Dominion Nuclear Connecticut, Inc.
Millstone Power Station
Rope Ferry Road
Waterford, CT 06385

Dominion

Cooling Water Alternatives
Essa review

→ DNC Response

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WATER MANAGEMENT BUREAU

October 3, 2002

D17347

Mr. James Grier
Supervising Sanitary Engineer
Permitting, Enforcement & Remediation Division, Water Management Bureau
Department of Environmental Protection
79 Elm Street
Hartford, CT 06106-5127

References:
1. Letter C10845, J.F. Grier to P. Jacobson, dated May 9, 2002.
2. Letter D17249, W. Matthews to M.J. Harder, dated August 31, 2001.
3. Letter D17339, D. Hicks to J. Grier, dated May 30, 2002.
4. Letter D17358, G.D. Hicks to J. Grier, dated July 26, 2002.

Millstone Power Station
Cooling-Water System Technology Study
<u>Response to DEP Comments</u>

Dear Mr. Grier:

By way of a letter dated May 9, 2002 (Reference 1), the Connecticut Department of Environmental Protection (DEP) requested from Dominion Nuclear Connecticut, Inc. (DNC) responses to questions, comments, or concerns regarding the review by DEP and its contractor, ESSA Technologies Ltd. (ESSA), of the final report on the use of once-through cooling water at Millstone Power Station (MPS), entitled "An Evaluation of Selected Cooling-Water System Alternatives for Millstone Power Station", which was submitted by DNC to DEP on August 31, 2001 (Reference 2). DNC notified DEP (Reference 3) that it anticipated responding on or before September 15, 2002. As discussed with the DEP on September 4, 2002, this response, by mutual agreement, is being submitted on or before October 4, 2002. The enclosed materials provide additional information, clarifications, and special studies that address each of the fifteen questions, requests, or concerns of DEP in a single, comprehensive response. The special studies include predictive thermal plume modeling performed by Dr. Eric Adams of the Massachusetts Institute of Technology and hydrodynamic modeling related to the use of groins or jetties to reduce entrainment that was completed by Alden Research Laboratory, Inc.

As requested by DEP, this submission also evaluates several additional alternatives. Those reviewed included several reduced flow-higher differential temperature (ΔT) alternatives for each unit during the larval winter flounder entrainment season, which are accomplished by using variable speed pumps. The latter alternatives also include as an option a 10% increase in flow during summer and early fall. Potential thermal effects associated with the increased ΔT alternatives are evaluated and discussed. DNC also evaluated the combined use of the Units 1 and 2 intake structures fitted with fine-mesh screens to address the cooling-water needs of Unit 2, an offshore fine-mesh screen facility serving both Units 2 and 3, and the placement of groins or jetties to reduce entrainment of Niantic River winter flounder larvae. DNC has concluded that these three options do not warrant further consideration.

A review of material presented in the Cooling-Water System Alternatives Report (Reference 2) indicated the need to revise certain data. For example, cost estimates for some of the alternatives presented in the report were revised. Certain financial analyses have been modified, mostly to reflect changes to the expected outage periods for installation of certain technology options. As a result, errata are incorporated where appropriate. Per your request for this information, a compact disc is provided that contains an Excel spreadsheet with various and detailed financial input parameters and assumptions. This information is necessary for estimating the cost of each technology option and was not included in the initial report.

DNC responded to the issue of nuclear safety and reliability, noting that both are inextricably linked. Included is an analysis and discussion by the Millstone Probabilistic Risk Assessment Group, which demonstrates that there is an added risk by operating with less than the full complement of condenser cooling-water pumps. Certain changes in intake technology may also require further detailed safety analyses and, possibly, approval by the United States Nuclear Regulatory Commission.

DNC also notes that an error was made in the calculation of equivalent-adults resulting from the entrainment at MPS of non-Niantic River winter flounder larvae. Revised calculations are presented as part of this submission and equivalent-adult estimates increased by about 14.5% from those presented in the Cooling-Water System Alternatives Report. DNC also is providing revised equivalent-adult calculations for tautog that are based on the University of Connecticut tautog study sponsored by DNC and recently submitted to DEP (Reference 4). The latter study showed that Long Island tautog are more fecund than found in a Virginia study providing reproductive information first used in the Cooling-Water System Alternatives Report. Equivalent-adult estimates were reduced by about 40% as a result of this new information. Finally, with respect to DEP Comment #9 in its May 9 letter, DNC may wish, at a later date, to provide a response to any comments stemming from ESSA's review of the winter flounder larval mass-balance model, which have not yet been received by DNC.

As there may be additional questions regarding this response, DNC personnel are available to meet with representatives of DEP and ESSA, if so desired. Please contact Mr. Paul Jacobson, Millstone Environmental Services at (860) 447-1791 ext. 2335 with any questions or to arrange such a meeting.

Very truly yours,

DOMINION NUCLEAR CONNECTICUT, INC.

Gerald D. Hicks
Director - Nuclear Safety and Licensing

Enclosure

cc: Mr. Ernest Beckwith
Connecticut Department of Environmental Protection
Marine Fisheries Office
P.O. Box 719
Old Lyme, CT 06371

Enclosure 1 to Letter No. D17347

RESPONSES TO QUESTIONS, COMMENTS, AND CONCERNS REGARDING THE AUGUST 31, 2001 REPORT "MILLSTONE POWER STATION AN EVALUATION OF COOLING-WATER SYSTEM ALTERNATIVES' AS NOTED IN THE LETTER OF MAY 9, 2002 FROM J. GRIER, CT DEP, TO DOMINION NUCLEAR CONNECTICUT, INC.

DOMINION NUCLEAR CONNECTICUT, INC.
MILLSTONE POWER STATION
NPDES PERMIT No. CT0003263

PO Box 128
Waterford, Connecticut 06385-0128
October 2002

Responses to Questions, Comments and Concerns Regarding the August 31, 2001 Report "Millstone Power Station An Evaluation of Cooling-Water System Alternatives" as Noted in the Letter of May 9, 2002 from J. Grier, CT DEP, to Dominion Nuclear Connecticut, Inc.

Introduction

In a letter dated May 9, 2002 sent by Mr. James Grier of the Connecticut Department of Environmental Protection (DEP) to Dominion Nuclear Connecticut, Inc. (DNC), fifteen questions, comments, or concerns were noted that were based on the review by DEP and its contractor, ESSA Technologies Ltd. (ESSA), of the August 31, 2001 report entitled "Millstone Power Station An Evaluation of Cooling-Water System Alternatives" (henceforth referred to as the "Cooling-Water System Alternatives Report"). DNC was asked to respond to these issues while further review of the Cooling-Water System Alternatives Report and of the NPDES permit renewal application for Millstone Power Station (MPS) proceeds. The following material provides a response to each comment of the May 9 letter, which is included verbatim before the response. In addition, DNC has included with this submission various corrections and supplementary information to the Cooling-Water System Alternatives Report, which follow the responses. Please note that any table previously presented in the Cooling-Water System Alternatives Report and updated in this submission is denoted as a "Revised Table", whereas any new information presented herein is given in a "Table" or "Figure".

I. Responses to DEP Questions, Comments, or Concerns

DEP Question, Comment, or Concern #1:

The study presents the benefits of a given alternative technology to reduce entrainment at Millstone Station (i.e. % reduction in condenser cooling water use) based on comparison to the currently total permitted maximum flowrate for Units 1, 2, and 3. This methodology underestimates all such benefits relative to the actual existing and planned future operation of Units 2 and 3 only. Thus all estimates of entrainment reduction must be revised to reflect the decision to retire Unit 1 and its contribution to total Station inflow.

DNC Response to Question, Comment, or Concern #1:

Estimates of entrainment reduction are based on the current state of operation at MPS. While DNC observed in a number of places (e.g., pp. ES-5; IN-2; I-1-1 and 2; II-2-17; II-4-10, -14; III-6, -8, and 10) throughout the Cooling-Water System Alternatives Report that the retirement of Unit 1 resulted in a 23% reduction in NPDES-permitted cooling-water use at MPS, percent reductions in cooling-water use as determined for the various alternatives evaluated were computed on the basis of Units 2 and 3 operation only. Likewise, the assessments of entrainment impact to the fish species evaluated found in Part II, Chapter 4 (see Sections 4.2.2 and 4.2.4 for details) were also done on the basis of two-unit operation - i.e., the effect of Unit 1 entrainment was removed in the Stochastic Winter Flounder Population Dynamics model projections of the Niantic River winter flounder population abundance by adjusting larval winter flounder production loss estimates made during three-unit operation downward by a conservative 20% to reflect the retirement of Unit 1. Similarly, later in the model time-series, production loss estimates were again readjusted downward to account for the anticipated retirement of Unit 2 in 2035 and to zero at the proposed retirement date for Unit 3 in 2045.

Percent cooling-water flow reduction depends upon the base flow used. Presently, NPDES-permitted three-unit flow, including both the circulating water systems (condenser cooling water) and service water systems (nuclear safety-related) for MPS is 1,964,800 gpm: a total of 444,000 gpm for Unit 1, 572,800 gpm for Unit 2, and 948,000 gpm for Unit 3 (see Revised Table 7.11-1, which follows the text of this response). With Unit 1 shut down, station design flow is 1,520,800 gpm. However, actual circulating water flow at Unit 2 differs from that permitted (504,000 gpm vs. 548,800 gpm) due to changes in equipment and other factors affecting pump operation (see discussion on pages I-30 and 31 in the Cooling-Water System Alternatives Report) and actual station cooling-water use is currently 1,476,000 gpm. In determining flow under reduced circulating water pump (CWP) operation, other constraints of the condenser circulating water system also may result in calculated flow rates not equal to nominal flow rates (see Revised Table 7.11-1).

Revised Table 7.11-1 presents percent reductions in flow as a result of selected flow reduction options presented in the Cooling-Water System Alternatives Report that were calculated on the basis of both current two-unit operation (with Unit 1 shut down and not included in calculating flow reductions) and reductions determined with respect to previous three-unit operation, which takes into consideration the shutdown of Unit 1. This allows an alternative by alternative comparison to be made under present operating condition of MPS and also with the additional reduction in flow resulting from the shutdown of Unit 1. Reductions in cooling-water use for other alternatives that are introduced for the first time in this response will be indicated where they are first mentioned.

REVISED TABLE 7.11-1. Summary of flow reduction alternatives and percent reduction in MPS cooling-water flow achieved relative to present two-unit and former three-unit operation (NPDES Permitted flow).

	Unit 1		Unit 2		Unit 3		Station	% flow reduction	% flow reduction
Description[a]	CWS	SWS	Tot CWS	SWS	Tot CWS	SWS	Total	With Unit 1 shut down	From permitted flow
	(gpm)	(gpm)	(gpm)	(gpm)	(gpm)	(gpm)	(gpm)	(%)	(%)
NPDES Permitted Flow	420,000	24,000	548,800	24,000	918,000	30,000	1,964,800	N/A	N/A
With Unit 1 shut down	0	0	504,000	24,000	918,000	30,000	1,476,000	N/A	23%
Single Unit Changes - Reduced Number of Operating CWPs[b]									
Unit 3 - 5 CWPs	0	0	504,000	24,000	803,600	30,000	1,361,600	8%	31%
Unit 3 - 4 CWPs	0	0	504,000	24,000	677,200	30,000	1,235,200	16%	37%
Unit 2 - 3 CWPs	0	0	403,200	24,000	918,000	30,000	1,375,200	7%	30%
Single Unit Changes - Condenser By-pass, Throttling, or Variable Speed CWPs									
Unit 3	0	0	504,000	24,000	690,000	30,000	1,248,000	15%	36%
Unit 2	0	0	412,000	24,000	918,000	30,000	1,384,000	6%	30%
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%	36%
U3 - 4 CWPs & U2 - 3 CWPs	0	0	403,200	24,000	677,200	30,000	1,134,400	23%	42%
Combined Unit Changes - Condenser By-pass, Throttling, or Variable Speed CWPs									
Units 2 & 3	0	0	412,000	24,000	690,000	30,000	1,156,000	22%	41%
Natural Draft Cooling Towers									
Full Flow - Unit 3	0	0	504,000	24,000	36,000	30,000	594,000	60%	70%
2/3 Full - Unit 3	0	0	504,000	24,000	333,000	30,000	891,000	40%	55%
Full - Unit 2	0	0	26,000	24,000	918,000	30,000	998,000	32%	49%
Full - Units 2 & 3	0	0	26,000	24,000	36,000	30,000	116,000	92%	94%
Mechanical Draft Cooling Towers									
Full - Unit 2	0	0	24,000	24,000	918,000	30,000	996,000	33%	49%
Full - Unit 3	0	0	504,000	24,000	36,000	30,000	594,000	60%	70%
Full - Units 2 & U3	0	0	24,000	24,000	36,000	30,000	114,000	92%	94%

[a] CWS = circulating water system and SWS = service water system.

[b] CWP = circulating water pumps.

DEP Question, Comment, or Concern #2/3:

The potential benefits of a greater (than currently permitted) maximum temperature differential (delta T) of the Unit discharges (DSNs 001B and 001C) and the total Station discharge (DSN 001) at the quarry cut have not been explored. It is possible that seasonally higher discharge temperatures are acceptable to reduce entrainment during critical winter flounder spawning periods. The Department has allowed higher delta Ts at other generating stations in Connecticut to achieve total water usage reduction benefits without adverse effect. Any changes must, of course, be consistent with currently adopted Connecticut water quality standards. Also, DNC's historical assumption of 100% mortality of entrained organisms would have to be carefully reexamined to make sure that a higher delta T would truly result in less entrainment losses. The Department would like to meet with DNC in order to fully scope out what needs to be done to address this issue.

DNC Response to Question, Comment, or Concern #2/3:

2/3.1 Introduction

Representatives of DNC and DEP met at the Hartford offices of DEP on July 30, 2002 to discuss this issue. Among the points of discussion was that present two-unit operation would serve as the base case for comparison for higher ΔT/lower flow operating alternatives. Potential effects of a higher ΔT/lower flow thermal plume were to be evaluated and any altered thermal plume had to meet Connecticut water quality standards. As a result, Stone and Webster, Inc. (S&W), DNC's engineering contractor for the cooling-water alternatives study, re-analyzed a number of cooling-water flow reduction options and evaluated an alternative with an approximate 50% increase in the present Units 2 and 3 condenser design ΔT limits of 24°F and 17°F to about 36°F and 27°F, respectively. In addition, DNC initiated an evaluation of potential thermal effects resulting from a higher ΔT. The newly proposed ΔT/lower flow alternatives are described and discussed in greater detail elsewhere in this document (see DNC Response to Question, Comment, or Concern #6). The response following below focuses on thermal effects issues.

2/3.2 Higher ΔT/Lower Flow Alternatives

An additional assumption for the higher ΔT/lower flow alternatives investigated was that turbine backpressure at each unit would not exceed 3 inch HgA (see the Response to Questions, Comments, or Concerns #5 and 6). This resulted in variable CWP flows that depended upon the inlet water temperature. For example, at inlet water temperatures of 35 to 55°F that are typically found during the larval winter flounder season, CWP flow at Unit 2 could be reduced by 38% to about 338,800 gpm and at Unit 3 by 39% to 558,900 gpm. Including service water flows, at the midpoint of the larval winter flounder period the combined MPS ΔT would be about 28.7°F at a total station discharge of 951,700 gpm. However, under this mode of operation, flow reduction becomes progressively less as inlet water temperature increases during late spring and summer in order to maintain turbine backpressure. At near peak summer water temperature of 70°F, total MPS flow under this alternative would be nearly the same as under present two-unit operation.

Another alternative examined was an allowance for an approximate 10% increase in cooling-water flow during summer and early fall to partially recover generation lost during the larval winter flounder season, during which time flow was reduced. This alternative had Unit 2 operating from about mid-June through mid-October at a ΔT of about 22°F with CWP flow of about 554,400 gpm and Unit 3 having a ΔT of approximately 14.75°F with CWP flow of 1,023,000 gpm. This operating condition resulted in a station discharge of 1,631,400 gpm (including service water flow) having a weighted average ΔT of 17.7°F during this time period.

Based on increases in ΔT at Units 2 and 3 in concert with lower flow, Dr. Eric Adams of The Massachusetts Institute of Technology completed an analysis of the MPS thermal plume in July 2002. This report (Adams 2002) is included at the end of the response to this comment. In his analysis, Adams (2002) used discharge temperatures of 33.7°F and 25.7°F and flow rates (combined CWP and service water flow) of nearly 370,000 gpm (equivalent to 825 cfs as used in Adams 2002) and 603,600 gpm (1,346 cfs) for Units 2 and 3, respectively. This resulted in a station discharge flow at the Millstone quarry cuts of 973,500 gpm (2,171 cfs) at a weighted average discharge temperature of 28.7°F. A second analysis examined a more severe thermal condition: operation of Unit 2 alone with its higher ΔT of 33.7°F. Water flow and ΔT for these alternatives (and the modeled conditions noted in the following paragraphs) are summarized in Table 2/3.2-1. Flow during the time periods when all three MPS units and when only Units 1 and 2 were in operation (both conditions with two quarry cut openings) are also given on this table as actual thermal effects found during these modes of operation at MPS are referred to in the discussion below.

TABLE 2/3.2-1. MPS operating conditions examined for potential thermal plume effects.

Operating condition	Approximate time period	MPS flow (gpm)	MPS ΔT (°F)
Former three-unit (Units 1-3) operation with two quarry cut openings	April 1986 - November 1995	1,964,800	19.7
Former two-unit (Units 1 and 2) operation with two quarry cut openings	August 1983 - April 1986	1,017,000	23.4
Increased ΔT / lower CWP flow (S&W analysis)	Larval winter flounder season (late March - early June)	951,700	28.7
10% increase in present CWP flow (S&W analysis)	mid-June - mid-October	1,631,000	17.7
Present two-unit (Units 2 and 3) operation (Adams 2001)	Year-round	1,476,000	19.0
Increased ΔT / lower CWP flow (Adams 2002)	-	973,500	28.7
Increased ΔT / lower CWP flow; Unit 2 operation only (Adams 2002)	-	370,000	33.7

Since the work of Dr. Adams and S&W proceeded in parallel, ultimately small differences in flow and temperature resulted between the studies, particularly as S&W investigated operational turbine backpressures smaller than the 4.25 inch HgA that provided the temperature and flow values used by Dr. Adams. However, the differences were small enough that neither the modeled plume sizes nor the resulting thermal effects are appreciably different between the postulated thermal plume conditions. In his most recent analysis, Adams (2002) compared lengths and widths of isotherms at four tidal states for Units 2 and 3 and Unit 2 alone under higher ΔT/lower flow to that of the former full three-unit thermal plume under normal cooling-water flow conditions (Tables 1a-1d; pp. 2-3 of Adams 2002). Since the basis for comparison was agreed to be the current two-unit thermal plume, data presented in Adams (2001) that was included in the Cooling-Water System Alternatives Report for two-unit, 10 CWP operation was used as the basis for comparison with the addition of predicted plume width and height data lacking in Adams (2001). Plume sizes at various tidal stages for the various MPS operating conditions are summarized in Table 2/3.2-2a-d. With reduced flows, the length and width of the isotherms are marginally smaller. However, the depth of each isotherm is very much reduced at the lower flow rates.

2/3.3 Entrainment Survival and Higher ΔT

Along with mechanical effects (e.g., pressure changes, abrasion) associated with passage through the condenser cooling-water system, entrained organisms also are affected by the rapid rise in temperature. Entrainment survival was discussed in Part II, Chapter 3, Section 3.2.5 of the Cooling-Water System Alternatives Report for winter flounder, Section 3.3.5 for tautog, and Section 3.4.5 for the other fishes evaluated. Entrainment survival studies for winter flounder at MPS were also given in Appendix A to Chapter 3. In a laboratory study, Itzkowitz and Schubel (1983) concluded that larval winter flounder, particularly younger, newly hatched larvae, were highly resistant to thermal shock. However, results of MPS entrainment survival studies showed that survival of entrained Stage 1 through 3 larval winter flounder was negligible, whereas about one-fifth of Stage 4 larvae and all of the few Stage 5 juveniles collected survived through a 96-hour holding period. This was contrary to the findings of Itzkowitz and Schubel (1983), perhaps because mechanical effects and interactions between mechanical and thermal effects were not evaluated in the latter study. Relatively more intensive entrainment survival studies conducted at the Oyster Creek Nuclear Generating Station (OCNGS) in Forked River, NJ showed that survival was highly correlated with ΔT (EA 1986). Based on the predictive relationship found, survival at OCNGS was predicted to be 0% at a ΔT of 21.5°F. Thus, it appears that increasing the ΔT resulting from present MPS operation would result in even lower survival of larval winter flounder. However, this loss would be offset by decreasing the number of larvae entrained under the lower flow options.

2/3.4 Potential Thermal Effects

Potential environmental impacts from a thermal plume discharged with a higher ΔT and lower flow than the present MPS operating condition are best evaluated by re-examining the thermal effects that occurred between August 1983 and April 1986, when MPS Units 1 and 2 were in operation and a second quarry cut was opened prior to the start-up

TABLE 2/3.2-2a. Lengths (L), widths (W) and depths (D) in feet of isotherms for conditions of maximum flood.

	Units 1-3 with normal flow			Units 2-3 with normal flow			Units 2-3 with reduced flow			Unit 2 with reduced flow		
Isotherm	L	W	D	L	W	D	L	W	D	L	W	D
12	460-720			390-660			430-610			260-410		
10	540-960			500-860			460-810			310-540		
8	700-1300			650-1100			590-1100			400-740		
6	1020-1820	1250	18	870-1550	1070	15	870-1540	1060	11	580-1030	710	11
4	1620-2500	2050	19	1380-2120	1740	16	1370-2120	1740	11	920-1410	1160	11
1.5	11000*	6800	21	9350	5780	18	9000	5770	11	6220	3850	11

TABLE 2/3.2-2b. Lengths (L), widths (W) and depths (D) in feet of isotherms for conditions of slack after flood.

	Units 1-3 with normal flow			Units 2-3 with normal flow			Units 2-3 with reduced flow			Unit 2 with reduced flow		
Isotherm	L	W	D	L	W	D	L	W	D	L	W	D
12	400-480			390-450			340-410			230-260		
10	560-640			530-620			480-540			320-360		
8	780-1000			730-900			660-850			440-570		
6	1360-2400	1360-2400	18	1160-2040	1160-2040	15	1150-2040	1150-2040	12	770-1360	770-1360	12
4	2100-3000	1480-3000	19	1780-2550	1260-2550	17	1780-2550	1260-2550	12	1190-1700	840-1700	12
1.5	4000	7400	21	3400	6290	19	3390	6290	12	2260	4190	12

TABLE 2/3.2-2c. Lengths (L), widths (W) and depths (D) in feet of isotherms for conditions of maximum ebb.

	Units 1-3 with normal flow			Units 2-3 with normal flow			Units 2-3 with reduced flow			Unit 2 with reduced flow		
Isotherm	L	W	D	L	W	D	L	W	D	L	W	D
12	720-920			670-840			610-780			410-520		
10	920-1320			830-1120			780-1120			520-750		
8	1320-2120			1120-1800			1120-1800			750-1200		
6	2080-4230	960-1940	17-19	1770-3600	820-1650	14-16	1760-3590	730-1650	11	1180-2390	490-1100	11
4	4200-7200	1830-3400	20-22	3570-6120	1560-2890	16-18	3560-6110	1550-2880	11	2380-4070	1040-1920	11
1.5	14000*	5700	22-24	11900	4840	19-20	11880	4840	11	7920	4100	11

TABLE 2/3.2-2d. Lengths (L), widths (W) and depths (D) in feet of isotherms for conditions of slack after ebb.

	Units 1-3 with normal flow			Units 2-3 with normal flow			Units 2-3 with reduced flow			Unit 2 with reduced flow		
Isotherm	L	W	D	L	W	D	L	W	D	L	W	D
12	480-560			490-650			410-480			270-320		
10	720-1000			760-950			610-850			410-570		
8	1260-2000			1100-1700			1070-1700			710-1130		
6	2500-4700	1420-4050	19-22	2120-4000	1200-3440	16-19	2120-4000	1200-3440	10	1410-2660	800-2290	10
4	4800-5470	4000-5130	21-24	4080-4650	3400-4360	18-19	4070-4640	3390-4350	10	2720-3090	2260-2900	10
1.5	10830	6270	23-26	9210	5330	19-21	9160	5320	10	6110	3550	10

of Unit 3. This effect was discussed in NUSCO (1987); this reference is appended to this response following the report of Adams (2002). In addition to this work, comprehensive quantitative information on the rocky intertidal community near MPS from 1979 through the present is presented in DNC (2002a), to which may be referred. With Unit 1 formerly having a higher ΔT (25°F) and lower flow (444,000 gpm combined circulating and service water flow) than Unit 3 at present, former operation of Units 1 and 2 together produced a total discharge of 1,017,000 gpm at a ΔT of 23.4°F (Table 2/3.2-1). This operating condition is most similar to the proposed higher ΔT/lower flow during the larval winter flounder season (954,000 gpm; ΔT of 28.7°F) and can help in making inferences regarding the more extreme case of Unit 2 operation alone at higher ΔT/lower flow (370,000 gpm; ΔT of 33.7°F).

Prior to August 1983 there was a single opening from the MPS quarry and the velocity and momentum of the Units 1-2 discharge carried the thermal plume into Twotree Island Channel (Figs. 2/3.4-1 and 2/3.4-2), whereupon it mixed with and lost heat to this large volume of tidally flushed water (54,000,000 gpm at average tidal flow and 132,000,000 gpm at maximum tidal flow; NUSCO 1983). Opening of the second quarry cut meant that the same volume of thermal effluent was discharged through twice the cross-sectional area. Thus, the thermal effluent plume lost velocity and momentum and the thermal effluent tended to mix with nearshore water. A pool of warm water remained in an area bounded by Fox Island on the east, the shoreline to the north, and the thermal plume to south and west. This body of heated water remained nearly isothermal along the shoreline between the quarry cuts and the southwest tip of Fox Island and was only about 5.5-7°F cooler than the undiluted thermal discharge, regardless of tidal stage. This operating condition did not cause an immediate change in the intertidal community as soon as the second cut was opened as Unit 2 was in an extended shutdown that lasted until January 1984 and Unit 1 was shutdown from mid-April until the end of June in 1984. However, once both units were simultaneously in operation and after water temperature in this area exceeded 82.5°F during the late summer of 1984, a profound change occurred in the intertidal community. Briefly, the warm water that now continuously remained in the embayment along the rocky shore area to the northeast of the new quarry cut to Fox Island exceeded the thermal tolerance of many species, such as the perennial seaweeds *Chondrus*, *Fucus*, and *Ascophyllum*. These forms were replaced by more opportunistic and warm water-tolerant taxa, including *Enteromorpha*, *Codium*, *Agardhiella*, and *Polysiphonia*. Overall, species diversity also decreased and the flora came to resemble that found in the Millstone quarry, which receives the undiluted effluent. Similarly, the invertebrate fauna found in the rocky intertidal community also changed. The annual timing and percent cover of barnacles (*Semibalanus* and *Balanus* spp.) was greatly reduced and finally eliminated as were the presence of predatory and grazing snails (*Urosalpinx cinerea* and *Littorina littorea*) and the blue mussel (*Mytilus edulis*). However, the area affected was limited to a small near-field area of shoreline close to the MPS quarry cuts. With no significant changes occurring at reference stations of the rocky intertidal sampling program, these changes in community structure were inconsequential to the local environment.

Subsequent to the start-up of Unit 3 in 1986, with its added cooling-water flow at a lower ΔT, the rocky intertidal habitat at Fox Island underwent further modification. A low intertidal community characterized by populations of

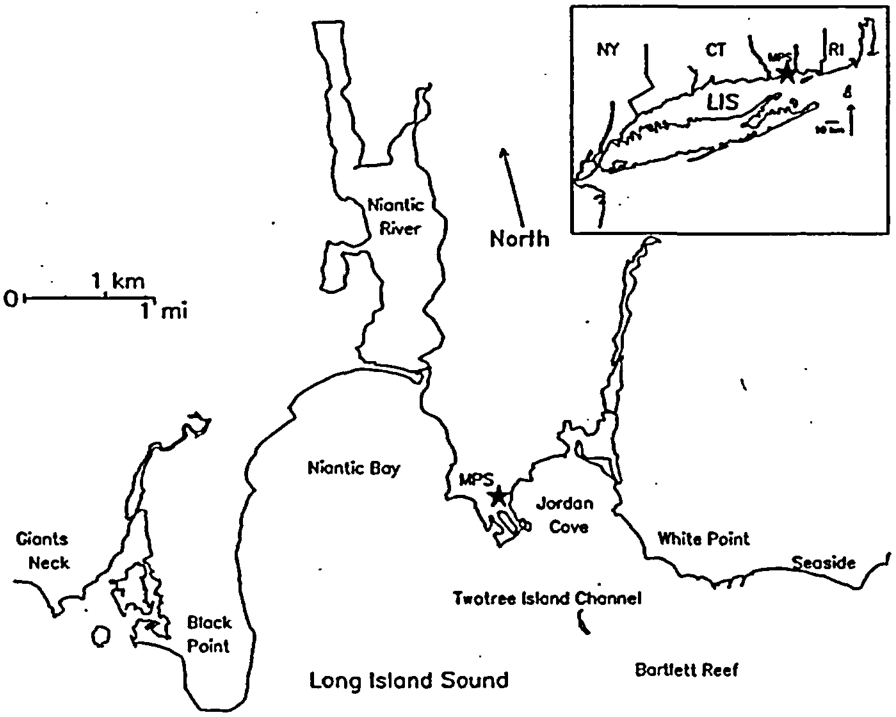


Fig. 2/3.4-1. Location of MPS and surrounding environs.

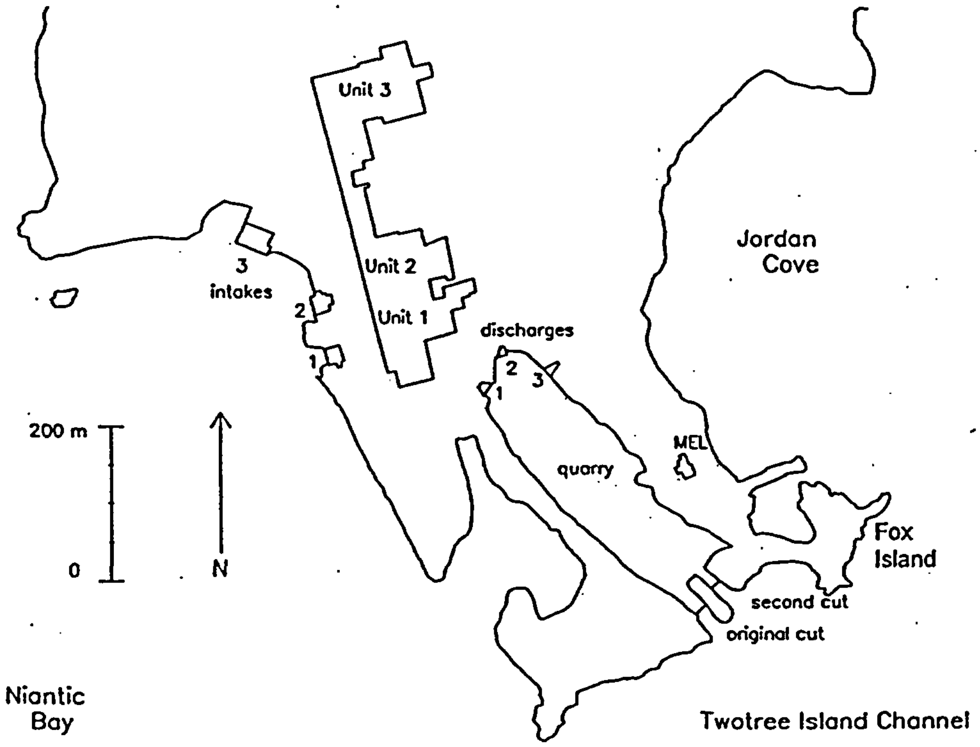


Fig. 2/3.4-2. The MPS site, showing the intake and discharge of each unit, the quarry, and the two quarry discharge cuts.

the seaweeds *Sargassum*, *Agardhiella*, *Gracilaria*, *Corallina*, and *Gelidium* developed and persisted, even during the 1996-98 period when all MPS units were shut down. The upper thermal tolerance limits of these macroalgae are unknown, but they are absent from the Millstone quarry each summer. Therefore, their limits presumably would be exceeded if annual maximum water temperatures were incremented by the proposed increased ΔT/lower flow effluent plume. Again, however, any changes would be limited in area and of little ecological consequence.

Thus, based on the findings reported in NUSCO (1987), a higher station ΔT in concert with lower flow with the present two quarry cuts would potentially alter the rocky shore community (attached algae, sessile or relatively sedentary invertebrates) in a small area of shoreline adjacent to the MPS discharge to Long Island Sound (LIS). Alterations to this community most likely would occur during late summer under conditions of high ambient water temperature. Changes to the community could possibly be even greater under worst-case conditions (i.e., Unit 3 in shutdown and Unit 2 in operation with flow of 370,000 gpm and ΔT of 33.7°F), such as might occur during an early fall Unit 3 refueling outage when ambient water temperature is close to its annual maximum. However, if normal plant operation at increased ΔT/lower flow occurs only in spring during the larval winter flounder season, then the effects may be less than they would be during higher ambient water temperatures. Also, as noted in Adams (2001, 2002), one way to reduce the near-field effects of the thermal plume would be to block off some portion to all of one of the quarry cut fish barriers to reduce the effective cross-sectional area of the discharge. This would cause the plume to more closely approximate the original two-unit, single cut condition. The thermal discharge would have more velocity and momentum, have less tendency to pool near the shoreline, and, therefore have less effect on the near-field rocky shore community. However, neither the potential ramifications to MPS operation nor consideration of engineering aspects (e.g., ability of fish barrier to withstand increased water pressure) of the barrier blockage suggestion by Dr. Adams have yet been evaluated, should this be considered to maintain nearby shoreline habitat.

One potential alternative is the coupling of a higher ΔT/lower flow during the larval winter flounder season with a 10% increase in present CWP flow from mid-June through mid-October. The latter mode of operation would result in a flow of 1,631,000 gpm at a ΔT of 17.7°F. Although not modeled by Dr. Adams, this operation would likely result in a thermal plume most closely resembling present two-unit operation (1,476,000 gpm at 19.0°F). Somewhat higher flow and lesser heat input would result in smaller plume size and reduced thermal effects. This plume and its effects would be less than the former three-unit thermal plume extensively evaluated in NUSCO (1988).

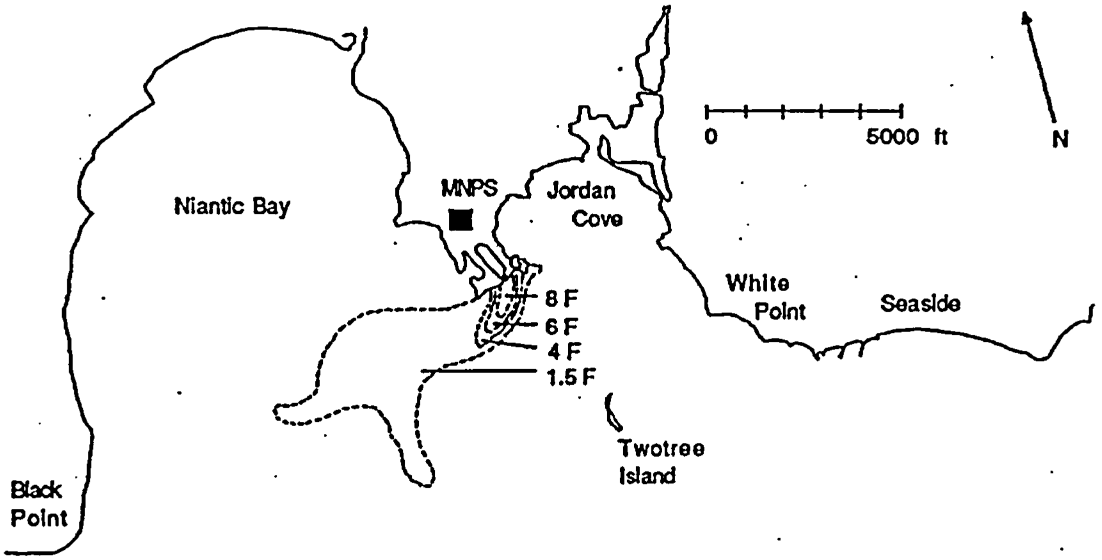
Another effect resulting from any higher thermal output from MPS is an increased potential for elevated temperature-related mortalities of fish in the Millstone quarry. Several isolated and small fish kills have occurred in the quarry during recent years in late summer (NNECO 1998; DNC 2001a). These incidents were concluded to have occurred when the absolute temperature in the quarry exceeded the innate thermal tolerance of the fish species affected. A higher ΔT may increase the probability of such incidents. Many of these fish (e.g., tautog, cunner, scup) likely enter the quarry as entrained eggs or larvae and remain there to grow and develop. Other fish (e.g., striped bass, gizzard shad) likely enter the quarry when elements of the fish barrier are pulled for necessary cleaning. Still others (e.g., striped mullet) have high sustained swim speeds and juveniles can enter the quarry through the fish barrier openings. The loss of relatively few fish in sporadic fish kills are inconsequential to their populations in LIS. Outside the quarry cut fish barriers, the MPS discharge attracts migrating fish, particularly larger forage and sport fishes. These fish are apparently able to enter and leave the area at will and without consequences to their populations, with the exception of increased harvest opportunities to recreational anglers.

Potential effects in the far-field of the MPS thermal plume were analyzed in DNC (2001b), which examined the 1.5°F isotherm under present two-unit operation with respect to the spawning and growth of indigenous aquatic organisms. This document described, in brief, the use of cooling water at MPS, physical aspects of the cooling-water system, the MPS thermal plume, and local hydrography. A history of thermal plume studies at the station was presented, including a copy of the detailed hydrothermal survey of the three-unit thermal plume that was completed in 1987 (NUSCO 1988). The effect of the 1.5°F isotherm on indigenous organisms was evaluated using findings from the extensive ecological studies at MPS and relevant literature. Organisms addressed included eelgrass, phyto- and zooplankton, benthic infauna, the rocky intertidal shoreline community, fishes, and birds and mammals.

