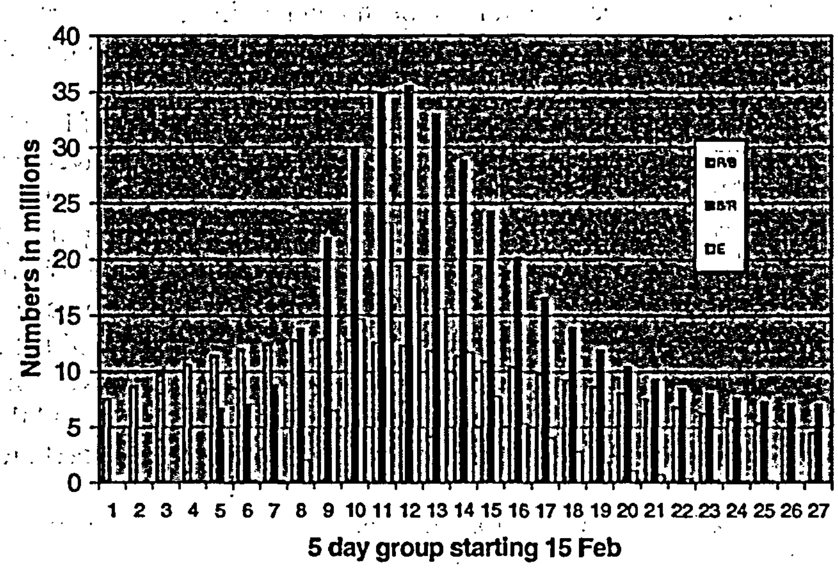
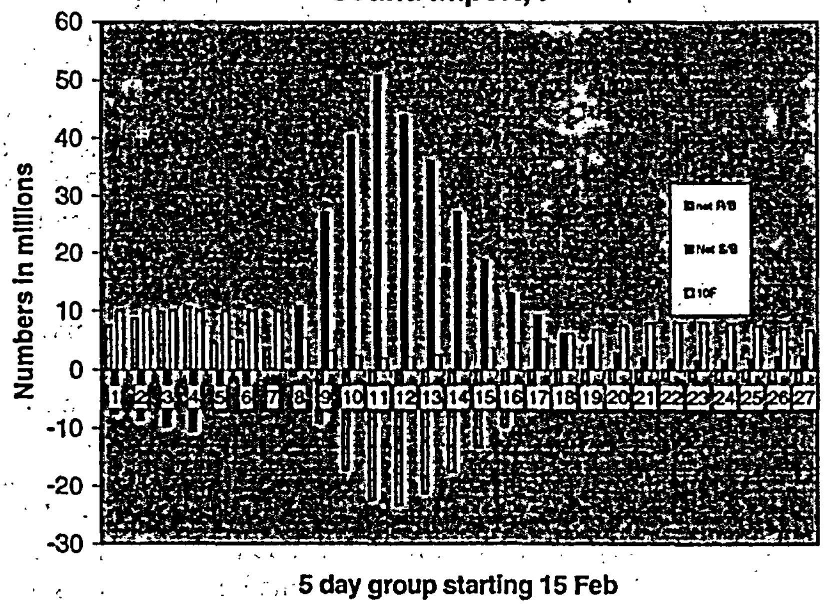


Figure 2b 1991 Data for net River import, net Sound import, F



2. Interpretation of R/B. In calculating F (Eq. 2), the model implicitly assumes that all R/B larvae are hatched in the river and are exiting the river for the first time. However, some larvae found in the river might have been hatched in the river, but might have resided previously in the bay, in which case they would be double-counted. Other larvae found in the river could have been hatched elsewhere and then been transported to the river; in this case they should never be included in the calculation of F. During 13 of the 16 years analyzed, the annual B/R exceeds the annual R/B and, on average for the 16 years, the annual B/R exceeds the annual R/B by 15%. This suggests that *most larvae attributed to R/B were probably not hatched in the river!* Assuming that all R/B larvae were hatched in the river, and that they are only being counted once, drastically overestimates F, and hence is very conservative. A similar situation occurs with the exchange of larvae between the bay and the sound, i.e., terms S/B and B/S. However, because transport at this boundary is governed primarily by tidal advection along the axis of Long Island Sound, there should be less back and forth exchange and the problem is probably less significant. In Section IV we discuss further the interpretation of R/B.

3. Calculation of B/R. The correlation between larval concentration at the mouth C_{toNR} and measured larval concentrations in the bay, C_{NB}, is

$$C_{toNR} = 128 + 2.1C_{NB} \qquad (4)$$

where concentrations are expressed as numbers per 500 m^3. As implied by the large intercept, the correlation is not very good which undoubtedly reflects the spatial non-uniformity in the bay. (See Assumption 4.) Furthermore, when $C_{NB} < 0.1$ Eq. 3 gives a substantial positive value for C_{toNR} and hence for B/R. When this occurs, the model sets B/R to zero. While this is physically reasonable (B/R *should* be zero if C_{NB} is really zero) there should be a compensating increase in B/R at other times during the season, since Eq. 3 represents a season-wide fit. As it is, the seasonal average B/R appears to be too low by about 7%. From Eq. 1, it can be seen that a higher average B/R would lead to a larger value of S/B and hence to a lower value of F. Hence this assumption is slightly conservative.

4. Well-mixed bay. The model treats Niantic Bay as spatially well-mixed. There is strong evidence that the bay is not well-mixed, as early in the season, the flux of larvae from the river to the bay does not result in a commensurate increase in measured bay concentrations. Bay concentrations are computed from measurements at only two locations, so one resolution would be to collect data at more locations. Concentrations in the bay are used to estimate various terms in the mass balance (e.g., Δ, B/R and M) which are less accurate due to the spatial non-uniformity. The well-mixed assumption also implies that the fraction of river larvae that are entrained is the same as the fraction of sound larvae that are entrained. Because the station intake is between the river mouth and the sound, there is no way to determine if this assumption is conservative or non-conservative, so it is labeled as neutral in Table 2.

IV Alternative assumptions to resolve mass balance issues

In the previous section, four issues were identified with the mass balance. The first two are the most likely to bias the attributed source of larval entrainment. These have to do with calculating and interpreting fluxes at the boundaries between river and bay and between bay and sound. Specifically, the model presently computes F (Eq. 2) using a net value of S/B and a gross value of R/B. We define this as ***Assumption 0*** which, as discussed previously, leads to an overestimate of F. Below we develop five alternative assumptions. The first three attempt to close the mass balance by estimating gross values of S/B and B/S, so that the gross value of S/B can be used in Eq. 2. The fourth approximation uses net values of both S/B and R/B in Eq. 2, and the fifth approximation uses field data to estimate the true fraction of R/B larvae that are actually hatched in the river and making their first passage to the bay.

Assumption 1: An instantaneous dye study described by Dimou and Adams (1989) was performed to estimate the fraction (c_1) of R/B that are entrained by the plant. Assuming that the bay is well-mixed, the same fraction of S/B should also be entrained. Accordingly

$$E = c_1(R/B + S/B) \qquad (5)$$

and, by Eq. 2,

$$F_1 = \frac{c_1(R/B)}{E} \qquad (6)$$

Figure 3a shows the sensitivity of F_1 to the value of c_1 for the year 1991. The dye study showed that about 20% of the dye was ultimately drawn into the intake. Dye is conservative, but if we account for mortality, c_1 would be about 0.17, which is the value used here. Early in the season R/B >> E. In such cases, any computed values of F_1 that exceed one are rounded down to one. In addition, F_1 is set to zero if E is zero.

Assumption 2: This uses the mass balance to calibrate a relationship for B/S early in the season when S/B is nearly zero (and hence there is only one unknown in Eq. 1). It would be nice to use early season data to correlate B/S with C_{NB}, but this is not possible because, early in the season, measured C_{NB} is nearly zero. As an alternative, B/S was correlated with R/B. Hence, early in the season

$$B/S = c_2(R/B) \qquad (7a)$$

and, later in the season when S/B > 0, a similar relationship was assumed

$$B/S = c_2(R/B + S/B) \qquad (7b)$$

Figure 3b shows the sensitivity of F_2 to the value of c_2 for the year 1991. Early season data for 1984-99 (collected until the time at which B/S peaks) imply that $c_2 = 0.95$, but this is likely too high. A large value of R/B early in the season should physically cause C_{NB}, Δ, M and B/R to also increase, which would limit the increase in B/S and decrease the value of c_2, but this is not observed in the data. It is likely that, early in the season, R/B is either too big or C_{NB} (and hence, Δ, M, and B/R) are too small. For lack of a better assumption, c_2 was set to 0.5.

Assumption 3: During 1991 larval concentrations were measured at a number of additional locations including Millstone Point and Black Point. See Figures 4 and 5. Flow measurements (Figure 4) as well as model calculations suggest that flood tide enters the bay near Millstone Point and exits the bay near Black Point, while ebb tide enters the bay near Black Point and exits the bay near Millstone Point. Data from Figure 5 indicates that, early in the season, larval concentrations are higher during ebb tide at Millstone Point and flood tide at Black Point (conditions contributing to B/S) than during flood at Millstone Point and ebb at Black Point (conditions contributing to S/B). Later in the season, the situation is reversed. We assume that, at any given time, the larger flux equals c_3 times the smaller flux. Thus early in the season (net S/B < 0)

$$B/S = c_3 S/B \tag{8a}$$

while later in the season (net S/B > 0)

$$S/B = c_3 B/S \tag{8b}$$

Figure 3c shows the sensitivity of F_3 to the value of c_3 for the year 1991. Data in Figure 5 suggest the value of c_3 is approximately 2. A problem with this closure assumption is that, like the rest of the mass balance, it assumes that the bay is well-mixed, whereas observed flow patterns (Figure 4) suggest that some larvae exit the bay soon after entering. The well-mixed assumption becomes more critical as c_3 approaches one.

Assumption 4 The previous three approaches try to solve for the gross value of S/B for use in Eq. 2 along with the gross value of R/B. Use of gross values for both fluxes makes the evaluation of F nominally consistent in that it allows double counting of larvae crossing both bay boundaries. It also counts larvae entering the bay that have not originated outside that particular boundary (i.e., larvae originally imported from the sound can enter the bay from the river and larvae originally from the river can enter the bay from the sound). As an alternative, Assumption 4 uses the net values of both S/B and R/B. The model already uses the net value of S/B, so the net value of R/B is computed as R/B minus B/R. If the net value of S/B is negative, F = 1 and if the net value of R/B is negative, F = 0.

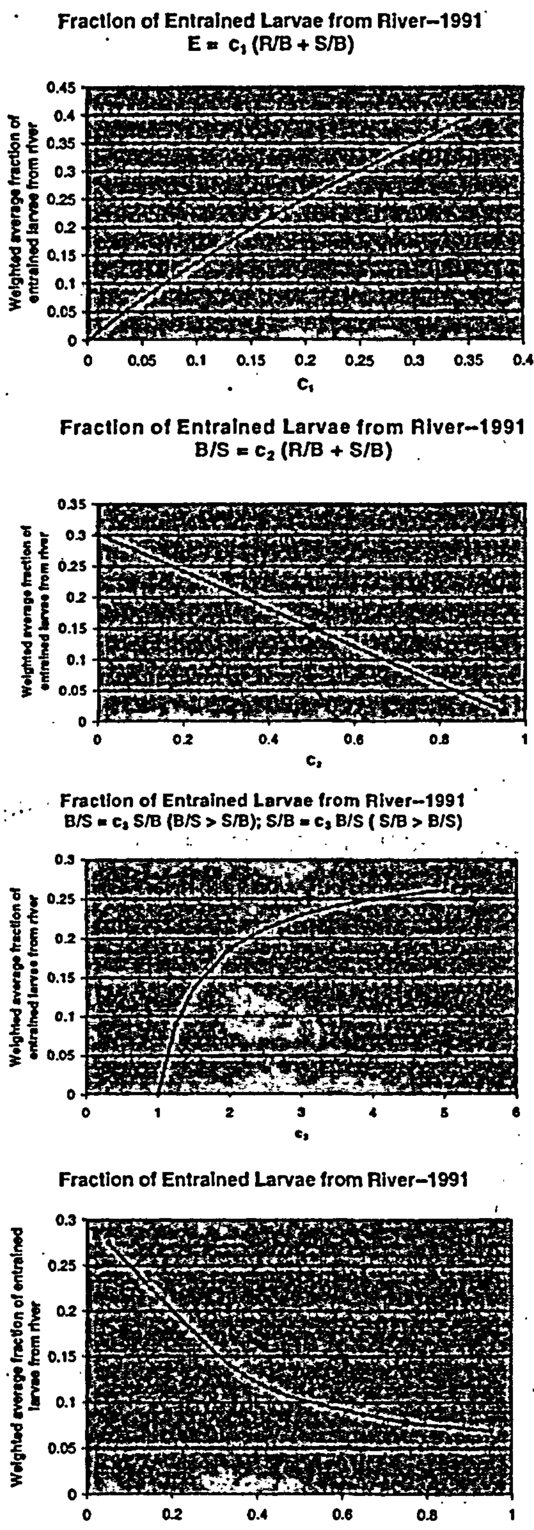


Figure 3 Sensitivity of F to model parameters c_1, c_2, c_3, and c_5.

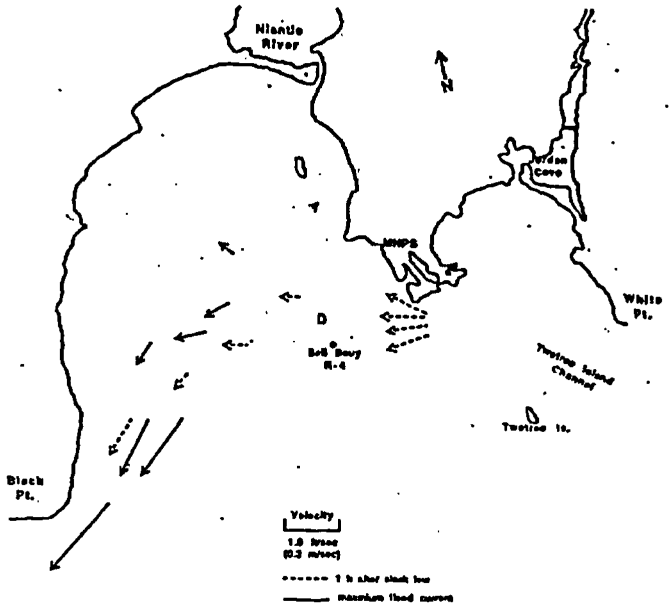


Figure 4a Tidal current direction and velocity in Niantic Bay for a flooding tide based on the results of drogue studies conducted in 1991 (NUSCO 1992)

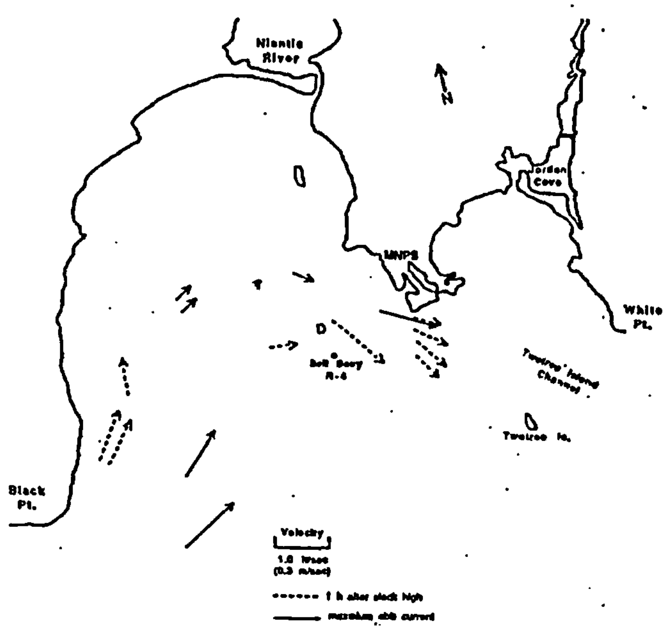


Figure 4b Tidal current direction and velocity in Niantic Bay for an ebbing tide based on the results of drogue studies conducted in 1991 (NUSCO 1992)

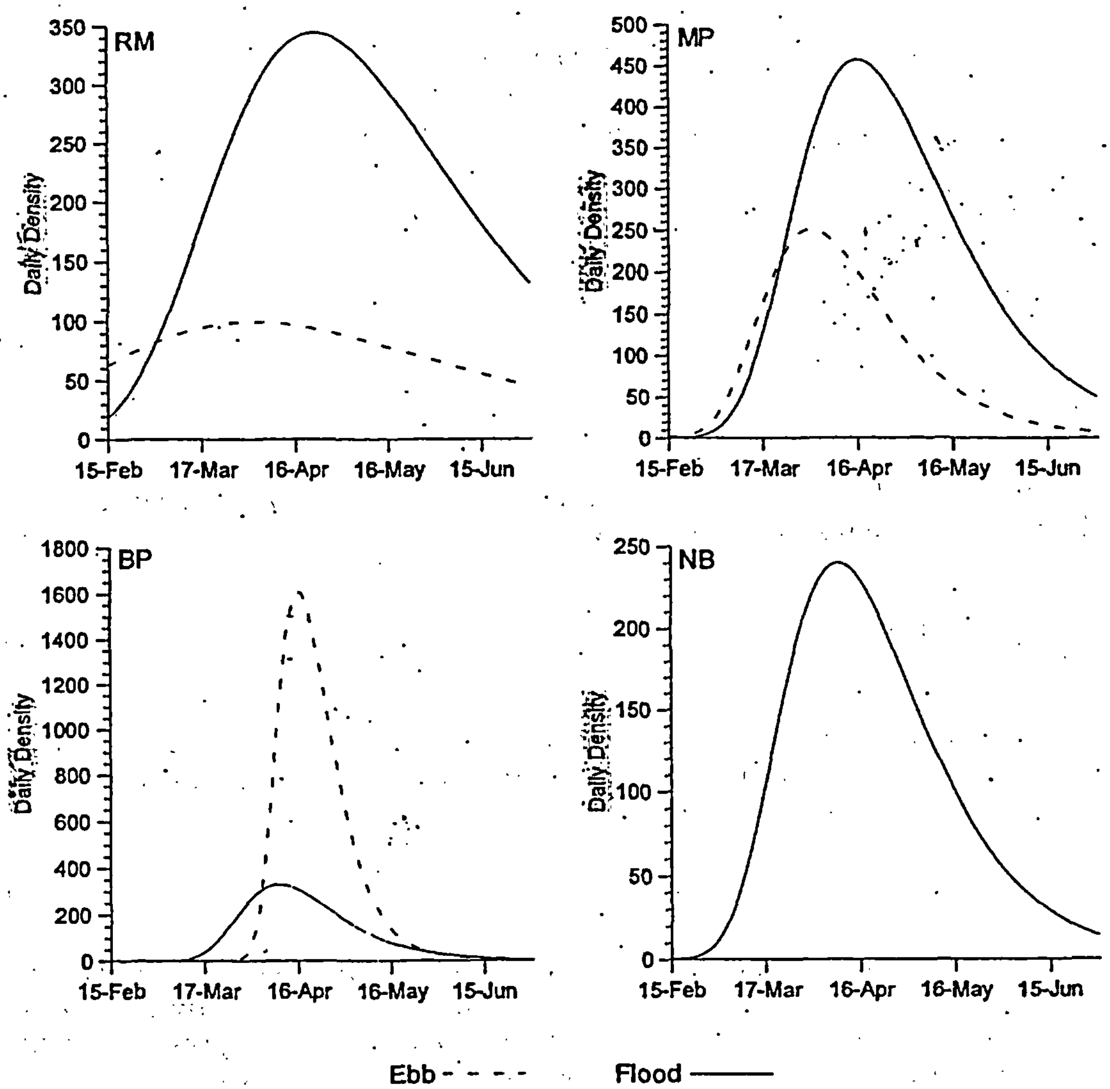


Figure 5 Measured Ebb and Flood tide larval concentrations at several stations in Niantic Bay. Text refers to Millstone Point (MP) and Black Point (BP). (NUSCO, 1992)

Assumption 5 None of the previous assumptions purports to calculate the fraction of B/R larvae passing from the river to the bay that are i) actually hatched in the river and ii) being transported to the bay for the first time. We examine these two limitations, starting with the latter.

Assume that, in time period i, the number of larvae hatched in the river and making their first passage to the river is X_i. This is the "effective" value of R/B that should be used in Eq. 2 to determine F_i. Assume that a fraction *r* of these larvae return to the river (as $B/R)_i$ and that a fraction *s* of those then survive in the river and are returned to the bay (as

$R/B)_i$. Continuing this process, the total number of larvae transported from the river to the bay would be

$$(R/B)_{iX} = X_i + X_i rs + X_i r^2 s^2 + ... = X_i/(1-rs) \quad (9)$$

while the total number transported from the bay to the river would be

$$(B/R)_{iX} = X_i r + X_i r^2 s + X_i r^3 s^2 + ... = X_i r/(1-rs) \quad (10)$$

The ratio of the two fluxes is

$$\frac{(B/R)_{iX}}{(R/B)_{iX}} = r \quad (11)$$

and the ratio of larvae making their first passage from river to bay to the total number being transported from river to the bay is

$$\frac{X_i}{(R/B)_{iX}} = 1 - rs \quad (12)$$

A return rate of $r \cong 0.34$ can be calculated from dye measurements taken at the river mouth during the continuous dye study described in Dimou and Adams (1989). The survival rate s can be calculated from

$$s = \exp(-kt_r) \quad (13)$$

where k is the daily mortality rate, equal to -ln(daily survival rate), and t_r is the mean time that larvae that are transported to the river from the bay spend in the river. For example, using a daily larval survival rate of 0.96 and assuming $t_r = 7$ days, gives s = 0.75 (the value used here). If $t_r = 1$ day, s would be 0.96, while if $t_r = 17$ days, s = 0.5. For a value of s = 0.75, the ratio of $X_i/(B/R)_i$ would be 0.75, suggesting a 25% reduction in the "effective" value of R/B in Eq. 2.

Under this scenario, the ratio of B/R to R/B would be about 0.34, while data in Figure 2a suggest that the ratio is generally much higher; indeed, averaged over 16 years, it is about 1.15 (there are actually more larvae transported to the river than from the river). To explain this higher ratio, we assume for each period of time a flux of Y_i larvae that are hatched outside of the river and are making their first passage to the river. Using the same parameters *r* and *s*, the total number of these larvae transported from the river to the bay is

$$(R/B)_{iY} = Y_i s + Y_i rs^2 + Y_i r^2 s^3 ... = Y_i s/(1-rs) \quad (14)$$

while the total number of larvae transported from the bay to the river is

$$(B/R)_{iY} = Y_i + Y_i rs + Y_i r^2 s^2 + \ldots = Y_i/(1-rs) \quad (15)$$

The total number (considering sources X_i and Y_i) of larvae transported from the river to the bay is

$$(R/B)_i = \frac{X_i}{1-rs} + \frac{Y_i s}{1-rs}, \quad (16)$$

the total transported from the bay to the river is

$$(B/R)_i = \frac{X_i r}{1-rs} + \frac{Y_i}{1-rs}, \quad (17)$$

and their ratio, which we denote R_i is

$$R_i = \frac{(B/R)_i}{(R/B)_i} = \frac{X_i r + Y_i}{X_i + Y_i s} \quad (18)$$

Rearranging Eq. 18,

$$Y_i = X_i \frac{R_i - r}{1 - R_i s} \quad (19)$$

and, combining with Eq. 16,

$$\frac{X_i}{(R/B)_i} = 1 - R_i s \quad (20)$$

For an assumed value of s (a value of 0.75 has been used), and measurements of $(R/B)_i$, $(B/R)_i$ (and hence R_i) for each five day interval, Eq. 20 can be used to calculated the effective value of (R/B) for use in Eq. 2, which results in

$$F_i{*} = \frac{(1-R_i s)F_i}{1-R_i s F_i} \quad (21)$$

Note that, early in the season, the value of $(B/R)_i$ is set to zero, so $X_i/(R/B)_i$ will be zero. For reasons discussed previously, this is conservative. For later periods of time, when R_i is large, the computed value of $X_i/(R/B)_i$ may be negative, which is physically impossible. This may be a signal that s should be lower (again a conservative assumption), perhaps reflecting retentive behavior of older larvae in the river. At any rate, the minimum value of $X_i/(R/B)_i$ is set to zero.

The above discussion concerns larval flux across the river-bay boundary. In principle it could be applied with any of the previous assumptions concerning the bay-sound boundary. We choose to use the net value of S/B as presently assumed in the mass balance. While this underestimates some imported larvae, it also allows for double counting larvae that make multiple passages across the bay-sound boundary.

V Results for 1984-1999

The above six assumptions were used to make mass balance calculations for each of the sixteen years, 1984-1991. Table 4 summarizes the values of F computed for each year and each assumption, along with various statistics.

Table 4 Variation in F with different assumptions during 1984-1999

Year	F_0	F_1	F_2	F_3	F_4	F_5	Ave	StdDev	CV
1984	0.34	0.38	0.17	0.21	0.01	0.01	0.19	0.16	0.85
1985	0.34	0.36	0.22	0.23	0.16	0.18	0.24	0.08	0.33
1986	0.21	0.14	0.11	0.12	0.00	0.01	0.10	0.08	0.83
1987	0.25	0.14	0.13	0.15	0.02	0.03	0.12	0.09	0.72
1988	0.22	0.14	0.13	0.14	0.07	0.08	0.13	0.06	0.43
1989	0.21	0.12	0.11	0.14	0.00	0.08	0.11	0.07	0.63
1990	0.28	0.20	0.14	0.17	0.01	0.01	0.14	0.11	0.79
1991	0.30	0.22	0.15	0.19	0.00	0.01	0.15	0.12	0.82
1992	0.16	0.08	0.08	0.10	0.01	0.01	0.07	0.06	0.78
1993	0.14	0.13	0.07	0.08	0.00	0.00	0.07	0.06	0.85
1994	0.29	0.20	0.15	0.17	0.02	0.02	0.14	0.11	0.75
1995	0.38	0.27	0.19	0.26	0.07	0.08	0.21	0.12	0.57
1996	0.61	0.73	0.45	0.43	0.45	0.47	0.52	0.12	0.23
1997	0.48	0.77	0.25	0.34	0.13	0.13	0.36	0.24	0.69
1998	0.34	0.35	0.18	0.23	0.06	0.06	0.21	0.12	0.60
1999	0.22	0.19	0.11	0.13	0.02	0.02	0.12	0.08	0.71
Ave	0.30	0.28	0.17	0.19	0.06	0.08	**0.18**	0.11	**0.66**
StdDev	0.12	0.21	0.09	0.09	0.11	0.12	0.12	0.05	0.19
Max	0.61	0.77	0.45	0.43	0.45	0.47	0.52	0.24	
Min	0.14	0.08	0.07	0.08	0.00	0.00	0.07	0.06	
CV	0.40	0.75	0.55	0.47	1.79	1.49	**0.65**	0.45	

From this table we note:

- With the current assumption, the annual percentage of entrained larvae originating from the river (F_0) averages 30%, while with the other five assumptions, the percentages range from 6 to 28%. The average for all six assumptions is 18%.
- For any given assumption, the year-to-year variability is given by the coefficient of variation (CV; ratio of standard deviation to mean) shown in the bottom row. The CV for the current assumption is 0.4 while the average CV for all six assumptions is

0.65. This implies that the alternative assumptions, though intended to be less biased, may be more variable as predictors.

- The variation among assumptions is given by the CV in the last column. The average value is 0.66 implying that uncertainty among the various assumptions is comparable to year-to-year variability.

VI Sensitivity to measured input parameters

The model is based on measurements of five variables: B/R, R/B, E, M, and Δ. Table 5 shows the sensitivity of the mass balance calculations for the year 1991 to a 25% variation in each variable. In each case the variation is in the direction that increases the fraction F of entrained larvae assigned to Niantic River. The second column, denoted F_0, uses the MEL mass balance closure (Assumption 0) and Column 3 gives the percentage change relative to the base case using this assumption. Columns 4-8 give results for Assumptions 1-5. Column 9 provides an average over all six assumptions and the last column gives the percentage change in F relative to the base case using this average.

Using either the MEL assumption, or the average of all six assumptions, it is clear that the model is most sensitive to uncertainty in the fluxes to and from the river, followed by uncertainty in the entrainment loss. The model is not very sensitive to uncertainty in mortality rates or changes in storage.

Table 5 Summary of 1991 Sensitivities

	F_0	%	F_1	F_2	F_3	F_4	F_5	Fave	%
Base	0.303	0.00	0.22	0.15	0.19	0.00	0.09	0.15	0.00
R/B*1.25	0.378	0.25	0.26	0.19	0.25	0.02	0.04	0.19	0.30
B/R*0.75	0.368	0.21	0.22	0.19	0.25	0.03	0.06	0.18	0.26
E*0.75	0.324	0.07	0.28	0.16	0.20	0.00	0.01	0.16	0.12
M*0.75	0.307	0.01	0.22	0.15	0.19	0.00	0.01	0.15	0.01
D*1.25	0.305	0.01	0.22	0.15	0.19	0.00	0.01	0.15	0.01

Table 6 gives an estimate of the uncertainty in the various parameters themselves, based on a review of the data collection procedures and conversations with MEL personnel (E. Lorda, 2000). *Assuming the uncertainty in each variable is independent*, the uncertainty in the average values of F_0 and F_{ave} would be

$$\sigma_{F0} = \sqrt{(2*25)^2 + (2*21)^2 + 7^2 + (4*1)^2 + (4*1)^2} = 66\,percent \qquad (22a)$$

$$\sigma_{F_{ave}} = \sqrt{(2*30)^2 + (2*26)^2 + 12^2 + (4*1)^2 + (4*1)^2} = 80\,percent \qquad (22b)$$

Table 6 Estimated uncertainty in mass balance measurements	
Variable	Estimated uncertainty
R/B	50
B/R	50
E	25
M	100
Δ	100

Uncertainty due to input uncertainty appears to be in the range of 50 to 100%, comparable with the uncertainty in model assumptions and the annual variability.

VII Summary and Conclusions

There are a number of reasons to suspect that many of the winter flounder larvae entrained by the Millstone Power Station are imported from outside of the Niantic River area. To help determine the source of entrained larvae, a mass balance model has been used with data from 1984 to the present. For the years 1984-1999, this model suggests that the fraction of entrained larvae coming from Niantic River (F) averages about 30% with a coefficient of variation (CV) of about 0.40.

This report demonstrates that these calculations are conservative (erring on the side of overestimating F). Accordingly, five alternative model assumptions have been developed. The 16-year average value of F (averaged over all 6 model assumptions) is 18% with CV = 0.65.

Calculations with all six assumptions are uncertain due to uncertainty in both the model assumptions and uncertainty in measured input data.. Both of these sources of uncertainty are estimated to affect the mean prediction of F by about 50-100%.

The greatest uncertainty concerns the measurements and model assumptions surrounding the larval fluxes between the Niantic River and Niantic Bay. Improved accuracy would be obtained with better measurements near the mouth (to resolve B/R and R/B) and within the bay (to resolve C_{NB}).

VIII References

Dimou, N. K. and Adams, E. E., 1989. Application of a 2-D Particle Tracking Model to Simulate Entrainment of Winter Flounder Larvae at the Millstone Nuclear Power Station, Report No. MIT-EL 89-002. MIT Energy Laboratory.

Dimou, N. K. Obst, A.T. Moeller, J. and Adams, E. E., 1990. Numerical Simulations of Fish Larvae Entrained at the Millstone Nuclear Power Station—Summary report covering period December 1989-August 2000. Report No. MIT-EL 90-003. MIT Energy Laboratory.

Ketchum, B. H., 1951. The exchange of fresh and salt waters in tidal estuaries. *J. Marine Research.* 10:18-37.

NUSCO, 1992. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1991.

APPENDIX D TO CHAPTER 3 OF PART II

LARVAL MASS BALANCE STUDIES AT MILLSTONE POWER STATION

Independent review performed for Dominion Nuclear Connecticut, Inc. by:

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July 6, 2001

Dr. Milan Keser, Manager
Millstone Environmental Laboratory
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Millstone Power Station
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Dear Dr. Keser:

I have taken the opportunity to review the sections of your Dominion Nuclear Connecticut, Inc. 1999 Annual Report pertaining to the larval winter flounder mass-balance calculations as per your request.

The approach described seems a reasonable means of accounting for all the potential inputs and outputs of larvae to the Niantic Bay system. The model and its results are well documented, and the sensitivity of the model to assumptions is clearly presented.

This model, and the documentation given for it in the 1999 Annual Report, will provide a good basis for evaluation the potential impact of entrainment on the population of winter flounder larvae in the Niantic system. As with any model, approximations and assumptions must be made in order to achieve an adequate yet tractable characterization of the system. The best modeling approaches I have seen are those that have their approximations and assumptions clearly described, as you and your staff have done for this model.

Please let me know if you require additional comment, and thank you for allowing me the opportunity to review this work.

Sincerely,

Patrick J. Sullivan
Assistant Professor of Population and Community Dynamics

PART II - CHAPTER 4

THE EFFECTIVENESS OF REDUCING ENTRAINMENT MORTALITY OF FISH EGGS AND LARVAE AT MNPS

4.1 INTRODUCTION

Chapter 2 of this report provides an evaluation of the applicability of implementing various intake technology alternatives at Millstone Nuclear Power Station (MNPS) to reduce cooling-water flow or entrainment mortality and species-specific biological data are presented in Chapter 3. Using this information, the effectiveness of reducing entrainment mortality of winter flounder, tautog, and the other designated fishes of regulatory concern is evaluated quantitatively in this chapter. An important assumption is that a reduction in entrainment mortality is directly proportional to a reduction in cooling-water flow and that the effects of this reduction will be propagated through the population dynamics of the species in question. Another important assumption is that no fish eggs or larvae are presumed to survive entrainment at MNPS. Thus, any evidence for survival of eggs or larvae following plant passage is ignored in the simulations or calculations found herein.

A fish population dynamics computer model known as the Stochastic Population Dynamics Model (SPDM) is used to assess the effect of MNPS on the Niantic River winter flounder. Also of importance in the model is the rate of fishing on the adult stock, which can remove considerable biomass each year. The specific model application is discussed in the following section and more detailed methods are given in Appendix B to this chapter. Because most winter flounder larvae entrained at the station come from sources other than the Niantic River (see Chapter 3 and Appendix B to Chapter 3), an equivalent-adult model described in Section 4.2.4 is used to evaluate losses of winter flounder larvae from other Long Island Sound (LIS) stocks. This method is also applied in assessing the entrainment of other selected fish species in Sections 4.3 and 4.4. Note that equivalent-adult models are conservative because they do not assume any compensatory mortality. An additional assessment of tautog egg entrainment is made using a method which compares entrainment to egg production in LIS and entrainment of Atlantic menhaden larvae is also examined using a population dynamics model formulated expressly for that purpose. Finally, the extensive time-series of monitoring data at MNPS along with relevant life history and population dynamics information for each species are examined for evidence of entrainment impact.

4.2 WINTER FLOUNDER

4.2.1 Background

Based on the work of Lorda (1982) and Reed et al. (1984), the SPDM was developed specifically to assess the effects of MNPS on the Niantic River winter flounder. The model was described in Lorda et al. (2000) and NUSCO (2000)

and has been presented in other previous annual MNPS environmental monitoring reports dating back to 1988. A summary description of the model is given in Appendix B to this chapter. For purposes of this study, the SPDM was slightly modified and applied to the task of evaluating the effectiveness of reductions in winter flounder larval entrainment resulting from various alternatives to reduce entrainment that were presented in Part I and discussed in Chapter 2 of Part II.

In addition to SPDM simulations and associated analyses, Section 4.2.5 of this chapter focuses on the abundance and entrainment of early life history stages of winter flounder and the inferences that can be drawn the relatively long time-series of empirical information available from MNPS monitoring studies. As the early life history of the European plaice has many similarities with that of the winter flounder, relevant literature for this species was also reviewed for this report to gain further insights into dynamics of winter flounder populations.

4.2.2 Quantification of Niantic River Winter Flounder Entrainment Impact

The potential impact of entrainment depends upon the age of each larva at the time it is entrained, because an older individual has a greater probability of contributing to the year-class than a younger one, due to a higher probability of survival. The number of individuals entrained from each developmental stage was estimated from the proportion of each stage collected at the MNPS discharge. Since the proportion of entrainment attributed to the Niantic River was estimated from mass-balance calculations (see Chapter 3, Table 3-9 and Appendix B to Chapter 3 for a complete discussion), the number of larvae for each stage could be allocated to either the Niantic River or other sources (Table 4-1). Most Stage 3 larvae entrained (the predominant stage collected at the MNPS discharges) apparently originated from sources other than the Niantic River. Because the number of larger larvae found in the Niantic River increases over the season, many larvae from other areas likely enter the river during flood tides as the season progresses.

The estimated number of each larval winter flounder stage entrained coming from the Niantic River was compared to the annual abundance estimates for that stage in the river to estimate the percentage of the production that was entrained annually (Table 4-2). Since 1984, these annual percentages of production loss (termed ENT), which are mathematically equivalent to a conditional entrainment mortality rate expressed as a percentage, ranged from 5.4 to 43.6% and had a geometric mean of 12.9%. The mass-balance calculations used to generate these percentages were based on actual daily condenser cooling-water volumes, which were generally less than full cooling-water capacity at MNPS. However, this time-series also included 3 years (1996-98) of relatively low cooling-water use due to extended unit shutdowns (see Chapter 3, Table 3-7) and which represented only 13.6 to 28.9% of available flow for those years (DNC 2001a). The values of ENT for these 3 years are believed to be unreasonably high as the mass-balance model assumes that all larvae not accounted for elsewhere have come from the Niantic River. A more complete discussion of the conservative nature of the mass-balance model regarding Niantic River winter flounder larvae may be found in the Appendices to Chapter 3, two of which were independent reviews of this model as requested by the DEP (DEP 2000a).

The sensitivity analyses completed by both DNC and independent consultants showed that the mass-balance model is conservative with respect to the fraction of Niantic River larval production that was entrained.

For this study, larval losses during 1971-99 were the same as those used for SPDM simulations found in NUSCO (2000: Table 42) and the values of ENT for 1986 through 1995 (actual period of three-unit MNPS operation) were used to generate a geometric mean of 16.16% to represent this 10-year period of three-unit operation (Table 4-3). This value was then adjusted by conservatively reducing it by 20% to 12.93% to account for the retirement of Unit 1 in SPDM population projections made from 2000 onwards. The mean entrainment value of 12.93% was further reduced to 7.78% in 2035 and to 0 in 2045 to account for the planned retirement of Units 2 and 3, respectively. These dates assume a 20-year renewal of the current operating licenses for Units 2 and 3, although as noted previously, no such request has been yet made to the U.S. Nuclear Regulatory Commission (NRC). Thus, in order to be conservative in the projections of potential reductions in larval entrainment, the population modeling was carried out as if the license renewal had been granted by the NRC to 2035 for Unit 2 and to 2045 for Unit 3. Because there is uncertainty in the annual estimates of ENT, the SPDM simulations described in the following section also included model projections based on "high" and "low" mean values of ENT for the 2002-2045 period, which were derived by scaling the corresponding mean ENT by a factor of 1.5 and 1/1.5, respectively (Table 4-3).

4.2.3 SPDM Application to Assess the Effectiveness of Reducing Entrainment of Niantic River Winter Flounder Larvae by Selected Cooling-Water Intake System Alternatives

The dynamics of the Niantic River winter flounder stock were simulated using the SPDM under several scenarios running from 1960, a decade before the operation of Unit 1, to 2045, the year of the projected shutdown of Unit 3, assuming a 20-year license renewal. The simulation scenarios included power plant effects that were based on actual or projected MNPS operations in each year (with or without implementing entrainment reduction alternatives) concurrently with annual fishing mortality rates (F), which were based on historic or projected rates of commercial exploitation and sport fishing for winter flounder in Connecticut or the Southern New England region.

A SPDM simulation is a relatively simple application of Monte Carlo methods (Rubinstein 1981) because only one population parameter, the age-0 survival rate, is stochastic. Since many independent random replicates of the time-series of population projections are generated, the mean population size for each year in the series and its standard error can be estimated. For this study, the number of replicates per simulation scenario was increased from 100, used in other recent SPDM applications, to 500. Trial runs of 1,000 replicates were also examined, but this doubling of the replication produced very little variation (e.g., population means calculated from 500 and 1,000 replicates differed by less than 0.1%). Simulation output consists of time-series of annual stock sizes generated under a specified set of population parameters and plant operation conditions, including random variability. The

geometric mean of the replicates is computed for each year in the projection and all stock projections are given in units of spawning biomass (lbs) because overfishing criteria often rely on assessments of biomass, which tend to be more conservative than those based on fish numbers. Furthermore, larval entrainment effects result in long-term stock reductions which can be quite different depending on whether the stock is expressed as fish numbers or as biomass. Population reproductive capacity is more accurately reflected by biomass, which takes into account the size of individual females (egg production is a function of length or weight), as well as the number of spawners. However, the mean weight of Niantic River female winter flounder spawners from 1977 through 2000 was determined to be 1.07 lbs, so over this period number and weight were nearly synonymous (Fig. 4-1). Although annual mean weight from 1995 through 2000 averaged 1.3 lbs, this value would likely decrease towards 1 lb if population size increased, since mean weight was determined to be exactly 1 lb during the period of 1977-85, when winter flounder were more abundant than at present.

Input parameters used in the SPDM include a schedule of annual fishing mortality rates (F), with an additional instantaneous mortality of 0.01 (termed IMP) accounting for impingement losses over the lifetime of each unit (NUSCO 1992); a schedule of annual larval entrainment conditional mortality rates (ENT) as described in Section 4.2.2 (Table 4-3) and NUSCO (2000: Table 42); a schedule of reduced ENT values resulting from any entrainment reduction alternatives simulated (to be discussed below); and the length of the time-series in years. Other data, rates, and inputs to the SPDM in this report are summarized in Table 4-4 and include the number of age-classes, age-specific rates of maturation, natural mortality, mean weight and fecundity at age, the estimated value of α_0, long-term mean estimates of β and ϕ, and February water temperature statistics (see Appendix A of Chapter 4).

In evaluating some of the larval entrainment reduction options, both the primary (March 22-June 5) and optimal (April 4-May 14) periods of larval winter flounder entrainment were used for condenser cooling-water flow reduction schemes (see Chapter 3, Section 3.2.4). Because the optimal season included 76% of potential larval winter flounder entrainment, reductions in entrainment as a result of flow reductions over the primary entrainment season were reduced by 24% to determine the effectiveness of, for example, shutting down one or more condenser cooling-water pumps during only the optimal season. This was done because having a shorter period during which one or more condenser cooling-water pumps would be shut down would enhance plant operability, safety, and economics. As discussed later in this section, increases in winter flounder biomass resulting from various reductions in entrainment mortality tended to be proportional to the fractional reductions, so outcome of other percent reductions not evaluated in this report may be found approximately by interpolation. Finally, a common starting date of 2002 was assumed in the simulations for the various percent reductions to go into effect. This simplifying assumption was made to facilitate comparisons of model output, even though as shown in Part I the time necessary for engineering, design, and construction for some alternatives (e.g., cooling towers) would take much longer than other feasible options (e.g., reducing the number of condenser cooling-water pumps in use). Earlier or

later implementation of an alternative would result in somewhat larger or smaller gains, respectively, in winter flounder biomass by the time of plant retirement.

Because the ability of a fish stock to withstand additional stress is reduced by fishing mortality (Goodyear 1980), the actual fishing exploitation rates on the spawning stock are critically important in simulations of long-term effects of larval entrainment. In the case of the Niantic River winter flounder stock, long considered overfished, current estimates of fishing mortality (≥0.74 since 1995) are about four times as much as natural mortality (0.2) and this factor remains the dominant force driving the dynamics of the spawning stock. Two separate series of simulations were carried out for this study using two different sets of annual instantaneous fishing mortality rates, F (Table 4-5; Fig. 4-2). In the first series, referred to as the "DEP simulations", the annual schedule of fishing rates was based on DEP estimates for LIS winter flounder beginning in 1984 (D. Simpson, CT DEP, Old Lyme, CT, pers. comm.). These estimates took into account both fishing effort and the effects of length-limits and other regulations implemented by the DEP to reduce fishing mortality in Connecticut. Based on discussions held with the DEP (D. Simpson, CT DEP, Old Lyme, CT, pers. comm.), the current rate of fishing mortality was chosen as F = 0.74 (termed the "DEP rate"), which was based on the mean of the last available annual point estimate of F (1999-2000) and the last available three-point moving average of F determined for age-4+ LIS winter flounder by DEP. The second series, referred to as the "SARC simulations", were specifically requested by the DEP (DEP 2000b) and the annual schedule of fishing rates (Table 4-5) from 1981 to 1997 was derived from Virtual Population Analysis of the Southern New England regional winter flounder stock as reported in NEFSC (1999). The mean of the last four available annual (1994-97) estimates of F for fully exploited fish of ages-4 through 6 were used to generate a mean value of F = 0.375 (termed the "SARC rate").

Both the DEP and SARC F rates were used from 2000 onwards in simulations projecting winter flounder stock size into the future. For each simulation series, age-classes 1 through 3 were considered not fully vulnerable to fishing mortality as a result of recent, more protective regulations, so correction factors were used to reduce the annual values of F for these ages (Table 4-4). It is worth noting that the SARC rate is approximately one-half the DEP rate (Fig. 4-2) and is also lower than the historic F = 0.40 believed to have been in operation during the mid-1970s to early 1980s when the Southern New England stocks of winter flounder were about an order of magnitude larger than at present. Given the current near-record low stock sizes of winter flounder in most of Southern New England (NEFSC 1999; Gottschall et al. 2000; Lynch 2000), the SARC rate must represent a large underestimate of actual exploitation rates by the fisheries in Rhode Island and Connecticut waters.

In the present application of SPDM, the effectiveness of reducing larval entrainment from the implementation of selected cooling-water alternatives was examined during separate and independent SPDM simulation runs under two different scenarios, each consisting of six stochastic time-series of female spawning stock sizes generated from

2002 through 2045. The first scenario was used to generate a single baseline time-series of stock projections with reduced biomass resulting from fishing and MNPS effects under present two-unit operation without any reduction in entrainment going forward, except for the retirement of each unit. The second scenario having the same schedule of fishing rates as the baseline scenario was used to generate five time-series of stocks with increased biomass produced by reducing the baseline ENT rates after 2002 by a different percentage corresponding to each of the five selected entrainment reduction alternatives (Fig. 4-3). These reductions of 6, 15, 35, 58, and 91% were chosen to represent a suite of postulated entrainment reductions resulting from the implementation of various feasible cooling-water alternatives that were discussed throughout Part I and in Chapter 2 of Part II of this report (Table 4-6). Two complete sets of simulations, one for each of the two schedules of fishing rates (DEP and SARC) discussed above were conducted. A summary of results of each assessment of intake technology alternatives was based on the direct comparison of projected annual mean stock sizes with and without entrainment reduction effects (i.e., differences between the baseline and each of the alternative time-series).

Prior to carrying out the simulations, as requested by the DEP (DEP 2000b), several calibration runs of SPDM were conducted to insure reasonable agreement between the population projections for 1999-2000 and recent abundance estimates of the Niantic River winter flounder female spawning stock. Although the DEP suggested that the time-series of adult stock size be used as a tuning index for the SPDM projections, no method was suggested. It was decided to first review relevant literature for potential updates of population parameter estimates used by the model, which could cause model output to match more closely the observed abundance time-series. The instantaneous natural annual mortality rate (M) of age-1 flounder used in all recent applications of the SPDM (i.e., M = 0.50 in Table 4, p. 31, NUSCO 2000) was perhaps too low since it amounts to a monthly attrition rate of only 4.1% (annual survival $S = e^{-M}$). Field sampling showed consistently that numbers of age-0 juvenile winter flounder decline rapidly during the 4 months following metamorphosis and settlement (see Chapter 3, Table 3-6), with a 17-year (1984-2000) mean survival rate of only 9.2% through this 4-month period, or an average monthly attrition rate of 45%. Specific information is lacking to calculate a mortality rate during late fall and winter and when this group of fish becomes age-1 in the following spring. Although M most likely decreases as these fish grow older and larger, mortality of these older immature fish nevertheless remains higher than that of adult fish. Data from a study of Mystic River, CT winter flounder (Pearcy 1962) that were discussed by Klein-MacPhee (1978) in a synopsis of biological data for winter flounder suggested a total survival rate of 0.41 for winter flounder between the ages 12.4 and 22.4 months. Since this survival rate is equivalent to an annual natural mortality rate of M = 1.07, or twice the rate used in SPDM, it was decide to calibrate the model output by progressively increasing the value of M = 0.50 for age-1 winter flounder. After a few trial runs of the SPDM using the DEP schedule of fishing rates (Table 4-5) and the same annual production losses (ENT) as in NUSCO (2000), the model output converged to current stock levels as shown in Figure 4-4. At the point in the calibration process at which model output matched field data-based adult stock sizes during the last 4 years, M for age-1 flounder was 0.8425. Since this value appeared reasonable,

although still less than the estimate of Pearcy (1962), it was substituted in the input data for the model (Table 4-4) and used for all simulations conducted during this study.

Next, an attempt was made to recalibrate the model in a similar manner, but this time using the SARC schedule of fishing rates (Table 4-5). The model projections shown in Figure 4-5 illustrate the results of simply substituting the SARC schedule of F rates while leaving the value of M = 0.8425 determined for age-1 flounder unchanged. It is clear that under the regime of SARC F rates the SPDM stock projections beginning in 1995 increase well above both field data-based stock sizes and model predictions using DEP exploitation rates. By 1998, model output under SARC F rates (Fig. 4-5) begins to show unrealistically high stock sizes of over 20,000 female spawners, a population size not seen in the Niantic River since 1990. The natural mortality rate for age-1 fish was then progressively increased in a series of trial runs of the model until the stock projections for the last 4-5 years converged to the field data-based estimates (Fig. 4-6). However, to achieve this it was necessary to increase age-1 M to 1.39, which is much higher than any estimate found in the literature. That this high value of M was not acceptable for the purposes of this study is illustrated in Figure 4-7, where the trajectory of the stock size projected beyond 2000 with the constant SARC rate F = 0.375 (Table 4-5) indicates an irreversible decline. Therefore, for the SARC simulations it was decided to use an M = 0.8425, the value calibrated for the DEP fishing rates as the only reasonable alternative. This unfortunately provides a clearly unrealistic baseline for this study (uppermost trajectory in Fig. 4-7), which predicts large spawning biomass increases after 1998 at levels 4 to 6 times that of recent stock size estimates. The reason for this behavior is clearly the application of fishing rates that bear no relation to the actual exploitation rates of winter flounder in Southern New England and particularly in Connecticut waters. This conclusion is supported by a very recent document (ASMFC 2001), where in a discussion of the status of the Southern New England and Mid-Atlantic (SNE/MA) winter flounder stock complex it is stated that "... the stock complex remains below its biomass target with fishing mortality in the 0.3 to 0.4 range. However, numerous state survey indices for the SNE/MA stock complex indicate that biomass has decreased." A cursory examination of the historical record on winter flounder exploitation rates, landings, and abundance estimates of spawning stocks throughout the region shows that current biomass could not be decreasing if the actual fishing mortality rates were in the range of 0.3 to 0.40.

The first complete series of simulations to investigate the effectiveness of selected alternatives to reduce larval entrainment were carried out using the DEP fishing rates (Table 4-5) and the three sets (mean, low, and high) of annual production losses shown in Table 4-3. Since five different levels of entrainment reduction were investigated, the total number of SPDM stochastic time-series of stock sizes generated was 3 x 5 x 500. The final fifteen time-series of mean annual stock sizes computed from each set of 500 stochastic replicates are shown in Figures 4-8 through 4-10. Each figure summarizes the simulation results for one of the three sets of assumed production losses due to entrainment and includes a baseline time-series simulated without any entrainment reduction effects in

addition to the five time-series corresponding to each of the five levels of entrainment reduction investigated. As was expected, the absolute benefits (i.e., direct increases from the baseline) resulting from reducing larval entrainment were consistently larger under the assumption of a constant high annual production loss (Fig. 4-10) than in the cases of mean or low production losses (Figs. 4-8 and 4-9). In all three cases, benefits were not substantial (defined as biomass increases >1,000 lbs) for entrainment reductions of less than 35% and it took an average of 20 years to achieve that level of stock improvement, as illustrated in Figure 4-11 for the case of mean annual production losses.

To summarize all the above simulations, the absolute biomass "gains" relative to the baseline were calculated year by year (as shown in Fig. 4-11) for each of the five reductions of larval entrainment investigated. These gains were then summed over the years (2002-45) and plotted as cumulative gains (Figs. 4-12 through 4-14) from which annual running averages were finally calculated (Figs. 4-15 through 4-17). Both cumulative and moving annual averages are useful for contrasting the effectiveness of the five levels of larval entrainment reductions simulated under various conditions. Summaries in Tables 4-7 and 4-8 give accumulated total biomass gains and increases in stock sizes relative to the baseline, respectively, after 10, 20, 30, and 43 years of plant operation for each alternative entrainment reduction; the last period ends in 2045, when Unit 3 was presumed to cease operating. Given the uncertainty of the fishing rate currently operating on the Niantic River winter flounder stock and the almost impossible task of keeping it stable over many years, projected biomass gains become less reliable with elapsed time after 2002. Therefore, projections of absolute biomass gains and stock size increases in Tables 4-7 and 4-8 should be used with caution. Clearly, the final values at the end of the series in 2045 are only indices useful for relative comparisons among the various entrainment reductions and power plant operation conditions simulated.

To provide some perspective on estimates of projected biomass increases (Tables 4-7 and 4-8), recreational and commercial landings of winter flounder in Connecticut waters were obtained from NMFS (2001) for 1981 through 1999 (Table 4-9). Using the series of DEP and SARC F rates compiled for use in this study (Table 4-5), exploitation rates (u) were calculated as follows:

$$u = (F / (F + M) \cdot (1 - \exp(-F - M)) \quad (1)$$

where M is the instantaneous natural mortality rate for adult winter flounder (0.2; Table 4-4). The annual exploitation rates were then used to estimate the annual winter flounder stock sizes (N) of winter flounder in Connecticut waters, which was presumed to be the aggregate of all stocks in LIS:

$$N = C / u \quad (2)$$

where C is total annual Connecticut landings of winter flounder in lbs. Because of variable F rates, biomass estimates also varied, but since 1993 the DEP-based biomass estimates were smaller (41-73%) than the SARC-

based estimates. Using DEP F rates, stock sizes of 2 to 4 million lbs decreased to less than 2 million lbs in 1991, whereas the SARC series showed stock biomass of 2 to 6 million lbs declining to about 1.5 to 2.7 million lbs (Table 4-9). Data from annual winter flounder abundance surveys were used to calculate the size of the exploitable biomass of Niantic River winter flounder for the same years. The annual standardized catches (DNC 2001a) of both male and female winter flounder present during the spawning season in the Niantic River were determined using the minimum legal size for retention (see Table 2 of NUSCO 2000), which was lower in some years for the recreational fishery than the commercial fishery. Since 1981, minimum size has increased from 8 to 12 inches (20.3 to 30.5 cm). Annual abundance by 0.5-cm size-class was converted to weight using a length-weight relationship determined for Niantic River winter flounder:

$$\text{weight in lbs} = ((0.00545)\cdot\text{length (in cm)}^{3.226}) / 1000)\cdot 2.205 \qquad (3)$$

Weights were summed over all size-classes and annual totals represented exploitable biomass for the Niantic Rover stock (Table 4-10). Exploitable stock size decreased from over 120 thousand lbs in 1981-82 to 4-7 thousand lbs in 1996-99 as abundance decreased and minimum size for exploitation increased. Through 1995, these values represented from about 1 to 3% of the LIS aggregated stock biomass, but were only about 0.3-0.6% in 1997 and 1999. The geometric means of both the DEP and SARC series indicated that the Niantic River winter flounder population probably made up less than 2% of the exploitable stock biomass in LIS.

A second set of simulations was conducted to comply with the specific DEP request to carry out a complete assessment using SARC fishing mortality rates (Table 4-5). All the other population parameters, annual production losses, entrainment reduction alternatives, and simulation scenarios were as in the DEP simulation series described above. The results of the SARC simulations are shown in Figures 4-18 through 4-20 for mean, low, and high annual production losses, respectively. It should be noted that the projected stock sizes start from a much higher level (over 17,000 lbs) than in the case of the DEP simulations (Figs. 4-8 through 4-10). Because of this higher initial level resulting from very low fishing rates in the previous 3 to 4 years (Table 4-5) and also after 2000, the baseline spawning biomass grows rapidly to between 22,000 and 28,000 lbs during the first 20 years of the simulation, depending upon the annual production losses assumed. The effect of the five levels of larval entrainment reduction investigated were also greatly magnified relative to the DEP simulation series. As for the baseline differences, the reasons for this were the larger scale effect and a fishing mortality that was half of that of the DEP series. Low fishing rates magnified the effects of reducing larval entrainment because the fraction of the resulting spawning biomass gain removed by fishing is smaller. The summarization of the SARC simulations involved the same calculations described above for the DEP series and, although no graphic summaries of the biomass gains were prepared, the cumulative biomass increases for each entrainment reduction relative to the baseline are listed in Table 4-7 together with the DEP series results. It was not surprising that at the end of the 43-year series the absolute biomass gains achieved under the SARC fishing rates were 65% to 90% larger than with the

DEP rates for the same entrainment reductions. As discussed before in this section, the validity of this assessment is greatly dependent on the fishing rates that will actually operate during in the next 10 to 40 years and there is little doubt that the SARC fishing rates used in these simulations do not correspond to current exploitation rates in Connecticut waters. Whether they will become closer to the actual rates affecting the Niantic River winter flounder in the near future is very much an open question.

To further illustrate the likely result of reducing larval entrainment by a substantial amount (e.g., >15%) and the disproportionate influence that fishing rates have, an additional set of two simulations were conducted that described the long term effects of removing MNPS Unit 1 under the two different fishing rates defined as DEP and SARC rates after 1999 in Table 4-5. For this purpose, the time-series (2000-45) of the Niantic River winter flounder stock projections was simulated with the two different fishing rates as if Unit 1 had not ceased operation in 1995. The latter was simulated by using a rate of annual production loss due to entrainment equal to 16.16%, the mean for the 10-year period of three-unit operation at MNPS (Table 4-3). These two time-series were plotted in Figure 4-21 together with the DEP and SARC baselines used in all the previous simulations, which assumed two-unit operation (i.e., with Unit 1 removed). The two levels of the stock trajectories resulting from the two fishing rates under a three-unit operation scenario (dashed lines) can be visually contrasted with the small biomass increases resulting from ceasing operation of Unit 1 (about a 23% reduction in entrainment) represented by the two-unit operation baselines (solid lines). Biomass increases for the same reduction in entrainment are larger for the SARC series, in which the fishing rate was about half that of the DEP series. However, even though biomass increases when plant operation is reduced, this increase is considerably less when F alone is reduced.

Finally, a simulation was conducted to help clarify the issue of the different scales by which spawning biomass responds to changes in mortality due to larval entrainment and to exploitation of adult fish. For commercially exploited and long-lived species like the winter flounder, the long-term effect of larval entrainment on adult fish biomass is relatively minor when compared to the effects of commercial exploitation. This occurs because larval entrainment impacts each year-class not only once but early in life when natural mortality is high, while commercial fishing impacts the year-class after the fish become vulnerable to the fishery year after year for as long as the year-class persists. Additionally, annual exploitation rates can be as high as 65% or more (such as for winter flounder in the early 1990s) while entrainment rates are generally much less. This was recently demonstrated by O'Connor (2001) who conducted a generic Leslie matrix-based comparative analysis and concluded that "...fishing has a more severe effect on future populations than chronic impacts that decrease only first-year survival or fecundity." However, it is difficult to quantify the difference in a stock response to these two types or mortality because it depends on complex factors, such as density-dependent processes early in the life of the fish and the age structure of the spawners, which changes with variable annual recruitment and fishing pressure. Population dynamics models

like the SPDM, with explicit representation of the age structure and integration of compensatory effects, are well-suited to simulate and help quantify the stock response to the two types of mortality discussed above.

The last simulation conducted in this study attempted to provide a direct comparison of the spawning biomass changes resulting from reducing larval entrainment and exploitation rates by the same percentage. For this purpose a single simulation of a modified baseline DEP series (2002-45) with the mean rate of production loss due to entrainment was carried out with the fishing rate F = 0.74 (equivalent to a 48% exploitation rate) that was reduced to F = 0.59 to simulate a 15% reduction of the annual exploitation rate (i.e., from 48 to 40.8%). The time-series of stock biomass sizes thus generated was plotted in Figure 4-22 together with the baseline and the series simulating a 15% larval entrainment reduction shown earlier in Figure 4-8. It is clear that the trajectory of stock sizes (top line) resulting from a 15% reduction in exploitation rate and no reduction of entrainment exhibits an immediate response and a spawning biomass that increases rapidly relative to the baseline (bottom line) showing no reduction in either fishing or entrainment rates. Alternatively, the middle line simulating the response to a 15% reduction in entrainment rate with no change in fishing exhibits a response delayed by 5 to 6 years and a spawning biomass with scant growth for the next 20 years or so. At the end of the series in 2045, the biomass gains resulting from reducing exploitation by 15% were more than one order of magnitude larger that those obtained by reducing larval entrainment by the same percentage. The latter difference is better illustrated in Figure 4-23, which displays the actual annual differences in biomass relative to the baseline, and in Figure 4-24, which displays the accumulated gains of biomass up to each year in the series. These results strongly suggest that the small gains from a larval entrainment reduction of 15%, achieved by some intake modification at great financial cost, could easily and quickly become undone by a rather small (e.g., <5%) increase in fishing rates.

Based on the modeling conducted for this report, a conclusion of this study is that technological solutions to the problem of larval entrainment can result in measurable and long-lasting improvement of the Niantic River winter flounder stock, but only if current exploitation rates can also be reduced substantially and permanently. In fact, the SPDM simulations indicated that even modest reductions in exploitation would result in immediate and greater stock improvement than from much larger reductions of larval entrainment.

4.2.4 The Effectiveness of Reducing Entrainment of Non-Niantic River Winter Flounder Larvae by Selected Cooling-Water Intake System Alternatives

Equivalent-adult estimates for winter flounder larvae entrained at MNPS that originated from sources other than the Niantic River were calculated using methods outlined in Saila et al. (1997). This model, which incorporates size-specific survival rates of larval and juvenile stages (Goodyear 1978; Saila et al. 1997) is an adaptation of the equivalent-adult model described by Horst (1975):

$$N_a = \Sigma N_i S_i \qquad (4)$$

where N_a is the estimated number of adult fish lost due to entrainment of eggs and larvae, N_i is the number of fish eggs or larvae entrained, and S_i is the probability of survival from stage i to adulthood. The parameter S_i uses estimates of lifetime fecundity (f_a) to produce estimates of survival to adulthood. Probability of egg survival to adulthood (S) is calculated as $S = 2/F_a$ and the probability of larval survival to adulthood (S_l) is calculated as $S_l = 2/S_e f_a$ where S_e is the probability of survival from egg to larvae. This method assumes that the population is at equilibrium and that the average lifetime fecundity of the species is known (Horst 1975; Goodyear 1978). Further, single estimates of annual adult, egg, and larval survival were derived and applied to all years assuming that these rates did not vary among years. Derivations of specific parameter estimates, use of surrogate values, and other assumptions are described below. This methodology was also used for the other selected fishes, which are discussed below in Sections 4.3 and 4.4.

Parameter estimates used in the calculation of equivalent-adults were from Niantic River winter flounder data, such as the information needed to calculate life-time fecundity (Table 4-11), or were obtained from Saila et al. (1997) and are listed in Table 4-12. The estimate of life-time fecundity of 600,080 is reasonably close to the observed current mean fecundity of 583,000 for the Niantic River population, which was calculated on the basis of observed size and abundance of Niantic River female spawners from 1977 through 2000 (DNC 2001a).

Estimates of numbers of larvae entrained that originated from sources other than the Niantic River could be obtained by subtraction in Table 3-9 of Chapter 3. However, stage-specific estimates of Niantic and non-Niantic River larvae were also calculated in NUSCO (2000) and values specifically for 1986 through 1995 (effective period of three-unit operation) found in Table 4-1 were used in the calculation of equivalent-adults. These estimates were derived from the mass-balance model described in Appendix B to Chapter 3. As noted in Section 4.2.2 for Niantic River winter flounder, entrainment estimates made during the three-unit period were conservatively reduced by 20% prior in making further calculations so that future entrainment rates under the present two operating MNPS units may be assessed. This 20% reduction in entrainment to assess the effectiveness of intake technology alternatives was also done in making equivalent-adult estimates for the other selected fishes presented in Sections 4.3 and 4.4. Because about 25% of age-3 females become mature, equivalent-adult calculations for non-Niantic River winter flounder were made through age-3, even though winter flounder only become fully recruited at age-4 and females fully mature at age-5. This procedure results in a larger estimate of equivalent-adults and a conservative estimate of entrainment loss.

Two-unit entrainment estimates were determined for each developmental stage for all non-Niantic River winter flounder larvae during the 10-year period from 1986 through 1995 (Table 4-13). Dominating winter flounder

entrainment, Stage 3 larvae made up the largest numbers of equivalent-adults. Annual total entrainment of non-Niantic River winter flounder ranged from about 35 million to 394 million and averaged 115 million larvae. Estimates of age-3 equivalent-adults lost due to entrainment of non-Niantic River flounder larvae during two-unit operation ranged between 6,295 and 50,070 fish and had a mean of 18,021 (Table 4-13). The estimated average annual loss may be reduced by the same fractions as used in Section 4.2.3 for Niantic River winter flounder larvae (6, 15, 35, 58, and 91%) to determine the effect of reductions in larval entrainment from the implementation of selected intake technology alternatives. The resulting equivalent-adult losses under these levels of entrainment reduction would be 16,940, 15,318, 11,714, 6,569, and 1,622 fish, respectively.

The estimated annual loss by entrainment of age-3 equivalent adult winter flounder from spawning stocks other than the Niantic River at MNPS is highly conservative due to several factors. This methodology itself is very conservative and does not include any mechanism for compensation at the population level. Extending the calculation only to age-3 ignores the fact that many of these fish will not become mature until age-4 or 5 and will be subjected to an additional year of both natural and fishing mortality. The non-Niantic River larvae entrained likely come from several sources, including spawning stocks associated with the Thames and Connecticut Rivers and perhaps also from more distant locations. Studies to directly assess the stock identification of winter flounder larvae entrained at MNPS using genetic and microelemental composition techniques were underway at the time this report was prepared and results will be provided to DEP when these studies are completed. Having larvae coming from several source populations spreads the risk of impact among them with a commensurate decrease in the probability that potential losses would affect the population dynamics of each. The areas available for spawning in the Thames River and off the mouth of the Connecticut River are also considerably larger than the Niantic River. Therefore, these other stocks are likely numerically larger than the Niantic River population as winter flounder population size tends to be proportional to their habitat area (Howell 1993). This would further reduce the effects of an impact to these populations.

In examining larval winter flounder entrainment, Crecco (1994) completed equivalent-adult calculations for eight coastal Connecticut power plants, including MNPS. His annual estimate for MNPS-entrained larvae (from all sources) was 23,344. Coincidentally, this is precisely the same estimate computed for MNPS if the mean (1986-95) equivalent-adult loss computed for Niantic River larvae (4,203) is added to the non-river total and re-adjusted upwards by 20%. This equivalent-adult estimate for MNPS was about 1,000 fish higher than the one computed by Crecco (1994) for Montville Station, located in the Thames River, although it is about 10,000 fish lower if the total for the adjacent AES Thames plant was added to the Montville Station total. The MNPS total was also about 1,800 fish less than the estimate for the New Haven Harbor power plant. Thus, these stations could be removing more winter flounder from single stocks than MNPS is from multiple sources. These fossil-fueled plants would be among those operating at a higher capacity if MNPS is required to constrain its operation and reduce electrical generation.

Crecco (1994) noted that power plant losses were not regarded as a serious loss to the Connecticut winter flounder resource, in the absence of other human effects, such as pollution and fishing. However, he concluded that power plant losses could reduce the compensatory reserve of winter flounder, particularly the cumulative effects of plants in eastern LIS, and this should be taken into consideration when determining biological reference points.