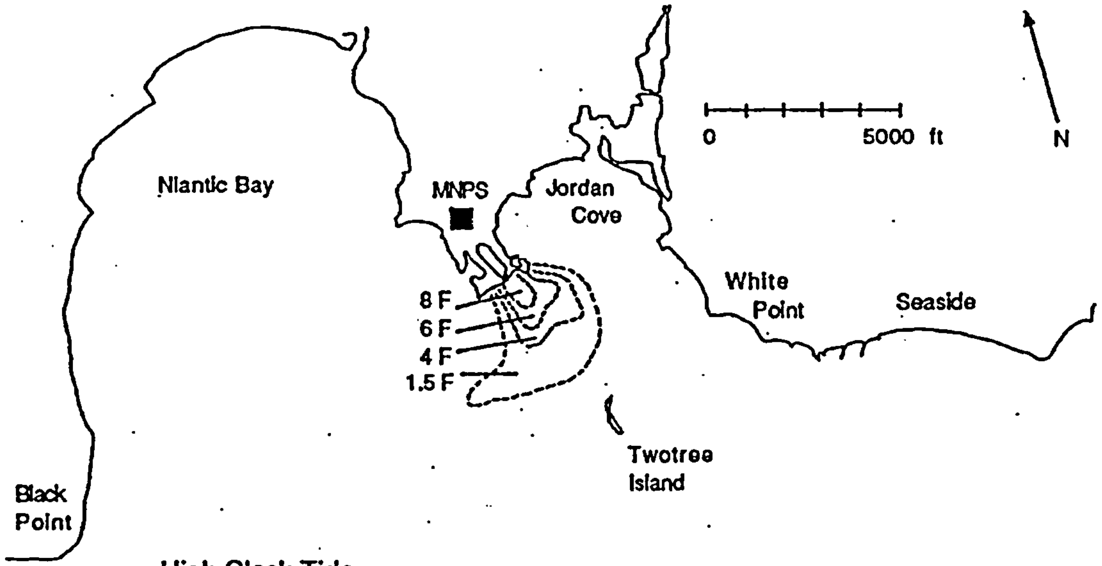
2/3.5 Consistency with Connecticut Water Quality Standards

It is important to note that for the increased ΔT/lower flow operational alternatives discussed here, the projected plumes would meet Connecticut Water Quality Standards (DEP 1992) as well as presently NPDES-permitted thermal allowances for MPS with only one potential exception, relative to a potential exceedance of the NPDES-permitted maximum discharge temperature of 105°F, which is discussed below. The thermal discharge would not affect water quality parameters listed for coastal and marine surface waters in DEP (1992). NPDES Permit limits for parameters such as pH and chemical constituents would remain in place and would be monitored in accordance with the permit. Allowing for a mixing zone of 8,000 feet as in the present NPDES permit, the average temperature of the receiving waters would not be warmed by more than 4°F nor would the increase in temperature exceed 83°F.

Guidelines for the zone of passage for aquatic organisms in DEP (1992) are given as no more than 25% of the cross-sectional area or volume of flow. The MPS thermal discharge for Units 2-3 at present and for the reduced flow options presented in this document would not impede a zone of passage for free swimming and drifting organisms. The largest volume discharge for the new options presented is 1,631,000 gpm for a 10% increase in present cooling-water flow during the summer and early fall. This total is only 3% of the average tidal flow of 54 million gpm through Twotree Island Channel and 0.1% of the maximum tidal flow. The present two-unit thermal plume and plumes for the reduced flow options and the 10% increased flow alternative are or would be smaller in surface area and volume than the thermal plumes from former three-unit MPS operation at four tidal stages shown in Figures 2/3.5-1 and 2/3.5-2.

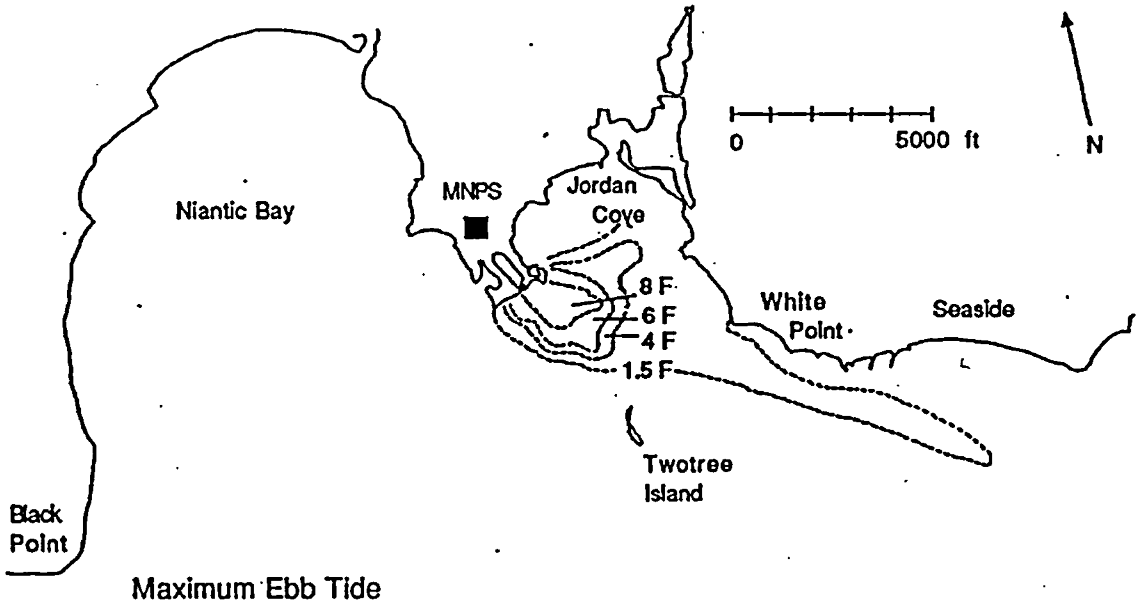


Maximum Flood Tide

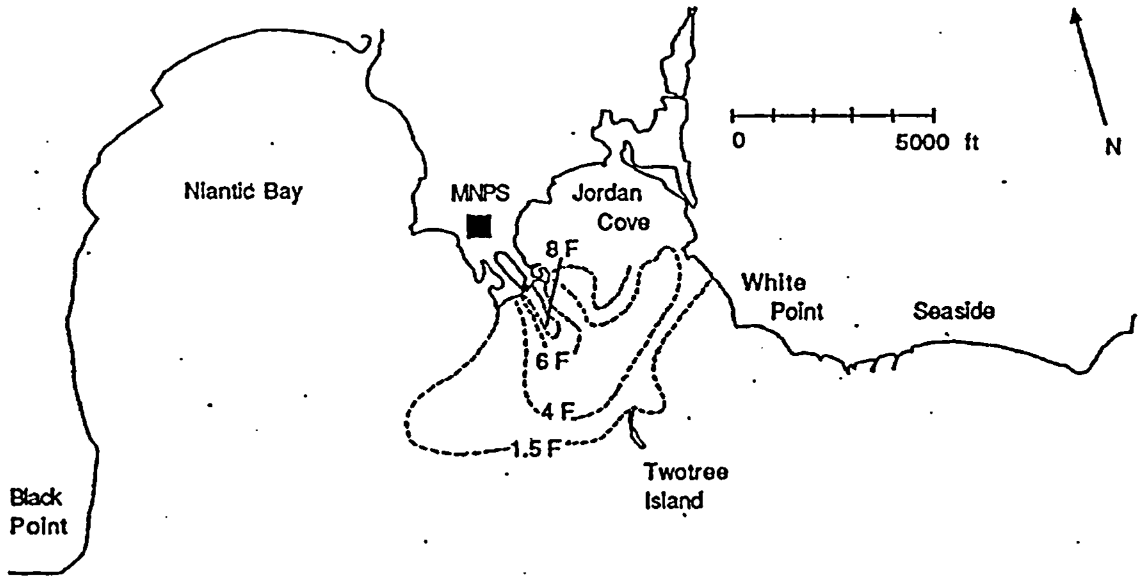


High Slack Tide

Fig. 2/3.5-1. Location of the former MPS three-unit thermal plume isotherms (1.5°F, 4°F, 6°F, and 8°F) at maximum flood and high slack tides (from NUSCO 1988).



Maximum Ebb Tide



Low Slack Tide

Fig. 2/3.5-2. Location of the former MPS three-unit thermal plume isotherms (1.5°F, 4°F, 6°F, and 8°F) at maximum ebb and low slack tides (from NUSCO 1988).

Presumably, however, shapes of these various plumes would be generally similar, although lower flow plumes would probably tend to pool up closer to the MPS quarry cuts and extend less into surrounding waters because of lesser water velocity and momentum. Most importantly, the depth of these plumes are much less than the former full-flow three-unit thermal plume. It is difficult to determine if the cross-sectional area of the 4°F isotherm for existing or proposed MPS thermal discharges would exceed 25% of the zone of passage for aquatic organisms, which is considered to be Twotree Island Channel. As shown on Figures 2/3.5-1 and 2/3.5-2 for MPS three-unit operation, the thermal plume (and its constituent isotherms) is highly dynamic and subject to considerable movement by tidal forces. At maximum flood and high slack tides (Fig. 2/3.5-1) the 4°F isotherm is confined to an area close to the MPS quarry discharges and considerable area is available for movement of organisms in the channel. At maximum ebb tide, the areal extent of the plume is larger, but it is pushed inshore by strong tides, again leaving a large area for passage in the channel (Fig. 2/3.5-2). Maximum extent and depth (18-19 feet; Table 2/3.2-2d) of the present two-unit 4°F isotherm occurs at low slack tide (i.e., slack after ebb), as it had been for the three-unit 4°F isotherm (Fig. 2/3.5-2). This projected two-unit plume height is about half the approximate average depth of 40 feet in Twotree Island Channel at mean lower low water on a line extending from navigational marker "3" off the northern end of Twotree Island to the Millstone quarry cuts, as determined from depth soundings given in NOAA (1993). The three-unit plume at this stage of tide is perpendicular to the east-west axis of Twotree Island Channel, with a wedge of 4°F water extending approximately three-quarters across the channel (Fig. 2/3.5-2). However, the depth of this isotherm in its farthest reaches would be quite shallow and approaching the surface, thus allowing for a considerable zone of passage. Subsequently, during the following flood tide the 4°F isotherm would again be moved to the west and confined closer to the MPS quarry cuts. From observations made over many years at MPS of both resident and highly migratory fishes found in and near the thermal plume and in Jordan Cove, there is no indication that the thermal plume impedes movement of aquatic organisms. The considerable diversity and numbers of fish found in the shore zone and deeper waters of Jordan Cove and nearby in the area just off the MPS intakes (DNC 2002b) is another indication of a lack of a thermal effects to local and migratory fish populations.

When operating at lower flow/higher ΔT there is a scenario whereby the NPDES-permitted maximum discharge temperature of 105°F presently allowed at MPS could be exceeded. This would occur if only Unit 2 was in operation and if ambient water temperature exceeds 71.3°F. Such a condition may be found at times in August or September. If DEP allows for an increase in permitted ΔT at MPS, an increase in maximum allowable discharge temperature would also alleviate the possibility of exceeding this particular parameter and the permit condition becoming an impediment to operation (i.e., required down-powering). Alternatively, the option to increase summer flows by 10% would also limit the potential to exceed 105°F, even if only Unit 2 was in operation.

2/3.6 Conclusion

In summary, the relatively small temperature increase imposed and short time of exposure due to the dynamic nature (i.e., rapid mixing, dilution, and tidal movements) of the MPS thermal plume results in little or no impact to aquatic biota. As noted above, after many years of study, no evidence of any thermal effects have been found for resident flora and fauna (e.g., eelgrass, benthic infauna, silversides, and rocky shore community in Jordan Cove).

References Cited in DNC Response to DEP Question, Comment or Concern #2/3

Adams, E.E. 2001. Thermal plume analysis for Millstone Power Station, Units 2-3. Appendix A to Chapter 2 of Part II. Millstone Power Station. An evaluation of cooling-water system alternatives. Submitted to the Connecticut Department of Environmental Protection, Hartford, CT. 13 pp. + 12 fig.

Adams, E.E. 2002. Thermal plume analysis for Millstone Power Station operating under conditions of reduced circulating water flow. 6 pp.

DEP (Connecticut Department of Environmental Protection). 1992. Water quality standards. Effective date May 15, 1992. State of Connecticut, Department of Environmental Protection, Water Management Bureau. 68 pp.

DNC (Dominion Nuclear Connecticut, Inc.). 2001a. Letter D17242 dated August 14, 2001 from K.M. McMullin, DNC, to J.F. Grier, CT DEP.

DNC. 2001b. Analysis of the Millstone Nuclear Power Station 1.5°F isotherm in relation to the spawning and growth of indigenous organisms. Enclosure to Letter D17272 dated December 6, 2001 from G.W. Johnson, DNC, to J.F. Grier, CT DEP.

DNC. 2002a. Rocky intertidal studies. Pages 89-122 *in* Monitoring the marine environment of Long Island Sound at Millstone Power Station, Waterford, Connecticut. Millstone Environmental Laboratory.

DNC. 2002b. Fish ecology studies. Pages 123-165 *in* Monitoring the marine environment of Long Island Sound at Millstone Power Station, Waterford, Connecticut. Millstone Environmental Laboratory.

EA (EA Engineering, Science, and Technology, Inc.). 1986. Entrainment and impingement studies at Oyster Creek Nuclear Generating Station 1984-1985. Prepared for GPU Nuclear Corporation, Morristown, NJ. EA Rep. GPU44G.

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.

NNECO (Northeast Nuclear Energy Company). 1998. Letter D13201 dated September 1, 1998 from F.C. Rothen, NNECO, to J.F. Grier, CT DEP.

NOAA (National Oceanic and Atmospheric Administration). 1993. Nautical chart 12372, ed. 27. Watch Hill to New Haven Harbor, Long Island Sound, Rhode Island-Connecticut. U.S. Department of Commerce, National Ocean Service, Coast and Geodetic Survey. Rockville, MD.

NUSCO (Northeast Utilities Service Company). 1983. Millstone Nuclear Power Station Unit 3 environmental report. Operating license stage. Vol. 2. Submitted to the U.S. Nuclear Regulatory Agency.

NUSCO. 1987. Ecological significance of community changes at Fox Island. Northeast Utilities Environmental Laboratory, Waterford, CT. 24 pp. + 15 fig. + 1 tab.

NUSCO. 1988. Hydrothermal studies. Pages 323-355 + attachment *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT. Three-unit operational studies, 1986-1987.

DEP Question, Comment, or Concern #4:

While recognizing that DNC has already responded at some length on this matter (i.e. its 2/26/02 response), ESSA is still of the opinion that the alternative of constructing effectively designed and positioned shoreline structures such as groins or jetties may have merit and deserves further consideration. At a minimum, a nearshore hydrographic modeling study of the effects of such a structure on current patterns in front of and adjacent to intakes should be conducted.

DNC Response to Question, Comment, or Concern #4:

As part of a larger research project initiated by the Electric Power Research Institute (EPRI) of Palo Alto, CA, a Computational Fluid Dynamics Model (CFDM) of water flow near MPS was developed by Alden Research Laboratory, Inc. The CFDM provided an ideal tool in which to evaluate the placement of one or more groins or jetties to potentially reduce the entrainment of Niantic River winter flounder larvae at MPS. Results of the Alden work (Richardson 2002) are attached following the DNC response to this comment. By necessity, this study had some simplistic assumptions in that winter flounder larvae were presumed to move passively as did water parcels, water flow was uniform from surface to bottom (as was the distribution of larvae), and all larvae originated at the mouth of the Niantic River. Limitations of this modeling study are discussed in more detail in Section 2.5 of Richardson (2002). Despite these caveats, the CFDM provided the means to assess the ability of such structures in reducing entrainment.

In summary, the Alden two-dimensional, depth-averaged hydrodynamic model showed that placement of two large (700 feet in length) groins placed perpendicular to the shoreline at Bay Point and at the northern end of the Millstone harbor opening were ineffective in reducing the amount of Niantic River water (and, hence, winter flounder larvae) entrained at MPS. Similarly, two shorter (400 feet) groins set perpendicular to the shore closer to the Units 1 and 3 intake structures also did not reduce the number of winter flounder larvae entrained. Under the Alden model, a much larger 2,300-foot long "L"-shaped barrier extending continuously from Bay Point in a southeasterly direction to approximately off the center of the Millstone harbor opening (see Fig. 18, p. 19 of Richardson 2002) was able to reduce by about 50% the amount of Niantic River water (and Niantic River winter flounder larvae) withdrawn by the plant. However, as discussed below, based on consideration of various factors, DNC does not believe that any jetty/groin option should be pursued further.

The modeled groin of 2,300 feet identified as having a potential to reduce entrainment of Niantic River winter flounder larvae would be constructed as a rubble mound structure of quarry stone (trap rock). A typical structure cross section is shown on Figure 4-1. The cross section design is based on criteria provided in "Design of Breakwaters and Jetties; Department of the Army (EM 1110-2-2904); 1986." The structure cross section has an armor stone layer for side slopes and crest, two under layers of graded stone, a core of smaller graded stone, and a bedding layer placed on the existing seabed.

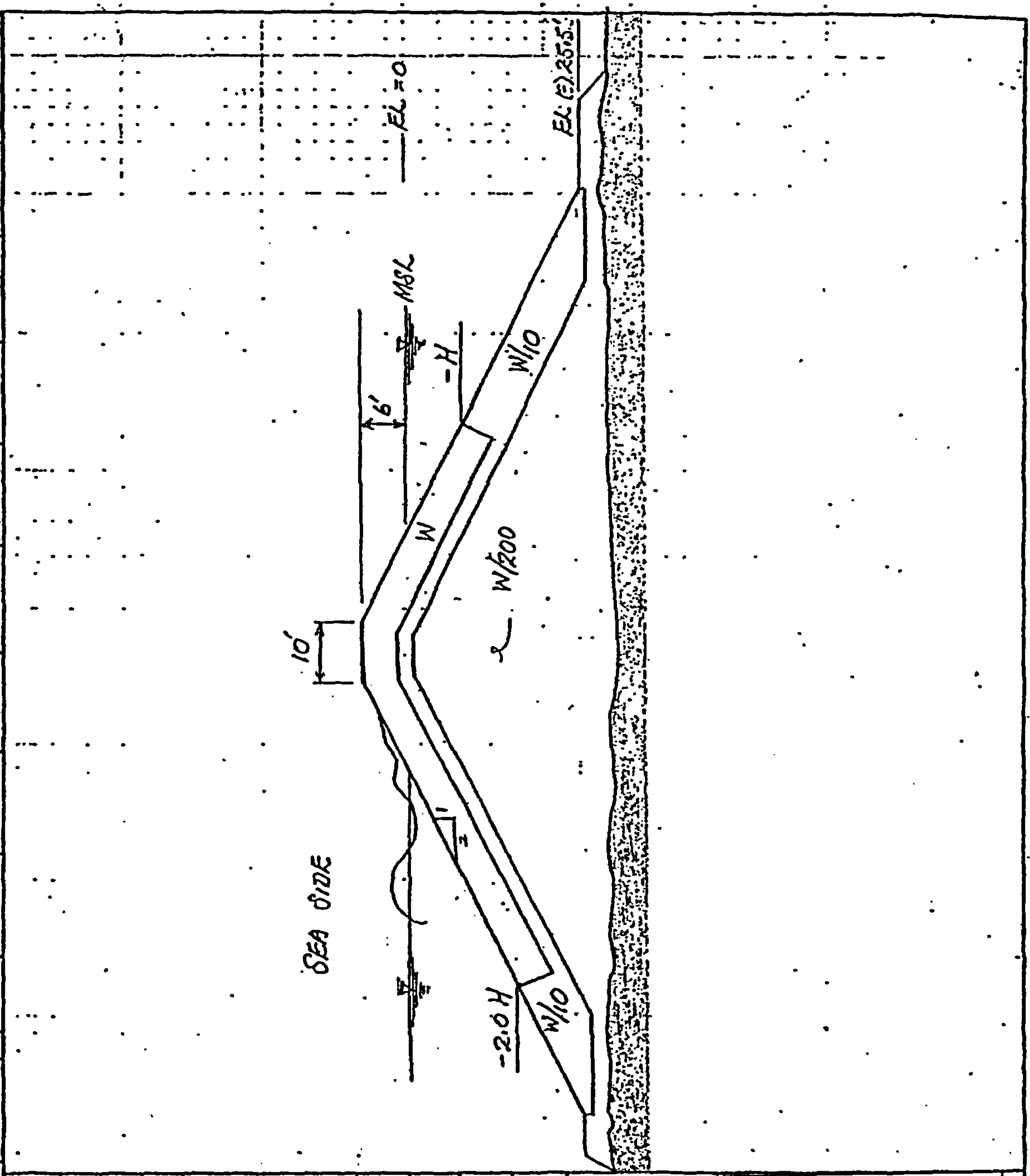


Figure 4-1.
Preliminary groin design with rubble-mount section for seaward wave exposure under zero-to-moderate overtopping conditions.

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An evaluation of onsite meteorological data recorded from January 1974 through December 1981 resulted in selection of a 50 mph wind as a basis for determining the design wave height for the groin sizing. The fetch across LIS at the site is approximately 15 miles (80,000 feet). These conditions would produce an average wave height of 5 feet and a significant wave height of 7.94 feet; the latter was used for the design. Estimated capital cost, including construction, for the groin is $28,328,000. A 45-year net present value (NPV) estimate was not made for this alternative.

Specific design parameters for the groin are as follows:

Design wave height	7.94 feet
Side slopes of groin	1V:2H
Groin crest elevation	+ 6.0 feet (MSL)
Groin crest width	10 feet
Total length of groin	2,300 feet
Water depth at toe of groin	31.5 feet

Armor stone layer specifications:

	Stone Weight	Layer Thickness
Armor stone layer for side slopes and crest	5,000 lbs	6.2 feet
First underlayer	500 lbs	2.9 feet.
Second underlayer	25 lbs	1.1 feet
Core	2.5 lbs	
Bedding layer	2.5 lbs	2.0 feet

Richardson (2002) noted several environmental considerations related to the 2,300-foot jetty/groin alternative modeled. These included impacts to navigation and public access; potential changes to sedimentation and erosion as a result of hydraulic changes, which were beyond the scope of his study to estimate but need to be carefully evaluated; effects of increased re-entrainment of the MPS thermal plume, which could possibly affect plant safety systems (i.e., service water system) in summer and perhaps also impact generation; and possible consequences to plant safety if the opening was blocked. Considerable efforts would also be required to license a structure of this magnitude, similar to that discussed below in Section 6.2.5 of the DNC response to DEP Questions, Comments, or Concerns #5 and 6 as related to a newly described offshore fine-mesh screen alternative for MPS.

Additional concerns (some also noted in Richardson 2002) regarding this option include the potential for entraining winter flounder larvae from stocks other than the Niantic River. This would occur because plant flow would not decrease and less Niantic River water withdrawn would be made up by other LIS water. Appendix B to Chapter 3 of Part II of the Cooling-Water System Alternatives Report discusses in detail the distribution and movements of winter flounder larvae in waters off MPS. High densities of winter flounder larvae found off Millstone Point during flood tide mean that these larvae would likely be drawn into the intake embayment formed by the L-shaped groin and subsequently entrained. Although the number of larvae entrained that originated from the Niantic River might be reduced, they would undoubtedly be replaced by larvae from other sources, which form a majority of the entrained winter flounder larvae at MPS (Crivello 2002; DNC 2002).

Other adverse environmental effects of a large groin include a potential for increased impingement. The L-shaped groin would form an embayment directly leading to the intake structures of Units 2 and 3. It is likely that many fish entering this area would eventually become impinged as they are at other power plants having dead-ended intake canals. Although both MPS units have fish return systems, mortality of species impinged ranges from about 10% or less to nearly 100%. Increased impingement would result in incrementally increasing effects to fish and shellfish populations. The terminus of each fish return sluiceway would also have to be moved a considerable distance so that organisms would not be released within the intake embayment and be subjected to re-impingement. This could be accomplished at a considerable expense (not estimated as part of this response) in addition to the cost of the groin itself. As a hard structure of considerable mass, the groin would also attract many fish and invertebrates. Some of these organisms, such as tautog, cunner, and lobster, would be able to maintain themselves within crevasses of the structure, but any eggs or larvae released by organisms resident within the intake embayment would be lost to entrainment.

In conclusion, due to the demonstrated ineffectiveness of jetties or groins in numerically reducing larval winter flounder entrainment at MPS, other environmental impacts probable (e.g., increased impingement) or yet to be fully evaluated (e.g., sedimentation and erosion), likely licensing difficulties, potential operational problems due to thermal plume re-entrainment, and high cost, DNC does not recommend further consideration of a jetty/groin alternative.

<u>References Cited in DNC Response to DEP Question, Comment or Concern #4</u>

Crivello, J. 2002. Report to Millstone Environmental Laboratory, Ecological Advisory Committee. Analysis of winter flounder larvae. University of Connecticut, Storrs, CT. Submitted under Letter D17306 dated March 14, 2002 from G.W. Johnson, DNC, to J. Grier, CT DEP.

DNC (Dominion Nuclear Connecticut, Inc.). 2002. Winter flounder studies. Pages 167-287 *in* Annual report 2001. Monitoring the marine environment of Long Island Sound at Millstone Power Station Waterford, Connecticut. April 2002.

Richardson, J.E. 2002. Evaluation of shoreline structures designed to minimize the entrainment of organisms into the cooling water intakes at the Millstone Power Station. Alden Research Laboratory, Inc., Holden, MA. 33 pp. + CD of Millstone jetty animations.

DEP Question, Comment, or Concern #5:

One of the most critical findings of the ESSA review concerns DNC's evaluation of the potential application of fine mesh traveling screens at the Station and the conclusions drawn with respect to the existing cooling water intake(s) design and BTA. Their analysis takes issue with DNC's prototype design, placement of fine vs. courser [sic] *screens, intake flow velocities, fish return system design, assumptions for cost estimates, etc. Given the importance of this issue, the Department expects DNC to address, in detail, all aspects of ESSA's review on this particular subject (see sections 2.2.6 - 2.2.8 of the ESSA report).*

DEP Question, Comment, or Concern #6:

In our opinion there are, as shown in the study, several alternatives by which DNC can reduce intake flows (e.g. new variable speed pumps, throttling of existing pumps, bypass, or re-circulation concepts, etc.) which, especially in combination with a potentially higher permitted delta T, could result in a significant reduced Station inflow and entrainment losses. The Department does not agree that the cost of these modifications is prohibitive. Some, in fact, (such as more efficient variable speed condenser circulation pumps) may serve to satisfy ongoing Station O&M needs and have attractive life-cycle payback costs.

DNC Response to Questions, Comments, or Concerns #5 and 6:

The following additional alternatives were reviewed to address DEP's comments concerning alternatives that could potentially reduce MPS flow and entrainment losses:

- Combined Unit 1 and 2 intakes with variable speed CWPs and fine-mesh screens
- Offshore fine-mesh screening facility
- Reduced CWP flow rates during the larval winter flounder season with higher condenser ΔT limits
- Reduced CWP flow rates during the larval winter flounder season with higher condenser ΔT limits and increased CWP flow rates during summer and early fall

An engineering evaluation and cost estimate were made for each of the above alternatives. Capital costs are given for each option, but the ultimate costs to DNC, i.e., the 45-year NPV, are presented and discussed below in the DNC Response to Questions, Comments, or Concerns #12-14 (see Table 12/14-2).

6.1 Combined Unit 1 and 2 Intake Structures

This alternative addresses the potential of using both the Unit 1 and 2 intakes for the Unit 2 cooling-water supply and allows for the use of fine-mesh traveling water screens for the entire cooling-water flow to Unit 2. Unit 1 is shut down and the Unit 1 intake could be used to provide additional flow area, thus reducing the traveling water screen approach velocity if used in conjunction with the Unit 2 intake. This alternative could be used to achieve the 0.5 fps approach velocity for backfit of fine-mesh screens intake without increasing the Unit 2 intake bay cross-sectional area.

6.1.1 Description of Alternative

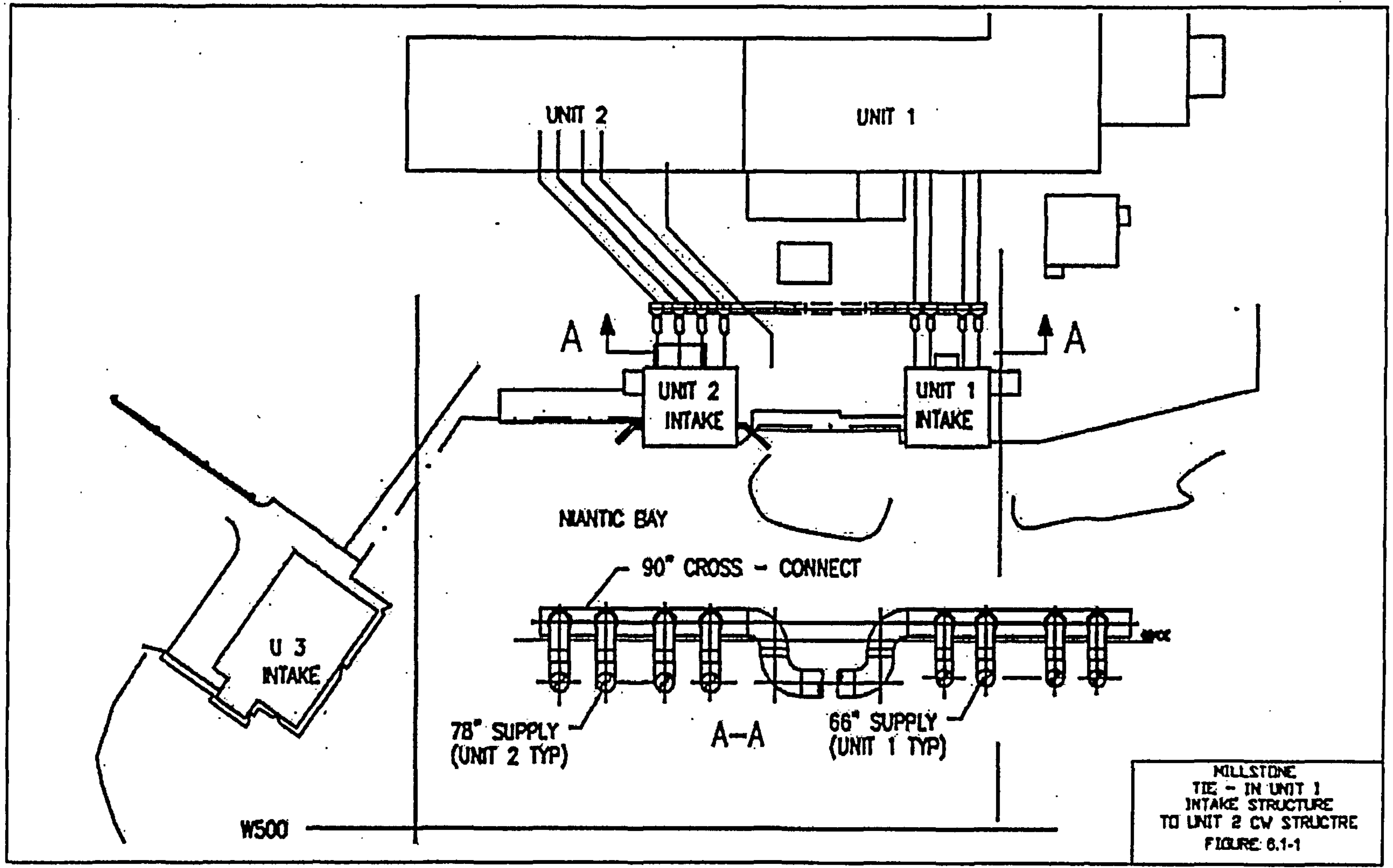
The Unit 1 intake structure would provide a portion of the circulating water to Unit 2. The objective would be to reduce the approach velocities to both sets of traveling screens to 0.5 fps, such that fine-mesh screens could be used for Unit 2. This would allow the Unit 2 coarse-mesh screening system to be replaced with a fine-mesh screening system without requiring a new intake structure or significant modifications to existing structures. Included also, as a combined technology with this alternative, are variable speed drives for the circulating water pumps that would allow the Unit 2 CWP flow rate to be reduced during the larval winter flounder season and returned to normal flow during the remainder of the year.

The Unit 1 intake would be activated to serve a portion of the flow needs for Unit 2. The motor drives for the exiting Unit 2 CWPs would be replaced with variable speed drives (VSDs). Four new smaller (one-eighth-size) CWPs would be placed in the Unit 1 intake bays. The existing Unit 2 pumps with the new VSDs would be slowed to deliver approximately one-half the design flow rate when the pumps in the Unit 1 intake are activated. The existing traveling screens in both the Unit 1 and Unit 2 intakes would be replaced with new fine-mesh fish handling traveling screens of the modified Ristroph design or equivalent, with accompanying fish sluicing systems to return captured fish eggs, fish larvae, and adult fish to LIS. New cross-connecting circulating water conduits would be installed to connect the pumps in the Unit 1 intake to the existing Unit 2 circulating water conduits. This cross-connecting piping would be located in front of the two intake structures. This arrangement is shown on Figure 6.1-1. The Unit 2 service water system would not be changed. The Unit 1 intake would only be used during the winter flounder season. After the end of the winter flounder season, the Unit 2 fine-mesh screen panels would be replaced with the original coarse-mesh screen panels, the Unit 1 CWPs would be shutdown and the cross-connect valves closed and the Unit 2 CWP flow rate would be increase to its original full rate of flow. Because of the flow split between the Units 1 and 2 intakes, a 0.5 fps approach velocity could be maintained at both intakes during the winter flounder season. This option results in a flow reduction of only 7% with fine-mesh screens expected to provide most reduction in entrainment mortality by screening off larvae. However, the effectiveness of fine-mesh screens in improving the survival of larval winter flounder is questionable and is discussed below in Section 6.2.7.

The specific component design parameters (cooling-water pumps and flow rates) for this alternative are as follows:

Units 1 and 2	4 CWPs

	Winter Flounder Season	Non-Larval Winter Flounder Season
Unit 1	158,000 gpm	0
Unit 2	247,200 gpm	504,000 gpm
Total	405,200 gpm	504,000 gpm
Approach velocity	0.5 ft/sec (during the larval winter flounder entrainment season only)	
Cross-connect pipe	90 inch ID with 4 butterfly valves	



MILLSTONE
TIE - IN UNIT 1
INTAKE STRUCTURE
TO UNIT 2 CW STRUCTRE
FIGURE 6.1-1

6.1.2 Testing the Suitability and Effectiveness of Fine-Mesh Screens

Prototype testing at the MPS site would be required to evaluate the viability of the proposed screening facility for safely collecting and transporting fish larvae and eggs back to the ocean and establishing reliable design criteria for the screening facility before initiating the permitting process for the modified structure and pumps. Please refer to Section 5.1.2 of the Cooling-Water System Alternatives Report for a detailed discussion of fine-mesh screen prototype testing at MPS. Section 6.2.7 below discusses in more detail the potential effectiveness of fine-mesh screens at MPS to reduce, in particular, the mortality of larval winter flounder.

6.1.3 Impact on MPS Performance

Figure 6.1-2 shows the relationship, for Unit 2, between the change in electrical generation rates for all CWPs operating and the reduced flow rate for the combined Units 1 and 2 intakes during the larval winter flounder entrainment season.

6.1.4 Capital and O&M Costs

The estimated capital cost for this alternative is summarized in Table 6.1-1. The capital cost was developed using the same methodology as described in Section 10 of the Cooling-Water System Alternatives Report.

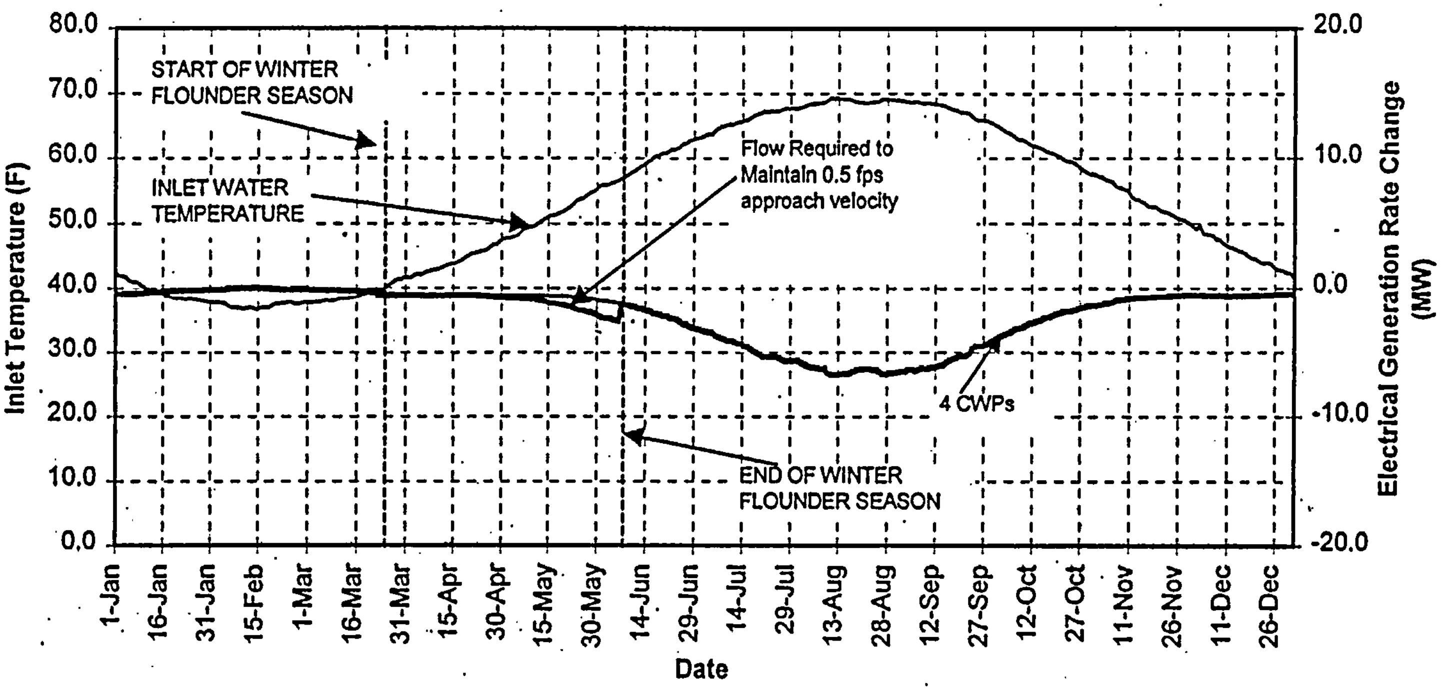
By utilizing an existing intake structure some construction related costs could potentially be reduced compared to an alternative that required additional intake bays to be constructed at Unit 2. This alternative would result in an increase in the annual maintenance costs due to the added equipment to the Unit 1 intake, increased removal and disposal of debris collected in trash baskets, periodic removal of trash collected on trash racks with trash rakes, screen and screen-wash system maintenance, CWP and screenwash pump maintenance and general maintenance on the structure. Pump maintenance would include an estimated normal annual maintenance cost plus a pump overhaul once every 10 years for each pump. In addition, the maintenance cost includes the effort to install and remove the fine-mesh screen panels before and after the winter flounder season. The 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 this alternative is $80,000 per year.

TABLE 6.1-1. Combined Units 1 and 2 intake structures - approximate cost estimate.

Item	Cost ($)
Unit 1 Demo/Removal – Pump Motor Sets	60,000
Unit 2 Demo/Removal – Existing Pump Motor Sets	80,000
Unit 1 New Installation – Pumps	1,620,000
Unit 2 New Installation – Pumps	1,950,000
Unit 1 Demo/Removal – Existing Screens & Screenwash System	115,000
Unit 2 Demo/Removal – Existing Screens & Screenwash System	115,000
Unit 1 New Installation – Screens & Screenwash System	3,100,000
Unit 2 New Installation – Screens & Screenwash System	3,390,000
New Electrical And I&C Facilities	310,000
Excavation	1,060,000
Demolition/Removal	130,000
New Installation (Cross Connecting Piping System)	1,950,000
Restoration	120,000
Electrical Equipment Building	1,000,000
	15,000,000
Labor Overtime and Productivity	840,000
Escalation (Brings Costs To Current 2002 Values)	530,000
Total Direct Cost:	**16,370,000**
Construction Services and Engineering (17%)	2,780,000
Indirect Construction	200,000
Spare Parts, First Fills	100,000
Transportation – Material	400,000
Warrantee	250,000
	20,100,000
AFI/Contingency (25%)	5,000,000
Total Capital Cost	**$25,100,000**

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

Figure 6.1-2: Millstone Unit 2 - Electric Generation Rate Change vs Variable Speed CWPs and Inlet Temperature



6.2 Offshore Fine-Mesh Screen Facility

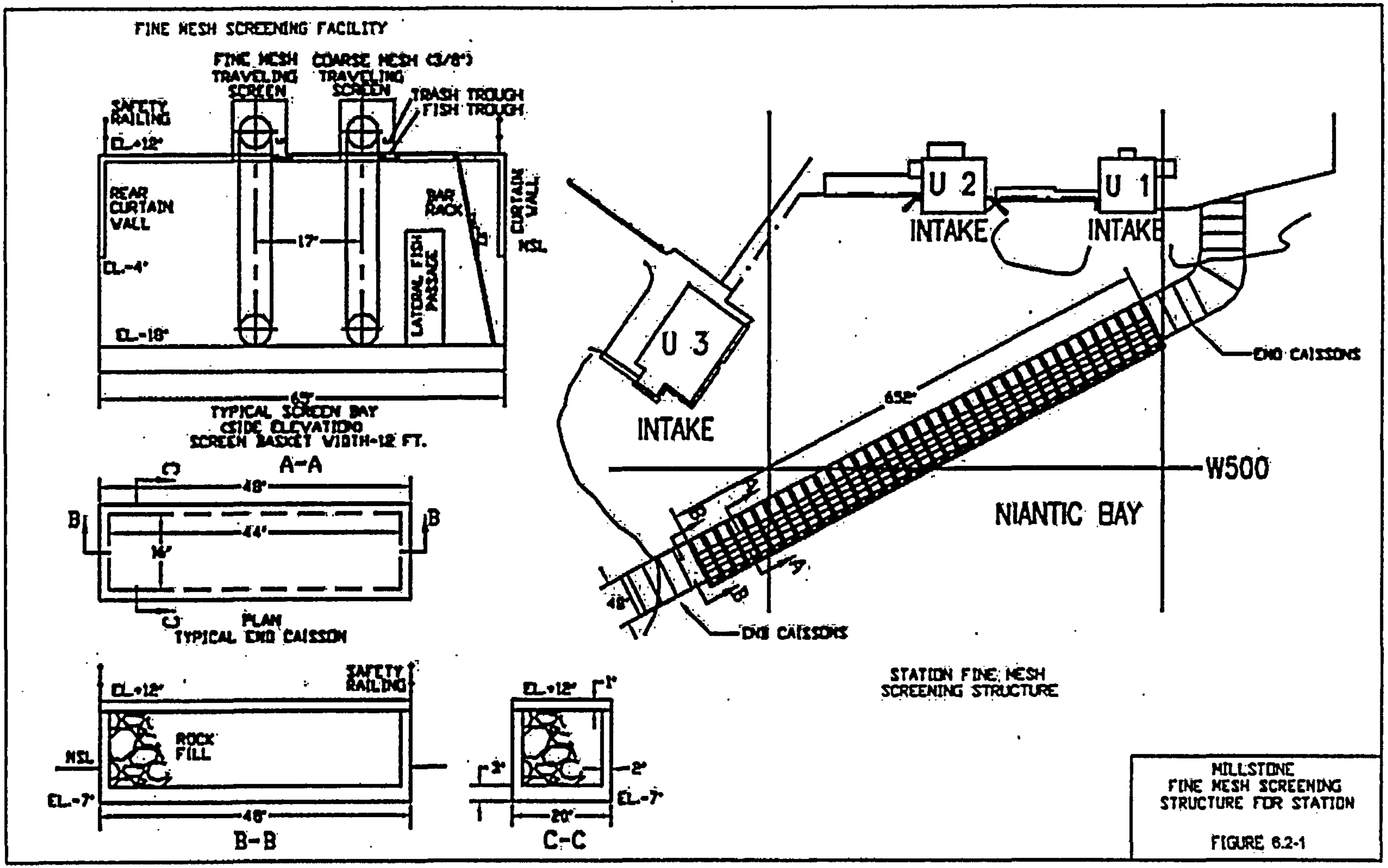
6.2.1 Description of Facility

This alternative addresses the potential for developing a single offshore fine-mesh screen facility that would service the entire station. The primary design objectives for the offshore fine-mesh screening facility are to provide screening for the combined circulating and service water flows to Units 2 and 3 and remove and safely return to Niantic Bay fish the biota drawn into the screening facility. The design approach velocity to the new offshore screens is 0.5 fps, which is the current industry standard for fine-mesh screening facilities. This new screening facility must also be able to handle the seasonally abundant seaweed and eelgrass detritus, which occurs at the site.

The preliminary design for the fine-mesh screen structure is shown on Figure 6.2-1. This design consists of constructing an entirely new through-flow screening structure across the embayment in which the MPS intakes are located. This alternative would completely isolate the existing MPS intakes from Niantic Bay. The structure consists of 36 reinforced concrete screening bays with end structures, which connect both ends of the screen structure to the shore. The end structures consist of concrete caissons filled with stone rubble for ballast. Access roads are provided on top of both end structures to provide access to the screen structure for cranes and other maintenance equipment. The entire screen structure is founded on a tremie concrete mat placed on the sea bottom. Each screen bay contains curtain walls on both upstream and downstream ends, coarse bar racks, a coarse mesh traveling screen equipped with both adult fish removal features and heavy debris handling features, and a fine-mesh traveling screen for capture, removal, and return of fish larvae and eggs. The screen structure would be equipped with two traveling rake systems to clean the trash racks.

Two fish removal sluicing systems would be provided to transport larger fish and the ichthyoplankton removed from the coarse- and fine-mesh screens, respectively, back to Niantic Bay. One sluice services the south half of the screening structure and one serves the north half of the structure. The actual locations for returning eggs, larvae, and fish would be established after additional studies have been completed, should this alternative be selected. The sluicing systems would be similar in design concept to the existing sluicing system for the Unit 3 intake, although larger in capacity. A lateral fish passageway would be provided in the structure between the trash racks and the coarse-mesh traveling screens to allow escapement of adult fish.

Separate trash sluicing systems would be provided to sluice debris collected on the coarse-mesh screens dumping to trash baskets mounted on the curtain walls at the rear of the screen structure. Trash sluices would be located under the deck structure. The preliminary concept would be to provide a trash collection basket for every 6 bays for a total of 6 collection baskets. A 20-foot wide clear deck area would be provided at the rear of the structure for maintenance vehicles and cranes for emptying trash baskets and screen equipment maintenance.



MILLSTONE
FINE MESH SCREENING
STRUCTURE FOR STATION

FIGURE 6.2-1

Both the coarse- and fine-mesh screens would be of the modified Ristroph design or equivalent, which includes Fletcher-type fish buckets on each screen basket. Dual pressure spray systems, and separate troughs for fish and debris would be provided on the coarse-mesh traveling water screens. The fine-mesh screens would only have a low pressure spray header and a fish return sluice for eggs and larvae. The screens would be capable of continuous operation and have multiple operating speed capability. The coarse-mesh screens would incorporate the heavy debris handling features of the existing Unit 3 traveling screens. The April and May time frame is the period of heavy debris loading, which is also the time frame for greatest larval winter flounder entrainment.

The coarse-mesh screens would be equipped with 3/8 inch (9.5 mm) mesh. The fine-mesh screens would be equipped with 0.5-mm mesh. This fine mesh is selected specifically to block eggs and larvae from entering the MPS intakes and allow for collection and return to Niantic Bay. Stage 3 winter flounder larvae, which are most susceptible to entrainment into the MPS intakes, are mostly commonly 5.5 mm to 7.5 mm in length.

Specific screen structure design parameters are provided below. The elevations are referenced to mean sea level (MSL).

Deck elevation	12 feet (MSL)
Invert elevation	–18 feet
Design flow per screen bay	40,900 gpm
Number of screen bays	36
Total design flow	1,472,000 gpm
Screen unit width	12 feet
Approach velocity to screens	0.5 fps

The invert elevation of –18 feet is selected based the approximate existing sea floor elevation of –18 feet in the proposed area of the screen structure. Setting the structure invert deeper would most probably result in eventual filling in by sea bed sediments up to the existing sea floor depth. Locating the structure invert at (approximately) the existing sea floor depth should avoid the need for maintenance dredging.

Advantages and disadvantages of the proposed screening facility are listed in the following table.

TABLE 6.2.1-1. **Advantages and disadvantages of a fine-mesh screening facility for entire station.**

Advantages	Disadvantages
• Meets best technology available (BTA) criteria for a screening facility. • Provides a barrier for early life stages of fish • Provides a means for returning collected eggs larvae and fish to Niantic Bay. • Results in no station performance penalties other than providing power to operate screening equipment, screen wash pumps and lighting for the structure. • Adds to station security by acting as a barrier to the existing intakes from the ocean.	• High capital cost • Requires an extensive and costly maintenance program to remove collected trash and maintain the many screens and screen wash systems in working order • Requires a long, extensive and uncertain permitting process • Requires a long implementation period to complete pilot testing, permitting and construction

6.2.2 Construction Approaches for Offshore Fine-Mesh Screening Facility

The screen structure must be able to be constructed and commissioned without requiring a major interruption to station operation. Two feasible construction methods would allow essentially no unit shutdowns. A commonly used approach for constructing near-shore marine structures similar to the proposed screen facility is to build a cofferdam, usually a double-walled sheet pile structure with concrete grout placed between the walls for water tightness around the structure, de-water and maintain de-watered the cofferdam, and construct the facility in the dry area within the cofferdam. In this case, the work would have to be done in at least two stages to avoid blocking flow to the MPS intakes during construction. For example, a cofferdam could be constructed for the south half of the structure. When the south half of the concrete screen structure is complete, the cofferdam would be removed and a second cofferdam installed for the north half of the structure. This would allow water to flow to the intakes through the open bays of the completed south half of the structure while the north half is being constructed. The traveling screens and related equipment would not be installed until after the entire structure is completed and cofferdams removed. The cofferdams in this case would be very costly and difficult to maintain dry and was therefore not considered.

An alternate approach would be to pre-cast the concrete portions of the structure in sections at a remote site (a ship building facility for example), transport the pre-cast sections by barge to the site and set them in place on a pre-prepared foundation on the sea floor with a barge crane. There are large ship building facilities (Quincy, MA, for example) in southern New England, which could do this work. The pre-prepared foundation would be a tremie concrete mat placed on a dredged sea floor surface. A preliminary study evaluated pre-casting the end caissons in single 20-ft wide sections and each screen structure bay in two sections. The bar racks would be installed in the pre-cast front sections. The traveling screens and all other mechanical equipment would be installed after the concrete structure is in place. Large sections are required because they must be stable individually by gravity against wave and current forces upon placement. The proposed sections would weigh approximately 500 tons each. A 1000-ton capacity barge crane would be required to handle and place these sections.

A third possible approach would be to float the pre-cast sections to the site and sink them in place. Preliminary buoyancy evaluations showed that approximately 28 feet of water depth would be required to float the sections. This water depth, even at high tide, is not available at the proposed structure site or approaching it in Niantic Bay. This approach is, therefore, not feasible in this case.

Detailed constructability studies would be required before a reliable and cost effective construction approach could be chosen. For this preliminary study, pre-casting the concrete sections, barging them to the site and placing them on a prepared foundation with a barge crane was selected to develop an order of magnitude cost estimate and preliminary schedule for constructing this screening facility.

6.2.3 Testing the Suitability and Effectiveness of Fine-Mesh Screens

Prototype testing at the MPS site would be required to evaluate the viability of the proposed screening facility for safely collecting and transporting fish larvae and eggs back to the ocean, and establishing reliable design criteria for the screening facility before initiating the permitting processes for the structure. Refer to Section 5.1.2 of the Cooling-Water System Alternatives Report for a detailed discussion of fine-mesh screen prototype testing at MPS. Section 6.2.7 below discusses in more detail the potential effectiveness of fine-mesh screens at MPS to reduce, in particular, the mortality of larval winter flounder.

6.2.4 Impact on MPS Performance

A significant impact to MPS performance of the offshore fine-mesh screen facility is the necessary added power requirements for operating the 72 traveling screens and the normally operating 18 screenwash pumps. A total of 2,500 kW would be required for the screenwash pumps and 540 kW for the traveling water screens. This fine-mesh screening facility would have no impact on station thermal performance.

6.2.5 Licensing and Permitting

In order to construct the proposed fine-mesh screen alternative, which encloses about 240,000 square feet (5.5 acres) of Niantic Bay and covers about 50,000 square feet of bottom habitat, a group of related state and federal permits would be required. The permits that might be required, based on the design and permitting approach, could include:

- Federal Coastal Zone Consistency Review (Administered by the Office of Long Island Sound Programs)
- U.S. Army Corps of Engineers 404 Dredge and Fill Permit
- Connecticut Water Quality Certificate

- Amendments to U.S. Nuclear Regulatory Commission (NRC) permit for new facility
- NPDES Permitting

The overall schedule and outcome of state and federal permitting is difficult to evaluate at this time. However, after conceptual design details are complete, it is likely that the state agencies could require at least 12 to 18 months to reach a decision on the permits required for this potential alternative.

6.2.6 Capital and O&M Costs

The estimated approximate capital cost for implementing the offshore fine-mesh screening facility is provided in Table 6.2.6-1. Annual maintenance costs would include removal and disposal of debris collected in trash baskets, periodic removal of trash collected on trash racks with trash rakes, screen and screen-wash system maintenance and general maintenance of the structure. Screenwash 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 the offshore fine-mesh screening facility is approximately $2,000,000 per year.

6.2.7 Effectiveness of Fine-Mesh Screens in Reducing Entrainment Mortality

DNC contends that impinged winter flounder larvae, in particular, may suffer as much mortality on fine-mesh screens as they would through entrainment. This topic was previously discussed in Part II, Chapter 2, Sections 2.3.2 and 2.4.1 of the Cooling-Water System Alternatives Report.

The ability of fine-mesh screens to successfully return live eggs or larvae previously impinged on fine-mesh screens depends on several factors, including the species of interest, concurrent debris loading and other materials impinged, and features of the plant intake system. Taft (2000) compiled information on fine-mesh screen use at power plants or from various laboratory studies. He found relatively few electrical generating stations either having or experimenting with the 0.5- to 1.0-mm fine-mesh screen size that would afford protection to larval winter flounder and other ichthyoplankton of interest at MPS. Of the six sites having or once using 0.5- to 1.0-mm fine-mesh screens, four were located in estuarine or marine waters: Big Bend in Tampa Bay, FL; Brayton Point in Mount Hope Bay, MA-RI; Barney Davis in Laguna Madre, TX; and Brunswick in the lower Cape Fear estuary, NC. Of these, Taft (2000) noted that Big Bend had light debris loading, Brayton Point seasonally moderate debris loading, Brunswick seasonally heavy debris loading, and Barney Davis heavy loading of seagrass. Based on past experience, MPS can be characterized as having seasonally heavy debris loading, with seaweeds predominating in spring and detached eelgrass in fall. In addition, occasionally heavy loading of jellyfish can occur in summer. Debris loads at MPS are exacerbated by storm conditions which both suspend material and carry debris to the intake structure if wind direction is unfavorable – particularly from the southwest.

TABLE 6.2.6-1. Offshore fine-mesh screen intake facility - approximate cost estimate.

Item	Cost ($)
Foundation Mat On Sea Bottom	2,800,000
End Caisson Sections	3,800,000
End Bays - Rear Sections	460,000
End Bays - Front Sections	440,000
Central Bays – Rear Sections	6,500,000
Central Bays – Front Sections	6,500,000
Screen Structure Equipment	30,800,000
Transport And Set Precast Units	3,700,000
Electrical And Control Equipment	3,000,000
	58,000,000
Labor Overtime And Productivity	6,000,000
Escalation (Brings Costs To Current 2002 Values)	2,200,000
Total Direct Cost:	66,200,000
Construction Services And Engineering (17%)	11,250,000
Indirect Construction	700,000
Spare Parts, First Fills	400,000
Transportation – Material	1,300,000
Warrantee	500,000
	80,350,000
AFI/Contingency (25%)	20,100,000
Total Capital Cost	$100,450,000

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

Taft (2000) noted that the plants using fine-mesh screens found them to be generally reliable and did not necessarily experience unusual clogging or cleaning problems. However, even though the Brunswick plant also has fixed 9.4-mm mesh screens at the mouth of its intake canal, which presumably eliminates much debris before it passes to the station intakes, Thompson (2000) noted that these fixed screens require considerable daily labor to keep clean and limit damage to equipment. Furthermore, although the fixed screens eliminated much of the debris, the fine-mesh screens often need to be rotated and washed continuously. Clogging events on the fine-mesh screens, which included events created by marine biota, sediment, and seaweeds, have led to plant shutdowns at Brunswick (Thompson 2000). Species composition of entrainment and impingement at power plants with fine-mesh screens also varied. Survival monitored at power plant sites or in experimental studies has been highly species- and life stage-specific. Work at Brunswick showed that effectiveness of fine-mesh screens in reducing entrainment ranged from 18 to 100% for fishes, varying by species and the month (Thompson 2000). Upon impingement on the fine-mesh screens, larval survival was also variable by species and screen rotation speed, ranging from 0-3% for Atlantic menhaden to 93% for *Paralichthys* spp. flounders. Taft (2000) noted that fishes such as anchovies and herrings showed low survival in most studies, whereas striped bass and white perch had moderate to high survival. He concluded that fine-mesh screens must be carefully evaluated for their potential in increasing the survival of the particular species and life stages to be protected. Depending again upon the species and life stage, mortality from impingement on fine-mesh screens could equal or exceed mortality due to entrainment. However, for a fine-mesh screen to be beneficial, impingement survival must be substantially greater than entrainment survival.

Of the power plants with fine-mesh screen testing experience summarized in Taft (2000), Brayton Point Station is the most similar to MPS in terms of species composition of fishes entrained or impinged. The Cooling-Water System Alternatives Report (Part II, Chapter 2, Section 2.4.1) detailed the experience of Brayton Point Station with fine-mesh screens as BTA to protect, in particular, larval winter flounder. In a 1984-86 study of the effectiveness of the Brayton Point angled fine-mesh screen system in reducing entrainment mortality, a total of 52,847 larval winter flounder was examined (LMS 1987). Of these larvae, about 20% were diverted through the fish diversion pumps, 28% were impinged on the fine-mesh screens, and 52% were entrained, having passed through the 1-mm fine-mesh screens. Some 11,426 specimens were examined for survival, which was determined first upon initial collection and then after 72 hours of holding. 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 hours, 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 hours, 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%. Total System Efficiency (TSE) in the Brayton Point study was defined as the probability that a larva would be alive after 72 hours, 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%. Note that Brayton Point had installed 1-mm fine-mesh screens, rather than the 0.5-mm screens advocated for MPS. Smaller mesh would likely result in higher impingement relative to entrainment with a corresponding low (5.5%) survival rate. Further, TSE for other larval fishes, including herrings, bay anchovy, seaboard goby, and tautog, was even less (<0.6%) than for winter flounder. LMS (1987) concluded that when the angled screen system at Brayton Point was equipped with the 1-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.

With reports of low survival or equivocal results also found in laboratory experiments assessing survival of winter flounder larvae on fine-mesh screens (ARL and SWEC 1981; Taft et al. 1981) and based on the operating experience at Brayton Point Station, fine-mesh screens do not appear to be the BTA to reduce entrainment mortality of larval winter flounder at MPS and their use is not recommended.

6.3 VARIABLE SPEED CIRCULATING WATER PUMPS

Two additional variations of variable speed drives for the Units 2 and 3 circulating water pumps are evaluated as follows:

- Variable speed circulating water pumps with reduced flow and higher condenser ΔT limits
- Variable speed circulating water pumps with seasonally adjusted flow and higher condenser ΔT limits

In both of the above alternatives the CWP flow, per unit, is reduced by as much as 38% (Unit 2) and 39% (Unit 3) during the larval winter flounder entrainment season. Pump flow reductions of this magnitude can only be reliably achieved with variable speed pump drivers. Attempting to throttle the pumps using system valves would result in the pumps being backed up on their performance curves into the unstable operating range. The Hydraulic Institute (ANSI/HI 9.6.3-1997; American National Standard for Centrifugal and Vertical Pumps for Allowable Operating Region) states that vertical pumps having specific speeds in the range of the MPS circulating water pumps should not be operated at less the 80% of their design operating point. Further, flow reduction by recirculating flow back to the intake bays is also not a viable method. Pump flow reductions of this magnitude using re-circulation pipes installed in the pump casings to short circuit pump flow back to the intake would, in all likelihood, create extremely adverse flow conditions at the pump suctions and in the intake.

The second variable speed alternative includes the capability to increase circulating water flow above the current design point as well as providing the capability to reduce pump flow. The objectives of this alternative are to provide the capability to reduce the Units 2 and 3 intake flows during the larval winter flounder season and during non-winter flounder entrainment period to increase the CWP flows of both units over design operating flow. This would achieve improved generating unit thermal performance at a time of year when the environmental impact of increased intake flows may not be as significant. CWP flow increases of up to 20% were evaluated. The results show that added CWP energy requirements for flow increases greater than 10% offset any potential generating unit output increases achievable by increasing circulating water flows through the condensers.

Changes in the circulating water system parameters from the design values would have to be evaluated to ensure that the system is not operating outside the design bases. The following are limitations to circulating water flow rate decreases and increases:

- ΔT across the condenser:

There are limits to the differential expansion of shell and tube bundles. A preliminary evaluation indicates that up to a 50% increase in ΔT above design can be accommodated by the existing condensers of Units 2 and 3. A more detailed analysis and evaluation of the condensers would be required to reliably determine if >50% increases to ΔT can be tolerated by the condensers. This evaluation considered a ΔT limit of 36°F for Unit 2 and 27°F for Unit 3.

- Turbine back pressure design limit:

Both the Unit 3 and Unit 2 turbines have a condenser backpressure limit of 4.5 inch HgA. In this evaluation turbine backpressure in the condenser is limited to a maximum of 3 inch HgA. This is the normal operation point for the system.

- Reduced condenser tube flow velocity:

The Heat Exchange Institute (HEI) recommends that condenser tube velocity not be less than 3 fps. Lower tube velocities can result in non-uniform tube flow velocity through the condenser.

- Increased system fouling:

Reduced flow velocities throughout the circulating water systems will result in increased fouling.

6.3.1 Variable Speed Drive Pumps – Unit 3

Variable speed drives for the circulating water pumps would allow reduction (and increase) in circulating water flow during periods of interest. A variable speed drive, which would operate the circulating water pumps either at rated flow or at either reduced or increased flow rates, is evaluated in this section. In all cases, new CWP motors would be required for the variable speed drives. The existing pumps are capable of handling reduced speed operation.

New CWPs are assumed to be required for the increased flow alternative. The existing CWP bays are designed to handle the design flow of the existing CWPs. It is assumed in this evaluation that these intake bays can accommodate a 10% pump flow increase. However, model studies of the intake bay will have to be conducted to confirm the adequacy of the intake bays for handling the increased flows.

6.3.1.1 Variable Speed Drives for Flow Reduction

Variable speed drives for the circulating water pumps would be used to reduce permitted condenser circulating water flow by as much as 39% during the winter flounder season and operate at normal rate of flow during the rest of the year. The limiting factor for reduced flow operation during the larval winter flounder season is a 3 inch HgA backpressure in the condenser at the turbine exhaust and the condenser ΔT limit of 27°F. The variable speed circulating water pumps would each operate at approximately 93,150 gpm with a total circulating water system flow of 558,900 gpm. Design CWP flow is 153,000 gpm with a total design condenser circulating water system flow of 918,000 gpm. Taking into account normal service water flow of 30,000 gpm, this would result in reduction of entrainment of marine organisms into the Unit 3 intake of up to 38% during the winter flounder season, while allowing the unit to operate at full power during the remainder of the year. If Unit 2 pumped its normal complement of cooling water, the percent flow reduction accounted for at Unit 3 is 24%, relative to two-unit operation.

6.3.1.2 Variable Speed Drives for Both Flow Reduction and Increase

Variable speed drives for the circulating water pumps would be used to reduce permitted condenser water flow by as much as 39% during the winter flounder season from mid-March to mid-May and increase circulating water flow by 10% during the summer and early fall months. As stated previously, the limiting factor for reduced flow operation during the larval winter flounder season is a 3 inch HgA backpressure in the condenser at the turbine exhaust and the condenser ΔT limit. During mid-June through mid-October, increasing the circulating water flow by approximately 10% would allow improved unit output. A 10% increased circulating water pump flow would be 170,500 gpm with a total circulating water system flow of 1,023,000 gpm plus 30,000 gpm for service water.

A range of increased circulating water flow rates was evaluated for this alternative up to a 20% increase in flow. However, this evaluation showed that increased pump power requirements for greater than 10% increases over design flow offset any gains in unit electrical generation output.

6.3.1.3 Pumping Energy Requirements

A 39% reduction in the pump speed would result in transposition of the pump performance curve to flows equal to 39% of the existing curve and a system total dynamic head requirement of 14.7 feet. This would result in a reduced power requirement for each pump from the existing 1,225 to 450 horsepower. The total pump energy requirements for 39% speed operation would be approximately 2,020 kW, compared with the existing value of 7,140 kW.

A 10% increase in the pump speed would result in transposition of the pump performance curve to flows equal to 110% of the existing curve and a system total dynamic head requirement of 36.8 feet. This would result in an increased pump power requirement for each pump from the existing 1,225 to 2,060 horsepower. The total pump energy requirements for 110% speed operation would be approximately 9,200 kW.

6.3.1.4 Variable Speed Operation

A variable circulating water flow can be achieved by controlling the speed of the pump motors. This can be accomplished by installing variable frequency drives (VFDs) for the existing motors. Medium voltage variable frequency drives that can run the circulating water pump motors in the range of 10-110% 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. Both 12- and 24-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. New motors are assumed to be required for both reduced speed and reduced/increased speed alternatives. The cost of the new motors is included in the cost estimates for these alternatives.

The six VFDs can be supplied from the 4,160-V switchgear 34A and 34B, three from each switchgear. The existing 4,160-V circuit breakers in the switchgear can be used. Preliminary estimates indicate that harmonic distortion produced by the VFDs is not significant and is likely to be well within the limits recommended by IEEE Std. 519-1992. Consequently, harmonic filters will not be required. If this alternative was 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.

6.3.2 Variable-Speed Pumps – Unit 2

Similar alternative variable speed drive alternatives, as discussed above for Unit 3 can also be applied to Unit 2.

6.3.2.1 Variable Speed Drives for Flow Reduction

Variable speed drives for the circulating water pumps would be used to reduce permitted condenser water flow by as much as 38% during the larval winter flounder entrainment season and operate at normal flow-rate during the rest of the year. The limiting factor for reduced flow operation during the larval winder flounder season is the 3 inch HgA backpressure in the condenser at the turbine exhaust and the condenser ΔT limit of 36°F. With Unit 2 service water flow of 24,000 gpm, this would result in reduction of entrainment of marine organisms into the Unit 2 intake of up to 37% during the sensitive winter flounder season, while allowing the unit to operate at full power during the rest of the year. At this flow reduction, the circulating water pumps would each operate at approximately 84,700 gpm with a total condenser water system flow of 338,800 gpm. Design CWP flow is 126,000 gpm with a total design circulating water system flow of 504,000 gpm. If Unit 3 pumped its normal volume of cooling water, the condenser cooling water reduction at Unit 2 results in a 11% decrease relative to present two-unit operation.

6.3.2.2 Variable Speed Drives for Both Flow Reduction and Increase

Variable speed drives for the circulating water pumps would be used to reduce circulating water flow by as much as 38% during the winter flounder season from late March to early June and increase circulating water flow by 10% from mid-June through mid-October. During the rest of the year the circulating water system would operate at normal rate of flow. As stated previously, the limiting factor for reduced flow operation during the winder flounder season is the 3 inch HgA backpressure in the condenser at the turbine exhaust and the condenser ΔT limit. This would result in reduction of entrainment of marine organisms into the Unit 2 intake of up to 37% of the total circulating water flow during the sensitive larval winter flounder entrainment season. During the summer, increasing the circulating water flow by 10% would allow improved unit output. During the rest of the year, the circulating water system would operate at normal design flow rates. A 10% increased CWP flow would be approximately 138,600 gpm with a total circulating water system flow of 554,400 gpm.

6.3.2.3 Pumping Energy Requirements

A 33% reduction in the pump speed would result in transposition of the pump performance curve to flows equal to 33% of the existing curve and a system total dynamic head requirement of 17.1 feet. This would result in a reduced power requirement for each pump from the existing 980 to 480 horsepower. The total pump energy requirements for 38% speed operation would be 1,420 kW, compared to the existing value of 3,400 kW.

A 10% increase in the pump speed would result in transposition of the pump performance curve to flows equal to 110% of the existing curve and a system total dynamic head requirement of 36.9 feet. This would result in an increased pump power requirement for each pump from the existing 980 to 1,680 horsepower. The total pump energy requirements for 110% speed operation would be 5,000 kW.

6.3.3 Impact On Unit Performance

Reduction in circulating water flow rate to each condenser would 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.

Reduced tube flow velocities would normally result in increased fouling of the condenser tubes. The load for each unit would have to be reduced as the condenser becomes 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 6.3-1 and 6.3-3 show the relationship for Units 3 and 2, 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. Figures 6.3-2 and 6.3-4 shows the same plots for Units 3 and 2, respectively, with circulating water system flow increased over design by 10%.

6.3.3 Capital and O&M Costs

The capital costs for VSDs with an increase in the condenser ΔT is the same as provided in Table 10.1-3 of the Cooling-Water System Alternatives Report. The capital costs for the VSDs and increased flow during the non-larval winter flounder entrainment season is provided in Table 6.3.3-1.

This alternative would result in an increase in the annual maintenance costs for Unit 2 of $20,000 and for Unit 3 of $30,000. This increased cost is due to increased pump and motor maintenance.

TABLE 6.3.3-1. VSDs with increased flow – summary of approximate costs.

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	4,033,000	6,340,000
Total Direct Cost:	**4,596,000**	**7,180,000**
Construction Management	321,000	500,000
Engineering	463,000	720,000
AFI/Contingency	1,331,000	2,105,000
Total Capital Cost:	**$6,711,000**	**$10,505,000**

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

Figure 6.3-1: Millstone Unit 3 - Electric Generation Rate Change vs Variable Speed CWP and Inlet Temperature

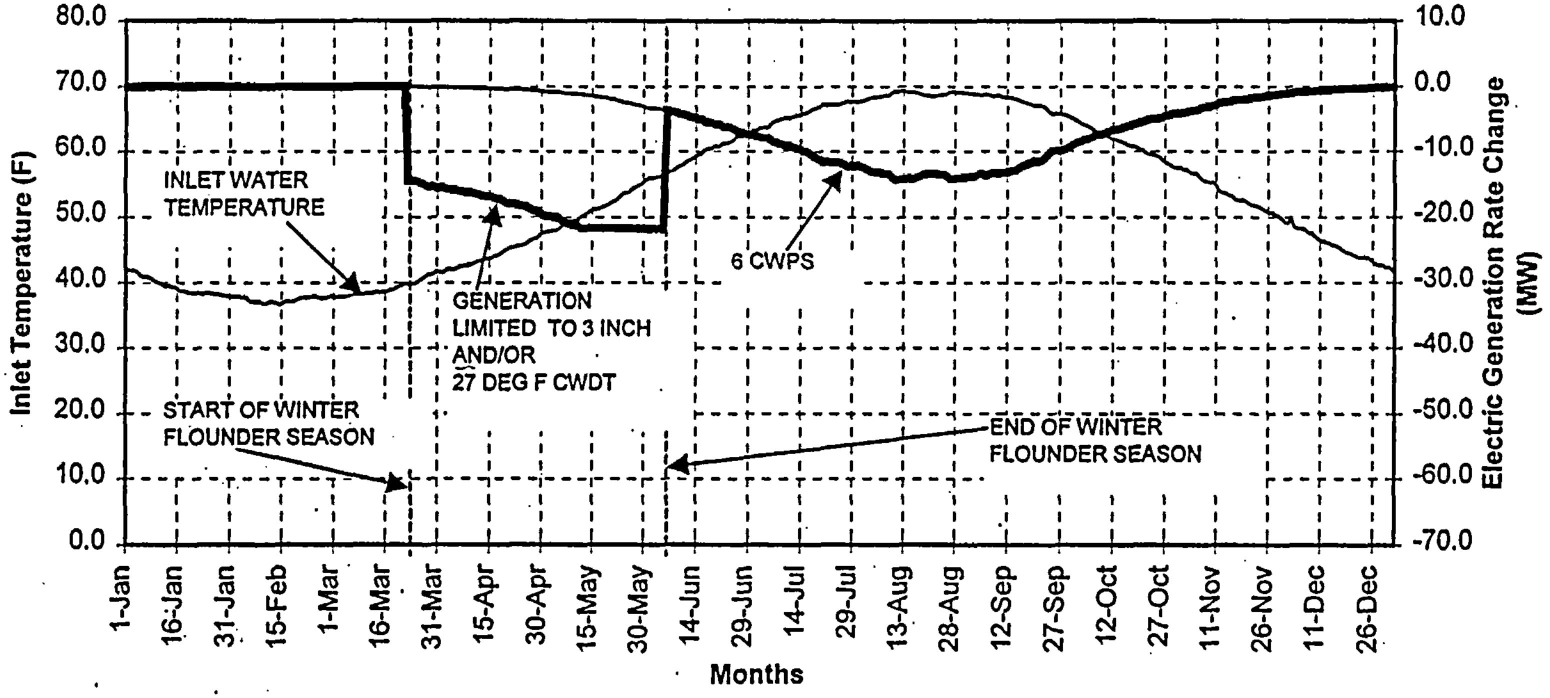


Figure 6.3-2: Millstone Unit 3 - Electric Generation Rate Change vs Variable Speed CWP/Increased CW Flow and Inlet Temperature

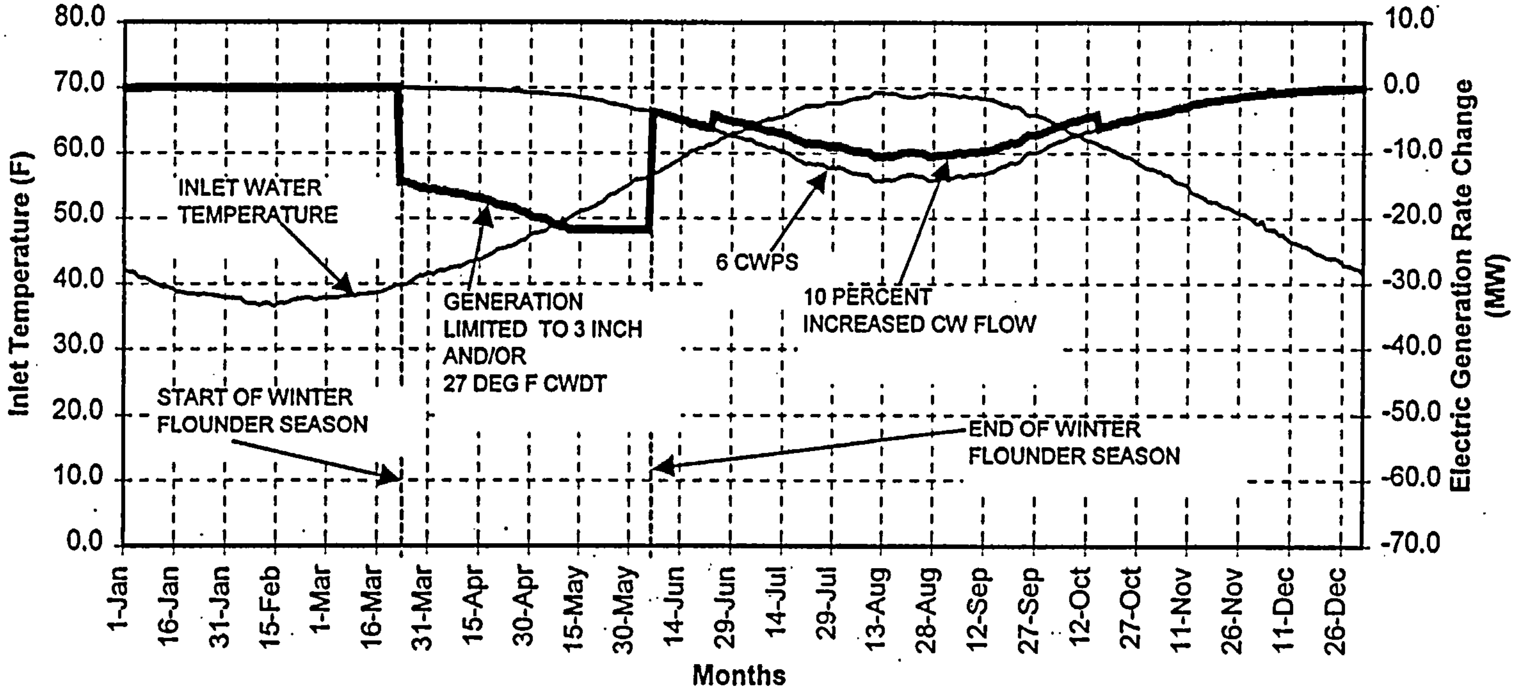


Figure 6.3-3: Millstone Unit 2 - Electric Generation Rate Change vs Variable Speed CWPs and Inlet Temperature

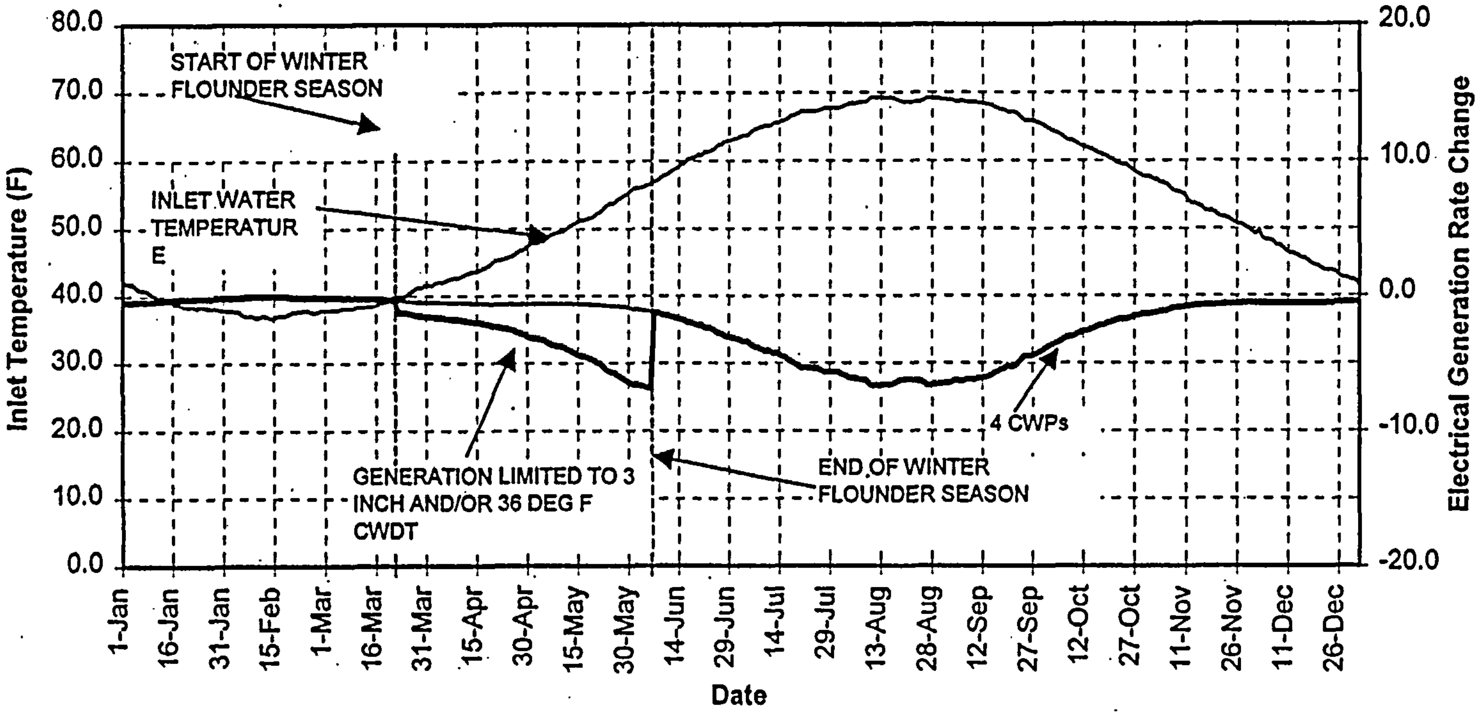
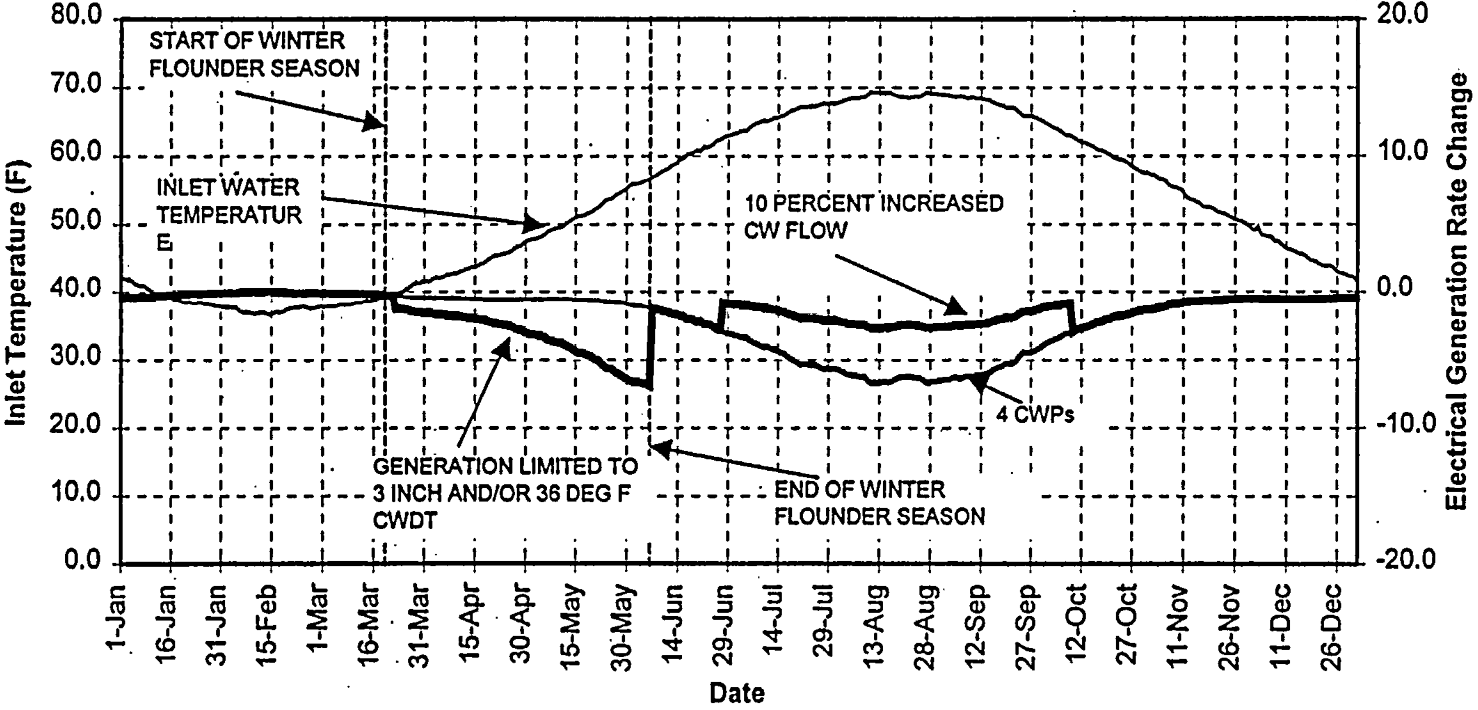


Figure 6.3-4: Millstone Unit 2 - Electric Generation Rate Change vs Variable Speed CWP/Increased CW Flow and Inlet Temperature



6.4 ADDITIONAL ALTERNATIVES SUMMARY

Table 6.4-1 summarizes the various flow reduction alternatives that have been discussed in this response. The table provides the percent flow reduction for each alternative during the winter flounder season relative to present two-unit operation and presently permitted three-unit flow. If variable speed pumps were to be installed at both Units 2 and 3, the flow and entrainment reduction is 36% relative to present two-unit operation and 52% relative to presently permitted three-unit flow.