4.2.5 Trends in Winter Flounder Abundance and the Formation of Year-class Strength

One of the goals of the winter flounder impact assessment modeling was to have the modeled time-series of adult female biomass match present abundance prior to making projections into the future (DEP 2000b). In Section 4.2.3, the SPDM was calibrated through an increase in age-0 mortality to match observed abundance of Niantic River female winter flounder. Model output then was used to illustrate how reductions in year-class abundance through larval entrainment at MNPS were lessened via five postulated levels of reduction in entrainment. But has the actual reduction in entrainment that already occurred as a result of the extended shutdowns of MNPS units from 1996 through 1998 and the retirement of Unit 1 (23% of former total station cooling-water use) resulted in substantive increases in winter flounder abundance? And, is the effect of entrainment directly related to the amount of cooling water used at MNPS? These questions as well as other findings regarding winter flounder abundance and recruitment may be addressed by examining information available from the long-term monitoring studies of Niantic River winter flounder and the extensive knowledge of this species available in the scientific literature.

A major premise in the assessment of impact on the Niantic River winter flounder stock has been that the magnitude of entrainment is dependent upon how many of their larvae were entrained. Larval winter flounder entrainment in general was discussed previously in Section 3.2.4 of Chapter 3. In particular, both flow and larval densities (see Chapter 3, Table 3-7) have varied over each larval season and among years (Fig. 4-25). Increased larval abundance has been seen in recent years, when some of the highest mean densities have been observed. The time-series of annual entrainment abundance (an index described by the *A* parameter of the Gompertz function; see Chapter 3, Section 3.2.4) and the annual volume of seawater used at MNPS have relatively similar coefficients of variation (CV; 49 and 44%, respectively). The entrainment estimates, however, have a CV of 71% because both larval densities and plant operation affect this estimate and they vary independently from year to year. A high larval abundance for a particular year is not functionally associated with high flow and vice versa. In fact, using Spearman's rank-order correlation (Snedecor and Cochran 1967; Hollander and Wolfe 1973), these two measures were not significantly correlated ($r = -0.231$; $p = 0.267$; $n = 25$). Thus, cooling-water flow alone cannot be used as a measure of plant effect, as the fraction of Niantic River larval production available to entrainment and its relation to total larval entrainment changes from year to year. Variable annual rates of entrainment appear to be real and may be related to physical processes (e.g., precipitation, winds) that vary both intra- and interannually during the larval developmental period when the abundance, distribution, natural mortality, and behavior of larvae are also variable.

An index of the annual rate of entrainment (number of larvae per unit volume of cooling water) may be computed by dividing the annual entrainment abundance index (i.e., *A* parameter of the Gompertz function) by the total volume of seawater entrained each year (Fig. 4-26). Based on the non-parametric Mann-Kendall test (Hollander and Wolfe 1973), the entrainment rate since 1976 has varied without a significant ($p = 0.293$) trend in slope. The entrainment rate time-series has a coefficient of variation (CV) of 56%, which is intermediate between density, flow, and numerical entrainment estimates. Thus, larval production and availability in Niantic Bay has remained stable despite increases in MNPS cooling-water use during 1986-95, the effective period of full three-unit operation. Also, reduced recruitment has not been the result of reduced larval abundance, because the latter has exhibited no trend after many years of MNPS operation.

Relationships between larval entrainment estimates and various indices of juvenile abundance were examined to determine if there has been an apparent direct effect of entrainment on a year-class. Annual entrainment estimates were significantly positively correlated with three abundance indices of age-0 juvenile winter flounder, including the median catch-per-unit-effort (CPUE) of age-0 fish taken in both early and late summer in the Niantic River and with age-0 juveniles taken at MNPS trawl monitoring program stations during late fall and early winter (Table 4-14). Although statistically significant, the form of the relationships between the entrainment estimates and these age-0 abundance indices was not obvious (Fig. 4-27). Entrainment estimates were not significantly correlated, however, with age-1 winter flounder collected in either the lower or upper Niantic River during the adult winter flounder surveys.

Densities of winter flounder larvae 7 mm and larger taken at the MNPS discharges (another index of abundance at the plant discharges) were significantly correlated (Spearman rank-order correlation; $r = 0.5679$; $p = 0.014$; $n = 18$) with abundance of Stage 4 larvae in the Niantic River (Fig. 4-28). As the significant correlation coefficients found between entrainment estimates and age-0 abundances were positive, they implied no apparent entrainment effect and indicated that the more larvae that were available for entrainment, the more that settled as demersal young in the Niantic River. However, even negative correlations between annual entrainment and abundance of early life history stages do not necessarily imply an entrainment impact unless positive correlations can be found between those early life history stages and mature female fish, which are lacking (Table 4-15).

Based on catches of settled age-0 winter flounder in sampling by 1-m beam trawl in the Niantic River since 1983, most fish were produced in 1988, 1992, 1994, 1995, and 2000, with particularly weak year-classes formed during the mid-1980s, 1989, 1993, 1996 (although age-0 winter flounder of this year-class were found to be numerous in fall and winter following that summer), and 1997 (see Chapter 3, Fig. 3-4). The largest larval winter flounder entrainment estimates at MNPS during the three-unit period were in 1992, 1995, and 2000 and the smallest estimates occurred during 1993 and 1996-98 (see Chapter 3, Table 3-7). This suggests that in some years, year-

class strength was strongly influenced by events during early life history stages resulting in abundant larvae and early settling juveniles. Thus, entrainment estimates only reflected emerging year-class strength rather than being the most important factor affecting numerical abundance. The examples of low mortality in 1988 and 2000 (Chapter 3, Table 3-6) and high mortality in 1990 also showed that mortality during the first summer on the nursery ground, which is totally unaffected by MNPS operation, profoundly influences year-class strength and ultimate recruitment to adult stocks of fish.

Year-class strengths are likely determined during larval and early juvenile life stages of marine fishes, yet these phases of life history are least understood (Sissenwine 1984; Bailey and Houde 1989a; Bradford 1992). Accordingly, formation of winter flounder year-class strength begins at egg deposition, or even before, given some known maternal influences on egg quality. For example, a study by Buckley et al. (1991) noted that female size and time of spawning affected various winter flounder reproductive parameters, including egg size, fecundity, and viability. They observed that embryos deposited earlier in the season by larger females appeared to have better survival than eggs produced by smaller fish late in the season. Biological consequences of the selective removal of large fish by fishing can be more profound than just reducing egg production because of the aspects of egg size and time of spawning relating to reproductive success (Trippel 1995; Conover 2000).

Compared to the winter flounder larval developmental period, less is known about the egg stage. Environmental factors have important implications on egg survival and hatching (Bunn et al. 2000). Keller and Klein-MacPhee (2000) reported that in a mesocosm study completed in Rhode Island, winter flounder egg survival, percent hatch, time to hatch, and initial size were greater in cooler than warmer systems. Morrison et al. (1991) reported high mortality of demersal Atlantic herring eggs in the Firth of Clyde, Scotland because of heavy deposition of organic matter resulting from a bloom of the diatom *Skeletonema costatum*. The decomposing material caused a depletion of oxygen and egg death due to anoxia. This diatom was one of the most abundant of the phytoplankton collected at MNPS during entrainment sampling from 1977 through 1980 (NUSCO 1981). However, highest densities occurred in summer, after the winter flounder egg incubation period. *S. costatum* was also a dominant form in the warm (about 1°C above current ambient mean water temperature) treatment in the mesocosm study of Keller and Klein-MacPhee (2000). Macroalgal and detrital mass have varied considerably among years of study in the Niantic River since the mid-1970s and the amount of organic material on the river bottom may have had some influence on the survival of demersal winter flounder eggs.

Based on a comparison of estimates of egg production and abundance of Stage 1 larvae (see Chapter 3, Section 3.2.3 and Fig. 3-2), egg mortality from unknown causes may be considerable in the Niantic River, but may also vary in a density-dependent fashion in some years. This apparent effect resulted in egg survival that could have been as much as four times higher during the period of 1995-99 (when adult abundance was particularly low) than in

previous years or in 2000. The mechanisms responsible for greater winter flounder egg survival were not studied, but hypotheses concerning this effect include less predation pressure because of fewer cues for predators under low egg abundance or better egg quality because of greater food resources shared among fewer adult females. Regarding predation on eggs, DeBlois and Leggett (1991) and Frank and Leggett (1984) found that both the amphipod *Calliopius laeviusculus* and winter flounder preyed heavily upon demersal capelin eggs, removing up to 39% and 5% of the production, respectively. They suggested that invertebrate predation on demersal fish eggs may be an important regulatory mechanism for population size in marine fishes having demersal eggs. Because demersal fish eggs are immobile and found in relatively dense patches, they may attract many predators (Bunn et al. 2000). In particular, the sevenspine bay shrimp has been observed feeding on winter flounder egg clusters in laboratory tanks (D. Taylor, University of Rhode Island, Narragansett, RI, pers. comm.).

Larval mortality can vary considerably from year to year (see Chapter 3, Section 3.2.3 and Table 3-5) and can have profound effects on the number of young that metamorphose and settle. Larval winter flounder mortality was found to be related to both larval density and April water temperatures (see Chapter 3, Fig. 3-3). Thus, even though egg abundance was approximately as low in 2000 as it was during 1995-99, enhanced egg survival or hatchability was not seen that year. However, relatively high abundance of older larvae suggested that larval survival was particularly good, perhaps reflecting a compensatory response related to low larval densities.

Intrinsic (e.g., growth) and extrinsic (e.g., predation) factors both affect survival. Several workers (Laurence 1977; Chambers et al. 1988) found that much of larval winter flounder mortality was concentrated in early life and at first feeding weeks after hatching, so the strength of a year-class could be determined by the availability of sufficient food after completion of yolk absorption. However, Keller and Klein-MacPhee (2000) noted in a mesocosm study that food availability was not the most important factor related to larval mortality as mortality was highest in their warm treatment, which also had the highest food availability. Daily mortality rates increased directly with the abundance of active predators in the mesocosms, but this may have been an effect of the relatively low numbers of predators in their experimental system. They further noted that daily growth and mortality rates were significantly and inversely related.

Predation is often one of the most important causes of larval fish mortality (Bailey and Houde 1989) and this has relevance to winter flounder larval populations. The relationship between winter flounder larvae and their predators was studied by Williams and Brown (1992), who found that escape response increased with increasing larval size, but that it remained slower than that of other larval fishes examined. Larval winter flounder are likely vulnerable to both fish and invertebrate predators. Although susceptible to attacks by planktivorous fishes, the temporal occurrence and abundance of fishes that could potentially prey on larval winter flounder are low, particularly during the early portion of the larval winter flounder season.

Most predation on winter flounder larvae is probably by invertebrate contact predators, such as anemones (Keller and Klein-MacPhee 2000), other cnidarians, and ctenophores, many of which have been previously identified as feeding on flatfish larvae. Evidence of a causal predator-prey relationship on larvae of European plaice and European flounder by the scyphomedusan *Aurelia aurita* and the ctenophore *Pleurobrachia pileus* was reported by Van der Veer (1985). However, most predation by these species occurred at the end of the larval plaice season and likely did not ultimately affect year-class strength (Van der Veer 1985; Van der Veer et al. 1990). Laboratory studies showed that successful capture of plaice larvae increased as medusal size of *A. aurita* increased (Bailey and Batty 1984). Pearcy (1962) stated that *Sarsia tubulosa* medusae were important predators of larval winter flounder in the Mystic River and had greatest impact on younger, less mobile larvae. Crawford and Carey (1985) reported large numbers of the moon jelly (*A. aurita*) in Point Judith Pond, RI and believed that they were a significant predator of larval winter flounder. Potential predators of winter flounder larvae in the Niantic River were medusae of the lion's mane jellyfish (*Cyanea* sp.), which can be abundant in the upper river (Marshall and Hicks 1962), including station A. A laboratory study showed that winter flounder larvae contacting the tentacles of the lion's mane jellyfish were stunned and ultimately died, even if not consumed by the medusa (NUSCO 1988). Also, in 1997 ctenophores, another larval fish predator, were present during the larval winter flounder season (NUSCO 1998a). However, the relationship between larval winter flounder and jellyfish biomass did not support a cause and effect relationship and the role that these and other planktonic predators have each year on ultimate year-class strength is yet unknown.

Physical, hydrodynamic processes occurring during the larval stage and settlement of juveniles can also affect the success of a year-class (Werner et al. 1997). This may occur by determining their rates of exposure to predation and food resources and location of settlement. Many winter flounder larvae are flushed from natal estuaries and transported by water currents within LIS. Variability may also be imposed on the transport of larvae by winds and work on other flatfishes is illustrative of these effects. Densities of settled juveniles of the brown sole in Japan were related to the frequency of onshore wind events (Nakata et al. 2000). Variable rates of transport in LIS can affect not only the availability of winter flounder larvae for entrainment at MNPS, but likely also where larvae are able to settle as juveniles. Both European plaice and stone flounder larvae use selective tidal transport to enter coastal nursery areas (Rijnsdorp et al. 1985; Yamashita et al. 1996a). Winter flounder larvae also appear to have an ability to enter nursery areas such as the Niantic River, as illustrated by a secondary peak in abundance of older larvae during the later stages of development. Nearly all pre-recruits are produced in the river and similar nursery habitats. The survival of larvae settling in Niantic Bay or other deeper areas outside of inshore nursery grounds is poor, probably because of high rates of predation. Similarly, Yamashita et al. (2000) found that small estuaries produced disproportionately more stone flounder juveniles than geographically much larger nursery areas found in shallow, more exposed areas of Sendai Bay, Japan.

For newly settled young of flatfishes, Van der Veer et al. (1990) speculated that, in general, predation by crustaceans may be a common regulatory process, although this may not be a strong effect in all areas (Nash and Geffen 2000). Predation by various caridean shrimps has been suggested as the cause of high mortality after metamorphosis for several flatfishes, including the winter flounder (Witting and Able 1993, 1995), European plaice (Lockwood 1980; Van der Veer and Bergman 1987; Pihl 1990; Van der Veer et al. 1990; Pihl and Van der Veer 1992; Gibson et al. 1995; Van der Veer et al. 2000a), Japanese flounder (Seikai et al. 1993), and stone flounder (Yamashita et al. 1996b). Smaller (10-20 mm) European plaice were preferentially preyed upon by the brown shrimp (Van der Veer and Bergman 1987). Similarly, Witting and Able (1993, 1995) found that the size of age-0 winter flounder significantly affected their probability of predation by sevenspine bay shrimp, with predation greatest at settlement for the smallest fish. Mortality decreased with size and young apparently outgrew predation by shrimp when they reached 17 to 20 mm in length, which meant that fish would have to double in length after settlement before attaining a size refuge from shrimp attacks. Predation was also related to shrimp density and steadily increased until reaching an asymptote at shrimp densities greater than $10.6 \cdot m^{-2}$ (Witting and Able 1995).

Other predators of juvenile winter flounder include the green crab (Fairchild and Howell 2000), larger fishes (e.g., grubby) and marine birds (e.g., double-crested cormorants) and predation likely continues throughout summer in shallow nursery habitats preferred by young winter flounder. Predation by several of these species on juvenile winter flounder in the Mystic River, CT estuary was suggested by Pearcy (1962). Manderson et al. (2000) reported that summer flounder preyed upon age-0 winter flounder in the Navesink River, NJ with selection increasing as juvenile winter flounder grew from 20 to 90 mm. Striped searobin prey heavily upon young winter flounder when they co-occur (Manderson et al. 1999). Green crab abundance in the Niantic River has increased substantially in recent years (Fig. 4-29). A non-parametric Mann-Kendall test showed a significant ($p < 0.0001$) positive trend in the slope of the annual catch of green crabs at the trawl monitoring program station in the Niantic River since 1976. Cormorant predation on winter flounder, in particular, has also been observed in the Niantic River. Winter flounder otoliths were identified in regurgitated pellets of cormorants nesting in areas near MNPS and over 100 active nests alone were found on Waterford Island, just off the mouth of the Niantic River (M. Male, Old Lyme CT, pers. comm.). Birt et al. (1987) found that close to their nesting colonies, cormorant predation depleted fish populations, including winter flounder, with higher fish densities seen in areas beyond the foraging range of these birds. Cormorant numbers in Connecticut increased 15% annually between 1986 and 1998 and by 14% in coastal New York (Wires et al. 2001). In Rhode Island, the annual increase from 1981 to 1990 was even greater (63%). Manderson et al. (2000) found that the presence of vegetation (eelgrass, macroalgae) decreased the vulnerability of young winter flounder to predation. Eelgrass beds in the Niantic River have decreased considerably in recent years (DNC 2001d), perhaps increasing the vulnerability of winter flounder to predation.

Another cause of mortality during the first year of life of winter flounder is from infection by the microsporidian parasite *Glugea stephani*, the severity of which can vary by fish size, density, and environmental factors such as water temperature (Takvorian and Cali 1981, 1984; Cali et al. 1986; Cali and Takvorian 1991; MacLean 1993). Irregular rates of infection in age-0 winter flounder can also introduce variation in winter flounder recruitment.

As for larvae, the time duration that settled juveniles spend in a vulnerable size range, which is related to growth rate, affects the vulnerability of young to predation by shrimp and other organisms. Variation in growth, which can depend upon specific location of settling, specific habitat within a location, temperature, or food (Sogard 1990; Sogard and Able 1992; Gibson 1994), may have significant implications for young winter flounder survival after metamorphosis. Al-Hossaini et al. (1989) reported greater growth for cohorts of European plaice that settled relatively early in Wales, but these fish also had higher mortality. Conversely, growth was slower in late-settling cohorts, but survival was higher. In contrast to shrimp predation, larger-sized age-0 flatfish may be preferentially selected by birds and certain fishes (Van der Veer et al. 1997). In addition, environmental effects, such as water temperature, on predators may greatly influence their ability to prey on young winter flounder. In particular, the effects of February water temperature on the recruitment of winter flounder is discussed below.

Temperature can also act indirectly across several early life history stages by affecting growth, development, and mortality. Van de Veer et al. (2000b) proposed that meristic elements, such as the number of vertebrae and fin rays, had effects seen later in the juvenile stage of young European plaice. Temperature-dependent characters, particularly vertebrae number (established during the egg stage) and fin ray number (during the larvae phase), appeared to be related to growth and mortality experienced later on by juveniles. This was likely related to variable performance in locomotion and predator avoidance responses. Thus, a non-genetic phenotypic plasticity found during very early life history that was influenced by environmental factors, in combination with events occurring later in life during the settled juvenile stage, could affect resulting year-class strength.

Variation in annual year-class strength of European plaice was suggested to occur in either the pelagic larval phase (Zijlstra and Witte 1985; Van der Veer 1986) or after settlement during the juvenile stage on nursery grounds (Nash and Geffen 2000). Van der Veer (1986), Van der Veer and Bergman (1987), and Bergman et al. (1988) noted that recruitment variability in plaice found in The Netherlands was stabilized between years as a result of a density-dependent regulatory process, predation on newly metamorphosed fish by caridean shrimp. In contrast, year-class strength of plaice in Swedish bays varied to a greater degree (CVs = 67-118%). The latter was thought related to the effects of temperature variation during the larval stage and more variable crustacean predation on newly metamorphosed young plaice found in more northerly waters (Pihl 1990; Pihl and Van der Veer 1992). However, variable hydrographical effects on settlement of young plaice may also have occurred in Sweden (Modin and Pihl 1994; Pihl et al. 2000). Thus, population regulation in flatfishes may be coarsely determined during the earliest life

history stages by variable survival of eggs and larvae and then fine-tuned by mortality of newly metamorphosed juveniles, which can be density-dependent beyond certain threshold levels of abundance (Van der Veer and Bergman 1987; Iles and Beverton 1991; Beverton and Iles 1992a, 1992b; Rose et al. 1995; Van der Veer et al. 2000a).

High recruitment of winter flounder is associated with cold winters and a significant effect of February water temperature has reduced variability in the Niantic River winter flounder stock and recruitment relationship (Appendix A to Chapter 4). The exact mechanism of how February temperatures, in particular, affect winter flounder recruitment remains unknown. Cold February water temperature was also suggested as an environmental influence that increased European plaice recruitment in both The Netherlands (Zijlstra and Witte 1985; Van der Veer 1986; Iles 1994; Van der Veer and Witte 1999; Van der Veer et al. 2000a) and in a small bay on the Irish Sea (Nash et al. 1994). Similarly, recruitment of plaice throughout much of the waters around the United Kingdom were negatively correlated with water temperatures during February-June, the period encompassing the drift of plaice eggs and larvae and settlement (Fox et al. 2000). February coincides with most winter flounder spawning, egg incubation, and hatching. These processes and larval growth are all temperature-dependent. Buckley et al. (1990) noted that the winter flounder reproductive process appears optimized for cold winter temperatures that are followed by a gradual spring warming. Keller and Klein-MacPhee (2000) reported winter flounder egg survival, percent hatch, and initial size were significantly greater and mortality rates lower in cool as opposed to warm experimental mesocosms. Adult acclimation temperatures and egg and larval incubation temperature affected larval size and biochemical composition. Cold winters and warm springs produced large larvae that were in the best condition at first feeding, which favored high survival and partly explained the observed correlation between cold years and strong year-classes of winter flounder. Townsend and Cammen (1988) noted that the metabolic rates of pelagic consumers are more sensitive to lower temperature than rates of photosynthesis by phytoplankton, which bloom more in response to the amount of solar radiation received, which is generally consistent over time each year. Therefore, a bloom in a cold year has the possibility of lasting longer before being grazed down by zooplankton. This allows for a greater contribution of organic matter to the benthos than in other years, benefiting juvenile demersal fishes that metamorphose just after the spring bloom of phytoplankton and have to outgrow various predators. The effect of temperature on potential prey or predators of larvae and newly metamorphosed juveniles, such as the sevenspine bay shrimp, may be an additional means for control of population abundance. The association of strong year-classes of plaice with cold winters likely occurred because predatory brown shrimp suffered high mortality during low water temperatures or migrated out of plaice nursery areas (Zijlstra and Witte 1985; Van der Veer 1986; Pihl 1990; Pihl and Van der Veer 1992; Van der Veer et al. 2000a). Keller and Klein-MacPhee (2000) also observed that the sevenspine bay shrimp remained inactive and buried within the sediments of cool experimental mesocosms, whereas they were active in the warm systems.

Potential effects of temperature and winter climate on winter flounder are further illustrated in Figures 4-30 and 4-31 by comparing a long-term (1959-98) index of annual winter flounder CPUE developed from weekly trawl sampling conducted by the University of Rhode Island (URI) near Fox Island in upper Narragansett Bay (Jeffries and Johnson 1974; Jeffries and Tereceiro 1985; Jeffries et al. 1989; M. Scherer, Marine Research, Inc., Falmouth, MA, pers. comm.) with the mean Providence, RI winter (December-February) air temperature (Anonymous 2000a) and the North Atlantic oscillation (NAO) index (Anonymous 2000b). The NAO index (Hurrell 1995) is based on the difference of normalized sea level pressures between Lisbon, Portugal (representing the Azores high pressure system) and Iceland (Icelandic low). Relatively high negative values of the NAO index result in colder, wetter, and windier winters for North America with respect to Europe and high positive values are related to milder winters in North America. When the temperature and NAO indices were lagged 2 and 3 years, respectively, with the normalized trawl CPUE index (each annual value divided by the largest value of the series), significant negative correlations (Spearman's rank-order correlation; Providence winter air temperature: $r = -0.586$, $p = 0.0001$, $n = 40$; NAO: $r = -0.531$, $p = 0.0004$, $n = 40$) were found. This result showed that winter flounder abundance (likely related to reproductive success) was highest during periods of relatively more severe North American winters, such as occurred in the mid-1960s and late 1970s.

The trend of generally warm winters found from the mid-1980s through the present, most likely in combination with higher fishing mortality rates, has likely kept winter flounder abundance depressed. Further investigations of relationships between climate and winter flounder abundance using the long-term URI winter flounder abundance dataset are currently underway (H. Walker, U.S. Environmental Protection Agency, Narragansett, RI, pers. comm.). One hypothesis under study is that warmer winter water temperatures have affected predation and survival of winter flounder during critical early life history stages. Warmer winter water temperatures in Rhode Island have also been correlated with smaller winter-spring phytoplankton blooms (Keller et al. 1999), which may have had consequences to marine food webs.

Recruitment of many fishes may also be affected by density-dependent processes occurring during the first year of life following completion of the larval stage (Bannister et al. 1974; Cushing 1974; Sissenwine 1984; Anderson 1988; Houde 1989a; Myers and Cadigan 1993a, 1993b; Bailey 1994). Bannister et al. (1974), Lockwood (1980), Van der Veer (1986), and Pihl et al. (2000) all reported density-dependent mortality for young plaice. Examination of some of these findings, however, indicate that greatest rates of mortality occurred only when extremely large year-classes of plaice were produced (i.e., three to more than five times larger than average). This was confirmed in analyses by Iles and Beverton (1991) and Beverton and Iles (1992a, 1992b), who reported that although density-dependent mortality was indicated for age-0 North Sea plaice, below a specific density ($1.8 \cdot m^{-2}$) mortality was likely density-independent. Pihl et al. (2000) noted that density-independent mortality was considerable, even at relatively high densities of plaice. The high production of young Niantic River winter flounder that occurred in 1988 because

of very low apparent mortality also showed no sharp peaks in abundance, with densities generally remaining below $1 \cdot m^{-2}$. However, high ($>2 \cdot m^{-2}$) densities of young winter flounder at LR during some weeks in early summer of 1990, 1994, and 1995 were followed by the steepest declines in abundance. Mortality rate at WA was also high in 1990, even though only moderate densities of young were found there. However, mortality rates during 1994 and 1995 were about average, although abundances were among the highest ever observed there. In contrast, relatively low densities were found at both stations during 1997, but the apparent mortality rate was high. Thus, the relationship between density and mortality rate for young winter flounder in the Niantic River is subject to considerable variability, with the population regulatory mechanism either not well-established or consistent from year to year.

A comparison of early and late season median catch-per-unit-effort (CPUE) of age-0 winter flounder in the Niantic River showed that initially large numbers of young present during late spring and early summer in some years did not necessarily result in high densities of fish at the end of summer (see Chapter 3, Fig. 3-4). Differences found between early and late summer were largely related to variation in mortality rates, which affected year-class abundance (see Chapter 3, Table 3-6). Notably, little observed mortality in 1988 and 2000 meant that modest initial sets of young resulted in relatively strong year-classes, whereas high mortality occurring during early summer in both 1990 and 1995 considerably reduced initially high densities by late summer. Above-average survival rates found during 1999-2000 should help these winter flounder year-classes remain abundant. However, success also depends upon mortality rates that affect these fish during the several years remaining before recruitment as seemingly abundant year-classes of young winter flounder found during the 1990s did not result in numerous adults (Simpson et al. 1996; Desfosse et al. 1998). Thus, neither the 3 years of extended shutdowns at MNPS nor the appearance of relatively numerous metamorphosed juveniles in recent years have resulted in a sharp rebound in abundance of Niantic River winter flounder. Considerable influence of natural mortality during the first several years of life and fishing mortality reducing adult spawner biomass remain the most important factors in determining recruitment and subsequent adult abundance. These factors also appear to be acting on a larger regional scale than just in the vicinity of MNPS, a discussion of which follows.

Comparisons were made among the annual abundance (Δ-mean CPUE; DNC 2001a) of adult winter flounder spawning in the Niantic River and regional abundance indices, including the spring CPUE of winter flounder from the DEP LIS-wide stratified random trawl survey (Johnson et al. 2000; D. Simpson, CT DEP, Old Lyme, CT, pers. comm.), the mean CPUE from a spring and fall stratified random trawl survey conducted by the Rhode Island Department of Fish and Wildlife (RIFW) within Narragansett Bay, RI (Lynch 1998; NEFSC 1999), a stratified random trawl survey conducted during spring by the Massachusetts Division of Marine Fisheries (MDMF) in state waters extending from the tip of Cape Cod to the Rhode Island border (NEFSC 1999; Howe et al. 1999; A. Howe, MDMF, Pocasset, MA, pers. comm.), and the previously mentioned URI trawl CPUE at Fox Island in upper

Narragansett Bay. Most regional abundance indices of winter flounder were strongly correlated (Spearman's rank-order correlation) with one another (Table 4-16). These correlations were positive, indicating no inverse trends in abundance among areas. The Δ-mean CPUE of adult winter flounder spawning in the Niantic River since 1976 was significantly correlated with two Rhode Island winter flounder CPUE indices, the RIFW Narragansett Bay trawl index ($r = 0.7814$) and the URI Fox Island series (0.7843), and also with the MDMF Southern Massachusetts index having catches expressed as biomass per tow (0.6370). A weaker, but still significant correlation was found with the DEP LIS-wide CPUE (0.5024). This may be due to a shorter time-series for comparison and also because the DEP trawl survey has limited sampling in eastern LIS (Gottschall et al. 2000).

Comparisons of normalized indices of abundance for these regional data sets showed good correspondence among them (Figs. 4-32 and 33). The two Rhode Island CPUE indices each had a peak in 1980, 2-3 years before the peak in abundance was observed in the Niantic River, perhaps because the Rhode Island catches had a larger component of younger fish than the mostly older spawning fish taken during the Niantic River adult winter flounder surveys (Fig. 4-32). Length-frequency distributions presented in Lynch (2000) showed that a considerable proportion of winter flounder taken in the RIFW Narragansett Bay trawl survey each year from 1990 to 2000 was less than 15 cm. Declines in abundance began in the early 1980s for both the Narragansett Bay and Niantic River winter flounder series. Winter flounder abundance in Narragansett Bay began declining in the late 1970s and has remained low for more than a decade (Gibson 1998). Numbers of fish have not rebounded to levels seen previously, although modest increases were apparent in the past few years. Although the Rhode Island catches increased from the early 1990s to a small peak in 1995, perhaps reflecting catch of fish from the relatively strong 1992 year-class, CPUE subsequently decreased in the years following. In comparison, a larger increase in abundance was seen for the DEP LIS CPUE through 1996, but this index has also decreased subsequently to the lowest values of this series in 1999 and 2000. In contrast, the Niantic River catch increased by two-thirds from its lowest point in 1996, although absolute population size remains modest (Fig. 4-33).

The DEP trawl data were also reported as a CPUE-at-age (Johnson et al. 2000). An examination of these data indicated that a majority of winter flounder taken during the LIS-wide survey were ages-1 through 3. As many of the female winter flounder taken in the Niantic River are age-4 or 5 and older, there may be a 1 to 2-year lag in abundance occurring between these two indices. In several instances on the plot comparing the LIS and Niantic River CPUE a lag may be indicated by offset peaks, but in other years changes in abundance co-occur in time. The annual standardized catches of Niantic River females at ages-3 through 6 were compared with the DEP CPUE-at-age for similarly aged winter flounder. Only the catches at age-3 were significantly correlated (Spearman's rank-order correlation; $r = 0.5416$; $p = 0.0247$; $n = 17$). Also, catch indices of fish for ages-4 and older in LIS and age-4+ females in the Niantic River were not significantly correlated ($r = 0.1593$; $p = 0.5414$; $n = 17$). Similarly,

significant correlations were not found between the DEP LIS-wide CPUE for fish of age-4+ or for LIS catches expressed in terms of biomass and any of the Rhode Island or Massachusetts abundance indices.

Coherence among abundance indices of winter flounder within a relatively small geographical region should be expected. Fox et al. (2000) reported synchrony in the recruitment of plaice throughout the entire waters of the United Kingdom, although abundances in adjacent areas tended to be most similar. According to NEFSC (1999), which is a recent stock assessment of winter flounder on the northeastern coast of the United States, each winter flounder abundance survey discussed above sampled a distinct geographical area and they were likely providing measures of different components of the same aggregated stock. Further, older winter flounder dominated catches in the Niantic River surveys, but younger fish were prevalent in the DEP LIS sampling. Based on catch-at-age data presented in NEFSC (1999), younger winter flounder were a large component of their survey catches as well. Thus, direct comparisons of these indices may need some qualification, even though temporal trends appeared to have some similarities. Also noted in NEFSC (1999) was that regional abundance surveys tended to present a continuum of optimistic to pessimistic trends in abundance and illustrated variable tracking of year-class strength when they were compared among one another. This was attributed to possible differences in the availability of winter flounder to sampling; this was also noted for the Niantic River studies. A further indication was given by the Atlantic States Marine Fisheries Commission Winter Flounder Management Board, who recently reported that stock biomass of the Southern New England and Mid-Atlantic winter flounder remained at below target levels, even though F was believed to be at 0.3-0.4 (ASMFC 2001). Some state surveys indicated that stock biomass has actually decreased. With improvement in stock status not observed in some member state waters, some Board members also questioned whether winter flounder distribution patterns have changed over time.

Finally, in a recent study on long-term recruitment trends of New England groundfish, Brodziak et al. (2001) concluded that nine of eleven stocks examined had a significantly declining trend in spawning stock biomass. Among these stocks, the 1963-96 time-series of Southern New England winter flounder showed significant declining trends for both spawning stock biomass and recruits-per-spawner. This result adds to the mounting empirical evidence supporting the notion that the decline in winter flounder abundance during the past 20 years or so has taken place over a wide regional scale and well beyond any possible influence of MNPS.

4.3 TAUTOG

With concern over declining tautog abundance in LIS, increased emphasis was placed on this species in MNPS monitoring studies beginning in the mid-1990s. The greatest impact of MNPS on tautog stocks is from the entrainment of eggs. As noted in Chapter 3, Section 3.3.2, pelagic tautog eggs are spawned during a short period in early evening, disperse rapidly from spawning sites by tidal transport, and hatch in less than 48 hours. Based on hydrodynamics, a conservative measure of the source area of eggs entrained at MNPS includes a radius of about 5 n

mi (5.75 mi). Within this area, greatest spawning activity appeared to occur east of Niantic Bay, but generally spawning was not restricted to nearshore waters. Egg mortality is high immediately following spawning, probably from predation, but mortality subsequently decreases in late evening or early morning, with an estimated daily egg mortality of 87%.

Losses of entrained tautog eggs were evaluated using equivalent-adult estimates. Equivalent-adult losses of tautog, Atlantic menhaden, anchovy, grubby, cunner, and American sand lance (the latter five species are given in the following section) were derived from numbers of entrained fish eggs or larvae using the approach developed by Horst (1975), which was described previously in Section 4.2.4.

Demographic and life history information for tautog were summarized in Chapter 3, Section 3.3. Average lifetime fecundity estimates (Table 4-17) were calculated using length-at-age data reported in Simpson (1989), a length-fecundity relationship reported by White (1996), adult survival rates reported by ASMFC (1996), information previously provided by DEP (D. Simpson, CT DEP, Old Lyme, CT, pers. comm), and female maturity schedules reported by Chenowith (1963). In his calculation of fecundity, White (1996) found that the average female tautog in Virginia spawned 61 times over the summer. At the time this report was written, DNC was supporting a study at the University of Connecticut investigating the reproduction of tautog in LIS; a report of this work will be sent to DEP when available. Initial results indicate that LIS tautog may be even more fecund than those in Virginia (E. Schultz, University of Connecticut, Storrs, CT, pers. comm.). The product of the reproductive parameters noted above produces a mean lifetime fecundity estimate of about 8.8 million eggs per female over a 22-year life span. Two-unit operation entrainment estimates for tautog eggs from 1986 through 1995 ranged between 1.1 and nearly 3 billion (Table 4-18). Translating these losses of tautog eggs into equivalent-adults gave annual totals ranging from 242 to 951 fish per year with a mean of 448 equivalent-adults.

A second method to put into perspective the entrainment of tautog eggs is a comparison of annual entrainment and the instantaneous standing stock estimates of tautog eggs in an area of LIS near MNPS that were reported in NUSCO (1997, 1998b). The instantaneous standing stock of tautog eggs within a 5 n mi radius (39.3 n mi^2 = 51.9 mi^2) of mid-Niantic Bay was calculated in 1996 using the geometric mean density of 16 offshore stations combined (Fig. 4-34). This standing stock of tautog eggs was in an area that was the source of condenser cooling water for MNPS. The geometric mean density of tautog eggs from each survey was extrapolated to a total based on the average depth of the stations sampled. Estimated numbers of tautog eggs within this 5 n mi radius of mid-Niantic Bay for the two sampling dates in 1996 were 5.024 billion on July 2 and 3.172 billion on July 9. These estimates of daily egg standing stock were assumed to underestimate daily spawning because sampling was conducted during the morning, approximately 12 hours after peak spawning, and thus did not account for egg mortality following spawning. Instantaneous standing stock estimates of tautog eggs were computed similarly using data taken at the

same 16 offshore stations in 1997, but with collections made at the time of daily peak spawning in late afternoon. Estimated daily standing stock of tautog eggs within the same 5 n mi radius of mid-Niantic Bay in 1997 was 7.236 billion on July 2 and 11.529 billion on July 11.

Due to the significantly greater (6 to 10 times) densities of tautog eggs found at nearshore stations compared to the offshore stations in 1997, separate daily standing stock estimates were calculated from 11 nearshore stations, also sampled during daily peak spawning (Fig. 4-34). Because the nearshore stations were within 0.5 n mi of the shoreline and extended 5 n mi to the east and west of Niantic Bay, the standing stock estimates encompassed an area 0.5·10 n mi or 5 n mi^2 (6.6 mi^2). Estimated numbers of eggs within this nearshore area were 1.639 billion on July 7 and 1.646 billion on July 14. A comparison of nearshore to offshore daily standing stock estimates per unit area indicated similar spawning activity, with an average standing stock per n mi^2 of 184 million (July 2) and 293 million (July 11) at offshore stations and 328 million (July 7) and 329 million (July 14) for nearshore stations. Based on a comparison of data from nearshore to offshore stations, the nearly equivalent standing stock estimates on an areal basis suggested similar spawning activity throughout Niantic Bay and adjacent inshore and offshore areas. The geometric mean of these standing stock estimates is 276 million·n mi^{-2}. Tautog annual egg entrainment estimates calculated for two-unit operation going forward ranged from 1.1 billion to 2.99 billion (Table 4-18). Therefore, these yearly estimates were equivalent to the production of spawning female tautog in an area of LIS approximately 4 to 11 n mi^2 found on only one day during the first two weeks of July, as based on densities observed in 1997. Because female tautog spawn repeatedly during a protracted summer spawning period, this loss is probably of little consequence to the LIS tautog stock.

The relatively small loss of tautog egg production to MNPS operation and annual equivalent-adult losses of less than 1,000 fish implies that entrainment effects are likely small. If egg losses due to entrainment have affected recruitment, then juvenile abundance should have decreased and the relative abundance of older fish increased in the short term. Based on catches made in the MNPS trawl monitoring program, the number of juvenile tautog has increased in recent years from a series low recorded in 1994 (Table 4-19). Similarly, juvenile tautog sampling in the northeastern U.S. also indicated a time-series low in 1994, followed by increasing abundance and with a strong year-class produced in 1998 (NEFSC 2000). As indicated by the DEP LIS spring trawl survey, overall abundance of tautog throughout LIS remained low as of 1999 (Johnson et al. 2000). However, abundance during fall sampling increased after 1997 due to greater abundance of ages-1 and 2 tautog, even though catches remained dominated by fish of ages-5 through 10. In addition to the catch of juvenile tautog in MNPS trawl monitoring, the number of newly recruited mature adults has not declined since the late 1980s, as determined from the selective catch of age-3 through 5 tautog in lobster pots in the Millstone area (Table 4-20). Therefore, no changes in the relative proportion of juveniles and adults were observed and abundance changes appeared unrelated to entrainment losses. In addition, the decline in juvenile and adult tautog abundance in LIS that began in the mid-1980s (Simpson et al. 1996)

coincided with a decreasing trend in eggs entrained at MNPS. If the decrease in adult abundance was caused by entrainment losses, then the reduction in egg abundance should have lagged the decline of juveniles by several years because females do not mature until age-3 or 4. Therefore, the lower abundance of tautog eggs was probably due a decline in spawning adults from fishing rather than the operation of MNPS. During the 1990s, F rate for tautog was estimated at about 0.54 (annual fishing mortality of 42%) and various survey biomass indices declined by more than half from the previous decade (ASMFC 1996). Stocks of tautog are susceptible to overfishing because of their long life span and slow growth and abundance would remain depressed until fishing mortality is reduced considerably. Recent reviews of the status of tautog indicated that F declined from a high of 0.71 in 1993 to 0.29 in 1998, although this mortality rate remained above the target of 0.15 (which is equal to M for tautog) and the species remains overfished and stock biomass requires further rebuilding (Stirratt 2000).

4.4 OTHER SELECTED FISHES

4.4.1 Atlantic menhaden

In order to calculate equivalent-adult estimates for entrained Atlantic menhaden larvae, estimates of mean lifetime fecundity were derived for age-2 fish using mean annual fecundity estimates reported by Dietrich (1979) and Arenholtz (1991). Annual adult survival rates were estimated using a natural mortality rate of M = 0.45 (Arenholtz 1991; Powell 1994), although this could presently be an underestimate (Vaughan et al. 2001), and a fishing mortality rate for age-2 and older fish of F = 1.10 (Vaughan et al. 2001). Arenholtz (1991) found that only about 20% of age-2 fish were sexually mature and that 80% of age-3 fish were mature. The cumulative product of these parameters produces a mean lifetime fecundity estimate for age-2 Atlantic menhaden of 15,293 eggs (Table 4-21). Survival of eggs to larvae was estimated as 0.02 (Ferraro 1981). Numbers of Atlantic menhaden larvae entrained by MNPS exhibited considerable interannual variability with two-unit entrainment estimates ranging from about 2.4 million to 165.6 million and averaging 45.3 million larvae during the 10-year period from 1986 through 1995 (Table 4-22). Consequently, estimates of equivalent-adults lost due to entrainment of larval Atlantic menhaden ranged from 15,693 to 1,082,846 with a mean of 296,082 fish during the 10-year period.

A second methodology used to evaluate the effect of MNPS on Atlantic menhaden is a population dynamics model termed MENDYN that was developed by the University of Rhode Island and presented in NUSCO (1983). Described as a self-regenerating dynamic pool model using a Leslie matrix formulation, this model considered both entrainment and impingement of menhaden, with the latter likely to have greater effects because this mortality is imposed on larger juvenile and adult fish having lower rates of mortality. In the summer and fall of 1971, an estimated 50 million larval and juvenile Atlantic menhaden were entrained or impinged at MNPS Unit 1, the only unit then in operation (NUSCO 1983). Since then, entrainment estimates of 50 million or greater were occasionally seen at MNPS (see Chapter 3, Table 3-12). However, the MENDYN model simulation assumed a worse-case scenario in which this level of mortality was extrapolated to three units, yielding a total annual mortality of 210

million juvenile menhaden of 3 months in age. This loss rate was further assumed to occur in each and every year over an expected 50-year life span for MNPS (note that a loss of this magnitude was only observed once during three-unit operation). Two simulations were made, one using density-independence and one using density-dependent population dynamics. These simulations were termed conservative and realistic, respectively, in NUSCO (1983). The conservative simulation projected a decrease in the size of the northern subpopulation (north of Chesapeake Bay) of 1.1% after 50 years relative to an unimpacted population. The realistic simulation resulted in a reduction in population size of 0.08% after 50 years of plant operation and the high annual rate of impact. It was concluded on the basis of this highly conservative analysis that effects of MNPS operation would be undetectable by field observations and that no detrimental changes would occur to the Atlantic menhaden population.

Unlike anchovies and American sand lance, the entrainment of larval menhaden has increased in recent years (see Chapter 3, Table 3-12) and this positive trend was significant (see Chapter 3, Section 3.4.4). Increasing numbers of juveniles have also been taken by seine monitoring in Jordan Cove since 1990 (DNC 2001b). The large increase in Atlantic menhaden abundance over the past decade indicated that MNPS has had minimal or no impact on their numbers, with abundance in northern waters likely increasing because of reduced fishing mortality along the Atlantic coast or a shift in distribution. Equivalent-adult calculations showed expected losses of about 272 thousand to just over 1 million in the later years of the calculations in Table 4-22, although annual equivalent-adult calculations could increase if present trends in population size continue. Nevertheless, even far larger annual losses due to MNPS operation, such as those highly conservatively modeled in NUSCO (1983), would result in trivial losses and would be of little consequence to the large coast-wide population of Atlantic menhaden, which sustains annual landings in the billions of fish and thousands of metric tons (Vaughan et al. 2001).

4.4.2 Anchovy

Demographic and life history information focusing on the bay anchovy is summarized in Chapter 3, Section 3.4. Bay anchovy have the capacity to become mature during the first year of life, but not all fish hatch early enough to become reproductive during their first summer. Therefore, the fraction of age-0 bay anchovy achieving sexual maturity was assumed to be 0.5 at age-0 and 1.0 for subsequent ages through the maximum of age-3 (Luo and Musick 1991; Wang et al. 1997). Bay anchovy spawn in discrete batches, spawning as many as 54 times in a given season with individual total annual egg production estimated at 45,110 (Luo and Musick 1991; Zastrow et al. 1991). This translates into a lifetime fecundity of approximately 108,586 eggs (Table 4-23). Many estimates of egg mortality rates are reported in the literature (see Chapter 3, Table 3-11), ranging from 0.40 to 1.94 per day. Lowest mortality rates were reported for fish in southern areas of the Atlantic Ocean and higher mortality rates were found in Chesapeake Bay and more northerly regions. An egg mortality rate of 1.66 was selected for LIS bay anchovy because this value is on the high end of the range of values and LIS is located toward the northern limit of the species range, where mortality rates would be expected to be higher (Bailey and Houde 1989; Houde 1989b).

MNPS entrains both eggs and larvae of anchovies. Two-unit operation entrainment estimates for anchovy eggs ranged between 4 million and 397 million from 1986-1995 and averaged 114.1 million. These values translated into losses of equivalent-adults ranging from 74 to 7,308 fish with a mean of 1,681 (Table 4-24). Numbers of anchovy larvae entrained during this same time period ranged from 95 million to 1.01 billion and averaged 480.1 million, with equivalent-adult losses of between 9,222 and 98,109 (Table 4-25). The 10-year mean was 37,204.

Densities of both anchovy eggs and larvae at the MNPS discharges showed significant negative trends since the 1970s (see Chapter 3, Section 3.4.4). However, this decrease in bay anchovy abundance appears to be a regional phenomenon. A sharp drop in larval anchovy abundance was measured over the past decade in Narragansett Bay, RI, where its representation in the percent composition of the ichthyoplankton decreased from about 90% to 8% from 1990 to 2000 (Klein-MacPhee 2001). The Maryland DNR Juvenile Finfish Seining Survey data also indicated that the bay anchovy population declined dramatically in Chesapeake Bay after 1993 (Price 1999). Due to relatively high rates of mortality in early life history, equivalent-adult losses from the entrainment of both eggs and larvae at MNPS would likely resulted in sustained annual losses, at most, of about 100,000 fish, with an average loss of less than 40,000 individuals. Morgan et al. (1995) reported that in Chesapeake Bay the bay anchovy exhibited little genetic variation, indicating a lack of stock structure. This feature would also serve to lessen any localized impacts as the population appears to be panmictic.

4.4.3 Grubby

Entrainment of grubby larvae is the primary plant impact on the resident grubby population. However, little information exists regarding the population demographics of grubby in LIS. Estimates of mean lifetime fecundity and mortality rates were estimated using published reports of mean annual fecundity (1,275), 50% reproductive maturity at age-1, a longevity of 5 years (Lazzari et al. 1989), and an annual survival rate of 0.40, which was chosen based on mortality schedules derived for other unfished benthic species with relatively short life spans (Mertz and Myers 1996; Rickman et al. 2000). The calculated mean annual lifetime fecundity estimate was 1,385 eggs per female (Table 4-26). Survival from the egg to larval stage was estimated based on an empirical study conducted by Pepin (1991), who examined the mortality schedules of pelagic early life history stages of marine fishes. He derived a generalized pelagic egg-to-larval mortality estimator using the relationship between incubation time and water temperature:

$$M_e = 0.65\, e^{0.066T} \quad (5)$$

where M_e is egg mortality rate, e is the constant natural logarithmic base, and T (in °C) is the environmental temperature during incubation (Pepin 1991). Using this relationship and the long-term mean water temperature of 5.5°C determined for the grubby incubation period from temperature data given in DNC (2001a), a total egg

mortality rate of M_e= 0.934 was derived, which translated into an egg survival rate of S_e = 0.393 (Table 4-27). This method of calculating egg survival is suspect because Pepin's (1991) method was based on empirical analysis of species with a pelagic egg and the grubby has a benthic egg stage. The relatively high egg survival rate calculated for grubby is logical, however, as other studies have shown egg survival can be inversely related to fecundity and incubation temperature, positively related to egg size, and generally higher for demersal eggs incubating in winter (Houde 1987, 1989b; Bailey and Houde 1989; Pepin 1991).

Grubby egg survival rates were expected to be high as they spawn in protected estuaries and nearshore areas, have adhesive benthic eggs, and are believed to guard their eggs after spawning (Lazzari et al. 1989). Entrainment of larval grubby was calculated for two-unit operation with annual numbers ranging from 25.6 million to 89.6 million fish from 1986 through 1995 (Table 4-27). The mean number of grubby larvae entrained during typical two-unit operation was 48.4 million. Estimates of equivalent-adults ranged from 94,114 to 329,398 fish and averaged 177,934 during the same 10-year period.

Despite relatively high calculated equivalent-adult losses, the grubby has been among the most stable of the fishes residing near MNPS, indicating that these values may be overestimates, perhaps due to uncertainties in the population parameters used. Based on the trawl monitoring program, grubby abundance has not declined over the 24-year period of sampling (see Chapter 3, Section 3.4.4). Fluctuations in annual catch have occurred, but these were likely due to natural variation and appeared unrelated to plant operation. Because the grubby is a relatively short-lived species maturing in 1 year, any changes in abundance resulting from the extended MNPS outage should have been apparent by this time. Since grubby abundance has been stable, it is likely that the plant has had little or no effect on this species. The grubby presents an interesting contrast to the winter flounder. Like the winter flounder, it most likely has a localized population, spawns a demersal egg in inshore waters during winter, and has a larva with a lengthy developmental period. It differs mostly in that it is not exploited by the fisheries and has shown no negative trend in abundance during MNPS operation, whereas the heavily fished winter flounder has shown a considerable decrease.

4.4.4 Cunner

The entrainment of eggs represents the greatest potential impact on the cunner population in the vicinity of MNPS. While considerable information is available documenting cunner biology and life history (see Chapter 3, Section 3.4 for an overview), little information could be found regarding survival or fecundity rates. Mean lifetime fecundity was estimated using age-specific fecundity schedules and a maximum longevity of 10 years reported in Nitschke et al. (2001). They reported an age-fecundity relationship as:

$$\log_{10} f = 3.8669 \cdot \log_{10} A - 2.0157 \cdot \log_{10} A^2 + 2.7869 \qquad (6)$$

where f is fecundity and A is age of the fish. This relationship accounted for over 57% of the variability in age-specific fecundity (Nitschke et al. 2001). About 80% of cunner become reproductively mature at age-2 and are assumed to be completely mature by age-3 (Dew 1976; Nitschke et al. 2001). Annual mean fecundity estimates resulting from these relationships are listed in Table 4-28. Adult cunner natural annual survival rates were estimated using the relationship between growth parameters and environmental temperature proposed by Pauly (1982). Using growth and environmental temperature information from 175 fish stocks, Pauly (1982) found a strong ($r^2 = 0.847$) linear relationship useful to estimate natural annual mortality rates in fish:

$$\log_{10} M = -0.0066 - 0.279 \cdot \log_{10} L_\infty + 0.6543 \cdot \log_{10} K + 0.4634 \cdot \log_{10} T \quad (7)$$

where M is the instantaneous natural mortality rate, L_∞ is the theoretical maximum size a fish can attain in its lifetime (here, 234.7 mm; Nitschke et al. 2001), K is the growth coefficient (here, 0.15; Nitschke et al. 2001), and T is the mean annual environmental temperature in °C (11.6°C or 53°F at the MNPS Units 1 and 2 intakes over the past 27 years; DNC 2001a). This relationship produced a natural annual mortality rate of 0.1933, which translated to a survival rate of 0.8242. This estimated survival rate was used to calculate the mean lifetime fecundity of 118,499 eggs per age-2 fish (Table 4-28). Estimated cunner egg entrainment during two-unit operation ranged from 2.1 billion to 4.6 billion and averaged 3.3 billion from 1986 through 1995 (Table 4-29). The resulting equivalent adult estimates due to losses of entrained cunner eggs range from 35,686 to 77,543 with a mean of 56,384 equivalent-adult fish during the 10-year period. Nitschke et al. (2001) assumed that the cunner was a determinate spawner (i.e., once per year), but noted some uncertainty. Many wrasses, including the tautog, are indeterminate spawners, breeding many times during a season. Thus, lifetime fecundity of cunner could be higher and equivalent-adult losses lower than calculated should the cunner prove to be an indeterminate spawner.

No temporal trends in abundance were observed in the density of cunner eggs at the MNPS discharges over a 24-year period (see Chapter 3, Section 3.4.4). Further, catch of age-0 cunner at the Jordan Cove trawl monitoring program (TMP) station was at an historic high in 1999 (DNC 2001b). A large decrease in catch occurred at the Intake TMP station in the early 1980s, but this was attributed to the removal in mid-1983 of the rock cofferdam that was in place during the construction of the Unit 3 intake structure. This rock cofferdam likely provided considerable habitat for cunner and increased their availability to sampling at this station. Based on equivalent-adult calculations, cunner would suffer relatively consistent losses averaging about 56,000 individuals each year, which is two orders of magnitude higher than losses calculated for tautog, despite having a mean egg entrainment only 1.69 times higher. Due to apparently high production of eggs, however, this loss has not resulted in an unacceptable decrease to the cunner population of LIS.

4.4.5 American sand lance

American sand lance larvae are entrained in relatively high numbers during late winter and early spring. Life history information is summarized in Chapter 3, Section 3.4, but little information exists regarding natural mortality and fecundity rates. Therefore, information on other sand lance species was used as a surrogate because the species of this genus have analogous life history strategies and comparable population demographics (Reay 1970). Because American sand lance have similar spawning and egg incubation periodicity as grubby, the same egg survival estimator (Pepin 1991) and parameter values were used to estimate egg survival, producing an egg to larval survival rate of 0.393 (Table 4-30).

To develop the mean lifetime fecundity estimate, the instantaneous natural annual mortality rate of M = 1.0 for the Newfoundland population of northern sand lance (Winters et al. 1983) was used in conjunction with age, maturity, and annual fecundity schedules of American sand lance reported by Westin et al. (1979). These values produced an mean lifetime fecundity estimate for an age-1 fish of 4,843 eggs (Table 4-30). As calculated for two-unit operation, numbers of American sand lance larvae entrained at MNPS ranged from about 4 million to 88 million fish and averaged 38.6 million during the 10-year period of 1986 through 1995 (Table 4-31). Estimates of equivalent-adults lost due to entrainment of larvae ranged from 4,206 to 92,522 with a mean of 40,542 during this same time period.

The American sand lance is a widely distributed coastal species demonstrating large-scale natural fluctuations in abundance. As indicated by larval densities (see Chapter 3, Table 3-12), sand lance abundance declined during the 1980s at the MNPS intakes. However, this decline was also apparent in other areas of the Northwest Atlantic Ocean and was unrelated to plant operation. Monteleone et al. (1987) noted that larval densities in LIS over a 32-year period (1951-83) were highest in 1965-66 and 1978-79. The latter peak was also evident throughout the entire range of American sand lance. This high abundance persisted throughout the Northwest Atlantic Ocean until 1981 and the decline that followed appeared to be inversely correlated with that of Atlantic herring and Atlantic mackerel (Nizinski et al. 1990). The latter two fishes prey heavily upon sand lance and following large decreases in their biomass from overfishing in the 1970s, sand lance increased in abundance (Sherman et al. 1981; Monteleone et al. 1987). In more recent years, both of these predators have again become more abundant (Stephenson and Kornfield 1990; Smith and Morse 1993; NMFS 1998) and sand lance abundance has decreased accordingly. Given the high abundance of American sand lance along the Atlantic coast, effects of MNPS operation are likely small and equivalent-adult calculations predicted annual losses of less than 100,000 fish at recent levels of abundance. This mortality is small in comparison to that typically associated with a forage species such as the sand lance. No increase were seen in this short-lived species as a result of the 3 years of reduced operation, although it is likely that any changes in abundance resulting from MNPS operation would be undetectable because of the small effect MNPS has on sand lance.

4.5 REFERENCES

Ahrenholz, D.W. 1991. Population biology and life history of the North American menhadens, *Brevoortia* spp. Mar. Fish. Rev. 53:3-19.

Al-Hossaini, M., Q. Liu, and T.J. Pitcher. 1989. Otolith microstructure indicating growth and mortality among plaice, *Pleuronectes platessa* L., post-larval sub-cohorts. J. Fish Biol. 35(Suppl. A):81-90.

Anderson, J.T. 1988. A review of size dependent survival during pre-recruit stages of fishes in relation to recruitment. J. Northw. Atl. Fish. Sci. 8:55-66.

Anonymous. 2000a. Monthly temperature averages for Providence, RI. Accessed via http://tgsv5.nws.noaa.gov/er/box/climate/PVDAVE.html. May 10, 2000.

Anonymous. 2000b. North Atlantic Oscillation (NAO) index - seasonal. Accessed via http://www.cgd.ucar.edu/cas/climind/nao_seasonal.html. May 11, 2000.

ASMFC (Atlantic States Marine Fisheries Commission). 2001. Winter flounder Management Board (January 29, 2001). Page 3 *in* ASMFC January 2001 meeting summary.

Bailey, K.M. 1994. Predation on juvenile flatfish and recruitment variability. Neth. J. Sea Res. 32:175-189.

Bailey, K.M., and R.S. Batty. 1984. Laboratory study of predation by *Aurelia aurita* on larvae of cod, flounder, plaice and herring: development and vulnerability to capture. Mar. Biol. (Berl.) 83:287-291.

Bailey, K.M., and E.D. Houde. 1989. Predation on eggs and larvae of marine fishes and the recruitment problem. Adv. Mar. Bio. 25:1-83.

Bannister, R.C.A., D. Harding, and S.J. Lockwood. 1974. Larval mortality and subsequent year-class strength in the plaice (*Pleuronectes platessa* L.). Pages 21-38 *in* J.H.S. Blaxter, ed. The early life history of fish. Springer-Verlag, New York.

Bergman, M.J.N., H.W. Van der Veer, and J.J. Zijlstra. 1988. Plaice nurseries: effects on recruitment. J. Fish Biol. 33 (Suppl. A): 210-218.

Beverton, R.J.H., and T.C. Iles. 1992a. Mortality rates of 0-group plaice (*Pleuronectes platessa* L.), dab (*Limanda limanda* L.) and turbot (*Scophthalmus maximus* L.) in European waters. II. Comparison of mortality rates and construction of life table for 0-group plaice. Neth. J. Sea Res. 29:49-59.

Beverton, R.J.H., and T.C. Iles. 1992b. Mortality rates of 0-group plaice (*Pleuronectes platessa* L.), dab (*Limanda limanda* L.) and turbot (*Scophthalmus maximus* L.) in European waters. III. Density-dependence of mortality rates of 0-group plaice and some demographic implications. Neth. J. Sea Res. 29:61-79.

Birt, V.L., T.P. Birt, D. Goulet, D.K. Cairns, and W.A. Montevecchi. 1987. Ashmole's halo: direct evidence for prey depletion by a seabird. Mar. Ecol. Prog. Ser. 40:205-208.

Bradford, M.J. 1992. Precision of recruitment predictions from early life stages of marine fishes. Fish. Bull., U.S. 90:439-453.

Brodziak. J.K.T., W.J. Overholtz, and P.J. Rago. 2001. Does spawning stock affect recruitment of New England groundfish? Can. J. Fish. Aquat. Sci. 58:306-318.

Buckley, L.J., A.S. Smigielski, T.A. Halavik, and G.C. Laurence. 1990. Effects of water temperature on size and biochemical composition of winter flounder *Pseudopleuronectes americanus* at hatching and feeding initiation. Fish. Bull., U.S. 88:419-428.

Buckley, L.J., A.S. Smigielski, T.A. Halavik, E.M. Caldarone, B.R. Burns, and G.C. Laurence. 1991. Winter flounder *Pseudopleuronectes americanus* reproductive success. II. Effects of spawning time and female size on size, composition and viability of eggs and larvae. Mar. Ecol. Prog. Ser. 74:125-135.

Bunn, N.A., C.J. Fox, and T. Webb. 2000. A literature review of studies on fish egg mortality: implications for the estimation of spawning stock biomass by the annual egg production method. Centre for Envir., Fish. and Aquacult. Sci., Sci. Ser. Tech. Rep. No. 111. Lowestoft, U.K. 37 pp.

Cali, A., and P.M. Takvorian. 1991. The incidence of *Glugea stephani* (Protozoa: Microsporidia) in winter flounder, *Pseudopleuronectes americanus* (Walbaum) from the New York-New Jersey Lower Bay Complex and factors influencing it. Can. J. Zool. 69:317-321.

Cali, A., P.M. Takvorian, J.J. Ziskowski, and T.K. Sawyer. 1986. Experimental infection of American winter flounder (*Pseudopleuronectes americanus*) with *Glugea stephani* (Microsporidia). J. Fish. Biol. 28:199-206.

Chambers, R.C., W.C. Leggett, and J.A. Brown. 1988. Variation in and among early life history traits of laboratory-reared winter flounder *Pseudopleuronectes americanus*. Mar. Ecol. Prog. Ser. 47:1-15.

Chenoweth, S.B. 1963. Spawning and fecundity of the tautog, *Tautoga onitis* (Linnaeus). M.S. Thesis. University of Rhode Island, Narragansett, RI. 60 pp.

Conover, D.O. 2000. Darwinian fishery science. Mar. Ecol. Prog. Ser. 208:299-313.

Crawford, R.E., and C.G. Carey. 1985. Retention of winter flounder larvae within a Rhode Island salt pond. Estuaries 8:217-227.

Crecco, V.A. 1994. Cumulative effects of impingement and entrainment from coastal power plants on winter flounder in Connecticut waters. CT Dept. Envir. Prot., Bu. Fish., Spec Pub. 19 pp. + 2 app.

Cushing, D.H. 1974. The possible density-dependence of larval mortality and adult mortality in fishes. Pages 103-111 *in* J.H.S. Blaxter, ed. The early life history of fish. Springer-Verlag, New York.

DeBlois, E.M., and W.C. Leggett. 1991. Functional response and potential impact of invertebrate predators on benthic fish eggs: analysis of the *Calliopius laeviusculus*-capelin (*Mallotus villosus*) predator-prey system. Mar. Ecol. Prog. Ser. 69:205-216.

DEP (Connecticut Department of Environmental Protection). 2000a. Letter C09872 dated February 16, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Comments on proposed cooling water alternatives scope of study.

DEP. 2000b. Letter C10302 dated July 13, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Comments on proposed cooling water alternatives scope of study.

Desfosse, J.C., M. Gibson, and D. Simpson. 1998. 1998 review of interstate fishery management plan for inshore stocks of winter flounder (*Pseudopleuronectes americanus*). Pages 130-138 *in* R.E. Beal, J.C. Desfosse, J.D.

Field, A.M. Shick, and T.L. Berger. Atlantic States Marine Fisheries Commission 1998 review of interstate fishery management plans. ASMFC Spec. Rep. No. 66.

Dew, C.B. 1976. A contribution of the life history of the cunner, *Tautogolabrus adspersus*, in Fishers Island Sound, Connecticut. Chesapeake Sci. 14:101-113.

Dietrich, C.S., Jr. 1979. Fecundity of the Atlantic menhaden, *Brevoortia tyrannus*. Fish. Bull., U.S. 77:308-311.

DNC (Dominion Nuclear Connecticut, Inc.). 2001a. Winter flounder studies. Pages 9-94 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 2000. Millstone Environmental Laboratory, Waterford, CT.

DNC. 2001b. Fish ecology studies. Pages 95-137 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 2000.

DNC. 2001c. Lobster studies. Pages 139-167 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 2000.

DNC. 2001d. Eelgrass. Pages 207-219 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 2000.

Fairchild, E.A., and W.H. Howell. 2000. Predator-prey size relationship between *Pseudopleuronectes americanus* and *Carcinus meanus*. J. Sea Res. 44:81-90.

Ferraro, S.P. 1981. Eggs and larvae of Atlantic menhaden (*Brevoortia tyrannus*) in the Peconic Bays, New York in 1972-74. Rapp. P.-v. Réun. Cons. int. Explor. Mer 178:181-182.

Fox, C.J., B.P. Planque, and C.D. Darby. 2000. Synchrony in the recruitment time-series of plaice (*Pleuronectes platessa* L.) around the United Kingdom and the influence of sea temperature. J. Sea Res. 44:159-168.

Frank, K.T., and W.C. Leggett. 1984. Selective exploitation of capelin (*Mallotus villosus*) eggs by winter flounder (*Pseudopleuronectes americanus*): capelin egg mortality rates and contribution of egg energy to the annual growth of flounder. Can. J. Fish. Aquat. Sci. 41:1294-1302.

Gibson, M.R. 1998. Recent trends in abundance, recruitment, and fishing mortality for winter flounder in Narragansett Bay and Rhode Island coastal waters. RI Div. Fish Wildl., Res. Ref. Doc. 98. (Not seen, cited *in* Keller and Klein-MacPhee 2000).

Gibson, R.N. 1994. Impact of habitat quality and quantity on the recruitment of juvenile flatfishes. Neth. J. Sea Res. 32:191-206.

Gibson, R.N., M.C. Yin, and L. Robb. 1995. The behavioural basis of predator-prey size relationships between shrimp (*Crangon crangon*) and juvenile plaice (*Pleuronectes platessa*). J. Mar. Biol. Assoc. U.K. 75:337-349.

Goodyear, C.P. 1978. Entrainment impact estimates using the equivalent adult approach. U.S. Fish Wildl. Serv., FWS/OBS-78/65. 14 pp.

Goodyear, C.P. 1980. Compensation in fish populations. Pages 253-280 *in* C.H. Hocutt and J.R. Stauffer, eds. Biological monitoring of fish. Lexington Books, Lexington, MA.

Gottschall, K.F., M.W. Johnson, and D.G. Simpson. 2000. The distribution and size composition of finfish, American lobster, and long-finned squid in Long Island Sound based on the Connecticut Fisheries Division Bottom Trawl Survey, 1984-1994. NOAA Tech. Rep. NMFS 148. 195 pp.

Hollander, M., and D.A. Wolfe. 1973. Nonparametric statistical methods. John Wiley and Sons, New York. 503 pp.

Horst, T.J. 1975. The assessment of impact due to entrainment of ichthyoplankton. Pages 107-118 *in* S.B. Saila, ed. Fisheries and energy production: a symposium. D.C. Heath and Company, Lexington, MA.

Houde, E.D. 1987. Fish early life dynamics and recruitment variability. Am. Fish. Soc. Sym. 2:17-29.

Houde, E.D. 1989a. Subtleties and episodes in the early life history of fishes. J. Fish Biol. 35(Suppl. A):29-38.

Houde, E.D. 1989b. Comparative growth, mortality, and energetics of marine fish larvae: temperature and implied latitudinal effects. Fish. Bull., U.S. 87:471-496.

Houde, E.D., J.C. Gamble, S.E. Dorsey, and J.H. Cowan, Jr. 1994. Drifting mesocosms: the influence of gelatinous zooplankton on mortality of bay anchovy, *Anchoa mitchilli*, eggs and yolk-sac larvae. ICES J. Mar. Sci. 51:383-394.

Howe, A.B., T.P. Currier, S.J. Correia, and J.R. King. 1999. United States Fish and Wildlife Service Federal Aid to Sport Fish Restoration Act annual report. Proj. No. F-56-R. Job no. 1, inshore bottom trawl survey. 11 pp. + 12 tab. + 7 fig.

Howell, P., A. 1993. Certain decisions with uncertain data: early life-history data and resource management. Am. Fish. Soc. Symposium 14:159-165.

Hurrell, J.W. 1995. Decadal trends in the North Atlantic Oscillation regional temperatures and precipitation. Science 269:676-679.

Iles, T.C. 1994. A review of stock-recruitment relationships with reference to flatfish populations. Neth. J. Sea Res. 32:399-420.

Iles, T.C., and R.J.H. Beverton. 1991. Mortality rates of 0-group plaice (*Pleuronectes platessa* L.), dab (*Limanda limanda* L.) and turbot (*Scophthalmus maximus* L.) in European waters. I. Statistical analysis of the data and estimation of the parameters. Neth. J. Sea Res. 27:217-235.

Jeffries, H.P., and W.C. Johnson. 1974. Seasonal distributions of bottom fishes in the Narragansett Bay area: seven-year variations in the abundance of winter flounder (*Pseudopleuronectes americanus*). J. Fish. Res. Board Can. 31:1057-1066.

Jeffries, H.P., and M. Terceiro. 1985. Cycle of changing abundances in the fishes of the Narragansett Bay area. Mar. Ecol. Prog. Ser. 25:239-244.

Jeffries, H.P., A. Keller, and S. Hale. 1989. Predicting winter flounder (*Pseudopleuronectes americanus*) catches by time series analysis. Can. J. Fish. Aquat. Sci. 46:650-659.

Johnson, M.W., D. Shake, and P.T. Howell. 2000. Job 2: marine finfish survey. Part 1: Long Island Sound trawl survey. 114 pp. *In* A study of recreational fisheries in Connecticut. CT Dept. Envir. Prot., Bur. Nat. Res., Fish. Div.

Keller, A.A., and G. Klein-MacPhee. 2000. Impact of elevated temperature on the growth, survival, and trophic dynamics of winter flounder larvae: a mesocosm study. Can. J. Fish. Aquat. Sci. 57:2382-2392.

Keller, A.A., C.A. Oviatt, H.A. Walker, and J.D. Hawk. 1999. Predicted impacts of elevated temperature on the magnitude of the winter-spring phytoplankton bloom in temperate coastal waters: a mesocosm study. Limnol. Oceanogr. 44:344-356.

Klein-MacPhee, G. 2001. Ichthyoplankton surveys - the Rodney Dangerfield of fishery science. Maritimes (University of Rhode Island Marine Programs) 42(4):10-13.

Laurence, G.C. 1977. A bioenergetic model for the analysis of feeding and survival potential of winter flounder, *Pseudopleuronectes americanus*, larvae during the period from hatching through metamorphosis. Fish. Bull., U.S. 75:529-546.

Lazzari, M.A., K.W. Able, and M.P. Fahay. 1989. Life history and food habits of the grubby, *Myoxocephalus aenaeus* (Cottidae), in a Cape Cod estuary. Copeia 1989:7-12.

Lockwood, S.J. 1980. Density-dependent mortality in 0-group plaice (*Pleuronectes platessa* L.) populations. J. Cons. int. Explor. Mer 39:148-153.

Lorda, E.C. 1982. The stochastic modeling of the dynamics of fish populations using nonlinear Leslie matrices: methodology, probabilistic analysis, and applications to the Georges Bank cod fishery. Ph.D. Thesis, University of Rhode Island, Narragansett, RI. 182 pp.

Lorda, E.C., D.J. Danila, and J.D. Miller. 2000. Application of a population dynamics model to the probabilistic assessment of cooling water intake effects of Millstone Nuclear Power Station (Waterford, CT) on a nearby winter flounder spawning stock. Env. Sci. Pol. 3:S471-482.

Luo, J., and J.A. Musick. 1991. Reproductive biology of bay anchovy in Chesapeake Bay. Trans. Am. Fish. Soc. 120:701-710.

Lynch, T.R. 1998. Assessment of recreationally important finfish stocks in Rhode Island coastal waters (trawl survey) 1976-1996. 1996 annual assessment. RI Div. Fish Wildl., Wakefield, RI. (not seen, cited by NEP and MRI 1998).

Lynch, T.R. 2000. Assessment of recreationally important finfish stocks in Rhode Island waters. Coastal fishery resource assessment trawl survey. RI Div. Fish Wildl., Wakefield, RI.

Manderson, J.P., B.A. Phelan, A.J. Bejda, L.L. Stehlik, and A.W. Stoner. 1999. Predation by striped searobin (*Prionotus evolans*, Triglidae) on young-of-the-year winter flounder (*Pseudopleuronectes americanus*, Walbaum): examining prey size selection and prey choice using field observations and laboratory experiments. J. Exp. Mar. Biol. Ecol. 242:211-231.

Manderson, J.P., B.A. Phelan, A.W. Stoner, and J. Hilbert. 2000. Predator-prey relations between age-1+ summer flounder (*Paralichthys dentatus*, Linnaeus) and age-0 winter flounder (*Pseudopleuronectes americanus*, Walbaum): predator diets, prey selection, and effects of sediments and macrophytes. J. Exp. Mar. Biol. Ecol. 251:17-39..

Marshall, N., and S.D. Hicks. 1962. Drift of medusae and their distribution in relation to the hydrography of the Niantic River, Connecticut. Limnol. Oceanogr. 7:268-269.

Mertz, G., and R.A. Myers. 1996. Influence of fecundity on recruitment of marine fishes. Can. J. Fish. Aquat. Sci. 53:1618-1625.

Modin, J., and L. Pihl. 1994. Differences in growth and mortality of juvenile plaice, *Pleuronectes platessa* L., following normal and extremely high settlement. Neth. J. Sea Res. 32:331-341.

Monteleone, D.M., W.T. Peterson and G.C. Williams. 1987. Interannual fluctuations in the density of sand lance, *Ammodytes americanus*, larvae in Long Island Sound, 1951-1983. Estuaries 10: 246-254.

Morgan, R.P. II, B.M. Baker, and J.H. Howard. 1995. Genetic structure of bay anchovy (*Anchoa mitchilli*) populations in Chesapeake Bay. Estuaries 18:482-493.

Morrison, J.A., I.R. Napier, and J.C. Gamble. 1991. Mass mortality of herring eggs associated with a sedimenting diatom bloom. ICES J. Mar. Sci. 48:237-245.

Myers, R.A., and N.G. Cadigan. 1993a. Density-dependent juvenile mortality in marine demersal fish. Can. J. Fish. Aquat. Sci. 50:1576-1590.

Myers, R.A., and N.G. Cadigan. 1993b. Is juvenile mortality in marine demersal fish variable? Can. J. Fish. Aquat. Sci. 50:1591-1598.

Nakata, H., M. Fujihara, Y. Suenaga, T. Nagasawa, and T. Fujii. 2000. Effect of wind blows on the transport of brown sole (*Pleuronectes herzensteini*) larvae in a shelf region of the Sea of Japan: numerical experiments with an Euler-Lagrangian model. J. Sea Res. 44:91-100.

Nash, R.D.M., and A.J. Geffen. 2000. The influence of nursery ground processes in the determination of year-class strength in juvenile plaice *Pleuronectes platessa* L. in Port Erin Bay, Irish Sea. J. Sea Res. 44:101-110.

Nash, R.D.M., A.J. Geffen, and G. Hughes. 1994. Individual growth of juvenile plaice (*Pleuronectes platessa* L.) on a small Irish Sea nursery ground (Port Erin Bay, Isle of Man, UK). Neth. J. Sea Res. 32:369-378.

NEFSC (Northeast Fisheries Science Center). 1999. Draft (1/19/99) report of the 28th Northeast regional stock assessment workshop (28th SAW). Stock assessment review committee (SARC) consensus summary of assessments. National Marine Fisheries Service, Woods Hole, MA.

NEFSC. 2000. 30th Northeast regional stock assessment workshop (30th SAW). Stock assessment review committee (SARC) consensus summary of assessments. National Marine Fisheries Service, Woods Hole, MA.

NEP and MRI (New England Power Company and Marine Research, Inc.). 1998. Finfish sampling. Pages F.1-F.177 *in* Brayton Point Station 1997 annual biological and hydrological report.

Nitschke, P., M. Mather, and F. Juanes. 2001. A comparison of length-, weight-, and age-specific fecundity relationships for cunner in Cape Cod Bay. N. Am. J. Fish. Man. 21:86-95.

Nizinski, M.S., B.B. Collette, and B.B. Washington. 1990. Separation of two species of sand lance, *Ammodytes americanus* and *A. dubius*, in the Western North Atlantic. Fish. Bull., U.S. 88:241-255.

NMFS (National Marine Fisheries Service). 1998. Status of fishery resources off the northeastern United States for 1998. NOAA Tech. Mem. NMFS-NE-115. 149 pp.

NMFS. 2001. Fisheries Statistics & Economics Division. Commercial fishing and marine recreational landings. Accessed via http://www.st.nmfs.gov/commercial/landings/annual landings.html and http://www.st.nmfs.gov/st1/recreational/data.html. July 27, 2001.

NUSCO (Northeast Utilities Service Company). 1981. Plankton ecology. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1980. 40 pp.

NUSCO. 1983. Section 5.5.3.3.4.3 Atlantic menhaden. Pages 5.1-36-5.1-47 *in* Millstone Nuclear Power Station Unit 3 environmental report. Operating license stage. Volume 2.

NUSCO. 1988. Winter flounder studies. Pages 149-224 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Three-unit operational studies, 1986-1987.

NUSCO. 1992. Winter flounder studies. Pages 7-109 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1991.

NUSCO. 1997. Fish ecology studies. Pages 9-58 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1996.

NUSCO. 1998a. Winter flounder studies. Pages 9-105 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1997.

NUSCO. 1998b. Fish ecology studies. Pages 107-160 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1997.

NUSCO. 2000. Winter flounder studies. Pages 9-112 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1999. Northeast Utilities Environmental Laboratory, Waterford, CT.

O'Connor, T.P. 2001. Comparing episodic, chronic, fishing, and non-fishing impacts on resource populations. Mar. Pol. Rev. 42:532-535.

Pauly, D. 1982. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer 39:175-192.

Pearcy, W.G. 1962. Ecology of an estuarine population of winter flounder *Pseudopleuronectes americanus* (Walbaum). Bull. Bingham Oceanogr. Coll. 18(1):1-78.

Pepin, P. 1991. Effect of temperature and size on development, mortality, and survival rates in the pelagic early life history stages of marine fish. Can. J. Fish. Aquat. Sci. 48:503-518.

Pihl, L. 1990. Year-class strength regulation in plaice (*Pleuronectes platessa* L.) on the Swedish west coast. Hydrobiologia 195:79-88.

Pihl, L., J. Modin, and H. Wennhage. 2000. Seasonal patterns of newly settled plaice (*Pleuronectes platessa* L.) along the Swedish Skagerrak archipelago. J. Sea Res. 44:65-80

Pihl L., and H.W. Van der Veer. 1992. Importance of exposure and habitat structure for the population density of 0-group plaice, *Pleuronectes platessa* L., in coastal nursery areas. Neth. J. Sea Res. 29:145-152.

Powell, A.B. 1994. Life history traits of two allopatric clupeids, Atlantic menhaden and gulf menhaden, and the effects of harvesting on these traits. N. Am. J. Fish. Man. 14:53-64.

Price, J. 1999. Research examines ecological impact of menhaden. Bay J. 8(10).

Purcell, J.E., D.A. Nemazie, S.E. Dorsey, E.D. Houde, and J.C. Gamble. 1994. Predation mortality of bay anchovy *Anchoa mitchilli* eggs and larvae due to scyphomedusae and ctenophores in Chesapeake Bay. Mar. Ecol. Prog. Ser. 114:47-58.

Reay, P.J. 1970. Synopsis of biological data on North Atlantic sand eels of the genus *Ammodytes*. (*A. tobianus*, *A. dubius*, *A. americanus* and *A. marinus*). FAO Fish. Synop. No. 82. 28 pp.

Reed, M., M.L. Spaulding, E. Lorda, H. Walker, and S.B. Saila. 1984. Oil spill fishery impact assessment modeling: the fisheries recruitment problem. Est. Coast. Shelf Sci. 19:591-610.

Rickman, S.J., N.K. Dulvy, S. Jennings, and J.D. Reynolds. 2000. Recruitment variation related to fecundity in marine fishes. Can. J. Fish. Aquat. Sci. 57:116-124.

Rijnsdorp, A.D., M. van Stralen, and H.W. Van der Veer. 1985. Selective tidal transport of North Sea plaice larvae *Pleuronectes platessa* in coastal nursery areas. Trans. Am. Fish. Soc. 114:461-470.

Rose, K.A., J.A. Tyler, R.C. Chambers, G. Klein-MacPhee, and D.J. Danila. 1995. Simulating winter flounder population dynamics using coupled individual-based young-of-the-year and age-structured adult models. Can. J. Fish. Aquat. Sci. 53:1071-1091.

Rubinstein, R.Y. 1981. Simulation and the Monte Carlo method. John Wiley and Sons, New York. 278 pp.

Saila, S.B., E. Lorda, J.D. Miller, R.A. Sher, and W.H. Howell. 1997. Equivalent adult estimates for losses of fish eggs, larvae, and juveniles at Seabrook Station with use of fuzzy logic to represent parametric uncertainty. N. Am. J. Fish. Man. 17:811-825.

Seikai, T., I. Kinoshita, and M. Tanaka. 1993. Predation by crangonid shrimp on juvenile Japanese flounder under laboratory conditions. Nippon Suisan Gakkaishi 59:321-326.

Sherman, K., C. Jones, L. Sullivan, W. Smith, P. Berrien, and L. Ejsymont. 1981. Congruent shifts in sand eel abundance in western and eastern North Atlantic ecosystems. Nature (London) 291:486-489.

Simpson, D.G. 1989. Population dynamics of the tautog, *Tautoga onitis*, in Long Island Sound. M.S. Thesis. Southern Connecticut State University, New Haven, CT. 65 pp.

Simpson, D.G., M.W. Johnson, and K. Gottschall. 1996. Job 2: marine finfish survey. Part 1: Long Island Sound trawl survey. Pages 23-59 *in* A study of recreational fisheries in Connecticut. CT Dept. Envir. Prot., Bur. Nat. Res., Fish. Div.

Sissenwine, M.B. 1984. Why do fish populations vary? Pages 59-94 *in* R.M. May, ed. Exploitation of marine communities. Springer-Verlag, New York.

Smith, W.G., and W.W. Morse. 1993. Larval dispersion patterns: early signals for the collapse/recovery of Atlantic herring *Clupea harengus* in the Georges Bank area. Fish. Bull., U.S. 91:338-347.

Snedecor, G.W., and W.C. Cochran. 1967. Statistical methods. The Iowa State University Press, Ames, IA. 593 pp.

Sogard, S.M. 1990. Parameters of habitat quality for epibenthic fishes and decapod crustaceans in New Jersey estuaries. Ph.D. dissertation, Rutgers University, New Brunswick, NJ. 195 pp. (Not seen, cited *in* Sogard and Able 1992).

Sogard, S.M., and K.W. Able. 1992. Growth variation of newly settled winter flounder (*Pseudopleuronectes americanus*) in New Jersey estuaries as determined by otolith microstructure. Neth. J. Sea Res. 29:163-172.

Stephenson, R.L., and I. Kornfeld. 1990. Reappearance of spawning Atlantic herring (*Clupea harengus*) on Georges Bank: population resurgence not recolonization. Can. J. Fish. Aquat. Sci. 47:1060-1064.

Stirratt, H. 2000. 2000 review of the ASMFC fishery management plan for tautog (*Tautoga onitis*).

Takvorian, P.M., and A. Cali. 1981. The occurrence of *Glugea stephani* (Hagenmuller, 1899) in American winter flounder, *Pseudopleuronectes americanus* (Walbaum) from the New York-New Jersey lower bay complex. J. Fish. Biol. 18:491-501.

Takvorian, P.M., and A. Cali. 1984. Seasonal prevalence of the microsporidian, *Glugea stephani* (Hagenmuller), in winter flounder, *Pseudopleuronectes americanus* (Walbaum) from the New York-New Jersey Lower Bay Complex. J. Fish. Biol. 24:655-663.

Townsend, D.W., and L.M. Cammen. 1988. Potential importance of the timing of spring plankton blooms to benthic-pelagic coupling and recruitment of juvenile demersal fishes. Biol. Oceanogr. 5:215-229.

Trippel, E.A. 1995. Age at maturity as a stress indicator in fisheries. BioScience 45:759-771.

Van der Veer, H.W. 1985. Impact of coelenterate predation on larval plaice *Pleuronectes platessa* and flounder *Platichthys flesus* stock in the western Wadden Sea. Mar. Ecol. Prog. Ser. 25:229-238.

Van der Veer, H.W. 1986. Immigration, settlement, and density-dependent mortality of a larval and early postlarval 0-group plaice (*Pleuronectes platessa*) population in the western Wadden Sea. Mar. Ecol. Prog. Ser. 29:223-236.

Van der Veer, H.W., and M.J.N. Bergman. 1987. Predation by crustaceans on a newly settled 0-group plaice *Pleuronectes platessa* population in the western Wadden Sea. Mar. Ecol. Prog. Ser. 35:203-215.

Van der Veer, H.W., B. Bies, and J.IJ. Witte. 2000b. Selective growth and mortality of juvenile 0-group plaice *Pleuronectes platessa* in the Dutch Wadden Sea: a consequence of irreversible non-genetic adaptation during early pelagic life. Mar. Ecol. Prog. Ser. 1979:273-283.

Van der Veer, H.W., T. Ellis, J.M. Miller, L. Pihl, and A.D. Rijnsdorp. 1997. Size-selective predation on juvenile North Sea flatfish and possible implications for recruitment. Pages 279-303 *in* R.C. Chambers and E.A. Trippel, eds. Early life history and recruitment in fish populations. Fish and fisheries series 21. Chapman and Hall, New York.

Van der Veer, H.W., A.J. Geffen, and J.IJ. Witte. 2000a. Exceptionally strong year classes in plaice *Pleuronectes platessa*: are they generated during the pelagic stage only, or also in the juvenile stage? Mar. Ecol. Prog. Ser. 199:255-262.

Van der Veer, H.W., L. Pihl, and M.J.N. Bergman. 1990. Recruitment mechanisms in North Sea plaice *Pleuronectes platessa*. Mar. Ecol. Prog. Ser. 64:1-12.

Van der Veer, H.W., and J.IJ. Witte. 1999. Year class strength of plaice *Pleuronectes platessa* in the Southern Bight of the North Sea: a validation and analysis of the inverse relationship with winter seawater temperature. Mar. Ecol. Prog. Ser. 184:455-257.

Vaughan, D.S., and J.W. Smith. 1988. Stock assessment of the Atlantic menhaden, *Brevoortia tyrannus*, fishery. NOAA Tech. Rep. NMFS 63. 18 pp.

Vaughan, D.S., J.W. Smith, E.H. Williams, and M.H. Prager. 2001. Analyses on the status of the Atlantic menhaden stock. Final version. Prepared for the ASMFC Menhaden Technical Committee. 48 pp. + app.

Wang, S.B., J.H. Cowan, K.A. Rose, and E.D. Houde. 1997. Individual-based modeling of recruitment variability and biomass production of bay anchovy in mid-Chesapeake Bay. J. Fish Biol. 51(suppl. A):101-120.

Werner, F.E., J.A. Quinlan, B.O. Blanton, and R.A. Luettich, Jr. 1997. The role of hydrodynamics in explaining the variability in fish populations. J. Sea. Res. 37:195-212.

Westin, D.T., K J. Abernethy, I.E. Meller, and B.A. Rogers. 1979. Some aspects of biology of the American sand lance, *Ammodytes americanus*. Trans. Am. Fish. Soc. 108:328-331.

White, G.G. 1996. Reproductive biology of tautog, *Tautoga onitis*, in the lower Chesapeake Bay and coastal waters of Virginia. M.S. Thesis, The College of William and Mary, Williamsburg, VA. 100 pp.

Williams, P.J., and J.A. Brown. 1992. Development changes in the escape response of larval winter flounder *Pleuronectes americanus* from hatch through metamorphosis. Mar. Ecol. Prog. Ser. 88:185-193.

Winters, G.H. 1983. Analysis of the biological and demographic parameters of the northern sand lance, *Ammodytes dubius*, from the Newfoundland Grand Bank. Can. J. Fish. Aquat. Sci. 40:409-419.

Wires, L.R., F.J. Cuthbert, D.R. Trexel, and A.R. Joshi. 2001. Status of the double-crested cormorant (*Phalacrocorax autitus*) in North America. Final report to U.S. Fish and Wildlife Service. University of Minnesota, Dept. Fish. Wildl., St. Paul, MN. 358 pp.

Witting, D.A., and K.W. Able. 1993. Effects of body size on probability of predation for juvenile summer and winter flounder based on laboratory experiments. Fish. Bull., U.S. 91:577-581.

Witting, D.A., and K.W. Able. 1995. Predation by sevenspine bay shrimp *Crangon septemspinosa* on winter flounder *Pleuronectes americanus* during settlement: laboratory experiments. Mar. Ecol. Prog. Ser. 123: 23-31.

Yamashita, Y., Y. Tsuruta, and H. Yamada. 1996a. Transport and settlement mechanisms of larval stone flounder, *Kareius bicoloratus*, into nursery grounds. Fish Oceanogr. 5:194-204. (Not seen, cited *in* Yamashita et al. 2000).

Yamashita, Y., H. Yamada, K.D. Malloy, T.E. Targett, and Y. Tsuruta. 1996b. Sand shrimp predation on settling and newly-settled stone flounder and its relationship to optimal nursery habitat selection in Sendai Bay, Japan. Pages 271-283 *in* Y. Wantanabe, Y. Yamashita, and Y. Oozeki, eds. Survival strategies in early life history stages of marine resources. A.A. Balkema, Rotterdam.

Yamashita, Y., T. Otake, and H. Yamada. 2000. Relative contributions from exposed inshore and estuarine nursery grounds to the recruitment of stone flounder, *Platichthys bicoloratus*, estimated using otolith Sr:Ca ratios. Fish Oceanogr. 9:316-327.

Zastrow, C.E., E.D. Houde, and L.G. Morin. 1991. Spawning, fecundity, hatch-date frequency and young-of-the-year growth of bay anchovy *Anchoa mitchilli* in mid-Chesapeake Bay. Mar. Ecol. Prog. Ser. 73:161-171.

Zijlstra, J.J., and J. IJ. Witte. 1985. On the recruitment of 0-group plaice in the North Sea. Neth. J. Zool. 35:360-376. (Not seen, cited *in* Van der Veer and Bergman 1987).

TABLE 4-1. Estimated number of winter flounder larvae entrained at MNPS by developmental stage from the Niantic River and other sources, based on mass-balance calculations for 1984 through 1999 (see NUSCO 2000 for details).

Year	Source	Stage 1 (X 10^6)	Stage 2 (X 10^6)	Stage 3 (X 10^6)	Stage 4 (X 10^6)
1984	Niantic River	0.2	14.9	13.9	3.1
	Other	0.1	24.0	24.8	3.5
1985	Niantic River	3.4	17.2	6.8	0.4
	Other	0.8	10.6	34.4	6.4
1986	Niantic River	0.7	7.5	15.5	4.4
	Other	1.5	24.5	60.4	10.9
1987	Niantic River	0.8	15.2	23.9	1.9
	Other	0.6	30.1	85.1	7.5
1988	Niantic River	3.9	9.5	24.6	1.5
	Other	1.1	7.7	114.3	22.9
1989	Niantic River	2.8	11.2	19.1	0.5
	Other	4.1	40.5	81.4	8.4
1990	Niantic River	0.9	6.2	27.7	3.7
	Other	0.8	12.2	72.7	9.0
1991	Niantic River	0.2	3.6	26.7	4.7
	Other	0.6	8.8	65.4	6.4
1992	Niantic River	5.6	10.1	55.7	8.8
	Other	30.1	54.1	295.5	33.1
1993	Niantic River	0.3	1.2	3.9	0.5
	Other	1.2	5.1	23.2	7.8
1994	Niantic River	2.8	12.4	29.0	6.2
	Other	2.6	24.4	80.8	16.7
1995	Niantic River	0.6	6.8	55.7	14.8
	Other	1.1	13.5	104.1	17.4
1996	Niantic River	13.2	12.7	4.1	0.3
	Other	1.6	4.2	11.6	3.9
1997	Niantic River	0.7	1.6	6.1	0.9
	Other	5.2	12.1	42.9	6.1
1998	Niantic River	0.9	5.0	16.2	3.8
	Other	0.3	2.8	37.8	17.0
1999	Niantic River	2.8	9.0	17.2	3.9
	Other	7.7	21.4	64.8	19.1

TABLE 4-2. Estimated abundance of winter flounder larvae in the Niantic River and the number and percentage of the production entrained from the Niantic River (ENT) by developmental stage from 1984 through 1999. Numbers of larvae entrained from the Niantic River were based on mass-balance calculations (see NUSCO 2000 for details).

Year	Stage of development	Niantic River abundance (X 10^6)	Entrainment from the Niantic River[a] (X 10^6)	% production entrained (ENT)
1984	Stage 1	2,543	9.8	0.4
	Stage 2	609	14.9	2.4
	Stage 3	299	13.9	4.6
	Stage 4	209	3.1	1.5
	Total		41.7	**9.0**
1985	Stage 1	2,757	14.9	0.5
	Stage 2	660	17.2	2.6
	Stage 3	324	6.8	2.1
	Stage 4	226	0.4	0.2
	Total		39.3	**5.4**
1986	Stage 1	2,155	11.1	0.5
	Stage 2	605	7.5	1.2
	Stage 3	316	15.5	4.9
	Stage 4	220	4.4	2.0
	Total		38.5	**8.7**
1987	Stage 1	2,602	33.0	1.3
	Stage 2	731	15.2	2.1
	Stage 3	381	23.9	6.3
	Stage 4	266	1.9	0.7
	Total		74.0	**10.3**
1988	Stage 1	4,245	80.4	1.9
	Stage 2	635	9.5	1.5
	Stage 3	229	24.6	10.7
	Stage 4	165	1.5	0.9
	Total		116.0	**15.0**
1989	Stage 1	3,465	63.8	1.8
	Stage 2	483	11.2	2.3
	Stage 3	159	19.1	12.0
	Stage 4	107	0.5	0.5
	Total		94.6	**16.6**
1990	Stage 1	1,683	31.8	1.9
	Stage 2	691	6.2	0.9
	Stage 3	190	27.7	14.6
	Stage 4	164	3.7	2.3
	Total		69.4	**19.6**
1991	Stage 1	3,099	12.6	0.4
	Stage 2	2,162	3.6	0.2
	Stage 3	658	26.7	4.1
	Stage 4	533	4.7	0.9
	Total		47.6	**5.5**

TABLE 4-2. (cont.).

Year	Stage of development	Niantic River abundance (X 10^6)	Entrainment from the Niantic River[a] (X 10^6)	% production entrained (ENT)
1992	Stage 1	1,896	22.0	1.2
	Stage 2	794	10.1	1.3
	Stage 3	292	55.7	19.1
	Stage 4	235	8.8	3.8
	Total		96.6	25.2
1993	Stage 1	1,079	11.3	1.0
	Stage 2	558	1.2	0.2
	Stage 3	101	3.9	3.9
	Stage 4	70	0.5	0.7
	Total		16.9	5.8
1994	Stage 1	1,592	26.3	1.7
	Stage 2	874	12.4	1.4
	Stage 3	438	29.0	6.6
	Stage 4	381	6.2	1.6
	Total		73.9	11.3
1995	Stage 1	793	38.0	4.8
	Stage 2	501	6.8	1.4
	Stage 3	208	55.7	26.8
	Stage 4	139	14.8	10.6
	Total		115.3	43.6
1996	Stage 1	398	23.3	5.9
	Stage 2	141	12.7	9.0
	Stage 3	43	4.1	9.5
	Stage 4	30	0.3	1.0
	Total		40.4	25.4
1997	Stage 1	706	5.6	0.8
	Stage 2	464	1.6	0.3
	Stage 3	242	6.1	2.5
	Stage 4	137	0.9	0.7
	Total		14.2	4.3
1998	Stage 1	477	5.4	1.1
	Stage 2	283	5.0	1.8
	Stage 3	133	16.2	12.2
	Stage 4	76	3.8	5.0
	Total		30.4	20.1
1999	Stage 1	401	16.8	4.2
	Stage 2	154	9.0	5.9
	Stage 3	96	17.2	17.9
	Stage 4	81	3.9	4.8
	Total		46.9	32.8
Geometric mean				12.9

[a] Note that entrainment estimates attributed to the Niantic River are higher than those given previously in Chapter 3, Table 3-8 due to adjustments made for Stage 1 entrainment.

TABLE 4-3. Estimated percentages of annual production loss (conditional mortality rate ENT) as used in the Niantic River winter flounder population dynamics model (SPDM) simulations from 2000 onwards for this report[a].

Method of calculation or Period for Use in SPDM Simulations	% ENT
MEAN Annual Production Loss Rates (base mean rates)	
Three-unit period (1986-95) geometric mean of annual loss rates[b]	16.16
Above mean scaled for two-unit operation going forward (2000-2034)	12.93
Reduced mean for only Unit 3 operation following Unit 2 retirement (2035-2044)	7.78
Unit 3 retirement (≥2045)	0
LOW Annual Production Loss Rates (base mean rates ÷ 1.5)	
Two-unit operation going forward (2000-2034)	8.5
Reduced mean for only Unit 3 operation following Unit 2 retirement (2035-2044)	5.0
Unit 3 retirement (≥2045)	0
HIGH Annual Production Loss Rates (base mean rates x 1.5)	
Two-unit operation going forward (2000-2034)	19.5
Reduced mean for only Unit 3 operation following Unit 2 retirement (2035-2044)	12.0
Unit 3 retirement (≥2045)	0

[a] The ENT values used in SPDM simulations for 1971-99 in this report were those given in Table 42 (p. 96) of NUSCO (2000).
[b] Determined from Table 4-2.

TABLE 4-4. Summary of data, rates, and other inputs used with the Niantic River winter flounder population dynamics model (SPDM) simulations found in this report.

Model input	Value used or available		
Number of age-classes in population	15		
Earliest age at which all females are mature	5		
Fraction mature, mean wt (lbs), and mean fecundity by age[a]:			
Age-1 females	0	0.011	0
Age-2 females	0	0.125	0
Age-3 females	0.25	0.497	232,088
Age-4 females	0.80	0.776	432,517
Age-5 females	1.00	1.096	700,390
Age-6 females	1.00	1.435	1,019,793
Age-7 females	1.00	1.628	1,216,926
Age-8 females	1.00	1.839	1,442,512
Age-9 females	1.00	2.068	1,699,372
Age-10 females	1.00	2.316	1,990,489
Age-11 females	1.00	2.584	2,319,011
Age-12 females	1.00	2.872	2,688,253
Age-13 females	1.00	3.182	3,101,703
Age-14 females	1.00	3.514	3,563,020
Age-15 females	1.00	3.869	4,076,040
Age after which total annual mortality is constant	4		
Instantaneous mortality rates M and F at age-1	0.8425[b]	F*0.02[c]	
Instantaneous mortality rates M and F at age-2	0.20	F*0.25	
Instantaneous mortality rates M and F at age-3	0.20	F*0.60	
Instantaneous mortality rates M and F at age-4+	0.20	F*1	
Initial number of female spawners	87,416[d]		
Mean fecundity of the stock (eggs per female spawner)	1,322,994[e]		
α_0 for the unfished (F = 0) stock	5.20[f]		
β from the three-parameter SRR (mean value from 1989-2000)	2.306×10^{-5}		
ϕ from the three-parameter SRR (mean value from 1989-2000)	-0.370		
Mean February (1977-96) water temperature (°C)	2.79		
standard deviation	1.18		
minimum temperature	0.36		
maximum temperature	4.76		

[a] Weight and fecundity at age for the Niantic River spawning stock at equilibrium (see Appendix A to Chapter 4, Table A4-4 for calculation).

[b] Re-calculated from the value of 0.5 used in NUSCO (2000) and based on simulations used to calibrate model population sizes to those measured by sampling in the annual Niantic River winter flounder population spawning surveys (see text for further explanation).

[c] Values of M remain constant during all spawning cycles or years simulated. Fish at ages-1-3 are partially recruited and the multipliers shown are used to reduce F accordingly.

[d] Corresponds to the unfished stock at equilibrium or replacement level, $P_{rep} = (\log_e[\alpha]/\beta$, where α and β are parameters of the Ricker stock and recruitment model for Niantic River winter flounder (see Appendix A to Chapter 4 for a discussion of winter flounder stock and recruitment parameters).

[e] Calculated for the Niantic River winter flounder female spawning stock at equilibrium in the absence of fishing (see Appendix A to Chapter 4 for a discussion of winter flounder stock and recruitment parameters).

[f] Indirectly calculated from life history parameters (see Appendix A to Chapter 4, Table A4-3 for a discussion of winter flounder stock and recruitment parameters).

TABLE 4-5. Winter flounder instantaneous fishing mortality rates (F) used in SPDM simulations for this study. Given are rates determined by CT DEP Marine Fisheries for LIS (1984-98) and by NEFSC (1999) for the Southern New England region (SARC; 1981-98). The 1999 rates shown were kept constant from 2000 onwards to assess the effectiveness of entrainment reduction alternatives.

Year	DEP F rates	SARC F rates
1981	0.70[a]	0.77
1982	0.70	0.45
1983	0.70	0.64
1984	1.28	0.57
1985	1.15	1.17
1986	1.11	0.57
1987	1.05	0.98
1988	1.10	1.38
1989	1.16	1.25
1990	1.52	1.10
1991	1.43	1.32
1992	1.40	1.01
1993	1.16	0.70
1994	1.08	0.32
1995	0.92	0.47
1996	0.75	0.40
1997	0.91	0.31
1998	0.82	0.375[b]
≥1999	0.74[c]	0.375

[a] Rates for 1981-83 for the DEP series from NUSCO (2000).
[b] Arithmetic mean of rates in the previous 4 years.
[c] Arithmetic mean of last three-point moving average and a 1999 annual rate estimate as determined by DEP.

TABLE 4-6. Fractional reductions in larval winter flounder entrainment mortality as a result of the implementation of various feasible intake technology alternatives at MNPS.

Alternative	Reduction in larval winter flounder entrainment: Primary season[a]	Optimal season[a]
Unit 3 operating with 5 condenser cooling-water pumps (cwps)	0.07	0.06
Unit 3 operating with 4 condenser cooling-water pumps	0.16	0.12
Unit 2 operating with 3 condenser cooling-water pumps	0.07	0.05
Unit 3 condenser bypass, throttled, or variable speed cwps	0.15	0.11
Unit 2 condenser bypass, throttled, or variable speed cwps	0.06	0.05
Combined Unit 3 operating with 5 cwps and Unit 2 operating with 3 cwps	0.15	0.11
Combined Unit 3 operating with 4 cwps and Unit 2 operating with 3 cwps	0.24	0.18
Combined Units 2 and 3 with condenser bypass, throttled, or variable speed cwps	0.25	0.19
Unit 3 with full-sized cooling tower	0.58[b]	0.58[b]
Unit 3 with 2/3-sized cooling tower	0.36	0.36
Unit 2 with full-sized cooling tower	0.34	0.34
Units 2 and 3 with full-sized cooling towers	0.91	0.91
Unit 3 with an offshore intake	0.31[c]	0.31[c]
Units 2 and 3 with an offshore intake	0.50[c]	0.50[c]

[a] The primary season for winter flounder entrainment is March 22-June 5 and the optimal season is April 4-May 14 (see Chapter 3, Section 3.2.4).
[b] Assumes that the cooling towers would operate throughout each season.
[c] Assumes that the entrainment of Niantic River winter flounder larvae would be reduced by 50% at the location proposed for an offshore intake.

TABLE 4-7. Summary of cumulative gains in Niantic River female winter flounder spawner biomass (lbs) relative to the baseline (i.e., population projection under present two-unit operation with no change in entrainment) projected by the SPDM after 10, 20, 30, and 43 years (at the expected retirement of MNPS in 2045) as a result of various reductions in larval entrainment mortality, and under two constant rates of fishing and three annual levels of production losses due to entrainment.

Time elapsed in years since 2002	Simulated reduction in larval entrainment	DEP rate (F=0.74) Cumulative gains when production loss due to entrainment was:			SARC rate (F=0.375) Cumulative gains when production loss due to entrainment was:		
		LOW[a]	MEAN	HIGH[b]	LOW[a]	MEAN	HIGH[b]
10	6%	245	359	512	787	1,184	1,751
	15%	613	900	1,286	1,967	2,960	4,384
	35%	1,435	2,114	3,032	4,595	6,919	10,261
	58%	2,389	3,528	5,082	7,622	11,488	17,060
	91%	3,772	5,592	8,101	11,977	18,070	26,885
20	6%	1,174	1,667	2,236	3,036	4,620	6,909
	15%	2,950	4,199	5,671	7,588	11,546	17,297
	35%	6,957	9,976	13,646	17,693	26,942	40,454
	58%	11,668	16,865	23,392	29,292	44,622	67,130
	91%	18,613	27,191	38,412	45,879	69,895	105,300
30	6%	2,683	3,773	4,914	5,585	8,634	13,209
	15%	6,745	9,526	12,534	13,941	21,535	32,982
	35%	15,931	22,731	30,515	32,413	50,032	76,660
	58%	26,753	38,537	52,877	53,486	82,449	126,263
	91%	42,723	62,422	87,747	83,385	128,217	195,899
43	6%	5,011	7,168	9,374	8,539	13,418	21,101
	15%	12,580	18,078	23,955	21,288	33,393	52,487
	35%	29,601	42,979	58,395	49,368	77,234	121,015
	58%	49,473	72,540	100,916	81,233	126,660	197,636
	91%	78,421	116,228	165,763	126,157	195,732	303,373

[a] The LOW production loss due to entrainment rate is the MEAN rate divided by 1.5 (see Table 4-3 for details).
[b] The HIGH production loss due to entrainment rate is the MEAN rate multiplied by 1.5 (see Table 4-3 for details).

TABLE 4-8. Summary of absolute increases in Niantic River female winter flounder stock size (spawner biomass in lbs) relative to the baseline (i.e., population projection under present two-unit operation with no change in entrainment) projected by the SPDM after 10, 20, 30, and 43 years (at the expected retirement of MNPS in 2045) as a result of various reductions in larval entrainment mortality, and under two constant rates of fishing and three annual levels of production losses due to entrainment.

Time elapsed in years since 2002	Simulated reduction in larval entrainment	DEP rate (F=0.74) Gains when production loss due to entrainment was:			SARC rate (F=0.375) Gains when production loss due to entrainment was:		
		LOW[a]	MEAN	HIGH[b]	LOW[a]	MEAN	HIGH[b]
10	6%	55	80	111	171	258	379
	15%	139	201	280	429	645	951
	35%	327	474	664	1,003	1,509	2,231
	58%	546	796	1,124	1,664	2,508	3,719
	91%	866	1,272	1,816	2,618	3,952	5,879
20	6%	123	171	220	251	389	595
	15%	308	431	561	626	970	1,487
	35%	730	1,032	1,371	1,455	2,254	3,460
	58%	1,229	1,758	2,386	2,400	3,712	5,702
	91%	1,970	2,861	3,991	3,736	5,765	8,839
30	6%	167	234	296	253	402	640
	15%	419	591	760	630	998	1,590
	35%	989	1,415	1,873	1,457	2,301	3,652
	58%	1,659	2,404	3,277	2,391	3,758	5,933
	91%	2,642	3,884	5,466	3,699	5,773	9,032
43	6%	176	271	379	180	301	522
	15%	439	678	964	447	743	1,280
	35%	1,019	1,582	2,311	1,028	1,693	2,874
	58%	1,674	2,608	3,890	1,676	2,733	4,567
	91%	2,587	4,032	6,098	2,572	4,141	6,782

[a] The LOW production loss due to entrainment rate is the MEAN rate divided by 1.5 (see Table 4-3 for details).
[b] The HIGH production loss due to entrainment rate is the MEAN rate multiplied by 1.5 (see Table 4-3 for details).

TABLE 4-9. Connecticut recreationally harvested and commercial landings (lbs) of winter flounder (NMFS 2001), total landings (C), instantaneous fishing mortality rates (F) determined by CT DEP Marine Fisheries for Long Island Sound (LIS; 1984-98) and by NEFSC (1999) for the Southern New England stock (SARC; 1991-98), calculated exploitation rate (u), and calculated stock size in lbs (N) of Long Island Sound winter flounder from 1981 through 1999.

Year	Recreational landings (lbs)	Commercial landings (lbs)	Total landings in lbs (C)	DEP F rate	DEP exploitation rate (u)[a]	DEP rate-based LIS stock biomass in lbs (N)[b]	SARC F rate	SARC exploitation rate (u)[a]	SARC rate-based LIS stock biomass in lbs (N)[b]
1981	668,097	1,153,200	1,821,297	0.70[c]	0.462	3,945,986	0.77	0.493	3,695,118
1982	905,542	1,134,500	2,040,042	0.70	0.462	4,419,914	0.45	0.331	6,165,292
1983	306,170	1,171,500	1,477,670	0.70	0.462	3,201,490	0.64	0.433	3,412,771
1984	1,220,359	1,308,900	2,529,259	1.28	0.668	3,786,378	0.57	0.398	6,362,759
1985	946,150	1,193,900	2,140,050	1.15	0.631	3,391,427	1.17	0.637	3,359,557
1986	609,506	569,400	1,178,906	1.11	0.619	1,905,450	0.57	0.398	2,965,728
1987	1,002,593	1,424,300	2,426,893	1.05	0.599	4,049,303	0.98	0.575	4,218,403
1988	891,997	749,900	1,641,897	1.10	0.616	2,667,366	1.38	0.694	2,367,499
1989	721,890	553,300	1,275,190	1.16	0.634	2,011,263	1.25	0.660	1,932,536
1990	434,690	1,063,090	1,497,780	1.52	0.725	2,064,547	1.10	0.616	2,433,238
1991	360,717	844,700	1,205,417	1.43	0.705	1,708,814	1.32	0.678	1,776,625
1992	151,419	704,300	855 719	1.40	0.698	1,225,361	1.01	0.586	1,460,764
1993	84,176	552,113	636,289	1.16	0.634	1,003,571	0.70	0.462	1,378,571
1994	99,463	307,000	406,463	1.08	0.609	667,256	0.32	0.250	1,628,942
1995	257,070	356,133	613 203	0.92	0.553	1,108,039	0.47	0.343	1,790,202
1996	116,961	-[d]	-	0.75	0.484	-	0.40	0.301	-
1997	237,116	426,474	663,590	0.91	0.550	1,207,316	0.31	0.243	2,732,667
1998	275,467	-[d]	-	0.82	0.514	-	0.375[e]	0.286	-
1999	69,090	377,403	446,493	0.74[f]	0.480	930,740	0.375	0.286	1,565,585

[a] $u = (F / (F + M)) \cdot (1 - \exp(-F - M))$, where M = instantaneous natural mortality rate = 0.20.
[b] $N = C / u$.
[c] Rates for 1981-83 for the DEP series from NUSCO (2000).
[d] Not available from NMFS (2001).
[e] Arithmetic mean of rates in the previous 4 years.
[f] Arithmetic mean of last three-point moving averages and a 1999 rate estimate as determined by DEP.

TABLE 4-10. Estimated exploitable biomass (lbs) of the Niantic River winter flounder spawning stock, stock size biomass of the Long Island Sound (LIS) winter flounder stock based on both the DEP and SARC instantaneous fishing mortality rates (F) used in this report, and the fraction that the Niantic River stock made up of the LIS winter flounder resource from 1981 through 1999.

Year	Niantic River exploitable[a] stock biomass (lbs)	DEP F rate-based stock biomass (lbs) estimate of LIS winter flounder[b]	% Niantic River of DEP F rate-based stock biomass (lbs)	SARC F rate-based stock biomass (lbs) estimate of LIS winter flounder[b]	% Niantic River of SARC F rate-based stock biomass (lbs)
1981	122,131	3,945,986	0.031	3,695,118	0.033
1982	127,706	4,419,914	0.029	6,165,292	0.021
1983	90,852	3,201,490	0.028	3,412,771	0.027
1984	50,463	3,786,378	0.013	6,362,759	0.008
1985	44,568	3,391,427	0.013	3,359,557	0.013
1986	38,697	1,905,450	0.020	2,965,728	0.013
1987	51,456	4,049,303	0.013	4,218,403	0.012
1988	68,566	2,667,366	0.026	2,367,499	0.029
1989	53,289	2,011,263	0.026	1,932,536	0.028
1990	30,521	2,064,547	0.015	2,433,238	0.013
1991	53,872	1,708,814	0.032	1,776,625	0.030
1992	30,412	1,225,361	0.025	1,460,764	0.021
1993	15,839	1,003,571	0.016	1,378,571	0.011
1994	21,710	667,256	0.033	1,628,942	0.013
1995	10,054	1,108,039	0.009	1,790,202	0.006
1996	4,370	-	-	-	-
1997	7,117	1,207,316	0.006	2,732,667	0.003
1998	4,829	-	-	-	-
1999	4,316	930,740	0.005	1,565,585	0.003
Geometric mean			0.017		0.013

[a] To be conservative, based on the minimum legal size for retention by the sport fishery, which in some years had lower size limits than the commercial fishery. See Table 2 of NUSCO (2000) for annual minimum size limits. Estimates include both males and females (see text for details).

[b] See Table 4-9 for calculation of stock biomass.

TABLE 4-11. Average lifetime egg production of an age-3 female winter flounder.

Age	Annual mean fecundity[a]	Survival probability[b]	Fraction mature[c]	Egg production
3	232,088	1.0000000	0.25	58,022
4	432,517	0.6440000	0.8	222,833
5	700,390	0.2515643	1.0	176,193
6	1,019,793	0.0982680	1.0	100,213
7	1,216,926	0.0247207	1.0	30,083
8	1,442,512	0.0062189	1.0	8,971
9	1,699,372	0.0015644	1.0	2,659
10	1,990,489	0.0003936	1.0	783
11	2,319,011	0.0000990	1.0	230
12	2,688,253	0.0000249	1.0	67
13	3,101,703	0.0000063	1.0	19
14	3,563,020	0.0000016	1.0	6
15	4,076,040	0.0000004	1.0	2
Total				600,080

[a] From NUSCO (2000: Table 35).
[b] M = 0.20 (NUSCO 2000), F = 0.74 and $F_{(age\text{-}3)} = 0.6 \cdot F$ (NEFSC 1999), $S = e^{-(M+F)} = 0.3906$
[c] From NUSCO (2000: Table 35).

TABLE 4-12. Total instantaneous mortality rate (Z) and fecundity (f_a) parameter estimates used in the calculation of equivalent-adults for non-Niantic River winter flounder.

Parameter	Definition	Value	Source
Z_e (total)	Egg survival from fertilization to hatch	1.628	Saila et al. (1997)
$Z_{l\,(3\text{-}7\,mm)}$	Larval survival 3 - 7 mm	0.702	Saila et al. (1997)
$Z_{l\,(>7\,mm)}$	Larval survival 7 mm to age-3	10.282	$Z_{l\,(>7\,mm)} = Z_{total} - Z_e - Z_l$
Z_{total}	Egg survival to age-3	12.612	$Z = \log_e(2/\text{fecundity}) \cdot (-1)$
f_a	Average lifetime fecundity	600,080	See Table 4-12

TABLE 4-13. Numbers of non-Niantic River winter flounder larvae entrained during two-unit operation, probability of survival to adulthood, and estimated number of equivalent-adults lost due to entrainment from 1986 through 1995 at MNPS.

Year	Stage	Number entrained (N_i)	Proportion of non-Niantic River fish[a]	Survival probability of egg to larva (S_e)	Survival probability of larva to adult (S_l)	Equivalent-adults (N_a)
1986	1	1,760,000	0.6818	0.138207	0.000024	29
	2	25,600,000	0.7656	0.097296	0.000034	671
	3	60,720,000	0.7958	0.023897	0.000139	6,739
	4	12,240,000	0.7124	0.005869	0.000568	4,952
	Total	100,320,000				12,391
1987	1	1,120,000	0.4286	0.138207	0.000024	12
	2	36,240,000	0.6645	0.097296	0.000034	825
	3	87,200,000	0.7807	0.023897	0.000139	9,495
	4	7,520,000	0.7979	0.005869	0.000568	3,407
	Total	132,080,000				13,738
1988	1	4,000,000	0.2200	0.138207	0.000024	21
	2	13,760,000	0.4477	0.097296	0.000034	211
	3	111,120,000	0.8229	0.023897	0.000139	12,753
	4	19,520,000	0.9385	0.005869	0.000568	10,403
	Total	148,400,000				23,388
1989	1	5,520,000	0.5942	0.138207	0.000024	79
	2	41,360,000	0.7834	0.097296	0.000034	1,110
	3	80,400,000	0.8100	0.023897	0.000139	9,082
	4	7,120,000	0.9438	0.005869	0.000568	3,816
	Total	134,400,000				14,087
1990	1	1,360,000	0.4706	0.138207	0.000024	15
	2	14,720,000	0.6630	0.097296	0.000034	334
	3	80,320,000	0.7241	0.023897	0.000139	8,111
	4	10,160,000	0.7087	0.005869	0.000568	4,088
	Total	106,560,000				12,550
1991	1	640,000	0.7500	0.138207	0.000024	12
	2	9,920,000	0.7097	0.097296	0.000034	241
	3	73,680,000	0.7101	0.023897	0.000139	7,297
	4	8,880,000	0.5766	0.005869	0.000568	2,907
	Total	93,120,000				10,457
1992	1	28,560,000	0.8431	0.138207	0.000024	581
	2	51,360,000	0.8427	0.097296	0.000034	1,483
	3	280,960,000	0.8414	0.023897	0.000139	32,970
	4	33,520,000	0.7900	0.005869	0.000568	15,036
	Total	394,400,000				50,070
1993	1	1,200,000	0.8000	0.138207	0.000024	23
	2	5,040,000	0.8095	0.097296	0.000034	140
	3	21,680,000	0.8561	0.023897	0.000139	2,589
	4	6,640,000	0.9398	0.005869	0.000568	3,543
	Total	34,560,000				6,295
1994	1	4,320,000	0.4815	0.138207	0.000024	50
	2	29,440,000	0.6630	0.097296	0.000034	669
	3	66,960,000	0.9654	0.023897	0.000139	9,015
	4	18,320,000	0.7293	0.005869	0.000568	7,586
	Total	119,040,000				17,320

TABLE 4-13 (continued).

Year	Stage	Number entrained (N_i)	Proportion of non-Niantic River fish[a]	Survival probability of egg to larva (S_e)	Survival probability of larva to adult (S_l)	Equivalent-adults (N_a)
1995	1	1,360,000	0.6471	0.138207	0.000024	21
	2	16,240,000	0.6650	0.097296	0.000034	370
	3	127,840,000	0.6514	0.023897	0.000139	11,615
	4	25,760,000	0.5404	0.005869	0.000568	7,904
	Total	171,200,000				19,910
Mean	1	4,984,000	0.5916	0.138207	0.0000016	84
	2	24,368,000	0.7014	0.097296	0.000023	605
	3	79,270,400	0.7957	0.023897	0.000092	10,967
	4	11,974,400	0.7677	0.005869	0.000375	6,364
	Total	114,726,400				18,021

[a] From mass-balance model reported in NUSCO (2000) and data given on Table 4-1.

TABLE 4-14. Spearman's rank-order correlations between the annual estimates of larval winter flounder entrainment at MNPS and the abundance indices of several post-entrainment early life history stages.

Index[a]	Niantic River early summer age-0 juveniles	Niantic River late summer age-0 juveniles	Fall-early winter river-bay age-0 juveniles	Niantic River winter-spring age-1 juveniles (lower river)	Niantic River winter-spring age-1 juveniles (upper river)
Annual estimate of entrainment at MNPS	0.5735[b] 0.0202 * 16	0.7892 0.0002 ** 17	0.4216 0.0402 * 24	-0.0805 0.7086 NS 24	0.0271 0.9098 NS 20

[a] Indices include the early and late summer median CPUE of age-0 winter flounder at two stations in the Niantic River, the Δ-mean CPUE of age-0 winter flounder taken at trawl monitoring program stations from November through February, and the Δ-mean CPUE of age-1 winter flounder taken in both the lower and upper portions of the Niantic River during the February-April adult spawning survey (see DNC 2001a for details).

[b] The three statistics shown in each correlation matrix element are:
correlation coefficient (r),
probability of a larger r (NS - not significant [$p > 0.05$], * - significant at $p \leq 0.05$, ** - significant at $p \leq 0.01$), and
number of annual observations (sample size).

TABLE 4-15. Matrix of Spearman's rank-order correlations among various winter flounder larval and Niantic River female spawner abundance indices.

Index[a]	Larvae (≥7 mm) at MNPS discharge	Niantic River early summer age-0 juveniles	Niantic River late summer age-0 juveniles	Fall-early winter river-bay age-0 juveniles	Niantic River winter-spring age-1 juveniles (lower river)	Niantic River winter-spring age-1 juveniles (upper river)
Age-3 female spawners[b]	0.0424[c] 0.8516 NS 22	-0.1978 0.5171 NS 13	-0.0637 0.8286 NS 14	-0.3380 0.1240 NS 22	0.7896 0.0001 ** 22	0.8390 0.0001 ** 18
Age-4 female spawners[b]	0.0792 0.7328 NS 21	-0.2098 0.5128 NS 12	-0.3297 0.2713 NS 13	-0.6604 0.0011 ** 21	0.7769 0.0001 ** 21	0.7451 0.0006 ** 17
Age-5 female spawners[b]	0.2962 0.2047 NS 20	-0.3909 0.2345 NS 11	-0.4546 0.1377 NS 12	-0.5548 0.0111 * 20	0.6574 0.0036 ** 20	0.6353 0.0082 ** 15

[a] Indices include the abundance index of larval winter flounder ≥7 mm at the MNPS discharge, the early and late summer median CPUE of age-0 winter flounder at two stations in the Niantic River the Δ-mean CPUE of age-0 winter flounder taken at trawl monitoring program stations from November through February, and the Δ-mean CPUE of age-1 winter flounder taken in both the lower and upper portions of the Niantic River during the February-April adult spawning survey (see DNC 2001a for details).

[b] Determined by applying an age-length key to the length distribution of annual standardized female abundances (see DNC 2001a for details).

[c] The three statistics shown in each correlation matrix element are:
correlation coefficient (r),
probability of a larger r (NS - not significant [$p > 0.05$], * - significant at $p \leq 0.05$, ** - significant at $p \leq 0.01$), and
number of annual observations (sample size).

TABLE 4-16. Matrix of Spearman's rank-order correlations among various regional winter flounder abundance indices (see text for details).

Abundance Index	RIFW - Narragansett Bay	URI - Fox Island	CT DEP - LIS	MDMF - Southern Mass.
Niantic River adult winter flounder survey (≥15 cm) Δ-mean CPUE	0.7814[a] 0.0001 ** 25	0.7843 0.0001 ** 25	0.5024 0.0398 * 17	0.6370 0.0011 ** 23
RIFW Narragansett Bay trawl survey spring and fall mean CPUE		0.8686 0.0001 ** 25	0.4585 0.0642 NS 17	0.6578 0.0006 ** 23
URI Fox Island annual geometric mean CPUE			0.3742 0.1389 NS 17	0.7135 0.0001 ** 23
CT DEP LIS spring geometric mean CPUE				0.0860 0.7428 NS 17

[a] The three statistics shown for each correlation matrix element are:
correlation coefficient (r),
probability of a larger r (NS - not significant [$p > 0.05$], * - significant at $p \leq 0.05$, ** - significant at $p \leq 0.01$), and
number of annual observations (sample size).

TABLE 4-17. Mean lifetime egg production of an age-3 female tautog.

Age	Length (mm)[a]	Annual mean fecundity[b]	Survival probability[c]	Fraction mature[d]	Egg production
3	223	506,762	1.0000000	0.8	405,410
4	273	1,741,462	0.8262800	1.0	1,438,935
5	317	2,827,998	0.6827380	1.0	1,930,782
6	354	3,741,676	0.5641330	1.0	2,110,803
7	386	4,531,884	0.2829550	1.0	1,282,319
8	414	5,223,316	0.1419240	1.0	741,314
9	439	5,840,666	0.0711860	1.0	415,774
10	460	6,359,240	0.0357050	1.0	227,057
11	478	6,803,732	0.0179090	1.0	121,848
12	493	7,174,142	0.0089830	1.0	64,445
13	507	7,519,858	0.0045050	1.0	33,877
14	519	7,816,186	0.0022600	1.0	17,665
15	529	8,063,126	0.0011330	1.0	9,136
16	538	8,285,372	0.0005690	1.0	4,714
17	545	8,458,230	0.0002850	1.0	2,411
18	552	8,631,088	0.0001430	1.0	1,234
19	558	8,779,252	0.0000720	1.0	632
20	562	8,878,028	0.0000360	1.0	320
21	567	9,001,498	0.0000180	1.0	62
22	570	9,075,580	0.0000090	1.0	82
	Total				8,808,918

[a] Length at age from Simpson (1989).
[b] Fecundity from White (1996).
[c] Instantaneous mortality rates (Z) were:
Natural (M) = 0.15 from ASMFC (1996).
Discard through age-6 (F) = 0.04 from Simpson (CT DEP, Old Lyme, CT, pers. comm.).
Fishing ages-7 through 22 (F) = 0.54 from ASMFC (1996).
[d] Female maturity from Chenowith (1963).

TABLE 4-18. Numbers of tautog eggs entrained during two-unit operation, probability of survival to adulthood, and estimated number of equivalent-adults lost due to entrainment from 1986 through 1995 at MNPS.

Year	Number entrained (N_i)	Survival probability (S_i)	Equivalent-adults (N_a)
1986	2,999,200,000	0.0000140198	681
1987	2,868,000,000	0.0000140198	951
1988	2,159,200,000	0.0000140198	490
1989	2,387,200,000	0.0000140198	542
1990	1,677,600,000	0.0000140198	381
1991	1,220,000,000	0.0000140198	277
1992	1,068,000,000	0.0000140198	242
1993	1,664,000,000	0.0000140198	378
1994	1,659,200,000	0.0000140198	377
1995	2,050,400,000	0.0000140198	466
Mean	1,975,280,000		448

TABLE 4-19. Total catch of tautog collected at selected stations in the MNPS trawl monitoring program annually from 1976 through 2000. See DNC (2001b) for details.

Year	NR	JC	IN	Total
1976	46	73	76	195
1977	15	113	70	198
1978	27	59	83	169
1979	47	56	70	173
1980	25	20	46	91
1981	126	24	28	178
1982	80	35	52	167
1983	31	19	40	90
1984	5	16	46	67
1985	25	27	47	99
1986	100	58	25	183
1987	26	33	13	72
1988	50	31	37	118
1989	36	23	25	84
1990	89	34	17	140
1991	67	44	13	124
1992	22	90	8	120
1993	15	51	26	92
1994	12	19	13	44
1995	129	73	28	230
1996	40	47	22	109
1997	36	26	24	86
1998	125	71	12	208
1999	238	138	27	403
2000	324	261	45	430

TABLE 4-20. Total catch of tautog collected at selected stations in the MNPS lobster pot monitoring program annually from 1988 through 2000. See DNC (2001b, 2001c) for details.

Year	IN	JC	TT	Total
1988	47	15	40	102
1989	25	22	20	67
1990	27	8	11	46
1991	48	7	27	82
1992	32	11	21	64
1993	64	12	26	102
1994	29	8	43	80
1995	14	18	10	42
1996	23	134	63	210
1997	12	27	16	55
1998	91	80	64	235
1999	97	86	28	211
2000	85	80	48	213

TABLE 4-21. Mean lifetime egg production of an age-2 Atlantic menhaden.

Age[a]	Mean length[a]	Annual mean fecundity[b]	Survival probability[c]	Fraction mature[d]	Egg production
2	155	11,487	1.00000	0.2	2,297
3	259	26,211	0.21224	0.8	4,451
4	296	124,733	0.04504	1.0	5,619
5	320	217,278	0.00956	1.0	2,078
6	337	311,431	0.00202	1.0	632
7	348	401,890	0.00043	1.0	173
8	355	473,986	0.00009	1.0	43
Total					15,293

[a] Age at maturity, mean length, and longevity from Arenholtz (1991).
[b] From Dietrich (1979) and Arenholtz (1991).
[c] M= 0.45 (Arenholtz 1991; Powell 1994); F = 1.10 (Vaughan et al. 2001).
[d] Maturity schedule from Arenholtz (1991) and Vaughan and Smith (1988).

TABLE 4-22. Numbers of Atlantic menhaden larvae entrained during two-unit operation, probability of survival to adulthood, and estimated number of equivalent-adults lost due to entrainment from 1986 through 1995 at MNPS.

Year	Number entrained (N_l)	Survival probability of egg to larva (S_e)[a]	Survival probability of larva to adult (S_l)	Equivalent-adults (N_a)
1986	5,600,000	0.02	0.0065389243	36,618
1987	2,400,000	0.02	0.0065389243	15,693
1988	4,800,000	0.02	0.0065389243	31,387
1989	165,600,000	0.02	0.0065389243	1,082,846
1990	32,800,000	0.02	0.0065389243	214,477
1991	46,400,000	0.02	0.0065389243	303,406
1992	41,600,000	0.02	0.0065389243	272,019
1993	22,400,000	0.02	0.0065389243	146,472
1994	56,800,000	0.02	0.0065389243	371,411
1995	74,400,000	0.02	0.0065389243	486,496
Mean	45,280,000			296,082

[a] From Ferraro (1981).

TABLE 4-23. Bay anchovy annual survival rates, proportion mature, mean fecundity and estimate of lifetime mean egg production.

Age	Survival probability to age[a]	Proportion mature[b]	Mean annual fecundity[c]	Lifetime fecundity (f_a)
0	1.000	0.5	45,110	22,555
1	0.790	1.0	45,110	35,637
2	0.624	1.0	45,110	28,153
3	0.493	1.0	45,110	22,240
Total				108,586

[a] From Wang et al. 1997.
[b, c] From Luo and Musick 1991.

TABLE 4-24. Numbers of anchovy eggs entrained during two-unit operation, probability of survival from egg to adulthood, and estimated number of equivalent-adults lost due to entrainment from 1986 through 1995 at MNPS.

Year	Number entrained (N_i)	Survival probability (S_i)	Equivalent-adults (N_a)
1986	396,800,000	0.0000184186	7,308
1987	28,800,000	0.0000184186	530
1988	12,000,000	0.0000184186	221
1989	4,000,000	0.0000184186	74
1990	20,800,000	0.0000184186	383
1991	112,800,000	0.0000184186	2,078
1992	12,800,000	0.0000184186	236
1993	181,600,000	0.0000184186	3,345
1994	130,400,000	0.0000184186	2,402
1995	12,800,000	0.0000184186	236
Mean	91,280,000		1,681

TABLE 4-25. Numbers of anchovy larvae entrained during two-unit operation, probability of survival to adulthood, and estimated number of equivalent-adults lost due to entrainment from 1986 through 1995 at MNPS.

Year	Number entrained (N_i)	Survival probability of egg to larva (S_e)[a]	Survival probability of larva to adult (S_l)	Equivalent-adults (N_a)
1986	1,012,800,000	0.19014	0.0000968690	98,109
1987	95,200,000	0.19014	0.0000968690	9,222
1988	304,000,000	0.19014	0.0000968690	29,448
1989	420,000,000	0.19014	0.0000968690	40,685
1990	787,200,000	0.19014	0.0000968690	76,255
1991	366,400,000	0.19014	0.0000968690	35,493
1992	132,800,000	0.19014	0.0000968690	12,864
1993	168,000,000	0.19014	0.0000968690	16,274
1994	412,000,000	0.19014	0.0000968690	39,910
1995	142,400,000	0.19014	0.0000968690	13,794
Mean	384,080,000			37,205

[a] Selected from the range of values reported by Wang et al. (1997), Purcell et al. (1994), and Houde et al. (1994).

TABLE 4-26. Mean lifetime egg production of an age-1 female grubby.

Age	Annual mean fecundity[a]	Survival probability[b]	Fraction mature[c]	Egg production
1	1,275	1.0000000	0.5	638
2	1,275	0.4000000	1.0	510
3	1,275	0.1600000	1.0	204
4	1,275	0.0256000	1.0	33
5	1,275	0.0006554	1.0	1
Total				1,385

[a,c] From Lazzari et al. (1989).
[b] Assumption based on empirical studies by Mertz and Myers (1996) and Rickman et al. (2000).

TABLE 4-27. Numbers of grubby larvae entrained during two-unit operation, probability of survival to adulthood, and estimated number of equivalent adults lost due to entrainment from 1986 through 1995 at MNPS.

Year	Number entrained (N_i)	Survival probability of egg to larva (S_e)[a]	Survival probability of larva to adult (S_l)	Equivalent-adults (N_a)
1986	43,200,000	0.3982	0.0015453184	158,817
1987	42,400,000	0.3982	0.0015453184	155,876
1988	89,600,000	0.3982	0.0015453184	329,398
1989	54,400,000	0.3982	0.0015453184	199,991
1990	37,600,000	0.3982	0.0015453184	138,229
1991	25,600,000	0.3982	0.0015453184	94,114
1992	58,400,000	0.3982	0.0015453184	214,697
1993	41,600,000	0.3982	0.0015453184	152,935
1994	44,800,000	0.3982	0.0015453184	164,699
1995	46,400,000	0.3982	0.0015453184	170,581
Mean	48,400,000			177,934

[a] $Z = 0.65 \cdot e^{0.066T}$ from Pepin (1991), T = 5.5°C (mean environmental temperature during incubation; from data given in DNC 2001a).

TABLE 4-28. Mean lifetime egg production of an age-2 female cunner.

Age[a]	Annual mean fecundity[b]	Survival probability[c]	Fraction mature[d]	Egg production
2	5,867	1.0000	0.8	4,693
3	14,897	0.8242	1.0	12,279
4	24,233	0.6794	1.0	16,464
5	31,988	0.5600	1.0	17,912
6	37,617	0.4615	1.0	17,362
7	41,227	0.3804	1.0	15,684
8	43,158	0.3136	1.0	13,533
9	43,785	0.2585	1.0	11,316
10	43,451	0.2130	1.0	9,256
Total				118,499

[a] Age at maturity and longevity from Dew (1976) and Nitschke et al. (2001).
[b] Fecundity from Nitschke et al. (2001).
[c] Survival rate calculated using relationship between growth parameters and environmental temperature as described by Pauly (1982).
[d] Female maturity from Dew (1976) and Nitschke et al. (2001).

TABLE 4-29. Numbers of cunner eggs entrained during two-unit operation, probability of survival to adulthood, and estimated number of equivalent adults lost due to entrainment from 1986 through 1995 at MNPS.

Year	Number entrained (N_i)	Survival probability (S_i)	Equivalent-adults (N_a)
1986	2,250,400,000	0.0000168778	37,982
1987	3,482,400,000	0.0000168778	58,775
1988	3,367,200,000	0.0000168778	56,831
1989	2,987,200,000	0.0000168778	50,417
1990	2,804,000,000	0.0000168778	47,325
1991	3,655,200,000	0.0000168778	61,692
1992	2,114,400,000	0.0000168778	35,686
1993	4,409,600,000	0.0000168778	74,424
1994	4,594,400,000	0.0000168778	77,543
1995	3,742,400,000	0.0000168778	63,163
Mean	3,340,720,000		56,384

TABLE 4-30. American sand lance annual survival rates, proportion mature, mean fecundity and estimate of lifetime mean egg production.

Age	Survival probability to age[a]	Proportion mature[b]	Mean annual fecundity[c]	Lifetime fecundity (f_a)
1	1.000	0.5	2,157	1,078
2	0.3679	1.0	5,097	1,875
3	0.1353	1.0	8,038	1,088
4	0.0498	1.0	10,978	547
5	0.1383	1.0	13,918	255
Total				4,843

[a] From Winters (1983).
[b,c] From Westin et al. (1979).

TABLE 4-31. Numbers of American sand lance larvae entrained during two-unit operation, probability of survival to adulthood, and estimated number of equivalent-adults lost due to entrainment from 1986 through 1995 at MNPS.

Year	Number entrained (N_i)	Survival probability of egg to larva (S_e)[a]	Survival probability of larva to adult (S_l)	Equivalent-adults (N_a)
1986	4,000,000	0.39280	0.0010514	4,206
1987	32,800,000	0.39280	0.0010514	34,486
1988	76,000,000	0.39280	0.0010514	79,906
1989	41,600,000	0.39280	0.0010514	43,738
1990	16,000,000	0.39280	0.0010514	16,822
1991	5,600,000	0.39280	0.0010514	5,888
1992	24,000,000	0.39280	0.0010514	25,233
1993	38,400,000	0.39280	0.0010514	40,373
1994	59,200,000	0.39280	0.0010514	62,242
1995	88,000,000	0.39280	0.0010514	92,522
Mean	38,560,000			40,542

[a] $Z = 0.65 \cdot e^{0.066T}$ from Pepin (1991), T = 5.5°C (mean environmental temperature during incubation; from data given in DNC 2001a).