Table 6.4-2 summarizes the effect on Unit performance for the alternatives. The change in unit performance includes the effect of pump power changes (i.e., increased or decreased) as well as the benefit of increased CWP flow during the non-winter flounder seasons.

References Cited in DNC Response to DEP Questions, Comments or Concerns #5 and 6

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.

LMS (Lawler, Matusky & Skelly Engineers). 1987. Brayton Point Station Unit No. 4 angled screen intake biological evaluation program. Prepared for New England Power Company.

Taft, E.P. III, R. Berger, L. Larsen, J.G. Holsapple, and L.W. Eberley. 1981. 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. 2000. Fish protection technologies: a status report. Env. Sci. Pol. 3:S349-S359.

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.

TABLE 6.4-1. Summary of flow reduction alternatives and percent reduction in MPS cooling-water flow achieved relative to present two-unit and former three-unit operation (NPDES Permitted flow).

	Unit 1		Unit 2		Unit 3		Station	% flow reduction	% flow reduction
Description[a]	CWS	SWS	Tot CWS	SWS	Tot CWS	Permit	Total	With Unit 1 shut down	From permitted flow
	(gpm)	(gpm)	(gpm)	(gpm)	(gpm)	(%)	(gpm)	(%)	(%)
Permit	420,000	24,000	548,800	24,000	918,000	30,000	1,964,800	N/A	N/A
With Unit 1 shut down	0	0	504,000	24,000	918,000	30,000	1,476,000	N/A	23%
Flow from combined Unit 1 and 2 intakes during larval winter flounder season (in conjunction with fine-mesh screens)									
Unit 2	0	0	405,200	24,000	918,000	30,000	1,377,200	7%	30%
Reduced flow during larval winter flounder season with increased ΔT limits									
Unit 2	0	0	338,800	24,000	918,000	30,000	1,310,800	11%	33%
Unit 3	0	0	504,000	24,000	558,900	30,000	1,116,900	24%	43%
Units 2 & 3 combined	0	0	338,800	24,000	558,900	30,000	951,700	36%	52%

[a] CWS = circulating water system and SWS = service water system.

TABLE 6.4-2. Additional alternatives – annual loss in unit performance.

Description	Unit No.	Annual Loss In Electric Output (MWe-hr)[a]	
		3/22 – 6/5	4/4 – 5/14
Offshore Fine-Mesh Screening Facility	2 & 3	26,630 (Annual)	
Combined Unit 1 & 2 Intakes	2	-622[b]	-582
Reduced CWP Flow Rate With Increase Condenser ΔT Limit	2	2,300	635
Seasonable Adjusted CWP Flow Rate With Increase Condenser ΔT Limit	2	-826[b]	-2495[b]
Reduced CWP Flow Rate With Increase Condenser ΔT Limit	3	23,000	12,730
Seasonable Adjusted CWP Flow Rate With Increase Condenser ΔT Limit	3	20,550[b]	10,270[b]

[a] Change in Unit performance includes the increase or decrease in pump power as well as station generating capacity.

[b] Change in Unit performance includes the benefit of increased CWP flow rate during the non-larval winter flounder season.

DEP Question, Comment, or Concern #7:

ESSA has remarked that planned outages could be used to reduce fish egg and larval entrainment at the Station during critical periods of ichthyoplankton occurrence. While the study contends that the cost of seasonal forced outages is high, i.e. estimated to range from $248M to 2.7B, there is no detailed analysis of how these estimates were derived. This information must be provided.

DNC Response to Question, Comment, or Concern #7:

Planned outages for refueling that seek to coincide with the larval winter flounder season remain a viable long-term option for minimizing entrainment. As indicated in the August 31, 2001 Cooling-Water System Alternatives Report and recent correspondence with the DEP (DNC 2002), MPS has been adjusting fuel purchases and outage lengths to achieve alternating spring/fall outages based on 18-month operating cycles. The current Unit 3 refueling outage began September 7, 2002 and, upon successful completion, the unit will then be on schedule to achieve alternating spring/fall outages commencing in Spring 2004. The most recent Unit 2 refueling outage occurred as planned on February 16, 2002 with projected refuelings in Fall 2003 and Spring 2005. The goal remains to target April 1 for the start of spring refuel outages, recognizing that the timing cannot be planned with absolute precision.

The cost estimates for shutdowns in the Cooling-Water System Alternatives Report assumed they would occur annually and independent of refueling outages. As a result, the cost is based on lost electric output and corresponding lost revenues over the entire larval season each year over the life of the unit. For example, as shown below on Table 7-1a, a total of 1,491,840 MW-hr is lost if a forced shutdown occurred at Unit 2 during the larval winter flounder season encompassing the period of March 22 through June 5. The resultant cost was estimated to be approximately $477,395,000 net present value (NPV), based on the price of energy during that larval period over the life of the units (Table 7-1b). Should a forced shutdown occur coincidentally with a refueling outage, the costs would be moderated, depending on the refueling outage length compared to the larval season chosen. Regardless, the magnitude of the costs from forced shutdowns make this option most cost-prohibitive.

<u>Reference Cited in DNC Response to DEP Question, Comment or Concern #7</u>

DNC (Dominion Nuclear Connecticut, Inc.). 2002. Letter D17363 dated July 30, 2001 from D. Hicks, DNC, to J.F. Grier, CT DEP.

TABLE 7-1a. Lost electric output (MW-hr) as a result of forced plant shutdowns[a].

Unit	Winter Flounder		Tautog		Combined
	3/22 - 6/5	4/4 - 5/14	5/3 - 8/22	5/29 - 7/12	3/22 - 8/22
2	1,491,840	806,400	2,237,760	887,040	3,064,320
3	1,967,524	1,063,526	2,951,286	1,169,879	4,041,400
2 and 3	3,459,364	1,869,926	5,189,046	2,056,919	7,105,720

TABLE 7-1b. Cost (net present value) as a result of forced plant shutdowns[a].

Unit	Winter Flounder		Tautog		Combined
	3/22 - 6/5	4/4 - 5/14	5/3 - 8/22	5/29 - 7/12	3/22 - 8/22
2	$477,395,000	$247,797,000	$949,010,000	$396,422,000	$1,207,588,000
3	$629,156,000	$326,544,000	$1,251,198,000	$522,630,000	$1,592,259,000
2 and 3	$1,066,210,000	$553,402,000	$2,120,015,000	$885,554,000	$2,697,804,000

[a] The input data and calculations for the information above are given in Appendix B attached to this document as a CD and are explained further in DNC's response to Questions, Comments, or Concerns #12-14.

DEP Question, Comment, or Concern #8:

Another key finding by ESSA is the study's absence of strategies that would combine technologies and operations to achieve mitigation of entrainment. In its 4/9/02 proposed rule to establish section 316(e) [sic] *CWA regulations for existing facilities, EPA has stated that combinations of technologies for entrainment reduction, including the use of fine mesh traveling screens, constitutes BTA for existing facilities which have intakes located in estuaries and oceans. Also, note the specific recommendations made by ESSA for alternative measures which were not considered in the study, such as potentially using Unit 1 recirculation* [sic] *pumps to reduce Unit 2/3 intake velocities and modification of the quarry discharge gates or Unit overflow weirs. Please respond to these points.*

DNC Response to Question, Comment, or Concern #8:

Several of the above alternative combinations suggested by ESSA are discussed in DNC's response to Questions, Comments, or Concerns #5 and 6. These include: 1) combining flow from the Unit 1 intake with that at Unit 2 with variable speed pumps and fine-mesh screens on each intake; 2) an offshore intake screen array with both fine- and coarse-mesh screens; 3) reduced flow from several options, such as variable speed pumps with higher ΔT during the larval winter flounder season; and 4) with this last option, higher flows during the summer to offset MWe lost during the larval winter flounder season.

While the Cooling-Water System Alternatives Report did not discuss specifically the use of one technology at Unit 2 and another at Unit 3, such as variable speed pumps at Unit 2 and throttling valves at Unit 3, the costs and percent flow reductions from these combinations can be inferred from Revised Table 7.11-1 in DNC Response to Question, Comment, or Concern #1 and in Revised Table III-4-1 found in the DNC Response to Questions, Comments, or Concerns #12-14, below.

DEP Question, Comment, or Concern #9:

The DEP Marine Fisheries Division staff has reviewed the study (including the supplemental winter flounder stock identification studies by UCONN and URI submitted 3/14/02) and has reservations concerning key assumptions, inputs, and conclusions drawn from the Stochastic Population model used by DNC as a predictive tool. It is critical that there is a consensus that the most accurate and scientifically supported data be utilized within the model such that it can be relied upon to aid in assessing the impacts of the Station's operation upon Niantic winter flounder spawning stocks [sic]. *To this end the Department is asking ESSA, as part of its existing contract with DEP, to undertake a peer review/analysis of this mass balance model and to assist us in resolving these concerns. We hope to scope out this work shortly to enable ESSA to initiate this review as soon as possible.*

DNC Response to Question, Comment, or Concern #9:

A more specific and detailed request for information on the mass-balance model was received from DEP via email on April 30, 2002. DNC complied with this request for information and at DEP's behest sent materials (SAS software disks, SAS program developed by DNC as the mass-balance model, mass-balance model dataset for the years 1984-99) to ESSA on June 12, 2002 (with a copy of the transmittal letter to DEP). Also sent with these materials were copies of previously reported studies that had relevance to mass-balance model formulation and additional copies of reports on larval winter flounder stock identification by Drs. Joseph Crivello of the University of Connecticut and R. Bradley Moran of the University of Rhode Island that were noted in the above comment. A final inclusion was a copy of an analysis of larval winter flounder entrainment by source, which incorporated the findings of the Crivello work, which was presented in the 2001 Annual Report submitted to DEP on April 29, 2002 and entitled "Monitoring the Marine Environment of Long Island Sound at Millstone Power Station Waterford, Connecticut". The June 12, 2002 letter also referred to sensitivity analyses of the mass-balance model performed by DNC and independently by Dr. Eric Adams of The Massachusetts Institute of Technology that were included in Cooling-Water System Alternatives Report (see Part II, Chapter 3, Appendices B and C).

To date, DEP has not yet provided DNC with the results of the ESSA analysis of the mass-balance model. DNC looks forward to further discussion with the DEP upon review of ESSA's evaluation.

DEP Question, Comment, or Concern #10:

The study states that the water velocity approaching the traveling screens for both Units 2 and 3 is 1.0 fps. In its 2/26 response to DEP regarding the Scope of Study, DNC cites approach velocities of 1.5 and 1.0 fps for Units 2 and 3 respectively. Please clarify this discrepancy. Also, please explain how and the precise location where these intake velocities were measured.

DNC Response to Question, Comment, or Concern #10:

The discrepancy noted in water velocity for Unit 2 may have resulted from the source of the information and whether a design calculation or actual measurement was cited, or how these data were interpreted. The Final Environmental Statement Related to the Continuation of Construction of Millstone Nuclear Power Station Unit 2 and the Operation of Units 1 and 2 (USAEC 1973; p. 3-3; cites MPC 1972) notes for Unit 2 that "water velocity in the channel dredged in front of the intake structure is estimated to be about 0.5 fps. The water velocity through the traveling screens is estimated at 1.66 fps." These intake flow velocities were engineering estimates as these documents were completed before Unit 2 was online.

Data presented in the 1976 316(b) Demonstration for MPS (NUSCO 1976) noted that Unit 2 had measured intake flow velocities of mostly 1.1 fps or less at the face of the trash racks, although one measured value was equal to 1.5 fps (Table 10-1). From these data, the average flow over the measured points is 0.55 fps. For Unit 3, the Environmental Report (NUSCO 1983; Vol. 2, p. 3.4-1) states that "the average velocity within the [Unit 3] pumphouse bays during normal operation at low water elevation is about 0.24 m/sec (0.8 fps)" whereas the Final Environmental Statement Related to the Proposed Construction of Millstone Nuclear Power Station Unit 3 (USAEC 1974; p. 3-6) noted that to reduce the potential for fish impingement the Unit 3 intake structures were designed "limiting the intake water approach velocity to not more than 1 fps". Similar to Unit 2, these intake flow velocities were engineering estimates as these documents were completed before Unit 3 was online.

TABLE 10-1. MPS Unit 2 intake velocity profiles in fps at the trash racks as measured on December 29, 1975 with a Cushing Engineering, Inc. electromagnetic water current meter (Model 632P). (From NUSCO 1976).

Bay:	A		B		C	D
Bay width:	½	¼	½	¾	½	½
Feet from bottom						
3	0.7	0.5	0.3	0.1	0.7	1.0
6	1.1	0.1	0.1	0.2.	0.7	1.2
9	1.0	0.4	0.3	0.3	0.8	1.1
12	1.5	0.3	0.4	0.4	1.0	1.1
15	1.3	0.6	0.6	0.6	0.9	1.1
18	0.4	0.4	0.3	0.2	0.5	0.4
21	0.4	0.4	0.2	0.3	0.4	0.3
24	0.3	0.4	0.3	0.1	0.2	0.5

References Cited in DNC Response to DEP Question, Comment or Concern #10

MPC (Millstone Point Company). 1972. Millstone Nuclear Power Station Unit 2 environmental report. Operating license stage.

NUSCO (Northeast Utilities Service Company). 1976. Environmental assessment of the condenser cooling water intake structures (316b demonstration). Vol. 1 and 2. Millstone Nuclear Power Station, Waterford, CT. Submitted to the State of Connecticut Department of Environmental Protection.

NUSCO. 1983. Millstone Nuclear Power Station Unit 3 environmental report. Operating license stage. Vol. 2. Submitted to the U.S. Nuclear Regulatory Agency.

USAEC (United States Atomic Energy Commission). 1973. Final environmental statement related to the continuation of construction of Unit 2 and the operation of Units 1 and 2. Millstone Point Co. Docket Nos. 50-245 and 50-336. June 1973. Directorate of Licensing.

USAEC. 1974. Final environmental statement related to the proposed construction of Millstone Nuclear Power Station Unit 3. Millstone Point Co., et al. Docket No. 50-423: February 1974. Directorate of Licensing.

DEP Question, Comment, or Concern #11:

Please provide detailed information relative to the condenser cooling water system chlorination process, amounts of chlorine used, peak concentrations, chlorination schedule etc. for Units 2 and 3.

DNC Response to Question, Comment, or Concern #11:

Chlorine in the form of dilute sodium hypochlorite solution (approximately 12.5%) is used at MPS to control biofouling within the condenser and service water cooling-water systems. Hypochlorite solution is injected at rates sufficient to sustain free available chlorine (FAC) levels for biofouling control and at the same time account for chlorine demand. The MPS NPDES Permit limits chlorination of the circulating water intake bays to no more than 2 hours per unit per day with a maximum discharge concentration of 0.25 mg/L FAC at the unit discharges into the quarry. In addition, the units cannot be chlorinated simultaneously.

The units typically chlorinate the circulating water intake bays once per week, although seasonal demand occasionally requires more frequent chlorination during summer. The intake bays are chlorinated sequentially, and hypochlorite is injected upstream of the CWPs. A review of FAC concentrations measured weekly at the unit circulating water condenser discharges in 2000 and 2001 suggests that FAC concentrations averaged 0.04 mg/L at Unit 2 and 0.08 mg/L at Unit 3. Maximum values at Units 2 and 3 were 0.07 and 0.15 mg/L, respectively. Based on FAC measurements, it is estimated that approximately 413 and 366 kg of free chlorine were discharged at Unit 2, while 1,819 and 1,370 kg were discharged at Unit 3 during 2000 and 2001, respectively.

Service water is chlorinated continuously at Units 2 and 3. This regime stems from the response of MPS to NRC IE Bulletin 81-03, "Flow Blockage of Cooling Water to Safety System Components by *Corbicula* sp. (Asiatic clam) and *Mytilus* sp. (mussel)". As a result of considerable study, and with DEP approval (Modified Permit, November 8, 1993), it was determined that continuous low level chlorination was necessary to minimize risks to the safety-related service water systems from mussel fouling. MPS subsequently recommended to the DEP that chlorine injection remain at rates sufficient to maintain FAC at the service water discharges on the order of 0.10 mg/L with a daily limit of 0.25 mg/L (Letter D01035 dated October 31, 1985). At Unit 3, hypochlorite is injected immediately downstream of the service water pumps while at Unit 2, hypochlorite is injected directly into the service water pump housings.

In examining measured FAC concentrations at the Unit 2 and 3 service water system discharges, average concentrations in 2000 and 2001 were approximately 0.11 mg/L (maximum of 0.23 mg/L) at Unit 2 and 0.14 mg/L (maximum of 0.23 mg/L) at Unit 3. Total amounts of free chlorine discharged in 2000 and 2001 at Unit 2 were estimated at 2,531 and 2,546 kg respectively, based on routine measurements. Amounts at Unit 3 in those years were 8,567 and 8,109 kg, respectively.

Since chlorine is partially consumed within the condenser and service water systems prior to measurement at the discharge points, the amounts of chlorine given above do not represent the total amount of hypochlorite used. Purchasing records suggest that MPS uses about 80,000 gallons of sodium hypochlorite per year for biofouling control.

DEP Question, Comment, or Concern #12:

The various cost analyses of the application of alternative treatment technologies presented in the study assumes, among many other variables, a station capacity factor of 96% over the life of the plant. Although this efficiency may have been achieved recently (since the 1999 start-up), it is extremely optimistic to expect this rate to be sustained for the indefinite future. Please provide justification for this assumption.

DEP Question, Comment, or Concern #13:

Appendix B of the Financial Model Results in Section 12.2 of Part 1 is missing.

DEP Question, Comment, or Concern #14:

Please respond to and provide the information requested by ESSA as outlined in section 3.1 of their report, the last 3 paragraphs in particular

DNC Response to Questions, Comments, or Concerns #12-14:

Questions, Comments, or Concerns #12 through 14 relate generally to Chapter 3.1 of the ESSA report, entitled "Overview of Costs of Lost Generation". In this chapter, ESSA discusses the various input parameters and assumptions used by DNC in estimating the relative cost of technology options. Some of ESSA's questions and statements apparently arose from not having been able to review Appendix B, as this information was not included in the Cooling-Water System Alternatives Report. To assist in the DEP's continuing review of this report, Appendix B is included with this document in the form of a Compact Disc. Appendix B is an Excel spreadsheet of considerable size and complexity containing the various financial input parameters and the financial results. As an example, the Inputs file contains information on escalation rates, weighted cost of capital, forced outage rate, taxes and for each option the capital and O&M costs, the MWe lost or gained for each technology option due to flow reduction, and construction outage duration and projected dates. Some of this information was previously included in Part I, Table 7.11-2 of the Cooling-Water System Alternatives Report and explained in Part I, Section 12. The Appendix B Net Present Value (NPV) file contains those data shown in Part I, Figure 12-2 and Part III, Table III-4-1. The Revenue file provides information on the price of energy used and the revenues lost or gained for each option and for each of the entrainment seasons (winter flounder and tautog and the combined time frames). Files are also provided for capitalization rates and tax depreciation as well as the details of revenue calculations for each technology option based on expected life of the plant, which is, in turn, predicated on license renewal. Note that the capital cost estimates are scoping level estimates and are subject to some uncertainty.

The Appendix B files provided here have been modified based on further review of the input parameters used in the financial formulations provided in the August 31, 2001 submittal of the Cooling-Water System Alternatives Report. The updated costs are provided in Revised Table III-4-1. For example, an outage period of 3 months had been incorrectly included (rather than none) in the cost estimates for the CWP on/off scenarios and this inadvertently

REVISED 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.

Options Evaluated in the Cooling-Water System Alternatives Report	45-year net present value determined for:			Flow reduction (% of total for Units 2 and 3)[a]	Winter flounder cumulative gain in biomass (lbs)[b]	Winter flounder stock size increase (lbs)[c]	Tautog annual gains (number)[d]
	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)				
Unit 3 operating with 5 condenser cooling-water pumps (CWP)	$1,088,000	$514,000	$6,141,000	8%	9,557	361	22
Unit 3 operating with 4 CWPs	$4,117,000	$1,950,000	$18,536,000	16%	19,280	723	43
Unit 2 operating with 3 CWPs	$1,097,000	$46,000	$66,696,000	7%	8,363	316	19
Combined Unit 3 operating with 5 cwps and Unit 2 with 3 CWPs	$2,185,000	$560,000	$72,837,000	15%	18,078	678	40
Combined Unit 3 operating with 4 cwps and Unit 2 with 3 CWPs	$5,214,000	$1,996,000	$85,232,000	23%	27,720	1,040	62
Unit 3 operating with 5 CWPs and with cross-connect (x-c)	$45,110,000	$44,541,000	$50,147,000	8%	9,557	361	22
Unit 3 operating with 4 CWPs and with x-c	$48,058,000	$45,936,000	$62,339,000	16%	19,280	723	43
Unit 2 operating with 3 CWPs and with x-c	$34,290,000	$33,239,000	$99,889,000	7%	8,363	316	19
Combined U3 operating w/ 5 CWPs, U2 w/ 3 CWPs; both with x-c	$79,400,000	$77,800,000	$150,036,000	15%	18,078	678	40
Combined U3 operating w/ 4 CWPs, U2 w/ 3 CWPs; both with x-c	$82,348,000	$79,175,000	$162,228,000	23%	27,720	1,040	62
Unit 3 operating with throttled condenser discharge valves	$24,521,000	$22,377,000	$37,874,000	15%	18,078	678	40
Unit 2 operating with throttled condenser discharge valves	$13,211,000	$13,026,000	$14,924,000	6%	7,168	271	16
Units 2 and 3 operating with throttled condenser discharge valves	$37,732,000	$35,403,000	$52,798,000	22%	26,514	994	59
Unit 3 operating with condenser by-pass lines	$5,068,000	$3,006,000	$18,167,000	15%	18,078	678	40
Unit 2 operating with condenser by-pass lines	$865,000	$735,000	$2,411,000	6%	7,168	271	16
Units 2 and 3 operating with condenser by-pass lines	$5,933,000	$3,741,000	$20,578,000	22%	26,514	994	59
Unit 3 operating with variable speed CWPs	$8,344,000	$7,092,000	$18,926,000	15%	18,078	678	40
Unit 2 operating with variable speed CWPs	$3,273,000	$3,594,000	$3,418,000	6%	7,168	271	16
Units 2 and 3 operating with variable speed CWPs	$11,617,000	$10,686,000	$22,344,000	22%	26,514	994	59

REVISED TABLE III-4-1 (continued).

Options Evaluated in the Cooling-Water System Alternatives Report	45-year net present value determined for:			Flow reduction (% of total for Units 2 and 3)[a]	Winter flounder cumulative gain in biomass (lbs)[b]	Winter flounder stock size increase (lbs)[c]	Tautog annual gains (number)[d]
	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)				
Unit 3 with full-sized natural draft cooling tower	-	-	$418,400,000[e]	60%	75,041	2,698	161
Unit 3 with 2/3-sized natural draft cooling tower	-	-	$269,792,000[e]	40%	49,119	1,808	108
Unit 2 with full-sized natural draft cooling tower	-	-	$225,885,000[e]	32%	39,295	1,440	86
Units 2 and 3 with full-sized natural draft cooling towers	-	-	$644,285,000[e]	92%	117,505	4,076	247
Unit 3 with full-sized mechanical draft cooling towers	-	-	$334,895,000[e]	60%	75,041	2,698	161
Unit 2 with full-sized mechanical draft cooling towers	-	-	$237,992,000[e]	33%	40,523	1,492	89
Units 2 and 3 with full-sized mechanical draft cooling towers	-	-	$572,887,000[e]	93%	118,782	4,121	250
Unit 3 with offshore intake	-	-	$220,189,000[e]	0%	38,067	1,440	0[f]
Units 2 and 3 with combined offshore intake	-	-	$364,799,000[e]	0%	62,534	2,248	0[f]
Unit 3 with fine-mesh screens	-	-	$154,260,000[e]	0%	0[g]	0[g]	0[g]
Unit 2 with fine-mesh screens	-	-	$110,691,000[e]	0%	0[g]	0[g]	0[g]
Conversion of station to gas fuel	-	-	$1,000,000,000[e]	65%	81,295	2,923	175
Shut down Unit 3 during spawning seasons	$629,156,000	$326,544,000	$1,592,259,000	50%	62,534	2,248	135
Shut down Unit 2 during spawning seasons	$477,395,000	$247,797,000	$1,207,588,000	27%	33,155	1,220	73
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	207
New Alternatives Presented in this Submission							
Fine-mesh screen - offshore array	-	-	$93,424,000[e]	0%	0[g]	0[g]	0[g]
Unit 2 intake combined with Unit 1, fine-mesh screens, variable speed CWPs	$36,132,000	$36,140,000	N/A	9%	10,755[g]	406[g]	0
Unit 3 variable speed CWPs, increased ΔT, 3 inch Hg back-pressure	$13,941,000	$10,315,000	N/A	24%	28,925	1,085	0
Unit 2 variable speed CWPs, increased ΔT, 3 inch Hg back-pressure	$5,213,000	$4,267,000	N/A	11%	13,261	497	0
Units 2 and 3 with variable speed CWPs, increased ΔT, 3 inch Hg back-pressure	$19,154,000	$14,582,000	N/A	36%	42,186	1,582	0

REVISED TABLE III-4-1 (continued).

Options Evaluated in the Cooling-Water System Alternatives Report	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)[a]	Winter flounder cumulative gain in biomass (lbs)[b]	Winter flounder stock size increase (lbs)[c]	Tautog annual gains (number)[d]
Unit 3 variable speed CWPs, increased ΔT, 3 inch Hg back-pressure, and increased flow during summer and early fall	$15,415,000	$11,779,000	N/A	24%[h]	28,925	1,085	0
Unit 2 variable speed CWPs, increased ΔT, 3 inch Hg back-pressure, and increased flow during summer and early fall	$5,101,000	$4,609,000	N/A	11%[h]	13,261	497	0
Units 2 and 3 with variable speed CWPs, increased ΔT, 3 inch Hg back-pressure, and increased flow during summer and early fall	$20,516,000	$16,388,000	N/A	36%[h]	42,186	1,582	0

[a] As noted, percent flow reductions are relative only to Units 2 and 3 totals. For percent flow reductions for these alternatives that include the retirement of Unit 1, see Revised Table 7.11-1 and Table 6.4-1 herein.

[b] 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%.

[c] 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%.

[d] Number of tautog (annual equivalent-adult estimates) determined over entire season of tautog egg entrainment. See the last section of this submission for a revised tautog equivalent-adult calculation.

[e] Various cooling tower, offshore intake, most 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.

[f] 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.

[g] Undetermined for fine-mesh screens, 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.

[h] Reductions in flow only during the larval winter flounder season with a 10% increase in flow at both Units 2 and 3 during the summer and early fall.

inflated the NPV. Differences from the previous submittal ranged from –$7.13 million for Unit 2 operating with throttled condenser discharge valves to –$109.25 million for combined operation of Unit 3 with either 5 or 4 CWPs and Unit 2 operating with 3 CWPs. Costs for the remaining reduced flow options, including operation using condenser by-pass lines and variable speed pumps, decreased only marginally due to changes in outage timing, which affected the cost of energy. Starting dates for construction were generally moved from 2003 to 2004 to account for a more realistic schedule to perform necessary engineering and other analyses prior to construction. Also, dates were scheduled for fall, when energy prices are lowest. The costs for cooling towers and the offshore intakes had either no changes or relatively small decreases relative to their overall costs. Also of note, these costs were calculated on completing construction in an expedient manner. To the extent that construction outages could be further postponed until 2005, when Unit 2 has a spring refueling outage and Unit 3 a fall refueling outage, costs could be further reduced for some of these options.

The NPV estimates for the new alternatives presented in this alternative are found in the final section of Revised Table III-4-1. The newly proposed offshore fine-mesh screen array serving both units is very costly at more than $93 million, although this cost would be less than converting each of the present Units 2 and 3 intake structures to accept fine-mesh screens. Pumping water through both Units 1 and 2 intake structures fitted with fine-mesh screens and variable speed pumps to serve Unit 2's cooling-water needs has an NPV expense of about $36 million. Use of variable speed pumps in this option would only decrease flow and larval winter flounder entrainment by only 7% relative to present MPS operation, with larvae impinged upon fine-mesh screens expected to be returned alive. However, as noted previously, the ability of fine-mesh screen options to improve the survival of fish eggs and larvae at MPS is questionable. The other new alternatives (variable speed CWPs, increased ΔT, 3 inch Hg back-pressure) would only be in operation during the larval winter flounder entrainment season. Costs (approximately. $4-14 million NPV) are greater than operation with reduced number of CWPs at MPS units, but also reduce flow by a larger percentage (up to 36% in combination). Also, the reliability of plant operation with reduced number of CWPs is a concern (see DNC Response to DEP Question, Comment, or Concern #16). At Unit 2, it would be advantageous (i.e., less costly) to operate with increased flow during summer and fall as there is a favorable gain in generation. However, the gain at Unit 3 does not offset the capital costs of the equipment needed.

To further aid in DEP's review, DNC has also included in Table 12/14-1 the underlying information on capital and O&M costs, construction periods and duration, outage periods and MWe-hr lost that are embedded in Appendix B for options found in the August 31, 2001 Cooling-Water System Alternatives Report and the new alternatives presented in this submission, with the exception of the groin alternative discussed in the DNC response to DEP Question, Comment. Or Concern #4. Again, these cost estimates should be viewed as preliminary.

The text which follows deals with specific requests for information in DEP Questions, Comments, or Concerns #12-14.

TABLE 12/14-1. Summary of cooling-water alternativelectric output related to its operation during the primary and optimal entrainment seasons fo

Description	Unit No.	COutput (MW-hrs)		
		Tautog		Winter Flounder & Tautog
		22	5/29 – 7/12	3/22 – 8/22
Fine-mesh Screening Facility for Entire Station	2 & 3	10 (Annual)		
Unit 1 & 2 Combined Intake	2	2	N/A	N/A
Variable Speed CW Pumps with Increased ΔT and 3 inch Backpressure Operating Limit				
- Unit 2	2		N/A	N/A
- Unit 3	3		N/A	N/A
Variable Speed CW Pumps with Increased ΔT, Increased Flow, and 3 inch Backpressure Operating Limit				
- Unit 2	2		N/A	N/A
- Unit 3	3	1	N/A	N/A
Reduced Flow Rate				
Reduced Number of Operating CWPs - **5 CWPs**	3		5,329	15,366
Reduced Number of Operating CWPs - **4 CWPs**	3		15,953	46,716
Reduced Number of Operating CWPs with Cross-Connect - **5 CWPs**	3	1	5,310	15,300

TABLE 12/14-1 (continued).

Description	Unit No.	COutput (MW-hrs)		
		Tautog		Winter Flounder & Tautog
		2	5/29 – 7/12	3/22 – 8/22
Reduced Number of Operating CWPs with Cross-Connect • 4 CWPs	3	[illegible]	15,786	46,135
Reduced Number of Operating CWPs • 3 CWPs	2	[illegible]	83,900	184,532
Reduced Number of Operating CWPs with Cross Connect • 3 CWPs	2	[illegible]	83,900	184,532
Throttling of Condenser Discharge Valves	3	[illegible]	14,636	44,224
Throttling of Condenser Discharge Valves	2		1,994	5,492
Recirculation				
Installation of Condenser By-pass Lines	3	[illegible]	14,329	43,156
Installation of Condenser By-pass Lines	2		1,773	4,724
Use of De-icing Line for Recirculation of CW Back to Intake	2		1,773	4,724
Variable Speed				
Variable Speed CWPs	3	[illegible]	11,278	32,547
Variable Speed CWPs	2	[illegible]	-82	-1,727
Two-Speed CWPs	3	[illegible]	N/A	N/A

TABLE 12/14-1 (continued).

Description	Unit No.	COutput (MW-hrs) ınder & Tautog 2 – 8/22		
Cooling Towers				
Natural Draft – 100% Capacity	3	15 (Annual)		
Natural Draft – 2/3 Capacity	3	17 (Annual)		
Mechanical Draft – 100% Capacity	3	15 (Annual)		
Natural Draft – 100% Capacity	2	12 (Annual)		
Mechanical Draft – 100% Capacity	2	11 (Annual)		
Offshore Intake				
Unit 3 Only	3	9) (Annual)		
Units 2 and 3 Combined	2 & 3	1) (Annual)		
Physical Barriers				
Fine-Mesh Screens	3	3	N/A	N/A
Fine-Mesh Screens	2	1'	N/A	N/A

Notes on following page.

Note 1: The capital cost does not include escalation.

Note 2: The construction period estimates were developek that may be required.

Note 3: For scheduling purposes, it was assumed that the

CWS Cross-Connect	12 n
CWS Throttling Valves	12 n
Condenser Bypass	12 n
Variable Speed Pumps	12 n
Two-speed Pumps	12 n
Recirculating (De-icing line)	12 n
Cooling Towers	18 n
Offshore Intake	18 n
Fine-Mesh Screens	18 n
Offshore Screening Facility	18 n
Combined U1 & 2 Intakes	12 n

During these periods planning, permitting, engine

Note 4: Refer to timeline for dates.

Note 5: Includes benefit of increased CWP flow rate durir

Capacity Factor Assumptions:

ESSA questioned whether a 96% capacity factor was reasonable for cost estimation purposes given information they apparently had available from the nuclear industry but did not reference. By way of clarification, a 96% *operating* capacity factor is used at MPS for various planning purposes. *Operating* capacity factor is the expected unit performance *between* planned outages. Planned outages are those that are scheduled well in advance with the grid dispatcher (i.e., refueling outages). A planned/unplanned outage rate of 4% is assumed to account for generation losses due to planned reductions for technical specification required equipment testing and surveillances, seasonal losses due to increase cooling-water temperatures, and other planned or unplanned outages/reductions that may occur during the planning period. As a result, DNC based its 2002 planning on projected operating capacity factors of 96%.

By comparison, during 2002, Unit 2 had projected a 32-day refueling outage and so the 2002 *annual* capacity factor for the unit was estimated at 87.6%:

$$((365 - 32)/365 * .96)) * 100$$

Any other known losses to generation that are expected during the year would be included in this calculation (i.e., coastdown prior to a refueling outage, losses for cooling-water system alternatives, etc.). Estimated losses from power reductions would be converted to equivalent full-power days. This methodology for annual capacity factor projections is used throughout the industry. Units 2 and 3 are on 18-month refueling cycles. The operating cycle would be from refueling outage end date to the next refueling outage start date. The refueling outage itself is not part of the operating cycle, and is not considered as part of the 4% planned/unplanned outage rate. The most recent cycle capacity factors are 96% and 97.6% for Units 2 and 3, respectively. For Unit 2, this represented the period from June 2000 to February 2002, when the unit shut down for refueling. For Unit 3, this operating capacity factor represented the period from June 1999 to February 2001. Since its last refueling outage, which ended March 31, 2001, Unit 3 operated for 526 consecutive days through September 7, when the unit shut down for its scheduled refueling outage and had an operating capacity factor of about 99%.