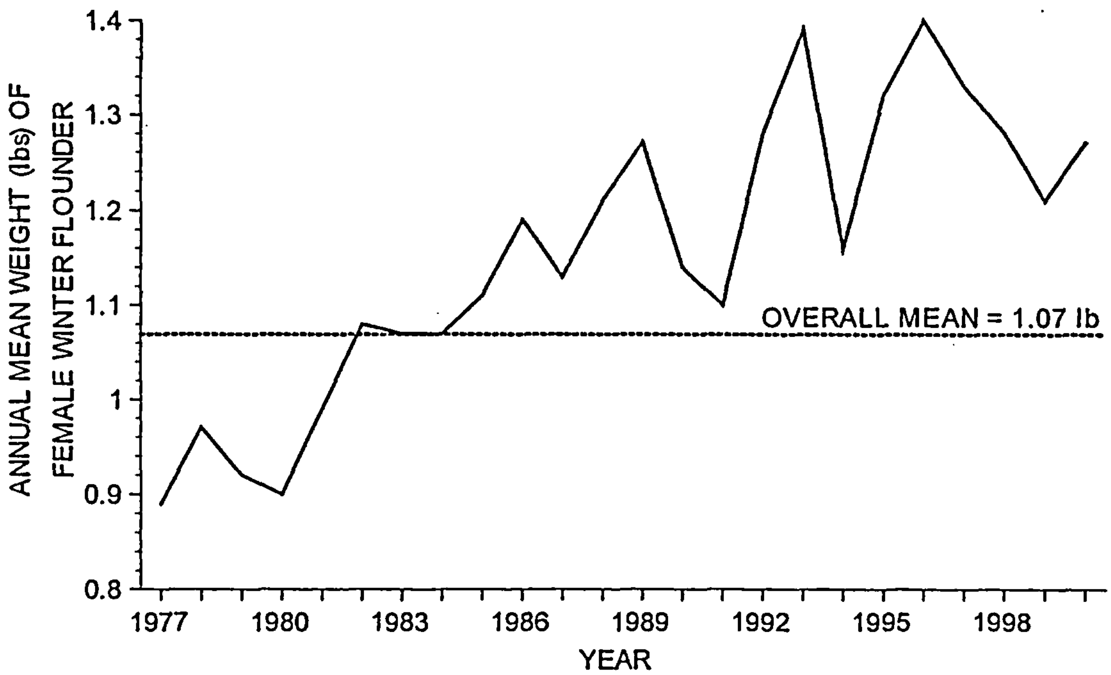

Fig. 4-1. Annual mean weight (lbs) of Niantic River female winter flounder spawners from 1977 through 2000. The overall grand mean was 1.07 lbs.

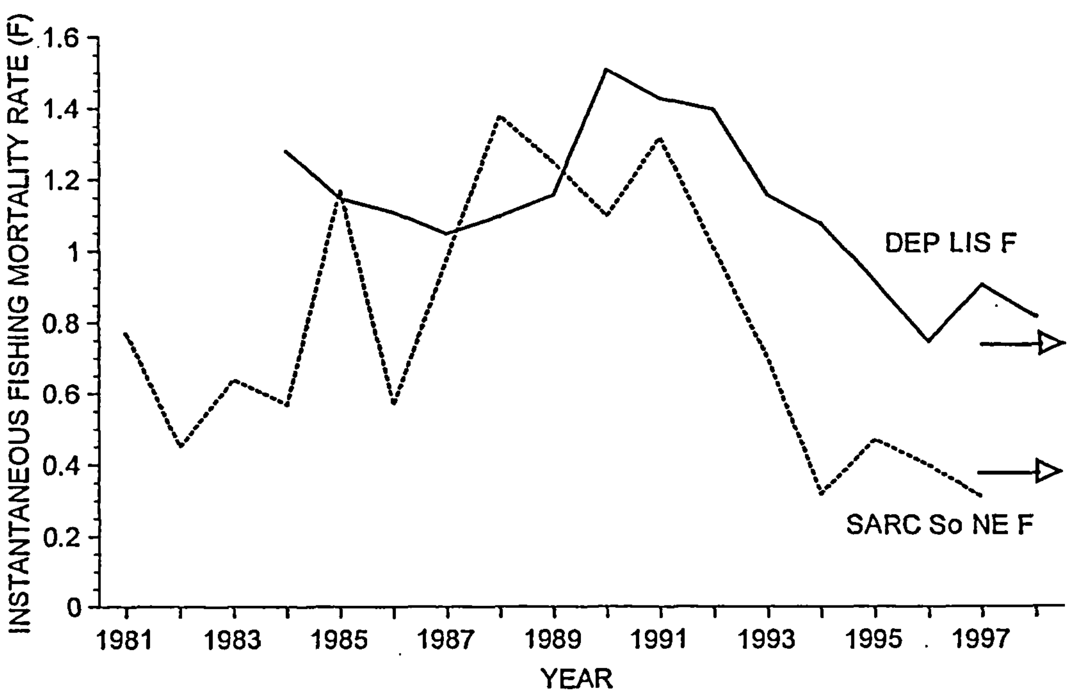

Fig. 4-2. Values of instantaneous fishing mortality rate (F) used in SPDM simulations of winter flounder found in this report. Shown are rates determined by CT DEP Marine Fisheries for LIS and by NEFSC (1999) for the Southern New England region (SARC). The arrows illustrate values used in the model going forward from 2000 (0.74 for DEP and 0.375 for SARC; Table 4-5).

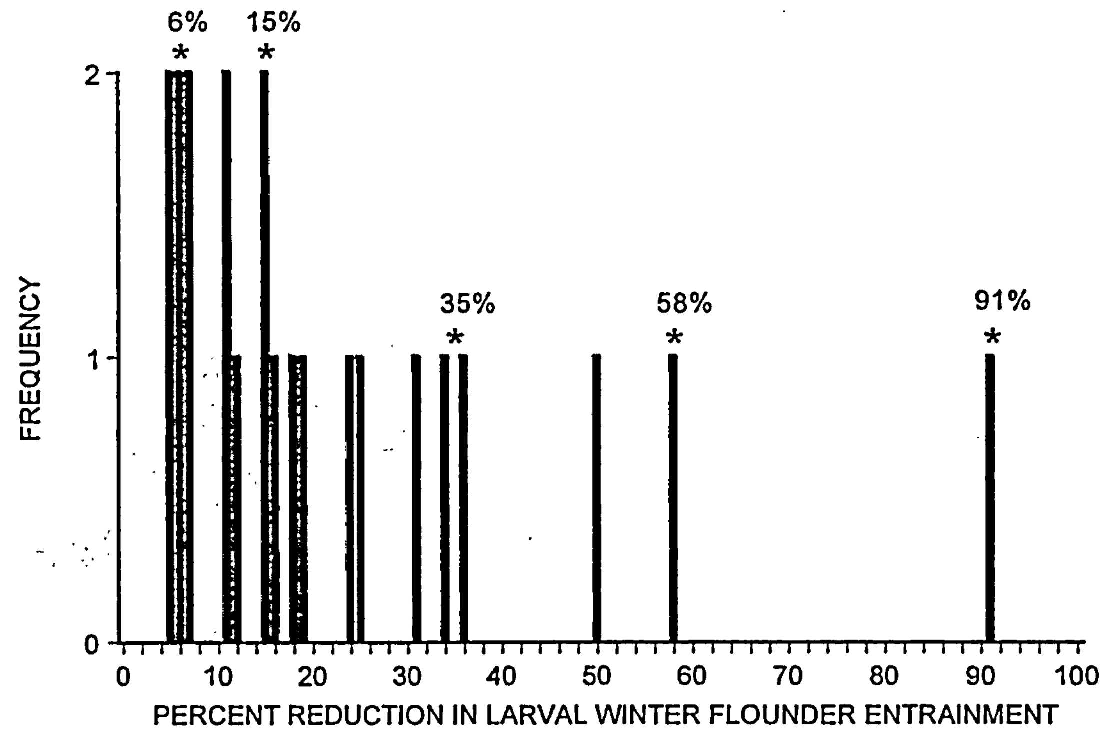

Fig. 4-3. Frequency of percent reductions in Niantic River larval winter flounder entrainment determined for selected intake technology alternatives at MNPS (see Table 4-6). The five percent reductions with the symbol * were selected for use in the SPDM simulations to assess the effectiveness in reducing ENT.

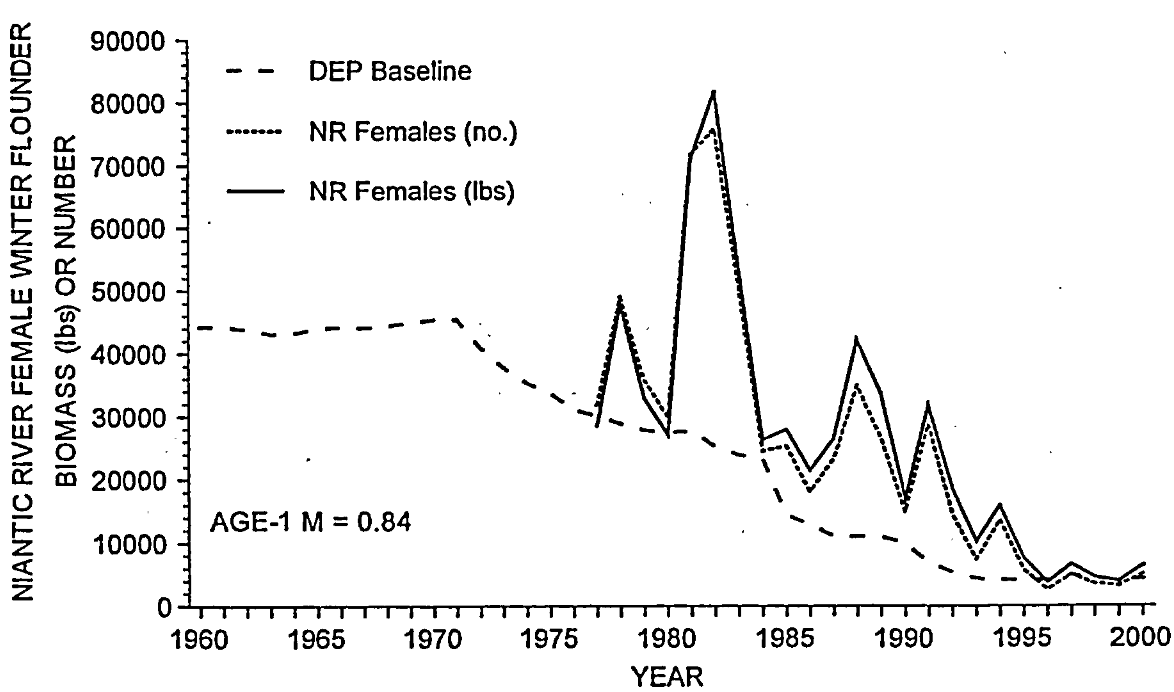

Fig. 4-4. Niantic River female winter flounder biomass (lbs) as projected with the SPDM using CT DEP fishing mortality rates for the purpose of calibrating this time-series to the number and biomass of females as estimated from annual spawning surveys. A natural mortality rate of 0.8425 was used for age-1 winter flounder in this model projection.

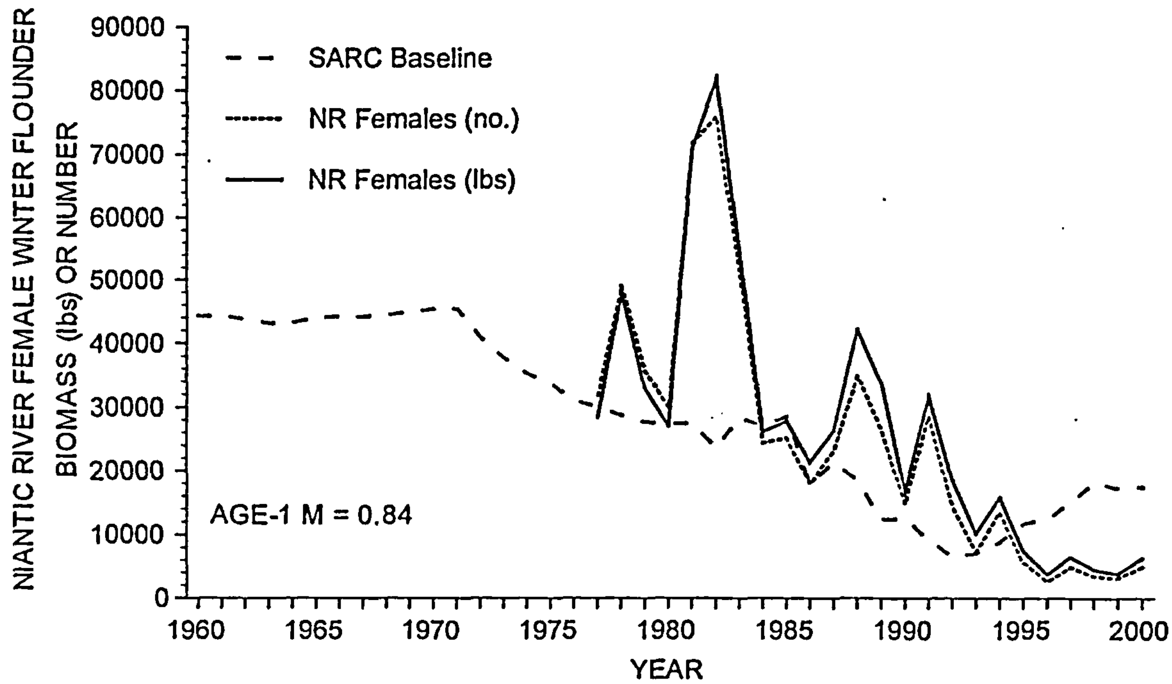

Fig. 4-5. Niantic River female winter flounder biomass (lbs) as projected with the SPDM using SARC fishing mortality rates for the purpose of calibrating this time-series to the number and biomass of females as estimated from annual spawning surveys. A natural mortality rate of 0.8425 was used for age-1 winter flounder in this model projection.

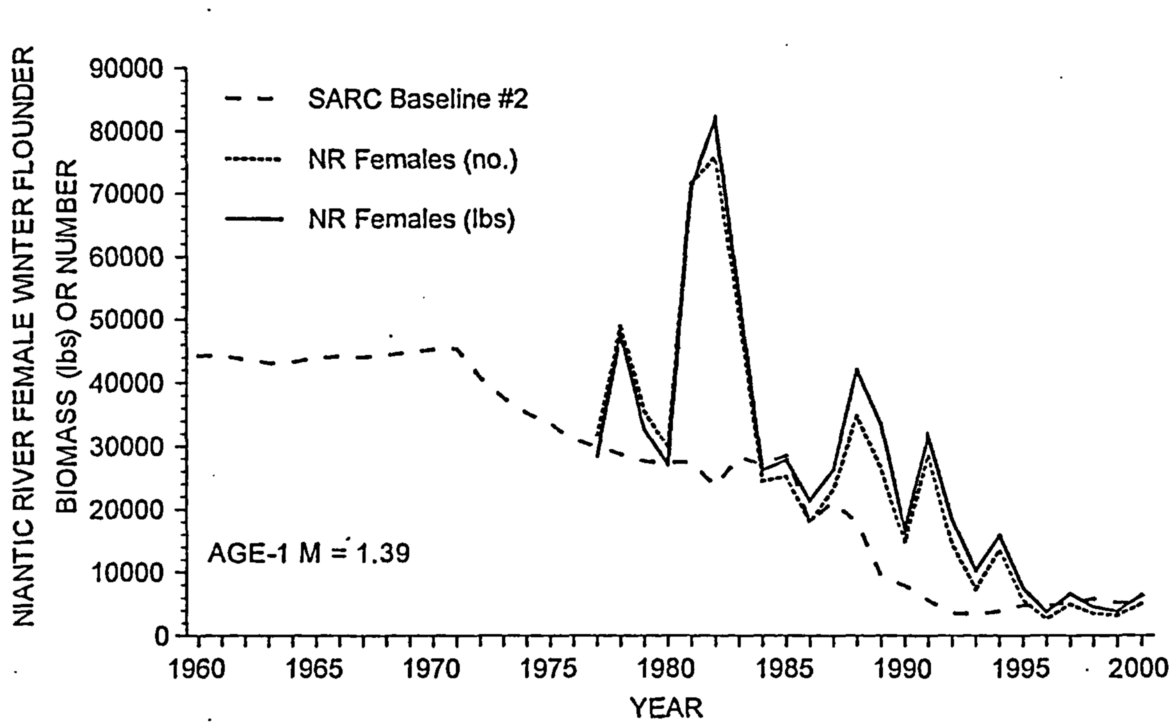

Fig. 4-6. Niantic River female winter flounder biomass (lbs) as projected with the SPDM using SARC fishing mortality rates for the purpose of calibrating this time-series to the number and biomass of females as estimated from annual spawning surveys. A natural mortality rate of 1.39 was used for age-1 winter flounder in this model projection.

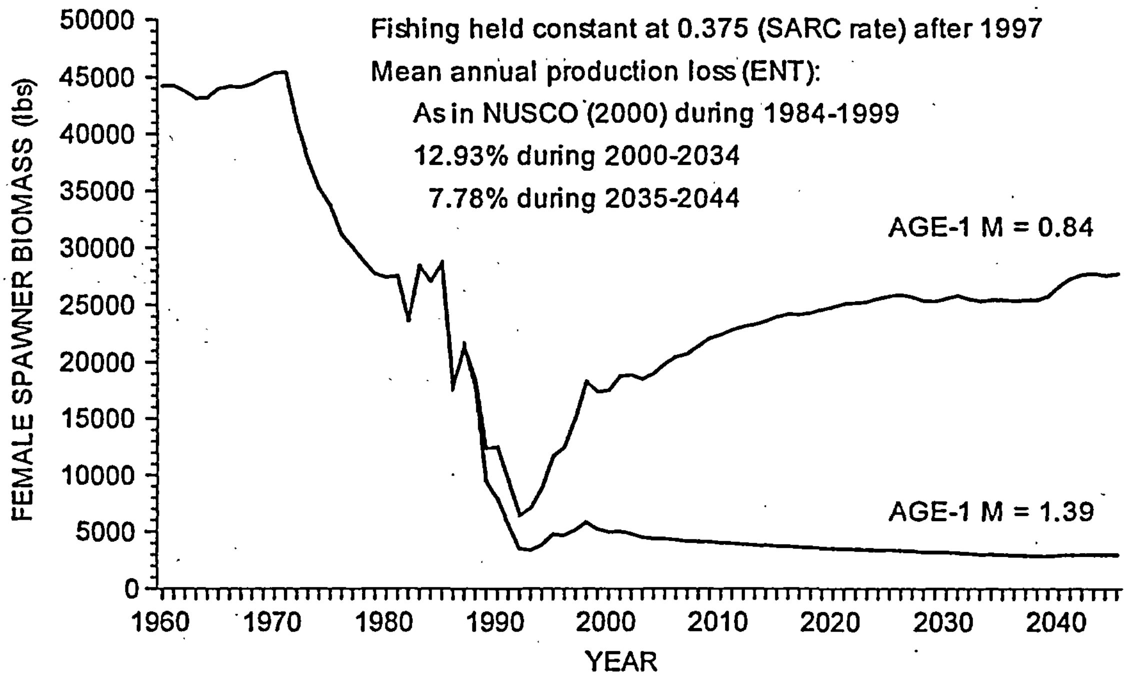

Fig. 4-7. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.375 (SARC rate), previously calculated annual production loss (ENT) for 1984-1999 (NUSCO 2000), a mean entrainment rate for 2000-2044, and with age-1 natural mortality rate set at either 0.8425 or 1.39 as used in the SARC baseline calibration simulations (Figs. 4-5 and 4-6).

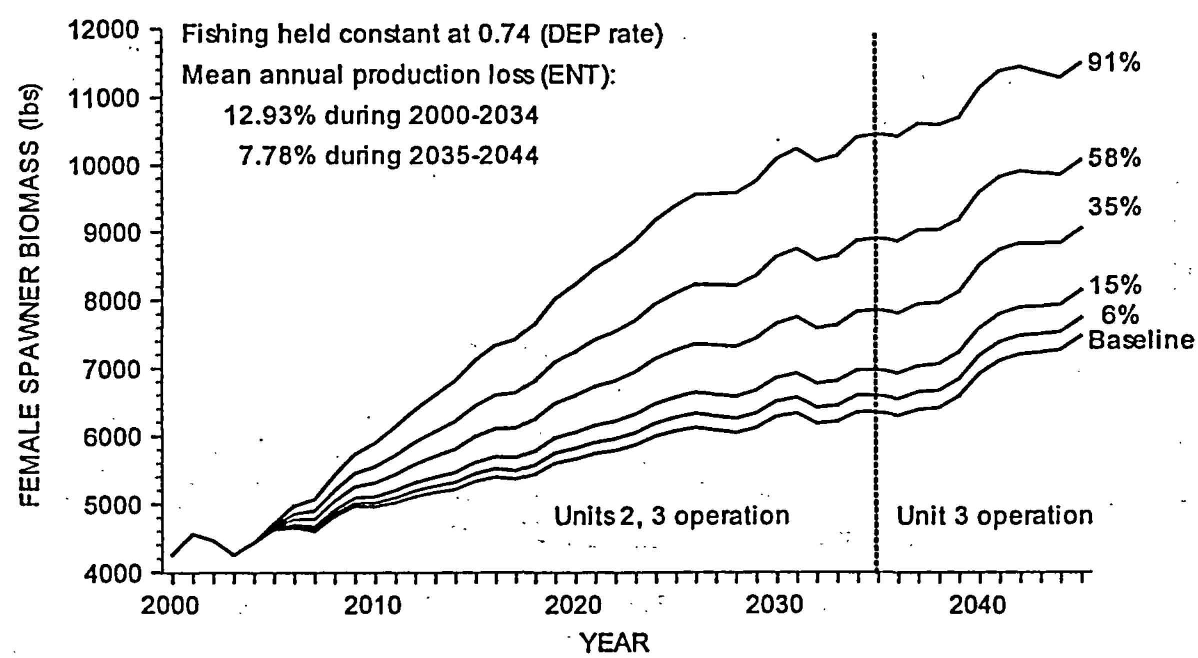

Fig. 4-8. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.74 and a mean annual production loss (ENT). Increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

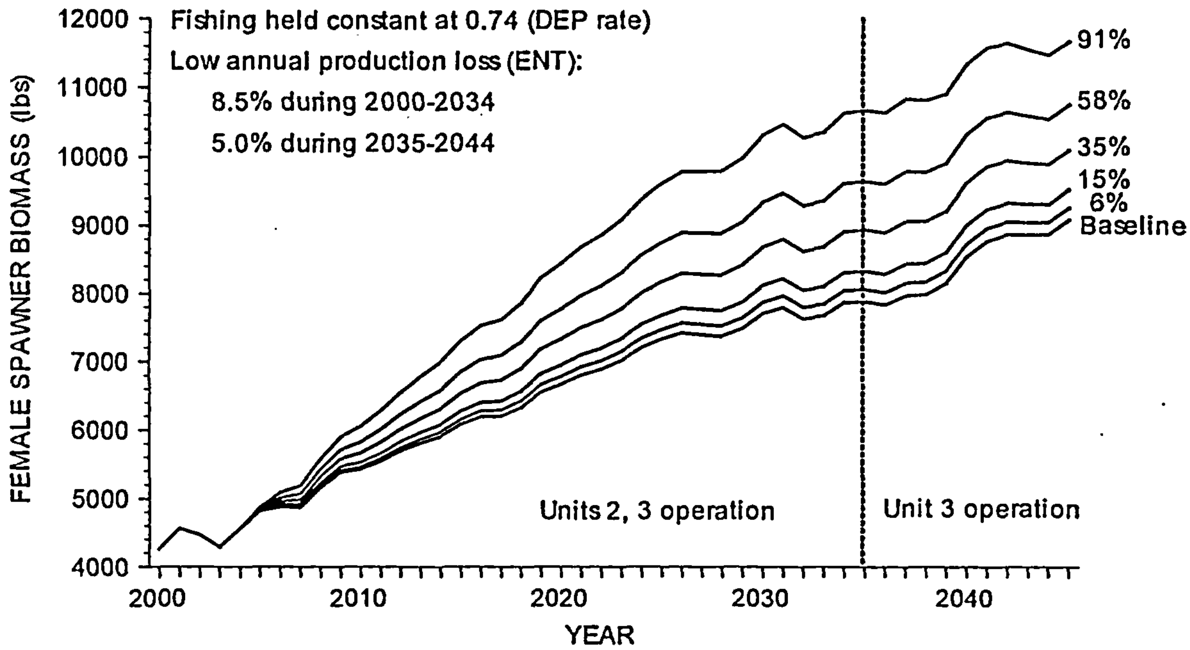

Fig. 4-9. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.74 and a low (mean+1.5) annual production loss (ENT). Increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

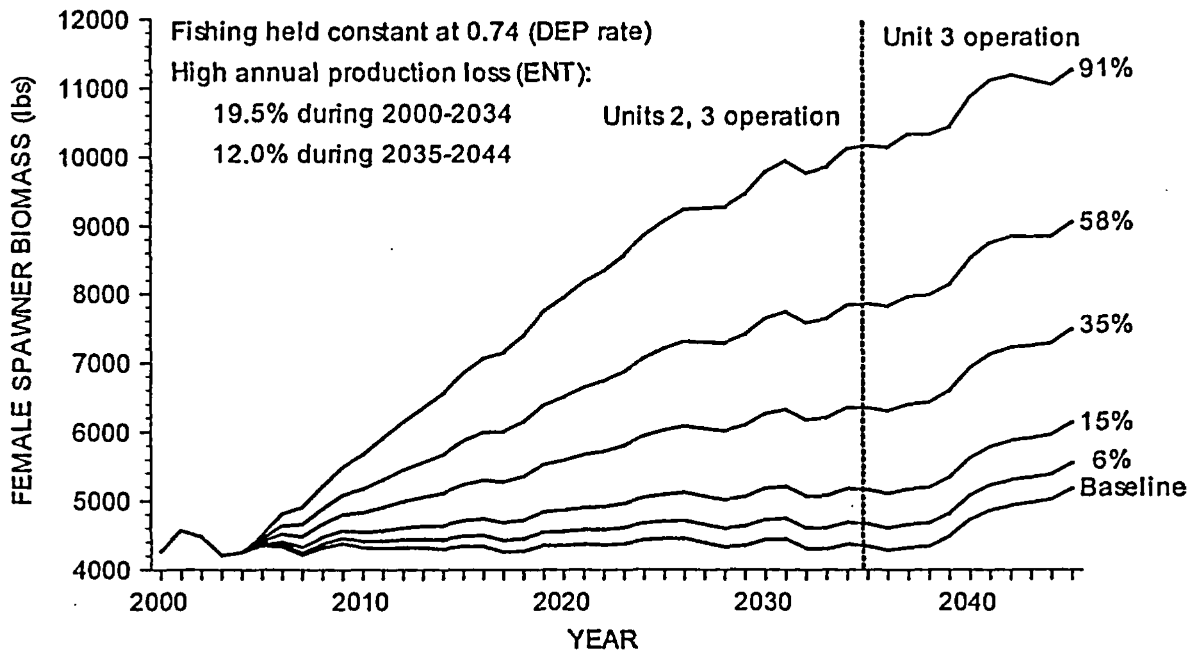

Fig. 4-10. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.74 and a high (mean·1.5) annual production loss (ENT). Increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

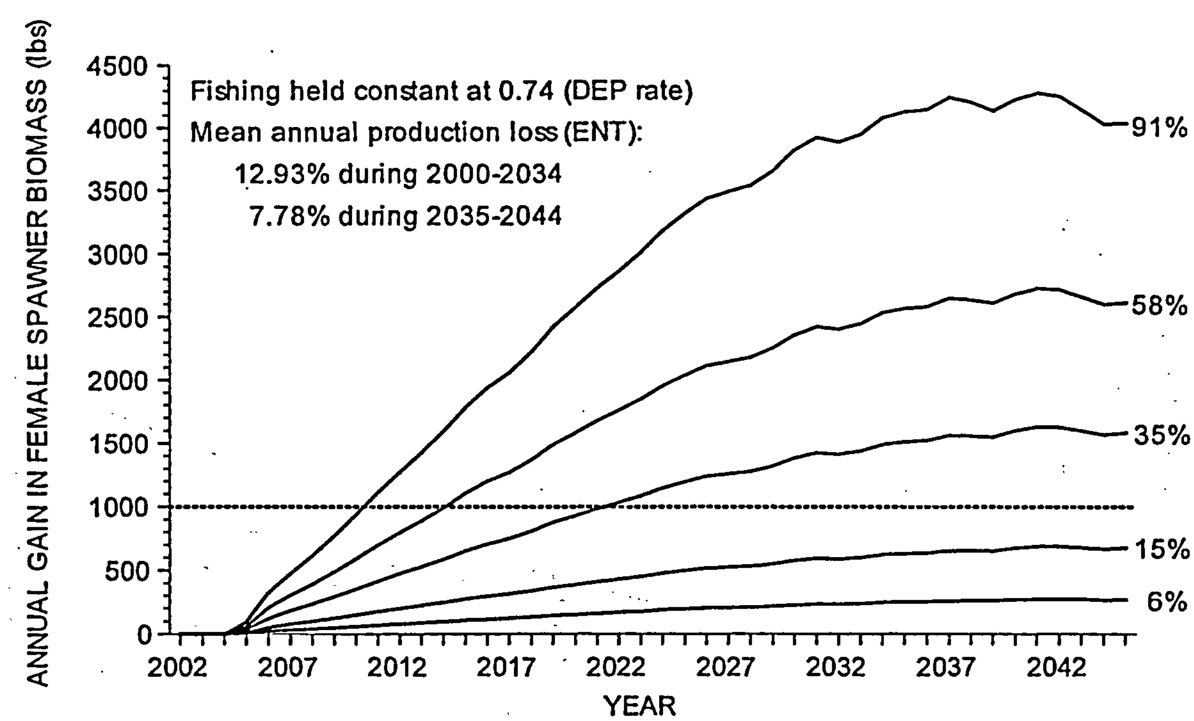

Fig. 4-11. Comparison of the annual gain in Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.74 and a mean annual production loss (ENT). Annual increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

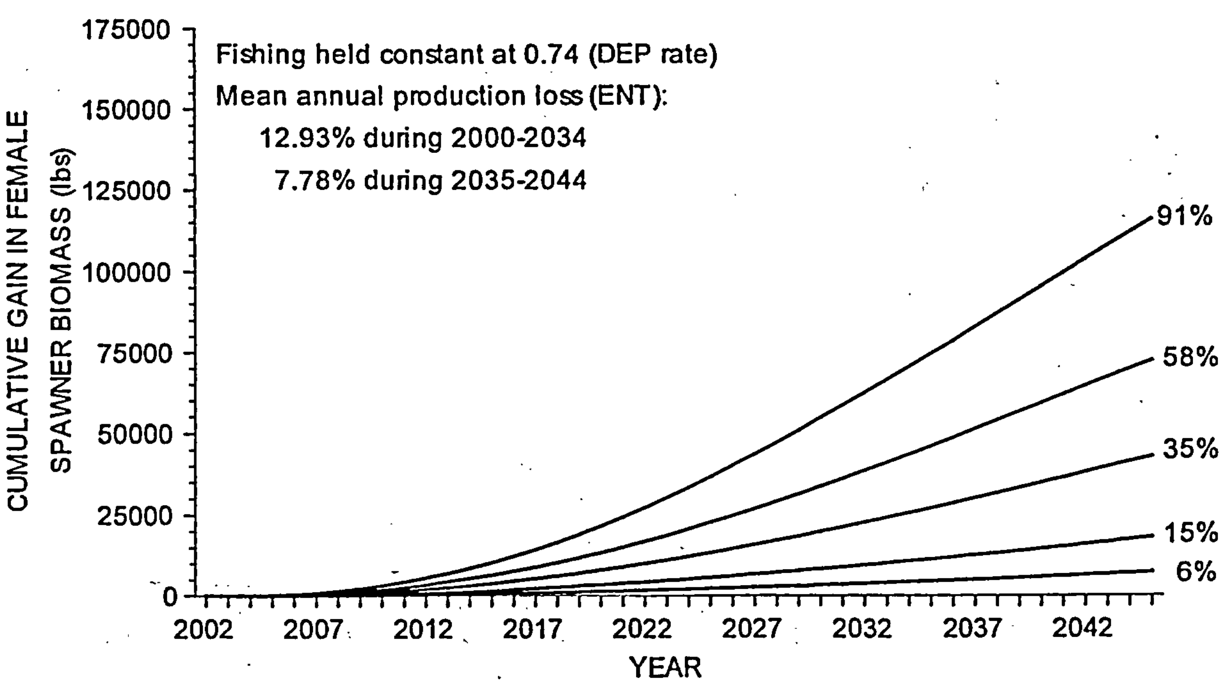

Fig. 4-12. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.74 and a mean annual production loss (ENT). Cumulative increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

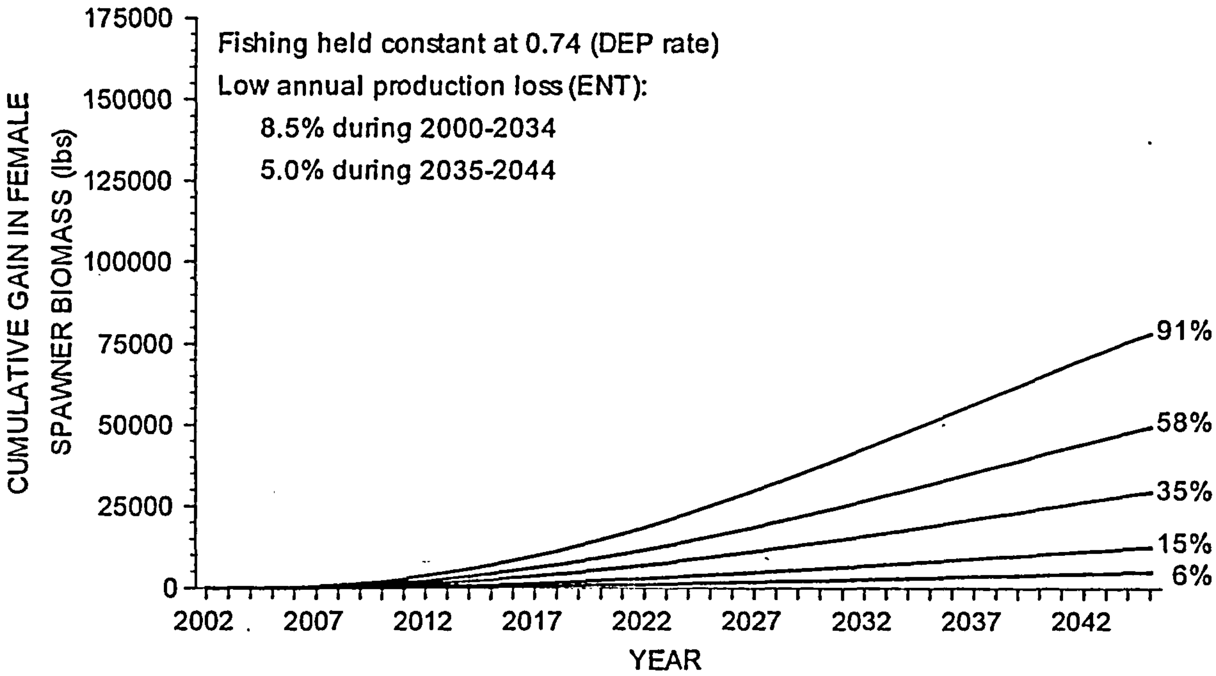

Fig. 4-13. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.74 and a low (mean+1.5) annual production loss (ENT). Cumulative increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

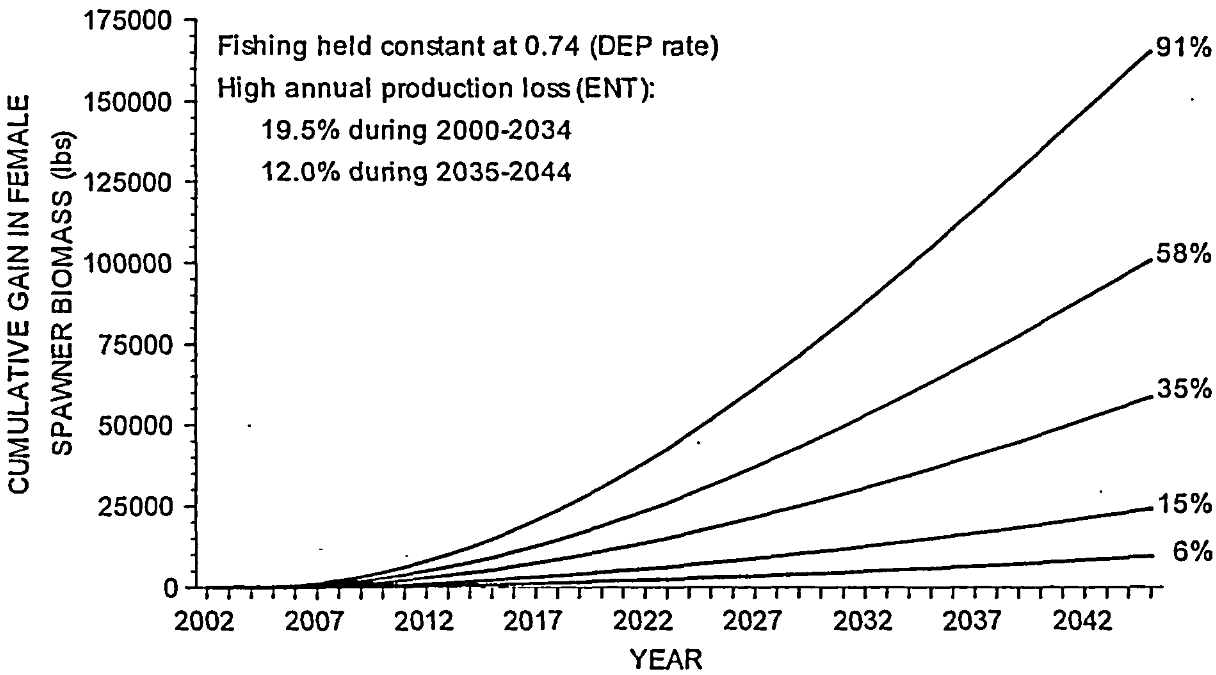

Fig. 4-14. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.74 and a high (mean·1.5) entrainment rate. Cumulative increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

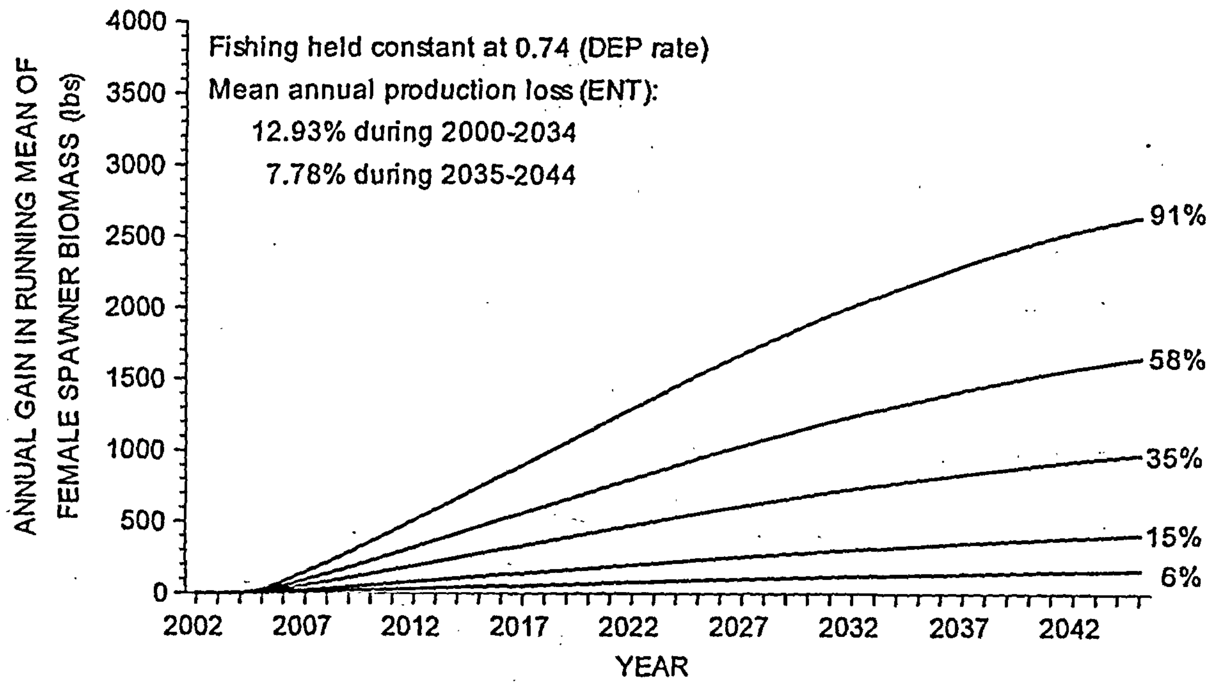

Fig. 4-15. Comparison of the annual mean of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.74 and a mean annual production loss (ENT). Annual mean increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

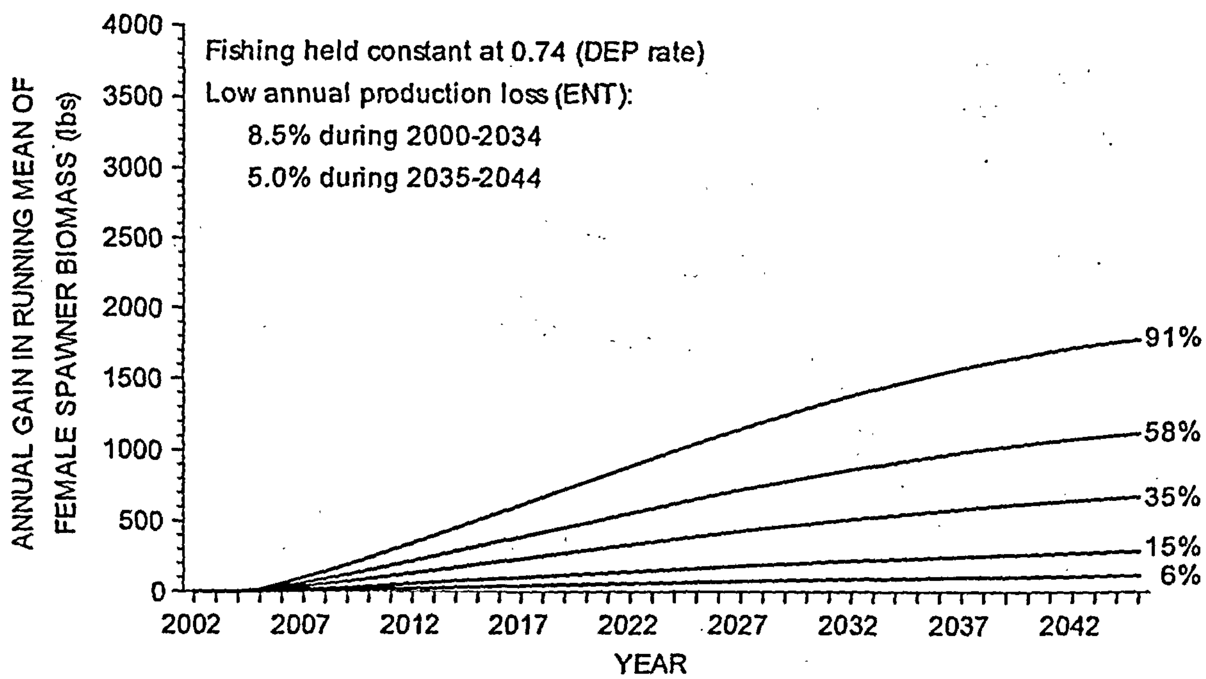

Fig. 4-16. Comparison of the annual mean of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.74 and a low (mean+1.5) annual production loss (ENT). Annual mean increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

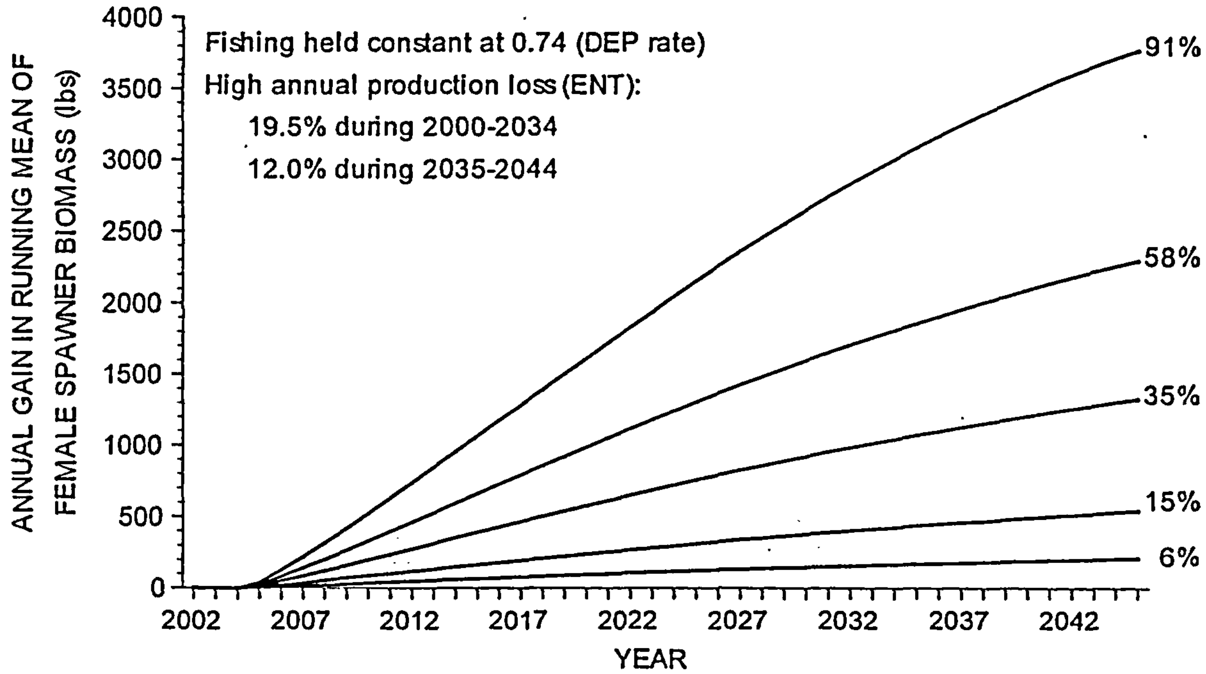

Fig. 4-17. Comparison of the annual mean of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.74 and a high (mean·1.5) annual production loss (ENT). Annual mean increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

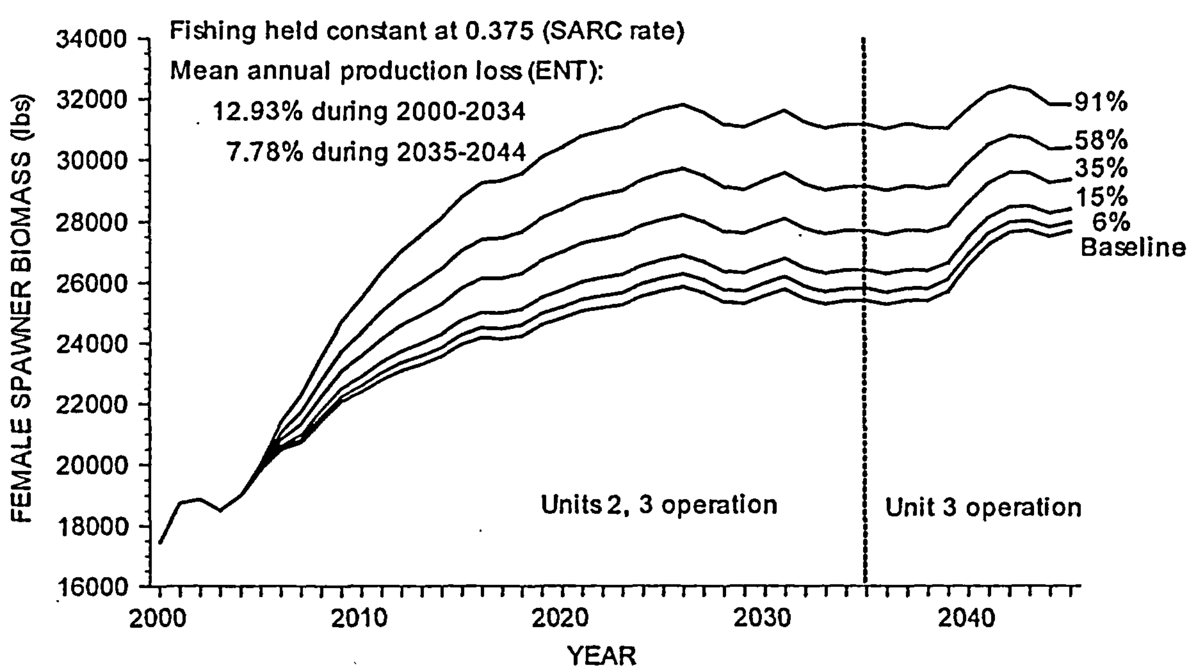

Fig. 4-18. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.375 and a mean annual production loss (ENT). Increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

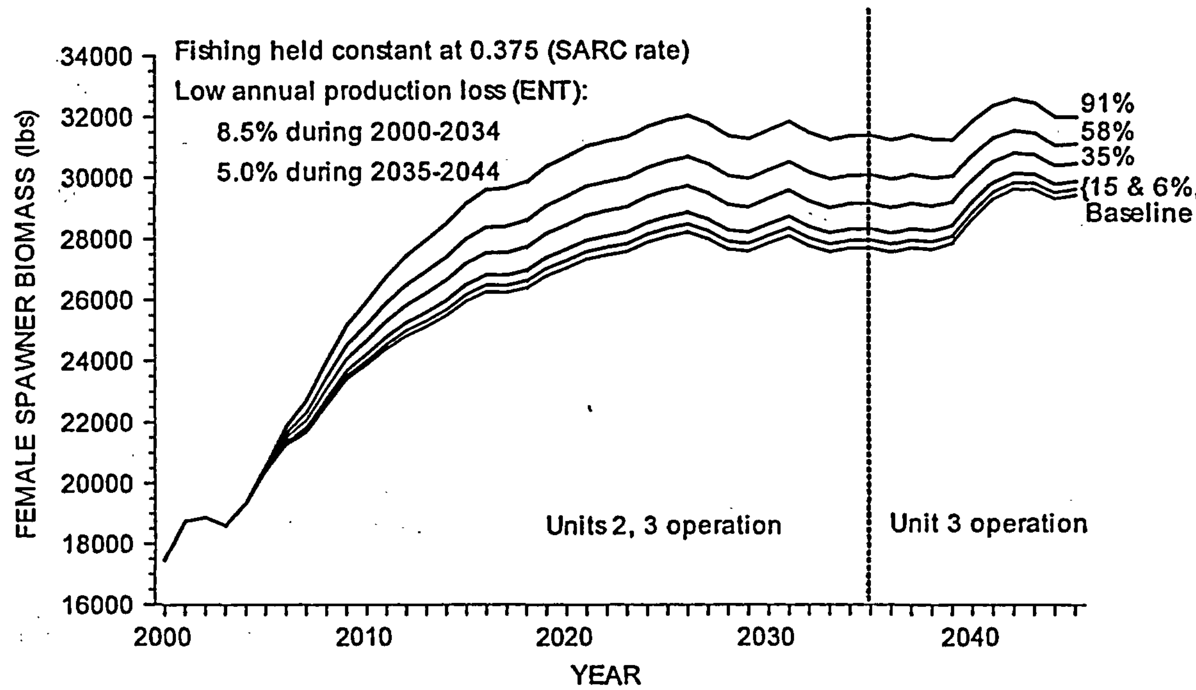

Fig. 4-19. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.375 and a low (mean+1.5) annual production loss (ENT). Increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

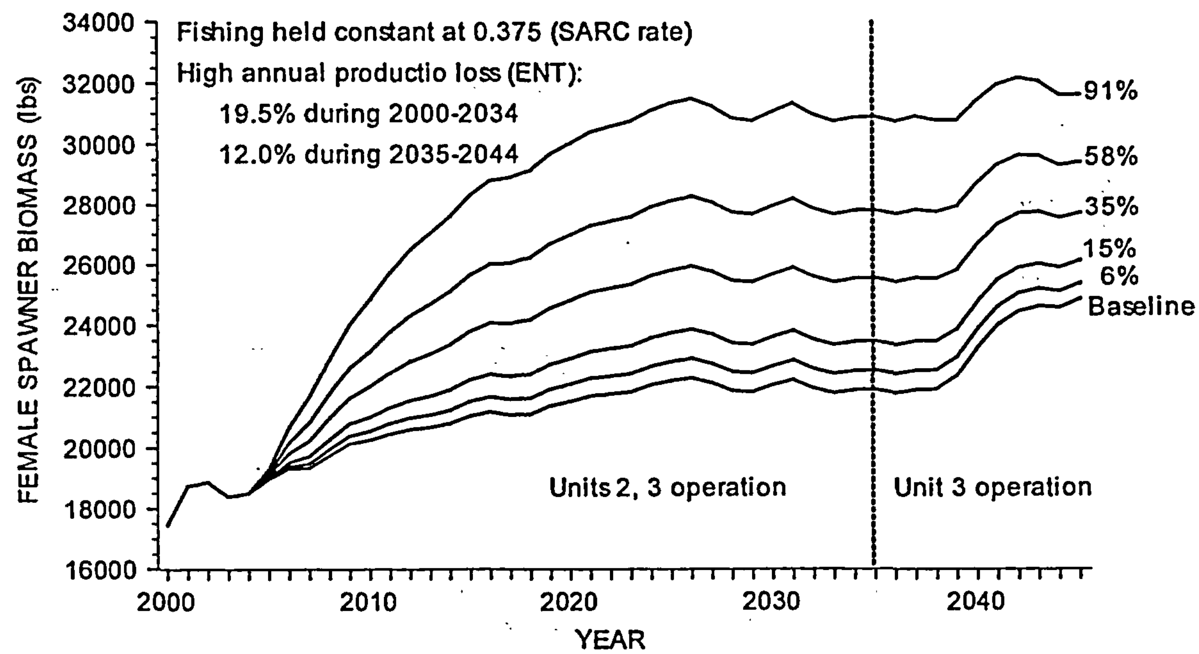

Fig. 4-20. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with a fixed fishing mortality rate of 0.375 and a high (mean-1.5) annual production loss (ENT). Increases in biomass from the baseline (no change in operation) as a result of postulated 6, 15, 35, 58, and 91% reductions in larval entrainment beginning in 2002 are shown.

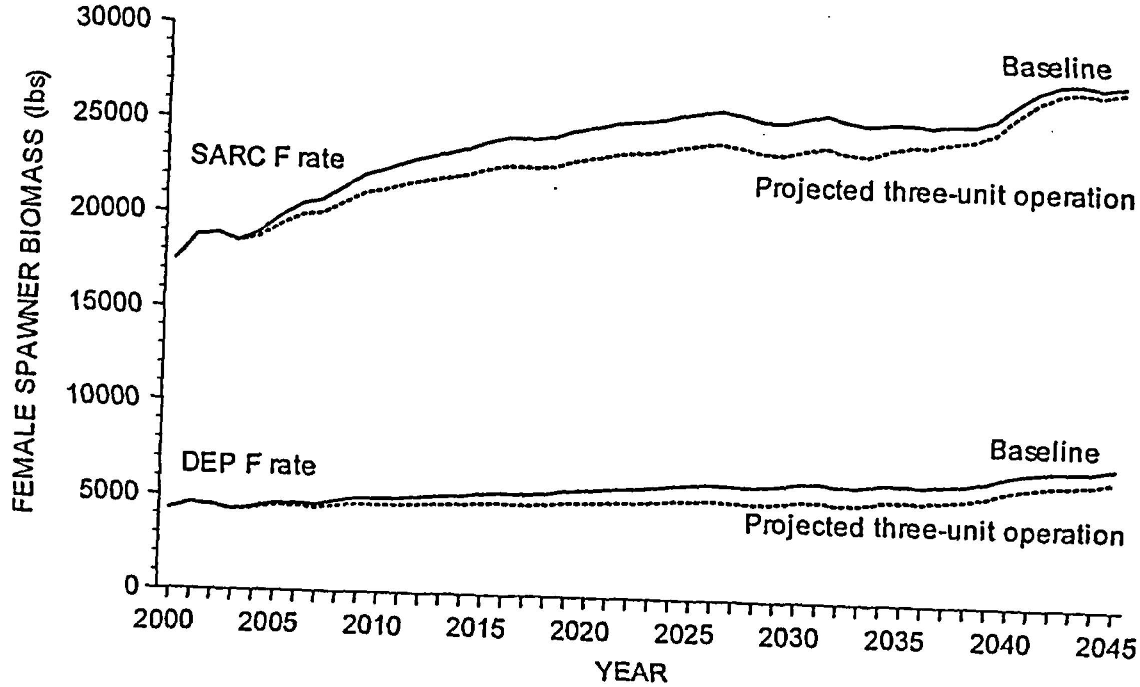

Fig 4-21. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with both the DEP and SARC fishing mortality rates and the mean entrainment rate at MNPS with present two-unit operation and with simulated three-unit operation (i.e., Unit 1 not retired).

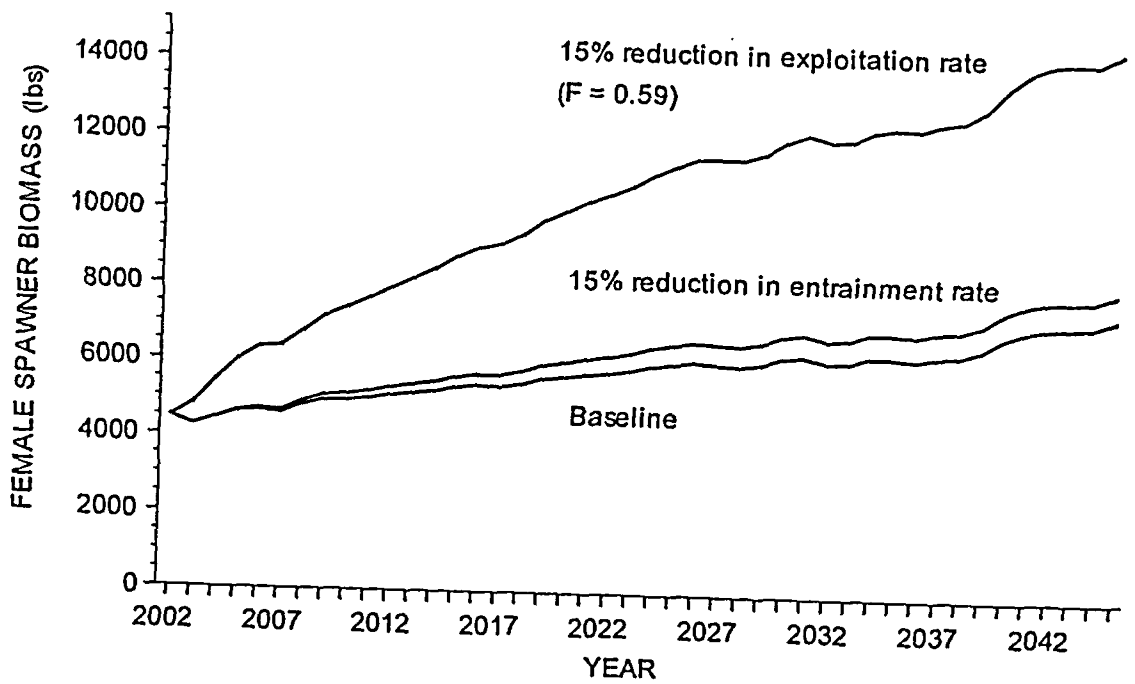

Fig 4-22. Comparison of Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM between the baseline and with both the DEP fishing exploitation rate and the mean production loss (ENT) at MNPS each reduced by 15%.

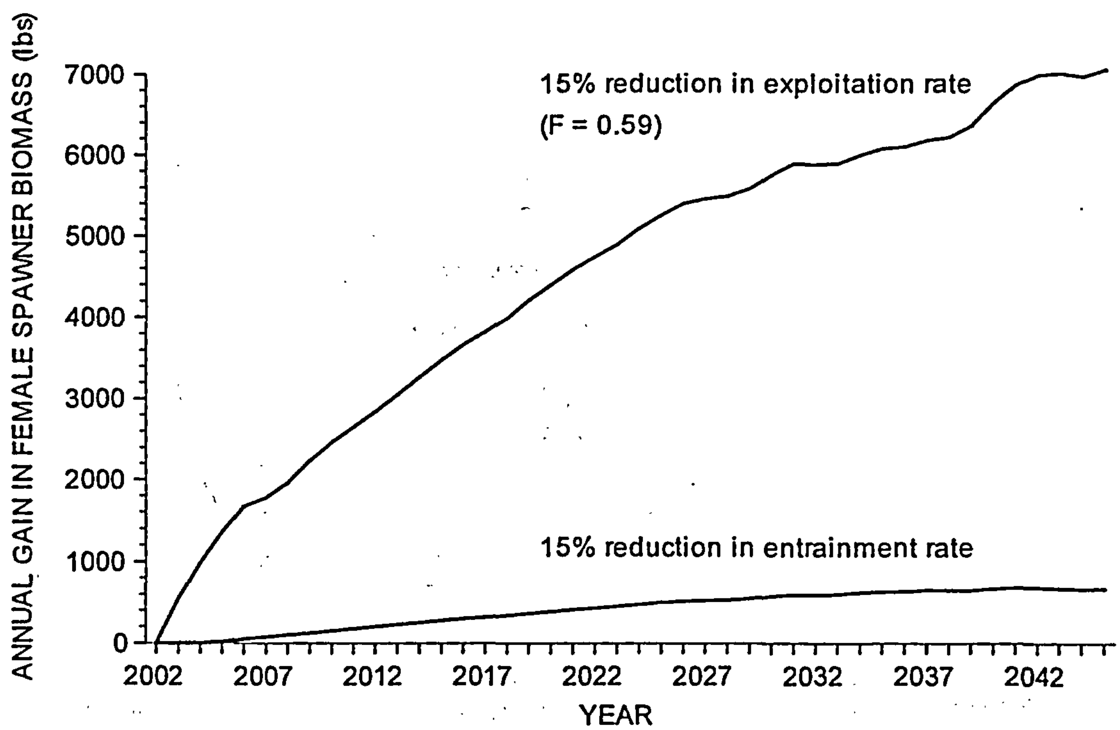

Fig. 4-23. Comparison of the annual gain in Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with both the DEP fishing exploitation rate and the mean production loss (ENT) at MNPS each reduced by 15%.

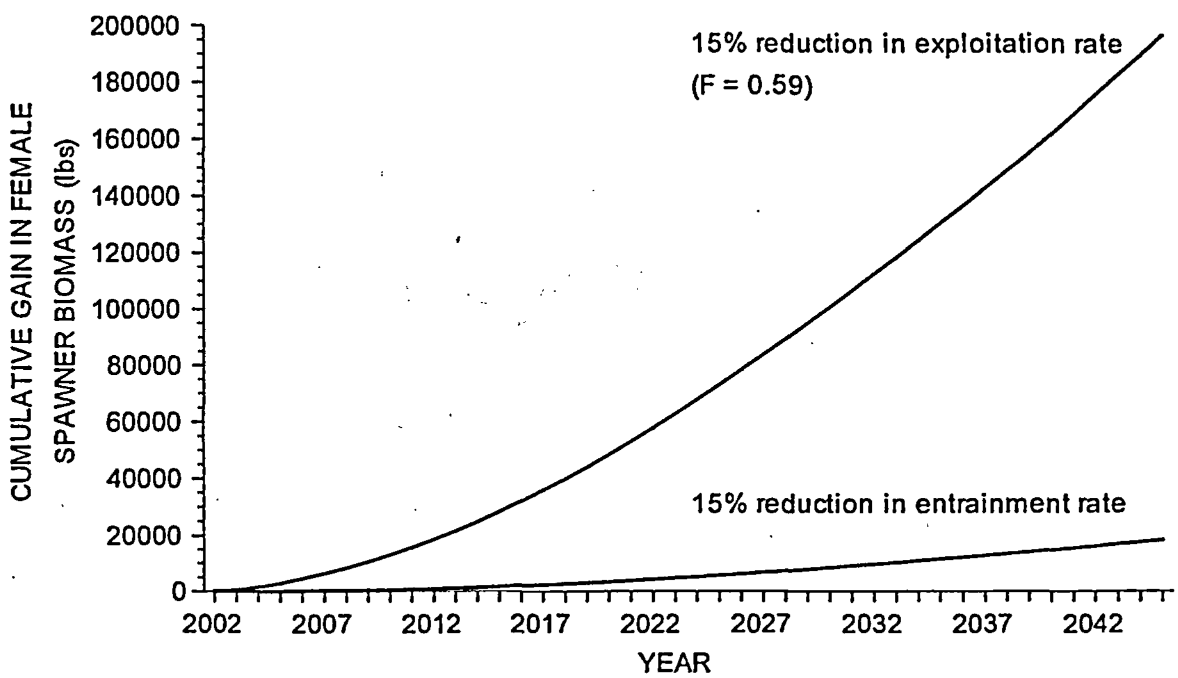

Fig. 4-24. Comparison of the cumulative gain in Niantic River female winter flounder biomass (lbs) as projected to the end of MNPS operation in 2045 using the SPDM with both the DEP fishing exploitation rate and the mean production loss (ENT) at MNPS each reduced by 15%.

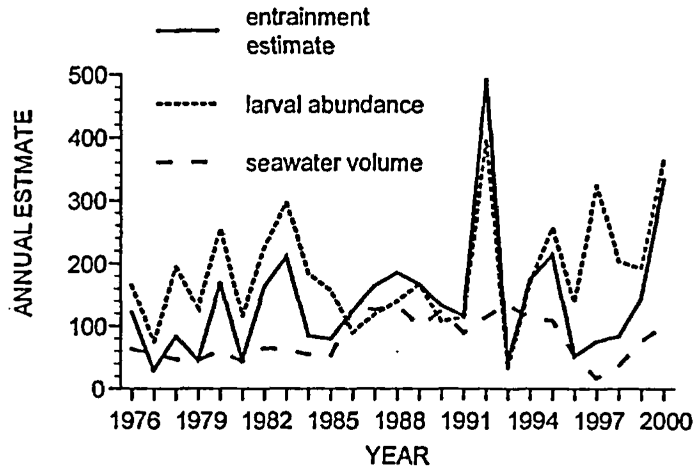

Fig. 4-25. Comparison between the annual estimates of larval winter flounder entrainment in millions, larval abundance at the MNPS discharges given as the annual mean density of larvae (*A* parameter of the Gompertz distribution), and seawater volume entrained in tens of millions of m^3 at MNPS from 1976 through 2000. Values of larval abundance were divided by 10 to fit the same scale as the other two measures.

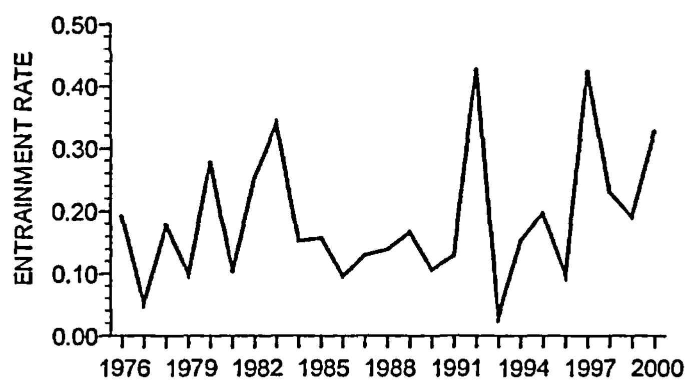

Fig. 4-26. Annual rate of entrainment of winter flounder larvae at MNPS, defined as the annual abundance index divided by the volume of seawater entrained each year from 1976 through 2000.

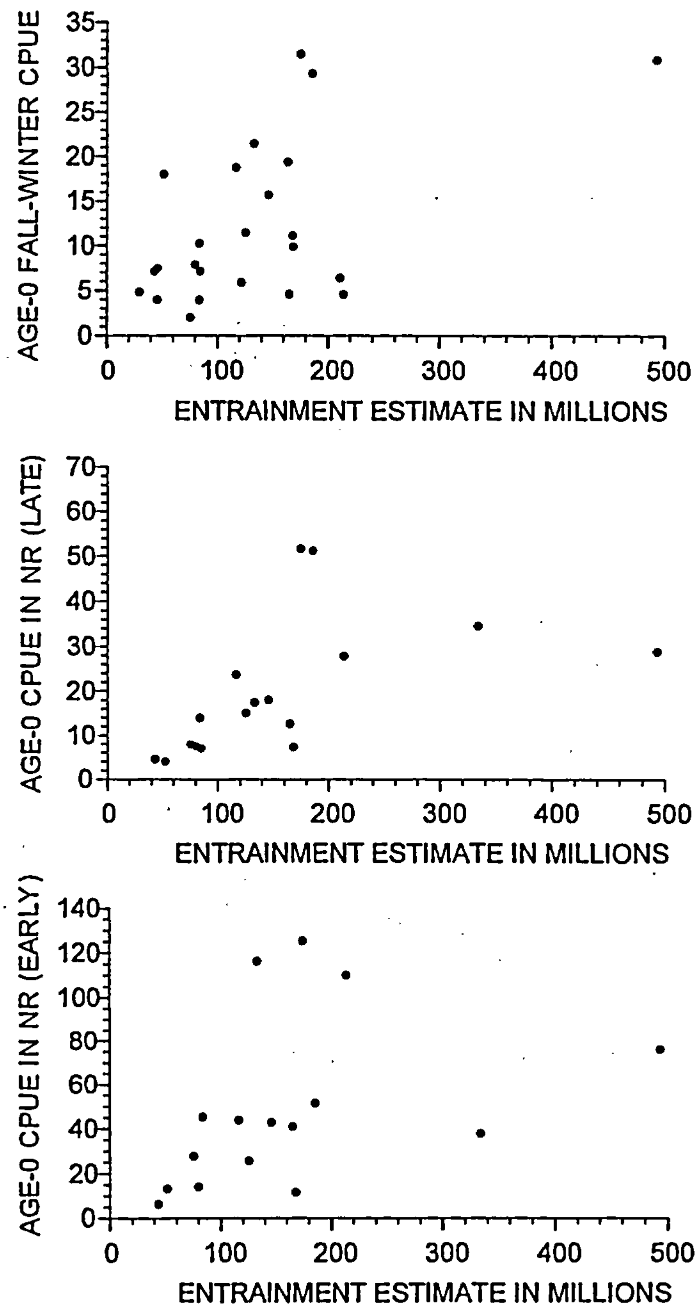

Fig. 4-27. Comparison between the 1-m beam trawl median CPUE of age-0 winter flounder taken at two stations in the Niantic River stations combined during both early (1985-2000) and late summer (1984-2000) and the late fall-early winter seasonal Δ-mean CPUE of age-0 winter flounder at trawl monitoring program stations (1976-99) with annual entrainment estimates of winter flounder larvae at MNPS. (Note that the vertical scales differ among the graphs).

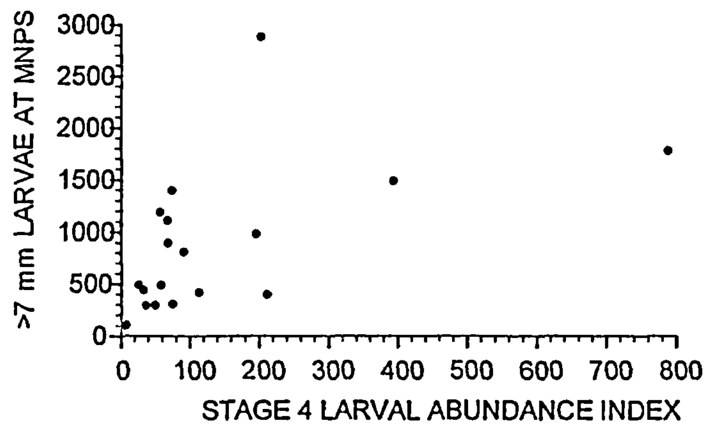

Fig. 4-28. Comparison between the abundance of Stage 4 winter flounder larvae taken in the Niantic River (*A* parameter of Gompertz function; 1983-2000) and larvae ≥7 mm taken at the MNPS discharges.

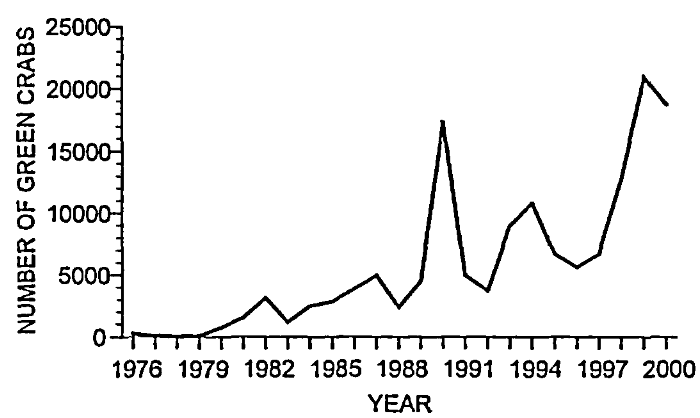

Fig. 4-29. Total number of green crabs taken each year at the Niantic River trawl monitoring program station from January 1976 through December 2000.

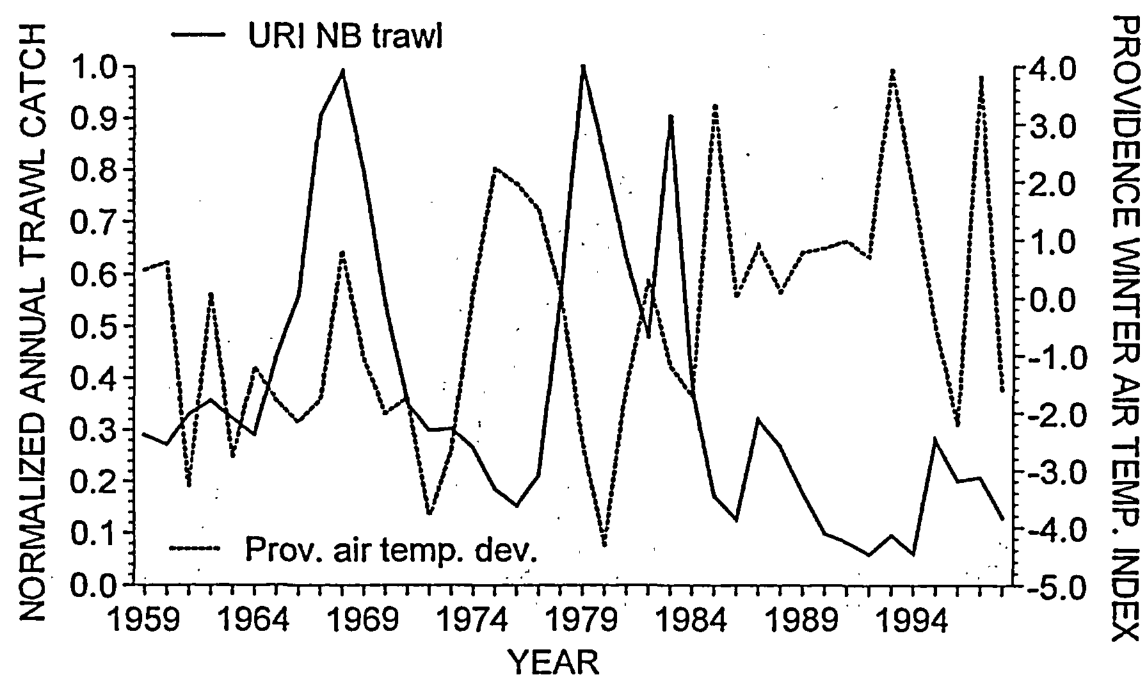

Fig. 4-30. Comparison of the normalized URI winter flounder trawl CPUE abundance index at Fox Island in Narragansett Bay, RI (URI NB trawl) and Providence, RI mean winter (December-February) air temperature index (Prov. air temp dev.) from 1959 through 1998.

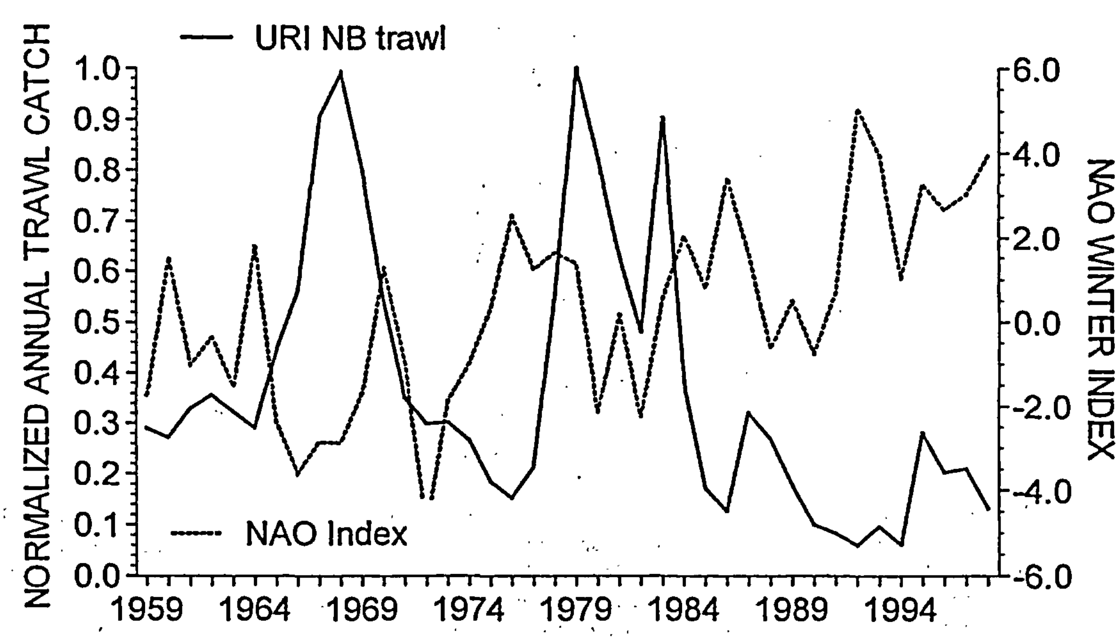

Fig. 4-31. Comparison of the normalized URI winter flounder trawl CPUE abundance index at Fox Island in Narragansett Bay, RI (URI NB trawl) and the North Atlantic Oscillation (NAO) winter index from 1959 through 1998.

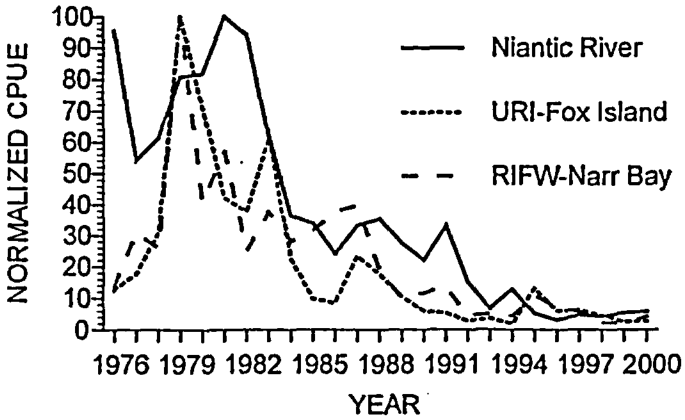

Fig. 4-32. Comparison of regional winter flounder abundances from 1976 through 2000. Included are the Δ-mean CPUE of fish larger than 15 cm taken in the Niantic River during the spawning season, the mean CPUE from Rhode Island Fish and Wildlife (RIFW) spring and fall trawl surveys in Narragansett Bay, and the annual geometric mean CPUE of winter flounder taken at the University of Rhode Island (URI) Fox Island trawl station in Narragansett Bay. Each CPUE series was normalized by dividing all values by the corresponding largest estimate and multiplying by 100.

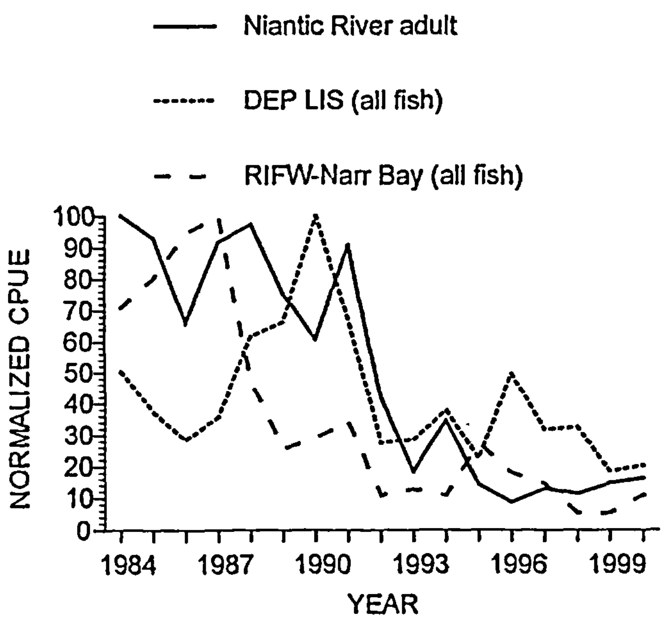

Fig. 4-33. Comparison of regional winter flounder abundances from 1984 through 2000. Included are the Δ-mean CPUE of fish larger than 15 cm taken in the Niantic River during the spawning season, the mean CPUE from Rhode Island Fish and Wildlife (RIFW) spring and fall trawl surveys in Narragansett Bay, and the annual geometric mean CPUE of winter flounder taken during April-June by Connecticut Department of Environmental Protection Marine Fisheries in Long Island Sound (DEP LIS). Each CPUE series was normalized by dividing all values by the corresponding largest estimate and multiplying by 100.

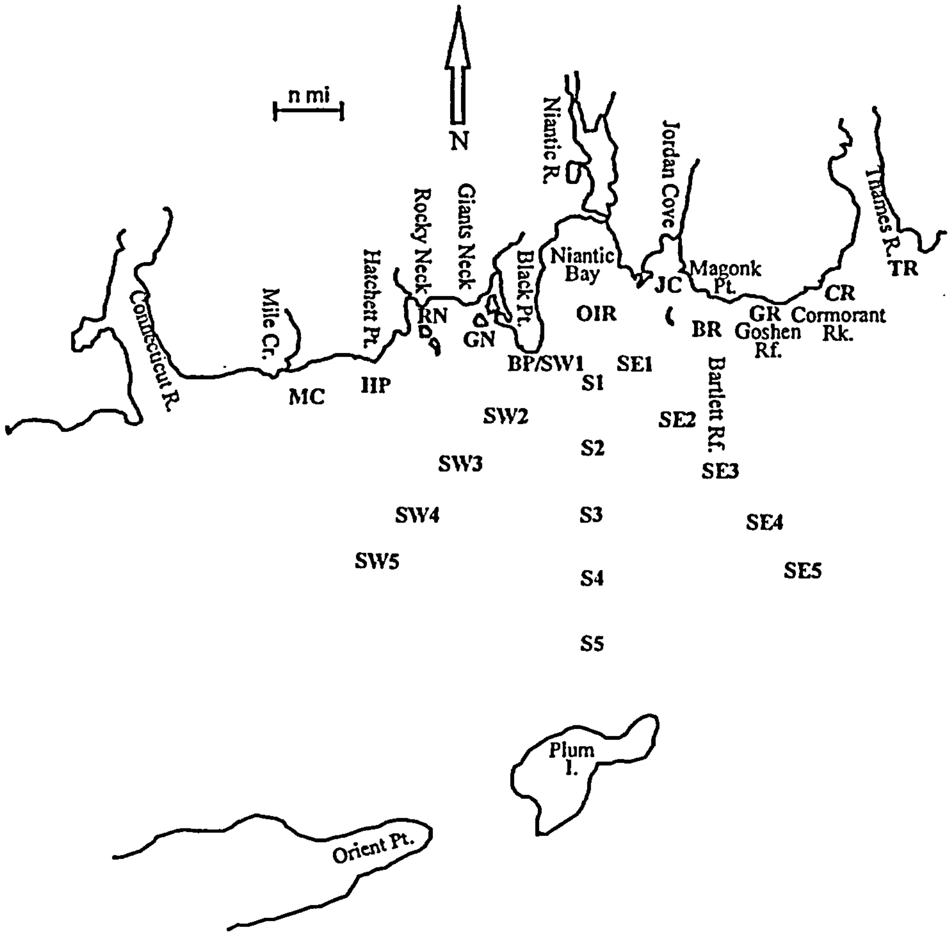

Fig. 4-34. Sampling sites for nearshore and offshore spatial distribution studies of tautog egg abundance conducted in July of 1996 and 1997 in LIS. Offshore spatial distribution stations (OIR, SE1-5, and SW1-5) were spaced at 1 n mi intervals and sampled in both years. Inshore stations (MC, HP, RN, GN, BP, JC, BR, GR, CR, and TR) were sampled only in 1997. See NUSCO (1997, 1998b) for details.

APPENDIX A TO CHAPTER 4 OF PART II

THE NIANTIC RIVER FEMALE WINTER FLOUNDER SPAWNING STOCK AND THE STOCK AND RECRUITMENT RELATIONSHIP

A4.1 INTRODUCTION

A stock and recruitment relationship (SRR) described by Ricker (1954, 1975) provides the basis for calculating survival rates from egg to immature fish during the first year of their life. This early life history survival rate is an essential component of the Stochastic Population Dynamics Model (SPDM) used for assessing the effectiveness of selected intake technology alternatives at Millstone Nuclear Power Station (MNPS) on the Niantic River winter flounder population as discussed in Chapter 4. The stock and recruitment data for determining the SRR form were derived from the catch-at-age of female winter flounder taken during the Niantic River spawning surveys (DNC 2001) and the methodology of calculation is described below. The annual estimates of female stock size were also used to calibrate the baseline of SPDM projections found in this report. This calibration was specifically requested by the Connecticut Department of Environmental Protection (DEP 2000a, b) as part of the MNPS intake technology study.

A4.2 QUANTIFICATION OF THE NIANTIC RIVER FEMALE WINTER FLOUNDER SPAWNING STOCK AND THE STOCK AND RECRUITMENT RELATIONSHIP (SRR)

When the spawning stock is made up of many year-classes, "recruitment" is defined as the total reproductive contribution over the life of each individual in a given year-class (Garrod and Jones 1974; Cushing and Horwood 1977). Therefore, the index of annual parental stock size for Niantic River winter flounder was based on derived egg production, and the index of recruits or year-class size was based on calculated egg production accumulated over the lifetime of the recruits. This method accounted for variations in year-class strength and in fecundity by size and age. The assumptions and methods used to age Niantic River winter flounder and to calculate female spawning stock size and an annual recruitment index expressed as equivalent numbers of spawning females were described in DNC (2001); some details are also summarized herein. Methods used to calculate the annual standardized catch index and total egg production of the parental stock from data collected during annual spawning surveys completed since 1977 in the Niantic River were given in DNC (2001) and these data are given in Table 3-4 of Chapter 3. A recruitment index was determined by applying an age-length key (DNC 2001) to the annual standardized catches of females partitioned into length categories. Aging females allowed for the determination of their numbers by year-class present in each age-class during successive spawning seasons. A common age-length key was used over all

years because Witherell and Burnett (1993) reported that no trends were observed in mean length-at-age during 1983-91 for Massachusetts winter flounder despite a 50% reduction in biomass during that period. From observations made of abundance and age over the years, a large fraction of age-3 females and considerable numbers of age-4 fish were apparently immature and not present in the Niantic River during the spawning season; all females age-5 and older were assumed to be mature. The total number of females was reduced to spawning females using length-specific proportions of mature fish estimated from annual catches in the Niantic River (DNC 2001: Fig. 10). Because the estimates of age-3 fish present in the Niantic River were thought to be unreliable as a large fraction of them were immature and not present on the spawning grounds, this estimation process was only carried through the 1996 year-class (i.e., age-4 females taken in 2000). The adjusted numbers of mature fish provided an index of the fully recruited year-class expressed as the aggregated number of adult females passing through each age-class. An implied assumption was that catches in the Niantic River were representative of the population, with the exception of immature fish, most of which did not enter the river until fully recruited to the spawning stock. Although this recruitment index could be used together with the annual number of adult females to derive the SRR, this would ignore size composition differences that affected annual egg production. Therefore, the above index was adjusted for differences in fecundity among fish using the length-fecundity relationship of Niantic River winter flounder:

$$\text{fecundity} = 0.0824 \cdot (\text{length in cm})^{4.506} \quad (1)$$

Also, since the recruitment index was based on total lifetime contribution of a year-class, estimates from more recent year-classes needed to be projected into the future. Therefore, an annual survival rate of 0.45 (equivalent to an instantaneous total mortality rate Z of 0.8) was applied to generate estimates of year-class egg production through 2007 (i.e., age-12 fish from the 1995 year-class). Finally, annual egg production was summed up over the lifetime of each year-class to determine a recruitment index as eggs, which was then converted to equivalent spawning females at the rate of one female for each 583,000 eggs, which is the calculated value of current mean fecundity for the Niantic River stock.

The Ricker SRR appeared best suited for use with the Niantic River winter flounder stock because the relationship between recruitment and spawning stock indices was a dome-shaped curve with substantial decline in recruitment when the stock was larger than average (NUSCO 1989). This particular form of a SRR has also been applied to other New England flounder stocks (Gibson 1989, 1993). Furthermore, Iles (1994) stated that a dome-shaped stock-recruitment relationship appeared to be generally consistent for a number of flatfish stocks and Brodziak et al. (2001) reported that Southern New England winter flounder demonstrated strong evidence of having stock-dependent recruitment. The mathematical form of Ricker's SRR is:

$$R_t = \alpha \cdot P_t \cdot \exp(-\beta \cdot P_t) \quad (2)$$

where R_t is the recruitment index for the progeny of the spawning stock P_t in year t and α and β are parameters estimated from the data. The α parameter describes the growth potential of the stock and $\log_e(\alpha)$, the slope of the

SRR at the origin, is equivalent to the intrinsic natural rate of increase (Roughgarden 1979) when the stock is not exploited. The β parameter is the instantaneous rate at which recruitment declines at large stock sizes due to some form of density-dependent mortality. The natural logarithm of winter flounder recruitment was found to be correlated with mean water temperature during February at the intakes of MNPS, which is when most spawning and early larval development occur (NUSCO 1988, 1989; temperature and climatic effects are also discussed below in Section 4.2.6). Therefore, using nonlinear regression methods (SAS Institute Inc. 1990), the parameters α and β were estimated initially by fitting the above equation to the data and then re-estimated under the assumption that there was a significant temperature effect. Following Lorda and Crecco (1987), Gibson (1987, 1993), Iles and Beverton (1998), Quinn and Deriso (1999: p. 91), and Planque and Frèdou (1999), the annual mean February water temperature (given in °C) was used as an explanatory variable added to Ricker's SRR equation to adjust the two-parameter SRR for temperature effects. This served to reduce recruitment variability and to obtain more reliable parameter estimates for the SRR. The temperature-dependent SRR had the form:

$$R_t = \alpha \cdot P_t \cdot \exp(-\beta \cdot P_t) \cdot \exp(\phi \cdot T_{Feb}) \qquad (3)$$

where the second exponential describes the effect of February water temperature on recruitment and the added parameter ϕ represents the strength of that effect. This effect either decreases or increases the number of recruits-per-spawner produced each year because temperature was defined as the deviation (T_{Feb}) of each particular mean February temperature from a long-term (1977-99) average of February water temperatures. When the February mean water temperature is equal to the long-term average, the deviation (T_{Feb}) becomes zero and the exponential term equals unity (i.e., no temperature effect). Thus, the temperature-modified Equation 3 reduces to its initial form (Eq. 2) under average temperature conditions.

Additionally, at the request of DEP (DEP 2000b), a depensatory form of SRR was investigated. Coincidentally, Walters and Kitchell (2001) recently emphasized that the risk of depensatory effects should be a goal of recruitment research. When depensation processes occur, the per capita recruitment rate decreases with decreasing parental stock size, which may lead to a rapid stock collapse. The two-parameter Ricker SRR (Eq. 2) was modified with the addition of another parameter, Ω, as suggested by Saila and Lorda (1982). The depensatory version of the Ricker SRR has the form:

$$R_t = \alpha \cdot (P_t)^{\Omega} \cdot \exp(-\beta \cdot P_t) \qquad (4)$$

where the parameter Ω must be greater than zero. When $\Omega > 1$ the SRR can describe both depensation below some threshold stock size and compensation for larger stock sizes, as in the two-parameter SRR (Eq. 2). When $\Omega = 1$, the above equation reverts to the standard two-parameter model.

Egg production estimated from annual spawning surveys was the basis for determining recruitment, because the abundance of other early life-stages have not been reliably correlated with adult winter flounder (DNC 2001). Both parental spawning stock size and recruitment indices were scaled to absolute population size using annual estimates of abundance, size frequency, maturity, egg production, and overall population mean fecundity. These scaled annual values were used with the Ricker SRR model as estimates of adult female spawning stock and potential female recruitment (Table A4-1). The two-parameter SRR model (Eq. 2) was initially fitted to these data. The stock growth potential parameter α (scaled as numbers of fish) for this model was estimated as 1.08 with a standard error of 0.35 (32% of the parameter value). This estimate of α and the estimate of β (the second model parameter) were used as initial values for fitting the three-parameter SRR model (Eq. 3) with temperature effects and the depensatory model (Eq. 4).

Fitting the depensatory model to the same data resulted in a parameter estimate for Ω that was not significantly different from 1. Therefore, a depensatory form of the SRR was not indicated for the Niantic River winter flounder population. Myers et al. (1995) examined spawner-recruit data for 128 fish stocks and reported that evidence for depensation was only indicated in three populations. They concluded that most observed fish population collapses could not be reasonably attributed to depensatory fish population dynamics. In another meta-analysis, Liermann and Hilborn (1997) found that no depensation was likely for fishes of four broad taxonomic groups, including pleuronectid flounders, but cautioned that both depensation and hypercompensation were possible for some stocks, given the broad range of their data distribution. In a simulation analysis, Frank and Brickman (2000) found that a SRR can appear to be compensatory even if the stock reproductive dynamics did not exhibit this behavior. They further noted, however, that species exhibiting social behavior, such as group mating or schooling were at most risk for depensation. Winter flounder do not exhibit these traits, which are mostly associated with pelagic fishes.

For the three-parameter SRR model with temperature effects (Eq. 3), all parameter estimates were significantly different from 0 and the model explained 71% of the variability associated with the recruitment index. Relationships resulting from fitting both the two- and three-parameter Ricker models separately to stock and recruitment data scaled to absolute population sizes are shown as the curved lines in the central portion of Figure A4-1 as follows: the unadjusted SRR (two-parameter model) is shown as the thinner solid line and the three-parameter model (SRR adjusted for T_{Feb}) is represented by the thicker solid line. The outermost two dashed lines illustrate low recruitment in the warmest year (Table A4-1; 1991, $T_{Feb} = +1.97$) and high recruitment in the coldest year (1977, $T_{Feb} = -2.43$). A similar plot, showing the effect of a range of water temperatures on the SRR of Irish Sea Atlantic cod (*Gadus morhua*), was shown by Planque and Frèdou (1999).

Using the three-parameter model, the parameter α was estimated as 1.125 and had a standard error of 0.252, which is 22% of the parameter value (Table A4-2). Differences among annual values of α seen in the time-series of

estimates were likely caused by increased fishing mortality on winter flounder in addition to the inherent instability of parameter estimates fitted to small data sets. In particular, the apparent influence of the 1988-96 data points on the estimate of α were illustrative of higher recent exploitation and poor recruitment. The Niantic River winter flounder population apparently now has a greatly diminished compensatory reserve due to rates of fishing that increased from 0.71 in 1985 to 1.10-1.33 by the mid-1990s. A recent instantaneous fishing mortality rate (F) as high as 1.02 was reported for LIS winter flounder by Johnson et al. (2000). Although spawning in inshore estuaries may protect winter flounder from fisheries directed specifically at spawning aggregations, fish moving to or from the spawning grounds are targeted by trawlers in fall and winter and spring, including within Niantic Bay. Furthermore, the Niantic River has a unique night spear fishery for winter flounder that occurs during the spawning and immediate post-spawning periods, which can be considered as a source of increased fishing mortality specific to this stock.

Relatively high abundance of juvenile winter flounder from the 1988 year-class was expected to increase numbers of adult fish during 1992-94 that would dominate the spawning population. Unfortunately, winter flounder from these large year-classes were removed quickly by fishing (Simpson et al. 1996). Also, the apparent lack of adult fish in Connecticut waters in more recent years, even though juvenile fish of the 1992 year-class appeared to be abundant, was noted by Simpson et al. (1996) as well as in the Niantic River studies (DNC 2001). Increases in adult abundance resulting from relatively numerous age-0 juveniles seen in the past several years may be apparent in forthcoming years as these fish mature and return as spawners. However, other factors may substantially reduce their numbers before reaching maturity, as was seen for the 1988 and 1992 year-classes.

The estimate of Ricker's β parameter, which describes the annual rate of compensatory mortality as a function of the stock size, was important in SPDM simulations. The present value for β is 1.886×10^{-5}, the lowest estimate of the series (Table A4-2). Previous values ranged between 1.961 and 2.583×10^{-5}. The current long-term (1989-2000) mean estimate of 2.306×10^{-5} for β was less than the average found during the mid-1990s because of three consecutive low estimates, suggesting a possible weakened capability to respond to changes in parent stock size. However, the present calculation does not include the contribution of year-classes after 1996. These year-classes had increasing numbers of juveniles found in the Niantic River (see Chapter 3, Fig. 3-4), which should result in better recruitment if mortality later during their immature years (ages-1-3) was not excessive.

The parameter ϕ, which reflects the magnitude of the effect of February temperature deviations (T_{Feb}) from the 1977-96 mean of 2.79°C (Table A4-1), has also been used as an SPDM input parameter and was estimated as –0.400 in 2000 (Table A4-2). The long-term mean for ϕ was –0.370 (range of –0.418 to –0.259). In general, February water temperatures have been warmer in recent years and estimates for the ϕ parameter have increased in

magnitude. The effect of February temperatures on winter flounder recruitment is discussed in Section 4.2.5 of Chapter 4.

The stock-recruitment-based estimates of α for the Niantic River winter flounder discussed above underestimate the true slope at the origin for this stock. The method of calculating annual recruitment included the effects of fishing on winter flounder age-2 and older as well as the entrainment of larvae at MNPS. Therefore, these direct estimates of α correspond to a compensatory reserve diminished by existing larval entrainment and exploitation rates. The concept of a compensatory reserve in fishing stocks and the effect of exploitation on the shape of the reproduction curve when the recruitment index is based on the exploited stock was discussed by Goodyear (1977: Fig. 1). Thus, if larval entrainment and fishing rates increase, the field estimates of recruitment will be smaller and so will the estimates of α (i.e., the remaining compensatory reserve). To assess impacts appropriately, the inherent potential of a stock to increase in the absence of fishing and plant effects must be determined. Crecco and Howell (1990) investigated the possibility of using indirect methods to estimate the true α parameter (i.e., α_0 for the unfished stock when $F = 0$). They used four indirect methods (Cushing 1971; Cushing and Harris 1973; Longhurst 1983; Hoenig et al. 1987; Boudreau and Dickie 1989) based on different life history parameters (Table A4-3). Because these methods did not depend upon direct estimates of recruitment, biases caused by changing fishing rates are avoided and independent means of validating SRR-based estimates are provided. The geometric mean of $\alpha_0 = 5.20$ calculated from these estimates was used in the SPDM. This parameter describes the inherent potential of a stock to increase because the natural logarithm of α is the slope of the SRR at the origin for the unfished stock (Ricker 1954) and that slope, in turn, corresponds to the intrinsic rate of natural increase of the population (Roughgarden 1979). Consequently, the large difference between the derived value of α_0 (5.20) and regression estimates of α based on field data reflects the difference in potential growth between unfished and highly exploited stocks of winter flounder. Use of an unfished stock as a starting point for a population dynamics simulation has a number of advantages, depending upon the particular scenario selected. The data-based estimates of the other two SRR parameters (β and ϕ in Table A4-2) used in the population simulations, however, do not depend upon fishing and entrainment rates, and since they are not directly related to current winter flounder abundance, their estimates were obtained as long-term averages of their series.

Finally, both the mean weight and fecundity of a Niantic River female winter flounder were calculated for a theoretical population of ages-1 through 15 at equilibrium for which only the instantaneous natural mortality rate (M) was assumed (i.e., the unfished population). These values were used in the SPDM simulations found in Chapter 4 and were derived from population data reported in (NUSCO 1990, 2000) and an estimated M of 0.2. The equilibrium calculation for this theoretical unfished stock showed a mean weight of 1.65 lbs per female and a mean fecundity of 1,322,994 eggs per spawner (Table A4-4).

A4.3 REFERENCES

Boudreau, P.R., and L.M. Dickie. 1989. Biological model of production based on physiological and ecological scaling of body size. Can. J. Fish. Aquat. Sci. 46:614-623.

Brodziak. J.K.T., W.J. Overholtz, and P.J. Rago. 2001. Does spawning stock affect recruitment of New England groundfish? Can. J. Fish. Aquat. Sci. 58:306-318.

Crecco, V.A., and P. Howell. 1990. Potential effects of current larval entrainment mortality from the Millstone Nuclear Power Station on the winter flounder, *Pseudopleuronectes americanus*, spawning population in the Niantic River. CT Dept. Envir. Prot., Bur. Fish., Spec Pub. 37 pp.

Cushing, D.H. 1971. The dependence of recruitment on parent stock in different groups of fish. J. Cons. int. Explor. Mer 33:340-362.

Cushing, D.H., and J.G.K. Harris. 1973. Stock and recruitment and the problem of density dependence. Rapp. P.-v. Réun. Cons. int. Explor. Mer 164:142-155.

Cushing, D.H., and J.W. Horwood. 1977. Development of a model of stock and recruitment. Pages 21-35 *in* J.H. Steele, ed. Fisheries mathematics. Academic Press, New York.

DEP (Connecticut Department of Environmental Protection). 2000a. Letter C09872 dated February 16, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Comments on proposed cooling water alternatives scope of study.

DEP. 2000b. Letter C10302 dated July 13, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Comments on proposed cooling water alternatives scope of study.

DNC (Dominion Nuclear Connecticut, Inc.). 2001. Winter flounder studies. Pages 9-94 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 2000. Millstone Environmental Laboratory, Waterford, CT.

Frank, K.T., and D. Brickman. 2000. Allee effects and compensatory population dynamics within a stock complex. Can. J. Fish. Aquat. Sci. 57:513-517.

Garrod, D.J., and B.W. Jones. 1974. Stock and recruitment relationships in the Northeast Arctic cod stock and the implications for the management of the stock. J. Cons. int. Explor. Mer 36:35-41.

Gibson, M.R. 1987. Preliminary assessment of winter flounder (*Pseudopleuronectes americanus*) stocks in Rhode Island waters. RI Div. Fish Wildl., Res. Ref. Doc. 87/7. 51 pp.

Gibson, M.R. 1989. Stock-recruitment relationships for winter flounder in the S. New England area and revised fishery reference points. RI Div. Fish Wildl., Res. Ref. Doc. 89/9. 10 pp + 5 fig.

Gibson, M.R. 1993. Stock assessment of winter flounder in Rhode Island, 1992: a report to the RI Marine Fisheries Council. RI Div. Fish Wildl., Res. Ref. Doc. 93/1. 79 pp + 14 fig.

Goodyear, C.P. 1977. Assessing the impact of power plant mortality on the compensatory reserve of fish populations. Pages 186-195 *in* W. Van Winkle, ed. Proceedings of the conference on assessing the effects of power-plant-induced mortality on fish populations. Pergamon Press, New York.

Hoenig, J.M., D.M. Heisey, W.D. Lawing, and H.D. Schupp. 1987. An indirect rapid methods approach to assessment. Can. J. Fish. Aquat. Sci. 44 (Suppl 2):324-338.

Iles, T.C. 1994. A review of stock-recruitment relationships with reference to flatfish populations. Neth. J. Sea Res. 32:399-420.

Iles, T.C., and R.J.H. Beverton. 1998. Stock, recruitment and moderating processes in flatfish. J. Sea Res. 39:41-55.

Johnson, M.W., D. Shake, and P.T. Howell. 2000. Job 2: marine finfish survey. Part 1: Long Island Sound trawl survey. 114 pp. *In* A study of recreational fisheries in Connecticut. CT Dept. Envir. Prot., Bur. Nat. Res., Fish. Div.

Liermann, M., and R. Hilborn. 1997. Depensation in fish stocks: a hierarchic Bayesian meta-analysis. Can. J. Fish. Aquat. Sci. 54:1976-1984.

Longhurst, A. 1983. Benthic-pelagic coupling and export of organic carbon from a tropical Atlantic continental shelf, Sierra Leone. Est. Coast. Shelf Sci. 17:261-285.

Lorda, E.C., and V.A. Crecco. 1987. Stock-recruitment relationship and compensatory mortality of American shad in the Connecticut River. Am. Fish. Soc. Symp. 1:469-482.

Myers, R.A., N.J. Barrowman, J.A. Hutchings, and A.A. Rosenberg. 1995. Population dynamics of exploited fish stocks at low population levels. Science 269:1106-1108.

NUSCO (Northeast Utilities Service Company). 1988. Winter flounder studies. Pages 149-224 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Three-unit operational studies, 1986-1987.

NUSCO. 1989. Winter flounder studies. Pages 239-316 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1988.

NUSCO. 1990. Winter flounder studies. Pages 9-77 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1989.

NUSCO. 2000. Winter flounder studies. Pages 9-112 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 1999. Northeast Utilities Environmental Laboratory, Waterford, CT.

Planque, B., and T. Frèdou. 1999. Temperature and recruitment of Atlantic cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci. 56:2069-2077.

Quinn, T.J. II, and R.B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York. 541 pp.

Ricker, W.E. 1954. Stock and recruitment. J. Fish. Res. Board Can. 11:559-623.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191. 382 pp.

Roughgarden, J. 1979. Evolutionary ecology of single populations. Pages 295-408 *in* The theory of population genetics and evolutionary ecology: an introduction. MacMillan Publishing Company, Inc., New York.

Saila, S.B., and E. Lorda. 1982. A generalization and critique of the Ricker stock-recruitment function. University of Rhode Island, Graduate School of Oceanography, Narragansett, RI. Tech. Rep. 82-17. 62 pp.

SAS Institute Inc. 1990. SAS/Stat user's guide. Vol. 2, GLM-VARCOMP. Version 6. Fourth ed. SAS Institute Inc., Cary, NC. 1686 pp. + index.

Simpson, D.G., M.W. Johnson, and K. Gottschall. 1996. Job 2: marine finfish survey. Part 1: Long Island Sound trawl survey. Pages 23-59 *in* A study of recreational fisheries in Connecticut. CT Dept. Envir. Prot., Bur. Nat. Res., Fish. Div.

Walters, C., and J.F. Kitchell. 2001. Cultivation/depensation effects on juvenile survival and recruitment: implications for the theory of fishing. Can. J. Fish. Aquat. Sci. 58:39-50.

Witherell, D.B., and J. Burnett. 1993. Growth and maturation of winter flounder, *Pleuronectes americanus*, in Massachusetts. Fish. Bull., U.S. 91:816-820.

TABLE A4-1. Annual Niantic River winter flounder stock-recruitment data based on indices of egg production in the 1977 through 1996 year-classes with mean February water temperature and deviations (T_{Feb}) from the mean. See DNC (2001) for details.

Year-class	Index of female spawners (P)[a]	Index of female recruits (R)[a]	R/P ratio	Mean February water temperature (°C)	Deviation from mean February water temperature (T_{Feb})
1977	24,573	51,414	2.09	0.36	-2.43
1978	42,283	42,642	1.01	1.09	-1.70
1979	28,877	35,653	1.23	1.48	-1.31
1980	23,935	30,949	1.29	2.38	-0.41
1981	63,942	28,065	0.44	2.63	-0.16
1982	75,543	27,917	0.37	1.56	-1.23
1983	50,308	27,285	0.54	3.74	0.95
1984	24,246	24,144	1.00	4.02	1.23
1985	26,284	20,104	0.76	2.36	-0.43
1986	20,546	18,332	0.89	3.38	0.59
1987	24,804	15,786	0.64	3.27	0.48
1988	40,473	11,197	0.28	2.67	-0.12
1989	33,034	8,072	0.24	3.24	0.45
1990	16,048	6,509	0.41	4.28	1.49
1991	29,544	4,752	0.16	4.76	1.97
1992	18,081	3,484	0.19	3.68	0.89
1993	10,289	3,284	0.32	3.10	0.31
1994	15,179	2,996	0.20	1.59	-1.20
1995	7,561	2,665	0.35	4.11	1.32
1996	3,793	1,809	0.48	2.12	-0.67
Mean	28,967	18,353	0.63	2.79	
CV	63%	80%		42%	

[a] Scaled number of female spawners and recruits from expected egg production; scaling factors used were 583,000 eggs per female (mean fecundity) and a multiplier of 27.7 to convert relative abundance to an absolute population size.

TABLE A4-2. Annual estimates of the modified three-parameter Ricker stock-recruitment function determined for the Niantic River winter flounder population from 1989 through 2000. See DNC (2001) for details.

Year of estimation	Year-classes included[a]	α[b]	Standard error	β ($X\ 10^{-5}$)	Standard error ($X\ 10^{-5}$)	ϕ	Standard error
1989	1977-85	2.646	0.599	2.228	0.456	-0.259	0.095
1990	1977-86	2.502	0.399	2.466	0.372	-0.264	0.064
1991	1977-87	2.226	0.518	2.140	0.461	-0.329	0.098
1992	1977-88	2.149	0.543	2.466	0.567	-0.357	0.010
1993	1977-89	1.977	0.566	2.523	0.642	-0.412	0.108
1994	1977-90	2.071	0.428	2.498	0.478	-0.379	0.077
1995	1977-91	1.710	0.380	2.583	0.516	-0.415	0.078
1996	1977-92	1.473	0.306	2.450	0.488	-0.418	0.075
1997	1977-93	1.442	0.283	2.399	0.463	-0.417	0.072
1998	1977-94	1.186	0.265	1.961	0.513	-0.381	0.082
1999	1977-95	1.082	0.265	2.071	0.570	-0.408	0.088
2000	1977-96	1.125	0.252	1.886	0.478	-0.400	0.082
	Mean	-		2.306		-0.370	

[a] Age-4 considered to be minimum age of recruitment.
[b] The compensatory reserve for an unfished stock (α_0) used in the SPDM is 5.20 (see Table A4-3).

TABLE A4-3. Methods of estimating the compensatory reserve parameter α_0 of the unfished Niantic River winter flounder based on several life history models (modified from Table 4 in Crecco and Howell 1990). See NUSCO (2000) for details of the derivation of this value.

Reference	Equation[a]	Data used[a]	Estimate of α_0
Boudreau and Dickie (1989)	$r_m = 2.88 \cdot weight^{-0.33}$	weight= 414 Kcal (0.71lb)	5.90[b]
Hoenig et al. (1987)	$r_m = 425.2 \cdot t_m^{-0.949}$	t_m = 1642 days (4.5 years)	5.47[b]
Longhurst (1983)	$r_m = 3K \cdot ([L_\infty / L_m] - 1)$	L_∞ = 19 inches K = 0.30 L_m = 13.55 inches	5.10[b]
Cushing (1971, 1973)	$\alpha_0 = 1.98 + 0.0306 \cdot FEC^{0.33}$	FEC = 600,000	4.45
Geometric mean			5.20

[a] r_m = annual intrinsic rate of population increase; weight is weight in Kcal at which 50% of female winter flounder first spawn; t_m = mean generation time in days; K and L_∞ are parameters of the von Bertalanffy growth equation and L_m is mean length; and FEC = mean fecundity.

[b] $\alpha_0 = \exp(r_m \cdot t_m)$, where t_m = 4.5 years (mean time to maturation for females).

TABLE A4-4. Biomass calculations for the Niantic River female winter flounder spawning stock at equilibrium based on an instantaneous natural mortality rate of M = 0.2 and an instantaneous fishing mortality rate of F = 0 (i.e., an unfished stock). See NUSCO (2000) for details.

Age	Female population size	Fraction mature	Number of mature females	Mean length (cm)	Mean weight of mature females (lbs)	Eggs per mature female	Spawning stock biomass (lbs)	Egg production (millions)
2	1,000.00	0.00	0.00	18.0	-	-	-	0.000
3	818.73	0.25	204.68	27.0	0.497	232,088	101.77	47.504
4	670.32	0.80	536.26	31.0	0.776	432,517	416.36	231.940
5	548.81	1.00	548.81	34.5	1.096	700,390	601.73	384.381
6	449.33	1.00	449.33	37.5	1.435	1,019,793	644.71	458.224
7	367.88	1.00	367.88	39.0	1.628	1,216,926	599.04	447.683
8	301.19	1.00	301.19	40.5	1.839	1,442,512	553.95	434.470
9	246.60	1.00	246.60	42.0	2.068	1,699,372	510.01	419.065
10	201.90	1.00	201.90	43.5	2.316	1,990,489	467.61	401.880
11	165.30	1.00	165.30	45.0	2.584	2,319,011	427.09	383.332
12	135.34	1.00	135.34	46.5	2.872	2,688,253	388.70	363.828
13	110.80	1.00	110.80	48.0	3.182	3,101,703	352.54	343.669
14	90.72	1.00	90.72	49.5	3.514	3,563,020	318.78	323.237
15	74.27	1.00	74.27	51.0	3.869	4,076,040	287.36	302.727
Total	5,181.19		3,433.08				5,669.66	4,541.941

Mean weight per mature female fish = (5,670 lbs + 3,433 mature females) = 1.65 lbs (~39.2 cm fish)

Mean fecundity (unfished stock) = 1,322,994 eggs per female spawner

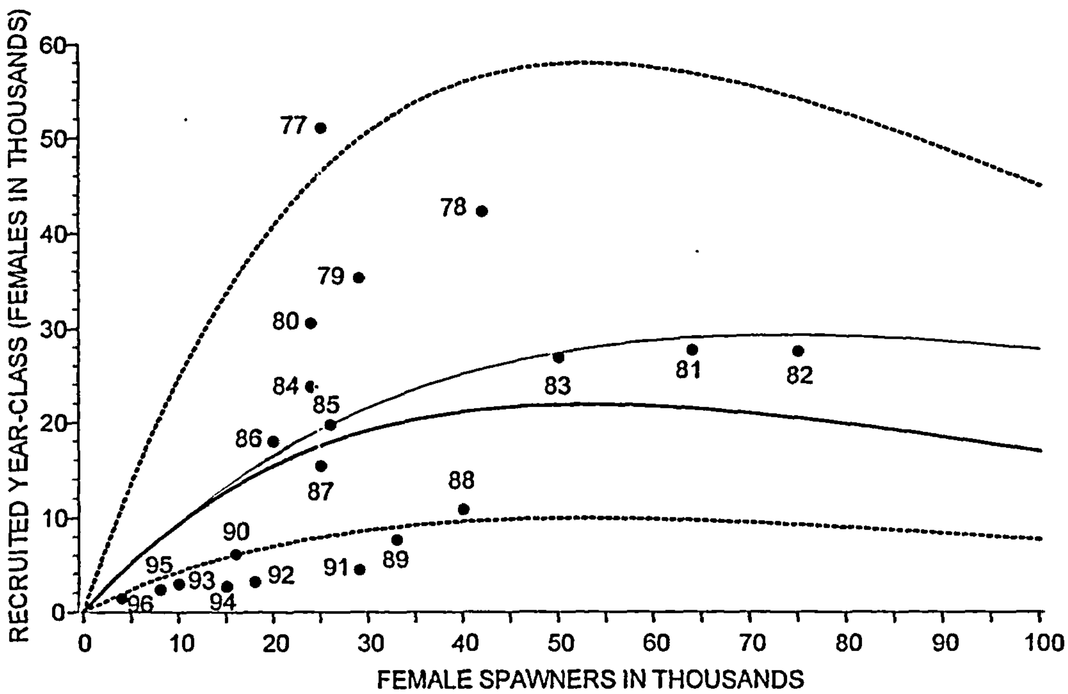

Fig. A4-1. Ricker SRRs of Niantic River winter flounder (see text for explanation of the four curves plotted). Calculated recruitment indices (see Table A4-1) of the 1977 through the 1996 year-classes are shown.

APPENDIX B TO CHAPTER 4 OF PART II

DESCRIPTION OF THE NIANTIC RIVER WINTER FLOUNDER STOCHASTIC POPULATION DYNAMICS MODEL

B4.1 INTRODUCTION

The Stochastic Population Dynamics Model (SPDM) is used in Chapter 4 to assess the effectiveness of selected intake technology alternatives at Millstone Nuclear Power Station (MNPS) on the Niantic River winter flounder population. The model and its application for this purpose are described below.

B4.2 DESCRIPTION OF THE STOCHASTIC POPULATION DYNAMICS MODEL USED TO ASSESS THE EFFECTIVENESS OF ENTRAINMENT REDUCTION ALTERNATIVES ON NIANTIC RIVER WINTER FLOUNDER

The SPDM developed for the Niantic River winter flounder stock includes a life-cycle module designed to generate new year classes of flounder that is based on the three-parameter Ricker form of the stock-recruitment relationship (SRR) discussed in Appendix A of Chapter 4. Although the SRR equation does not appear explicitly in the model formulation, the SPDM equation which computes mortality through the first year of winter flounder life was derived from the SRR and assumes a Ricker-type form of recruitment. Beyond that point (i.e., age-1) in the life-cycle simulation, the population model simply keeps track of the annual changes in abundance of each year-class resulting from natural mortality and fishing, together with growth in size and increased fecundity. Population updates take place at the beginning of each model time-step of length equal to 1 year. The projection of adult fish populations over time has been implemented in many models by means of Leslie matrix equations (e.g., Hess et al. 1975; Saila and Lorda 1977; Vaughan 1981; Spaulding et al. 1983; Goodyear and Christensen 1984; Reed et al. 1984). In the SPDM, winter flounder were projected over time by grouping fish into distinct age-classes and by carrying out the computations needed (mostly additions and multiplications) iteratively over the age index (1 through 15) and over the number of years specified for each simulation. This approach was algebraically identical to the Leslie matrix formulation, helped the understanding of how the model works, and simplified the computer code when describing the fish population either as numbers of fish or as biomass (allowing for size variation within each age-class). A similar implementation of an adult fish population dynamics simulation was used by Crecco and Savoy (1987) in their model of Connecticut River American shad. The Niantic River winter flounder SPDM and its application to impact assessment work at MNPS was reviewed in Lorda et al. (2000).

Model components are conceptually illustrated as the solid-line boxes shown in Figure B4-1 and describe the SPDM as used in the present study. The box with dashed lines corresponds to the mass-balance calculations (discussed in

Appendix B to Chapter 3) dealing with spatial larval distribution and entrainment loss estimates, which are not an integral part of the SPDM. Model components are briefly described in Figure B4-1, with the more important ones, such as the module labeled age-0 cohort (box 3) and the two random inputs (boxes 3A and 3B), described in more detail below. The most critical aspects in the formulation of a stock-recruitment based population model are the specific equation and parameters used to calculate total mortality during the first year of life of the fish (i.e., from egg to age-1). The equation used for this purpose in the SPDM was derived from Ricker's equilibrium equation for Z_0 (total instantaneous mortality from egg to maturation age). This involved the extension of stock-recruitment theory, which was developed for fish that spawn only once, to iteroparous fish like winter flounder with multi-age spawning stocks. The form of the equation as used in the present model is:

$$Z_{0,t} = \log_e(FEC) + \log_e(ASF) - \log_e(\alpha) + n_t - \phi \cdot WT_t - Z_{1,2} + \beta \cdot P_t \quad (1)$$

where the subscript t denotes the time-step (each time-step represents a year) and non-subscripted terms remain constant from year to year; α, β, and ϕ are the parameters of the SRR, but with $\alpha = \alpha_0$, the theoretical rate of increase in the absence of fishing, estimated from winter flounder life history parameters independently of the Niantic River stock and recruitment data (the SRR and derivation of α_0 was described in Appendix A of Chapter 4); FEC is the mean fecundity of the stock expressed as the number of female eggs produced per female spawner; ASF is a scaling factor to adjust α for the effect of a multi-age spawning stock; n_t and WT_t are independent random variates from two specified normal distributions described below; $Z_{1,2}$ is the instantaneous mortality rate through the immature age-classes; and the term ($\beta \cdot P_t$) is a feed-back mechanism that simulates stock-dependent compensatory mortality, which varies according to the size of the annual spawning stock P_t. The complete derivation of the above equation was given in NUSCO (1990: appendix to the winter flounder section). The scaling factor ASF is a multiplier that converts age-3 female recruits into their spawning potential during their lifetimes. This spawning potential is defined as the cumulative number of mature females from the same year-class that survive to spawn year after year during the lifetime of the fish. The algebraic form of this multiplier is identical to the numerator of Equation A-4 in Christensen and Goodyear (1988).

When simulating plant effects such as larval losses due to entrainment, the parameter α in Equation 1 is reduced by a factor that represents the equivalent loss of annual egg production. A similar scaling of α was described by Myers et al. (1999) in dealing with the estimation of α with low abundance of spawners. Stochasticity in the SPDM (Fig. B4-1) has two annual components: a random noise term (n_t) that represents uncertainties associated with the estimate of Ricker's α_0 parameter, and the term ($\phi \cdot WT_t$) that represents environmental variability in the form of random deviations from the long-term mean February water temperature. These two components of annual variability enter the calculation of each new year-class via the mortality from egg to maturation (Eq. 1). The random noise term n_t is simulated as annual independent random variates from a normal distribution with zero mean and variance equal to σ^2. The value of σ^2 was chosen during the model calibration runs as the amount of variance required to generate short time-series of projected spawning stocks with a coefficient of variability (CV)

similar to that observed in field data; for this study the projected spawning stock sizes from 1980 through 2002 had CVs ranging from 65 to 95%. Similarly, the term $\phi \cdot WT_t$ includes random water temperature values (WT_t) that come from a normal distribution with mean and variance, which are the sample mean and variance of February water temperatures at the MNPS intakes from 1977 through 1996.

Major assumptions of the SPDM relate to the underlying form of the SRR used and the reliability of the SRR parameter estimates, which was discussed in Appendix A to Chapter 4. Because the SPDM incorporated the Ricker form of SRR, it was assumed that stock-dependent compensation and the postulated effect of water temperature on larval survival applied reasonably well to the Niantic River winter flounder stock. A second assumption was that the β and ϕ parameters of the SRR could be estimated from annual time-series of field data and that, in particular, the value of α_0, which was based on life history parameters only, was a reasonable estimate. Although the population was not assumed to be at steady state, the average fecundity and annual survival rates for fish age-1 and older were assumed to remain fairly stable over the period corresponding to the time-series data used to estimate the SRR parameters. Although this last assumption can generally be met in the case of fecundity rates and adult natural mortality, fishing mortality rates for winter flounder have been much less stable. Changes in exploitation rates from year to year should not cause estimation problems as long as the changes are not systematic (i.e., change in the same direction year after year). Because these assumptions are seldom completely met, early applications of the model (NUSCO 1990) included calibration runs to validate predictions under both deterministic and stochastic modes by comparing model results to recent series of stock abundance data. A new calibration to match model projections to current population estimates was requested explicitly by the DEP (DEP 2000) for this study and results are discussed in Chapter 4, Section 4.2.3.

Finally, no temperature trend or large-scale environmental changes (e.g., global warming) are assumed to occur during the 2002-45 period simulated for this study. However, this assumption may not be entirely accurate as there has been a consistent pattern of warmer than average water temperatures in LIS during late winter and early spring in recent years (Foertch 2000; Fig. B4-2). Because these periods coincide with winter flounder spawning, egg incubation, larval development, metamorphosis and settling, and early demersal life, temperature-dependent effects could affect the reproductive success of winter flounder and its ultimate population size (see Chapter 4, Section 4.2.5 for a discussion of temperature effects). Similarly, no trends in fishing rate were assumed to occur beyond 1999. Although this last assumption is very unrealistic, given the recent 20-year history of dramatic changes in fishing rates, it was nevertheless a necessary one for the application of SPDM to assess the effectiveness of the selected intake technology alternatives investigated in this study. The issue of recent fishing rates and the expectation of declining fishing mortality in the near future are critical to the validity of this study and are discussed in Section 4.2.3 of Chapter 4.

B4.3 REFERENCES

Christensen, S.W., and C.P. Goodyear. 1988. Testing the validity of stock-recruitment curve fits. Am. Fish. Soc. Monogr. 4:219-231.

Crecco, V.A., and T. Savoy. 1987. Fishery management plan for the American shad in the Connecticut River. CT Dept. Envir. Prot., Bur. Fish., Spec. Pub. 140 pp.

DEP (Connecticut Department of Environmental Protection). 2000. Letter C10302 dated July 13, 2000 from M.J. Harder, DEP, to F.C. Rothen, NNECO. Comments on proposed cooling water alternatives scope of study.

Foertch, J. 2000. Seawater temperatures in Long Island Sound: 1978-1998. Pages 53-71 *in* R.B. Whitlatch and J.R. Wood-Martin, eds. Proc. Fourth Biennial Long Island Sound Res. Conf. The Connecticut Sea Grant Program, Groton, CT.

Goodyear, C.P., and S.W. Christensen. 1984. Bias-elimination in fish population models with stochastic variation in survival of the young. Trans. Am. Fish. Soc. 113:627-632.

Hess, K.W., M.P. Sissenwine, and S.B. Saila. 1975. Simulating the impact of entrainment of winter flounder larvae. Pages 1-30 *in* S.B. Saila, ed. Fisheries and energy production: a symposium. D.C. Heath and Co., Lexington, MA.

Lorda, E.C., D.J. Danila, and J.D. Miller. 2000. Application of a population dynamics model to the probabilistic assessment of cooling water intake effects of Millstone Nuclear Power Station (Waterford, CT) on a nearby winter flounder spawning stock. Env. Sci. Pol. 3:S471-482.

Myers, R.A., K.G. Bowen, and N.J. Barrowman. 1999. Maximum reproductive rate of fish at low population sizes. Can. J. Fish. Aquat. Sci. 56:2404-2419.

NUSCO (Northeast Utilities Service Company). 1990. Winter flounder studies. Pages 9-77 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Annual report 1989.

Reed, M., M.L. Spaulding, E. Lorda, H. Walker, and S.B. Saila. 1984. Oil spill fishery impact assessment modeling: the fisheries recruitment problem. Est. Coast. Shelf Sci. 19:591-610.

Saila, S.B., and E. Lorda. 1977. Sensitivity analysis applied to a matrix model of the Hudson River striped bass population. Pages 311-332 *in* W. Van Winkle, ed. Assessing the effects of power-plant-induced mortality on fish populations. Pergamon Press, New York.

Spaulding, M.L., S.B. Saila, E. Lorda, H. Walker, E. Anderson, and J.C. Swanson. 1983. Oil-spill fishery impact assessment model: application to selected Georges Bank fish species. Est. Coast. Shelf Sci. 16:511-541.

Vaughan, D.S. 1981. An age structure model of yellow perch in western Lake Erie. Pages 189-216 *in* D.G. Chapman and V.F. Gallucci, eds. Quantitative population dynamics. International Co-operative Publishing House, Fairland, MD.

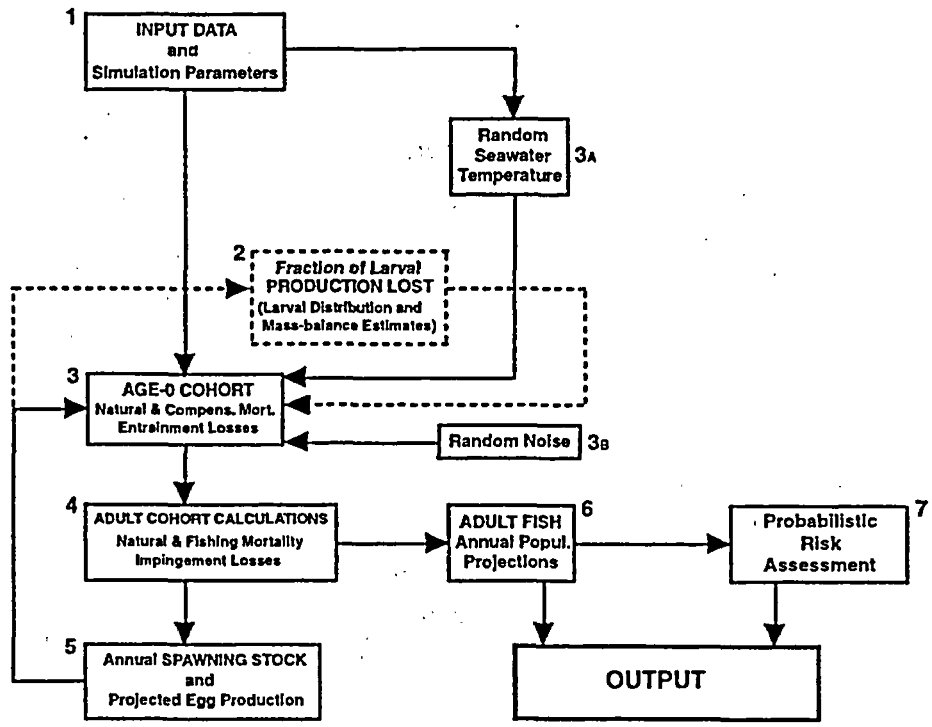

Fig. B4-1. Diagram of the stochastic fish population dynamics simulation model (SPDM) used to assess long-term effects of larval winter flounder entrainment at MNPS. The computer implementation of SPDM is in Fortran77. Brief descriptions of the computer program components referenced in the diagram follow:

1. Subprogram that process the input data files (Table 4-8 shows a sample of the main input file). The subprogram also verifies data ranges and stores parameters and data used for each simulation in common memory.
2. Auxiliary programs (not an integral part of SPDM) that estimate the annual fraction of Niantic River flounder production lost to larval entrainment. These estimates are based annual larval production, cooling water flow at the plant intakes, tidal exchange rates between Niantic Bay and River, and mass-balance calculations of weekly larval densities near the plant intakes in Niantic Bay.
3. Subprogram that calculates the number of young fish surviving to the end of their first year of life. Natural and compensatory mortality are described using a Ricker-type recruitment equation incorporating a temperature-dependent term. Survival reduction due to larval entrainment is explicitly described as additional mortality.

3A. Subroutine that generates random normal deviates of mean water temperature with given mean and variance derived from water temperature data during critical larval development (input in box 3).

3B. Subroutine that generates random standard normal deviates to simulate random variability in the natural mortality rates of early life stages of winter flounder (input in box 3).

4. Subprogram that updates the numbers of adult fish in each age group at the end of each time-step or year. This process is implemented with a Leslie matrix which accepts random variation in selected parameters. Natural and fishing mortality rates in addition to fish losses caused by impingement are used in the calculations.
5. Subroutine that calculates annual egg production from fecundity-at-age and the annually updated age structure calculated in box 4. This annual egg production is the population feed-back that starts each new cycle in box 3.
6. Subroutine that summarizes the adult population numbers and annual catch as biomass by age-class.
7. Subprogram that conducts a probabilistic risk analysis, if desired, when the population dynamics are simulated as an stochastic process. Reference biological points "at risk" of being exceeded are provided with the initial input.

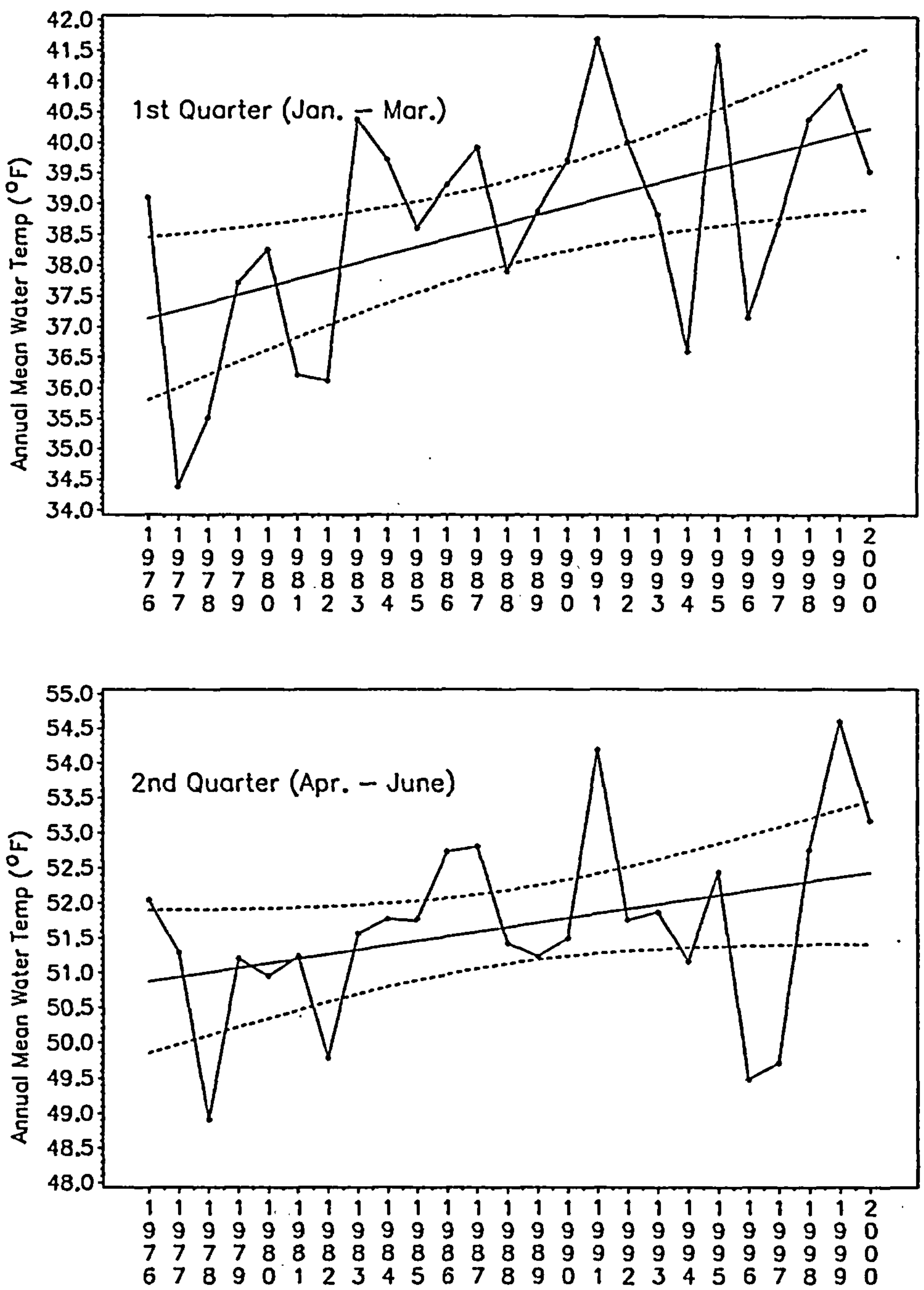

Fig. B4-2. Annual mean water temperature (°F) during the first (January-March) and second (April-June) quarters of the year calculated from average daily mean temperature at the intakes of MNPS Units 1 and 2 from 1976 through 2000 (points connected by solid line). A regression line (solid line) with 95% confidence interval (dashed lines) determined for each series of annual quarterly means is also shown.

PART II - CHAPTER 5

STOCK ENHANCEMENT OF WINTER FLOUNDER BY HATCHERY PRODUCTION AND STOCKING

5.1 INTRODUCTION

Stock enhancement can represent a potentially sound management strategy for marine fishes if the release of large numbers of larvae or juveniles compensate for high natural mortality rates found in early life stages of fish or overcome problems associated with overfishing to increase the abundance of older juveniles and adults (Polovina 1991; Munro and Bell 1997; Travis et al. 1998). However, other scientists have shown that marine stock enhancement failed to augment natural reproduction, at least if only larvae are released (Kristiansen et al. 1997). As presented in Section 5.2, some precedent has been established in using hatchery augmentation to mitigate a fish stock affected by the operation of one or more power plants. A stock enhancement alternative was investigated for winter flounder because of all the species considered in this report, most is known about the culture of winter flounder (Section 5.3) and hatchery production would likely have the highest probability of success for this species. The relatively high commercial and recreational value of winter flounder has made stock enhancement or aquaculture economically viable and resulted in increased work on the culture of this species. As noted in Section 5.5, winter flounder stock structure, behavior, and distribution also allows for an experimental approach in ascertaining the success or failure of a stock enhancement program. Juvenile winter flounder prefer shallow water habitats in estuaries and embayments and do not disperse during the first summer of life. This stationary behavior pattern enhances the opportunity to evaluate the performance of stocked winter flounder (juvenile survival and growth) compared to other species discussed elsewhere in this report.