Industry sources indicate that the average annual capacity factors for U.S. nuclear units are increasing. The 1999 annual average capacity factor was reported as 85.2%, 2000 was 90.1%, and 2001 was 91.0%.[1] The year-to-date U.S. nuclear performance through May 2002 is 90.8%.[2] Industry sources also indicate that refueling outage durations are decreasing. In 1999, the industry average was 41.5 days; the median was 39 days. In 2000, the industry average was 39.9 days, and the median was 35 days[2], which means that half of the operating nuclear units completed refueling outages in 35 days or less. Over the next 5-year planning horizon, DNC will be working to continually reduce its outage duration as MPS is now a merchant facility and does not have the ability to pass along certain costs to ratepayers. For these reasons, DNC believes that its financial projections based on a 96% operating

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[1] Source: Electric Utility Cost Group

[2] Source: Nuclear Energy Institute (www.nei.org)

cycle capacity factor are reasonable for the purposes of evaluating the relative cost and benefit of cooling-water intake alternatives. Outages affect the cost estimation here in so far as construction of the various technology options requires extended outages adding to the revenues lost. For example, in Revised Table III-4-1, adding cross connects to the inlets of the condensers requires an additional 3 months of shutdown, materially adding to the NPV. In calculating NPV, costs attributable to construction outages beyond the normal refueling time period overwhelm any costs due to small changes in the projected 4% non-refueling outages or downpowers.

Seasonal Changes in MWe Lost:

As indicated in the last three paragraphs of Section 3.1 (DEP Question, Comment, or Concern #14), ESSA requested additional discussion and clarification relative to the seasonal changes in MWe lost due to increasing water temperatures as shown in Figures 7.2.1 and 7.2.2 of the Cooling-Water System Alternatives Report.

As stated above, the interpretation of seasonal changes in MWe lost should be aided by the additional data provided in Appendix B. Figures 7.2.1 and 7.2.2 show the change in Unit generation rate as a function of inlet water temperature for the entire year at full flow and with fewer pumps operating. The referenced figures, as ESSA correctly suggests, show the dramatic impact of summer water temperatures on power production. Even at full condenser cooling-water flow there is lost generation during summer due to lost efficiencies in heat transfer. During the periods of interest for larval entrainment reduction, the loss in unit performance is less than at the time when the inlet water temperature is at its maximum value. The effect on cost or lost revenues is amplified by the higher price or value of a MW-hr in summer. As a result, further flow reduction from any of the options considered, such as variable speed pumps, throttling values or pumps off will further exacerbate this condition during the summer. As a consequence, any reductions in flow should be clearly targeted toward the season of larval occurrence. Thus, the loss in unit performance (MW-hrs) provided in Table 7.11.2 and used in the financial analyses Tables 12.2 and III-4-1 of the Cooling-Water System Alternatives Report reflect only the larval winter flounder and the tautog egg entrainment seasons.

As shown on the referenced figures, the larval season for winter flounder is generally from the end of March to the beginning of June. Based on over 20 years of entrainment monitoring, most of the winter flounder larvae occur from April through mid May. MWe lost during this period from flow reductions are lower than later in June, and certainly less than summer, but occur nonetheless as shown in Figures 7.2.1, 7.2.1 and in Table 7.11-2 of the Cooling-Water System Alternatives Report. For this reason, DNC had projected costs based on the two winter flounder periods for comparison, assuming the flow reduction occurred only during the dates shown, even though these figures show the impact on MWe over the entire year. Allowance for a higher ΔT during the larval winter flounder period decreases the revenues lost to some extent as indicated in DNC's response to Questions, Comments, or Concerns #5 and 6 and, as suggested by the DEP in its May 9, 2002 letter, should be considered in any final resolution to the question of Best Technology Available.

During the tautog egg entrainment season, the impact on revenues is much greater than during the winter flounder larval season as there is a greater overlap with summer increases in water temperature and the corresponding increase in the price of electricity. The period of tautog egg occurrence is also shown on Figures 7.2.1 and 7.2.2. The impact on cost and revenues lost during the tautog entrainment season only are given in the Appendix B NPV file and are repeated here in Table 12/14-2 for ease of reference. Note that the information in Revised Table III-4-1 was a subset of the cost information given in Appendix B in that the tautog season alone was not shown in Table III-4-1. It was felt that showing the entire winter flounder and tautog egg entrainment seasons in comparison to the winter flounder larval season fully demonstrated the negative cost consequences of reducing flow during the tautog spawning season. Given the dramatic increase in revenues lost during the tautog reproductive season and the low number of equivalent-adult tautog protected (for a revision of the equivalent-adult estimates given in the Cooling-Water System Alternatives Report, see below: Revision to Part II, Chapter 4, Section 4.3 of the Cooling-Water System Alternatives Report - Tautog), there appears to be little or no additional ecological benefit to reducing flow past the larval winter flounder season. Conversely, increasing design flow during the summer may offset the MWe losses that occur during the winter larval flounder season should a flow reduction option be implemented then. The benefit of this option is discussed in more detail in the response to Question, Comments, or Concerns #5 and 6.

Again, it is noted that the costs for reducing flow during the tautog season are limited to the dates provided in the referenced figures, in Appendix B and in Part I, Revised Table III-4-1, not for the entire year. In some cases, the cost differential between flow reductions during the larval winter flounder season and the combined winter flounder and tautog seasons are moderated by having used an average cost of energy over the periods being evaluated. This dampens the higher cost of electricity during summer and underestimates the revenues lost during the summer. Had DNC applied monthly electric prices to monthly estimates of lost MWe, the lost revenues during summer would be even higher than shown.

TABLE 12/14-2. Revised Net Present Value (NPV) estimates for cooling-water system alternatives in $1,000 (from NPV file in Appendix B).

			NPV in 000's by Season				
			Winter Flounder		Tautog		Flounder & Tautog
	Summary	Unit	3/22 - 6/5	4/4 - 5/14	5/3 - 8/22	5/29 - 7/12	3/22 - 8/22
	Reduced Flow Rate						
1	Reduced Number of Operating CWPs - 5	3	$ (1,088)	$ (514)	$ (6,214)	$ (2,468)	$ (6,141)
2	Reduced Number of Opearting CWPs - 4	3	$ (4,117)	$ (1,950)	$ (17,817)	$ (7,257)	$ (18,536)
3	Reduced Number of Operating CWPs with Cross Connect - 5	3	$ (45,110)	$ (44,541)	$ (50,226)	$ (46,491)	$ (50,147)
4	Reduced Number of Operating CWPs with Cross Connect - 4	3	$ (48,058)	$ (45,936)	$ (61,671)	$ (51,215)	$ (62,339)
5	Reduced Number of Operating CWPS - 3	2	$ (1,097)	$ (46)	$ (71,894)	$ (34,448)	$ (66,696)
6	Reduced number of Operating CWPs with Cross Connect - 3	2	$ (34,290)	$ (33,239)	$ (105,087)	$ (67,640)	$ (99,889)
7	Throttling of Condenser Discharge Valves	3	$ (24,521)	$ (22,377)	$ (36,815)	$ (26,988)	$ (37,874)
8	Throttling of Condenser Discharge Valves	2	$ (13,211)	$ (13,026)	$ (14,956)	$ (13,758)	$ (14,924)
	Recirculation						
9	Installation of Condenser By-Pass Lines	3	$ (5,068)	$ (3,006)	$ (17,225)	$ (7,566)	$ (18,167)
10	Installation of Condenser By-Pass Lines	2	$ (865)	$ (735)	$ (2,504)	$ (1,432)	$ (2,411)
11	Use of De-icing Line for Recirculation of CW Back to Intake	2	$ (311)	$ (181)	$ (1,950)	$ (879)	$ (1,858)
	Variable Speed						
12	Variable Speed CWPs	3	$ (8,344)	$ (7,092)	$ (18,901)	$ (11,141)	$ (18,926)
13	Variable Speed CWPs	2	$ (3,273)	$ (3,594)	$ (4,021)	$ (4,008)	$ (3,418)
	Cooling Towers		Annual NPV in 000's				
14	Natural Draft - 100 Capacity	3	$ (418,400)				
15	Natural Draft - 2/3 Capacity	3	$ (269,792)				
16	Mechanical Draft - 100% Capacity	3	$ (334,895)				
17	Natural Draft - 100% Capacity	2	$ (225,885)				
18	Mechanical Draft - 100% Capacity	2	$ (237,992)				
	Offshore Intake						
19	Unit 3 Only	3	$ (220,189)				
20	Unit 2 and 3 Combined	2&3	$ (364,799)				

TABLE 12/14-2 (continued).

	Summary	Unit	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
	Physical Barries		**Annual NPV in 000's**				
21	Fine-Mesh Screens	3			$ (154,260)		
22	Fine-Mesh Screens	2			$ (110,691)		
			NPV in 000's by Season				
	Plant Shutdown						
23	Unit 2 Shutdown	2	$ (477,395)	$ (247,797)	$ (949,010)	$ (396,422)	$ (1,207,588)
24	Unit 3 Shutdown	3	$ (629,156)	$ (326,544)	$ (1,251,198)	$ (522,630)	$ (1,592,259)
25	Units 2 & 3 Shutdown	2 & 3	$ (1,066,210)	$ (553,402)	$ (2,120,015)	$ (885,554)	$ (2,697,804)

Correction to Cooling-Water System Alternatives Report as a Result of ESSA's Comment:

Referring to ESSA's comment on Page 13, Section 3.1, last paragraph, ESSA is correct that operating with a higher inlet water temperature and reduced number of CWPs will result in a decrease in unit performance. Line 9 on Page I-34 should be revised to read as follows: "Figure 7.2-2 shows the change in electrical generation rate as a function of the inlet water temperature and number of operating CWPs".

Contribution to Regional Capacity:

ESSA projects that over time the relative importance of MPS to the regional electric grid will diminish as new power sources are brought on line. In addition, they speculate that "it is the economic importance of electric power that is important to the regional economy, not the source of electricity. The costs to ratepayers and to the regional economy will be much less". This logic might have prevailed in a regulated electric market dominated by the traditional vertically integrated utilities that can absorb through ratepayers the added cost of regulation. As a merchant facility, the measure of success at MPS is whether the station can compete in the market place on price, whether it can continue to be maintained in a safe and reliable manner and whether it can continue to remain financially viable on its own. In that regard, the cost of alternate condenser cooling-water intakes directly impacts the long-term operation and availability of any merchant electric plant such as MPS and is a fundamental consideration in determining BTA.

Lost Revenues Due to Unplanned Outages Caused by Operation at Reduced Flow:

The relationship between operation at reduced flow and increased risk for shutdowns is discussed below in the DNC Response to Question, Comment, or Concern #16.

DEP Question, Comment, or Concern #15:

Please respond to the issues raised by ESSA as outlined in section 3.7 of their report.

DNC Response to Question, Comment, or Concern #15:

Additional information on fine-mesh screens is provided in the DNC Responses to Questions, Comments, or Concerns #5 and 6. As noted throughout this document, DNC does not believe that the use of fine-mesh screens will substantially reduce ichthyoplankton entrainment mortality at MPS.

DEP Question, Comment, or Concern #16:

Section 4.0 of the ESSA report states that most of the nuclear safety issues cited by DNC in its study center on reliability concerns and that these reliability margins can be restored by a combination of mitigating actions. This section raises a significant number of technical issues in this regard. Please respond to this finding in general and to any particular matter with which DNC takes issue.

DNC Response to Question, Comment, or Concern #16:

In Section 4.0, "Validity of Cited Safety Issues Associated with Alternate Technologies and Flow Reductions", ESSA provides information regarding the relationship between alternate cooling-water technologies and the increased risk of reactor trips. Specifically, they test the validity of safety issues raised by DNC in the August 31, 2001 Cooling-Water Systems Alternatives Report. ESSA concludes on page 24 of their report that "many of the concerns expressed in DNC Study Section 7.0 do not appear to affect the ability of the plant to shut down safely as they do not affect any safety class systems". ESSA also concludes that " however, the reliability of the plant could be affected, depending on how flow reductions or other cooling methods are implemented. There appear to be ways of mitigating the reliability concerns expressed in Section 7 for most of the alternatives discussed".

In response to these general conclusions, DNC wishes to provide additional information regarding nuclear safety, specifically the ability of safety systems to respond to a reactor trip and how the nuclear industry and the U.S. Nuclear Regulatory Commission (NRC) view the likelihood of reactor trips. First of all, nuclear power plant safety and reliability are inextricably linked -- they are not separate and distinct issues. Any reactor trip challenges the safety systems and plant operators and calls into question the plant's reliability. That some of the safety concerns raised in the DNC study may not affect the ability of the plant to shut down is not the issue. The issue is preventing reactor trips. Accordingly, the ability of a nuclear power plant to safely shut down while relying on its safety systems does not justify or minimize the added risk of shutdowns associated with operations at reduce flow or other technology options, such as fine-mesh screens. Any new design and method of operation must undergo a rigorous review of risk of reactor trip and incorporate measures to limit that risk compared to the original design basis.

In this regard, the NRC has established performance standards related to unplanned reactor trips and evaluates power plant operators against these criteria. This concept and the underlying regulatory citations are explained in more detail in the analysis performed by the Millstone Probabilistic Risk Assessment Group entitled "Risk Assessment of Proposed Cooling Water System (CWS) Alternatives to Mitigate Impact on Marine Life in the Long Island Sound", which is attached following this response. This assessment, drawing on past experience including condenser backwashes, demonstrates the added risk of reactor trip from operating with less than the full complement of operating CWPs. While this risk assessment looked quantitatively at operation with pumps off, it also assessed qualitatively those options listed in Question, Comment, or Concern #6, including, for example, throttling valves and variable speed CWPs. In the case of these two options, the added risk of a reactor trip may be lower in relation to the pumps-off option, but there is risk nonetheless which will have to be addressed in any detailed design as part of technology selection and implementation. This design evaluation must include the ability of plant operators to diagnose and respond to the new operating scenarios likely to result in a reactor trip. As a consequence, the selection of an alternate cooling-water technology will necessarily require further evaluation beyond the scope of review provided by ESSA in Chapter 4.0 of their report and beyond the caveats provided in the DNC August 31, 2001 Cooling-Water System Alternatives Report prior to implementation. Further, operational changes of this sort must be reviewed and approved by the NRC before the plant can proceed.

The text which follows are responses to specific issues raised by ESSA in Chapter 4.

ESSA's Comment in the 1st Paragraph of Page 20 on operation with reduced number of CWPs:
ESSA recommended that "studies could be conducted to determine the load at which the Unit(s) could be operated with reduced number of CWPs operating with no additional risk of tripping the plant on specific transients".

DNC Response:
The unit could be operated at a reduced reactor power to limit steam flow to the condenser and limit the turbine back-pressure. Additional studies would be required to determine the corresponding reactor power. However, reducing the reactor power would result in additional reduction in unit performance. As a result, this analysis was not pursued further for this report.

ESSA's Comment in the 1st Paragraph of Page 21 on "Condensate Water Chemistry:
ESSA noted that "[a]nother problem cited for operation with reduced cooling water flow is degraded condensate oxygen chemistry. There is no explanation in the DNC Study of why this occurs".

DNC Response:
Section 7.2.2.1 (Unit Reliability) of the Cooling-Water System Alternatives Report discusses Condition Reports (CRs) that were issued against the Unit 3 circulating water system. The review identified adverse plant conditions that involved a risk to generation and identified 30 CRs that had a high impact and 20 CRs that had a small impact on plant operation. One of the examples sited as having a small impact on plant operation was degraded condensate oxygen chemistry resulting from decreased circulating water flow.

A requirement for dissolved oxygen (DO) action level limits on the Unit 3 condensate pump discharge originated with the implementation of the EPRI-developed Secondary Water Chemistry Guidelines. These guidelines were used as the basis for the secondary chemistry program implemented at Unit 3. To comply with EPRI Guidelines, MPS procedures specify an upper limit of 10 ppb measured at the condensate pump discharge as an Action Level 1 (AL1). Unit 3, by procedure, is not allowed to operate for longer than 7 days with the DO concentration above the AL1 limit. Operating in AL1 for 7 days requires escalation to AL2 and subsequent reduction in the reactor power level to 33%.

There are basically two reasons for controlling DO in the condensate. First, to maintain electrochemical potential in the steam generator sufficiently low to limit the risk of secondary side Intergranular Attack/Stress Corrosion Cracking to the tube materials. Second, to minimize the quantity of reducible metal oxides (including hematite and copper oxides), which are transported to and accumulated within the steam generators, and can also cause Intergranular Attack/Stress Corrosion Cracking to the tube materials.

An investigation of the potential effects from operating with higher than normal levels of DO suggested that DO levels are increasingly difficult to maintain below AL1 when the inlet water temperature rises above 70°F. This is due to reduced heat transfer from the condenser to the circulating water and increased turbine back-pressure. In addition, elevated DO concentrations occur with reduced CWS flow rates through the condenser and fouling of the condenser. Plant operating data showed that when the condenser back-pressure exceeded approximately 2.7 inch Hg, the DO concentration exceeded the AL1 limit. With reduced flow, this condition could occur throughout the period from late June through October each year. However as stated in Section 7.2.2.1 of the Cooling-Water System Alternatives Report, the DO condition has been resolved, which was based on a further technical review of this issue, as summarized in the following paragraph.

At MPS, the Chemistry Performance Index (CPI) is one of the station's Key Performance Indicators and is based on an equation developed by the World Association of Nuclear Operators. The CPI provides station management with a single, correlatable measure of steam generator degradation relative to plant chemistry. The CPI, in use since 1994, is a six-factor formula which compares certain steam generator and balance-of-plant parameters to mean industry values. Acquired industry knowledge about one of the factors, condensate DO, warranted a re-examination of the CPI and the merits of including a condensate DO factor in the equation. A rigorous study conducted by the MPS Secondary Chemistry Group with the concurrence of the Steam Generator Reliability Committee and Dissolved Oxygen Task Force concluded that the condensate DO factor should be removed from the CPI calculation. It was determined that the performance of the condensers, with respect to air in-leakage and removal, is optimal for its given design. The focus on DO transport to the steam generators was shifted from condensate to final feedwater. Condensate DO remains as a diagnostic parameter.

The issue of condensate DO and its impact on the CPI resulted in operating the Unit 3 condensers while injecting significant amounts of nitrogen (N_2). The injection of N_2 resulted in the lowering of condensate DO, but it also effectively increased condenser pressure (i.e., reduced vacuum). The increase in condenser pressure from N_2 injection reduces the margin to operational limits for condenser pressure if circulating water flow is reduced. However, since the sampling point for DO transport was moved from the condensate to final feedwater, Unit 3 no longer injects N_2 into the condensers to control condensate DO to meet the CPI. Therefore, condensate DO is no longer an issue relative to reducing cooling-water flow at Unit 3.

ESSA's Comment in Section 4.2.5 on Page 22 on "Alternative Flow Reduction Method":
ESSA, during their site visit to MPS, observed that both the Units 2 and 3 circulating water discharge structures at the Millstone quarry are equipped with gate slots at the discharge openings into the quarry. They suggest that an alternative to pump throttling using the pump discharge valves to reduce pump flow would be to install discharge gates or partial gates in these existing gate slots to obstruct part of the discharge area to the quarry as a means to reduce circulating water flow rate. This concept is explained further in Section 4.2.5 of the ESSA report.

DNC Response:
The intended purpose of the existing gate slots in the discharge structures of the two units is to provide isolation capability for each discharge structure and discharge tunnel such that they can be de-watered for cleaning and maintenance without disturbing operation of the other unit. Gates or stop log sets designed to be placed in these slots are in general intended to be installed and removed when the unit is shut down and the pressure drop across the gate or stop log is essentially zero. When the gates are installed, the discharge structure and tunnel up to the condenser can be de-watered. After maintenance is complete the tunnel and discharge structure would be flooded with the gates in place and the gates removed under zero differential pressure conditions before unit start-up.

This type of gate or stop log system is not designed to be installed, adjusted or removed with the circulating water pumps in operation. As ESSA correctly points out, this option would require substantial modification structurally and mechanically to operate in the flows experienced at the unit discharges.

Similarly, the use of gates or stop logs in the existing slots at the quarry discharge structure to throttle circulating would require substantial modification. A structural evaluation of the existing gate slot structures would be required to determine if these structures can support the hydraulic forces generated on the gates during throttling operation. These forces are opposite to the design hydrostatic forces on the gates when the discharge structure is de-watered and, therefore, this evaluation is essential.

Sluice gates are available with controls, which are suitable for throttling. Such gates, of the size necessary for controlling the circulating water discharge of either operating MPS unit, generally require their own frame or have rollers and rails for ease of operation under differential pressure. It is highly unlikely that the existing gate slot structures could accommodate and support new gates with controls. Additional structures would be required to support new gates with controls and like the unit discharge stop log option above offer no advantage over the throttling valve alternative discussed in the Cooling-Water System Alternatives Report.

ESSA's Comments in Section 4.2.6 on Page 23 on Natural Draft Cooling Towers, Impact on Unit 2 Performance:

ESSA questions DNC's suggestion that the series pumping system for the Unit 2 Natural Draft Cooling Tower alternative is a compromising factor to unit safety. They also question why this is not cited as a potential problem for the proposed Unit 3 natural draft cooling tower alternatives. The same issue also relates to the mechanical draft cooling tower alternatives for the two units because the circulating water systems for both natural draft and mechanical draft cooling tower alternatives for the two units are essentially the same design.

ESSA states that series pumping systems are common in power plants and cite condensate pumps/feedwater pumps, feedwater booster pumps/feedwater pumps and heater drain pumps installed in series with feedwater pumps as examples.

DNC Response:

Unit 3 vs. Unit 2 Cooling Tower Alternatives

There is a fundamental difference in the designs of the existing Unit 3 and Unit 2 circulating water systems, which dictate different pumping systems for the proposed cooling tower retrofit alternatives for the two units. As discussed in Section 7.6.1 of the Cooling-Water System Alternatives Report, the design pressure of the Unit 3 condenser water boxes and circulating water piping is 80 psig. This design pressure is adequate for a standard closed loop circulating water pumping system with a single pump station located at the cooling tower basin. In this case, the pumps draw cooled water from the tower basin and pump it through the condenser and back up to the cooling tower fill. As a result, there is no technical reason to require a series supply/return pumping system with two pump stations as is proposed for the Unit 2 cooling tower retrofit alternatives. Therefore, the reliability and safety issues relative to series pump stations does not apply to Unit 3.

As discussed in Section 7.7 of the Cooling-Water System Alternatives Report, the design pressure of the existing Unit 2 condenser water boxes and circulating water pipe is 25 psig. Because a higher pump head is required for a standard closed loop circulating water system with a single pump station, the design pressure for the closed-loop portion of the system would have to be increased 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 replacement effort would create a massive disruption during construction of the new cooling system 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, the standard single pump station closed loop cooling system alternative is not feasible for Unit 2.

The series pump station alternative, which uses low head pumps at the cooling tower basin to pump the cooled water from the tower basin through the condenser, and the second pump station to pump the heated condenser discharge flow back to the cooling tower is the only feasible alternative for Unit 2. This two-pump station alternative will not exceed the design pressure of the existing condenser and existing circulating water conduits and uses the existing discharge tunnel to the quarry instead of new large-diameter pipe.

Reliability Issues Related to Series Circulating Water Pump Stations

CWPs as proposed for the closed loop cooling tower retrofit alternatives for Unit 2 are high capacity, low head pumps with relatively flat performance curves. The examples of series pump systems cited by ESSA, such as condensate/feed pumps that are commonly used in power stations are, by comparison, low capacity, high head pumps with relatively steep performance curves. Low head, high capacity pumps, when operating in direct series tend to cycle. It is difficult to maintain operation of such a series system at a constant flow because small differences in head result in large changes in pump flow. In the preliminary design for Unit 2 closed loop cooling tower alternatives, this problem is conceptually addressed by interconnection of the pump station suction to the quarry as well as to the discharge from the condenser. Imbalances in flow rates between the two pumping stations would be made up for by either drawing from or discharging the excess to the quarry. This concept would require further analysis to develop a reliable design.

A second operational complication associated with a series pumping system with multiple pumps in each station occurs with any pump trip in either of the pump stations. Also, because there are double the number of pumps, the probability of a pump trip is doubled. When a pump trips, a pump in the companion pump facility must be immediately shut down to maintain flow balance in the system. This requires closer operator attention and more complicated actions than would be required for a system with a single pump station. The increased probability for a pump trip and the rapid operator reactions required to avoid flow imbalance is what creates the reliability issue for series pump system on Unit 2.

ESSA's Comment in Section 4.3 on Page 24 on "Comment on Heat Balances":

ESSA indicated that the original heat balance provided did not support Figure 7.2-1 of the Cooling-Water System Alternatives Report.

DNC Response:

The original Unit 2 heat balance model calculated a temperature rise across the condenser of approximately 24°F. However, based on plant data, the actual ΔT across the condenser during the summer is approximately 27°F. The heat balance model was revised to account for this increased ΔT when the temperature of the inlet water temperature was greater than 55°F. This revised model was used to determine the change in unit performance when operating with a reduced number of CWPs. The Unit 2 alternative that assumed operation of only 3 CWPs required that the reactor power level be reduced in order to maintain the ΔT below the NPDES Permit limit of 32°F. This resulted in the large loss in unit performance as shown in Figure 7.2-1 of the August 31, 2001 Cooling-Water System Alternatives Report.

The new Unit 2 heat balance diagrams provided to ESSA were based on the revised heat balance model and are the basis for the data in the report. As can be seen from Figure 7.2-1 of the Cooling-Water System Alternatives Report, the large loss in unit performance occurs during the summer tautog entrainment period and not during the larval winter flounder entrainment period.

Risk Assessment of Proposed Cooling Water System (CWS) Alternatives to Mitigate Impact on Marine Life in the Long Island Sound

Prepared By

Millstone Probabilistic Risk Assessment (PRA) Group

Risk Assessment of Proposed Cooling Water System (CWS) Alternatives to Mitigate Impact on Marine Life in the Long Island Sound

Objectives:

This report has been prepared by the Millstone Probabilistic Risk Assessment (PRA) Group for the Environmental Services Department to document the risk associated with proposed cooling water (CW) intake systems alternatives to mitigate the impact on marine life in the Long Island Sound.

Scope of PRA Analysis:

Section I of this report summarizes the results reported in Technical Evaluation MG-EV-02-0002 (Ref. 1) with respect to the risk of operating Millstone Units 2 and 3, respectively, with one circulating water (CW) pump in the trip position to reduce the entrainment of fish eggs and larvae at the Millstone Power Station. Attachment 1 of this report contains this Technical Evaluation.

The scope of analysis presented in the PRA Technical Evaluation covers the following aspects:

a) A review of the Unit 2 and 3 plant-specific operating experience to determine if there had been instances of automatic reactor trips due to loss of circulating water flow to one main condenser bay.

b) Assessment of potential risk of operating with one tripped CW pump at either Unit 2 or Unit 3.

c) Effect of power reduction on offsite grid stability.

In addition, Table 1 of Section II in this report provides qualitative risk insights of the various proposed circulating water system alternatives (Ref. 4). These insights are intended to augment the information reported in the Technical Evaluation (Ref. 1).

Finally, Section III of the report discusses the NRC concerns of potential adverse impact of unplanned reactor trips on public health and safety.

Section I: Quantitative Risk Assessment

The key results of PRA Technical Evaluation MG-EV-02-0002, Rev. 0, can be summarized as follows:

1. Plant-Specific Operating Experience (OE):

   1.1 Millstone Unit 2:

   Four plant trips occurred during the period from April 1982 through May 2001, and were associated with the circulating water system. Based on this past operating experience, plant operation with one tripped CW pump increases the potential for reactor trip and, hence, potential for damaging the reactor core as a result of challenging the safety systems. For example, the thermal and reactivity transients arising from a reactor trip may cause one (or two) of the power-operated relief valves (PORVs) to stick in the open position and, hence, causing a loss of coolant (LOCA) event.

   Currently, the historical average of unplanned rector trips at Millstone Unit 2 is about 2.43 trips per year exceeds the industry average value of 1.26 trips per year for Pressurized Water Reactors (PWRs) per NUREG/CR-5750 published in February 1999.

   1.2 Millstone Unit 3:

   During the period from May 1990 through November 1998, there have been three instances where Millstone Unit 3 experienced reactor trips when operating with one CW pump out of service. Based on this operating experience, Millstone Unit 3 is highly susceptible to reactor trips when operating with one CW pump in the trip position, especially, during periods of excessive debris buildup.

2. Given a reactor trip, there is a finite probability of incurring reactor core damage. For Millstone Unit 2, this conditional core damage probability is about 1.1E-6. For Millstone Unit 3, the conditional probability of core damage given a reactor trip is about 3.7E-6.

   As discussed in Section III of this report, a reactor trip and the potential for subsequent core damage, poses concerns to public health and safety.

3. In the event of having to decrease the reactor power should a second CW pump fail randomly, the impact on grid voltage stability is primarily dependent on the power demand and the margin available.

Section II: Qualitative Risk Insights

Several options have been proposed (Ref. 4) to reduce the adverse impact of Millstone Station on the marine life (such as winter flounder larvae, tautog eggs, ... etc) in the Long Island Sound. The main objective of these alternatives is to reduce the circulation water flow at the Unit 2 and 3 Intake Structures, respectively, and hence reduce entrainment of fish eggs and larvae during specific months of the year. These alternatives were evaluated against several criteria including: hardware and implementation costs, required plant modifications, operational constraints, and potential plant risk (i.e., likelihood of causing a reactor trip). Some of these alternatives were screened out based on cost or have been judged to be not feasible to implement.

Table 1 below provides a qualitative assessment of the potential risk associated with each of the five proposed alternatives. .

Table 1: Qualitative Risk Assessment of the Proposed Alternatives for Circulating Water Intake System at Millstone Units 2 and 3, Respectively

Option/Alternative	Potential Plant Risk
1. Reduce number of operating circulating water pumps (CWPs).	Risk Level: High Comments: • There is a potential for a second CW pump in the same bay to fail randomly and, hence, causing a reactor trip. • In such case, an attempt to recover the original CW pump that was removed from service may not be successful due a fail-to-start failure mode.
2. Reduce number of operating circulating water pumps (CWPs) with new cross-connects.	Risk Level: Low Comments: • The cross-connect may prevent loss of CW in a given bay. • Human error in performing the cross-connect may cause potential risk.
3. Throttling of condenser discharge valves.	Risk Level: Medium Comments: • This option requires the Operator to throttle the condenser discharge valves from the Control Room. Hence, there is a potential for human error while attempting to "tweak" these valves to maintain the condenser backpressure at some desired value.

Option/Alternative	Potential Plant Risk
4. Installation of condenser bypass lines.	Risk Level: Low <u>Comments</u>: • Some initial valve lineup would be required and probably no action would be required after that.
5. Variable speed motor for the CW pumps.	Risk Level: Low <u>Comments</u>: • Operator action would be required initially to adjust the speed of the pump(s). • There is no reduction in the number of CW pumps, i.e., none would be removed from service to meet the required flow reduction.

Section III: Regulatory Concerns of Unplanned Nuclear Reactor Trips

Unplanned reactor trips/scrams (both automatic and manual) pose safety concerns to the nuclear licensees as well as the Nuclear Regulatory Commission (NRC). As a result, the NRC has recently revised its regulatory oversight processes of inspection, assessment, and enforcement for commercial nuclear power plants. The complete oversight process is provided in NUREG-1649, "New NRC Reactor Inspection and Oversight Program," and SECY 99-007, "Recommendations for Reactor Oversight Process Improvement," as amended in SECY 99-007A.

Under the NRC Reactor Oversight Process, the nuclear licensees are required to submit quarterly performance indicators (PI) reports to the NRC for use in its licensee safety assessment process. Among the seven Cornerstones, which are monitored by the NRC regulatory oversight framework, is the "Initiating Events" Cornerstone. There are three performance indicators in this Cornerstone:

- Unplanned (automatic and manual) trips per 7,000 critical hours. The value of 7,000 hours is used because it represents one year of reactor operation at an 80% capacity factor. This performance indicator monitors the number of unplanned trips. It measures the rate of reactor trips (i.e., scrams) per year of operation at power and provides an indication of initiating event frequency.

- Reactor Trips with loss of normal heat removal per 12 quarters. This performance indicator monitors unplanned automatic and manual trips that involve a loss of the main condenser pathway for decay heat removal and, hence, requiring the initiation of an alternate means of decay heat removal. Such trips necessitate the availability of accident mitigating systems and are, therefore, more risk significant than uncomplicated scrams.

  The loss of main condenser vacuum represents one of the conditions that result in the loss of normal heat removal pathway where decay heat cannot be removed through the main condenser.

- Unplanned power changes per 7,000 critical hours. This performance indicator monitors the number of unplanned changes in reactor power of greater than 20% full-power per 7,000 hours of critical operation.

The key insight of the discussion presented in Section III is that operation of either Millstone Units with one circulating water pump in the trip position could challenge the main condenser vacuum and result in an unplanned reactor trip which could adversely impact public health and safety.

References:

1. "Public risk impact of operating with one circulating water pump tripped at Millstone Units 2 and 3, respectively," PRA Technical Evaluation # MG-EV-02-0002, Rev. 1, dated August 29, 2002.
2. "Review of the Evaluation of Cooling Water System Alternatives to Reduce Entrainment at Millstone Nuclear Power Station," Draft Report prepared by ESSA technologies Ltd, Toronto, ON, for the Bureau of Water Management, Connecticut Department of Environmental Protection, March 28, 2002.
3. Letter to Paul Jacobson from the State of Connecticut Department of Environmental Protection, dated May 9, 2002.
4. "An Evaluation of Cooling Water System Alternatives," Report submitted by Dominion Nuclear Connecticut, Inc., to the State of Connecticut Department of Environmental Protection, August 31, 2001.

Attachment 1

Probabilistic Risk Assessment

Technical Evaluation

MG-EV-02-0002, Rev. 1

"Public Risk Impact of Operating with One Circulating Water Pump Tripped at Millstone Unit 2 and 3"

1. Purpose:

This technical evaluation determines the public risk impact of operating with one circulating water pump tripped at either Millstone Unit 2 or 3.

2. Discussion:

To lessen the environmental impact of Millstone Station on the population of winter flounder larvae and tautog eggs, a proposal has been made to operate the units with one circulating water pump tripped during spawning season. This will reduce the total flow extracted from the Long Island Sound, which is postulated to decrease the loss of winter flounder larvae and tautog eggs. The winter flounder larvae spawning season is between 3/22 and 6/5, whereas the tautog season is between 5/3 and 8/22 (Ref. 5.3). Therefore, the proposed timeframe of operation with one circulating water pump tripped at each plant is between 3/22 and 8/22 or 5 months.

However, the practice of operating with one circulating water pump tripped makes the units susceptible to a plant trip. The circulating water pumps provide cooling water from the Long Island Sound to the main condenser, which ultimately removes heat generated by the reactor coolant system. The main condenser is subdivided into bays with 2 circulating water pumps supplying cooling to each bay. Millstone Unit 2 has 2 condenser bays served by 4 circulating water pumps; Millstone Unit 3 has 3 condenser bays and 6 circulating pumps. Failure to supply cooling to one condenser bay results in a plant trip. Therefore, operating with one circulating water pump tripped makes each unit vulnerable to a plant trip due to failure of the circulating water pump in the affected condenser bay.

Although the nominal reactor trip event is not considered within the plants' licensing basis analysis, it is modeled within the Probabilistic Risk Assessment (PRA) since it presents a challenge to the plants' ability to achieve a safe shutdown. The reactivity, RCS integrity, and RCS decay heat removal safety functions are required to operate following a reactor trip to ensure safe shutdown and thus, prevent core damage.

3. Safety Significance

This evaluation will perform the following:

- Investigate plant operating history to determine the possibility of an automatic plant trip due to failure of the second circulating water pump in the affected condenser bay,
- Determine the public risk impact associated with an automatic plant trip, and
- Examine the effect of down powering the unit on offsite grid stability.

Plant Operating History

A review of plant operating history was performed to determine if there had been any instances of either unit incurring an automatic plant trip due to loss of circulating water flow to one condenser bay. The search yielded the following:

Unit 2

On 4/4/82, the unit tripped on low condenser vacuum due to a loss of C and D circulating water pumps caused by plugged intake screens. (Ref.: MP2 Scram History logbook).

On 5/24/93, a turbine trip (and subsequent reactor trip) occurred because of a high stator cooling water temperature arising from the isolation of the B bay for mussel cooking and the resultant high temperature water being diverted into the operating A and C bays. (Ref.: System Engineer's Incident Report, May 24, 1993)

On 4/29/01, the unit trip occurred due to a loss of a second circulating water pump, which caused a degraded condenser vacuum and the turbine trip. (Ref.: Root Cause Investigation of CR-01-04614)

On 5/7/01, the unit was manually tripped due to the loss of two circulating water pumps supplying cooling to one condenser. The A circulating pump and its traveling screen were tagged out for work in the bay; the traveling screen in the adjacent B bay was also tagged out for diver protection. Accumulating seaweed and eelgrass on the B screen eventually caused the screen high differential pressure, which tripped the B pump. (Ref.: Root Cause Investigation of CR-01-04910)

Based on the above operating history, one circulating water bay out-of-service increases the potential for a reactor trip and the associated challenge to the plant safety systems due to the thermal and reactivity transient arising from the trip.

Unit 3

On 5/10/90, a manual reactor trip occurred due to rapid buildup of seaweed on the B traveling screen resulting in trip of the B circulating water pump which was supplying both waterboxes in the condenser bay. (Ref. 5.4)

On 4/5/92, after performing thermal backwash of the E circulating water pump bay and while preparing to perform thermal backwash of the F bay, the E circulating water pump tripped resulting in loss of circulating water to 1 condenser bay causing a reactor trip. (Ref. 5.4)

On 11/11/98, with the A circulating water pump removed from service to facilitate back-flushing the A waterbox, high delta P across the B traveling screen caused the B circulating water pump to trip resulting in a reactor trip. (Ref. 5.4)

Based on the history, there have been 3 instances where Unit 3 experienced a reactor trip when operating with one circulating water pump out of service. Furthermore, each event occurred either directly due to rapid debris buildup or during attempts to prevent excessive debris buildup from occurring (i.e., when back-flushing). Therefore, the conclusion is that Unit 3 is highly susceptible to incurring a reactor trip when operating with one circulating water pump tripped during periods of excessive debris buildup.

Public Risk Impact

The proposed timeframe of operation with one circulating water pump tripped is between 3/22 and 8/22 or 5 months. This 5-month period between spring and fall is considered a high debris activity period at the intake structures in which 5 of the 7 reactor trip events due to debris occurred at both plants.

Unit 2

Assuming that Unit 2 will be operating for the next 30 years with license extension granted on the condition of one circulating water pump tripped during the spawning season, the plant will be operating in the reduced mode for an equivalent of 12 of those years. Based on the operating history, we can expect at least one reactor trip in those years with one circulating water bay out-of-service.

According to the most recent PRA model update (Ref. 5.1), the reactor trip event contributes 2% of the total core damage frequency, which translates into the conditional core probability of 1.1E-6. Therefore, the proposed configuration change would increase the probability of incurring a core damage event by 1.1E-06.

Unit 3

If Unit 3 is assumed to be in operation for the next 40 years, the plant is postulated to be operating with one circulating water pump tripped for 16 of those years.

Based on the large exposure time of 16 years and plant operating experience indicating that 3 trips have occurred when operating with one circulating water pump out of service, it is concluded that at least one reactor trip would occur due to loss of circulating water to one condenser bay.

According to the most recent PRA model (Ref. 5.2), the reactor trip event contributes 24% to the total core damage frequency, which translates into a conditional core damage probability of 3.7E-06. Therefore, the proposed configuration change increases the probability of incurring a core damage event by 3.7E-06.

The effect of reduced power on offsite grid stability

Running the plants at reduced power would not have much impact on the stability of the grid voltage; there are sufficient reserves to meet the demand. In the summer months however, when the power demand is at its peak, the margin will decrease. This may impact the grid stability.

A plant trip at Millstone will cause a small, momentary voltage instability on the grid. The voltage dip will be short-lived however, until the standby units start and synchronize to the grid.

4. Conclusion

The PRA section recommends the following:

1. Operating with one circulating water pump tripped for extended time periods represents a significant risk to public safety.

5. References

5.1 PRA99YQA-02863S2, Rev. 3, "MP2 Final Quantification." (in preparation)
5.2 PRA00YQA-01769S3 "Millstone 3 EDG AOT Extension Study" Rev. 1.
5.3 Millstone Power Station, "An Evaluation of Cooling Water System Alternatives," August 31, 2001.
5.4 Calculation No. PRA94YQA-01051-S3, Rev. 2, "MP3 Data Update."

II. Errata and Supplementary Information Regarding the August 31, 2001 Report "Millstone Power Station An Evaluation of Cooling-Water System Alternatives"

As part of its response to DEP questions, comments, and concerns regarding the August 31, 2001 Cooling-Water System Alternatives Report, DNC in the following is providing additional information correcting errors noted since the submittal of the report and providing supplementary information to be considered in this matter. This includes a correction to the equivalent-adult calculations for non-Niantic River winter flounder larvae and a re-analysis of tautog entrainment equivalent-adult calculation based on the University of Connecticut tautog fecundity study that was submitted to DEP on July 26, 2002.

A. Correction to Part II, Chapter 4, Section 4.2.4 of the Cooling-Water System Alternatives Report - The Effectiveness of Reducing Entrainment of Non-Niantic River Winter Flounder Larvae by Selected Cooling-Water Intake System Alternatives

Section 4.2.4 of Chapter 4 of Part II of the Cooling-Water System Alternatives Report presents equivalent-adult calculations for non-Niantic River winter flounder larvae entrained at MPS. In a review of this material during early summer of 2002, several errors were noted and are hereby corrected. Most importantly, a mortality rate used in the calculation of average lifetime egg production (fecundity) of an age-3 female winter flounder (Table 4-11) was not converted to a survival rate, resulting in an error in the fecundity calculation. A Revised Table 4-11 follows this text. The footnotes to this table were also changed for purposes of clarity. As a result of the mortality rate correction, lifetime egg production was reduced from 600,080 as reported in the Cooling-Water System Alternatives Report to 535,705. This new estimate also meant that the total instantaneous mortality rates (Z) used in determining equivalent-adults were incorrect; the corrected Revised Table 4-12 follows. Also, note that in the original Table 4-12, $Z_{1\,(3\text{-}7mm)}$ was incorrectly given on a per mm basis rather than for the entire span of this life stage, although the calculations based on this value had been done correctly. Several other errors on Table 4-12, including using "survival" instead of "mortality" with the definitions of Z, an incorrect citation, and a table reference under the column "Source" are corrected here as well. With corrected estimates of lifetime fecundity and mortality rates, re-calculated equivalent-adult calculations are given in Revised Table 4-13 below. On average, equivalent-adult totals are about 14.5% higher than initially presented in the Cooling-Water System Alternatives Report as a result of these corrections. Statements made in the Cooling-Water System Alternatives Report regarding the highly conservative nature of equivalent-adult calculations, however, remain valid.

References Cited in DNC Correction to Part II, Chapter 4, Section 4.2.4 of the Cooling-Water System Alternatives Report

NEFSC (Northeast Fisheries Science Center). 1999. Draft (1/19/99) report of the 28th summary of assessments. National Marine Fisheries Northeast regional stock assessment workshop (28th SAW). Stock assessment review committee (SARC) consensus Service, Woods Hole, MA.

NNECO (Northeast Nuclear Energy Company). 1987. Attachment 1: Millstone Unit No. 3 Equivalent-adult revised calculation. Submitted under letter B12700 dated October 7, 1987 from E.J. Mroczka, NNECO, to U.S. Nuclear Regulatory Commission, Washington, DC (with copies to C. Fredette and E. Smith, CT DEP).

NUSCO (Northeast Utilities Service Company). 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.

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.

REVISED TABLE 4-11. Average lifetime egg production of an age-3 female winter flounder.

Age	Annual mean fecundity[a]	Survival (S) probability[b]	Fraction mature[c]	Egg production
3	232,088	1.0000000	0.25	58,022
4	432,517	0.5251875	0.8	181,722
5	700,390	0.2051382	1.0	143,677
6	1,019,793	0.0801270	1.0	81,713
7	1,216,926	0.0312976	1.0	38,087
8	1,442,512	0.0122248	1.0	17,634
9	1,699,372	0.0047750	1.0	8,115
10	1,990,489	0.0018651	1.0	3,713
11	2,319,011	0.0007285	1.0	1,689
12	2,688,253	0.0002846	1.0	765
13	3,101,703	0.0001111	1.0	345
14	3,563,020	0.0000434	1.0	155
15	4,076,040	0.0000170	1.0	69
Total				535,705

[a] From NUSCO (2000: Table 35).

[b] $S = e^{-(M+F)}$ where M = 0.20 (NUSCO 2000) and F = 0.74 except for age-3 where $F_{(age\text{-}3)} = 0.6 \cdot F$ or 0.444 (NEFSC 1999). Thus, $S_{(age\text{-}3)} = 0.525$ and $S^{(age\text{-}4+)} = 0.391$.

[c] From NUSCO (2000: Table 35).

REVISED 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 instantaneous mortality from fertilization to hatch	1.628	NNECO (1987)
$Z_{1\,(3\text{-}7\text{ mm})}$	Larval instantaneous mortality, 3 - 7 mm	2.832	Saila et al. (1997)
$Z_{1\,(>7\text{ mm})}$	Larval instantaneous mortality, 7 mm to age-3	8.038	$Z_{1\,(>7\text{ mm})} = Z_{total} - Z_e - Z_{1\,(3\text{-}7)}$
Z_{total}	Egg instantaneous mortality to age-3	12.498	$Z = -\log_e(2/\text{fecundity})$
f_a	Average lifetime fecundity	535,705	See Revised Table 4-11

REVISED 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 age-3 equivalent-adults lost due to entrainment from 1986 through 1995 at MPS.

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	0.137793	0.000027	33
	2	25,600,000	0.7656	0.096714	0.000039	757
	3	60,720,000	0.7958	0.023471	0.000159	7,686
	4	12,240,000	0.7124	0.005696	0.000655	5,716
	Total	100,320,000				14,191
1987	1	1,120,000	0.4286	0.137793	0.000027	13
	2	36,240,000	0.6645	0.096714	0.000039	930
	3	87,200,000	0.7807	0.023471	0.000159	10,0829
	4	7,520,000	0.7979	0.005696	0.000655	3,933
	Total	132,080,000				15,704
1988	1	4,000,000	0.2200	0.137793	0.000027	24
	2	13,760,000	0.4477	0.096714	0.000039	238
	3	111,120,000	0.8229	0.023471	0.000159	14,545
	4	19,520,000	0.9385	0.005696	0.000655	12,008
	Total	148,400,000				26,814
1989	1	5,520,000	0.5942	0.137793	0.000027	89
	2	41,360,000	0.7834	0.096714	0.000039	1,251
	3	80,400,000	0.8100	0.023471	0.000159	10,358
	4	7,120,000	0.9438	0.005696	0.000655	4,405
	Total	134,400,000				16,103
1990	1	1,360,000	0.4706	0.137793	0.000027	17
	2	14,720,000	0.6630	0.096714	0.000039	377
	3	80,320,000	0.7241	0.023471	0.000159	9,251
	4	10,160,000	0.7087	0.005696	0.000655	4,719
	Total	106,560,000				14,365
1991	1	640,000	0.7500	0.137793	0.000027	13
	2	9,920,000	0.7097	0.096714	0.000039	272
	3	73,680,000	0.7101	0.023471	0.000159	8,322
	4	8,880,000	0.5766	0.005696	0.000655	3,356
	Total	93,120,000				11,963
1992	1	28,560,000	0.8431	0.137793	0.000027	652
	2	51,360,000	0.8427	0.096714	0.000039	1,671
	3	280,960,000	0.8414	0.023471	0.000159	37,603
	4	33,520,000	0.7900	0.005696	0.000655	17,356
	Total	394,400,000				57,283
1993	1	1,200,000	0.8000	0.137793	0.000027	26
	2	5,040,000	0.8095	0.096714	0.000039	157
	3	21,680,000	0.8561	0.023471	0.000159	2,952
	4	6,640,000	0.9398	0.005696	0.000655	4,090
	Total	34,560,000				7,226
1994	1	4,320,000	0.4815	0.137793	0.000027	56
	2	29,440,000	0.6630	0.096714	0.000039	754
	3	66,960,000	0.9654	0.023471	0.000159	10,282
	4	18,320,000	0.7293	0.005696	0.000655	8,757
	Total	119,040,000				19,849

REVISED 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	0.137793	0.000027	24
	2	16,240,000	0.6650	0.096714	0.000039	417
	3	127,840,000	0.6514	0.023471	0.000159	13,247
	4	25,760,000	0.5404	0.005696	0.000655	9,124
	Total	171,200,000				22,812
Mean	1	4,984,000	0.5916	0.137793	0.000027	95
	2	24,368,000	0.7014	0.096714	0.000039	682
	3	79,270,400	0.7957	0.023471	0.000159	12,508
	4	11,974,400	0.7677	0.005696	0.000655	7,346
	Total	114,726,400				20,631

[a] From mass-balance model reported in NUSCO (2000) and data given in Part II, Chapter 4, Table 4-1 of the Cooling-Water System Alternatives Report.

B. Revision to Part II, Chapter 4, Section 4.3 of the Cooling-Water System Alternatives Report - Tautog

Annual equivalent-adult calculations for tautog egg entrainment were presented in Section 4.3, Chapter 4, Part II of the Cooling-Water System Alternatives Report. Among the information used in these calculations was a length-fecundity relationship reported by White (1996). White's work was done in Virginia and he found that the average female tautog in Virginia waters spawned 61 times during the summer spawning season. Subsequent to the submittal of the Cooling-Water System Alternatives Report, a tautog reproductive study in LIS sponsored by DNC was completed by researchers at the University of Connecticut. A report of this work (LaPlante and Schultz 2002) was recently submitted to DEP (DNC 2002).

Female LIS tautog also spawn repeatedly over the course of the summer. LaPlante and Schultz (2002) calculated a predictive length-fecundity relationship showing that LIS tautog were considerably more fecund than White had reported for Virginia fish (see Fig. 15, p. 31 in LaPlante and Schultz 2002). A comparison of the two length-fecundity relationships is given in Table T-1, below. Larger female tautog, in particular, produce more eggs in Connecticut waters in comparison to Virginia and, overall, LIS tautog produced 1.67 times the eggs of Virginia fish per year. Because the length-fecundity relationship for LIS tautog is more appropriate to use in equivalent-adult calculations for assessment of MPS impact, new equivalent-adult calculations were completed and are found below in Revised Tables 4-17 and 4-18. Other information used in performing the calculations remained the same as in the Cooling-Water System Alternatives Report: length-at-age from Simpson (1989), mortality rates from ASMFC (1996; reference inadvertently omitted from the Cooling-Water System Alternatives Report and is included in References Cited below), and a tautog female maturity schedule from Chenoweth (1963).

Because of the higher fecundity found for LIS tautog, the newly revised annual equivalent-adult estimates are smaller than given in the Cooling-Water System Alternatives Report, in which the mean annual equivalent-adult estimate for entrained tautog eggs during two-unit MPS operation from 1986 through 1995 was 448. Based on the re-calculated equivalent-adult totals, the new mean is 269 tautog, a reduction of about 40%. This resulted in smaller annual gains in the number of tautog equivalent-adults from the implementation of various cooling-water alternatives as shown on Revised Table III-4-1, found above in the DNC Response to DEP Questions, Comments, or Concerns #12 through 14. As such, there are only small gains in tautog numbers relative to the costs of the options presented. Additional assessments of the potential impact of MPS on tautog were presented in Section 4.3, Chapter 4, Part II of the Cooling-Water System Alternatives Report. These analyses also showed relatively little effect of MPS to tautog, even though annual egg entrainment estimates are relatively large. This revision of the equivalent-adult calculations reinforces the conclusion that MPS is likely having a small effect on the tautog resource of LIS.

References Cited in DNC Revision to Part II, Chapter 4, Section 4.3 of the Cooling-Water System Alternatives Report

ASMFC (Atlantic States Marine Fisheries Commission). 1996. Draft fisheries management plan for tautog. Public hearing summary. Washington, DC. 10 pp.

Chenoweth, S.B. 1963. Spawning and fecundity of the tautog, *Tautoga onitis* (Linnaeus). M.S. Thesis. University of Rhode Island, Narragansett, RI. 60 pp.

DNC (Dominion Nuclear Connecticut, Inc.). 2002. Enclosure to Letter D17358 dated July 26, 2002 from G.D. Hicks, DNC, to J.F. Grier, CT DEP.

LaPlante, L.H., and E.T. Schultz. 2002. Estimating the fecundity of tautog (*Tautoga onitis*) in Long Island Sound. Submitted to Millstone Environmental Laboratory. 38 pp. + 7 appendices.

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.

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.

TABLE T-1. Comparison between predicted annual mean fecundity and egg production of female tautog based on the findings of LaPlante and Schultz (2002) for Long Island Sound (LIS) and White (1996) for Virginia (VA) waters.

Age	Length (mm)	LIS annual mean fecundity	LIS egg production	VA annual mean fecundity	VA egg production	Ratio of LIS to VA estimates
3	223	1,261,414	1,009,132	506,762	405,410	2.49
4	273	2,208,323	1,824,694	1,741,462	1,438,935	1.27
5	317	3,614,789	2,467,954	2,827,998	1,930,782	1.28
6	354	5,470,848	3,086,286	3,741,676	2,110,803	1.46
7	386	7,828,991	2,215,252	4,531,884	1,282,319	1.73
8	414	10,712,739	1,520,395	5,223,316	741,314	2.05
9	439	14,174,345	1,009,015	5,840,666	415,774	2.43
10	460	17,932,839	640,292	6,359,240	227,057	2.82
11	478	21,938,292	392,893	6,803,732	121,848	3.22
12	493	25,951,609	233,123	7,174,142	64,445	3.62
13	507	30,357,197	136,759	7,519,858	33,877	4.04
14	519	34,724,088	78,476	7,816,186	17,665	4.44
15	529	38,839,339	44,005	8,063,126	9,136	4.82
16	538	42,958,461	24,443	8,285,372	4,714	5.18
17	545	46,461,946	13,242	8,458,230	2,411	5.49
18	552	50,251,159	7,186	8,631,088	1,234	5.82
19	558	53,744,085	3,870	8,779,252	632	6.12
20	562	56,206,568	2,023	8,878,028	320	6.33
21	567	59,443,936	1,070	9,001,498	62	6.60
22	570	61,475,186	553	9,075,580	82	6.77
Total			14,710,663		8,808,918	1.67

REVISED 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	1,261,414	1.0000000	0.8	1,009,132
4	273	2,208,323	0.8262800	1.0	1,824,694
5	317	3,614,789	0.6827380	1.0	2,467,954
6	354	5,470,848	0.5641330	1.0	3,086,286
7	386	7,828,991	0.2829550	1.0	2,215,252
8	414	10,712,739	0.1419240	1.0	1,520,395
9	439	14,174,345	0.0711860	1.0	1,009,015
10	460	17,932,839	0.0357050	1.0	640,292
11	478	21,938,292	0.0179090	1.0	392,893
12	493	25,951,609	0.0089830	1.0	233,123
13	507	30,357,197	0.0045050	1.0	136,759
14	519	34,724,088	0.0022600	1.0	78,476
15	529	38,839,339	0.0011330	1.0	44,005
16	538	42,958,461	0.0005690	1.0	24,443
17	545	46,461,946	0.0002850	1.0	13,242
18	552	50,251,159	0.0001430	1.0	7,186
19	558	53,744,085	0.0000720	1.0	3,870
20	562	56,206,568	0.0000360	1.0	2,023
21	567	59,443,936	0.0000180	1.0	1,070
22	570	61,475,186	0.0000090	1.0	553
	Total				14,710,663

[a] Length at age from Simpson (1989).
[b] Fecundity from LaPlante and Schultz (2002).
[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 Chenoweth (1963).

REVISED 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 MPS.

Year	Number entrained (N_i)	Survival probability (S_i)	Equivalent-adults (N_a)
1986	2,999,200,000	0.0000001360	408
1987	2,868,000,000	0.0000001360	390
1988	2,159,200,000	0.0000001360	294
1989	2,387,200,000	0.0000001360	325
1990	1,677,600,000	0.0000001360	228
1991	1,220,000,000	0.0000001360	166
1992	1,068,000,000	0.0000001360	145
1993	1,664,000,000	0.0000001360	226
1994	1,659,200,000	0.0000001360	226
1995	2,050,400,000	0.0000001360	279
Mean	1,975,280,000		269

Enclosure 2 to D17347

THERMAL PLUME ANALYSIS FOR MILLSTONE POWER STATION OPERATING UNDER CONDITIONS OF REDUCED CIRCULATING WATER FLOW

By

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Introduction

The purpose of this report is to perform additional thermal plume analyses for the Millstone Power Station using the approach of Adams (2001). In that earlier report, I examined the size of the thermal plume for the current Units 2-3 operation under a number of flow options, including use of the current 10 circulating water pumps as well as reduced flow resulting from use of 9, 8 and 7 pumps. The reduced flow was considered as a way to minimize the entrainment of fish larvae. The analysis involved scaling the results of earlier mathematical model studies (Stolzenbach and Adams, 1979) that had been calibrated against field observations.

The present analysis considers two additional scenarios:

1. operation of Units 2-3 with an even greater flow reduction
2. operation of just Unit 2 with the same flow reduction as in 1 (representing conditions when Unit 3 is out of service).

Flows and Temperature Rises

Maximum condenser temperature rises of 36 °F and 27 °F were taken for Units 2 and 3 respectively (P. Jacobson, personal communication). Corresponding flow rates of 86475 gpm for each of the 4 circulating water pumps of Unit 2 and 95600 gpm for each of the 6 circulating water pumps for Unit 3 were obtained from spread sheets provided by Dale Graves of Stone and Webster. The spreadsheets assume turbine backpressures of 4.25 in Hg for each unit.

Unit 2 operates with two service water pumps rated at 12000 gpm each and Unit 3 operates with two service water pumps rated at 15000 gpm each. The combined flow rate for Unit 2 is thus (4*86475 + 2*12000)/448.5 = 825 cfs, while that for Unit 3 is (6*95600 + 2*15000)/448.5 = 1336 cfs. Since there is no thermal loading associated with the service water, corresponding discharge temperatures for each unit are 33.7 °F (Unit 2) and 25.7 °F (Unit 3). For Scenario 1 the combined flow rate is 2171 cfs and the weighted average discharge temperature is 28.7 °F. For Scenario 2, the flow is simply 825 cfs and the temperature rise is 33.7 °F.

Results and Discussion

Methodology described in Adams (2001) was used to compute the plume dimensions (isotherm lengths, widths and depths) under four tidal conditions. Results are displayed in Table 1 for the above two scenarios as well as for historical operation of Units 1-3 with no reduction in flow.

Table 1a Lengths (L), widths (W) and depths (H) in feet of isotherms for conditions of maximum flood

	Units 1-3 with normal flow			Units 2-3 with reduced flow			Unit 2 with reduced flow		
Isotherm	L	W	H	L	W	H	L	W	H
12	460-720			430-610			260-410		
10	540-960			460-810			310-540		
8	700-1300			590-1100			400-740		
6	1020-1820	1250	18	870-1540	1060	11	580-1030	710	11
4	1620-2500	2050	19	1370-2120	1740	11	920-1410	1160	11
1.5	11000*	6800	21	9000	5770	11	6220	3850	11

Table 1b Lengths (L), widths (W) and depths (H) in feet of isotherms for conditions of slack after flood

	Units 1-3 with normal flow			Units 2-3 with reduced flow			Unit 2 with reduced flow		
Isotherm	L	W	H	L	W	H	L	W	H
12	400-480			340-410			230-260		
10	560-640			480-540			320-360		
8	780-1000			660-850			440-570		
6	1360-2400	1360-2400	18	1150-2040	1150-2040	12	770-1360	770-1360	12
4	2100-3000	1480-3000	19	1780-2550	1260-2550	12	1190-1700	840-1700	12
1.5	4000	7400	21	3390	6290	12	2260	4190	12

Table 1c Lengths (L), widths (W) and depths (H) in feet of isotherms for conditions of maximum ebb

	Units 1-3 with normal flow			Units 2-3 with reduced flow			Unit 2 with reduced flow		
Isotherm	L	W	H	L	W	H	L	W	H
12	720-920			610-780			410-520		
10	920-1320			780-1120			520-750		
8	1320-2120			1120-1800			750-1200		
6	2080-4230	960-1940	17-19	1760-3590	730-1650	11	1180-2390	490-1100	11
4	4200-7200	1830-3400	20-22	3560-6110	1550-2880	11	2380-4070	1040-1920	11
1.5	14000*	5700	22-24	11880	4840	11	7920	4100	11

Table 1d Lengths (L), widths (W) and depths (H) in feet of isotherms for conditions of slack after ebb

	Units 1-3 with normal flow			Units 2-3 with reduced flow			Unit 2 with reduced flow		
Isotherm	L	W	H	L	W	H	L	W	H
12	480-560			410-480			270-320		
10	720-1000			610-850			410-570		
8	1260-2000			1070-1700			710-1130		
6	2500-4700	1420-4050	19-22	2120-4000	1200-3440	10	1410-2660	800-2290	10
4	4800-5470	4000-5130	21-24	4070-4640	3390-4350	10	2720-3090	2260-2900	10
1.5	10830	6270	23-26	9160	5320	10	6110	3550	10

Compared with historical operation with Units 1-3, operation with Units 2-3 under reduced flow (Scenario 1) will generate smaller isotherms. This is primarily because of the lower rate of heat addition (two units rather than three). Additionally, as the flow rate decreases, the temperature rise increases. Since the discharge cross-sectional area (through two quarry cuts) remains the same, the discharge velocities are reduced. The combination of reduced discharge velocity and increased discharge temperature produces lower values of the modified densimetric Froude number F_O' (Eq. 1 of Adams, 2001), implying less mixing and shorter, shallower plumes.

In Scenario 2 the above factors are amplified further. The even lower heat rejection (only one unit), the reduced flow (and hence reduced velocities) and the higher discharge temperatures (Unit 2 has higher ΔT than Unit 3) all contribute to shorter and shallower isotherms.

Because of the reduced mixing, near field analysis suggests that the plume will not penetrate deeply into the ambient water. Hence the predicted maximum depths of the 6, 4 and 1.5 °F isotherms are all actually equal to the initial discharge depths of 10-12 feet, depending on tidal stage.

Although the size of given isotherms is smaller, the additional scenarios experience higher peak temperatures. For example, with Scenario 2 the maximum plume temperature rise would be the discharge temperature rise of 33.7 °F, which is significantly higher than the corresponding temperature rise of approximately 20 °F characterizing the historical Units 1-3 operation.

It should also be mentioned that, as the densimetric Froude number decreases, there is a greater tendency for the ambient bay water to intrude *into* the quarry, beneath the overlying *outgoing* heated discharge. To evaluate this condition, a slightly different definition of densimetric Froude number is used:

$$F_o = \frac{u_o}{\sqrt{g\beta\Delta T_o h_o}} \qquad (1)$$

F_O defined above differs from F_O' defined previously in the use of the discharge opening depth h_O rather than the square root of half the discharge area ℓ_o as the governing length scale. As before, u_O, g, β *and* ΔT_O are the discharge exit velocity, acceleration of gravity, coefficient of thermal expansion and discharge temperature rise. The critical value of F_O below which intrusion takes place is one (Stolzenbach et al., 1973). Indeed, when F_O falls below one, the depth of the outgoing flow $h_O{}^*$, adjusts itself so that the value of F_O, based on $h_O{}^*$ becomes one (Ryan, et al., 1974).

The values of F_O for the three scenarios are shown in Table 2. The range reflects variation over season and tide, with the lowest values occurring during the summer, when the value of β is greatest (meaning the density difference corresponding to a given temperature difference is greatest), and at high tide, when the velocity u_0 is lowest and the depth h_0 is greatest.

Table 2 Minimum and Maximum values of densimetric Froude number for different scenarios

Scenario	Minimum F_o (summer, high tide)	Maximum F_o (winter, low tide)
Units 1-3 with normal flow	2.8	5.3
Units 2-3 with reduced flow	1.1	2.1
Unit 2 with reduced flow	0.4	0.7

For Scenario 1 the value of F_0 approaches 1 at high tide during summer, while for Scenario 2 F_0 is well below 1. Thus I would expect to see ambient seawater intruding into the quarry for Scenario 2.

The higher near field temperatures, reduced near field mixing, and tendency for ambient bay water intrusion all result from the lower velocities and higher temperatures of the reduced flow scenarios. As considered in Adams (2001), one way to offset this tendency is to block off several of the louvres that are currently used to prevent fish from passing upstream into the quarry. Reducing the number of (open) louvres would reduce the effective cross-sectional area and increase the velocity, both of which would increase mixing. In Adams (2001) I analyzed the number of blank louvres needed to make the plume from Units 2-3 match approximately the historical plume with Units 1-3. As the number of pumps was reduced, the number of blank louvres was increased. For conditions of 7 pumps (approximately a 30 percent reduction in flow relative to the maximum of 10 pumps) between 9 and 11 blank louvres were required, depending on the specific objective (i.e., whether it was desired to match dilution, near field temperature rise or characteristic near field length). With Scenario 1, which results in somewhat greater than 30 percent flow reduction, I would expect that at least this number would need to be removed. Since there are 11 louvres per quarry cut, one might consider blanking all of the louvres at one cut. With Scenario 2, an even greater number would need to be blanked if one wanted to match historical conditions with Units 1-3. Of course, this scenario would not last long, and it would not be necessary to revert all of the way back to historical conditions; hence blanking of a lesser number of louvres could be justified.

If desired, I can repeat the previous analysis to provide more precise numbers.

References

Ryan, P.J., Harleman, D.R.F. and Stolzenbach, K.D., 1973. "Surface heat loss from cooling ponds", *Water Resources Research* 10(5): 930-938.

Stolzenbach, K.D., and Harleman, D.R.F., 1973. "3-D Heated Surface Jets", *Water Resources Research* 9(1): 129-137.

Stolzenbach, K. D. and Adams, E.E., 1979 "Thermal plume modeling of the Millstone Nuclear Power Station", report presented to Northeast Utilities Service Company.

D17347

Enclosure 3

Ecological Significance of Community Changes at Fox Island

January 1987

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INTRODUCTION

The nuclear power plants at Millstone Point, CT discharge condenser cooling water through an 8 acre former granite quarry into Long Island Sound. Prior to the opening of the second quarry cut in August 1983, the Fox Island-Exposed community (FE) was similar to intertidal communities locally (NUSCo 1984) and throughout New England (Vadas 1972; Mathieson et al. 1981). The low intertidal zone was dominated by *Chondrus crispus*, the mid intertidal by a *Fucus vesiculosus* and *Ascophyllum nodosum* canopy over *Balanus balanoides*, and the high intertidal by blue-green algae and *Balanus*. Several species of ephemeral algae (e.g., *Petalonia, Scytosiphon, Ceramium, Polysiphonia, Enteromorpha, Monostroma, Ulva*) were found throughout the intertidal on a seasonal basis. Two species of snails, *Littorina littorea*, a grazer, and *Urosalpinx cinerea*, a carnivore, were present in low percentages but have been shown to have a major effect on community development and structure (Lubchenco and Gaines 1981; Lubchenco 1983; NUSCo 1985; Watson and Norton 1985).

The similarity between the community at FE, prior to 1983, and those throughout the area resulted from the absence of thermal incursion from the plume discharged through a single cut; Fox Island-Exposed water temperatures were < 1 °C above ambient (ΔT < 10 °C). Once the second quarry cut was opened in August 1983, water temperatures along the shore between the discharge cuts and FE increased. With a single unit in operation (as in the period immediately following the opening), water temperatures at FE were 4-5 °C above ambient; with two units operating (as during most of 1984), ΔT was up to 10 °C. This regime did not alter community structure until the summer of 1984, when temperatures above 28 °C exceeded the physiological limits of many intertidal species. Tissue damage was first seen in *Ascophyllum* plants in August 1984. By September, a community dominated by perennial algae such as *Ascophyllum, Fucus*, and *Chondrus* was replaced by one composed of opportunistic ephemeral species, such as *Enteromorpha* spp., *Polysiphonia* spp., and blue-green algae. By December, *Codium fragile* occupied much of the area colonized by initial ephemeral species.

The objective of this report is to describe the changes in the Fox Island-Exposed community following the opening of a second quarry cut, and to evaluate the ecological significance of the alterations to the FE community structure and local *Ascophyllum* populations.

MATERIALS AND METHODS

Water temperatures in this report were derived from the EDAN (Environmental Data Acquisition Network) system, which continuously monitors a variety of environmental parameters and records at 15 minute intervals. Ambient water temperatures were recorded by sensors in Unit 1 and Unit 2 intake bays, and effluent water temperatures by sensors in the quarry cuts. Temperatures at FE and the experimental *Ascophyllum* stations (FL and FN; Fig. 1) were interpolated, based on measured ΔT, and verified over several tidal cycles with a portable thermistor and strip chart recorder. Fox Island-Exposed is one of nine rocky intertidal sites (Fig. 2) sampled as part of an on-going environmental monitoring program. For a complete description of sampling methodology, see NUSCo 1986. Methods, as they apply to this report, are described below.

Qualitative algal samples were collected monthly at FE and plants were identified to the species level. Quantitative data were collected bimonthly; five permanent vertical transects were divided into three zones with a variable number of 50 x 50 cm quadrats, depending on the slope. Percentage of substratum coverage by each plant and animal species, and free space, was determined within each quadrat. *Ascophyllum nodosum* populations have been monitored at White Point, Giants Neck (both control sites, 1.6 km east and 5.6 km west of the discharge, respectively), and at Fox Island (experimental site, $<$ 100 m east of the second quarry cut). Fifty tagged plants with five marked apices on each were measured monthly to determine incremental growth and plant mortality. New sets of plants were tagged each spring and were measured monthly until the following April. A new experimental *Ascophyllum* station (FN) was established in April 1985, approximately 250 m from the discharge, following the loss of the original experimental population (at FL) to thermal stress (NUSCo 1986).

Data Analysis

Relative abundance of intertidal organisms was estimated on the basis of percentage of substratum covered by each taxon. Unoccupied substratum was classified as free space. Similarity between communities was determined by a standardized form of the Bray-Curtis coefficient (Sanders 1960), calculated as:

$$S_{jk} = \sum_{i=1}^{n} \min(P_{ij}, P_{ik})$$

where P(ij) is the percentage of species (i) at station (j), P(ik) is the percentage for station (k), and (n) is the number of species in common. A flexible-sorting, clustering algorithm was applied to the resulting similarity matrix. The calculations were performed on untransformed percentages.

Ascophyllum growth data are reported as mean growth ±2 standard errors; means are compared using 2-sample t-tests (PROC TTEST, SAS Institute Inc. 1982). A probability level of $\alpha = 0.05$ was used to determine statistical significance.

RESULTS AND DISCUSSION

Temperature Data

When the effluent plume from one or two operating units was directed through a single quarry cut, its velocity and momentum carried it into Twotree Channel, where it mixed with and lost heat to a large volume of tidally flushed water. Water temperature at Fox Island-Exposed was within 2 °C of ambient (Fig. 3, regime 1), regardless of tidal stage.

With two quarry cuts the same volume of effluent was discharged through twice the area and the plume lost half its momentum. This broader, slower plume mixed with nearshore water and remained in the area bounded by Fox Island on the east, shoreline on the north, and the thermal plume itself on the south and west. This heated water produced nearly isothermal water temperature along the shore between the cuts and the southwest tip of Fox Island, only 3-4 °C cooler than undiluted effluent in the quarry (Fig. 3, regime 2). Again, this occurred regardless of tidal stage.

When Unit 3 added its discharge to the effluent plume, the added momentum carried the plume into Twotree Channel where it was subjected to tidal flushing. On the flood stage of the tide the effluent was directed westward, away from Fox Island, and at high tide ambient water temperatures were recorded at FE. Minimum temperatures were recorded during high tide at FL (original *Ascophyllum* study site) as well, but they remained 3-4 °C above ambient. On the ebbing tide, the plume was forced eastward across Fox Island, and at low tide maximum temperatures occurred at both FE and FL (up to 8-9 °C above ambient temperature). Minimum temperature water occurred for approximately 3 hours out of a 12-hour tidal cycle; elevated temperatures would occur during the remainder of the 12-hour tidal cycle. These conditions are modelled in Figure 4 and produce regime 3 temperatures illustrated in Figure 3. Water temperatures are dependent on both the number of units operating and cooling water flow; therefore, conditions are likely to vary from year to year as each unit undergoes scheduled and unscheduled shut-downs.

Description of Fox Island-Exposed community prior to second cut opening, March 1979-August 1983

The intertidal community at FE, prior to the second cut opening, was typical of communities in the Greater Millstone Bight area (NUSCo 1984). Seasonal patterns of distribution at FE were similar to those at the other monitoring sites (NUSCo 1983). The flora was diverse: between 72-78 algal species were present at FE each year between 1979-1984.

Each intertidal zone was characterized by a typical species complex. The high intertidal, Zone 1, was dominated by barnacles and blue-green algae. *Fucus vesiculosus* and *Ascophyllum nodosum* were dominant members of the mid-intertidal community, with *Fucus* averaging over 60% cover at FE from 1979-1981 (Fig. 5a), similar to other stations (e.g., FS, Fig. 5b). *Ascophyllum* reached 95% cover along the 150 m of shoreline between the discharge and Fox Island (NUSCo 1982). Understory barnacles were also abundant in the mid intertidal at FE (Fig. 6a) averaging approximately 50% from 1981-1983, which is similar to the Fox Island-Sheltered barnacle population (Fig. 6b). *Chondrus crispus* dominated the low intertidal at FE, averaging approximately 60% cover (Fig. 7a), similar to other stations, e.g., WP (Fig. 7b). Epiphytes (*Monostroma* spp., *Polysiphonia* spp., *Ulva lactuca*, and *Ceramium* spp., for example) were associated with fucoids and *Chondrus* in the lower intertidal areas. The relative abundance of species found at this site was comparable to those at other sites locally (NUSCo 1984).

Littorina littorea was an important grazer in the community, although its abundance was usually less than 2%. These snails remove epiphytes from perennial algae, and clear areas of intertidal rock, making space available for colonization by other plants and animals, especially in spring and autumn (NUSCo 1983). *Urosalpinx cinerea*, the oyster drill, was the most important predator in the FE community, feeding on barnacles and mussels. Like *Littorina*, the percent coverage of *Urosalpinx* was low (maximum of 2% in autumn, Fig. 6a). These patterns of distribution seen at Fox Island-Exposed were similar to those noted throughout the rocky intertidal monitoring area (NUSCo 1983, 1984).

The similarity between FE and other rocky shore stations can be illustrated by summarizing pre-second cut percent cover data (March 1979-July 1983) as a clustering dendrogram (Fig. 8). Three major groupings are apparent at the 35% level, representing low, mid, and high intertidal areas. Fox Island-Exposed, Zones 2 and 3 (FE2 and FE3) show high similarity to other low and mid intertidal areas; and Fox Island-Exposed, Zone 1 (FE1) clusters with Zone 2 because of high abundance of *Fucus*. The abundance of *Fucus* in Zone 1 of FE is a result of a higher degree of exposure (spray zone, more available moisture), not proximity to the discharge (NUSCo 1981).

Description of post-second cut community changes

The Fox Island-Exposed community was not affected immediately after the second cut was opened. A single unit was in operation and effluent temperatures were not sufficiently high to cause such changes. In early 1984 with Units 1 and 2 operating, winter and spring ambient water temperatures were sufficiently cool that even a 10-12 °C ΔT did not raise FE water temperature above 27 °C. However, as temperatures exceeded 28 °C in August-September 1984, physiological limits of the intertidal community were exceeded. The FE community dominated by perennial algal species (*Chondrus*, *Fucus*, *Ascophyllum*) was replaced by one composed of opportunistic algae (initially *Enteromorpha* spp., eventually including *Codium fragile*, *Agardhiella subulata*, and *Polysiphonia* spp.).

Algal species present in the vicinity of the FE transect area have been fewer in number since the opening of the second cut (e.g., 67 species collected from September 1984 to September 1986 vs. 105 species collected from March 1979 to August 1983, Table 1). Noticeable in this decreased diversity was the loss of the major perennials *Chondrus crispus* and *Ascophyllum nodosum.* Loss of these host plants also resulted in the loss of several small red and brown epiphytic species (e.g., *Polysiphonia lanosa* and *Elachista fucicola*). Additions to the FE flora were mostly inconspicuous epiphytes. Of the 6 species new to FE since September 1984, all but *Cladophora ruchingeri* have been found at other rocky shore stations, and all but *Desmotrichum* and *Asperococcus* have been identified in quarry collections (NUSCo 1985). Opportunistic greens, such as *Enteromorpha* spp. and *Codium fragile,* as well as warm water tolerant reds such as *Polysiphonia* spp. and *Agardhiella subulata,* dominated the area between the FE transects and discharge cuts. These species had been found previously at FE, but usually only in trace amounts in summer and early autumn. Now, the species are dominant components of the community over most of the sampling period, and the flora found between FE and the discharges closely resembles that of the quarry (NUSCo 1985). Species composition at the other rocky shore sites did not change.

Quantitative Studies: The use of attached algae and animals as indicator species

Important components of rocky shore communities locally and throughout New England (e.g., *Fucus, Chondrus,* ephemeral algae, barnacles, and snails), were abundant at FE before the opening of the second quarry cut and for nearly a year after its opening. The similarity between FE and control stations was an indication of community stability. Subsequent alterations to patterns of abundance are an indication of community impact. Responses of the *Ascophyllum* population and other taxa in the cove between FE and the discharges also suggest impact. These responses will be discussed in a subsequent section.