Although perhaps technically possible to implement, the ramifications of a stock enhancement program to winter flounder genetics, in particular, warrants careful consideration of potential negative effects as loss of genetic variability is almost inevitable from hatchery stocking operations (Reisenbickler and McIntyre 1977; Lennan and Lapuscinski 1986). Such potential biological ramifications of stock enhancement programs are discussed in Section 5.4. Finally, even if technical and scientific issues can be resolved, the success of a stock enhancement program, particularly one in which relatively young specimens would be released, is not assured because of the high natural mortality rates experienced by these fish.

5.2 UTILITY INDUSTRY STOCK ENHANCEMENT PROGRAMS

The release of hatchery-reared fish as a mitigation alternative to offset power plant entrainment and impingement is not unprecedented. As part of a settlement agreement among various utilities, federal and state regulators, and intervenors with regards to several Hudson River power plants and open-cycle cooling systems, one provision called for the construction and operation of a hatchery for striped bass (Barnthouse et al. 1988a). This hatchery was to produce about

600,000 young-of-the-year (age-0) striped bass averaging 76 mm in length for stocking in the Hudson River each year (Barnthouse et al. 1988b). The feasibility of this approach, however, was based on the long history of the culture of striped bass and a 3-year study in 1973-75 during which 318,585 young striped bass were stocked into the Hudson River during a pilot project (McLaren et al. 1988). These fish were marked by fin clipping and coded wire nose tags prior to release and were found to have survival equal to or significantly better than wild fish of the same age. Production of these fish was a large undertaking and required capturing and spawning adult fish from the Hudson River and incubating and hatching eggs at the Verplanck, NY hatchery. Small larvae were then air-shipped to federal, state, and private hatcheries in Florida, Oklahoma, or North Carolina, where after acclimation in troughs, fish were stocked into freshwater rearing ponds or tanks. Following a period of fast summer development and growth to 75 to 150 mm in length, the fish were shipped back to New York for stocking.

As part of comprehensive environmental mitigation settlement with the state of California, the San Onofre Nuclear Generating Station, a power plant having twin 1,181 MWe units located on the Pacific Ocean coast in San Clemente, CA, constructed a hatchery to produce and release white seabass (SCE 2001). One of the plant's two owners, Southern California Edison Company funded the $1.2 million cost for the hatchery and the other owner, San Diego Electric & Gas Company, provided the hatchery site in Carlsbad, CA. A report indicated that the utilities have spent nearly $5 million to date on the hatchery and its operation, which can produce nearly 40,000 white seabass annually (Mehta 2001). An angler organization takes the fish from the hatchery when they are 3 inches in length and holds them in pens located in various coastal harbors. After growing to 8 inches, the fish are tagged and released into the wild.

A study pertinent to the present analysis was a recent stocking of approximately 15,000 age-0 winter flounder produced at a hatchery in Chatham, MA (Llennoco, Inc, 2001). This stock enhancement was completed as part of a mitigation program initiated at Pilgrim Nuclear Power Plant, a 655 MWe nuclear-powered unit located in Plymouth, MA. The young, averaging about 28 mm in length, were released during July 2000 into portions of Plymouth-Kingston-Duxbury Bay, MA. However, follow-up sampling failed to catch any of these fish, which had been marked with a visual implant fluorescent elastomer tag (J. O'Connell, Llennoco, Inc., Chatham, MA, pers. comm.). Nevertheless, the stocking was continued in 2001 and sampling was initiated in late spring of 2001 to follow this cohort of fish. With improved observational techniques, some recaptures were noted (J. O'Connell, Llennoco, Inc., Chatham, MA, pers. comm.).

5.3 HATCHERY PRODUCTION OF WINTER FLOUNDER

According to several researchers (Perlmutter 1947; Topp 1965; White and Stickney 1973; Klein-MacPhee 1978), winter flounder were apparently cultured in the late 1800s through at least the early 1940s because it was thought that the release of larvae would increase adult population size. Perlmutter (1947) reported catch records of fish taken for hatchery spawning that were available from the U.S. Fish and Wildlife Marine Hatcheries at Boothbay Harbor, ME for 1910-40 and at Woods Hole, MA for 1919-41. Apparently these operations ceased sometime in the early 1940s.

Klein-MacPhee (1978) noted that the effectiveness of this winter flounder stocking program was never established. No scientific or technical papers were cited in several extensive bibliographies of winter flounder (Topp 1965; White and Stickney 1973; Klein-MacPhee 1978) regarding the success or failure of this work, other than several very early papers (Rathbun 1893; Brice 1898; Bumpus 1898a, 1898b, 1900; Mead 1909) on winter flounder culture techniques.

Releases of marine fish larvae, even large numbers of them, may be unlikely to result in substantial augmentation to natural populations. For example, Kristiansen et al. (1997) reported on a release of 18 million newly hatched Atlantic cod larvae that were uniquely genetically marked into a nearly landlocked fjord in Norway. They found that the larvae suffered a loss of 23% per day for the first 10 days after stocking, a rate which was reduced by half for the following month. After 1 year, less than 120 juveniles were estimated to remain alive. They also presented a brief historical summary of larval cod releases in Norway and North America, which apparently have had little success in augmenting natural recruitment, even with up to 200 million larvae released annually. Thus, because of the very high rates of mortality during the larval phase of life history plus the high probability that larvae can be swept away by currents, particularly those with relatively long periods of pelagic development such as winter flounder, larger metamorphosed juvenile marine fish should be preferentially released to ensure any likelihood of stock enhancement success.

Saila et al. (1965) evaluated the theoretical biomass of juvenile winter flounder necessary to sustain an equilibrium yield of 2 million lbs for the Rhode Island Sound fishery. They determined that the stock weight of newly metamorphosed larvae necessary to sustain the empirical average yield under average rates of mortality was 6,500 kg, or 18 billion individuals. Even releasing 10 million larvae to this fishery would only add 0.06 to 1% to the equilibrium yield if mortality and growth of stocked larvae were similar to those of wild fish. Saila et al. (1965) next assumed that winter flounder could be reared artificially for about 150 days after hatching before release. The standing stock of 5-month old juveniles calculated under average values of growth and mortality represented a biomass equal to 56% of the calculated equilibrium yield. This occurred because extremely rapid growth during early life history stages provided for biomass increases which were greater than the amount removed by natural mortality. Therefore, the biomass of stocked young winter flounder necessary to significantly augment natural populations would have to be very high. They suggested that increasing basic productivity of nursery areas or controlled pond culture would have a higher probability of success for improving the fishery than the release of even large numbers of juveniles.

Hatchery culture of winter flounder differs in many respects from that for striped bass, trout or salmon, which can be readily reared in freshwater using artificial diets. Although most flatfishes have not been cultured as extensively or as successfully as these species, considerable work on the culture of winter flounder has taken place on this species since this topic was first presented in NUSCO (1993). For example, Litvak (1999) noted the potential of the winter flounder as an aquaculture species in Canada and summarized information on spawning, egg incubation, larval rearing, metamorphosis, feeding, growth, economics, and prospects for future development. Because growth rates in the

hatchery can be an order of magnitude higher than those in the wild, he thought that the winter flounder was an ideal candidate for aquaculture, although questions remained concerning optimum stocking densities in aquaculture cages, specific diets, and differences in growth potential by spawning stocks. As shown by both Litvak (1999) and Llennoco, Inc. (2001), relatively large numbers of juvenile winter flounder can be successfully produced in a hatchery setting. These juveniles can be used to augment natural recruitment through stocking. Thus, technical considerations in winter flounder hatchery production appear to be largely solved or at least manageable. Among the impediments are developmental and behavioral effects related to culture and potential effects of stocking on wild stocks, which are discussed in the following section.

5.4 BIOLOGICAL CONSIDERATIONS FOR STOCK ENHANCEMENT

Phenotypic as well as genetic differences can occur between hatchery-reared and wild fish (Burke et al. 2000). Experience with the culture of other flatfishes illustrates potential problems related to artificial production of winter flounder. For example, developmental anomalies are not uncommon in cultured fish. The Japanese common flounder, a sibling species to the winter flounder, was cultured and young were released into coastal waters of that country to increase the harvest by the fishery (Kuronuma and Fukusho 1984). They reported that 14.4% of the hatchery fish were deformed or exhibited other abnormalities to some degree. Proportions ranging from 13 to 95% of cultured Japanese flounder (a paralichthyid flounder) displayed abnormal pigmentation, which is believed to have been caused by inadequate nutrition during rearing (Kuronuma and Fukusho 1984; Sproul and Tominaga 1992). Abnormal pigmentation in a flatfish limits its ability to maintain cryptic coloration. Fairchild and Howell (1999) determined in a laboratory study that cultured winter flounder juveniles required at least 90 days to color adapt and match a natural substrate. Also, if juveniles had not been exposed to sediment in culture, they required several days before showing improvement in burying skills. The anomalies of abnormal pigmentation and unnatural behavior of hatchery-produced young could lead to abnormally high rates of predation when these fish are released into the wild.

Unnatural sex ratios may perhaps be another consequence of fish culture, depending upon the developmental biology of the species in question. This may have unforeseen consequences if the enhancement program is successful. The sex ratio of Japanese flounder was altered by ambient water temperature during a critical stage of development when sex was determined (Kitano et al. 1999). Reversal of genetic females to physiological males, however, was found in both wild and hatchery-produced fish (Yamamoto and Kitano 1999). Although nearly equal sex ratios of Japanese flounder were often observed in wild populations, up to 80% of batches of hatchery-produced fish were male. Water temperature and handling effects were thought to produce the sex reversal in hatcheries (Yamamoto and Kitano 1999) and biochemical techniques were developed to ascertain sex ratio as early as possible during their development (Kitano et al. 1999). No information was found on whether the gender of winter flounder could be subject to change as a result of environmental factors or cultural practices during development.

Hatchery disease problems are another potential issue in fish culture and may be detrimental to wild fish if diseases are transmitted to them through stocking. Bergh et al. (1992) noted the effects of bacterial and viral diseases and physical factors on the development of Atlantic halibut eggs and larvae in culture. They noted that early life stage mortalities remain a major factor in limiting the commercial success of halibut aquaculture. Iida (1989) and Muroga (1992) reported mass mortalities of larval and juvenile Japanese flounder in rearing ponds caused by viral diseases. Intensive culture also may limit the ability to control some diseases and parasites and to ensure good water quality for growth and development.

Hatchery fish may exhibit abnormal or less fit behavior, which may result in increased mortality through predation after release. Kellison et al. (2000) compared the differences in behavior and survival between age-0 hatchery-reared and wild summer flounder. Hatchery fish spent significantly more time swimming in the water column, took significantly longer time to demonstrate cryptic coloration on new substrate, and were significantly more prone to predation by blue crabs than were wild juvenile summer flounder. Conditioned hatchery fish, however, survived crab predation better than non-conditioned fish. They concluded that hatchery-reared summer flounder juveniles were not well-equipped to survive in the wild compared to naturally produced fish, but conditioning to natural predator stimuli may reduce predation after release. Fairchild and Howell (2000) conducted predator-prey experiments on young winter flounder (cultured and wild) using the green crab as the predator. They found that winter flounder at all sizes from 11 to 70 mm in total length could be preyed upon by green crabs having a similar size range in carapace width. However, mortality was highest when the largest crabs were paired with the smallest winter flounder. They recommended that only age-0 winter flounder larger than 20 mm should be stocked to limit predation by green crabs and also by the sevenspine bay shrimp, which can also prey heavily upon smaller winter flounder (Witting and Able 1993, 1995). This is of particular concern in the Niantic River, where sevenspine bay shrimp are commonly caught in collections made with a 1-m beam trawl during summer while sampling for age-0 winter flounder and green crabs have become extremely abundant in recent years at the Niantic River station sampled as part of the otter trawl monitoring program (Fig. 5-1).

Because the winter flounder population is composed of discrete spawning stocks associated with estuaries or coastal areas (Lobell 1939; Perlmutter 1947; Saila 1961), wild fish presumably imprint to a specific spawning area, likely during a period in early life history. However, this may be a complex process and is poorly understood in most migratory fishes, with the exception of salmon (McCleave et al. 1984; McKeown 1984). This presents serious complications for a winter flounder stock enhancement program because nothing is known about this characteristic in this species. Whether or not surviving stocked juveniles would join wild fish for spawning in Niantic River or whether they would scatter elsewhere after becoming mature is unknown. Waples (1999) noted that hatchery-produced Pacific salmon do not necessarily stray any more than wild fish, although this effect apparently has differed greatly among various hatcheries producing fish; rates also varied among wild populations. Choice of release site and perhaps time of release may affect the rate of straying. Straying may exacerbate or alleviate potential problems associated with stocked

fish: that of genetic impacts, which is discussed further below. A high degree of straying of stocked fish may have lesser consequences to the genetics of a specific population, particularly if abundance of wild fish is small relative to the number of stocked fish surviving to become spawners. Although considerable straying may not lead to faster increases in abundance at the stocking site, these fish should result in positive effects to the fisheries when fish from all breeding populations commingle in offshore waters following the spawning season and become available to fishers.

Genetic issues are a paramount consideration before advocating fish stocking to supplement natural reproduction. Holt (1993) and Stickney (1994) noted that there has been much debate over the stocking of hatchery-reared young to offset declining populations and increase fishery yields. Life history traits and genetics should be important considerations for fish culture programs and the natural genetic diversity and variation of wild fish should be maintained as much as possible. A detailed discussion of the advantages, disadvantages, and effects of stocking fish with respect to the genetics of natural populations would be necessarily complex and beyond the scope of this work. However, the importance of genetic considerations and other potentially deleterious effects of stocking were discussed in detail by Ryman and Utter (1987) and papers therein, Kapuscinski and Philippi (1988), Hilborn (1992), Munro and Bell (1997), Tringali and Bert (1998), and Utter (1998). Briefly, traits that enhance growth, survival, and reproduction in the wild may be different from those selected for in a hatchery (Kapuscinski and Philippi 1988; Travis et al. 1998). Therefore, genetic integrity and loss of genetic variability in wild fish may be compromised by the release of hatchery fish. Higher individual fecundity of most marine fishes also results in potentially greater susceptibility to genetic issues from cultural practices than for trout or salmon. As noted above, hatchery management practices may also produce juveniles poorly equipped to function in the wild. Thus, fish should be raised and selected in hatcheries that are more representative of natural conditions rather than those simply better suited for culture.

An example of possible dangers of stock enhancement to the genetics of indigenous stocks of wild fish was given by Secor et al. (1992). In one year at a South Carolina striped bass hatchery, only six females accounted for 50% of all larval production. In another year, one female produced 92% of all young stocked. Extensive use of a few large females by hatcheries could decrease effective population number (N_e); N_e should be large enough to avoid inbreeding. Deleterious effects of genetic bottlenecks and inbreeding in striped bass populations remain unknown, but the striped bass, like the winter flounder, is an iteroparous fish with relatively long life span and highly variable recruitment. Recommended levels of N_e for broodstock used in fishery recovery programs are 200 to 424 females (Kincaid 1976; Tave 1986). Therefore, for fish like striped bass and winter flounder, a prudent strategy would be to spawn many more smaller females than a few larger ones to achieve similar egg production (Secor et al. 1992). Inbreeding and genetic management of hatchery fish stocks were discussed further by Gall (1987) and Allendorf and Ryman (1987).

The success or failure of a stocking program should be evaluated by identifying fish produced in a culture facility and determining their contribution to the wild population. The fraction of stocked juveniles taken in research trawls or their

contribution to commercial fishing landings after fish are recruited should be a measure of the worth of a stocking enhancement program. For example, this could be accomplished by tagging or marking fish using traditional fishery biology methods. Stocked Japanese flounder have been marked by clipping fins, injecting latex dye, or using anchor tags (Sproul and Tominaga 1992). However, these particular methods may have limited effectiveness because of regeneration of fins, inability to see dye marks because of growth, or loss of tags. As noted previously, because a significant proportion of cultured flounder also may display abnormal pigmentation, this can actually serve as a natural tag when the fish are released into the wild (Kuronuma and Fukusho 1984; Sproul and Tominaga 1992). Using an inheritable genetic marker (Holt 1993; Kristiansen et al. 1997) is another possible means for identifying hatchery-produced fish. Winter flounder juveniles produced at a Massachusetts hatchery have been marked prior to their release with a fluorescent elastomer tag injected subcutaneously on the blind side of the fish (Llennoco, Inc. 2001). The fish produced at this facility for stocking to date were thought to have been too small for the implantation of a coded wire tag (CWT) at release (B. Morgan, Llennoco, Inc., Chatham, MA, pers. comm.). However, Thrower and Smoker (1984) marked pink salmon averaging 33 mm in length and 0.25 g in weight with a CWT, although the adipose fin of each fish was also clipped to facilitate future identification. A CWT would be advantageous because it can be detected for many years, including after tagged fish recruit into the adult spawning population. Potential disadvantages include the need to sacrifice the fish to recover the tag, the need for advanced technological equipment to insert and detect a CWT, and relatively high expense associated with a CWT program (Guy et al. 1996). Also, specialized tagging methodologies and equipment would likely have to be developed specifically for juvenile winter flounder.

The Japanese flounder, which has many life history characteristics similar to the summer flounder in the United States, has been cultured and stocked into marine waters of Japan for nearly two decades, so a relatively lengthy period has existed for the evaluation and effectiveness of this stock enhancement program. In one study, Japanese flounder were spawned at a mariculture facility and larvae were raised there through metamorphosis (Sproul and Tominaga 1992). In late spring, juveniles from 15 to 40 mm in length were transferred to eight stations along the Hokkaido coast for additional growth before release. Approximately one million juveniles have been released since the inception of this program, with targeted annual production of 100,000 juveniles per year. Using a mathematical model that considered a number of biological and economic costs and benefits, Sproul and Tominaga (1992) reported a positive net economic benefit from this fishery enhancement stocking program. However, a number of unique features were relevant to this situation, including highly restricted access to a tightly controlled commercial fishery in Japan, the fact that this species has one of the highest values of any of the indigenous Japanese fishes landed (particularly live specimens), strong government support for the technical and social aspects of this program, and the non-consideration of the construction costs of the mariculture facility, which was also used to produce other species. They noted that the factors most strongly influencing their economic model were the survival rate of young after release and the annual costs of capital (i.e., interest rates) necessary to run the project. More recent estimates place annual stockings of the Japanese flounder

in the order of several hundred thousands to millions of juveniles released with stocked fish making up from 33 to 85% of the fish landed in certain locations (Nakamura 1999).

Other effects of these large-scale releases of hatchery-produced Japanese flounder were also investigated. A release-recapture experiment involving some 40,000 stocked juveniles was designed to determine the condition of both early and late season release periods and effects on wild Japanese flounder juveniles using RNA/DNA ratios (Gwak et al. 1999; Tominaga et al. 1999). The RNA/DNA ratio for early-released fish was consistently higher than wild juveniles collected simultaneously, but was lower in late-released fish. This suggested that releases should be timed to coincide with higher natural food abundances (e.g., mysid shrimps) that would probably increase survival. This concept was supported by the work of Tanaka et al. (1999), who noted that high densities of young resulting from mass releases in a relatively small area resulted in food deficiencies or likely interference in feeding between the introduced and wild fish.

Waters (1999) summarized issues related to the potential culture of summer and southern flounders in North Carolina. The major concerns were how well hatchery fish would perform in the wild and what effect they would have upon the receiving waters and wild fish already living in those waters. Agencies or groups releasing hatchery-raised fish need to know the carrying capacity of the receiving water and how many fish to release, what size of fish to release, when and where to release them, how to condition juveniles to feed on natural prey and to avoid predators, how these fish might migrate and if they would return to the waters stocked, any genetic changes that might occur to the wild stock as a result of the stocking, and the potential for diseases that may be introduced from a hatchery. By itself, large variation in annual year-class strength in flatfishes appears to imply that excess capacity is available, but it is not known how stocking may affect other species. The genetic diversity of wild stocks should be preserved by using broodstock from areas where fish are intended to be released and to include the genetic variability as found in the wild. A pilot study was recommended prior to any large-scale releases to answer these questions and examine potential problems. Kapuscinski and Philippi (1988) also recommended that long-term monitoring be undertaken to investigate the success of hatchery-reared fish in natural environments. Despite potential problems associated with fish enhancement programs, Waples (1999) countered some of the arguments and misconceptions about hatcheries and fish stocking and Munro and Bell (1997) gave examples of both successful and non-viable marine fish stocking programs. Both Waples (1999) and Ham and Pearsons (2001) offered suggestions on minimizing risks associated with stocking on wild fish and their environment. Stocking programs must have clearly defined goals and proper fish breeding practices can minimize effects to wild fish genetics. Costs and benefits can become more favorably balanced by containing undesirable risks and outcomes.

Fish stocking also has attending social consequences which must be considered. The public has traditionally viewed stocking as a panacea to fisheries problems, when in reality stocking is usually only a short-term symptomatic cure for broader population, habitat, or social dysfunction within the fishery. Stocking may be perceived to be in the public

benefit and can have public relations value, but, as noted above, may have detrimental consequences to wild populations. Fisheries management has evolved into a goal and objective-focused paradigm (Nielsen 1999; Krueger and Decker 1999) where stocking of fish is used as a management strategy to achieve specific objectives targeted towards broad future-oriented goals. These goals usually focus on increasing yield or rehabilitating and enhancing native stocks (Stroud 1986), both of which are relevant to winter flounder management in the Niantic River and Long Island Sound. If a fish stocking program is successful in producing adult fish it can also produce desired responses in both fish population dynamics (increased abundance) and in the fishery (increased catch rates). These, in turn, can lead to unwanted increases in effort, exploitation rate, and ultimately the need to increase stocking rates (Fig 5-2). Further, termination of stocking programs are often difficult to justify once a fishery is established due to public fear that the fishery would decrease in success after stocking is terminated. Therefore, it is important to clearly define the stock enhancement management plan and directly link the stocking strategy to stated goals and objectives.

5.5 NIANTIC RIVER WINTER FLOUNDER STOCK ENHANCEMENT

What degree of production would be necessary to supplement Niantic River winter flounder to mitigate larval entrainment? The stochastic population dynamics modeling found in Chapter 4 of this report showed that various reductions in entrainment mortality could result in increases to Niantic River female winter flounder spawner biomass, given other fixed model conditions, such as constant fishing mortality rates going forward into the future. Largest increases were associated with the largest reductions in cooling-water flow, although elsewhere it is shown from empirical results based on continuous sampling that cooling-water use, entrainment estimates, and winter flounder year-class strength are not well correlated. However, if a certain level of entrainment were to be mitigated by a stocking enhancement program, an increase in biomass can be hypothesized if the hatchery-produced fish had similar survival rates as the wild population. Therefore, based on a number of assumptions, particularly in regards to mortality rates, some approximate calculations can be made regarding the effectiveness of a stock enhancement program in increasing the adult spawning population or exploitable biomass.

Besides questions of broodstock selection, among the factors to be considered in a stock enhancement program are: at what size to stock juvenile fish, when and where to stock them, and how many to stock? Because in most years young-of-the-year winter flounder grow more slowly from mid- to late summer (Fig. 5-3), there would be no advantage in holding hatchery-reared fish beyond July. In addition, by July most wild fish taken in sampling by 1-m beam trawl at two shallow-water stations in the Niantic River (DNC 2001) exceed the 20 mm threshold recommended by Fairchild and Howell (2000) to limit losses from crab and shrimp predation. Stocking at this time would also be advantageous to the hatchery because holding fish longer would require more resources such as feed, larger fish may create crowding problems, and there would be a continuing risk of loss to disease or mishaps (e.g., water system failure).

As noted in the concluding paragraph of Section 5.4, stocking rate should be related to the carrying capacity of the system in question. Thus, it would be advantageous to examine typical densities of age-0 winter flounder found in the Niantic River during summer when stocked fish would be introduced. Early (May-July) and late (August-September) seasonal densities of age-0 winter flounder have varied considerably since 1984 (Fig. 5-4; Table 5-1). Combining catch data from both stations, median late summer densities from 1984 through 2000 ranged from 4.5 to 52.1 age-0 winter flounder per 100 m^2 of bottom. The mean of these values is $20 \cdot 100m^{-2}$. Although very high densities (maximum of $126 \cdot 100m^{-2}$) were occasionally seen in early summer, apparent high rates of mortality reduced numbers considerably in years of extreme abundance, particularly when average weekly densities exceeded $2 \cdot m^{-2}$, resulting in considerably reduced densities in late summer (DNC 2001). This could represent increased predation mortality as a result of high densities, effects of competition for food resources, or perhaps the spread of density-dependent diseases such as *Glugea stephani* (Takvorian and Cali 1981, 1984; Cali and Takvorian 1991). Largest year-classes observed in late summer (e.g., 1988, 1994) had densities of about $50 \cdot 100m^{-2}$, which may represent the maximum carrying capacity of the Niantic River, although this assumes that these stations are representative of juvenile winter flounder habitat throughout much of the river. Although in most years the abundance of age-0 winter flounder was similar at these two stations, in others (e.g., 1995) late summer abundance differed considerably, indicating potential differences in habitat quality or perhaps predation (Table 5-1). In 1983, four stations were sampled in the Niantic River for age-0 winter flounder during summer, including the presently sampled station LR along with a station adjacent to the Connecticut National Guard camp (CNGC) located on the western shore of the river, just offshore of this area near the navigational channel, and immediately south of Sandy Point in the northern portion of the main river basin. Abundance at the latter two sites was considerably less than at the first two stations (NUSCO 1984). In 1984, the station near the CNGC on the west side of the river was moved in the middle of the summer to the WA site on the eastern shoreline (NUSCO 1985). Abundance immediately increased, although it was not known if this was simply due to better sampling efficiency at the newer station (i.e., less macroalgae present). Thus, the river may have a mosaic of habitats that can support more or less juvenile winter flounder. In any event, the number of fish to be stocked probably should not result in densities exceeding $50 \cdot 100m^{-2}$ and based on the long-term average density, stocking conservatively should not add more than 20 juveniles per 100 m^2. This figure could be adjusted annually depending upon whether early season abundance is high or low.

To determine stocking rate, the area of potential nursery habitat needs to be known. A very rough approximation of the Niantic River shoreline from its mouth to Sandy Point and back (including Smith and Keeny Coves) is 10 km. Assuming that the optimal juvenile winter flounder habitat lies within 50 m of the shoreline results in a potential stocking area of 0.5 million m^2. Note that this ignores most of the upper river arm and many areas of extensive flats in the lower river that knowingly or probably hold young winter flounder. Stocking fish at a rate of 0.2 per m^2 along the shoreline equates to some 100,000 young winter flounder that could be introduced into the river in most years, probably without causing detrimental density-dependent effects to wild fish.

To determine the likely contribution of stocked fish to the Niantic River winter flounder population, estimated mortality rates of age-0 and older winter flounder can be applied to the initial number of 100,000 juveniles released and subsequent estimates (Table 5-2). Based on sampling from 1984-2000 (DNC 2001), the average long-term monthly survival rate of young winter flounder during summer is about 55% (see Chapter 3, Table 3-6; approximate mean of values for stations LR and WA). This figure is equivalent to a daily total instantaneous natural mortality rate (M) of 0.02 for a 91-day period from July 1 (time of initial stocking) to the end of September, when young typically begin offshore movements. The total cumulative M for this period is 1.82. The number of young was expected to be reduced from 100,000 to 16,203 during this time. From October 1 through December 31, a lower daily M of 0.015 was assumed, further reducing the number of stocked fish to 4,076 by the end of the year. During the subsequent year as age-1 juveniles, a daily M of 0.0025 (total annual M of 0.9) was assumed, based on an estimate provided by Pearcy (1962). By January 1 of the following year (start of age-2), the number of fish was determined to be 1,657. For winter flounder age-2 and older an annual M of 0.2 was assumed to apply and these fish were also assumed to be partially recruited (25%) into the fishery (NEFSC 1999). Thus, at an assumed instantaneous fishing mortality rate (F) of 0.8, the annual instantaneous mortality rate of Z (= M + F) for age-2 winter flounder was 0.4 (0.2 + 0.25·0.8). The number of winter flounder was then reduced to 1,111 at age-3. Age-3 winter flounder remain partially recruited (60%) and an annual Z of 0.68 was applied (0.2 + 0.6·0.8). The number of fully recruited adult winter flounder at age-4 was therefore 563. Assuming the long-term average sex ratio of about 1.5 females per male (DNC 2001), 338 of these fish would be female. This number represents about 8% of the mean of calculated annual Niantic River female stock sizes from 1995 through 2000 (see Chapter 3, Table 3-4).

Of final consideration is that some males and females must be removed from the wild spawning population each year to enable hatchery production of eggs and larvae. Assuming that fish from other winter flounder stocks would not be used to supplement Niantic River spawners, this would eliminate these fish from spawning naturally in the Niantic River in a population already in a reduced state of abundance. The number of fish to be removed is unknown at this time and would have to be determined based on the desired rate of stocking and estimates of the efficiency of the hatchery in producing these juveniles. These fish, however, could be released back into local waters following spawning. Also, as noted previously, progeny of relatively few crosses in a hatchery can potentially lead to loss of genetic diversity. The effects of genetic degradation on the fitness of fish stocks in their natural environment is difficult to assess with certainty. Harada (1986) developed a theoretical analysis of the genetic difference between wild and cultured individuals and showed that the effect of reproductively maladapted individuals is negative, although these effects might be reduced by releasing a high ratio of females. Because even small changes in genomic composition may have important implications, exploratory simulation modeling may provide a method to assess potential problems associated with stock enhancement programs. McKenna (2000) recently developed a simplistic population dynamics model as a tool to illustrate potential problems resulting from the mixture of populations having different fitness values and

experiencing different growth and mortality rates. The model of McKenna (2000) may be a valuable tool to evaluate winter flounder stock enhancement and is suggested for that purpose.

5.6 CONCLUSION

Although the hatchery production of young winter flounder is technically feasible, a stock enhancement program is not an applicable or practical method of mitigating larval winter flounder entrainment at MNPS without further study or discussion. The ultimate success of a winter flounder stocking program in increasing population sizes and yield to the fisheries remains fraught with uncertainties. A stocking program may have limited success unless large numbers of metamorphosed juveniles could be released as stocking of larvae has been shown to have little effect.

Large-scale efforts by governmental agencies stocking various flounders in Japan have increased fishery yields, but were the result of the introduction of hundreds of thousands to millions of young. In Japan, studies continue on the effects of massive stocking efforts to wild populations, an impact which should also be studied in the Niantic River. Recent developments in the culture of winter flounder make it likely that large numbers of fish can be produced for stocking into appropriate areas, but a balance needs to be made between mitigating entrainment losses and carrying capacity. Also, the ultimate increase to the adult spawning population or yield to the fisheries is uncertain. A program associated with a nuclear power plant in Massachusetts recently found some stocked fish among the wild population of young, but their long-term survival needs to be demonstrated. Increased efforts in conditioning hatchery-produced fish to develop normal pigmentation, avoid predators, and feed in the wild would be necessary. The operation of a culture facility near MNPS would also require the removal of many gravid female winter flounder each winter from the Niantic River. This would be necessary to produce the large numbers of larvae and demersal young needed to offset mortality and to maintain genetic diversity of cultured fish and reduce potential genetic effects to the wild population. The success of stocking should be evaluated by long-term monitoring studies, which require a reliable method of tagging and recapturing these fish, perhaps for a period of several years.

Because of the uncertainties of a fish replenishment program, this chapter should be regarded as a preliminary evaluation of stock enhancement as an entrainment mitigation methodology. Further discussions with the Connecticut Department of Environmental Protection, other appropriate natural resource agencies, and scientific experts would be desirable before undertaking a significant stock enhancement program, which would also require the approval of appropriate regulatory agencies. A review of examples of successful and unsuccessful stock enhancement programs and factors to be considered in stocking fish as summarized in Munro and Bell (1997) is suggested as an appropriate starting point.

5.7 REFERENCES

Allendorf, F.W., and N. Ryman. 1987. Genetic management of hatchery stocks. Pages 141-159 *in* N. Ryman and F. Utter, eds. Population genetics and fishery management. University of Washington Press, Seattle.

Barnthouse, L.W., R.J. Klauda, D.S. Vaughan, and R.L. Kendall, eds. 1988a. Science, law, and Hudson River power plants: a case study in environmental impact assessment. Am. Fish. Soc. Monogr. 4. 347 pp.

Barnthouse, L.W., J. Boreman, T.L. Englert, W.L. Kirk, and E.G. Horn. 1988b. Hudson River settlement agreement: technical rationale and cost considerations. Pages 267-273 *in* L.W. Barnthouse, R.J. Klauda, D.S. Vaughan, and R.L. Kendall, eds. Science, law, and Hudson River power plants: a case study in environmental impact assessment. Am. Fish. Soc. Monogr. 4.

Bergh, Q., G. H. Hansen, I. Huse, and A. Jelmert. 1992. Studies on diseases of cultured juvenile Atlantic halibut. Pages 1-5 *in* R.S. Svrjcek, ed. Control of disease in aquaculture. NOAA Tech. Rep. NMFS 111.

Brice, J.J. 1898. The flatfish or winter flounder. *In* A manual of fish-culture, based on the methods of the United States Commission of Fish and Fisheries. Rep. U.S. Comm. Fish., for 1897, 23 (appendix):215-218, plate 59. (Not seen, cited *in* Topp 1965).

Bumpus, H.C. 1898a. The breeding of animals at Woods Hole during the month of March, 1898. Science, N.S. 7(171):485-487. (Not seen, cited *in* Topp 1965).

Bumpus, H.C. 1898b. On the identification of fish artificially hatched. Amer. Nat. 32:407-412. (Not seen, cited *in* Topp 1965).

Burke, J.S., J.P. Monaghan, Jr., and S. Yokoyama. 2000. Efforts to understand stock structure of summer flounder (*Paralichthys dentatus*) in North Carolina, USA. J. Sea Res. 44: 111-122.

Cali, A., and P.M. Takvorian. 1991. The incidence of *Glugea stephani* (Protozoa: Microsporidia) in winter flounder, *Pseudopleuronectes americanus*, from the New York - New Jersey Lower Bay Complex and factors influencing it. Can. J. Zool. 69:317-321.

DNC (Dominion Nuclear Connecticut, Inc.). 2001. Winter flounder studies. Pages 9-94 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report 2000. Millstone Environmental Laboratory, Waterford, CT.

Fairchild, E.A., and W.H. Howell. 1999. (Abstr.). Site, season and substrate: defining an optimal release strategy for a winter flounder stock enhancement. Fourth Int. Sym. on Flatfish Ecol., 18-23 October, 1999, Atlantic Beach, NC.

Fairchild, E.A., and W.H. Howell. 2000. Predator-prey size relationship between *Pseudopleuronectes americanus* and *Carcinus meanus*. J. Sea Res. 44:81-90.

Gall, G.A.E. 1987. Inbreeding. Pages 47-88 *in* N. Ryman and F. Utter, eds. Population genetics and fishery management. University of Washington Press, Seattle.

Guy, C.S., H.L. Blankenship, and L.A. Nielsen. Tagging and marking. Pages 353-383 *in* B.R. Murphy and D.W. Willis, eds. Fisheries techniques, 2nd ed. American Fisheries Society, Bethesda, MD.

Gwak, W-S., O. Tominaga, Y. Hondo, T. Tsuzaki, K. Nogami, H. Fushimi, and M. Tanaka. 1999. (Abstr.). Nutritional conditions of released and wild Japanese flounder juveniles evaluated by RNA/DNA ratios. Fourth Int. Sym. on Flatfish Ecol., 18-23 October, 1999, Atlantic Beach, NC.

Ham, K.D., and T.N. Pearsons. 2001. A practical approach for containing ecological risks associated with fish stocking programs. Fisheries (Bethesda) 26:15-23.

Harada, Y. 1992. Genetic difference between wild and released individuals and the resource enhancement effect of stocking: a theoretical analysis. Nippon Suisan Gakkashi 58:2269-2275.

Hilborn, R. 1992. Hatcheries and the future of salmon in the Northwest. Fisheries (Bethesda) 17:5-20.

Holt, G.J. 1993. The potential role of larval fish culture in alleviating population and habitat losses. Am. Fish. Soc. Sym. 14:167-172.

Iida, Y., K. Masumura, T. Nakai, M. Sorimachi, and H. Matsuda. 1989. A viral disease occurred in larvae and juveniles of Japanese flounder, *Paralichthys olivaceus*. Aquat. Animal Health 1:7-12. (Not seen, cited *in* Yoshimizu and Kimura 1992).

Kapuscinski, A.R., and D.P. Philippi. 1988. Fisheries genetics: issues and priorities for research and policy development. Fisheries (Bethesda) 13:4-10.

Kellison, G.T., D.B. Eggleston, and J.S. Burke. 2000. Comparative behaviour and survival of hatchery-reared versus wild summer flounder (*Paralichthys dentatus*). Can. J. Fish. Aquat. Sci. 57:1870-1877.

Kincaid, H.L. 1976. Effects of inbreeding on rainbow trout populations. Trans. Am. Fish. Soc. 105:273-280.

Kitano, T., E. Yamamoto, M. Tanaka, and K. Takamune. 1999. (Abstr.). Detection of cytochrome P450 aromatase mRNA by RT-PCR is an excellent method for sex distinction of early juveniles in Japanese flounder (*Paralichthys olivaceus*). Fourth Int. Sym. on Flatfish Ecol., 18-23 October, 1999, Atlantic Beach, NC.

Klein-Mac Phee, G. 1978. Synopsis of biological data for the winter flounder, *Pseudopleuronectes americanus* (Walbaum). NOAA Tech. Rep. NMFS Circ. 414. 43 pp.

Krueger, C.C., and D.J. Decker. 1999. The process of fisheries management. Pages 33-54 *in* C.C. Kohler and W.A. Hubert, eds. Inland fisheries management in North America. American Fisheries Society, Bethesda, MD.

Kristiansen, T.S., K.E. Jørstad, H. Otterå, O.I Paulse, and T. Svåsand. 1997. Estimates of larval survival of cod by releases of genetically marked yolk-sac larvae. J. Fish Biol. 51(Suppl. A):264-283.

Kuronuma, K., and K. Fukusho. 1984. Rearing of marine fish larvae in Japan. IDRC-TS47e. International Development Research Centre, Ottawa, ON, Canada. 94 pp.

Lennan, J.R., and R.D. Kapuscinski. 1986. Application of a genetic fitness model to aquaculture. Aquacult. 57:81-87.

Litvak, M.K. 1999. The development of winter flounder (*Pleuronectes americanus*) for aquaculture in Atlantic Canada: current status and future prospects. Aquacult. 176:55-64.

Llennoco, Inc. 2001. Marine laboratory/hatchery. Accessed via http://www.chathamma.com/llennoco. May 21, 2001.

Lobell, M.J. 1939. A biological survey of the salt waters of Long Island, 1938. Report on certain fishes. Winter flounder (*Pseudopleuronectes americanus*). Suppl. 28th Ann. Rep., N.Y. Cons. Dep., Pt. I:63-96.

McCleave, J.D., G.P. Arnold, J.J. Dodson, and W.H. Neill (eds.). 1984. Mechanisms of migration in fishes. Plenum Press, New York. 574 pp.

McKeown, B.A. 1984. Fish migration. Timber Press, Beaverton, OR. 224 pp.

Mead, A.D. 1909. A method of fish culture and of transporting live fishes. Pages 79-106 *in* 39th Annu. Rep. Comm. Inland Fish. Rhode Island. (Not seen, cited *in* Klein-MacPhee 1978).

Mehta, S. 2001. San Onofre work to be checked. Accessed via http://latimes.qpass.com/cgi-bin/qpass.cgi?QIID=lt99+105573& LATID=459219. April 16, 2001.

McKenna, J.A. 2000. GENEPOP: a heuristic simulation population dynamics and genetics model with special relation to fisheries. Ecol. Model. 127:81-95.

McLaren, J.B., J.R. Young, T.B. Hoff, I.R. Savidge, and W.L. Kirk. 1988. Feasibility of stocking age-0 striped bass in the Hudson River. Pages 286-291 *in* L.W. Barnthouse, R.J. Klauda, D.S. Vaughan, and R.L. Kendall, eds. Science, law, and Hudson River power plants: a case study in environmental impact assessment. Am. Fish. Soc. Monogr. 4.

Munro, J.L., and J.D. Bell. 1997. Enhancement of marine fisheries resources. Rev. Fish. Sci. 5:185-222.

Muroga, K. 1992. Bacterial and viral diseases of marine fish during seed production. Pages 57-61 *in* R.S. Svrjcek, ed. Control of disease in aquaculture. NOAA Tech. Rep. NMFS 111.

Nakamura, R. 1999. (Abstr.). Stock enhancement trials by releasing hatchery-raised Japanese flounder juveniles in the Tokyo Bay: prominently high percentage recaptured with rapid growth. Fourth Int. Sym. on Flatfish Ecol., 18-23 October, 1999, Atlantic Beach, NC.

NEFSC (Northeast Fisheries Science Center). 1999. Draft (1/19/99) report of the 28th Northeast regional stock assessment workshop (28th SAW). Stock assessment review committee (SARC) consensus summary of assessments. National Marine Fisheries Service, Woods Hole, MA.

Nielsen, L.A. 1999. History of inland fisheries management in North America. Pages 3-32 *in* C.C. Kohler and W.A. Hubert, eds. Inland fisheries management in North America. American Fisheries Society, Bethesda, MD.

NUSCO (Northeast Utilities Service Company). 1984. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report, 1983. 65 pp.

NUSCO. 1985. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Annual report, 1984. 74 pp.

NUSCO. 1993. Feasibility study of cooling water system alternatives to reduce winter flounder larval entrainment at Millstone Units 1, 2, and 3. Parts I and II. Berlin, CT. Submitted by Letter D06112 dated January 27, 1993 from C.F. Sears, NUSCO, to T. Keeney, Commissioner, DEP.

Pearcy, W.G. 1962. Ecology of an estuarine population of winter flounder *Pseudopleuronectes americanus* (Walbaum). Bull. Bingham Oceanogr. Coll. 18:1-78.

Perlmutter, A. 1947. The blackback flounder and its fishery in New England and New York. Bull. Bingham Oceanogr. Coll. 11:1-92.

Polovina, J.J. 1991. Evaluation of hatchery releases of juveniles to enhance rockfish stocks, with application to Pacific Ocean perch *Sebastes alutus*. Fish. Bull., U.S. 89:129-136.

Rathbun, R. 1893. Report upon the inquiry respecting food-fishes and the fishing grounds. Rep. U.S. Comm. Fish., for 1889 to 1891, 17:97-171. (Not seen, cited *in* Topp 1965).

Reisenbickler, R.R., and J.D. McIntyre. 1977. Genetic difference in growth and survival of juvenile hatchery and wild steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 34:123-128.

Ryman, N., and F. Utter, eds. 1987. Population genetics and fishery management. University of Washington Press, Seattle. 420 pp.

Saila, S.B. 1961. A study of winter flounder movements. Limnol. Oceanogr. 6:292-298.

Saila, S.B., D.H. Horton, and R.J. Berry. 1965. Estimates of the theoretical biomass of juvenile winter flounder, *Pseudopleuronectes americanus* (Walbaum) required for a fishery in Rhode Island. J. Fish. Res. Board Can. 22:945-954.

SCE (Southern California Edison Company). 2001. Environment. SONGS marine mitigation. Accessed via http://www.sce.com/songs_env/mitig.html. May 14, 2001.

Secor, D.H., J.M. Dean, T.A. Curtis, and F.W. Sessions. 1992. Effect of female size and propagation methods on larval production at a South Carolina striped bass (*Morone saxatilis*) hatchery. Can. J. Fish. Aquat. Sci. 49:1778-1787.

Sproul, J.T., and O. Tominaga. 1992. An economic review of the Japanese flounder stock enhancement project in Ishikari Bay, Hokkaido. Bull. Mar. Sci. 50:75-88.

Stickney, R.R. 1994. Use of hatchery fish in enhancement programs. Fisheries (Bethesda) 19:6-13.

Stroud, R.H. (ed.). 1986. Fish culture in fisheries management. American Fisheries Society, Bethesda, MD. 481 pp.

Takvorian, P.M., and A. Cali. 1981. The occurrence of *Glugea stephani* (Hagenmuller, 1899) in American winter flounder, *Pseudopleuronectes americanus* (Walbaum) from the New York-New Jersey lower bay complex. J. Fish. Biol. 18:491-501.

Takvorian, P.M., and A. Cali. 1984. Seasonal prevalence of the microsporidian, *Glugea stephani* (Hagenmuller), in winter flounder, *Pseudopleuronectes americanus* (Walbaum) from the New York-New Jersey Lower Bay Complex. J. Fish. Biol. 24:655-663.

Tave, D. 1986. Genetics for fish hatchery managers. AVI Publishers, Westport, CT. 305 pp. (Not seen, cited *in* Secor et al. 1992).

Thrower, F.P., and W.W. Smoker. 1984. First adult return of pink salmon tagged as emergents with binary-coded wires. Trans. Am. Fish. Soc. 113:803-804.

Tominaga, O., S.-I. Kunitoh, W-S. Gwak, Y. Hondo, T. Tsusaki, A. Nogami, and M. Tanaka. 1999. (Abstr.). An in situ estimate of daily ration of hatchery-reared Japanese flounder (*Paralichthys olivaceus* released in Wakasa Bay, the Sea of Japan. Fourth Int. Sym. on Flatfish Ecol., 18-23 October, 1999, Atlantic Beach, NC.

Topp, R.W. 1965. An annotated bibliography of the winter flounder, *Pseudopleuronectes americanus* (Walbaum). Mass. Div. Mar. Fish., Mass. Coop. Fish. Unit Paper No. 1. 30 pp.

Travis, J., F.C. Coleman, C.B. Grimes, D. Conover, T.M. Bert, and M. Tringali. 1998. Critically assessing stock enhancement: an introduction to the Mote Symposium. Bull. Mar. Sci. 62:305-311.

Tringali, M.D., and T.M Bert. 1998. Risk to genetic effective population size should be an important consideration in fish stock-enhancement programs. Bull. Mar. Sci. 62:641-660.

Utter, F. 1998. Genetic problems of hatchery-reared progeny released into the wild, and how to deal with them. Bull. Mar. Sci. 62:623-640.

Waples, R.S. 1999. Dispelling some myths about hatcheries. Fisheries (Bethesda) 24:12-23.

Waters, E.B. 1999. Flounder aquaculture and stock enhancement in North Carolina: issues, opportunities and recommendations. North Carolina Sea Grant Publ. UNC-SG-99-02. 24 pp.

White, D.B., and R.R. Stickney. 1973. A bibliography of flatfish (Pleuronectiformes) research with partial annotation. Georgia Mar. Sci. Center Tech. Rep. Ser. No. 73-6. 77 pp.

Witting, D.A., and K.W. Able. 1993. Effects of body size on probability of predation for juvenile summer and winter flounder based on laboratory experiments. Fish. Bull., U.S. 91:577-581.

Witting, D.A., and K.W. Able. 1995. Predation by sevenspine bay shrimp *Crangon septemspinosa* on winter flounder *Pleuronectes americanus* during settlement: laboratory experiments. Mar. Ecol. Prog. Ser. 123: 23-31.

Yamamoto, E., and T. Kitano. 1999. (Abstr.). Importance of the sex determining characteristics in flatfish study. Fourth Int. Sym. on Flatfish Ecol., 18-23 October, 1999, Atlantic Beach, NC.

Yoshimizu, M., and T. Kimura. 1992. Viral infections of cultured fish in Japan. Pages 43-47 *in* R.S. Svrjcek, ed. Control of disease in aquaculture. NOAA Tech. Rep. NMFS 111.

TABLE 5-1. Seasonal 1-m beam trawl median CPUE (number·100m^{-2}) of age-0[a] winter flounder at two stations in the lower Niantic River (LR and WA) from 1983 through 2000.

Survey year[a]	Station	Season[b]	Tows used for CPUE	Median CPUE estimate	95% confidence interval for median CPUE	Coefficient of skewness[c]
1983	LR	Early	30	32.7	20.0 - 50.7	2.29
	LR	Late	27	10.0	8.0 - 13.3	0.49
1984	LR	Early	40	18.8	16.7 - 25.0	0.63
	LR	Late	36	6.3	3.8 - 7.5	0.58
	WA	Late	32	11.3	8.0 - 17.5	0.94
1985	LR	Early	40	13.3	10.0 - 16.3	0.91
	LR	Late	32	7.0	6.0 - 8.0	0.97
	WA	Early	40	15.0	10.0 - 20.0	0.81
	WA	Late	32	9.0	8.0 - 10.0	0.70
1986	LR	Early	39	33.8	23.3 - 40.0	0.33
	LR	Late	36	13.8	12.5 - 17.5	0.80
	WA	Early	40	21.7	12.5 - 26.7	1.49
	WA	Late	36	18.1	15.0 - 20.0	2.03
1987	LR	Early	40	59.2	53.3 - 73.3	-0.12
	LR	Late	36	17.9	12.5 - 26.7	0.70
	WA	Early	40	28.3	21.7 - 38.3	0.27
	WA	Late	36	10.6	6.0 - 13.8	0.83
1988	LR	Early	40	61.3	52.5 - 72.5	0.37
	LR	Late	36	60.0	50.0 - 70.0	1.17
	WA	Early	40	40.0	32.5 - 51.7	0.13
	WA	Late	36	38.3	33.3 - 51.7	0.22
1989	LR	Early	40	17.5	11.7 - 21.7	0.09
	LR	Late	36	8.8	7.0 - 11.3	0.84
	WA	Early	40	10.0	8.3 - 13.8	1.16
	WA	Late	34	5.5	4.0 - 10.0	0.66
1990	LR	Early	40	156.3	137.5 - 187.5	1.05
	LR	Late	36	20.0	15.0 - 52.5	1.10
	WA	Early	40	68.8	50.0 - 95.0	0.62
	WA	Late	36	13.5	10.0 - 19.0	1.20
1991	LR	Early	44	77.5	51.7 - 90.0	0.96
	LR	Late	36	21.7	18.3 - 28.3	0.75
	WA	Early	44	37.9	30.0 - 43.3	1.34
	WA	Late	36	25.8	21.3 - 31.7	1.27
1992	LR	Early	40	90.0	57.5 - 122.5	1.16
	LR	Late	36	28.1	23.8 - 33.3	0.51
	WA	Early	40	74.6	56.7 - 82.5	1.35
	WA	Late	36	30.0	27.5 - 32.5	0.23
1993	LR	Early	20	10.6	7.0 - 15.0	0.68
	LR	Late	20	5.0	3.0 - 7.0	1.15
	WA	Early	20	5.0	3.8 - 7.5	2.57
	WA	Late	20	5.5	4.0 - 10.0	0.77

TABLE 5-1. (continued).

Survey year[a]	Station	Season[b]	Tows used for CPUE	Median CPUE estimate	95% confidence interval for median CPUE	Coefficient of skewness[c]
1994	LR	Early	20	128.8	125.5 - 172.5	0.38
	LR	Late	20	62.9	38.3 - 75.0	0.26
	WA	Early	20	126.3	92.5 - 192.5	0.31
	WA	Late	20	49.2	35.0 - 55.0	-0.79
1995	LR	Early	20	87.5	52.5 - 140.0	1.82
	LR	Late	20	15.8	12.0 - 26.7	1.96
	WA	Early	20	116.3	85.0 - 137.5	2.31
	WA	Late	20	55.0	28.3 - 70.0	0.59
1996	LR	Early	20	8.8	5.0 - 15.0	0.27
	LR	Late	20	3.0	3.0 - 6.0	1.42
	WA	Early	20	21.7	11.7 - 27.5	1.30
	WA	Late	20	6.2	3.0 - 7.0	1.76
1997	LR	Early	20	19.2	16.7 - 25.0	1.03
	LR	Late	20	7.0	2.0 - 10.0	0.29
	WA	Early	20	53.8	35.0 - 80.0	0.59
	WA	Late	20	9.5	6.3 - 20.0	0.92
1998	LR	Early	20	46.3	32.5 - 60.0	0.18
	LR	Late	20	15.0	6.7 - 20.0	1.08
	WA	Early	20	45.0	25.0 - 65.0	1.42
	WA	Late	20	13.0	8.0 - 25.0	1.00
1999	LR	Early	20	47.5	25.0 - 80.0	1.30
	LR	Late	20	29.2	16.0 - 35.0	0.57
	WA	Early	20	37.5	27.5 - 57.5	2.16
	WA	Late	20	17.1	11.7 - 18.8	1.13
2000	LR	Early	20	38.8	10.0 - 67.5	0.52
	LR	Late	20	27.5	22.5 - 35.0	1.34
	WA	Early	20	40.0	22.5 - 58.3	0.35
	WA	Late	20	47.9	35.0 - 52.5	0.75

[a] For age-0 fish, the year-class is the same as the survey year.
[b] Early season corresponds to late May through July and late to August through September.
[c] Zero for symmetrically distributed data.

TABLE 5-2. Based on estimated rates of natural mortality (M), calculated number of winter flounder remaining at various dates following a theoretical initial stocking of 100,000 juveniles into the Niantic River on July 1.

Initial age	Period	Days elapsed	Initial number	Daily M[a]	Daily survival[b] rate (%)	Total M[a] for the period	Total survival[b] rate (%) for the period	Final number surviving
0	July 1 - September 30	91	100,000	0.02	98.0	1.82	16.2	16,203
0	October 1 - December 31	92	16,203	0.015	98.5	1.38	25.2	4,076
1	January 1 - December 31	365	4,076	0.0025	99.8	0.90	40.7	1,657
2	January 1 - December 31	365	1,657	0.00101	99.9	0.40	67.0	1,111
3	January 1 - December 31	365	1,111	0.00186	99.8	0.68	50.7	563

[a] M is the instantaneous natural mortality rate. Total M for a period = (daily M)·(days elapsed).
[b] Survival = e^{-M}, where e is the base of natural logarithms.

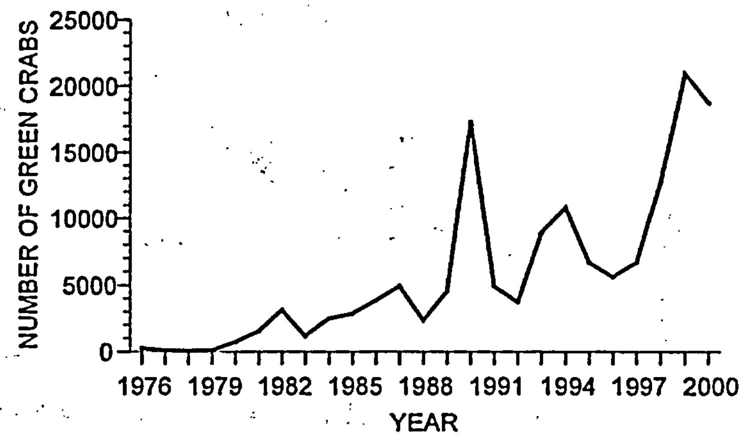

Fig. 5-1. Total number of green crabs taken each year at the Niantic River trawl monitoring program station from January 1976 through December 2000.

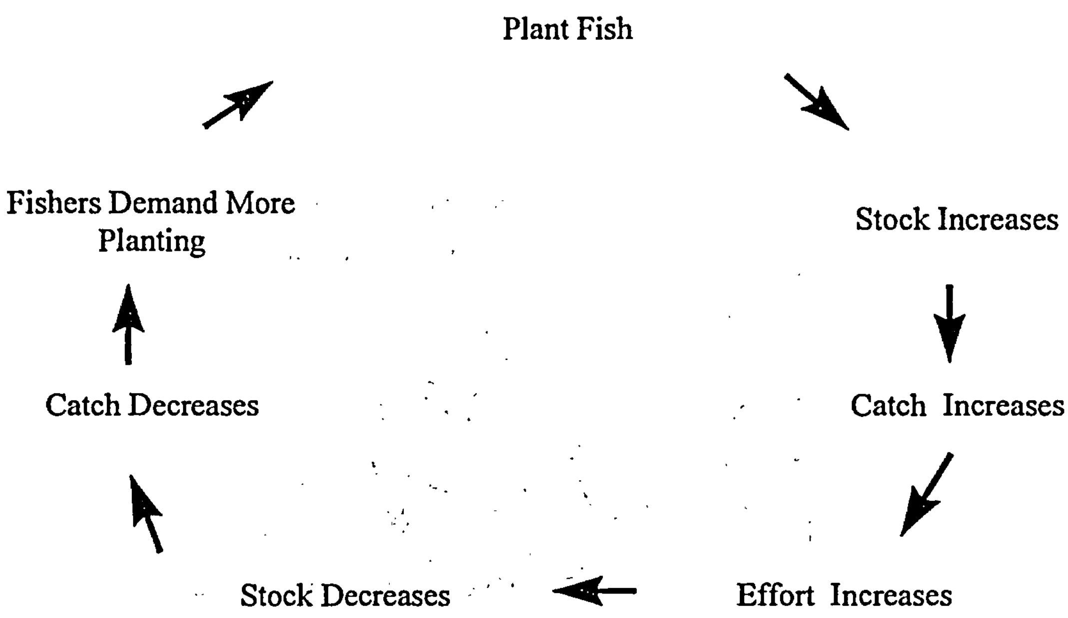

Figure 5-2. Fish stocking cycle portraying the linkage between stocking, stock size, catch rates, effort, and demand of fishers.

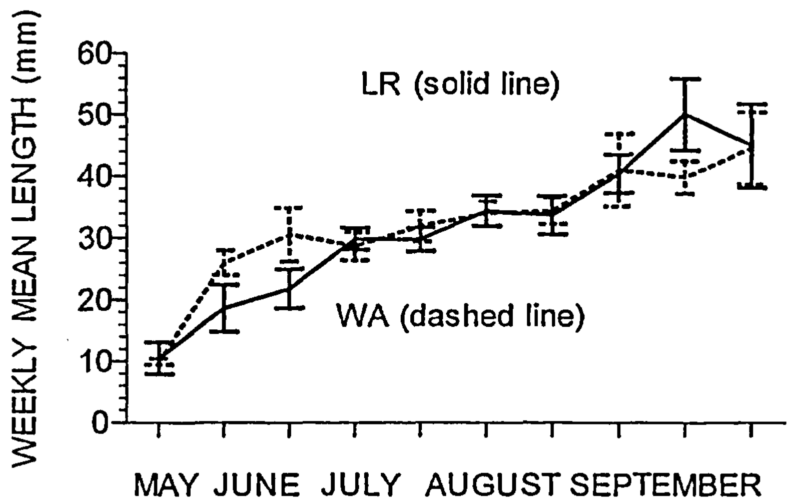

Fig. 5-3. Biweekly mean length (±2 standard errors) of age-0 winter flounder taken at two stations in the Niantic River in 1998. This year was chosen for illustration because mean lengths attained were among the smallest observed at both stations since 1984.

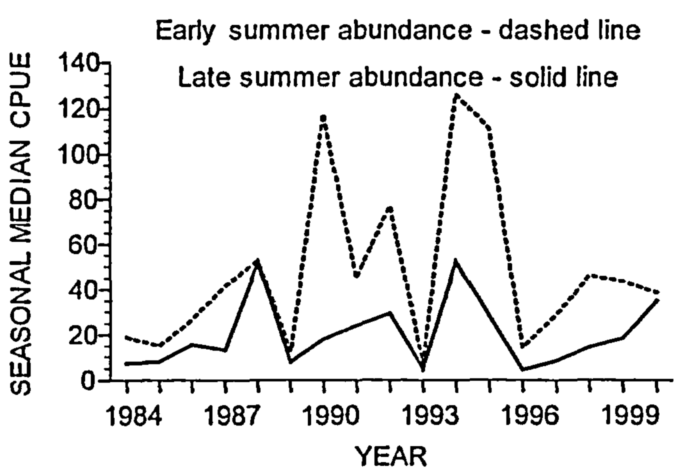

Fig. 5-4. Comparison between the early and late summer seasonal 1-m beam trawl median catch-per-unit-effort (CPUE) at two Niantic River stations combined from 1984 through 2000.

PART III

SUMMARY OF TECHNOLOGICAL, ENVIRONMENTAL, BIOLOGICAL, ECONOMIC, AND SOCIAL EVALUATIONS OF COOLING-WATER SYSTEM ALTERNATIVES AT MILLSTONE NUCLEAR POWER STATION

August 31, 2001

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PART III

SUMMARY OF TECHNOLOGICAL, ENVIRONMENTAL, BIOLOGICAL, ECONOMIC, AND SOCIAL EVALUATIONS OF COOLING-WATER SYSTEM ALTERNATIVES AT MILLSTONE NUCLEAR POWER STATION

1.0 INTRODUCTION

The purpose of this part of the report is to provide a summary evaluation of cooling-water intake system alternatives in light of the technical, environmental, biological, and economic considerations discussed throughout this report. Section 2 summarizes engineering and environmental evaluations made previously in Parts I and II, particularly the applicability of various alternatives examined for potential implementation at Millstone Nuclear Power Station (MNPS) by Dominion Nuclear Connecticut, Inc. (DNC). Based on projected effects of continued two-unit operation with once-through cooling as a baseline, reductions in flow or entrainment mortality as a result of implementing various alternative cooling-water technologies are quantified. Section 3 recounts results of the Stochastic Population Dynamics Model (SPDM) simulations for Niantic River winter flounder and equivalent-adult calculations for non-Niantic River winter flounder, tautog, and other selected fish species. In Section 4, increases in Niantic River female winter flounder stock biomass (lbs) or equivalent-adult numbers of tautog relative to present operation are compared to the costs determined for each viable technology. The economic and societal benefits of MNPS operation to Connecticut are detailed in Section 5. Section 6 provides a conclusion and recommendation as a result of this study.

2.0 THE TECHNICAL FEASIBILITY OF IMPLEMENTING SELECTED COOLING-WATER SYSTEM ALTERNATIVES AT MNPS AND ASSOCIATED ENVIRONMENTAL IMPACTS

Several intake system alternatives or methodologies for reducing entrainment or entrainment mortality examined in Parts I and II of this report were clearly not feasible for installation at large power plants, not workable at steam electric plants regardless of their size, remain as unproven technologies, or could not be implemented at MNPS. These technologies, which are more fully discussed below, include: behavioral barriers, sills, infiltration intake, rotary drum screens, Gunderboom, fine-mesh barrier net, porous dike, wedge-wire screens, and dry cooling towers.

Behavioral barriers were deemed inadequate to protect ichthyoplankton at the MNPS intakes because these organisms, by definition, have little or no control over their horizontal movements and cannot respond to a stimulus to avoid a cooling-water intake. Similarly, physical barriers such as sills, which would not reduce nor completely screen the volume of cooling-water flow at MNPS, are ineffective in reducing entrainment of planktonic organisms. Although an infiltration intake would largely avoid the entrainment of aquatic organisms, it requires highly specific hydrological and geological conditions to operate correctly. No power plants in North America use this type of intake for cooling water,

and it is unlikely that the large volumes of water required by MNPS could be sustained by using this type of system. Conventional rotary drum screens in most cases are inadequate to protect large fish, let alone ichthyoplankton, although angled rotary drum screens appear to be better in diverting at least juvenile and adult fish away from hydroelectric or irrigation intakes. However, no such screens have been used at thermal power plants, even at small units. Based on some experiments in France, claims have been made that fine-mesh rotary drum screens in conjunction with a fish pump return impinged ichthyoplankton back to source waters alive. However, further information could not be found to substantiate this claim, and no experience exists with this type of system in North America. Consequently, it remains an unproven technology.

Likewise, several barrier-type technologies, including a Gunderboom, fine-mesh barrier net, and porous dike, were found to be not technically feasible for MNPS. These technologies, designed to completely screen water flow and reduce entrainment and impingement, were the subject of experiments at one or more power plants in the northeastern United States. In each case examined, problems of debris loading and clogging limited the use of these barrier systems to reduce entrainment. Furthermore, these barrier-type systems have only been applied at stations drawing considerably less water than MNPS Units 2 and 3. Because the MNPS intakes are so close together, it would not be feasible to consider a barrier for only one unit, given the relatively large surface area needed to filter cooling-water flow. This results in another negative aspect of a barrier system, namely, the relatively large area that would have to be cordoned off from public use, including navigation and sport and commercial fishing activities. In its only trial, a fine-mesh barrier net designed to screen out ichthyoplankton failed because of debris loading and it remains as an unproven technology. In the only long-term study of a Gunderboom used at a power plant, its effectiveness in reducing entrainment was questionable and considerable operational difficulties were revealed. Based on an infiltration rate supplied by the manufacturer, the minimum size of a Gunderboom needed to provide necessary cooling-water volume would be about 5,000 feet in length. At lower filtering rates, such as used with the Gunderboom at Lovett Station on the Hudson River in New York, a barrier of approximately 2 miles in length would be necessary. Booms of these magnitudes would remove a highly productive area presently used for sport fishing and commercial and sport lobstering, block easy access to Millstone Harbor, would probably pose a hazard to navigation, and would likely be strongly opposed by the public and many of the necessary permitting agencies. Based on experience at Lovett Station, debris loading, biofouling, and high sea conditions in Long Island Sound (LIS) would likely prove onerous to a Gunderboom deployment. A porous dike, another experimental technology with little operating experience, would also require an extremely large surface area to work at MNPS and has numerous operational and safety questions associated with its use. Also, it is unclear as to how effective a porous dike is in eliminating entrainment or whether organisms become entrapped within the dike itself. Biofouling that hinders water infiltration may be a significant operational problem. Finally, the attraction of fish, such as tautog and cunner that would spawn on a reef-like dike, may also contribute to entrainment rather than minimize it for these and similar species.

A wedge-wire screen intake can reduce entrainment and has been successfully used at several power plants. However, site-specific factors such as the size of the unit, cooling-water volume requirements, debris loading, biofouling concerns, and intake location need to be carefully considered before advocating the use of this technology at MNPS. Wedge-wire screens have been almost exclusively used for closed-cycle power plants using small volumes of intake water and not at facilities with large water volume requirements. Only two relatively large power plants in the United States presently use wedge-wire screens, but neither has mesh openings sufficiently small enough to exclude all ichthyoplankton or smaller juvenile fish (EPRI 1999). In comparison to these stations, MNPS Unit 3 alone requires about 2.67 times the cooling-water volume as the J.H. Campbell facility in Wisconsin and about twice as much as Eddystone Units 1 and 2 on the Delaware River in Pennsylvania. Because most marine ichthyoplankton are relatively small, the slot openings (6.4-9.5 mm) used at these two freshwater-sited stations would not substantially reduce entrainment at MNPS, particularly of winter flounder larvae and the eggs and larvae of cunner and tautog. To greatly reduce entrainment of these forms, smaller (1-2 mm) mesh and more wedge-wire screen elements would be required at MNPS relative to other stations. In addition, biofouling and debris loading and removal have been noted as problems in proposed use of wedge-wire screens. Therefore, wedge-wire screens have had limited application at large power plants and have not been advocated for installation at large coastal marine power plants.

Dry cooling towers were also examined as an option. Although they would largely eliminate the need for cooling water, a dry tower is not technically feasible at MNPS because there is not enough available space onsite for the large cooling arrays needed. Further, there are significant costs and increased operating penalties associated with this technology, which were greater than for the natural draft and mechanical draft cooling towers also evaluated.

Other technologies examined in Parts I and II are viewed as technically feasible to implement at large coastal power plants. These technologies, which are further discussed below, are: fine-mesh screens, natural and mechanical draft cooling towers, offshore intake, reduced flow options, and forced outages. While technically feasible at MNPS, each is problematic in some manner.

Fine-mesh screens, which reduce entrainment of organisms by increasing their impingement and subsequent removal, have been the subject of several laboratory experiments and have been used at a few marine power plants. However, fine-mesh screens are also subject to increased biofouling and debris loading that, in some cases, can jeopardize plant operation and safety. Thus, their use is highly site-specific. Fine-mesh screen systems have had inconsistent performance in reducing entrainment mortality of ichthyoplankton and macrozooplankton. Mortality appears to be highly species- and life-stage specific, as well as perhaps site-specific (e.g., intake velocities, screen design, removal system, debris loads). In particular, both experimental work and operating experience at Brayton Point Station in Massachusetts showed that fine-mesh angled screens were ineffective in decreasing mortality of winter flounder, tautog, bay anchovy, and many other marine fish larvae, for which less than 10% were successfully returned alive. The

problem of entrainment simply became one of impingement, resulting in high larval mortality. Successful applications of fine-mesh screens have occurred at locations that generally entrain relatively large or particularly robust species, such as those found in freshwater systems. LMS (1989) concluded that the use of fine-mesh screens on conventional vertical traveling screens has not been demonstrated as an effective technology for reducing impingement mortality or entrainment losses. SWEC (1984) noted that fine-mesh screens were not effective for fish eggs or larvae less than 10 mm in length, which would include all larval stages of winter flounder, grubby, cunner, and tautog and smaller larvae of Atlantic menhaden, anchovies, and sand lance.