Fucus

Fucus vesiculosus dominates the mid intertidal throughout New England, particularly at stations with moderate exposure to prevailing winds and waves (cf. Keser and Larson 1984). At Fox Island-Exposed, *Fucus vesiculosus* dominated the canopy in Zone 2 prior to the opening of the second quarry cut, despite a significant drop in peak coverage between 1981-1982 (Fig. 5a). This decrease in *Fucus* cover prior to the second cut opening was unrelated to water temperature. The decrease was part of a natural 3-5 year cycle of *Fucus* abundance; this cycle has been observed at other stations (e.g., Fig. 5b; also see NUSCo 1985), and by other researchers (Niemeck and Mathieson 1976; Keser and Larson 1984). Thermal impact, a result of the second quarry opening, interrupted the *Fucus* population cycle at FE; the recovery expected after a settlement of germlings in spring 1984 did not occur. *Fucus* cover at FE decreased to zero in September 1984, due to the high temperature of FE water (> 28 °C). Others have also reported the lethal effects of high water temperatures on *Fucus* populations (Kanwisher 1966; Vadas et al. 1976).

Fucus vesiculosus germlings settled at FE again in spring 1985, and peaked in substratum cover in July at about 5%. However, by September 1985 as water temperatures exceeded 28 °C, *Fucus* cover again fell to zero. In 1986, *Fucus* resettled in spring, and grew to about 25% cover in July. With 3 units in operation, average summer water temperatures at FE were lower than they had been in 1984 or 1985 (Fig. 3). Some plants survived the summer of 1986 but in September, while the *Fucus* cover was still 15%, most plants were heavily epiphytized (indicating some degree of stress).

Chondrus

Chondrus crispus dominates low intertidal and shallow subtidal rocks throughout New England, the Canadian Maritimes, and Northern Europe. *Chondrus* also dominated the low intertidal at FE prior to the opening of the second quarry cut. Understory *Chondrus* cover averaged 60% throughout the study period (Fig. 7). This perennial maintained its cover until September 1984 when its cover decreased to zero due to water temperatures in excess of 28 °C. *Chondrus* cover at other rocky shore stations (e.g., White Point, Fig. 7b) has consistently remained high throughout the study.

Studies by Newell and Pye (1968), Montfort et al. (1955), Mathieson and Burns (1971) and Ried (1969) show that *Chondrus crispus* exhibits decreasing growth and survival above 21 °C, and Prince (1971) showed 100% mortality of spores after 4-10 days at 27 °C (from Mathieson and Prince 1973). MacFarlane (1956) states that severe injury to *Chondrus* holdfasts could ruin a bed for several years. As of September 1986 *Chondrus* has not repopulated FE and as long as water temperatures in excess of 28 °C occur periodically, none can be expected to colonize substratum at this site.

Barnacles

Barnacles contribute to the structure of rocky intertidal communities in temperate-boreal regions throughout the world (Stephenson and Stephenson 1972). As elsewhere, *Balanus balanoides* is an important component in the Millstone Point area. *Balanus* dominated the understory substratum coverage in the mid-intertidal at FE, similar to the *Balanus* population at FS (Fig. 6). *Balanus* showed predictable patterns of occurrence prior to the opening of the second discharge cut, similar to those reported elsewhere (e.g., Grant 1977). Generally, barnacles settled in early spring, and coverage increased into early summer, as these individuals grew. Peak abundance for barnacles (80%) occurred in June. Barnacle cover decreased as barnacles were lost in autumn to predation, and later, to winter storms, but never fell below 25% between 1981 and the opening of the second quarry cut (August 1983).

However, in the year following the second cut opening, *Balanus* reached a low substratum cover in October-December 1983, and at a much lower percentage (4% vs. 35%) than previously seen. A new barnacle set in spring 1984 reached the usual 80% peak but the population was entirely lost in September 1984 due to high water temperatures. *Balanus* recovered and established a large population in spring 1985 only to die off completely in late summer, again due to high temperature. This process was repeated in spring 1986, except the population survived late summer temperatures and as of September 1986 had 10% cover. As with *Fucus vesiculosus*, the survival of barnacles is attributed to the periodic incursion of ambient temperature water resulting from 3-unit operation.

Snails

As noted above, *Urosalpinx cinerea* is the most important intertidal predator in our area, and contributes to the annual cycle of barnacle occurrence. Predatory snails were not excluded from Fox Island-Exposed immediately following the opening of the second cut (1 unit operating); in fact, their abundance and activity continued later into the winter of 1983-84 than in past years (Fig. 6). However, *Urosalpinx* cover dropped to zero in both September 1984 and September 1985 (2 units operating), indicating that *Urosalpinx* avoids temperatures in excess of 28 °C. Significantly, the presence of *Urosalpinx* in September 1986 is further evidence that 3-unit operating conditions produce water temperatures below their lethal limit.

Prior to the opening of the second cut, grazing snails (mostly *Littorina littorea*) averaged 1-2% substratum cover in the mid intertidal, and their activity was associated with seasonal declines in ephemeral algal cover (NUSCo 1983). As with *Urosalpinx*, the abundance of *Littorina* did not change appreciably until September 1984 when their substratum cover fell to zero. Since that time, *Littorina* has been absent from FE or present only as a trace. Predictably, reduced grazing pressure has contributed to the year-round abundance of ephemeral algae at FE.

Ephemerals

Ephemeral algal species, especially epiphytes on *Chondrus crispus*, *Fucus vesiculosus*, and *Ascophyllum nodosum*, were important seasonal components of the intertidal community prior to the opening of the second quarry cut (Fig. 9). Major components of this group (*Polysiphonia*, *Enteromorpha* spp., *Codium fragile*, *Monostroma*, *Agardhiella*) will be addressed separately in order to follow the succession of these opportunistic species.

Polysiphonia spp.

Prior to the opening of the second cut, *Polysiphonia* spp. occurred at FE (as at other stations) primarily as an epiphyte on *Fucus* and *Chondrus*, e.g., *P. harveyi*, or on rock, *P. novae-angliae*. Plants of these species would generally peak in abundance in autumn, with considerable variability in population numbers from year to year.

Following the opening of the second cut, *Polysiphonia* cover increased to approximately 60% in November 1983. *Polysiphonia* spp. were the dominant ephemerals from the time of the second quarry opening in August 1983 until July 1984, when *Enteromorpha* spp. became dominant. The decline in *Polysiphonia* was related to loss of attachment space; the host plants were eliminated from the community in September 1984, and *Enteromorpha* settled so densely as to inhibit further settlement of other species on rock. Since that time, *Polysiphonia* spp. have developed populations that cover up to 20%, on rock and as an epiphyte on *Codium* and *Agardhiella*.

Enteromorpha spp.

Enteromorpha is a green ephemeral alga which is known to tolerate stressed and unstable environments, analagous to a terrestrial weed (Vadas 1979). The life history of *Enteromorpha* plants makes it an ideal opportunistic colonizer (Fahey 1953; Menge 1975). Its rapid growth and reproductive turnover allow it to quickly occupy available substrata, and in the absence of grazing pressure, populations persist for many months (NUSCo 1985). *Enteromorpha* spp. (Fig. 9) were present in low percentages (< 10%) at FE prior to the opening of the second cut and population peaks occurred in summer; the occurrence and size of these populations were limited by grazing *Littorina*. One year after the second cut was opened, *Enteromorpha* population abundance in the low intertidal increased and surpassed that of *Polysiphonia* spp., and was the dominant population (ca. 85%) from September-December 1984 until it was outcompeted by *Codium fragile*. The following winter (1985-86), *Enteromorpha* spp. was dominant again (60% cover) for nearly three months because of winter damage to *Codium* (cf. Fralick and Mathieson 1972). Since December 1985, *Enteromorpha* spp. were present at FE but the population did attain more than 10% substratum cover.

Codium fragile

Codium fragile, a large siphonous green alga (introduced to Long Island Sound in 1957, Bouck and Morgan 1957), is also considered an algal weed (Ramus 1971). *Codium* has been found throughout the Millstone Point area and played a minor role in the FE community prior to the second cut opening (Fig. 9). *Codium* reached its highest percent cover (10-15%) in late autumn 1979, but was present only intermittently until December 1984. *Codium* is reported to be competitively inferior to established populations of benthic macroalgae, e.g. *Chondrus* (Malinowski and Ramus 1973), but after these populations were eliminated by lethal temperatures *Codium* was able to outcompete the *Enteromorpha* population in the low intertidal, climbing to its peak (90%) in May-July 1985. *Codium* remained the dominant alga at FE until the following November when its population diminished to 20% substratum cover owing to low winter temperatures and fragmentation; *Enteromorpha* then became dominant (60%) in the community. *Codium* regained dominance three months later in March 1986 and has continued to be the most prevalent alga at FE. Owing to its tolerance to both warm water and winter temperatures and, its ability to regenerate from a basal holdfast (Fralick and Mathieson 1972), *Codium* is expected to remain a major component of the low intertidal community at FE.

Monostroma spp.

Prior to the opening of the second cut, *Monostroma* spp. (mostly *M. pulchrum*, an annual green epiphyte of *Chondrus* and *Fucus*) peaked in early spring (25-45%) and were lost from the community before mid-summer. Once the second cut was opened, *Monostroma* spp. never repopulated the FE transect area, but occurs around the tip of Fox Island and at other rocky shore stations. As with *P. harveyi*, the decline was related to the loss of host plants.

Agardhiella subulata

Agardhiella subulata, a fleshy red alga, has become an important component of the Fox Island-Exposed community, following the opening of the second cut. Prior to 1983, *Agardhiella* had been found at FE (and at other stations), usually only in trace amounts and most commonly in summer. It has also been found as a minor seasonal component of other New England floras (Taylor 1957, as *Agardhiella tenera*; Schneider et al. 1979, as *Neoagardhiella baileyi*). It has been abundant year-round in the MNPS quarry (Schneider 1981; NUSCo 1985); *Agardhiella's* presence at FE is another indication of the thermal impact at this station.

Mytilus edulis

Mytilus edulis, the blue mussel, is another organism that contributes to the Fox Island-Exposed community. *Mytilus* is a preferred food for *Urosalpinx*, and prior to the opening of the second cut, and for a year after, predation limited the abundance of mussels to trace amounts, or at most, 1%. In September 1984, all mussels were eliminated from FE, a result of high water temperatures from 2-cut/2-unit operation during the period of high ambient water temperatures (cf. Read and Cumming 1967; Gonzalez and Yevich 1976; Johnson et al. 1983). They were not found again at FE until 1986 when under 3-unit operation, mussels settled, developed, and maintained their populations. In Zone 2, for example, mussel coverage was 4% in May, 29% in July, and 19% in September 1986. Survival was related to decreased predators, and, of course, less than lethal water temperatures.

Despite their abundance at FE, mussels have not been found along the shore between Fox Island and the discharges. The apparent inability of *Mytilus edulis* to colonize this area, as well as lower *Fucus* and barnacle abundance (relative to FE), and relatively higher abundance of *Enteromorpha*, are related to a change in water circulation patterns following start-up of Unit 3. Water temperatures under 3-unit operating conditions are no longer isothermal from FE to the quarry cuts as they had been under 2-cut/2-unit conditions, a fact corroborated by temperature data from the original Fox Island *Ascophyllum* study site (see Temperature Data above).

Similarity indices, as clustering dendrograms

A clustering dendrogram of percent similarity can be used to summarize 2-cut/2-unit operation (Fig. 10a). In this 1984-1985 dendrogram, three groups and one pair of outliers were apparent at the 45% similarity level, representing the three shore zones and excluding Zones 2 and 3 at Fox Island-Exposed (FE2 and FE3). In contrast to pre-second cut operation (Fig. 8), FE1 lost its *Fucus* cover, and now clustered with other Zone 1 sites which were dominated by free space and barnacles. Changes to FE2 and FE3 communities (replacement of *Fucus* and *Chondrus* by *Enteromorpha* and *Codium*) were apparent in the low degree of similarity between these entities and any other association.

A clustering dendrogram of the most recent data (11/85-9/86) shows that the benthic community at Fox Island-Exposed has undergone additional changes, related to 3-unit operation (Fig. 10b). The three intertidal zones, and one outlier, can be distinguished at approximately the 25% similarity level. FE1 and FE2 group together and contribute to the Zone 2 cluster. The abundance of ephemerals and *Fucus* since spring 1986 caused FE1 to cluster with Zone 2 sites, as it had prior to the opening of the second cut. The outlier to Zone 3, FE3, links at only a low degree of similarity, indicating that the low intertidal community at Fox Island-Exposed is still very different from those at other stations. The abundance of *Codium* and *Agardhiella*, and the absence of *Chondrus*, contribute substantially to this dissimilarity.

Ascophyllum nodosum Studies

Since 1979, the rocky intertidal monitoring program has included studies of *Ascophyllum nodosum*, a large perennial alga that is abundant in low and mid intertidal areas locally, as well as throughout New England, the Canadian Maritimes, and Northern Europe. *Ascophyllum* has been studied extensively throughout its range, and its vegetative and reproductive phenology is well documented (David 1943; Printz 1959; Baardseth 1970; Sundene 1973; Mathieson et al. 1976; Wilce et al. 1978). *Ascophyllum* growth rate has been shown to be sensitive to water temperature changes, especially increases to ambient temperature (Vadas et al. 1976,1978; Stromgren 1977; Wilce et al. 1978; Keser and Foertch 1982). Because of this alga's response to water temperature change and its mode of linear growth, it is an important biomonitoring tool in the rocky intertidal program. Details of growth and mortality of local *Ascophyllum* are summarized below.

From April 1979 through May 1983, *Ascophyllum* plants (tips) at Fox Island grew longer than those at White Point or Giants Neck (Fig. 11a). In the year representative of this growth pattern, 1982-1983, *Ascophyllum* tips grew longer because of the 2-3 °C ΔT at FL under single quarry cut conditions, showing a higher growth rate earlier in spring and an extended growing season in late autumn (Fig. 11b). The increased tip length at FL resulted from faster growth from April to July; growth rate during the remainder of the year was similar to growth rates at the control stations, and that recorded for *Ascophyllum* plants throughout their geographical range (cf. Vadas et al. 1976, 1978; Stromgren 1977; Wilce et al. 1978; Keser and Foertch 1982).

During the 1983-84 growing season, FL water temperatures were 2-3 °C above ambient from April to July, and average tip length was significantly longer at FL than at the control sites (Fig. 12a). Just after August 1983 when the second quarry cut opened and only one unit was in operation, the water temperature at FL rose to 7-9 °C above ambient and plants were exposed to a maximum temperature of about 27 °C. Growth rate at FL decreased sharply from August to October until temperatures decreased (Fig. 12b). When both units were operating in spring 1984, elevated water temperatures (12-13 °C above ambient, ca. 20 °C at the end of April 1984) were within the range of temperatures for optimal growth of *Ascophyllum*, and enhanced growth at FL; average tip length and growth rate were significantly greater there than at the control sites.

When two units were operating and discharging through two quarry cuts, as in the 1984-85 growing season, water temperature averaged 12-13 °C warmer than at the control sites, resulting in high initial growth at FL in April-June (Fig. 13a). In July, temperatures exceeded 25 °C and growth rate at FL decreased sharply (Fig. 13b). By August, water temperatures exceeded 28 °C and *Ascophyllum* plants died at FL, whereas plants at GN and WP were healthy. Other researchers have related increased water temperatures to physiological stress. Chock and Mathieson (1979) found the maximum net photosynthesis for summer *Ascophyllum nodosum* plants to be at 18-21 °C and found a "conspicuous decrease" beyond 24 °C. Thermal injury to *Ascophyllum* was determined between 30-35 °C (Kanwisher 1966), while enhancement at 22 °C, gradual demise at 26 °C, and complete thallus destruction at temperatures above 30 °C was recorded by Vadas et al. (1978).

A new Fox Island station was established in April 1985, following the loss of *Ascophyllum* that occurred at FL in 1984. This station was located at the first available *Ascophyllum* population around Fox Island-Exposed, approximately 200 m from the discharges (Fig. 1); water temperature at FN was 0-2 °C warmer than at controls in spring 1985 (with only 2 units in operation). *Ascophyllum* growth at FN was higher than at the control sites from April to May, but for the remainder of the season neither average tip length nor growth rate differed significantly between FN and GN (Fig. 14). The decrease in average tip length at FN between September and October was caused by the loss of plants during Hurricane Gloria on September 27, 1985.

The response of the *Ascophyllum* population at FN tagged in spring 1986 and exposed to 3-unit operating conditions (Fig. 15) resembles that of the original experimental *Ascophyllum* population at FL prior to 1983, exposed to single cut operating conditions (Fig. 11). The longer tips at FN (Fig. 15a) result from higher growth rates in spring (Fig. 15b); growth rates at all stations are similar in late summer and autumn.

Ascophyllum is not expected to recolonize at FL, even under periodic optimal conditions. Absence of *Ascophyllum* recolonization after experimental or natural substratum denudation, and very slow recovery of harvested populations has been reported repeatedly (David 1943; Knight and Parke 1950; Virville 1953; Printz 1956,1959; Boney 1965; Baardseth 1970; Sundene 1973; Keser and Larson 1984).

SUMMARY-ECOLOGICAL SIGNIFICANCE

Ecological studies of a rocky intertidal community in the vicinity of the MNPS thermal effluent (specifically, at Fox Island-Exposed), conducted during 2-unit operation prior to the opening of the second quarry cut (August 1983), showed no effects attributable to thermal stress. Dynamics of the FE community were similar to those reported throughout the Millstone area (NUSCo 1983) and throughout New England (Vadas 1972; Wilce et al. 1978; Mathieson et al. 1981). Enhanced growth (tip length) of an *Ascophyllum* population ca. 100 m from the discharge, relative to the control populations, resulted from higher growth rates in spring; this relationship is consistent with water temperatures 1-2 °C above ambient at the experimental *Ascophyllum* station (cf. Vadas et al. 1976, 1978; Wilce et al. 1978). The absence of thermal impact was related to the effluent plume characteristics; the velocity of the plume from a single quarry cut carried most of the thermal effluent offshore away from intertidal areas.

Following the opening of the second cut, we recorded a number of changes to the FE community; these changes were directly attributable to exposure to increased water temperatures. Further, we were able to distinguish between 1, 2, and 3-unit operating conditions. For example, with a single unit in operation, thermal effects were seen primarily as increased abundance of ephemeral algae and decreased growth rate of *Ascophyllum* during periods of highest water temperature. These impacts were transient, and did not exceed the communities' resilience or ability to recover, at least during the period when 2-cut/1-unit conditions prevailed.

The impact of 2-cut/2-unit operation was more noticeable. Summer water temperatures in excess of 27 °C resulted in extensive changes to the rocky intertidal communities between FE and the discharges. Populations of perennial algae (*Chondrus*, *Fucus*, *Ascophyllum*) and sessile invertebrates (*Balanus*, *Mytilus*) were eliminated, and intertidal snails (*Littorina* spp., *Urosalpinx*) moved from the impacted area. The community that subsequently developed showed lower diversity, and was dominated by ephemeral algae (especially *Enteromorpha* spp.) and those species that are tolerant of, or require higher water temperatures for optimal colonization and growth, e.g., *Codium* and *Agardhiella*. This community resembled that found in the quarry itself (Schneider 1981; NUSCo 1985).

The structure and condition of the rocky shore community changed again following start-up of Unit 3 in spring 1986. Effluent plume characteristics caused periodic incursion of ambient temperature water to FE for about 3 hours per tidal cycle, and warm water (to 9 °C above ambient) for the remaining 9 hours of each tidal cycle. Average temperatures at FE did not exceed 27 °C in 1986, and populations of barnacles, mussels, and *Fucus* that settled in spring 1986 survive to the present. However, this survival may be related to the fact that all three units were not operating at full power simultaneously throughout the study period.

The region of direct and biologically detectable thermal influence is limited to the Fox Island cove (ca. 150 m) and has not increased in area since Unit 3 began operation. This length of shoreline represents less than 1% of the rocky intertidal substrata available in the Greater Millstone Bight. Although the cove area is small, the ecological significance of its community must be addressed; we must ensure that we can assess changes that might occur over a wider area in the future. As noted previously, varying number of units, operating at varying power levels, for various lengths of time, during various times of the year will result in a very complex set of environmental conditions at FE. Nevertheless, some generalizations regarding the community changes may be made.

One change resulting from the thermal impact has been a shift in species abundance patterns at FE. Species approaching their southern geographical limits are rarer (or absent) and found for a shorter time during the year, and species with warm water tolerances are more abundant and found over an extended growing season relative to control stations. The loss of *Chondrus* and increased abundance of *Agardhiella* are examples of this shift; the same phenomenon has been noted in the effluent quarry flora (NUSCo 1985).

Another change noted at FE since thermal incursion can be generalized as a shift from a community dominated by perennial algae (late successional stages, in classical ecological terms) to one of ephemeral or opportunistic species (early successional stages). In the former case, much of the energy that enters the system goes into development of massive thalli and chemical and structural defenses against herbivory. In the latter case, growth rate and turnover are fast, thalli are generally small and delicate, and energy is shunted primarily into reproduction and dispersal.

However, comparison of pre- and post-second cut communities based on classical ecological principles (e.g., succession) may be misleading. For example, *Ascophyllum* releases up to 50% of its wet weight standing crop each year when it sheds its reproductive receptacles (hardly typical of a classic climax species), and both *Ascophyllum* and *Fucus* are also known to release large amounts of dissolved organic matter. Further, the ability of *Codium* to regenerate from a persistent, over-wintering holdfast provides continuity of the population and accounts for the description of *Codium* as a pseudoperennial. In short, both pre- and post-second cut communities at FE have been productive, in terms of both carbon fixed and nutrients recycled to the environment. For example, annual production of a dense *Enteromorpha* mat was estimated at 1100 g C m^{-2} (Pregnall and Rudy 1985), and measurements of *Codium* have been extrapolated to estimate maximum production-potential at 4.7 kg C m^{-2} (Wassman and Ramus 1973). These rates of carbon fixation are comparable to those of established *Fucus/Ascophyllum* stands (ca. 750-1500 g C m^{-2}; Topinka et al. 1981).

All species found in the cove since the thermal impact are commonly found in Long Island Sound. However, their abundance and persistence in the FE community indicates a physically unstable environment. The degree of stress is related to the number of units in operation (especially during the summer when ambient water temperature is highest) and total effluent flow.

This thermal stress is expected to continue to prevent the recovery of *Chondrus* and *Ascophyllum* populations at FE. Colonizing, germling and juvenile stages are more susceptible to environmental impact than are established adults (Bird and McLachlan 1974). Given temperatures above those required for spore settlement, recovery to pre-experimental levels is not expected as long as high water temperatures, periodically or throughout the year, prohibit recruitment of major perennials. Even populations of barnacles and *Fucus* which settle in spring when water temperatures are low, are stressed and mostly gone by late summer; the long-term effects on these organisms is unknown, but it is unlikely that they will achieve pre-experimental abundance either.

Despite the expected permanence of the changes seen at Fox Island-Exposed, we must again emphasize their limited scope Significant thermal effluent of MNPS on the intertidal community of Greater Millstone Bight is not foreseen, on the basis of data collected and analyzed since the opening of the second quarry cut in August 1983. The area affected is less than 1% of total intertidal area of Millstone Bight. No addition, deletion, or significant change in abundance of any species occurred at our reference stations. The reproductive strategies of local intertidal organisms ensure an adequate supply of reproductive material for normal recolonization as shown by our experiments.

LITERATURE CITED

1. Baardseth, E. 1970. Synopsis of biological data on knobbed wrack *Ascophyllum nodosum* (Linnaeus) Le Jolis. FOA Fisheries, Synopsis #38, Rev. 1.

2. Bird, C.J. and J. McLachlan. 1974. Cold-hardiness of zygotes and embryos of *Fucus* (Phaeophyceae, Fucales). Phycologia 13:212-225.

3. Boney, A.D. 1965. Aspects of the biology of the seaweeds of economic importance. Adv. Mar. Biol. 3:105-253.

4. Bouck, G.B. and E. Morgan. 1957. The occurrence of *Codium* in Long Island waters. Bull. Torrey Bot. Club 84:384-387.

5. Chock, J.S. and A.C. Mathieson. 1979. Physiological ecology of *Ascophyllum nodosum* (L.) LeJolis and its detached ecad *scorpioides* (Hornemann) Hauck (Fucales, Phaeophyta). Bot. Mar. 22:21-26.

6. David, H.M. 1943. Studies in the autecology of *Ascophyllum nodosum* Le Jol. J. Ecol. 31:178-199.

7. Fahey, E.M. 1953. The repopulation of intertidal transects. Rhodora 55:102-108.

8. Fralick, R.A. and A.C. Mathieson. 1972. Winter fragmentation of *Codium fragile* (Sur.) Hariot subsp. *tomentosoides* (van Goor) Silva. J. Phycol. 8:147-152.

9. Gonzalez, J.G. and P. Yevich. 1976. Responses of an estuarine population of the blue mussel *Mytilus edulis* to heated water from a steam generating plant. Mar. Biol. 34:177-189.

10. Grant, W.W. 1977. High intertidal community development on a rocky headland in Maine, U.S.A. Mar. Biol. 44:15-25.

11. Johnson, G., J. Foertch, M. Keser, and B. Johnson. 1983. Thermal backwash as a method of macrofouling control at Millstone Nuclear Power Station, Waterford, Connecticut, USA. in Symposium on Condenser Macrofouling Control Technologies: The State of the Art. EPRI CS-3343 RP1689-9 Section 25, 15 pp.

12. Kanwisher, J.W. 1966. Photosynthesis and respiration in some seaweeds. in H. Barnes (ed). Some Contemporary Studies in Marine Science. George Allen Unwin Ltd., London. pp. 407-420.

13. Keser, M. and J. Foertch. 1982. Colonization and growth of *Ascophyllum nodosum* in New England. Presented at First International Phycological Congress, St. John's, Newfoundland. August 9, 1982.

14. Keser, M. and B.R. Larson. 1984. Colonization and growth dynamics of three species of *Fucus*. Mar. Ecol. Prog. Ser. 15:125-134.

15. Knight, M. and M.W. Parke. 1950. A biological study of *Fucus vesiculosus* L. and *F. serratus* L. J. Mar. Biol. Assoc. U.K. 29:437-514.

16. Lubchenco, J. 1983. *Littorina* and *Fucus*: effects of herbivores, substratum heterogeneity, and plant escapes during succession. Ecology 64:1116-1123.

17. ____ and S.D. Gaines. 1981. A unified approach to marine plant-herbivore interactions. I. Populations and communities. Ann. Rev. Ecol. Syst. 12:405-437.

18. MacFarlane, C.I. 1956. Irish moss in the Maritime Provinces. Nova Scotia Res. Fdn. 20 pp.

19. Mathieson, A.C. and R.L. Burns. 1971. Ecological studies of economic red algae. I. Photosynthesis and respiration of *Chondrus crispus* Stackhouse and *Gigartina stellata* (Stackhouse) Batters. J. Exp. Mar. Biol. Ecol. 7:197-206.

20. Mathieson, A.C. and J.S. Prince. 1973. Ecology of *Chondrus crispus* Stackhouse in *Chondrus crispus*. M.J. Harvey and J. McLachlan (eds), Nova Scotian Institute of Science, Halifax. p. 53-79.

21. Mathieson, A.C., N.B. Reynolds and E.J. Hehre. 1981. Investigations of New England marine algae II: the species composition, distribution and zonation of seaweeds in the Great Bay estuary system and the adjacent open coast of New Hampshire. Bot. Mar. 24:533-545.

22. Mathieson, A.C., J.W. Shipman, J.R. O'Shea, and R.C. Hasevlat. 1976. Seasonal growth and reproduction of estuarine fucoid algae in New England. J. Exp. Mar. Biol. Ecol. 25:273-284.

23. Malinowski, K.C. and J. Ramus. 1973. Growth of the green alga *Codium fragile* in a Connecticut estuary. J. Phycol. 9:102-110.

24. Menge, J. 1975. Effect of herbivores on community structure on the New England rocky intertidal region: distribution, abundance, and diversity of algae. Ph. D. thesis, Harvard Univ. 164 pp.

25. Montfort, C., A. Ried and I. Ried. 1955. Die Wirkung Kurzfristiger warmer Bader auf Atmung und Photosynthese im Vergleich von eurythermen und Kaltstenothermen Meeresalgen. Beitr. Biol. Pflanzen 31(2,3): 349-375.

26. Newell, R.C. and V.I. Pye. 1968. Seasonal variations in the effect of temperature on the respiration of certain intertidal algae. J. Mar. Biol. Ass. U.K. 48:341-348.

27. Niemeck, R.A. and A.C. Mathieson. 1976. An ecological study of *Fucus spiralis* L. J. exp. mar. Biol. Ecol. 24:33-48.

28. NUSCo (Northeast Utilities Service Company). 1981. Rocky Shore. Pages 1-41 in Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1980.

29. _____. 1982. Rocky Shore. Pages 1-41 in Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1981.

30. _____. 1983. Rocky Shore. Pages 1-39 in Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1982.

31. _____. 1984. Rocky Shore. Pages 1-31 in Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1983.

32. _____. 1985. Rocky Intertidal Studies. Pages 1-41 in Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1984.

33. _____. 1986. Rocky Intertidal Studies. Pages 1-38 in Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1985.

34. Pregnall, A. M. and P. P. Rudy. 1985. Contribution of green macroalgal mats (*Enteromorpha* spp.) to seasonal production in an estuary. Mar. Ecol. Prog. Ser. 24:167-176.

35. Prince, J. 1971. An ecological study of the marine red alga *Chondrus crispus* in the waters off Plymouth, Massachusetts. Ph. D. Thesis, Cornell University, Ithaca, N.Y. 193 pp.

36. Printz, H. 1956. Recuperation and recolonization in *Ascophyllum*. Second Int. Seaweed Symp. Braarud, T. and N.A. Sorenson (eds), Pergamon Press London. p. 194-197.

37. Printz, H. 1959. Phenological studies of marine algae along the Norweigian coast. Mat.-Naturv. Klasse No. 4. 28 pp.

38. Ramus, J. 1971. *Codium*: the Invader. Discovery 6(2):59-68.

39. Read, K.R.H. and K.B. Cumming. 1967. Thermal tolerance of the bivalve molluscs, *Modiolus modiolus* L. and *Brachidontes demissus* Dillwyn. Comparative Biochemistry and Physiology. 22:149-155.

40. Ried, A. 1969. Physiologische Aspekte der Veitekalzonierung von Algen des marinen Littorales. Ber. Deut. Bot. Ges. 82:127-141.

41. Sanders, H.L. 1960. Benthic studies in Buzzards Bay. III. The structure of the soft bottom community. Limnol. Oceanogr. 5:138-153.

42. SAS Institute Inc. 1982. SAS user's guide: statistics, 1982 edition. SAS Institute Inc., Cary, N.C. 584 pp.

43. Schneider, C.W. 1981. The effect of elevated temperature and reactor shutdown on the benthic marine flora of the Millstone thermal quarry, Connecticut. J. Therm. Biol. 6:1-6.

44. ____, M.M. Suyemoto, and C. Yarish. 1979. An Annotated Checklist of Connecticut Seaweeds. State Geological and Natural History Survey of Connecticut, Department of Environmental Protection. Bulletin 108. 20 pp.

45. Stephenson, T.A. and A. Stephenson. 1972. Life between Tide Marks on Rocky Shores. Academic Press, London. 383 pp.

46. Stromgren, T. 1977. Short-term effects of temperature upon the growth of intertidal fucales. J. Exp. Mar. Biol. Ecol. 29:181-195.

47. Sundene, O. 1973. Growth and reproduction in *Ascophyllum nodosum* (Phaeophyceae) Norw. J. Bot. 20:249-255.

48. Taylor, W.R. 1957. Marine algae of the northeastern coast of North America. Univ. of Mich. Press, Ann Arbor. 509 pp.

49. Topinka, J., L. Tucker, and W. Korjeff. 1981. The Distribution of fucoid macroalgal biomass along central coastal Maine. Bot. Mar. 24:311-319.

50. Vadas, R.L. 1972. Marine algae. Pages 250-310 <u>in</u> Third Annual Report on Environmental Studies. Maine Yankee Atomic Power Company.

51. ____. 1979. Seaweeds: An overview; ecological and economic importance. <u>in</u> Pathology of seaweeds: Current status and future prospects. Experientia 35(4):429-433.

52. _____, M. Keser, and P.C. Rusanowski. 1976. Influence of thermal loading on the ecology of intertidal algae. in Esch, G.W. and R.W. MacFarlane (eds). Thermal Ecology II. ERDA Symposium Series, Augusta, GA. p. 202-251.

53. _____. 1978. Effect of reduced temperatures on previously stressed populations of an intertidal alga. in Thorp, J.H. and J.W. Gibbons (eds). DOE Symposium Series, Springfield, VA. p. 434-451. (CONF-771114, NTIS).

54. Virville, Ad. Davy de. 1953. Depeuplement de la flore marine sur les Cotes Occidentales du Cotentin. Int. Seaweed Symp. 1:26-28.

55. Watson, D.C. and T.A. Norton. 1985. Dietary preferences of the common periwinkle, *Littorina littorea* (L.). J. Exp. Mar. Biol. Ecol. 88:193-211.

56. Wilce, R.T., J. Foertch, W. Grocki, J. Kilar, H. Levine, and J. Wilce. 1978. Flora: Marine Algal Studies. in Benthic Studies in the Vicinity of Pilgrim Nuclear Power Station, 1969-1977. Summary Report, Boston Edison Co. p. 307-656.

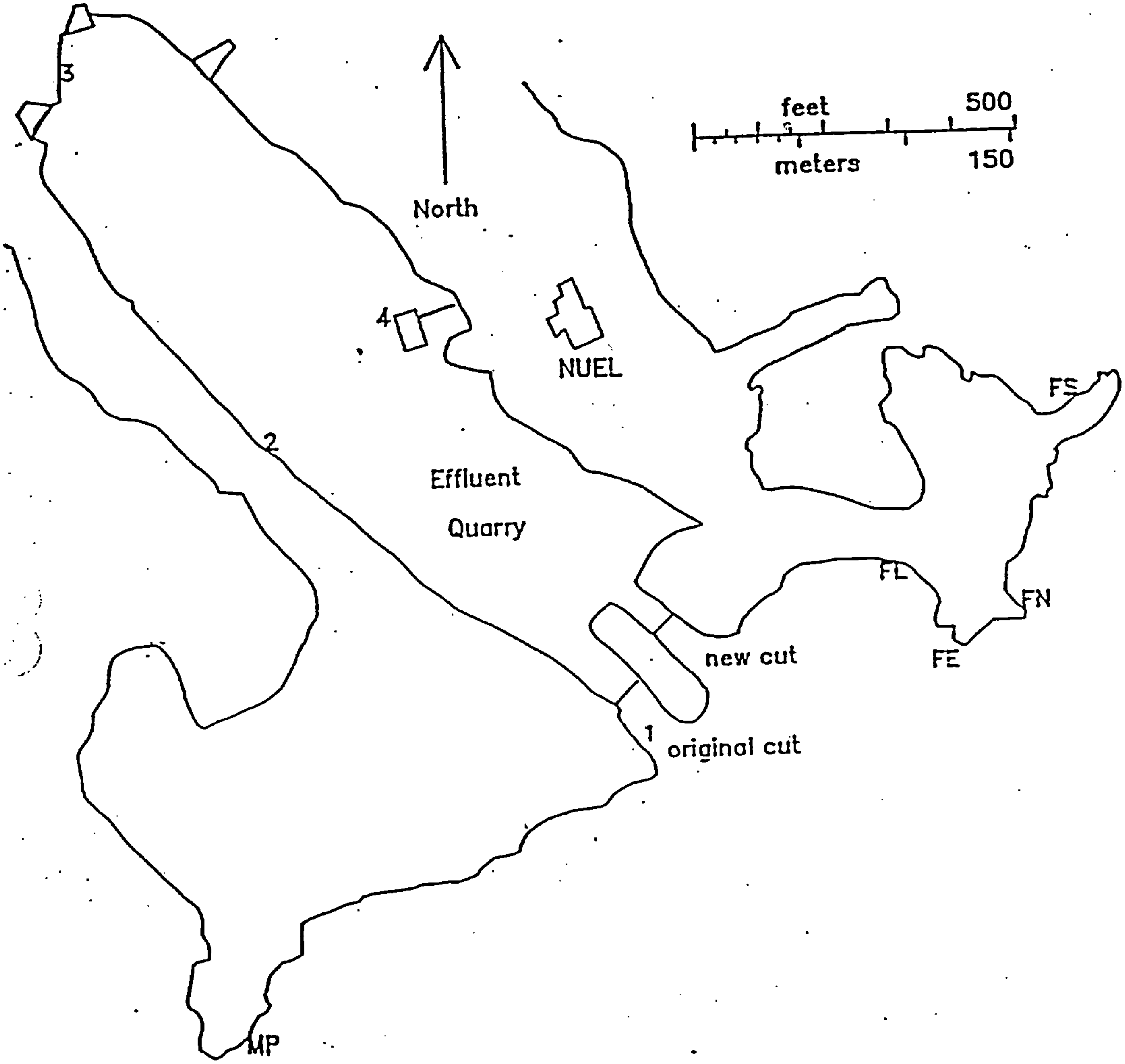

Figure 1. Detail map of MNPS vicinity. FL = original experimental *Ascophyllum* site (1979-1984), FN = new experimental *Ascophyllum* site (1985-present), 1-4 = effluent quarry collection regions.

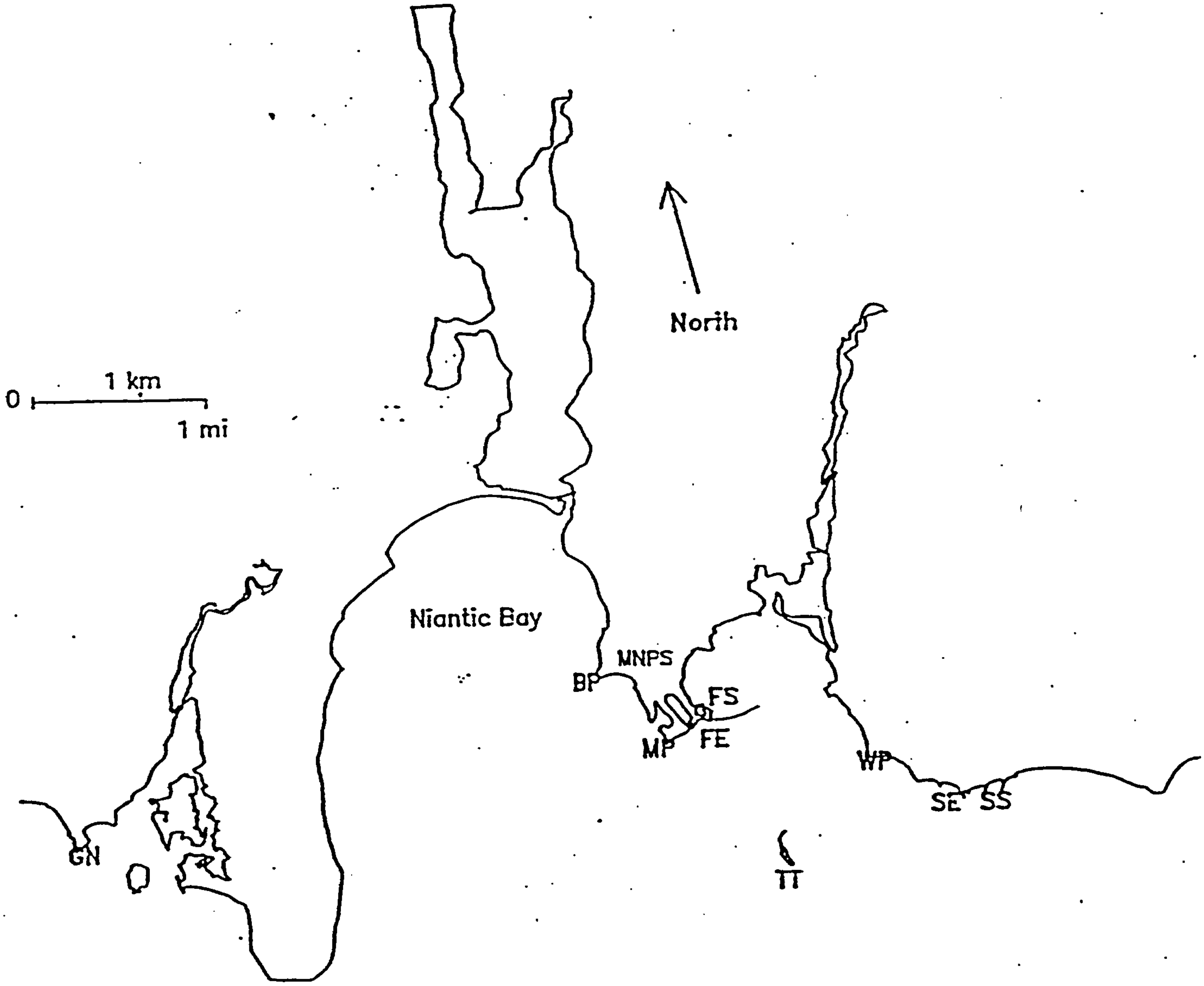

Figure 2. Location of rocky intertidal sampling sites. GN=Giants Neck, BP=Bay Point, MP=Millstone Point, FE=Fox Island-Exposed, FS= Fox Island-Sheltered, TT=Twotree Island, WP=White Point, SE= Seaside Exposed, SS=Seaside Sheltered.