Another problem with fine-mesh screens is debris loading. At MNPS, the original 0.188-inch mesh traveling water screens installed at Unit 3 in 1986 were all eventually replaced with 0.375-inch mesh screens as of 1992, primarily because of forced plant outages due to debris loading, particularly during storms (NUSCO 1988, 1990). Thus, fine-mesh screen technology, whether used on a conventional traveling screen or in conjunction with an angled screen intake system, would result in an unacceptable operational safety risk for MNPS. Further, high impingement rates of jellyfish, as occurs during summer at MNPS, exacerbates mortality of organisms impinged concurrently. Because of the potential for debris loading, biofouling, and increased impingement without evidence of increased ichthyoplankton survival, fine-mesh screens, although technically feasible to install, are not a suitable mitigation alternative at MNPS. If advocated for use at MNPS, a full-scale demonstration of a fine-mesh screen would be needed to quantify the potential biological effectiveness of such a system, identify optimum design features and operating conditions, and identify engineering problems, such as debris removal capacity, or constraints that might be imposed by site conditions. Estimated costs of fine-mesh screens systems for MNPS were also relatively high, about $154 million for Unit 3 and $114 million for Unit 2.

Full-sized natural or mechanical draft cooling towers would reduce cooling-water requirements at an individual unit by over 90% and a two-thirds-size natural draft cooling tower at Unit 3 would reduce total station water use by about 40% relative to present two-unit operation. Total entrainment reduction at MNPS would therefore depend upon the size of the tower and the unit or units chosen for implementation. Engineering difficulties, very high costs, and permitting, siting, and community issues are formidable obstacles in retrofitting any type of cooling tower to an MNPS unit. Considerable engineering and construction difficulties would be expected in building a cooling tower and its discharge and inlet lines because of the numerous buried utilities onsite, including some that are related to nuclear safety. Further, because of its design, an installation of a cooling tower at Unit 2 would significantly complicate operation and reduce system reliability and safety. Cooling towers also impact plant performance resulting in lower generation, especially during warmer months when power demand is highest. Cooling towers are extremely expensive to construct and operate, with an estimated range of costs to MNPS from approximately $241 to $659 million for various options examined. Additional environmental effects expected from cooling tower operation include discharge of blowdown, increased chlorine use, aesthetics, noise, possible discharge of pathogenic bacteria, and potential impacts to migrating

birds. A mechanical draft helper tower would also increase ground fogging and icing and would be even noisier than a natural draft tower because of its fans.

Another highly costly ($220-377 million) alternative, an offshore intake for MNPS, was considered at a location to specifically reduce the entrainment of Niantic River winter flounder larvae. Based on the densities of winter flounder larvae in LIS, total entrainment of this species may not necessarily decrease, although the impact is likely allocated to additional spawning stocks, thereby reducing the risk to any particular population. For a few species, such as the grubby, entrainment would probably decrease, whereas for others (e.g., tautog), little difference would likely be found between egg and larval densities at the present MNPS intakes and the proposed offshore intake location. Furthermore, it is likely that for some species, including anchovies, Atlantic menhaden, and American sand lance, entrainment may actually increase because these larvae are more common offshore than nearshore. Based on the experience of Seabrook Station in New Hampshire, impingement may not be a significant problem with an offshore intake, but some species (e.g., scup) may experience increased impingement because of the intake location. Greatest impingement would likely be associated with storm events. Further experience at Seabrook Station indicated that bar rack spacing at the intake would have to be on the order of 4 to 5 inches to avoid entraining harbor seals, which have become increasingly common in Southern New England and LIS (Payne and Schneider 1984; Blaylock et al. 1995). One environmental effect expected from an offshore intake is associated with increased use and discharge of chlorine, used as a biocide in the intake tunnel. Mortality of entrained and impinged organisms may be exacerbated by the continuous application of chlorine, although the pressure changes alone experienced by these organisms within a deep intake tunnel or through the use of booster pumps may be enough to induce high rates of mortality. Other, but no less significant, engineering and environmental considerations result from the proposed location of the offshore intake in LIS, include dredging effects from the potential construction of a cut and cover tunnel, the length of which would be about 1 mile. This work would also pose significant permitting issues.

Flow reductions could be accomplished by reducing the number of circulating-water pumps in operation, reducing the flow through these pumps, taking up water from other than the source water body (e.g., re-circulation schemes), or by simply shutting down one or both of the operating units during selected time periods. The concept of flow reduction as a method of reducing entrainment has been successfully used at several locations, including three plants (nuclear and fossil) on the Hudson River in New York, the Brunswick nuclear plant in North Carolina, and Brayton Point in Massachusetts. For the first two examples, flow was reduced by using fewer circulating water pumps and throttled flows. The Hudson River example also entailed a carefully managed plan for operational shutdowns, which permitted the one nuclear and two fossil-fueled stations to operate most economically while achieving desired reductions in entrainment mortality. The Brayton Point plant re-implemented closed-cycle cooling by re-circulating discharge water at a unit originally designed and built for that specific mode of operation. Flow restrictions reduced entrainment mortality by about 30% at the Brunswick and Brayton Point plants, and between 24-27% in the Hudson River system

for the most important species found there (striped bass, white perch, and American shad). In comparison, MNPS has already reduced flow by about 23% from baseline operating conditions due to the shutdown of Unit 1 in November 1995 and its subsequent retirement.

With the exception of two-speed circulating water pumps and use of tempering lines for re-circulation, the flow reduction schemes proposed in Part I of this report (reduced number of circulating water pumps with or without condenser cross-connect valves, throttled condenser discharge valves, use of condenser by-pass lines, and variable speed pumps) are technically feasible to implement at MNPS. All these options result in a loss of generation (i.e., MWe-hours lost) by their operation, which is summed to determine the associated costs. Generation and economic losses are particularly high if flow reductions are implemented during late spring and summer. To determine this loss required the calculation of a series of unit heat balances for flow reduction alternatives, in which the electrical generation was limited up to the absolute limits of ΔT as allowed in the current NPDES Permit. This analysis of MWe-hours lost disregarded current station operating procedures and practices that further limit generation when flow is reduced to ensure that any ambient water temperature condition or condenser fouling does not create an exceedance of the NPDES Permit ΔT limits. Therefore, in subsequent economic and air emissions calculations, the MWe-hours lost and resulting economic penalties and air emissions totals are conservative and would have been greater if the station operating procedures and practices had also been imposed in the analysis, as generation would be reduced more than shown. However, if the renewed NPDES Permit contains an exemption from present ΔT limits that allows for an exceedance because of transient temperature conditions or condenser fouling if flow reduction measures are implemented, then the lost MWe-hours, costs, and air emissions would be as those modeled.

Although cooling-water flow reduction at MNPS result in an increased ΔT, additional environmental impacts would likely be minimal from the discharge of the higher temperature water. Higher discharge temperatures would be coupled with lower volume of discharge, with a smaller geographical extent to the thermal plume and little net change to thermal loading of the local environment, although more immediate shoreline impacts may occur because a lower volume discharge from the Millstone Quarry would have less velocity and momentum. Conversely, increased ΔT would probably increase the mortality of any ichthyoplankton presently surviving through-plant passage at MNPS.

Forced outages result in considerable economic costs to the station, ranging from approximately $248 million to $2.7 billion, depending upon when they would be implemented. Of significance, extended shutdowns during periods of high power demand in winter and summer may leave the Connecticut and New England electric grid vulnerable as a result of reduced generating capacity from the shutdown of the large, baseload MNPS units.

Another method to reduce cooling-water flow in comparison to present operation would be to convert MNPS from a nuclear-fueled power plant to combined cycle natural gas-fueled plants. However, the extremely high costs, estimated

at $1 billion, and difficulties of converting MNPS to a gas-fueled facility that were described in Part I of this report make this option impractical. Included in these difficulties are licensing and nuclear plant decommissioning issues, gas fuel availability, and pipeline construction issues.

As discussed in more detail in Chapter 4 of Part II, increased operation of other coastal Connecticut power plants in lieu of MNPS operation, whether as a result of flow reduction by any means or forced plant shutdowns, would also result in increased entrainment and impingement of winter flounder and other fishes at other Connecticut generating stations. Some of these stations already may be having a greater effect than MNPS on local stocks of winter flounder because they have similar or larger impacts to winter flounder through entrainment and impingement (Crecco 1994).

Stock enhancement of winter flounder was also examined in Chapter 5 of Part II as a potential method of mitigating entrainment losses. Although hatchery production appears technically feasible, a number of biological and ecological issues are associated with the stocking of fish which bear careful consideration. A program to stock young-of-the-year winter flounder into the Niantic River may not be successful unless large numbers of young fish are released, but this also puts these fish into competition with wild fish. Further, adults would have to be removed from a currently depressed population to supply the hatchery-produced progeny. Because of genetic issues associated with hatchery production, care must be taken in making a sufficient number of crosses to maintain genetic heterogeneity. Hatchery-reared fish would likely need conditioning to increase their survival in a natural environment following stocking. Follow-up studies would be necessary, in fact, to ascertain the survival of stocked fish and to estimate their contribution to the adult spawning population. Because a number of issues have been identified in using stocked fish to mitigate effects of larval winter flounder entrainment at MNPS, it is suggested that this option be further discussed with the Connecticut Department of Environmental Protection (DEP) and other appropriate agencies before advocating its use to mitigate entrainment losses. Because of the uncertainty of this option, no cost estimates were made.

3.0 PROJECTED EFFECTS OF ENTRAINMENT AND BENEFITS TO WINTER FLOUNDER AND OTHER FISHES FROM REDUCTIONS IN ENTRAINMENT MORTALITY

As a general matter, this report shows that small (≤15%) reductions in larval winter flounder entrainment achieved by reducing the number of circulating water pumps in operation or by other methods to reduce water flow result in only relatively modest gains in accumulated biomass or stock size, even 43 years after implementation. Larger reductions in larval entrainment result in greater increases of winter flounder biomass, but these reductions would only be possible by making extreme changes to present plant design, including the addition of various-sized natural or mechanical draft cooling towers for one or both units, an offshore intake for one or both units, or conversion of the station to combined cycle gas plants.

Tables III-3-1 and III-3-2 reiterate SPDM results from Part II, Chapter 4, Section 4.2.3. The SPDM projections were carried out until 2045, the assumed retirement date for Unit 3 following an assumed 20-year license renewal. These tables show cumulative gains and absolute increases in stock size (both in lbs), respectively, for Niantic River winter flounder relative to a baseline of continued two-unit operation with once-through cooling until end of plant life. Results are given at four points in time (10, 20, 30, and 43 years after 2002) for various simulated reductions in larval entrainment (6, 15, 35, 58, and 91%), under three postulated entrainment production loss rates (low, mean, and high), and for two instantaneous fishing mortality rates (F) used in this study (DEP F rate = 0.74 and SARC F rate = 0.375). As expected, more accumulated biomass or increased stock size relative to the baseline was found for greater reductions in entrainment, under the lower SARC F rate, and after a longer period of time. Simulated entrainment reduction was also more effective when production loss due to entrainment was assumed to be higher than the mean rather than lower. To provide some perspective on the estimates of biomass gains in these two tables, the estimated size of the current exploitable (i.e., based on minimum legal size) Niantic River winter flounder stock (males and females) is between 4 and 5 thousand lbs of adult fish. This figure represents less than 2% of the aggregate of winter flounder stocks responsible for total landings of this species in Connecticut.

Analyses and discussion in Part II, Chapter 4, Section 4.2.3 show that the SARC F rate is likely too low to be operating at present for LIS winter flounder. Unless simulated fishing rates are close to current rates and remain stable for about the next four decades, model projections of biomass using either F rate could be unreasonably large or small. Even considering that the DEP F rate is a more realistic estimate of current fishing, it is unlikely that fishing mortality would remain stable over the entire period of MNPS operation until 2045.

Overall effectiveness of entrainment reduction options must be balanced against recent empirical evidence. Even after extended shutdowns of all MNPS units during 1996-98 and the subsequent retirement of Unit 1, which resulted in a reduction of 23% in station cooling-water use, there has not been a substantive increase in Niantic River winter flounder spawner biomass, although fish produced in 1998 will not be fully recruited until 2002. Trends in the abundance of the Niantic River stock have followed those of other Southern New England stocks, suggesting widely-occurring environmental influences affecting reproductive success and similar exploitation rates to adult fish. Relatively large year-classes of young winter flounder were produced both before and after the shutdown period and appeared to be independent of plant operation. Monitoring of winter flounder larvae and demersal age-0 juveniles in the river showed that variable natural events profoundly affect growth and natural mortality rates during the first year of life, which in turn affects ultimate abundance of adult fish. Events occurring during the next 2 to 3 years of juvenile life also apparently cause further reductions in expected recruitment. Many of the factors affecting winter flounder year-class strength are detailed in Part II, Chapter 4, Section 4.2.5.

Equivalent-adult calculations were made for non-Niantic River winter flounder, tautog, and the other selected fishes in Chapter 4 of Part II, results of which are summarized in Table III-3-3. These conservative (i.e., no compensatory mortality assumed) calculations were made using mean annual entrainment losses under present two-unit operation. The calculations indicated a mean annual equivalent-adult loss of 18,021 non-Niantic River winter flounder, which when adjusted for former three-unit operation was the same number that Crecco (1994) estimated for MNPS. Despite numerically high annual entrainment of tautog eggs, the average annual equivalent-adult loss was only 448 tautog, which reflects the very high natural mortality rate that tautog eggs experience. Another analysis for the serially (i.e., many times in a year) spawning tautog showed that the entire annual entrainment represented the total egg production in a limited area of LIS occurring on only one day in July.

Mean annual equivalent-adult estimates for the other five fishes were numerically higher. However, more uncertainty is associated with several of these calculations as parameter estimates of mortality rates in early life history or fecundity are lacking or uncertain, particularly for grubby and American sand lance. Losses of the grubby, in particular, may be overestimated. Apparently, however, egg or larval entrainment for these five species have not resulted in adverse impacts. A population dynamics model for Atlantic menhaden indicated that this species could sustain continued higher annual losses than have occurred without affecting population size. Monitoring data showed no significant declining trend in abundance for Atlantic menhaden or grubby. Where decreases occurred (bay anchovy, American sand lance), they were found over a large geographical region of the northeastern Atlantic Ocean and were apparently due to natural causes, such as predation interactions. The grubby presents an interesting contrast to the winter flounder. Like the winter flounder, it most likely has a localized population, spawns a demersal egg in inshore waters during winter, and has a larva with a lengthy developmental period. It differs mostly in that it is not exploited by the fisheries and has shown no negative trend in abundance during MNPS operation, whereas the heavily fished winter flounder has shown a considerable decrease.

4.0 ASSESSMENT OF SELECTED COOLING-WATER SYSTEM ALTERNATIVES AT MNPS

This section evaluates selected cooling-water alternatives both in terms of their costs and the ecological benefits derived from actual implementation. Costs, given in 45-year net present value (2001 dollars) of various cooling-water intake options first presented in Section 12 of Part I, reduction in cooling-water flow or entrainment associated with each, both the cumulative gain in biomass and increase in Niantic River winter flounder female stock size biomass relative to two-unit operation from Tables III-3-1 and III-3-2, and gains in equivalent-adults of tautog from Table III-3-3 for each cooling-water intake alternative are summarized in Table III-4-1. For this comparison, cost information was determined for both the primary (March 22-June 5) and optimal (April 4-May 14) larval entrainment seasons for winter flounder (as defined in Part II, Chapter 3, Section 3.2.4) and the entire combined winter flounder larval and tautog egg entrainment seasons (March 22-August 22). This season encompasses most of the entrainment of the species selected

for examination in this report. As shown on Table III-4-1, biomass gains for winter flounder are presented for only the primary entrainment season. Estimates for the optimal season for winter flounder may be found by multiplying the values shown by 0.76, which is the fraction of the primary season made up by the optimal season. Options for various cooling towers, offshore intakes, fine-mesh screens, and conversion to a gas-fueled facility have only an annual cost associated with them. Since these alternatives represent significant change to plant design, they would or must be operated year-round as opposed to operational or technological reductions in cooling-water flow that can be implemented seasonally to reduce economic penalties associated with their use.

Although resulting in the largest gains in winter flounder and tautog because these alternatives reduce entrainment by the greatest percentage, the options for various cooling towers and offshore intakes and the gas plant conversion would be very costly (approximately $220 million to $1 billion) to implement. Because of the high costs, the gains in winter flounder biomass and tautog numbers are also costly on a per-unit basis. Considerable engineering and licensing difficulties are posed by these alternatives, which were discussed in Part I. The fine-mesh screens are not only relatively costly ($114-154 million), but, as noted in Section 2 above, based on relevant experience they would likely do little to decrease mortality of fish eggs and larvae entering the plant intakes, so no gain in winter flounder or tautog biomass is anticipated.

Various means to reduce cooling water flow (reducing condenser cooling-water pumps, throttling discharge valves, using condenser by-pass lines, and installing variable speed pumps) would range in cost from $0.7 to 194 million, depending upon the option and season implemented. While less costly than the major changes to plant design and while they have greater chance to overcome technical, engineering, and licensing constraints associated with their implementation, these options do not offer substantial reductions in cooling-water flow and entrainment. MNPS would therefore incur a significant economic penalty to implement them with only modest gains expected in winter flounder biomass and numbers of tautog. Since these options do not reduce entrainment to the degree estimated for the major plant design alternatives, the costs for increasing winter flounder and tautog biomass were disproportionately high, particularly since it is assumed that small incremental flow reductions would result in positive increases in biomass or number. As noted throughout this report, the retirement of Unit 1 in 1995 resulted in a permanent reduction in cooling-water flow of 23%, and the 3 years of extended plant shutdown of Units 2 and 3 (1996-98) did not result in commensurate increases in the Niantic River winter flounder population. Therefore, efforts to improve the Niantic River winter flounder population by implementing small reductions in cooling-water use may result in only marginal benefits to stock size, but at costs that are disproportionate to potential benefits. Accordingly, such initiatives are neither BTA nor prudent.

To put the costs of the alternatives into perspective, Connecticut commercial and recreational landings and commercial value of winter flounder (NMFS 2001) may be compared to the calculated gains given in Table III-4-1. Combined

landings decreased from 1 to 2 million lbs annually during 1981-91 to about 400-600,000 lbs in the late 1990s (Table III-4-2). Based on the dollar values given for 1994-99 (1996 and 1998 data were missing), the value per pound of winter flounder landed in Connecticut was $0.73. Based on information given in DOC (1999), which included landings of winter flounder in the northeastern U.S. during 1997 and their total ex-vessel revenues, the average ex-vessel price of landed winter flounder was computed as $1.33 per lb. Altogether, the annual economic impact of all commercial fishing activities (excluding shellfish) in Connecticut was $147 million annually from 1995 to 1997 (DEP undated a). This was a conservative estimate and did not include direct income to fishers or boat owners, the sale of boats and equipment, or consumer demand for fisheries products. Connecticut recreational fishing expenditures and economic impact are also considerable (DEP undated b; Hicks et al. 1999; Steinback and Genter 2001). DEP (undated b) noted that recreational fishing had a net economic impact of $443 million in 1996. However, winter flounder represented only 4% of the total number of fish landed in 1996 and averaged 10% of total landings by number from 1981 through 1998 (MacLeod 2000). In spite of the economic, social, ecological, and intrinsic values that winter flounder and other fishes have to the citizens of Connecticut, the gains in biomass or population size are very costly in comparison to the economic value of the fish, particularly as the Niantic River winter flounder makes up a very small fraction (<2%) of the state's winter flounder resource.

5.0 ECONOMIC AND SOCIETAL BENEFITS OF MNPS TO THE STATE OF CONNECTICUT

The economic benefit of MNPS to Connecticut, particularly the state's southeastern region, was the subject of a study commissioned by the station and conducted by the University of Connecticut (Carstensen et al. 2000), which is included as Appendix A to Part III. Information from this study, other economic data, the contribution of MNPS in meeting the electrical capacity demands of New England, and the station's role in bettering the air quality of Connecticut and the region are summarized below.

5.1 REGIONAL ECONOMIC BENEFIT

An essential consideration when evaluating the relative costs and benefits of options to reduce entrainment rates at MNPS is the overall economic value the station represents to the southeast region of Connecticut and, indeed, to the entire state. The study performed by Carstensen et al. (2000) indicated a substantial economic benefit when expressed in dollars returned to the state's economy from MNPS operations. For example, the total payroll from MNPS in 1999 was estimated at $118 million. Procurement, payroll, and property taxes for the station total about $204 million annually.

By developing a baseline 20-year forecast for various sectors of the economy, Carstensen et al. (2000) were able to calculate the economic benefit provided by the operations of MNPS. The station's estimated contribution in terms of value of goods and services to the public utility sector is $982.35 million annually. Contributions to other

sectors, including professional services, construction, machines and computers, business services, and wholesale trades, are also substantial. These amounts total approximately $240 million annually with the maximum benefit accruing to New London County.

Similar benefits are seen in employment and the overall regional economy due to MNPS operations. For example, the projected annual employment in the state attributed to the station is estimated to be 4,227 jobs annually. The Transportation and Public Utilities sector includes about 1,094 jobs in Connecticut alone due to MNPS. The construction sector benefits by about 555 jobs annually and, of these, 383 are located in New London County. The population linked to plant operations is also substantial and includes about 5,803 people annually in Connecticut and 3,567 people in New London County. Personal income attributed to MNPS is $225.45 million annually in New London County and $372.70 million annually in Connecticut.

The Gross Regional Product (GRP), defined as the dollar value of final goods and services produced in a county, and attributed to MNPS, is about $486 million in New London County and, over the 20-year planning horizon, totals about $5 billion. Total Connecticut GRP present valued and summed over the 20-year horizon is estimated to total about $12 billion due to MNPS operation. Similarly, Connecticut's net tax revenue benefit from the station is about $28.25 million annually, after subtracting the induced expenditures resulting from government services. A corollary analysis indicates that, in New London County, for each $1 of state and local government spending due to MNPS operation, Connecticut's Gross State Product (GSP) gains $133. As a result, the overall economic contribution of MNPS to the regional and state economies is considerable and must be considered in decisions affecting the future viability of the station.

5.2 REGIONAL ELECTRICAL CAPACITY

The contribution of MNPS to the region's electrical demand is discussed in two relevant reports: 1) a review by the Connecticut Siting Council (CSC) of twenty-year forecasts of loads and resources by Connecticut electric utilities (CSC 2000), and 2) the Carstensen et. al. (2000) report referenced herein. Information in each of these reports is taken partly from forecasts developed by Connecticut's utilities, specifically Connecticut Light and Power Company, United Illuminating Company, and the Connecticut Municipal Energy Electric Cooperative. Of significance is the fact that the MNPS units, while they represented about 31% of Connecticut's generating capacity, contributed about 45% of the state's electrical energy in 2000, indicating their relative importance to the energy needs of the region. As demonstrated below, however, electricity demand will continue to grow, making the nuclear contribution ever more important.

At the time the above reports were prepared in 2000, Connecticut and the New England region, as represented by the Independent System Operator New England (ISO-NE), had been forced into contingency plans to avoid power

outages. Since then, the region's electrical capacity margin has not improved. The CSC has approved 3,162 megawatts (MW) of new capacity, but only 2,106 MW were predicted by the Council to be in service before 2002. Load growth predicted by Connecticut's utilities is expected to increase at an annual compound growth rate of between 0.73 and 1.5% over the next 20 years. Per capita electric consumption is projected to increase from 8,854 kilowatt-hours (kWh) in 1990 to 10,691 kWh in 2015, based on data from the Connecticut Office of Policy and Management. Using an average of the utilities' load growth projection (0.9%), the year 2019 total peak load in Connecticut is expected to increase by 1,413 MW from the 1999 peak load of 7,826 MW. According to ISO-NE, load growth in New England is expected to grow at 1.5% annually. If the load growth was comparable to that experienced during the 1990s, the CSC suggested that Connecticut and the New England region "will continue to face a challenge to accurately identify peak demand and to supply electricity."

Carstensen et al. (2000) also predict that without generation at MNPS, the price of electricity is likely to increase above already high regional rates, not only increasing the cost of doing business in Connecticut, but creating a disincentive to new business development. Moreover, price stability will be negatively affected as the percent of electricity generated with oil and gas increases. The growing electricity demand in New England, the large percent contribution that MNPS makes to Connecticut's energy needs, and the economic value of the station to the state's economy demonstrate a compelling need to balance the cost of potential alternative cooling-water technology options with a need to maintain the economic viability of the station.

5.3 CONTRIBUTIONS TO AIR QUALITY

In addition to the above benefits, as a nuclear electric generating facility, MNPS has also benefited the air quality of the state and the region. Because of the importance of this issue, an analysis of emissions associated with various alternatives evaluated is included in this report as Appendix B to Chapter 2 of Part II. All feasible intake technology options evaluated except variable speed pumps for Unit 2 would result in increased air emissions, including nitrogen oxides (NO_X), sulfur dioxide (SO_2), and carbon dioxide (CO_2) as electrical generation at MNPS would need to be made up by fossil generation elsewhere in Connecticut or the nearby region. The amounts of air pollutants vary by option, but were highest for shutdowns encompassing entire reproductive seasons for winter flounder or winter flounder and tautog combined, followed by the conversion of the station to combined cycle natural gas plants.

Since Unit 1 began operation in 1970, MNPS has spared the burning of more than 400 million barrels of oil. As a result, the station avoids the emission of large quantities of air pollution over the available alternatives. For instance, at ISO New England 1999 Marginal Emission Rates, for a single year in which Units 2 and 3 operate at an 80% capacity factor, the station would avoid the emissions of approximately 14 thousand tons of NO_X, 58 thousand tons of SO_2, and more than 10 million tons of CO_2. In a single day of full power operation, Units 2 and 3 avoid the emissions of 200 tons of SO_2, 48 tons of NO_X, and more than 37 thousand tons of CO_2. For perspective on the

above numbers, the NO_X Budget Program's 2000 ozone season NO_X emissions for the entire State of Connecticut was a total of 4,697 tons. Total Greenhouse Gas emissions in 1995 for the entire state (all sectors) were just over 43 million tons of CO_2 Equivalent. Further, recent sustained operation of both Units 2 and 3 resulted in capacity factors in excess of 90% and future operation at this level would result in additional benefits to air quality.

6.0 CONCLUSION AND RECOMMENDATION

The determination as to whether the current cooling-water intakes of MNPS represent BTA for minimizing adverse ecological impact and, specifically in this case, minimizing the potential impact on fish species due to entrainment, requires a balancing of risks and benefits. In this report, the design, capacity, construction, location, and operational feasibility of several possible cooling-water system alternative technologies were evaluated to either reduce entrainment of fish larvae or entrainment mortality. The relative benefit or potential increase in species abundance was estimated and compared to the total cost of each alternative. Options including plant shutdown, planned refueling outages, and winter flounder stock enhancement were also evaluated. Other important considerations included the relative benefit the station provides to Connecticut and New England electrical capacity needs, the station's contribution to the regional economy, and the benefits that the station provides to air quality, each being substantial.

The relative merits of each technology alternative were evaluated further in the context of existing knowledge about species-specific life histories and trends in abundance and occurrence over approximately the last 25 years that ecological monitoring has been performed in LIS waters near MNPS. These data have been compared to plant operations to assess current plant impacts and the likelihood of future impacts. Local changes in abundance and species composition have been compared to regional trends as well. These analyses suggest that the relationship between MNPS operation and changes in marine communities and/or specific fish species of commercial or trophic value is tenuous at best.

In the case of winter flounder, reductions in cooling-water flow already achieved from the shutdown of Unit 1 and other extended outages where flow was substantially reduced have not resulted in substantial increases in the Niantic River population nor in local abundance reflected by trawl sampling. Local and regional trends suggest that factors other than MNPS are regulating abundance. Population dynamics modeling, for example, demonstrates that fishing mortality rates overwhelmingly drive adult winter flounder recruitment. Natural events, such as climatic factors, particularly temperature, and abundance of predators, also profoundly affect reproductive success and recruitment. For the other important fish species analyzed, equivalent-adult comparisons derived from entrainment data and current trends in abundance demonstrate that the existing once-through cooling water systems are not causing adverse impacts.

While many technology options were clearly not feasible, those evaluated further were found to be disproportionately costly or provided relatively little benefit to the selected fish species, including tautog and winter flounder. The assessment of all options evaluated suggests a substantial risk that reductions in entrainment and the corresponding increases in fish abundance would be inconsequential in comparison to naturally occurring changes that are driven by ecological processes.

Accordingly, at this time, DNC is not recommending alternative technologies other than the existing once-through cooling-water system. This conclusion is not meant to ignore the local and regional importance of winter flounder and other fish species of concern here. On the contrary, there is growing evidence that habitat protection and enhancement may provide the overall outcomes desired. Such options may offer opportunities to achieve these outcomes, which are consistent with the goals of the Magnuson-Stevens Fishery Conservation and Management Act (Sustainable Fisheries Act) in preserving essential fish habitat and assist efforts of DEP to improve water quality in LIS through reductions in nutrient loadings. These are options that DNC would like to discuss and pursue further with the DEP.

7.0 REFFERENCES

Blaylock, R.A., J.W. Hain, L.J. Hansen, D.L. Palka, and G.T. Waring. 1995. Harbor seal (*Phoca vitulina*): Western North Atlantic stock. Pages 112-115 *in* U.S. Atlantic and Gulf of Mexico marine mammal stock assessments. NOAA Tech. Mem. NMFS-SEFSC-363.

Carstensen, F., W. Lott, S. McMillen, H. Varol, and M. Arik. (2000). The impact of the Millstone Nuclear Power Plant on Connecticut's economy: a dynamic impact analysis. Connecticut Center for Economic Analysis, University of Connecticut, Storrs, CT. 50 pp.

Crecco, V.A. 1994. Cumulative effects of impingement and entrainment from coastal power plants on winter flounder in Connecticut waters. CT Dept. Envir. Prot., Bu. Fish., Spec Pub. 19 pp. + 2 app.

CSC (Connecticut Siting Council). 2000. Connecticut Siting Council review of Connecticut electric utilities' twenty-year forecasts of loads and resources. Accessed via http://www.state.ct.us/csc/paul/forecast/f2000/ report2000.htm. May 25, 2001.

DEP (Connecticut Department of Environmental Protection). Undated (a). Economic impact of commercial fishing in Connecticut. 2 pp.

DEP. Undated (b). The economics of recreational fishing in Connecticut. 2 pp.

DOC (U.S. Department of Commerce). 1999. Northeast multispecies fishery: Amendment 9 to the northeast multispecies fishery management plan. 50 CFR Part 648. U.S. Dept. Commerce, NMFS, NOAA. Fed. Reg. 64(55):13952-13958.

Gautam, A. (ed). 1996. Our living oceans. The economics of U.S. fisheries 1996. U.S. Dept. Commerce, NOAA, NMFS. Accessed via http://www.st.nmfs.gov/st1/econ/oleo.oleo.html.

Hicks, R., S. Steinback, A. Gautam, and E. Thunberg. 1999. Volume II: the economic value of New England and mid-Atlantic sportfishing in 1994. NOAA Tech. Mem. NMFS-F/SPO-38. 45 pp.

LMS (Lawler, Matusky & Skelly Engineers). 1989. Intake technologies: research status. Electric Power Research Institute, Palo Alto, CA. EPRI GS-6293. Project 2214-4 final report.

MacLeod, R.E. 2000. Job 1: marine angler survey. 32 pp. *In* A study of recreational fisheries in Connecticut. CT Dept. Envir. Prot., Bur. Nat. Res., Fish. Div.

NMFS (National Marine Fisheries Service). 2001. Fisheries Statistics and Economics Division, commercial fisheries and marine recreational fisheries statistics. Accessed via: http//www.st.nmfs.gov. July 27, 2001.

NUSCO (Northeast Utilities Service Company). 1988. Progress report on the Millstone Unit 3 fish return system. Enclosure 2 to Letter D02278 dated October 28, 1988 from E.J. Mroczka, NUSCO, to L. Carothers, Commissioner, CT DEP. 4 pp.

NUSCO. 1990. Millstone Unit 3 fish return system. Letter D02278 dated April 30, 1990 from E.J. Mroczka, NUSCO, to A. Freund, Chief, Bureau of Water Management, CT DEP.

Payne, P.M., and D.C. Schneider. 1984. Yearly changes in abundance of harbor seals at a winter haul-out site in Massachusetts. Fish. Bull., U.S. 82:440-442.

Steinback, S., and B. Genter. 2001. Marine angler expenditures in the northeast region, 1998. NOAA Tech. Mem. NMFS-F/SPO-47. 63 pp.

SWEC (Stone and Webster Engineering Corporation). 1984. Advance intake technologies study. EPRI CS-3644. Project 2214-2 final report. Electric Power Research Institute, Palo Alto, CA.

TABLE III-3-1. Summary of cumulative gains in Niantic River female winter flounder spawner biomass (lbs) relative to the baseline (i.e., population projection under present two-unit operation with no change in entrainment) projected by the SPDM after 10, 20, 30, and 43 years (at the expected retirement of MNPS in 2045) as a result of various reductions in larval entrainment mortality, and under two constant rates of fishing and three annual levels of production losses due to entrainment. See Part II, Chapter 4 for details.

Time elapsed in years since 2002	Simulated reduction in larval entrainment	DEP rate (F=0.74) Cumulative gains when production loss due to entrainment was:			SARC rate (F=0.375) Cumulative gains when production loss due to entrainment was:		
		LOW[a]	MEAN	HIGH[b]	LOW[a]	MEAN	HIGH[b]
10	6%	245	359	512	787	1,184	1,751
	15%	613	900	1,286	1,967	2,960	4,384
	35%	1,435	2,114	3,032	4,595	6,919	10,261
	58%	2,389	3,528	5,082	7,622	11,488	17,060
	91%	3,772	5,592	8,101	11,977	18,070	26,885
20	6%	1,174	1,667	2,236	3,036	4,620	6,909
	15%	2,950	4,199	5,671	7,588	11,546	17,297
	35%	6,957	9,976	13,646	17,693	26,942	40,454
	58%	11,668	16,865	23,392	29,292	44,622	67,130
	91%	18,613	27,191	38,412	45,879	69,895	105,300
30	6%	2,683	3,773	4,914	5,585	8,634	13,209
	15%	6,745	9,526	12,534	13,941	21,535	32,982
	35%	15,931	22,731	30,515	32,413	50,032	76,660
	58%	26,753	38,537	52,877	53,486	82,449	126,263
	91%	42,723	62,422	87,747	83,385	128,217	195,899
43	6%	5,011	7,168	9,374	8,539	13,418	21,101
	15%	12,580	18,078	23,955	21,288	33,393	52,487
	35%	29,601	42,979	58,395	49,368	77,234	121,015
	58%	49,473	72,540	100,916	81,233	126,660	197,636
	91%	78,421	116,228	165,763	126,157	195,732	303,373

[a] The LOW production loss due to entrainment rate is the MEAN rate divided by 1.5 (see Part II, Chapter 4, Table 4-3 for details).
[b] The HIGH production loss due to entrainment rate is the MEAN rate multiplied by 1.5 (see Part II, Chapter 4, Table 4-3 for details).

TABLE III-3-2. Summary of absolute increases in Niantic River female winter flounder stock size (spawner biomass in lbs) relative to the baseline (i.e., population projection under present two-unit operation with no change in entrainment) projected by the SPDM after 10, 20, 30, and 43 years (at the expected retirement of MNPS in 2045) as a result of various reductions in larval entrainment mortality, and under two constant rates of fishing and three annual levels of production losses due to entrainment. See Part II, Chapter 4 for details.

Time elapsed in years since 2002	Simulated reduction in larval entrainment	DEP rate (F=0.74) Gains when production loss due to entrainment was:			SARC rate (F=0.375) Gains when production loss due to entrainment was:		
		LOW[a]	MEAN	HIGH[b]	LOW[a]	MEAN	HIGH[b]
10	6%	55	80	111	171	258	379
	15%	139	201	280	429	645	951
	35%	327	474	664	1,003	1,509	2,231
	58%	546	796	1,124	1,664	2,508	3,719
	91%	866	1,272	1,816	2,618	3,952	5,879
20	6%	123	171	220	251	389	595
	15%	308	431	561	626	970	1,487
	35%	730	1,032	1,371	1,455	2,254	3,460
	58%	1,229	1,758	2,386	2,400	3,712	5,702
	91%	1,970	2,861	3,991	3,736	5,765	8,839
30	6%	167	234	296	253	402	640
	15%	419	591	760	630	998	1,590
	35%	989	1,415	1,873	1,457	2,301	3,652
	58%	1,659	2,404	3,277	2,391	3,758	5,933
	91%	2,642	3,884	5,466	3,699	5,773	9,032
43	6%	176	271	379	180	301	522
	15%	439	678	964	447	743	1,280
	35%	1,019	1,582	2,311	1,028	1,693	2,874
	58%	1,674	2,608	3,890	1,676	2,733	4,567
	91%	2,587	4,032	6,098	2,572	4,141	6,782

[a] The LOW production loss due to entrainment rate is the MEAN rate divided by 1.5 (see Part II, Chapter 4, Table 4-3 for details).
[b] The HIGH production loss due to entrainment rate is the MEAN rate multiplied by 1.5 (see Part II, Chapter 4, Table 4-3 for details).

TABLE III-3-3. Mean annual numbers of fish eggs and larvae projected to be entrained at MNPS under present two-unit operation and resulting estimates of equivalent-adults lost at MNPS. See Part II, Chapter 4 for details.

Species	Mean number of eggs entrained	Mean number of larvae entrained	Equivalent-adult loss from entrained eggs	Equivalent-adult loss from entrained larvae	Species total of equivalent-adults
Winter flounder[a]:	-		-		
Stage 1		4,984,000		84	
Stage 2		24,368,000		605	
Stage 3		79,270,000		10,967	
Stage 4		11,974,000		6,364	18,021
Tautog	1,975,280,000	-	448	-	448
Atlantic menhaden	-	45,280,000	-	296,082	296,082
Bay anchovy	91,280,000	384,080,000	1,681	37,205	38,886
Grubby	-	48,400,000	-	177,934	177,934
Cunner	3,340,720,000	-	56,384	-	56,384
American sand lance	-	38,560,000	-	40,542	40,542

[a] Number of non-Niantic River winter flounder larvae as determined by the mass-balance model.

TABLE III-4-1. Summary of cooling-water intake alternatives evaluated for MNPS, associated 45-year costs (net present value) of each option, and expected gains in abundance of winter flounder (lbs) and tautog (numbers of equivalent-adults) relative to baseline levels (current two-unit operation with once-through cooling) in going forward.

Alternative Evaluated	45-year net present value determined for: Primary winter flounder season (March 22 - June 5)	Optimal winter flounder season (April 4 - May 14)	Combined winter flounder and tautog seasons (March 22 - August 22)	Flow reduction (% of total for Units 2 and 3)	Winter flounder cumulative gain in biomass (lbs)[a]	Winter flounder stock size increase (lbs)[b]	Tautog annual gains (number)[c]
Unit 3 operating with 5 condenser cooling-water pumps (cwp)	$63,226,000	$62,652,000	$68,278,000	8%	9,557	361	36
Unit 3 operating with 4 cwps	$66,254,000	$64,088,000	$80,673,000	16%	19,280	723	72
Unit 2 operating with 3 cwps	$48,212,000	$47,235,000	$113,811,000	7%	8,363	316	31
Combined Unit 3 operating with 5 cwps and Unit 2 with 3 cwps	$111,438,000	$109,887,000	$182,089,000	15%	18,078	678	67
Combined Unit 3 operating with 4 cwps and Unit 2 with 3 cwps	$114,466,000	$111,323,000	$194,484,000	23%	27,720	1,040	103
Unit 3 operating with 5 cwps and with cross-connect (x-c)	$64,015,000	$63,446,000	$69,052,000	8%	9,557	361	36
Unit 3 operating with 4 cwps and with x-c	$66,963,000	$64,841,000	$81,244,000	16%	19,280	723	72
Unit 2 operating with 3 cwps and with x-c	$48,630,000	$47,653,000	$114,228,000	7%	8,363	316	31
Combined U3 operating with 5 cwps, U2 with 3 cwps; both with x-c	$112,645,000	$110,099,000	$183,280,000	15%	18,078	678	67
Combined U3 operating with 4 cwps, U2 with 3 cwps; both with x-c	$115,593,000	$112,494,000	$195,472,000	23%	27,720	1,040	103
Unit 3 operating with throttled condenser discharge valves	$32,735,000	$30,590,000	$46,087,000	15%	18,078	678	67
Unit 2 operating with throttled condenser discharge valves	$20,338,000	$20,154,000	$22,051,000	6%	7,168	271	27
Units 2 and 3 operating with throttled condenser discharge valves	$53,073,000	$50,744,000	$68,138,000	22%	26,514	994	98
Unit 3 operating with condenser by-pass lines	$5,039,000	$2,977,000	$18,139,000	15%	18,078	678	67
Unit 2 operating with condenser by-pass lines	$848,000	$717,000	$2,394,000	6%	7,168	271	27
Units 2 and 3 operating with condenser by-pass lines	$5,887,000	$3,694,000	$20,533,000	22%	26,514	994	98
Unit 3 operating with variable speed cwps	$8,187,000	$6,936,000	$18,769,000	15%	18,078	678	67
Unit 2 operating with variable speed cwps	$3,169,000	$3,491,000	$3,315,000	6%	7,168	271	27
Units 2 and 3 operating with variable speed cwps	$11,356,000	$10,427,000	$22,084,000	22%	26,514	994	98

TABLE III-4-1 (continued).

Alternative Evaluated	45-year net present value determined for: Primary winter flounder season (March 22 - June 5)	Optimal winter flounder season (April 4 - May 14)	Combined winter flounder and tautog seasons (March 22 - August 22)	Flow reduction (% of total for Units 2 and 3)	Winter flounder cumulative gain in biomass (lbs)[a]	Winter flounder stock size increase (lbs)[b]	Tautog annual gains (number)[c]
Unit 3 with full-sized natural draft cooling tower	-	-	$418,000,000[f]	60%	75,041	2,698	269
Unit 3 with 2/3-sized natural draft cooling tower	-	-	$269,392,000[f]	40%	49,119	1,808	179
Unit 2 with full-sized natural draft cooling tower	-	-	$241,246,000[f]	32%	39,295	1,440	143
Units 2 and 3 with full-sized natural draft cooling towers	-	-	$659,246,000[f]	92%	117,505	4,076	412
Unit 3 with full-sized mechanical draft cooling towers	-	-	$334,495,000[f]	60%	75,041	2,698	269
Unit 2 with full-sized mechanical draft cooling towers	-	-	$253,354,000[f]	33%	40,523	1,492	147
Units 2 and 3 with full-sized mechanical draft cooling towers	-	-	$587,849,000[f]	93%	118,782	4,121	417
Unit 3 with offshore intake	-	-	$219,876,000[f]	0%	38,067	1,440	0[d]
Units 2 and 3 with combined offshore intake	-	-	$377,363,000[f]	0%	62,534	2,248	0[d]
Unit 3 with fine-mesh screens	-	-	$154,176,000[f]	0%	0[e]	0[e]	0[e]
Unit 2 with fine-mesh screens	-	-	$113,506,000[f]	0%	0[e]	0[e]	0[e]
Conversion of station to gas fuel	-	-	$1,000,000,000[f]	65%	81,295	2,923	291
Shut down Unit 3 during spawning seasons	$629,156,000	$326,544,000	$1,592,259,000	50%	62,534	2,248	224
Shut down Unit 2 during spawning seasons	$477,395,000	$247,797,000	$1,207,588,000	27%	33,155	1,220	121
Shut down Units 2 and 3 during spawning seasons	$1,066,210,000	$553,402,000	$2,697,804,000	77%	97,325	3,437	345

[a] Cumulative gain in Niantic River winter flounder female spawning stock biomass (lbs) as of 2045 relative to baseline levels, assuming that exploitation corresponds to the DEP fishing rate (F = 0.74) and that flow reductions occur during the primary larval winter flounder entrainment season (March 22-June 5). Values for the optimal entrainment season (April 4-May 14) may be found by multiplying biomass estimates by 76%.

[b] Niantic River winter flounder female spawning stock biomass increase (lbs) as of 2045 relative to baseline levels, assuming that exploitation corresponds to the DEP fishing rate (F = 0.74) and that flow reductions occur during the primary larval winter flounder entrainment season (March 22-June 5). Values for the optimal entrainment season (April 4-May 14) may be found by multiplying biomass estimates by 76%.

[c] Number of tautog (annual equivalent-adult estimates) determined over entire season of tautog egg entrainment.

[d] Assumed to reduce the entrainment of Niantic River winter flounder larvae by 31 and 50%, but likely no net change in the entrainment of tautog eggs.

[e] Undetermined, but due to relatively low survival of winter flounder and most other fish larvae at the Brayton Point Station, assumed to be ineffective in increasing biomass.

[f] Various cooling tower, offshore intake, fine-mesh screen, and gas plant options are assumed to operate year-round, not just during any particular larval season, and costs are for life-of-plant.

TABLE III-4-2. Connecticut recreationally harvested and commercial landings (lbs) and commercial value ($) of winter flounder from 1981 through 1999. Data are from NMFS (2001).

Year	Recreational landings (lbs)	Commercial landings (lbs)	Commercial value
1981	668,097	1,153,200	$426,740
1982	905,542	1,134,500	$465,199
1983	306,170	1,171,500	$586,000
1984	1,220,359	1,308,900	$654,450
1985	946,150	1,193,900	$596,950
1986	609,506	569,400	$341,640
1987	1,002,596	1,424,300	$1,324,599
1988	891,997	749,900	$697,407
1989	721,890	553,300	$514,569
1990	434,690	1,063,090	$988,675
1991	360,717	844,700	$785,571
1992	151,419	704,300	$654,999
1993	84,176	552,113	$513,465
1994	99,463	307,000	$285,000
1995	257,070	356,133	$430,921
1996	116,961	-[a]	-
1997	237,116	426,474	$501,364
1998	275,467	-[a]	-
1999	69,090	377,403	$389,180

[a] Not available from NMFS (2001).

APPENDIX A TO PART III

THE IMPACT OF THE MILLSTONE NUCLEAR POWER PLANT ON CONNECTICUT'S ECONOMY: A DYNAMIC IMPACT ANALYSIS

Independent analysis performed for Northeast Nuclear Energy Company by:

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THE IMPACT OF THE MILLSTONE NUCLEAR POWER PLANT ON CONNECTICUT'S ECONOMY:

A Dynamic Impact Analysis

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February 5, 2001

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Executive Summary

The Connecticut Center for Economic Analysis (CCEA) at the University of Connecticut coordinating with Clarke & Co. of Boston, Massachusetts performed a regional and statewide economic impact analysis of the current operations of Millstone Nuclear Power Plant located in the Town of Waterford in New London County. This analysis reports the salient effects resulting from direct and indirect employment, in-state procurement, electric power sales, and state and local taxes paid using the REMI model, a dynamic input-output model of Connecticut and its eight counties. We assume the primary market for Millstone is New London County. As such, New London County is singled out for separate analysis to capture the local impact. In addition to spillover effects from New London, Millstone has direct effects through its operations across Connecticut. As a result, this report considers Millstone's impact on the State as a whole. We separately consider its impact on Fairfield, New Haven and Hartford Counties.

We model the impact of Millstone as a *reduction or supply shock* in electricity sales to each County. The extent of the shock for each County is calculated by estimating the population-adjusted electricity sales for each County. We estimate the total annual electricity generation of Millstone for the year 2000 by taking twelve times the June 2000 electricity generation figure. In June 2000, the two nuclear power stations generated 1,353 million kilowatt-hours. This figure is a conservative estimate considering that production is highest in the summer peak months of July and August. The total estimated electricity generated by Millstone 2 and Millstone 3 multiplied by the average rate for generation services, estimated by Connecticut Light and Power, provides total sales. Using 4.813 cents per kilowatt-hour (exclusive of transmission, distribution, and decommissioning costs), we estimate that the total sales from electricity generation are about $800 million for the year 2000. Millstone's 1999 statewide payroll was $118 million; its 1999 Connecticut procurement totaled almost $53 million, and Millstone employed 1,737 people. ***Millstone's sales, procurement and employment drive the economic impact of its ongoing operations.***

Economic and Fiscal Impact of the Millstone Nuclear Power Plants

Gross State Product and Personal Income

The key results reported are gross state product (GSP) and aggregate personal income. GSP is the dollar value of all final goods and services produced in the State in one year (GRP is the regional amount). GSP exceeds the REMI baseline forecast in each County and the State as a result of Millstone's operations. The largest county GRP impact in the State is in New London County in annual average terms. The average annual increases in GRP are $486 million in New London County (5 %), $163 million in Fairfield County (0.42 %), and $201 million for Hartford County (0.53 %), compared to $1,126 million for the State of Connecticut (0.9 %). All figures are shown in nominal dollars and average percent changes and are relative to the REMI forecast. Average annual additions to GRP are the annual gains in GRP over the baseline forecast averaged over the number of years of the scenario. The present value of GRP increases are $2.16 billion, $1.67 billion, $1.77 billion, $5.15 billion and $12.05 billion in Hartford, New Haven, Fairfield, New London Counties and Connecticut, respectively, using a discount factor of 6.5% over the twenty-year horizon. Present value represents the total value today of a stream of future payments each discounted to the present. We conclude that these values represent substantial *positive* contributions to the Connecticut economy.

The largest impact on aggregate personal income in annual average and in present value terms is in New London County. Personal income increases by $225.45 million in New London County (2.85 %), $37.85 million in Fairfield County (0.08 %), $40.45 million in Hartford County (0.13 %), $23.55 million in New Haven County (0.09 %), and, in the State it increases by $372.70 million (0.28 %), all in annual average terms expressed in nominal dollars. In present value terms, these nominal increases represent $2.46 billion, $417.83 million, $445 million, $262.95 million and $4.09 billion in New London, Fairfield, Hartford and New Haven Counties and in the State, respectively.

Employment and Population

In addition to GSP and personal income, Millstone creates significant employment in the Counties and the State as a whole, relative to the baseline forecast. Millstone's operations create 4,227 additional jobs on an annual average basis in

Connecticut (0.23%). Most of the employment increase occurs in New London County (2.14 %), followed by Fairfield (0.09 %), Hartford (0.09 %) and New Haven Counties (0.05 %) with annual average increases of 2,850; 434; 513 and 200 jobs, respectively.

The consequent increases in personal income and economic activity cause people to move to the State because of increased job opportunities. The change in the population in the State and in the Counties separately is significant compared to the REMI baseline forecast. In annual average terms, Connecticut gains 5,803 people (0.18 %) from the Millstone's operations. New London County, with the largest impact in all categories, gains 3,567 people (1.41 %) during the study period on average annually.

State and Local Taxes

The ongoing operations of Millstone create new tax revenue at the state and local levels. In our analysis we include the $33 million property tax paid by Millstone to the Town of Waterford. Millstone's operations affect *induced* government spending. As people move to the State and there is more economic activity, the government spends more to maintain the level of public services, such as for education and police, than in the past. State tax revenue is dependent on general economic activity. The rise in GSP and personal income that accompanies the increase in expenditures made through Millstone's payroll and procurement, increases tax collections both in the County and the State. Total state taxes increase $17.95 million from New London County, $5.01 million from Fairfield County, $6 million from Hartford County, $4.43 million from New Haven, and $37.58 million in Connecticut on average annually in nominal dollars. In present value terms, there is an increase of $404.73 million in additional state taxes paid in Connecticut over the twenty-one year period as a result of Millstone's operations in the State.

Net state tax revenue (exclusive of local taxes) is calculated by subtracting induced government spending from total state tax revenue. Positive net state tax revenue means that because of Millstone's operations, the State has a net gain in tax revenue. In our case, the net state tax revenue is positive in all Counties and in the State as a whole. This means that Millstone's operations produce a net gain in tax revenues in Connecticut. Because Millstone generates more tax revenue than induced government spending statewide in such forms as education and police, net tax revenues in the State are positive.

Net state tax revenues increase in the State as a whole by $28.25 million (nominal) in annual average terms. This number corresponds to $313.85 million (nominal) in present value terms for net state tax revenues in Connecticut. The largest increase in net state tax revenue is in New London County with $15.4 million in annual average terms, and the net present value of the increase is $168.46 million (both nominal).

Millstone's operation increases local taxes generated in the Counties and in the State as a whole, both in annual average and in present value terms. The local tax increase is highest in New London County, with $7.84 million (nominal) in annual averages. This is an increase in addition to the $33 million property tax Millstone pays to the Town of Waterford representing 66% of its 1999 property tax revenue and 58% of its 1999 total revenue. The present value of the increase over the study period is $78.36 million (nominal).

Table 8 reproduced below provides a summary of Millstone's economic and fiscal impacts. Appendix I presents results for local property and state taxes for four counties and Connecticut. Appendix II presents summary tables of selected REMI results for four counties and Connecticut. Appendix III summarizes the REMI modeling strategy for the Millstone impact analysis.

Table 8: Summary Results for Millstone Nuclear Powerplant

	Fairfield		Hartford		New Haven		New London		Connecticut	
Variable	Average Annual Change	Present Value	Average Annual Change	Present Value	Average Annual Change	Present Value	Average Annual Change	Present Value	Average Annual Change	Present Value
Private Non-Farm Employment	434	-	513	-	200	-	2850	-	4227	-
Gross State Product ($ Ml Nominal)	$163.19	$1,767.03	$200.68	$2,161.65	$155.47	$1,669.97	$485.65	$5,151.49	$1,126.08	$12,049.92
Personal Income ($ Ml Nominal)	$37.85	$417.83	$40.45	$445.00	$23.55	$262.95	$225.45	$2,457.25	$372.70	$4,085.07
Disposable Income ($ Ml Nominal)	$30.45	$334.06	$31.86	$348.04	$18.42	$204.14	$178.76	$1,934.92	$295.01	$3,211.12
Population	461	-	605	-	369	-	3567	-	5803	-
Total State Tax Revenue ($ Ml Nominal)	$5.01	$54.46	$6.00	$64.83	$4.43	$47.90	$17.95	$192.22	$37.58	$404.73
Total Local Tax Revenue ($ Ml Nominal)	$1.02	$10.03	$1.33	$13.25	$0.81	$8.20	$7.84	$78.36	$12.75	$127.61
Induced Gov't Spending ($ Ml Nominal)	$1.91	$18.69	$3.82	$37.88	$1.61	$16.38	$4.15	$38.64	$15.17	$147.78
Net State Tax Revenue ($ Ml Nominal)	$3.84	$42.97	$3.65	$41.54	$3.44	$37.83	$15.40	$168.46	$28.25	$313.85
Net Local Tax Revenue ($ Ml Nominal)	$0.29	$2.83	($0.14)	($1.34)	$0.19	$1.89	$6.24	$63.49	$6.91	$70.71

Connecticut Energy Mix and Millstone Nuclear Plants

Considering the total electricity generation capability and the increasing demand for it in Connecticut, existing state capacity is not enough to meet demand. Therefore, Connecticut currently has to import electricity to meet its ever-increasing demand. According to the Connecticut Siting Council's (CSC) estimates, the increase in total peak demand between 1998 and 2018 will be about 20%. Moreover, according to CSC, the maximum state generation capacity to serve peak demand in 1999 was 6,268 MW, and the expected peak demand was 6,300 MW. Table 3 reproduced below clearly illustrates this point: Connecticut has to import electricity from neighboring states to meet its demand.

Table 3: Connecticut Generation Capability in 1999

[illegible]		[illegible]
	Total Connecticut Generation (No Import)	6,278
	Excluding Millstone and Import	4,268
	Transmission Import Capability	2,000
	Maximum Capacity with Millstone and Import	8,278
	Maximum Capacity w/out Millstone	*6,268*
Demand		
	Expected Peak Demand	6,300

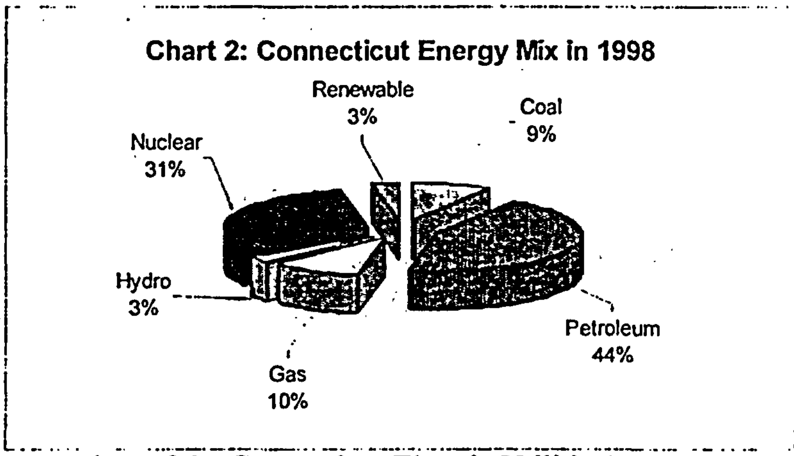
Source: Connecticut Siting Council
At http://www.state.ct.us//csc/paul/htmlrev/forcst99.htm

As Table 3 indicates, Millstone is an important source of electricity in Connecticut. The absence of Millstone would likely generate two important impacts in addition to other economic impacts: (1) the State would have to import electricity using up to its maximum import capability, because the short-term replacement of a major electricity generators is difficult. Importing will increase the already high-electricity price (which is the fourth highest in the nation with an average 10.3 cents per kilowatt-hour) in Connecticut, thereby increasing the cost of doing business. Other things being equal, this would create disincentives for businesses to relocate to or expand in Connecticut, and (2) importing more from the neighboring states, as the CSC argues, will further deteriorate Connecticut's air quality. Importing additional electricity from states located west and south of Connecticut means that electricity generating plants in those

states would likely use more high-sulfur fuels and lead to increased migration of sulfur and nitrogen oxides into Connecticut. Therefore, CSC argues Connecticut should minimize electricity imported from other states.

To better understand the place of nuclear energy in Connecticut's economy, Chart 2 reproduced below presents the 1998 Connecticut Energy Mix. Chart 2 shows the fraction of potential electricity generation capacity in Connecticut including both Utility and Non-Utility sources.

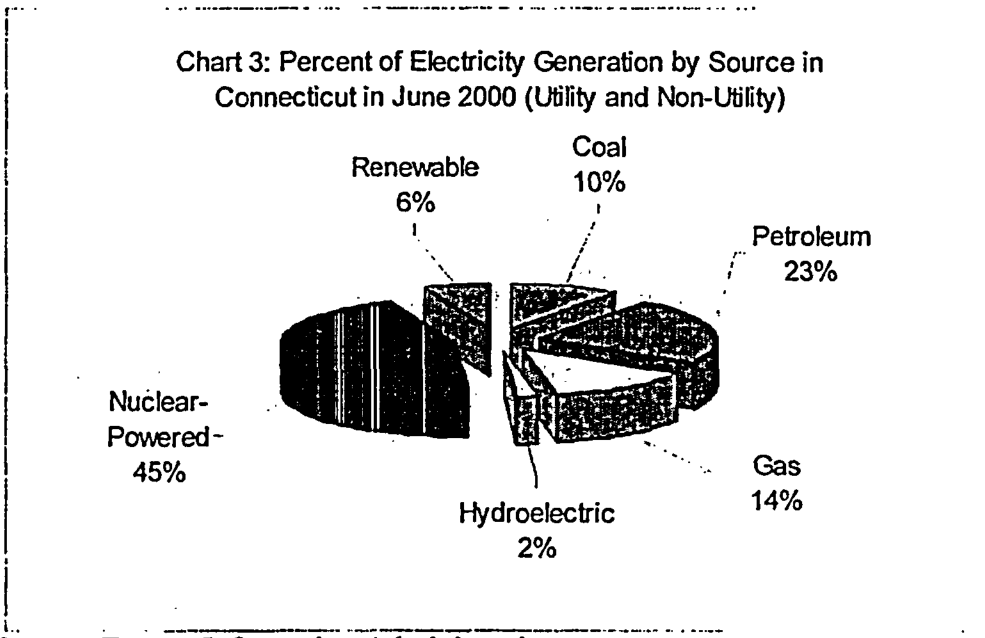
Source: Calculated from Connecticut Siting Council, 1999,



"Review of the Connecticut Electric Utilities' 1999 Twenty-Year Forecasts of Loads and Resources" at http://www.state.ct.us/csc/paul/htmlrev/forcst99.htm

As is clear from Chart 2, nuclear energy constitutes about one-third of Connecticut's energy mix in terms of electricity generation capability. Next are oil-fired plants, which become more costly in the face of increasing oil prices in 2001 and beyond. As oil prices increase, nuclear energy will be preferred due to the higher cost of operating oil-fired plants and the negative impact of the oil-and coal-fired plants on air quality.

Probably because of both cost and environmental considerations, as depicted in Chart 3 reproduced below, nuclear-power stations contributed about 45% of the electricity actually generated in Connecticut in June 2000. This shows how important Millstone is to the Connecticut economy and to our quality of life. According to Chart 3, even though oil-fired plants could contribute 44% of the Connecticut Energy mix (Chart 2), in June 2000, they accounted for only 23% of total electricity generation in Connecticut.



Source: Energy Information Administration at http://www.eia.doe.gov/cneaf/electricity/emp/html.

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Introduction

The Connecticut Center for Economic Analysis (CCEA) at the University of Connecticut coordinating with Clarke & Co. of Boston, Massachusetts performed a regional and statewide economic impact analysis of the current operations of Millstone Nuclear Power Plant located in the Town of Waterford in New London County. This analysis reports the salient effects resulting from direct and indirect employment, in-state procurement, electric power provision, and state and local taxes paid. In this analysis, we counterfactually subtract Millstone's current operations from the state economy to determine its current impact on Connecticut, New London County, Hartford County, Fairfield County and New Haven County.

We use the REMI model, a dynamic input-output model of Connecticut and its eight counties. The REMI model forecasts the economy in its present form as a baseline. Because Millstone ***already exists*** in the baseline model, we ***counterfactually*** remove it from the State economy. Our results can then be interpreted conversely to show the positive impact of its continuing operations. The counterfactual approach answers the question, how much would Connecticut, New London, and three other major Counties' economies (Fairfield, Hartford and New Haven) suffer if Millstone's facilities and related services disappeared from Connecticut. This approach then tells us how much Millstone currently contributes to the State and its County economies.

In order to fully assess the impact of the operations of Millstone Nuclear Power Stations in Connecticut, we proceed in the following order: first, we lay out the methodology and assumptions governing our approach to the study of nuclear power plants in Connecticut. Second, we look at Connecticut's energy profile and the contribution of the Millstone Nuclear Plants to the Connecticut and the Town of Waterford economy. In this context, we briefly highlight the direct economic impact of Millstone aside from electricity generation. Third, we present the direct and indirect economic impacts of Millstone on the Connecticut's and major counties' economies by looking at detailed population changes, economic output and employment changes by sector and jobs by occupation. Finally, we present a detailed fiscal impact of Millstone's operations, as well as a general summary of our findings.

Methodology and Assumptions

I. Model

For this analysis, we use the REMI model calibrated and updated annually by Regional Economic Models, Inc. of Amherst, MA. This model is a dynamic, multi-sector, regional economic model of Connecticut developed specifically for the Connecticut Center for Economic Analysis. This model provides detail on all eight counties in the State of Connecticut and any amalgamation of these counties. The REMI model includes all of the major inter-industry linkages among 466 private industries, which are aggregated into some 49 major industrial sectors. With the addition of farming and three public sectors (State & local government, civilian federal government, and military), there are a total of 53 sectors represented in the model for all eight counties.

At the heart of the model is the extensive modeling of sectoral input-output relationships for the states by the U.S. Department of Commerce. The REMI model creates a dynamic interface among the many sectors of the economy, which allows the economy to adjust and react just as the real economy would. In addition, there is a substantial demographic component to the model, which is able to track the inflow and outflow of population by demographic categories based on economic conditions. Detailed results from the model are available in Appendix II at the end of the report.

The REMI model forecasts the Connecticut economy in its present form as a baseline. Any changes in the economy are either added to or subtracted from that baseline forecast depending on the nature of the change. Because Millstone ***already exists*** in the baseline model, the most accurate measure of Millstone's impact is estimated by ***counterfactually*** removing Millstone from the economy. Intuitively, the results contained in this report measure the losses to the economy resulting from the absence of the Millstone Nuclear Power Plants. However, these same results can be interpreted as the positive impact of Millstone's continuing operations by reversing the signs of the economic variables.

This analysis considers two main geographic regions. We assume the primary market for Millstone is New London County. As such, New London County is singled out for separate analysis to capture the local impact. In addition to spillover effects from New London, Millstone has direct effects through operations around the State. This

statewide reach provides a benefit across the State. As a result, this report also considers Millstone's impact on the State as a whole. We consider its impact on three other counties.

II. Assumptions

Due to the nature of the energy sector, we develop assumptions that best capture the impact of Millstone Nuclear Power Stations on Connecticut's economy. Even though electricity produced in a local area is consumed by local customers, total generation is still considered a part of the overall generation capacity of the State, and it should be treated as such rather than an isolated local source.

Considering the nature of Millstone and the overall generating capacity of Connecticut as well as the difficulty in this sector to compensate the retiring or shutdown of a major power plant in the short run, we decided to model a *supply shock* in electricity sales to each County. The extent of the shock for each County is calculated by estimating the population-adjusted electricity sales for each County. The calculations regarding the consumption share of each County is presented in Table 1.

Table 1: Assumptions Regading the Economic Impact Analysis

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fairfield	26	4,256,159	4.813	$205
Hartford	25	4,204,569	4.813	$202
Litchfield	6	920,299	4.813	$44
Middlesex	5	761,686	4.813	$37
New Haven	24	4,028,426	4.813	$194
New London	8	1,247,562	4.813	$60
Tolland	4	669,274	4.813	$32
Windham	3	533,674	4.813	$26
Connecticut	**100**	**16,621,650**	**4.813**	**$800**

Source: Consumption amount is calculated from Energy Information Administration, Department of Energy at http://www.eia.doe.gov.
Kilowatt-hour rate for generation services (kWh) is obtained from Connecticut Light and Power rate information files at Connecticut Utility Department at http://www.cud.state.ct.us.

Using population to measure the consumption share of each County, Fairfield, Hartford, New Haven, and New London are the primary counties benefiting from the

operation of these plants. We estimate the total electricity generation of Millstone for the year 2000 by taking the June 2000 electricity generation figure multiplied by 12 to get an annual estimated total output of electricity generated by the Millstone 2 and Millstone 3 power stations. In June 2000, these two nuclear power stations generated 1,353 million kilowatt-hours. This figure is a conservative estimate considering that production is highest in the summer peak months in July and August.

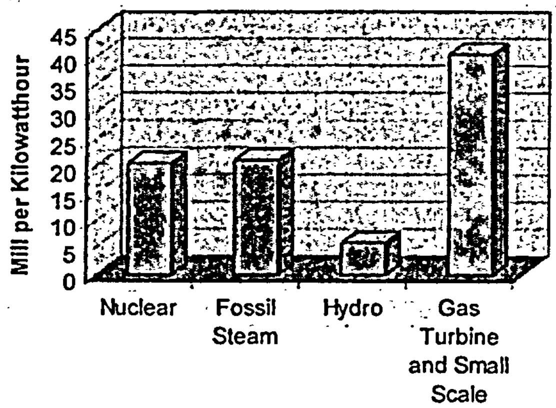
The total estimated electricity generated by Millstone 2 and Millstone 3 multiplied by the average rate for generation services, estimated by Connecticut Light and Power and filed at Connecticut Utility Department, provides total sales. The amount used for this calculation is 4.813 cents per kilowatt-hour (exclusive of transmission, distribution, and decommissioning costs). Consequently, we estimate that the total revenue of Millstone 2 and Millstone 3 from electricity generation services is about $800 million for the year 2000.

Direct Economic Impact of Millstone 2 and Millstone 3 on The Connecticut Economy

As the Connecticut Siting Council aptly puts it, "by releasing no sulfur oxides, nitrogen oxides, or carbon dioxide, nuclear power essentially represents a zero-air-emission generation source."[1] With the required safety measures and maintenance, nuclear energy is a clean alternative to other sources of electricity. The Millstone Nuclear Stations received the ISO 14001 certification for environmental excellence, which was the second station receiving this award among over 100 nuclear stations in the nation.[2] In terms of average operating expenses as mills per kilowatt-hour, nuclear plants, as presented in Chart 1, are less expensive than other plants, except hydroelectric.

[1] Connecticut Siting Council, 1999, "Review of the Connecticut Electric Utilities' 1999 Twenty-Year Forecasts of Loads and Resources," at http://www.state.ct.us/csc/paul/htmlrev/forcst99.htm.
[2] For more information, see http://www.millstonestation.com/pressreleases/

Chart 1: Average Operating Expenses for Utilities in 1996 (Mills per Kilowatthour)



A mill is equal to 1/1000 of the U.S. $

Source: http://www.energyonline.com/Restructuring/energydb/avgexp.html.

Besides these friendly environmental and direct sales effects, Millstone Power employs people, purchases goods and services and pays taxes to local authorities in order to maintain their operations. In 1999, Millstone paid $33 million in property taxes to the Town of Waterford in New London County. This amount constitutes 66% of Waterford's property tax revenue and 58% of the Town's total revenue for the year ending June 1999.

Moreover, when we look at the employment figures, New London County benefits from the presence of the power stations considerably as the total payroll amounted to $118 million in 1999. Employment by place of residence shows that the main beneficiaries of the nuclear stations' payroll are New London, Hartford and Middlesex Counties. As Table 2 indicates, local hiring constitutes an important impact of these stations on the Waterford's economy. We report only total payroll for Millstone employees irrespective of their place of residence.

Table 2: Millstone Nuclear Plants Direct Spending in 1999 in Connecticut					
Counties	Procurement (Million)	Payroll (Million $)	Property Tax (Million)	Total (Million)	Employment by Residence
Fairfield	$0.841	--	--	$0.841	2
Hartford	$17.291	--	--	$17.291	132
Litchfield	$0.157	--	--	$0.157	1
Middlesex	$2.396	--	--	$2.396	174
New Haven	$5.147	--	--	$5.147	49
New London	$26.839	$118.107	$33.000	$177.946	1312
Tolland	$0.115	--	--	$0.115	24
Windham	$0.166	--	--	$0.166	43
Connecticut	**$52.952**	**$118.107**	**$33.000**	**$204.059**	**1737**

In terms of procurement, New London County receives the lion's share with about $27 million annually. Following this is Hartford County with $17 million, New Haven County with $5 million, and Middlesex County with $2.5 million. As Millstone changes ownership, management has stated that there will be changes in its procurement pattern toward purchasing more from local vendors than from out-of-state vendors.

As Table 2 clearly indicates, Connecticut is the real beneficiary from Millstone's operations. Millstone's procurement, payroll, and property tax total about $204 million. As we clearly lay out in the following sections, this is in addition to the production of $800 million of clean electricity.

Connecticut Energy Mix and Millstone Nuclear Plants

When we look at the total electricity generation capability and the increasing demand for it in Connecticut, existing state capacity is not enough to meet demand. Therefore, Connecticut currently has to import electricity to meet its ever-increasing demand. According to the Connecticut Siting Council's (CSC) estimates, the increase in total peak demand between 1998 and 2018 will be about 20%. Moreover, according to CSC, the maximum state generation capacity to serve peak demand in 1999 was 6,268 MW, and the expected peak demand was 6,300 MW. As Table 3 clearly illustrates this point, Connecticut has to import from neighboring states to meet its demand.

Table 3: Connecticut Generation Capability in 1999

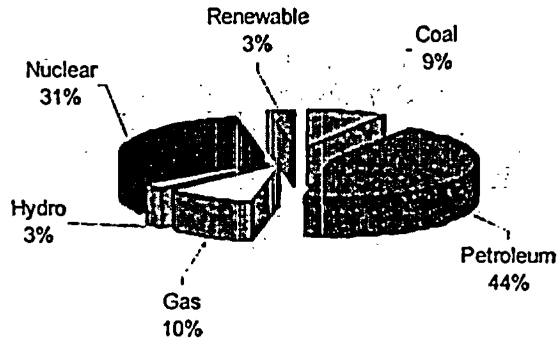
[illegible]		[illegible]
	Total Connecticut Generation (No Import)	6,278
	Excluding Millstone and Import	4,268
	Transmission Import Capability	2,000
	Maximum Capacity with Millstone and Import	8,278
	Maximum Capacity w/out Millstone	6,268
Demand		
	Expected Peak Demand	6,300

Source: Connecticut Siting Council
At http://www.state.ct.us//csc/paul/htmlrev/forcst99.htm

As Table 3 indicates, the Millstone units are an important source of electricity in Connecticut. The absence of the Millstone Units would likely generate two important impacts in addition to other economic impacts: (1) the State would have to import electricity using up to its maximum import capability, because the short-term replacement of a major electricity generator is difficult. Importing will increase the already high-electricity price (which is the fourth highest in the nation with an average 10.3 cents per kilowatt-hour) in Connecticut, thereby increasing the cost of doing business. Other things being equal, this would create disincentives for businesses to relocate to or expand in Connecticut, and (2) importing more from the neighboring states, as the Connecticut Siting Council argues, will further deteriorate Connecticut's air quality. Importing more electricity from the states located west and south of Connecticut means that the plants in those states would likely use more high-sulfur fuels and lead to the increased migration of sulfur and nitrogen oxides into Connecticut. Therefore, CSC argues Connecticut should minimize the amount of electricity imported from other states.

To better understand the place of nuclear energy in Connecticut's economy, Chart 2 presents the Connecticut Energy Mix in 1998. Chart 2 shows the fraction of potential electricity generation capacity in the State including both Utility and Non-Utility sources.

Chart 2: Connecticut Energy Mix in 1998

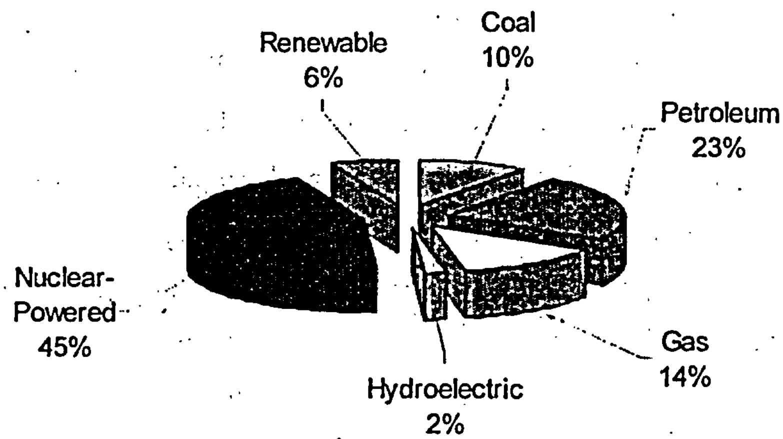


"Source: Calculated from Connecticut Siting Council, 1999, Review of the Connecticut Electric Utilities' 1999 Twenty-Year Forecasts of Loads and Resources" at http://www.state.ct.us/csc/paul/htmlrev/forcst99.htm

As it is clear from Chart 2, nuclear energy constitutes about one-third of Connecticut's energy mix in terms of electricity generation capability. Next are oil-fired plants, which might become more costly in the face of increasing oil prices in 1999 and 2000. As oil prices increase, nuclear energy will be preferred due to the higher cost of operating oil-fired plants and the negative impact of the oil-and coal-fired plants on air quality. Unfortunately, Connecticut does not have much potential to generate electricity from hydroelectric plants, which is both a low-cost way of generating electricity and environmentally sound (neglecting lost wildlife habitat and displaced people).

Probably because of both cost and environmental considerations, as depicted in Chart 3, in June 2000, about 45% of the electricity actually generated in Connecticut was contributed by nuclear-powered stations. This shows how important the Millstone Units are to the Connecticut economy and to the quality of life in Connecticut. According to Chart 3, even though oil-fired plants could contribute to 44% of the Connecticut Energy mix (Chart 2), in June 2000, they accounted for only 23% of total electricity generation in Connecticut.

Chart 3: Percent of Electricity Generation by Source in Connecticut in June 2000 (Utility and Non-Utility)



Source: Energy Information Administration at http://www.eia.doe.gov/cneaf/electricity/emp/html.

Considering the importance of nuclear stations in the Connecticut energy market, in the context of recent restructuring efforts to open generation services to competition to reduce the cost of electricity, the next sections evaluate the *direct and indirect* impact of Millstone operations on the State economy as a whole, as well as on four selected County (Hartford, Fairfield, New Haven and New London) economies. First, our focus is on the impact of Millstone on output (the value of goods and services produced) and employment by sector, and employment by occupation. Then, we look at the issue from the fiscal point of view and analyze how Millstone affects tax-related variables over the forecast period of twenty-one years (2000-2020).

Millstone's Direct and Indirect Impact on Output by Sectors, and Employment by Sectors and Occupation Categories.

<u>*Output by Selected Sectors*</u>

Electricity generation plants affect all aspects of the economy. However, some sectors are affected more than others from the operation of nuclear power plants due to their relation with certain industries as these industries provide input to the power generation process. Moreover, some industries provide specialized professional services to nuclear power stations. Therefore, certain industries or sectors will be affected significantly when a nuclear station ceases to operate or, conversely, starts up. As Table 4 indicates, the major effect in terms of output (the value of goods and services produced) of the operation of a nuclear power station is on the Industrial Machinery, Public Utilities, Construction, Wholesale, Miscellaneous Professional Services and Miscellaneous Business Services sectors.

Table 4: Annual Average Output Changes by Sector Relative to Baseline Forecast Output Level in 2000 by Sectors (Million 92 $)*

Variable	Fairfield		Hartford		New Haven		New London		Connecticut	
	Baseline Output in 2000	Annual Average Change	Baseline Output in 2000	Annual Average Change	Baseline Output in 2000	Annual Average Change	Baseline Output in 2000	Annual Average Change	Baseline Output in 2000	Annual Average Change
Stone,Clay,Etc.	$131	$0.16	$113	$0.25	$139	$0.10	$25	$0.79	$587	$1.75
Machine & Computer	$2,370	$7.17	$3,752	$15.11	$1,572	$5.79	$271	-$0.24	$9,690	$36.66
Mining	$35	$0.01	$18	$0.37	$16	$0.08	$3	$0.09	$88	$0.69
Construction	$2,459	$5.39	$2,435	$7.42	$2,207	$1.48	$663	$39.91	$9,348	$57.43
Public Utilities	$660	$151.58	$998	$168.21	$844	$166.49	$596	$364.76	$3,472	$982.35
Eating & Drinking	$694	$0.27	$846	$0.55	$654	$0.28	$245	$2.84	$2,877	$4.46
Wholesale Trade	$3,565	$5.20	$4,007	$8.58	$2,684	$2.92	$297	$10.17	$11,433	$28.43
Misc. Business Service	$3,783	$7.87	$3,033	$7.71	$2,367	$2.93	$432	$21.81	$10,299	$41.23
Misc. Professional Ser	$2,736	$8.66	$1,706	$2.68	$1,067	$0.62	$378	$66.84	$6,290	$79.67
Education	$370	$0.04	$384	$0.12	$843	$0.29	$101	$0.44	$2,070	$1.08

*Annual Average Change Calculations are Based on the Forecast Results Between 2000 and 2020

In the first column under each county and Connecticut, the baseline forecast output (gross sales) level in selected sectors in the selected counties and Connecticut is presented to give an idea of the level of output in each sector due to the ongoing operations of the Millstone Nuclear Stations. The annual average change calculations are based on the result of our counterfactual simulation without Millstone for the years between 2000 and 2020. All values presented in the table are calculated in millions of 92 dollars. The annual average change reflects the cumulative changes from the baseline forecast divided by 21 and is positive reflecting Millstone's positive contribution to the State economy.

As expected, the sector in the economy with the largest impact in terms of output is Public Utilities. In annual average terms, this reflects a $982.35 (28 %) million statewide increase in output. The numbers in parentheses reflect change with regard to the 2000 baseline forecast level. Similarly, the annual average increases in aggregate output are $168 (17 %) million, $167 (20 %) million, $152 (23 %) million, and $365 (61 %) million in Hartford, New Haven, Fairfield and New London Counties, respectively.

Miscellaneous Professional Services, Construction, Machine and Computer, Miscellaneous Business Services and Wholesale Trade are the second most impacted sectors with statewide average annual increases in output of $80 (1.3 %) million, $57 (0.6 %) million, $37 (0.4 %) million, 41 (0.4 %) million and $28 (0.3 %) million, respectively. New London County would be affected more than other counties in the aforementioned sectors. Regarded counterfactually, New London County experiences a contraction primarily in the Public Utilities sector. Following this sector are Miscellaneous Professional Services, Construction and Miscellaneous Business Services Sectors. The effect in output in other counties is not significant in all sectors, except in the Public Utilities sector where it is impacted significantly in all remaining counties (Hartford, New Haven and Fairfield).

Employment by Sector

Table 5: Annual Average Changes in Employment by Sector Relative to Baseline Forecast Employment Level by Sector in 2000*

Variable	Fairfield		Hartford		New Haven		New London		Connecticut	
	Baseline Employment Level in 2000	Annual Average Change	Baseline Employment Level in 2000	Annual Average Change	Baseline Employmen t Level in 2000	Annual Average Change	Baseline Employmen t Level in 2000	Annual Average Change	Baseline Employment Level in 2000	Annual Average Change
Manufacturing**	68,476	17	77,749	49	61,432	30	20,874	-258	274,386	-134
Mining	541	0	254	4	312	1	60	2	1,484	9
Construction	26,262	53	25,668	71	23,665	15	7,043	383	100,335	555
Trans./Public Uti	22,279	7	28,611	21	22,666	7	6,925	1053	88,903	1,094
Fin/Ins/Real Est	57,615	27	78,799	32	32,272	11	6,466	34	195,351	117
Retail Trade	83,919	28	93,647	63	77,513	29	25,430	386	331,201	562
Wholesale Trade	26,232	30	32,880	57	22,251	20	2,693	71	91,923	189
Services	215,420	270	204,674	211	186,042	86	61,955	1169	759,219	1,814
Agri/For/Fish Se	7,791	2	5,032	3	3,667	1	1,833	11	23,022	21

*Annual Average Change Calculations are Based on the Result of Forecast Between 2000 and 2020.
**Negative value in New London County is due to the increase in competition for labor in New London County generated by the expansion of the manufacturing sector as a result of Millstone.

As Table 5 indicates, in terms of the annual average increase in employment, the Service sector is affected more than other sectors in the Table. Again, to reiterate, the changes are average annual changes from the baseline forecast. The first column gives the level of employment in the selected sectors in each County and the State of Connecticut in the year 2000. One significant observation in Table 5 is that the annual average change in employment in the Manufacturing sector is negative in New London County and Connecticut, even though in New Haven, Hartford and Fairfield Counties, the impact is positive as a result of Millstone 2 and 3. This result is mainly due to the fact that Millstone leads an expansion in manufacturing industry and the competition for labor in New London County increases. Increasing demand in both durable and non-durable manufacturing as well as service and public utilities sectors generates labor shortages.

The average annual increase in employment due to Millstone Power Stations in the Transportation and Public Utilities sectors is about 1,094 (1.2 %) jobs in Connecticut. The same change is about 21 (0.07 %), 7 (0.03 %), 7 (0.03 %), and 1,053 (15 %) jobs in Hartford, New Haven, Fairfield and New London Counties, respectively. Considering the total number of jobs in these sectors in Connecticut in 2000, which is about 90,000, the average annual change of 1,094 jobs is a significant impact created by the Millstone Power Station. Moreover, employment in Construction, Retail Trade and Services are greatly affected by Millstone's operations.

An even greater impact is on employment in the Services sector, as this sector experiences an annual average change of 1,814 (0.2 %) jobs in Connecticut, of which 1,169 jobs are from New London County (1.9 %). Besides New London County, Fairfield and Hartford Counties experience an annual average increase of 270 (0.13 %) and 211 (0.1 %) jobs in Services sector, respectively.

When we counterfactually remove Millstone, electricity generation capability would be substantially reduced in Connecticut, and in turn, new investments and electricity import would increase the cost of electricity. Increasing electricity cost will translate into increasing relative cost of doing business in Connecticut, which will either force companies to relocate or introduce measures to increase productivity and perhaps,

reduce the number of employees to remain competitive in their respective sectors even as capital intensity should be reduced instead.

The average annual increase in employment is about 555 (0.6 %) jobs in the Construction sector in Connecticut as a whole. This is a substantial expansion in a crucial sector as it indicates an increase in the number of start-up activities throughout the State. Among the four counties, New London would be affected most with an annual average increase in employment in the Construction sector of 383 (5.4 %) jobs. Hartford, Fairfield and New Haven Counties follow with 71 (0.3 %), 53 (0.2 %) and 15 (0.06 %) jobs, respectively.

Retail Trade and Wholesale Trade in Connecticut experience an average annual increase in employment of 562 (0.17 %) and 189 (0.21 %) jobs, respectively. New London and Hartford Counties in the Wholesale Trade sector and New London County in the Retail Trade sector experience an annual average increase of 71 (2.6 %), 57 (0.17 5) and 386 (1.5 %) jobs, respectively. The average annual change in employment in the Wholesale Trade and Retail Trade sectors in Fairfield County is 30 (0.11 %) and 28 (0.03 %) jobs, respectively. Table 6 gives further detail about the employment level by analyzing the impact of the Millstone Nuclear Power Station on employment by occupation.

Employment by Occupation Categories

Table 6 presents the effect of Millstone Nuclear Power operations on selected occupational categories. The annual average change from the baseline model is given in the second column under each reported County and Connecticut. Table 6 makes it clear that Construction Trade is the most impacted occupational category in Connecticut with an annual average increase of 252 (0.5 %) jobs. Electrical Equipment Mechanics and Electric Installation and Repair ranks second in terms of annual average change with 73 (0.8 %) jobs gained, considering the baseline level of 9,590 jobs in these occupations in Connecticut in 2000. Engineering and Science Technicians, Engineers and Management Support as occupational categories experience an annual average increase of 124 (0.5 %), 137 (0.49 %) and 238 (0.35 %) jobs, respectively. Even though the annual average change looks small, the number of jobs in Electric Power Generator Operators and

Distributors increase significantly considering the size of this occupation category. The average annual increase in this category in Connecticut is 35 (6.6 %) jobs whose total size is about 534 jobs in 2000.

When we look at the changes in occupational categories across the counties, New London County gains more than do others considering the baseline levels of occupational categories in New London and the corresponding annual average changes in those categories.

Table 6: Annual Average Changes in Employment by Occupation Relative to Baseline Forecast and Baseline Employment Level in 2000*

Variable	*Fairfield*		*Hartford*		*New Haven*		*New London*		*Connecticut*	
	Baseline Employment Level in 2000	*Annual Average Change*	*Baseline Employment Level in 2000*	*Annual Average Change*	*Baseline Employment Level in 2000*	*Annual Average Change*	*Baseline Employment Level in 2000*	*Annual Average Change*	*Baseline Employment Level in 2000*	*Annual Average Change*
Engineers	8,324	13	8,606	9	5,466	3	2,482	109	**27,745**	**137**
Physical scientists	1,246	3	919	1	833	0	316	23	**3,617**	**27**
Comput, math & oper res	7,558	15	8,139	13	5,144	5	1,417	76	**24,653**	**112**
Life scientists	781	1	645	1	665	0	248	8	**2,601**	**10**
Elec pwr gen plant oper/dis	98	0	158	0	127	0	95	34	**534**	**35**
Management support	20,765	26	22,588	20	13,603	7	4,025	178	**68,298**	**238**
Engin & scienc tech & tech	7,153	11	6,549	8	4,987	3	1,702	100	**22,777**	**124**
Electr equip mech, inst & re	2,413	2	2,905	4	2,671	1	681	65	**9,590**	**73**
Gas & petro plant & syst	109	0	51	0	38	0	16	4	**230**	**4**
Construction trades	12,554	22	12,896	30	11,153	7	3,733	179	**48,407**	**252**

*Annual Average Change Calculation is Based on the Result of Forecast Between 2000 and 2020.

When we make a size-of-occupation and change-in-occupation comparison across the counties, the annual average change in occupations in New London County is more sensitive to Millstone operations than the same occupational categories in New Haven, Hartford, and Fairfield. In the following section, we highlight changes in some of the important economic variables due to Millstone.

Economic and Fiscal Impact of the Millstone Nuclear Power Plants

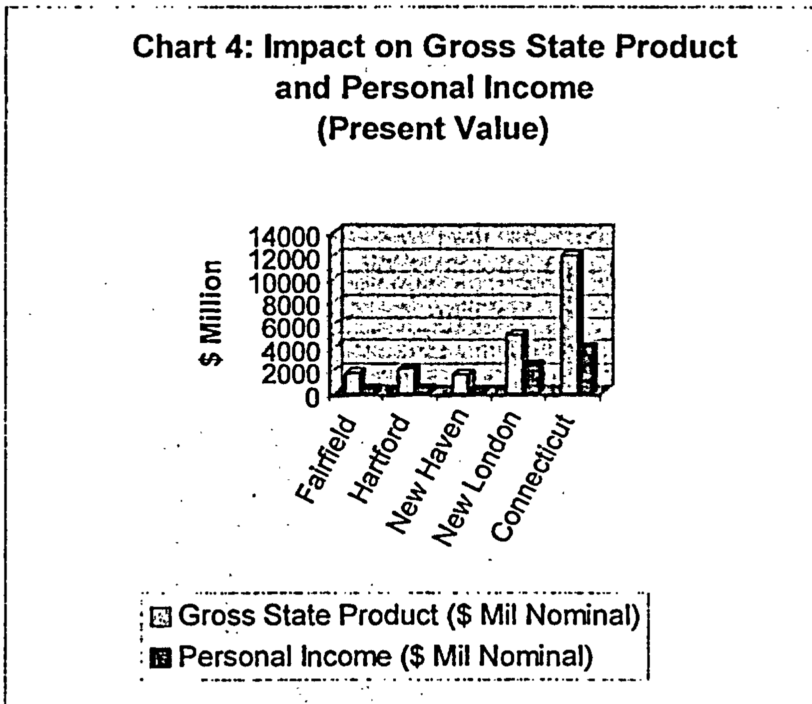
Gross State Product and Personal Income

The key variables reported are gross state product (GSP) and aggregate personal income. GSP is the dollar value of all final goods and services produced in the State in one year. GSP is calculated using a value-added approach, in which the value added at each stage of the production process is aggregated to yield the final value. Intermediate goods are excluded from this calculation to avoid double counting. The dollar value of all final goods and services produced in a county is referred as Gross Regional Product (GRP). GSP is above the baseline forecast in each County and the State as a result of Millstone's operations. The largest County GRP impact in the State is in New London County in terms of annual averages. The average annual increases in GRP are $486 million in New London County (5 %), $163 million in Fairfield County (0.42 %), and $201 million for Hartford County (0.53 %), compared to $1,126 million for the State of Connecticut (0.9 %) (all figures in nominal dollars). The smallest impact is in New Haven County with an $156 million increase in its GRP due to Millstone (0.55 %). Average annual additions to GRP are the annual gains in GRP over the baseline forecast averaged over the number of years of the scenario. The present value of GRP increases $2.16 billion, $1.67 billion, $1.77 billion, $5.15 billion and $12.05 billion in Hartford, New Haven, Fairfield, New London Counties and Connecticut, respectively, using a discount factor of 6.5% over the twenty-year horizon. Present value represents the total value today of a stream of future payments each discounted to the present. We conclude that these values represent substantial *positive* contributions to the Connecticut economy.

Another important variable is the change in aggregate personal income of Connecticut residents due to ongoing operations of Millstone. The largest county impact on personal income in annual average and in present value terms is in New London

County. Personal income increases by $225.45 million in New London County (2.85 %), $37.85 million in Fairfield County (0.08 %), $40.45 million in Hartford County (0.13 %), $23.55 million in New Haven County (0.09 %), and, in the State it increases by $372.70 million (0.28 %), all in annual average terms expressed in nominal dollars. In present value terms, these nominal increases represent $2.46 billion, $417.83 million, $445 million, $262.95 million and $4.09 billion in New London, Fairfield, Hartford and New Haven Counties and in the State, respectively.

Chart 4 reports the changes in GSP and personal income for the selected Counties and for the State as a whole in present value terms.



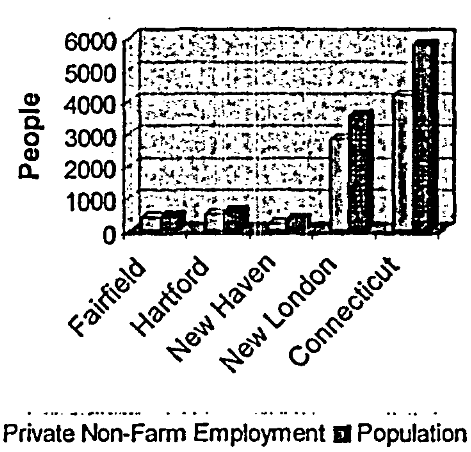
Employment and Population

In addition to GSP and personal income, Millstone creates a significant amount of employment in the Counties and the State as a whole, relative to the baseline forecast. Millstone's operations result in 4,227 additional jobs on an annual average basis in

Connecticut (0.23 %). Most of the employment increase occurs in New London County (2.14 %), followed by Fairfield (0.09 %), Hartford (0.09 %) and New Haven Counties (0.05 %) with annual average increases of 2,850; 434; 513 and 200 jobs, respectively.

The consequent increases in personal income and economic activity cause some people to move to the State because of increased job opportunities. The change in the population in the State as a whole and in the Counties separately is significant compared to the baseline forecast. In annual averages, Connecticut gains 5,803 people (0.18 %) from Millstone's operations. New London County, with the largest impact in all categories, gains 3,567 people (1.41 %) during the study period on average annually. Among the counties, the smallest impact on population is in New Haven County with an annual average increase of 369 people (0.05 %). Fairfield (0.05 %) and Hartford Counties (0.07 %) experience an annual average increase of 461 and 605 people, respectively. Chart 5 gives the changes in population for the Counties and for the State in annual averages.

Chart 5: Impact on Employment and Population (Annual Averages)



These four key economic variables in our analysis demonstrate the importance of Millstone not only to the regional economies, but also to the State as a whole. We

conclude that Millstone makes a substantial economic contribution to the State of Connecticut and its regional economies. The second part of our analysis examines the changes in State and local tax revenue associated with Millstone's operations in Connecticut.

State and Local Taxes

As explained above, the baseline forecast already incorporates the existence of Millstone, and we counterfactually remove it from the economy to determine its current impact on the economy. The loss would cause a decline in general economic activity. In particular, Gross State Product (GSP) and personal income would fall resulting in a decline in income, sales, use and profits taxes in the State. In addition, the decline of employment and population leads to a decrease in the value of local property and, thus, local property taxes. Conversely, continuing and expanding Millstone's activities in the State increase economic activity and all tax revenues. In our analysis we include the $33 million property tax paid by Millstone to the Town of Waterford.

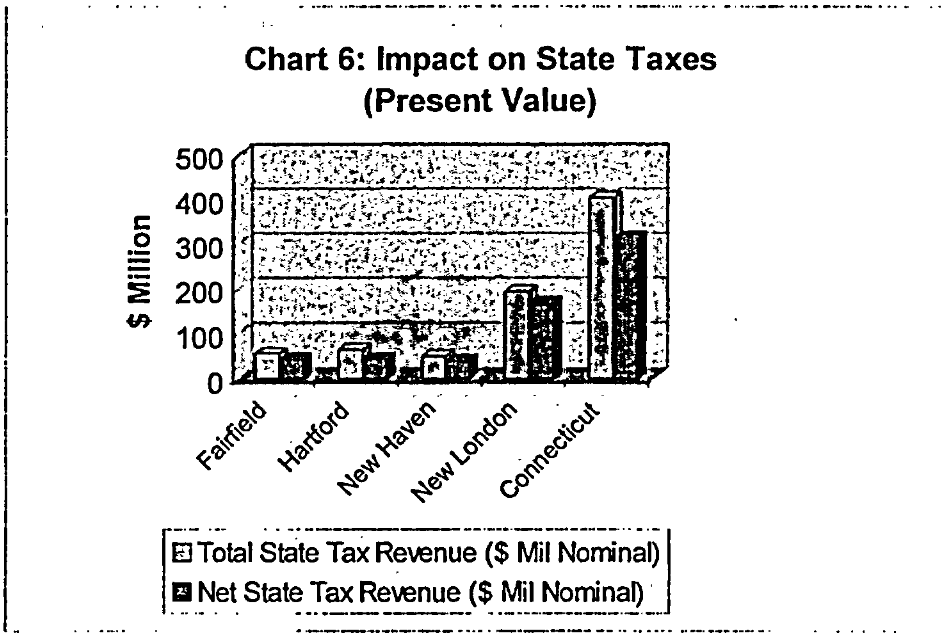
In addition to these basic tax changes, Millstone's operations affect *induced* government spending. As people move to the State and there is more economic activity, the government spends more to maintain the level of public services, such as for education and police, than in the past. This adjustment occurs endogenously, that is, within the model based on current and projected levels of government spending and population change.

State tax revenue is dependent on general economic activity. The increase in GSP and personal income that accompanies the increase in expenditures made through Millstone's payroll and procurement increase tax collections through the channels discussed above both in the County and the State. Total State taxes increase $17.95 million from New London County, $5.01 million from Fairfield County, $6 million from Hartford County, $4.43 million from New Haven, and $37.58 million in Connecticut on average annually in nominal dollars. In present value terms, there is an increase of $404.73 million in additional state taxes paid in Connecticut over the twenty-one year period as a result of Millstone's operations in the State.

As individuals move to the State, induced government spending increases. Induced government spending increases by $15.17 million (nominal) in annual average terms statewide. In present value terms, the change in induced government spending is $147.78 million (nominal) in the State over the study period. Among the Counties, the largest impact on induced government spending is in New London County. Induced government spending increases by $4.15 million (nominal) in annual average terms, and the change is $38.64 million (nominal) in present value terms in New London County.

The more important fiscal impact variable is the change in net taxes. Net state tax revenue (exclusive of local taxes) is calculated by subtracting the state contribution to Millstone, (which we assume is zero) and induced government spending from total state tax revenue. Positive net state tax revenue means that because of Millstone's operations, the State has a net gain in tax revenue. In our case, the net state tax revenue is positive in all Counties and in the State as a whole. This means that Millstone's operations produce a net gain in tax revenues in the State as a whole. It is because Millstone generates more tax revenue than induced government spending statewide in such forms as education and police that net tax revenues in the State are positive.

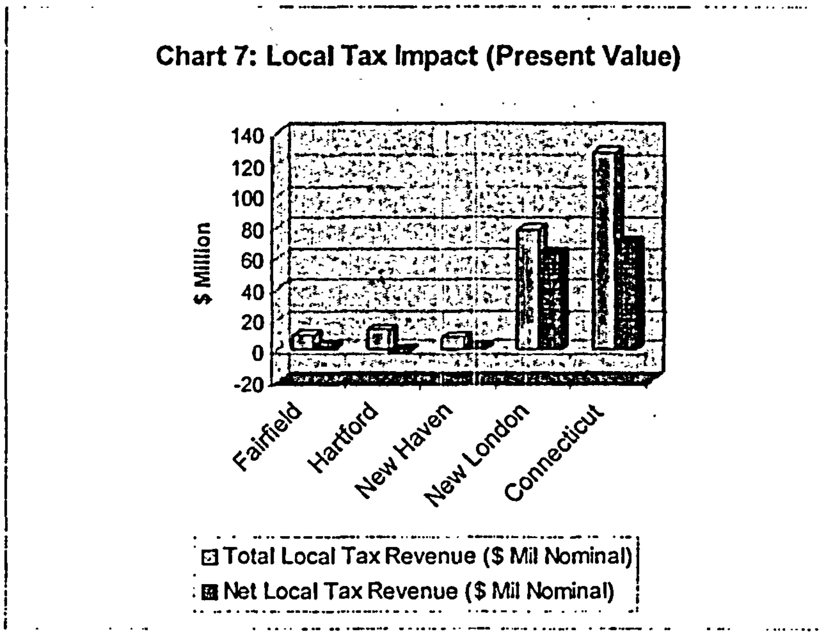
Net state tax revenues increase in the State as a whole by $28.25 million (nominal) in annual average terms. This number corresponds to $313.85 million (nominal) in present value terms for net state tax revenues in Connecticut. The largest increase in net state tax revenue is in New London County with $15.4 million in annual average terms, and the net present value of the increase is $168.46 million (both nominal). Net state tax revenue increases least in New Haven County by $3.44 million in annual average terms. This number corresponds to a $37.83 million in net state tax revenues in present value terms. Chart 6 gives the changes in total and net state tax revenue in present value terms for the State as a whole and for each County separately.



Millstone's operations increase local taxes generated in the Counties and in the State as a whole, both in annual average and in present value terms. The local tax increase is highest in New London County, with $7.84 million (nominal) in annual averages. This is an increase in addition to $33 million property tax Millstone pays to the Town of Waterford. The present value of the increase over the study period is $78.36 million (nominal). The smallest impact on local taxes is in New Haven County. Local tax revenue in New Haven County increases by $0.81 million (nominal) in annual average terms. The overall increase in local tax revenue for the whole State is $12.75 million (nominal) in annual average terms. The present value of the increase in local tax revenue over the study period is $127.61 million (nominal) for the entire State.

After we subtract induced government spending, the Town of Waterford, each County and the State have a net gain in local tax revenues, whereas net local tax revenues generated in Hartford County show annual average decreases. This is due to the excess of induced government spending over tax revenues calculated in that County. The net local tax revenues in Hartford County decrease by $0.14 million (nominal) in annual average terms. The present value of the decrease is $1.34 million (nominal). Connecticut as a whole experiences an annual average increase in net local tax revenues

of $6.91 million (nominal), which corresponds to the present value of $70.71 million (nominal). Chart 7 shows these gross and net new local tax revenues in the State and each County.



Benefit and Cost Metrics

As with any large economic activity there are costs and benefits. The chief benefits of Millstone's ongoing operations are the increased employment and personal income, as well as its contribution through many channels to gross state product. Millstone's operations require that the State and local municipalities spend money for public services such as police and education to support these operations and all of their consequent economic activity. The tax revenues generated from these primary and secondary activities should (and do) more than offset the expenditures. To measure the benefit to cost ratio we calculate three metrics that ostensibly capture the benefit/cost concept. Because personal income, gross state product, induced government spending and tax revenues vary over time (the study period is twenty years), we calculate the present value of these variables for the ratios. Table 7 presents the ratios regarding the State of Connecticut's and four selected Counties' gain due to Millstone. The first takes

into account the present value of Gross State Product and Gross Regional Product in each County and induced government spending due to Millstone Nuclear Power. Results indicate that due to Millstone's ongoing operations, in New London County, for each dollar of state and local government spending, Connecticut gains $133 in GSP. In other counties and Connecticut, the impact is similar but less than in New London. In Fairfield County, for each dollar of government spending, the State gains $95 in GSP.

Table 7: Benefit/Cost Analysis of The Removal of Millstone Power Stations from Baseline Economy

Benefit/Cost Metrics	Fairfield	Hartford	New Haven	New London	Connecticut
Gross State Product (Mil $) / Induced Govt Spending ($ Mil)	95	57	102	133	82
Personal Income ($ Mil) / Induced Govt Spending ($ Mil)	22	12	16	64	28
Total Taxes ($ Mil)/ Induced Govt Spending ($ Mil)	3	2	3	7	4

In New Haven County, for each dollar of state and local government spending, the State's gain is $102; in Hartford County, $57; and in Connecticut, $82. These calculations are based on the assumption and forecast results that from Millstone's operation, the State benefits by supporting the variety of economic activity created by Millstone's operations.

The second ratio in Table 7 takes into account aggregate personal income and induced government spending both in present value terms. In this case, even though the ratio is smaller than the previous one, it is still significant. In New London County, the increase in aggregate personal income will be $64 for each dollar of induced government spending. In Fairfield and New Haven Counties, the ratios are 22 and 16, which means that the increases in personal income are $22 and $16 for each dollar of induced government spending, respectively. The ratios in Connecticut and Hartford County are 28 and 12, indicating that the increases in personal income in the State and Hartford County are $28 and $12 for each dollar of induced government, respectively. In other words, Millstone operations imply that each additional dollar of public spending leverages from 12 to 64 additional dollars in personal income, and from 57 to 133 additional dollars of GSP (GRP).

The third ratio in Table 7 looks at total taxes (both local and state) and induced government spending both in present value terms. In Fairfield and New Haven Counties, total revenue from taxes is three times more than induced government spending. The lowest ratio is in Hartford County and the highest in New London County with 2 and 7, respectively. In Connecticut, the ratio is 4, indicating that total revenue from taxes is four times more than induced government spending in Connecticut due to Millstone.

A summary of our findings with regard to the Millstone's economic and fiscal impacts is given in Table 8. Appendix I presents results for local property and state taxes for four counties and the State. Appendix II presents summary tables of selected REMI output for four counties and the State of Connecticut. Appendix III summarizes the modeling strategy for REMI for Millstone.

Table 8: Summary Results for Millstone Nuclear Powerplant										
	Fairfield		Hartford		New Haven		New London		Connecticut	
Variable	Average Annual Change	Present Value	Average Annual Change	Present Value	Average Annual Change	Present Value	Average Annual Change	Present Value	Average Annual Change	Present Value
Private Non-Farm Employment	434	-	513	-	200	-	2850	-	4227	-
Gross State Product ($ Mil Nominal)	$163.19	$1,767.03	$200.68	$2,161.65	$155.47	$1,669.97	$485.65	$5,151.49	$1,126.08	$12,049.92
Personal Income ($ Mil Nominal)	$37.85	$417.83	$40.45	$445.00	$23.55	$262.95	$225.45	$2,457.25	$372.70	$4,085.07
Disposable Income ($ Mil Nominal)	$30.45	$334.06	$31.86	$348.04	$18.42	$204.14	$178.76	$1,934.92	$295.01	$3,211.12
Population	461	-	605	-	369	-	3567	-	5803	-
Total State Tax Revenue ($ Mil Nominal)	$5.01	$54.46	$6.00	$64.83	$4.43	$47.90	$17.95	$192.22	$37.58	$404.73
Total Local Tax Revenue ($ Mil Nominal)	$1.02	$10.03	$1.33	$13.25	$0.81	$8.20	$7.84	$78.36	$12.75	$127.61
Induced Gov't Spending ($ Mil Nominal)	$1.91	$18.69	$3.82	$37.88	$1.61	$16.38	$4.15	$38.64	$15.17	$147.78
Net State Tax Revenue ($ Mil Nominal)	$3.84	$42.97	$3.65	$41.54	$3.44	$37.83	$15.40	$168.46	$28.25	$313.85
Net Local Tax Revenue ($ Mil Nominal)	$0.29	$2.83	($0.14)	($1.34)	$0.19	$1.89	$6.24	$63.49	$6.91	$70.71

Appendix I:
TAX TABLES

one Nuclear-Fairfield County

llions of Dollars)	2000	2001	2002	2003	2004	2005	[illegible]	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	[illegible]	2020
...come Taxes																					
Personal Income	38.6	38.9	38.0	36.7	35.3	34.1	33.3	33.0	32.9	33.2	33.8	34.6	35.6	36.8	38.1	39.5	41.0	42.7	44.4	46.2	48.1
Income Tax	1.0	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3
Sales and Use Taxes																					
Gross State Product	144.8	144.0	143.4	143.1	143.5	144.4	146.3	148.1	150.4	153.3	156.6	160.3	164.2	168.4	172.9	177.7	182.5	187.7	192.9	198.4	203.9
Sales and UseTaxes	2.9	2.9	2.9	2.9	2.9	2.9	2.9	3.0	3.0	3.1	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1
Corporate Profits Taxes																					
Gross State Product	144.8	144.0	143.4	143.1	143.5	144.4	146.3	148.1	150.4	153.3	156.6	160.3	164.2	168.4	172.9	177.7	182.5	187.7	192.9	198.4	203.9
Profits tax	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9
Local Property Taxes																					
Project Directly	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Population	116.7	248.7	321.7	374.0	414.2	443.2	463.7	479.5	492.6	502.1	510.0	516.8	522.5	527.3	531.4	534.5	536.7	537.9	538.9	537.9	537.4
Total Property Taxes	0.2	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.5	1.5
TOTAL TAXES	4.8	5.0	5.1	5.1	5.2	5.3	5.3	5.4	5.5	5.7	5.8	6.0	6.1	6.3	6.5	6.7	6.9	7.1	7.4	7.6	7.8
TAX CREDITS/STATE CONTRIBUTIONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX CREDITS/LOCAL CONTRIBUTIONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INDUCED GOVERNMENT SPENDING	0.3	0.7	1.0	1.2	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.5	2.6	2.7	2.7	2.8
NET TAXES	4.4	4.2	4.1	3.9	3.8	3.8	3.7	3.7	3.7	3.7	3.8	3.9	3.9	4.0	4.1	4.3	4.4	4.5	4.7	4.8	5.0
PRESENT VALUE OF TOTAL TAXES	$64.48																				
PRESENT VALUE OF TOTAL STATE TAXES	$54.46																				
PRESENT VALUE OF TOTAL LOCAL TAXES	$10.03																				
PRESENT VALUE OF TAX CREDITS/INDUCED SPENDING	$18.69																				
PRESENT VALUE OF NET TAXES*	$45.80																				
PRESENT VALUE OF NET STATE TAXES*	$42.97																				
PRESENT VALUE OF NET LOCAL TAXES	$2.83																				

*Induced spending allocated according to relative shares of spending.

Millstone Nuclear-Hartford County (Millions of Dollars)	2000	2001	2002	2003	2004		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Income Taxes																						
Personal Income	38.6	40.3	40.2	39.3	38.0		36.8	35.9	35.6	35.6	35.9	36.5	37.4	38.4	39.6	41.0	42.5	44.0	45.7	47.5	49.3	51.2
Income Tax	1.0	1.1	1.1	1.1	1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.3	1.3	1.4
Sales and Use Taxes																						
Gross State Product	169.8	171.2	172.3	173.3	174.9		176.9	179.6	182.4	185.7	189.5	193.8	198.6	203.6	208.9	214.5	220.4	226.7	233.1	239.5	246.3	253.2
Sales and UseTaxes	3.4	3.4	3.4	3.5	3.5		3.5	3.6	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.7	4.8	4.9	5.1
Corporate Profits Taxes																						
Gross State Product	169.8	171.2	172.3	173.3	174.9		176.9	179.6	182.4	185.7	189.5	193.8	198.6	203.6	208.9	214.5	220.4	226.7	233.1	239.5	246.3	253.2
Profits tax	0.8	0.8	0.8	0.8	0.8		0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1
Local Property Taxes																						
Project Directly	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Population	166.8	353.4	457.5	531.7	581.5		612.9	631.2	644.5	653.4	659.9	664.2	668.7	672.4	674.9	676.8	677.8	677.2	675.8	673.6	671.3	669.1
Total Property Taxes	0.3	0.6	0.8	0.9	1.0		1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9
TOTAL TAXES	5.5	5.8	6.1	6.2	6.3		6.4	6.5	6.7	6.8	7.0	7.1	7.3	7.5	7.7	8.0	8.2	8.4	8.7	8.9	9.2	9.5
TAX CREDITS/STATE CONTRIBUTIONS	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX CREDITS/LOCAL CONTRIBUTIONS	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INDUCED GOVERNMENT SPENDING	0.7	1.6	2.1	2.6	2.9		3.2	3.4	3.6	3.8	3.9	4.1	4.2	4.4	4.5	4.7	4.8	4.9	5.0	5.2	5.3	5.4
NET TAXES	4.7	4.3	3.9	3.6	3.4		3.2	3.1	3.1	3.0	3.0	3.1	3.1	3.2	3.2	3.3	3.4	3.5	3.6	3.8	3.9	4.1
PRESENT VALUE OF TOTAL TAXES	$78.08																					
PRESENT VALUE OF TOTAL STATE TAXES	$64.83																					
PRESENT VALUE OF TOTAL LOCAL TAXES	$13.25																					
PRESENT VALUE OF TAX CREDITS/INDUCED SPENDING	$37.88					*Induced spending allocated according to relative shares of spending.																
PRESENT VALUE OF NET TAXES*	$40.20																					
PRESENT VALUE OF NET STATE TAXES*	$41.54																					
PRESENT VALUE OF NET LOCAL TAXES	($1.34)																					

MILLSTONE NUCLEAR POWER S. ,ONS AND CONNECTICUT ECONOMY

stone Nuclear-New Haven County (Millions of Dollars)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Income Taxes																					
Personal Income	25.4	25.8	25.1	24.0	22.8	21.6	20.7	20.3	20.1	20.2	20.5	21.0	21.6	22.3	23.2	24.1	25.0	26.1	27.1	28.3	29.5
Income Tax	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8
Sales and Use Taxes																					
Gross State Product	127.1	128.9	130.7	132.5	134.6	137.2	140.2	142.7	145.5	148.6	152.0	155.7	159.4	163.5	167.5	171.8	176.2	180.7	185.2	190.1	195.0
Sales and UseTaxes	2.5	2.6	2.6	2.6	2.7	2.7	2.8	2.9	2.9	3.0	3.0	3.1	3.2	3.3	3.3	3.4	3.5	3.6	3.7	3.8	3.9
Corporate Profits Taxes Gross State Product	127.1	128.9	130.7	132.5	134.6	137.2	140.2	142.7	145.5	148.6	152.0	155.7	159.4	163.5	167.5	171.8	176.2	180.7	185.2	190.1	195.0
Profits tax	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.9
Local Property Taxes Project Directly	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Population	121.0	252.1	317.4	360.7	386.0	399.2	404.4	405.7	404.7	402.6	400.5	398.3	396.7	395.0	393.2	391.5	389.4	387.6	385.6	384.2	383.2
Total Property Taxes	0.2	0.4	0.5	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1
TOTAL TAXES	4.0	4.3	4.4	4.5	4.6	4.7	4.7	4.8	4.9	5.0	5.1	5.2	5.4	5.5	5.7	5.8	6.0	6.1	6.3	6.5	6.6
TAX CREDITS/STATE CONTRIBUTIONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX CREDITS/LOCAL CONTRIBUTIONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INDUCED GOVERNMENT SPENDING	0.4	0.8	1.0	1.2	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.8	1.9	1.9	2.0	2.0	2.1	2.1	2.2
NET TAXES	3.6																				
PRESENT VALUE OF TOTAL TAXES	$56.10																				
PRESENT VALUE OF TOTAL STATE TAXES	$47.90																				
PRESENT VALUE OF TOTAL LOCAL TAXES	$8.20																				
PRESENT VALUE OF TAX CREDITS/INDUCED SPENDING	$16.38																				
PRESENT VALUE OF NET TAXES*	$3.40																				
PRESENT VALUE OF NET STATE TAXES*	$37.83																				
PRESENT VALUE OF NET LOCAL TAXES	$1.89																				

*Induced spending allocated according to relative shares of spending.

Millstone Nuclear- New London County (Millions of Dollars)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Income Taxes																					
Personal Income	197.8	205.9	207.2	207.2	206.3	205.1	204.6	205.9	207.9	210.8	214.4	218.9	223.5	228.8	234.6	240.9	247.5	254.8	262.4	270.7	279.2
Income Tax	5.3	5.6	5.6	5.6	5.6	5.5	5.5	5.6	5.6	5.7	5.8	5.9	6.0	6.2	6.3	6.5	6.7	6.9	7.1	7.3	7.5
Sales and Use Taxes																					
Gross State Product	402.6	402.2	399.4	398.9	400.2	403.9	410.6	419.0	429.3	441.4	455.2	470.7	487.8	506.3	526.4	547.8	569.8	593.8	617.9	644.4	670.9
Sales and UseTaxes	8.1	8.0	8.0	8.0	8.0	8.1	8.2	8.4	8.6	8.8	9.1	9.4	9.8	10.1	10.5	11.0	11.4	11.9	12.4	12.9	13.4
Corporate Profits Taxes																					
Gross State Product	402.6	402.2	399.4	398.9	400.2	403.9	410.6	419.0	429.3	441.4	455.2	470.7	487.8	506.3	526.4	547.8	569.8	593.8	617.9	644.4	670.9
Profits tax	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.9	2.0	2.0	2.1	2.2	2.2	2.3	2.4	2.5	2.6	2.7	2.9	3.0
Local Property Taxes																					
Project Directly																					
Population	1038.0	2170.0	2684.0	3085.0	3390.0	3602.0	3752.0	3860.0	3936.0	3988.0	4022.0	4042.0	4048.0	4039.0	4019.0	3988.0	3947.0	3899.0	3850.0	3801.0	3755.0
Total Property Taxes	1.6	3.5	4.5	5.3	6.0	6.6	7.0	7.5	7.8	8.2	8.5	8.8	9.1	9.3	9.6	9.8	10.0	10.1	10.3	10.5	10.7
TOTAL TAXES	16.8	18.9	19.8	20.6	21.4	22.0	22.6	23.3	23.9	24.7	25.4	26.2	27.0	27.9	28.8	29.7	30.6	31.5	32.5	33.5	34.6
TAX CREDITS/STATE CONTRIBUTIONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX CREDITS/LOCAL CONTRIBUTIONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INDUCED GOVERNMENT SPENDING	-0.204	0.70	1.38	1.97	2.49	2.94	3.31	3.67	4.00	4.31	4.59	4.85	5.08	5.32	5.53	5.73	5.93	6.14	6.32	6.49	6.66
NET TAXES	17.0	18.2	18.5	18.7	18.9	19.0	19.3	19.6	19.9	20.4	20.8	21.4	22.0	22.6	23.2	23.9	24.6	25.4	26.2	27.0	27.9
PRESENT VALUE OF TOTAL TAXES	$270.58																				
PRESENT VALUE OF TOTAL STATE TAXES	$192.22																				
PRESENT VALUE OF TOTAL LOCAL TAXES	$78.36																				
PRESENT VALUE OF TAX CREDITS/INDUCED SPENDING	$38.64																				
PRESENT VALUE OF NET TAXES*	$231.94																				
PRESENT VALUE OF NET STATE TAXES*	$168.46																				
PRESENT VALUE OF NET LOCAL TAXES	$63.49																				

Millstone Nuclear-Connecticut (Millions of Dollars)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Income Taxes																					
Personal Income	344.0	356.6	356.1	351.8	345.8	339.9	335.6	335.6	337.3	341.1	346.6	354.1	362.3	371.8	382.6	394.0	406.1	419.6	433.4	448.5	464.0
Income Tax	9.3	9.6	9.6	9.5	9.3	9.2	9.1	9.1	9.1	9.2	9.4	9.6	9.8	10.0	10.3	10.6	11.0	11.3	11.7	12.1	12.5
Sales and Use Taxes																					
Gross State Product	943.1	947.1	947.5	951.0	957.7	968.6	984.9	1002.5	1023.8	1048.4	1075.9	1106.4	1139.3	1174.6	1212.2	1252.0	1292.5	1336.5	1380.6	1427.8	1475.4
Sales and UseTaxes	18.9	18.9	19.0	19.0	19.2	19.4	19.7	20.1	20.5	21.0	21.5	22.1	22.8	23.5	24.2	25.0	25.9	26.7	27.6	28.6	29.5
Corporate Profits Taxes																					
Gross State Product	943.1	947.1	947.5	951.0	957.7	968.6	984.9	1002.5	1023.8	1048.4	1075.9	1106.4	1139.3	1174.6	1212.2	1252.0	1292.5	1336.5	1380.6	1427.8	1475.4
Profits tax	4.2	4.2	4.2	4.2	4.2	4.3	4.4	4.4	4.5	4.6	4.8	4.9	5.1	5.2	5.4	5.6	5.7	5.9	6.1	6.3	6.5
Local Property Taxes Project Directly Population	1691.0	3547.0	4450.0	5122.0	5606.0	5929.0	6141.0	6287.0	6385.0	6449.0	6489.0	6512.0	6519.0	6508.0	6482.0	6442.0	6389.0	6326.0	6261.0	6198.0	6140.0
Total Property Taxes	2.7	5.7	7.4	8.8	9.9	10.8	11.5	12.2	12.7	13.2	13.7	14.2	14.6	15.0	15.4	15.8	16.1	16.4	16.8	17.1	17.4
TOTAL TAXES	35.0	38.5	40.2	41.5	42.7	43.7	44.7	45.7	46.8	48.1	49.4	50.8	52.2	53.8	55.4	57.0	58.7	60.4	62.2	64.1	66.0
TAX CREDITS/STATE CONTRIBUTIONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAX CREDITS/LOCAL CONTRIBUTIONS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INDUCED GOVERNMENT SPENDING	1.19	4.96	7.40	9.39	10.99	12.29	13.34	14.25	15.08	15.83	16.54	17.20	17.84	18.45	19.01	19.56	20.07	20.57	21.06	21.56	22.04
NET TAXES	33.8	33.6	32.8	32.2	31.7	31.4	31.3	31.5	31.8	32.2	32.8	33.6	34.4	35.3	36.4	37.5	38.6	39.9	41.1	42.5	44.0
PRESENT VALUE OF TOTAL TAXES	532.3																				
PRESENT VALUE OF TOTAL STATE TAXES	$404.73																				
PRESENT VALUE OF TOTAL LOCAL TAXES	$127.61																				
PRESENT VALUE OF TAX CREDITS/INDUCED SPENDING	$147.78																				
PRESENT VALUE OF NET TAXES*	$384.56																				
PRESENT VALUE OF NET STATE TAXES*	$313.85																				
PRESENT VALUE OF NET LOCAL TAXES	$70.71																				
*Induced spending allocated according to relative shares of spending.																					

Appendix II:
REMI OUTPUT

Millstone Nuclear Power Plants Differences as Compared to REMI Standard Regional Control Fairfield County, CT									
Variable	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2010*	*2015*	*2020*
Employment (Thous)	0.7761	0.6914	0.6186	0.5528	0.4988	0.4564	0.3797	0.3932	0.4227
GRP (Gross Regional Produ	0.1218	0.1187	0.1158	0.1132	0.1111	0.1095	0.1067	0.1087	0.1119
Personal Income (Bil Nom $	0.03855	0.0389	0.03799	0.03669	0.03533	0.0341	0.03376	0.03954	0.04807
PCE-Price Index 92$	0.01906	0.02412	0.02582	0.02577	0.02464	0.02315	0.01683	0.01553	0.01616
Real Disp Pers Income (Bil	0.01745	0.01648	0.01541	0.01445	0.01366	0.01302	0.01256	0.0138	0.01538
Population (Thous)	0.1167	0.2487	0.3217	0.374	0.4142	0.4432	0.51	0.5345	0.5374
Economic Migrants	0.1156	0.1284	0.06612	0.04744	0.0327	0.02113	0.000658	-0.00273	-0.00459
Total Migrants	0.1156	0.1283	0.06609	0.04739	0.03264	0.02108	0.000512	-0.00296	-0.00489
Labor Force	0.1045	0.1761	0.2112	0.2252	0.2336	0.2365	0.2319	0.2411	0.2603
Demand (Bil 92$)	0.06044	0.05382	0.04751	0.04184	0.03696	0.03301	0.02664	0.0295	0.03435
Output (Bil 92$)	0.2243	0.2169	0.21	0.2038	0.1987	0.1945	0.1878	0.191	0.1964
Relative Profitability Manufa	-0.00017	-0.00021	-0.00023	-0.00023	-0.00022	-0.0002	-0.00013	-0.00011	-9.8E-05
Labor Intensity	-3.52E-06	-1.7E-05	-2.8E-05	-3.6E-05	-4.2E-05	-4.5E-05	-4.7E-05	-4.3E-05	-3.8E-05
Regional Purchase Coeffici	-6.4E-05	-5.8E-05	-5.2E-05	-4.7E-05	-4.1E-05	-3.5E-05	-2E-05	-1.2E-05	-7.4E-06
Imports (Bil 92$)	0.03488	0.03125	0.02775	0.02461	0.02182	0.0195	0.0156	0.01693	0.01954
Self Supply (Bil 92$)	0.02556	0.02257	0.01976	0.01723	0.01514	0.01351	0.01105	0.01257	0.01482
Exports US/ROW (Bil 92$)	-0.00136	-0.00295	-0.00443	-0.00575	-0.00682	-0.00763	-0.00874	-0.00822	-0.00785
Exports - MR (Multi-Region)	0.04826	0.04547	0.04283	0.04051	0.03849	0.0368	0.03364	0.03481	0.03757
Wage Rate (Thous Nom$)	0.01191	0.01551	0.01659	0.01655	0.01574	0.01457	0.01022	0.009659	0.01093

Millstone Nuclear Power Plants
Differences as Compared to REMI Standard Regional Control
New Haven County, CT

Variable	2000	2001	2002	2003	2004	2005	2010	2015	2020
Employment (Thous)	0.3751	0.3334	0.2942	0.2582	0.229	0.2072	0.1782	0.1962	0.2178
GRP (Gross Regional Produc	0.1113	0.1104	0.1094	0.1085	0.1078	0.1075	0.107	0.1086	0.1105
Personal Income (Bil Nom $)	0.02536	0.02583	0.02513	0.02399	0.02275	0.0216	0.02048	0.02406	0.0295
PCE-Price Index 92$	0.01753	0.02051	0.02071	0.01939	0.01747	0.01538	0.008896	0.008118	0.008606
Real Disp Personal Income (	0.01278	0.01248	0.01183	0.01115	0.01051	0.009954	0.009285	0.01009	0.01124
Population (Thous)	0.121	0.2521	0.3174	0.3607	0.386	0.3992	0.4005	0.3915	0.3832
Economic Migrants	0.1199	0.1275	0.05964	0.03629	0.01842	0.006007	-0.00786	-0.00565	-0.00491
Total Migrants	0.1199	0.1275	0.05961	0.03626	0.0184	0.005987	-0.0079	-0.0057	-0.00499
Labor Force	0.1245	0.2192	0.2616	0.2828	0.2908	0.2909	0.2643	0.2652	0.2826
Demand (Bil 92$)	0.03971	0.03637	0.03252	0.02883	0.02567	0.02309	0.01943	0.02194	0.02531
Output (Bil 92$)	0.2033	0.1999	0.1964	0.1934	0.1909	0.189	0.1869	0.1895	0.1928
Relative Profitability Manufac	-0.00013	-0.00016	-0.00016	-0.00015	-0.00013	-0.00011	-4.9E-05	-3.6E-05	-3.2E-05
Labor Intensity	-2.80E-06	-9.1E-06	-1.5E-05	-1.9E-05	-2.2E-05	-2.3E-05	-2.4E-05	-2E-05	-1.7E-05
Regional Purchase Coefficie	-8.2E-05	-8E-05	-7.7E-05	-7.2E-05	-6.7E-05	-6.2E-05	-4.4E-05	-3.5E-05	-3E-05
Imports (Bil 92$)	0.02288	0.02123	0.01931	0.01736	0.01565	0.01421	0.01192	0.01309	0.01483
Self Supply (Bil 92$)	0.01684	0.01514	0.0132	0.01147	0.01001	0.008898	0.007511	0.008846	0.01048
Exports US/ROW (Bil 92$)	-0.00076	-0.00156	-0.00226	-0.00281	-0.00319	-0.00342	-0.0031	-0.00246	-0.00213
Exports - MR (Multi-Region) (	0.01711	0.01616	0.01532	0.01455	0.01388	0.01334	0.01229	0.01299	0.01433
Wage Rate (Thous Nom$)	0.01048	0.01155	0.01118	0.01017	0.008869	0.007519	0.003849	0.003502	0.003914

Millstone Nuclear Power Plants Differences as Compared to REMI Standard Regional Control Hartford County, CT									
Variable	2000	2001	2002	2003	2004	2005	2010	2015	2020
Employment (Thous)	0.835	0.7656	0.7026	0.6414	0.5898	0.5493	0.4838	0.5068	0.5435
GRP (Gross Regional Produ	0.1476	0.1455	0.1431	0.1408	0.1389	0.1374	0.1349	0.1374	0.1413
Personal Income (Bil Nom $	0.03864	0.04031	0.0402	0.03926	0.03804	0.0368	0.03648	0.04251	0.05122
PCE-Price Index 92$	0.02641	0.03238	0.03416	0.03351	0.03171	0.02933	0.02122	0.01973	0.01991
Real Disp Personal Income (	0.01869	0.01851	0.01785	0.01707	0.01631	0.01565	0.01499	0.01624	0.01792
Population (Thous)	0.1668	0.3534	0.4575	0.5317	0.5815	0.6129	0.6642	0.6778	0.6691
Economic Migrants	0.1649	0.1818	0.09575	0.06402	0.03908	0.02127	-0.00476	-0.00685	-0.0093
Total Migrants	0.1649	0.1818	0.0957	0.06397	0.03903	0.02122	-0.00489	-0.00704	-0.00955
Labor Force	0.1678	0.2973	0.3611	0.3972	0.4143	0.42	0.4008	0.408	0.4351
Demand (Bil 92$)	0.07448	0.06932	0.06351	0.0578	0.05258	0.04828	0.04122	0.04486	0.05083
Output (Bil 92$)	0.2543	0.2481	0.242	0.2364	0.2316	0.2277	0.2218	0.2261	0.233
Relative Profitability Manufac	-0.000178	-0.00023	-0.00024	-0.00023	-0.00021	-0.00018	-0.0001	-7.8E-05	-6.5E-05
Labor Intensity	-2.86E-06	-1.2E-05	-2E-05	-2.6E-05	-3E-05	-3.3E-05	-3.4E-05	-2.9E-05	-2.2E-05
Regional Purchase Coefficie	-0.000106	-0.00011	-0.00011	-0.00011	-0.0001	-9.7E-05	-7.7E-05	-6.4E-05	-5.5E-05
Imports (Bil 92$)	0.04146	0.0391	0.03647	0.03374	0.03108	0.02885	0.025	0.02675	0.02978
Self Supply (Bil 92$)	0.03302	0.03022	0.02704	0.02407	0.0215	0.01944	0.01621	0.01812	0.02105
Exports US/ROW (Bil 92$)	-0.00124	-0.00267	-0.00401	-0.00514	-0.00601	-0.00664	-0.00706	-0.00621	-0.00548
Exports - MR (Multi-Region)	0.0415	0.0396	0.03796	0.03645	0.03508	0.03393	0.03163	0.03324	0.03646
Wage Rate (Thous Nom$)	0.01368	0.01694	0.0175	0.0167	0.01521	0.01343	0.007774	0.006481	0.006454

Millstone Nuclear Power Plants
Differences as Compared to REMI Standard Regional Control
New London County, CT

Variable	2000	2001	2002	2003	2004	2005	2010	2015	2020
Employment (Thous)	4.968	4.554	4.19	3.871	3.601	3.38	2.878	2.839	2.939
GRP (Gross Regional Produ	0.3348	0.3277	0.3189	0.312	0.3066	0.3031	0.308	0.3329	0.3654
Personal Income (Bil Nom $)	0.1978	0.2059	0.2072	0.2072	0.2063	0.2051	0.2144	0.2409	0.2792
PCE-Price Index 92$	0.4959	0.6042	0.6524	0.6616	0.65	0.628	0.5109	0.4507	0.4386
Real Disp Personal Income (	0.0999	0.09955	0.09696	0.09497	0.09324	0.09177	0.09199	0.09675	0.1027
Population (Thous)	1.038	2.17	2.684	3.085	3.39	3.602	4.022	3.988	3.755
Economic Migrants	1.029	1.105	0.482	0.3534	0.2404	0.1547	-0.01594	-0.06711	-0.07593
Total Migrants	1.029	1.105	0.4817	0.353	0.2401	0.1544	-0.01675	-0.06825	-0.07736
Labor Force	0.8706	1.466	1.686	1.827	1.91	1.945	1.922	1.963	2.031
Demand (Bil 92$)	0.7317	0.696	0.6595	0.6289	0.5995	0.5751	0.5285	0.5433	0.5813
Output (Bil 92$)	0.5327	0.5157	0.4966	0.4815	0.4697	0.4614	0.4648	0.5056	0.5597
Relative Profitability Manufac	-0.00502	-0.00643	-0.00709	-0.00729	-0.00722	-0.007	-0.00549	-0.00451	-0.00406
Labor Intensity	-1.57E-04	-0.00103	-0.00173	-0.00228	-0.0027	-0.00303	-0.00375	-0.00377	-0.00356
Regional Purchase Coefficie	-0.00691	-0.00667	-0.0066	-0.00652	-0.00636	-0.00622	-0.00552	-0.00505	-0.00481
Imports (Bil 92$)	0.5551	0.5301	0.5062	0.4862	0.466	0.4492	0.4176	0.4297	0.4587
Self Supply (Bil 92$)	0.1766	0.1659	0.1533	0.1427	0.1335	0.1259	0.1108	0.1135	0.1226
Exports US/ROW (Bil 92$)	-0.00863	-0.01845	-0.02778	-0.03616	-0.0432	-0.04886	-0.06125	-0.06068	-0.05759
Exports - MR (Multi-Region)	0.000526	-0.00204	-0.00453	-0.00676	-0.00865	-0.01018	-0.01282	-0.01245	-0.0114
Wage Rate (Thous Nom$)	0.6525	0.7008	0.7171	0.7183	0.709	0.6947	0.6596	0.6861	0.7651

Millstone Nuclear Power Plants Differences as Compared to REMI Standard Regional Control Connecticut									
Variable	2000	2001	2002	2003	2004	2005	2010	2015	2020
Employment (Thous)	7.393	6.749	6.173	5.653	5.216	4.866	4.155	4.191	4.406
GRP (Gross Regional Produc	0.8085	0.7947	0.7782	0.7644	0.7533	0.7456	0.7437	0.7763	0.8198
Personal Income (Bil Nom $)	0.344	0.3566	0.3561	0.3518	0.3458	0.3399	0.3466	0.394	0.464
PCE-Price Index 92$	0.05302	0.06451	0.06868	0.06848	0.06602	0.06253	0.04767	0.04242	0.04199
Real Disp Personal Income (	0.1728	0.1712	0.1657	0.1606	0.1559	0.1519	0.1493	0.1584	0.1706
Population (Thous)	1.691	3.547	4.45	5.122	5.606	5.929	6.489	6.442	6.14
Economic Migrants	1.675	1.81	0.8397	0.5891	0.3808	0.2267	-0.044	-0.101	-0.1091
Total Migrants	1.675	1.81	0.8392	0.5886	0.3803	0.2263	-0.04519	-0.1026	-0.1112
Labor Force	1.522	2.63	3.1	3.375	3.524	3.578	3.473	3.529	3.675
Demand (Bil 92$)	0.9617	0.9077	0.8506	0.8004	0.7536	0.7149	0.6456	0.6726	0.7299
Output (Bil 92$)	1.385	1.347	1.308	1.274	1.247	1.227	1.212	1.266	1.34
Relative Profitability, Manufac	-0.000486	-0.00062	-0.00067	-0.00067	-0.00065	-0.00061	-0.00044	-0.00036	-0.00032
Labor Intensity	-1.38E-05	-8.1E-05	-0.00014	-0.00018	-0.00021	-0.00024	-0.00029	-0.00028	-0.00026
Regional Purchase Coefficie	-0.000848	-0.00081	-0.00079	-0.00077	-0.00073	-0.0007	-0.0006	-0.00053	-0.00049
Imports (Bil 92$)	0.5638	0.5388	0.5128	0.49	0.4668	0.4474	0.4127	0.4265	0.4563
Self Supply (Bil 92$)	0.3978	0.3689	0.3378	0.3104	0.2868	0.2675	0.2329	0.2461	0.2737
Exports US/ROW (Bil 92$)	-0.01303	-0.02787	-0.04173	-0.05389	-0.06384	-0.07152	-0.08475	-0.08099	-0.07567
Exports - MR (Multi-Region) (	0	0	0	0	0	0	0	0	0
Wage Rate (Thous Nom$)	0.05481	0.06065	0.06211	0.06154	0.05968	0.05726	0.05022	0.05106	0.05669

Appendix III:
Modeling Strategy

Stage 1: Policy Variables

- ✓ Output without employment and investment (because we are not tearing down the building) (Population weighted distribution across the counties).
- ✓ Nullify intermediate input induced by sales (we have precise amount of money Millstone spends for goods and services in Connecticut. Therefore, we do not want the model to take care of intermediate input issue).
- ✓ Intermediate input (as final sale) by counties and sectors.
- ✓ Employment by place of work (public utilities and miscellaneous professional services) all in New London County.
- ✓ Wage Adjustment for New London County

Stage 2: Policy Variables

- ✓ All the variables from stage 1 ***PLUS***
- ✓ State and local spending (we know *a priori* that Millstone pays $33 million property tax. This tax is part of the total output of Millstone. Therefore, removing Millstone will reduce the government spending by $33 million. However, at the first stage, total induced government spending was less than $33 million. We take the difference between $33 million and induced government spending, and insert the difference as new policy variable into the model. The purpose of this exercise is to see how much impact the decrease in local spending would have on overall economy).
  - ✓ When we run the model and get the results, in the tax worksheet, we take the difference between model generated induced government spending and $33million property tax. The difference will be reported as the net induced government spending (exclusive of $33 million).