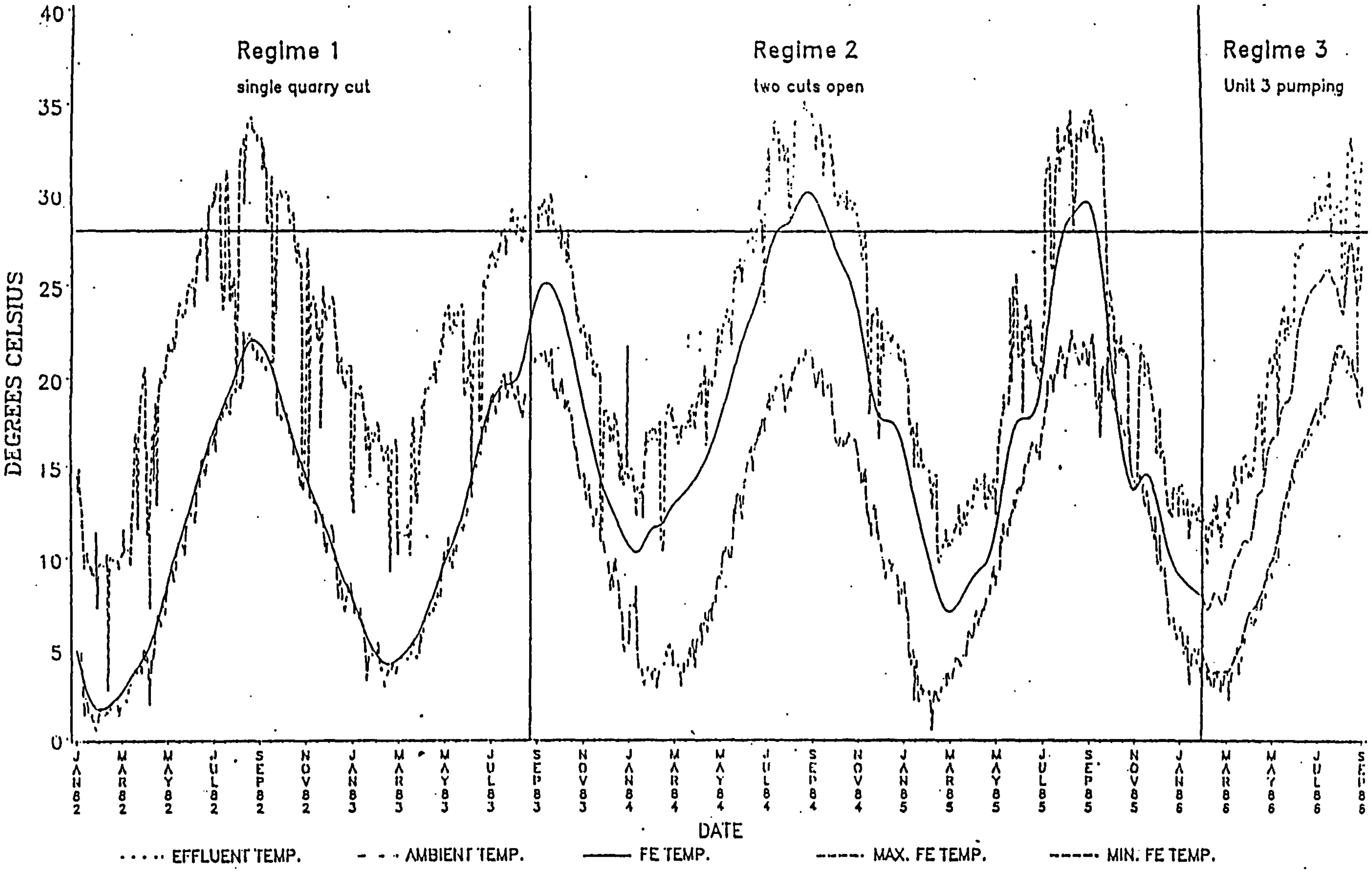

Figure 3. Water temperatures near MNPS, 1982-1986, showing results of 2nd quarry cut opening: regime 1= discharge through a single cut, regime 2=one or two operating units discharging through two cuts, regime 3=three operating units discharging through two cuts.

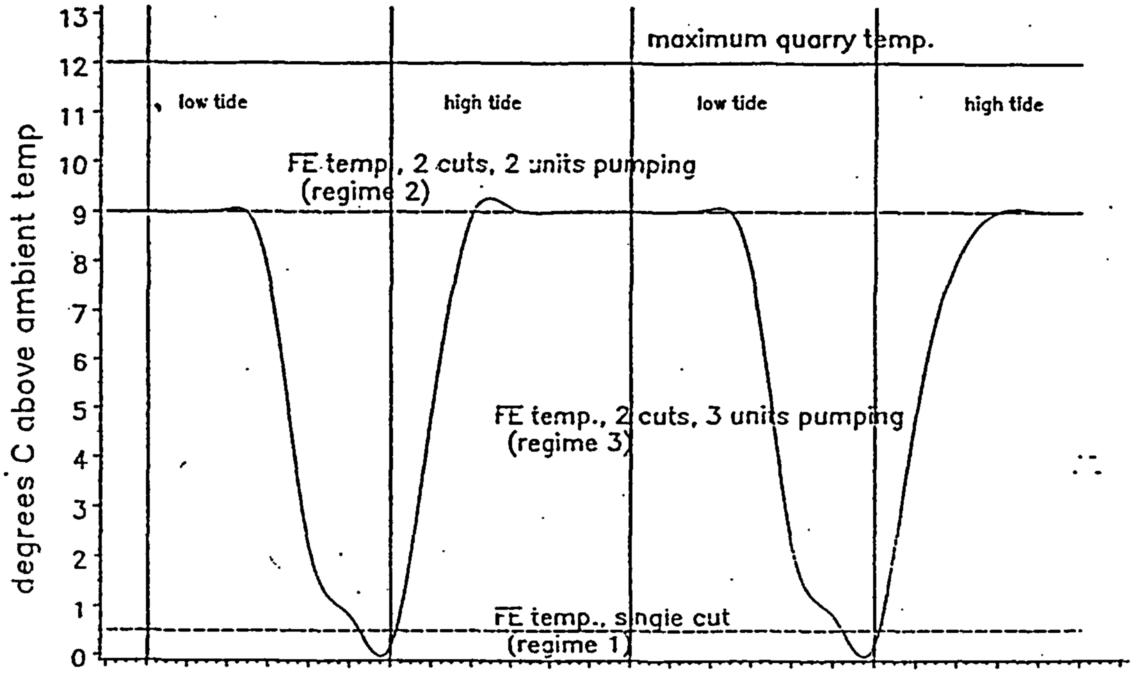

Figure 4. Idealized model of water temperatures at Fox Island-Exposed, related to number of quarry cuts and number of units operating, under 'worst-case' conditions (maximum delta T). Water temperatures under other operating conditions discussed in text. Regimes refer to Figure 3.

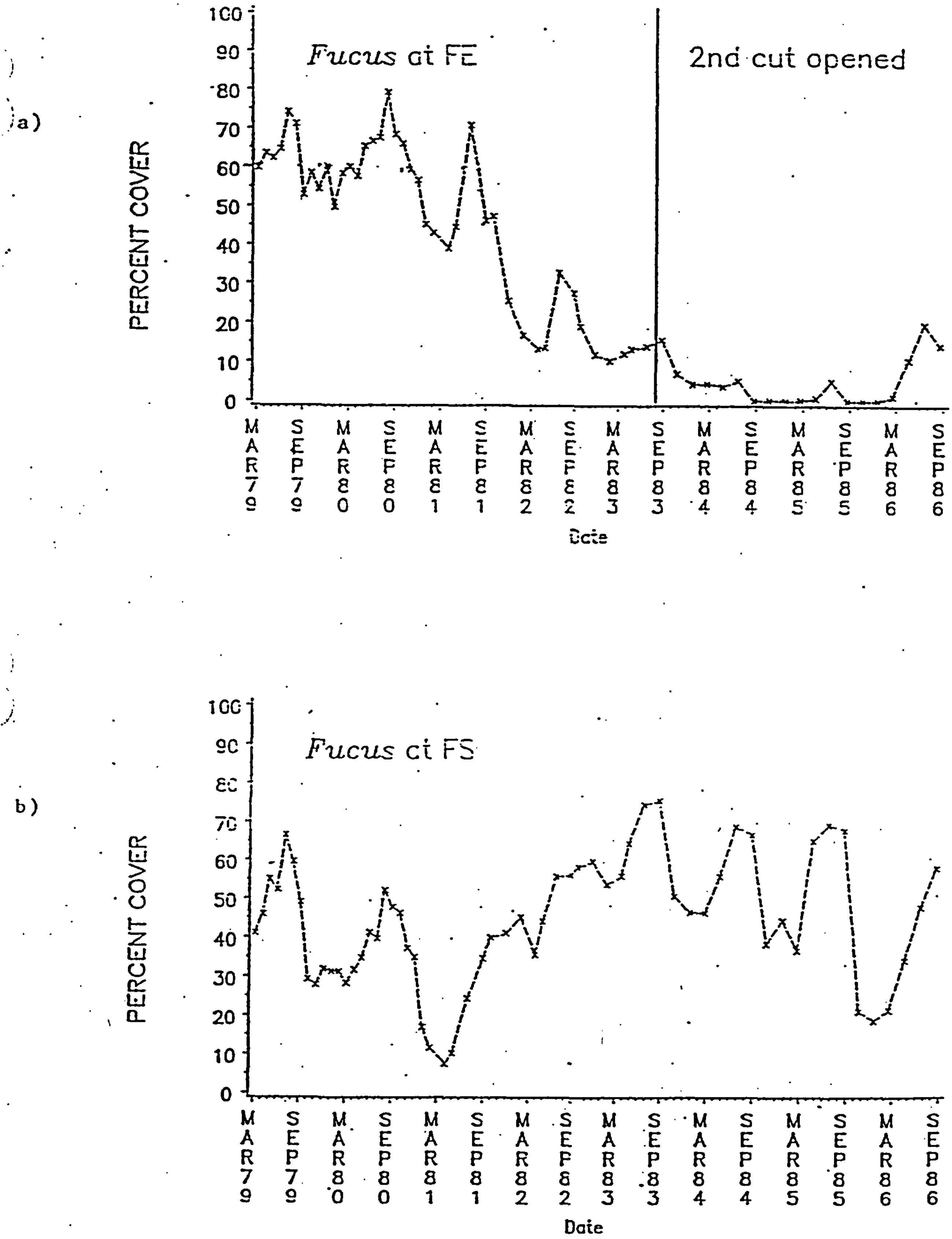

Figure 5. Abundance of Fucus as percent cover in Zone 2, from March 1979-September 1986: a) at Fox Island-Exposed (thermally impacted since August 1983), and b) at Fox Island-Sheltered (representative of unimpacted stations).

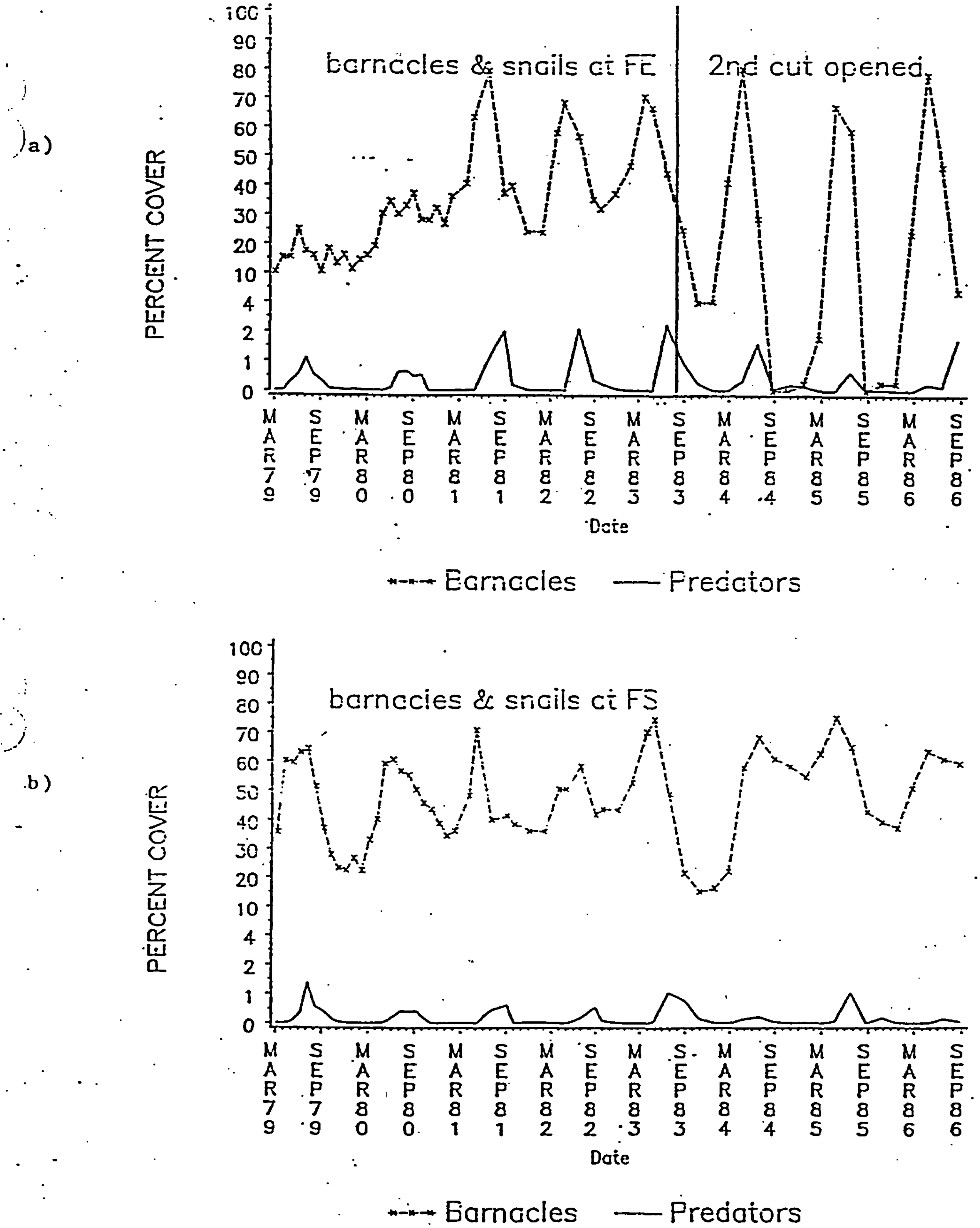

Figure 6. Abundance of barnacles and predatory snails as percent cover in Zone 2, from March 1979-September 1986: a) at Fox Island-Exposed (thermally impacted since August 1983), and b) at Fox Island-Sheltered (representative of unimpacted stations).

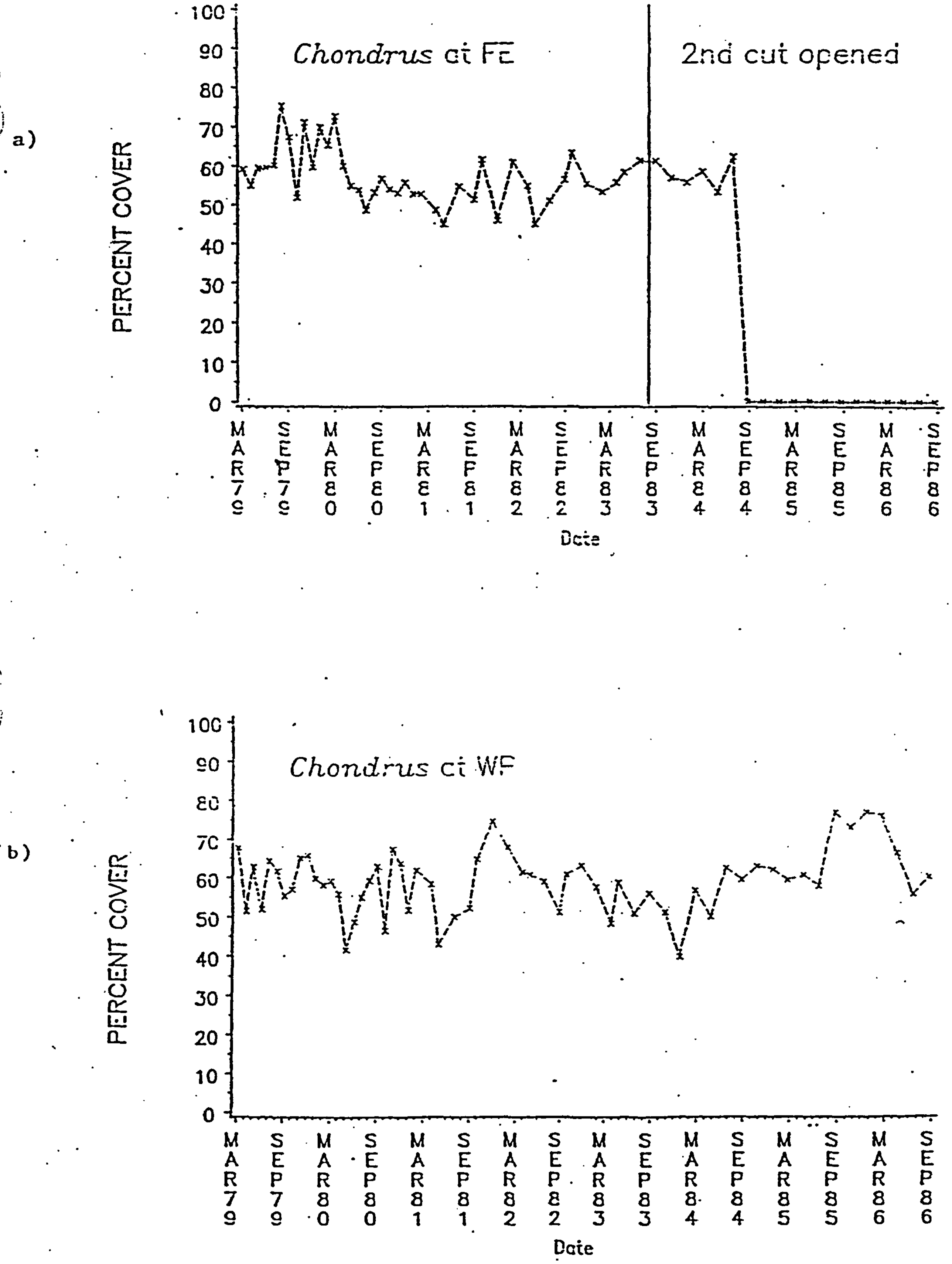

Figure 7. Abundance of Chondrus as percent cover in Zone 3, from March 1979-September 1986: a) at Fox Island-Exposed (thermally impacted since August 1983), and b) at White Point (representative of unimpacted stations).

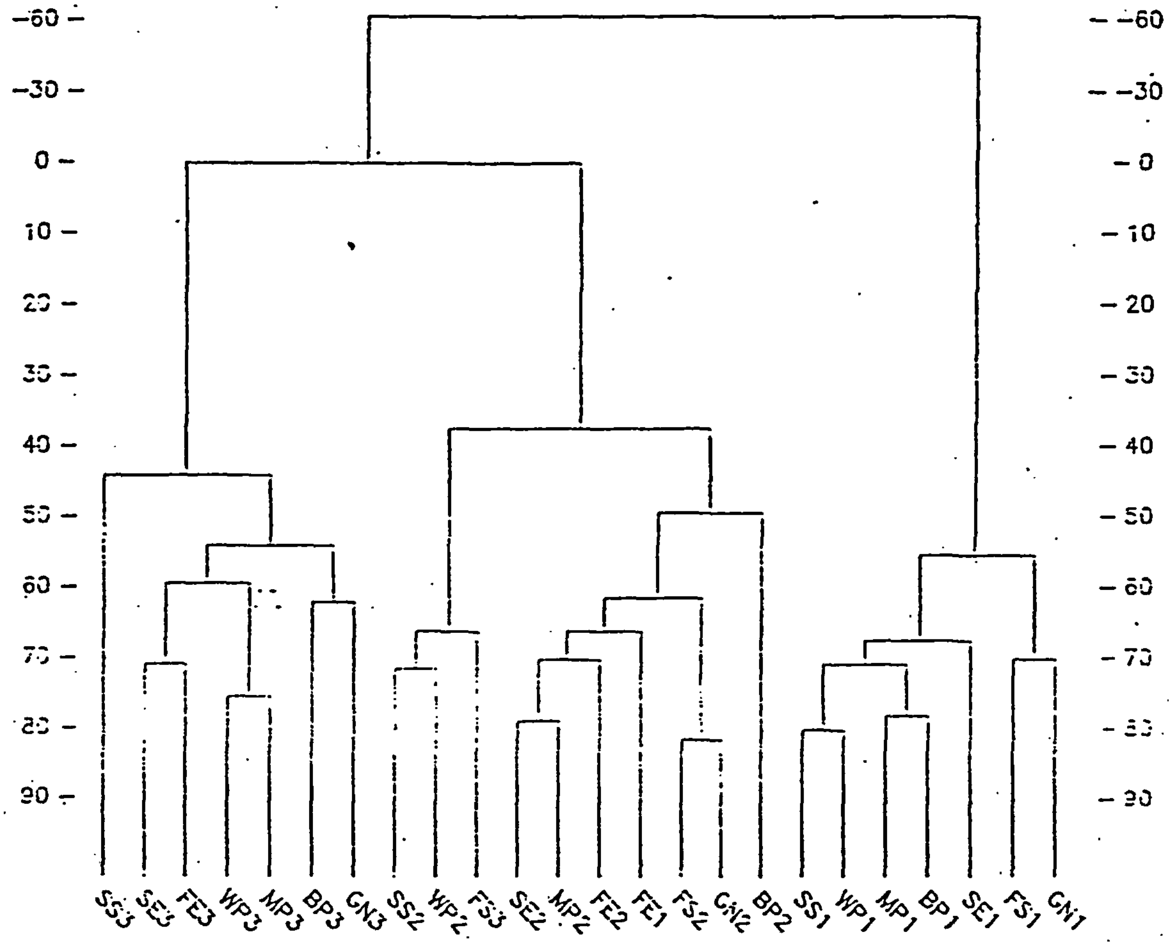

Figure 8. Clustering dendrogram of percent similarity, by station and zone, March 1979-July 1983.

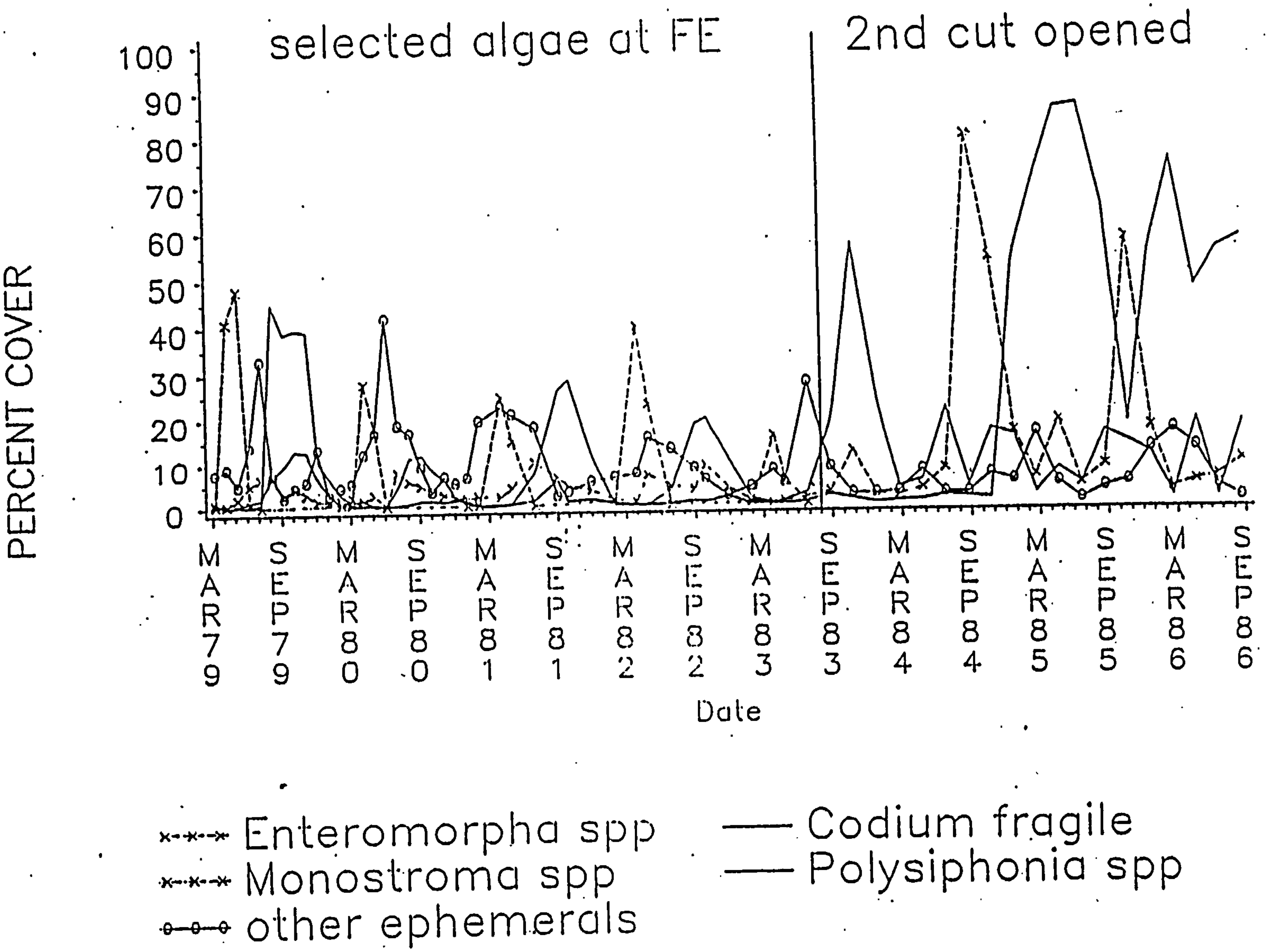

Figure 9. Abundance of ephemeral algae at Fox Island-Exposed as percent cover in Zone 3, from March 1979-September 1986. Prior to August 1983, representative of unimpacted stations; subsequently, thermally impacted.

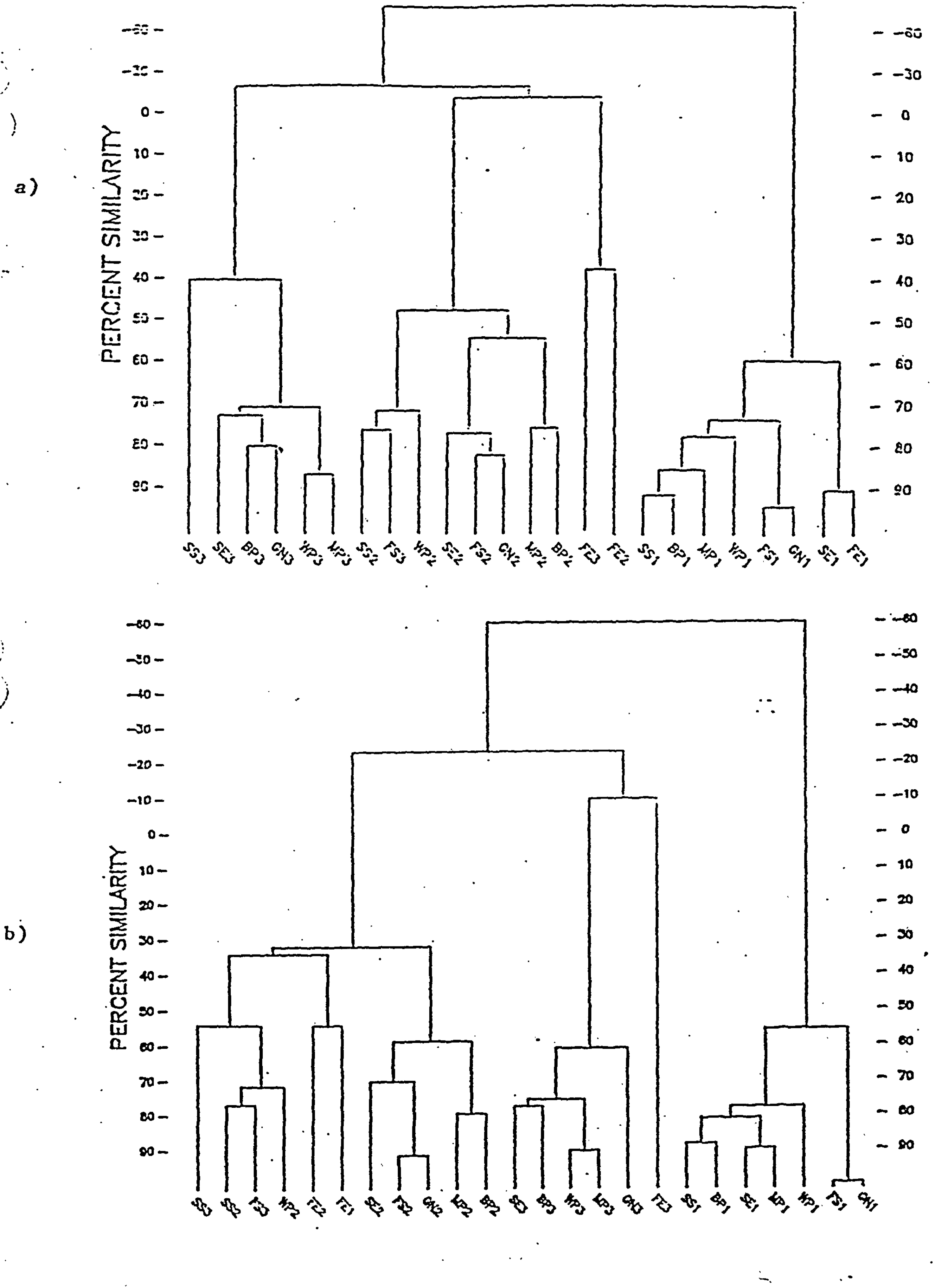

Figure 10. Clustering dendrogram of percent similarity, by station and zone: a) November 1984-September 1985, and b) November 1985-September 1986.

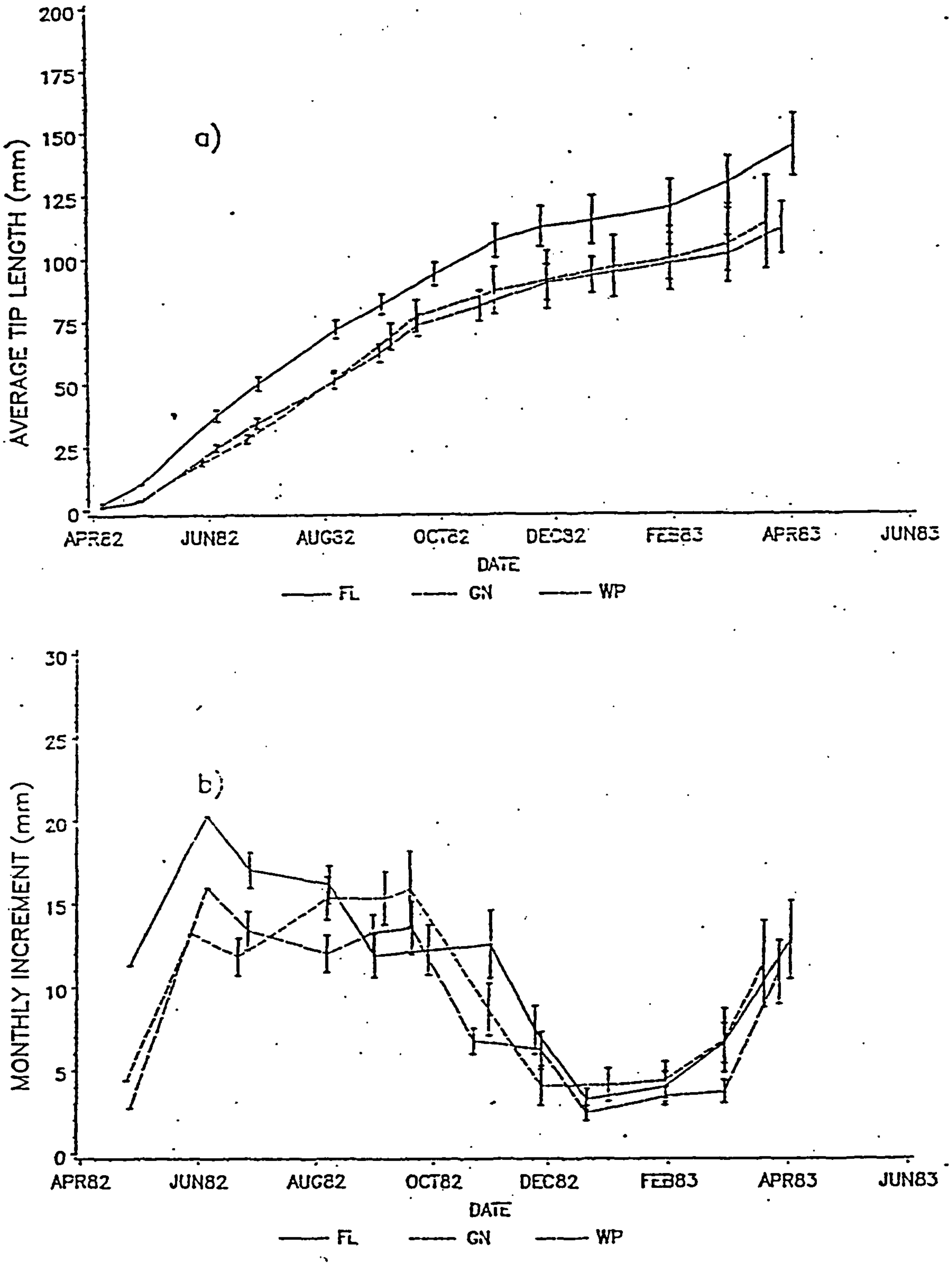

Figure 11. *Ascophyllum* growth, 1982-83: a) as average tip length, and b) as average monthly increments. Data are plotted as means ±2 standard errors.

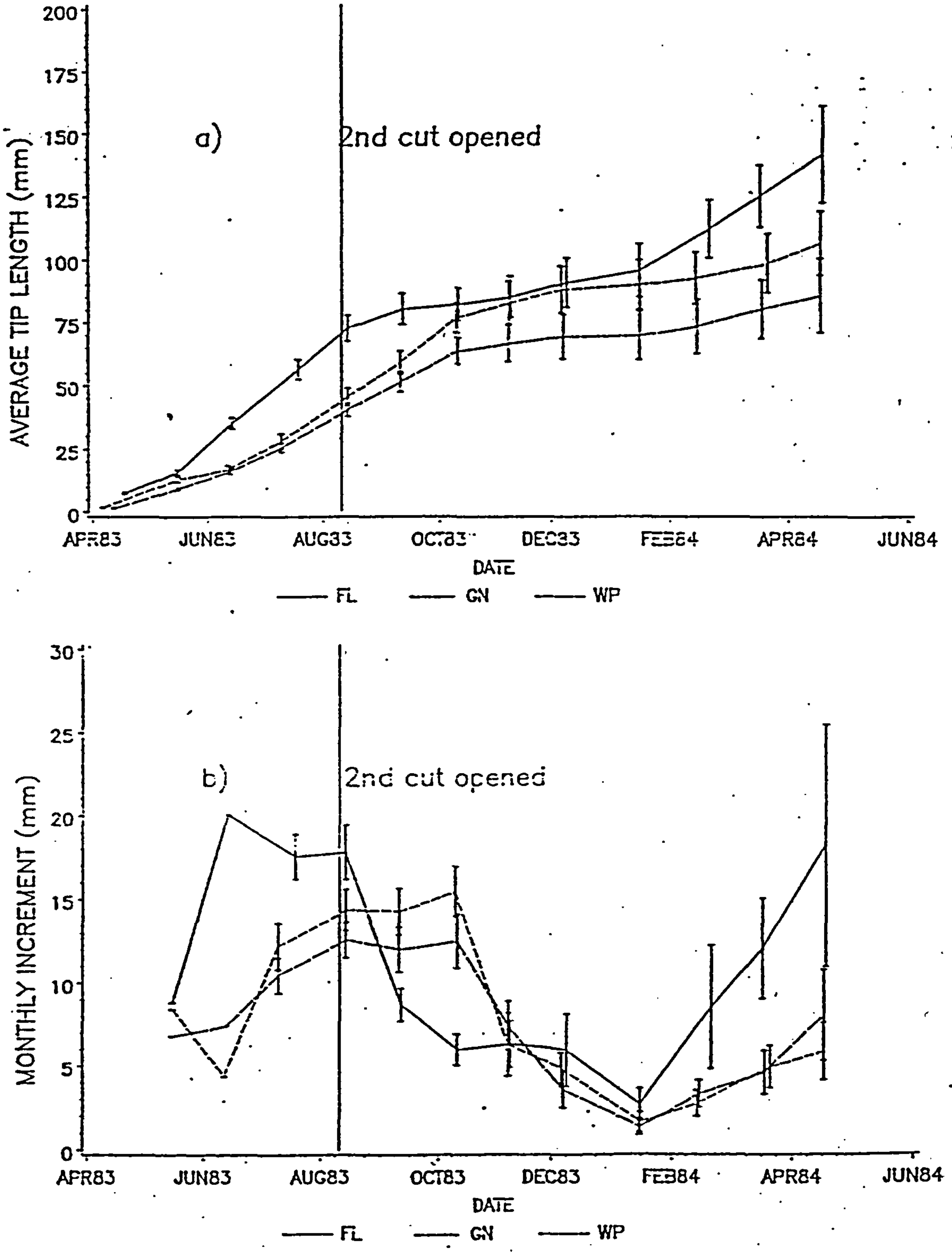

Figure 12. *Ascophyllum* growth, 1983-84: a) as average tip length, and b) as average monthly increments. Data are plotted as means ±2 standard errors.

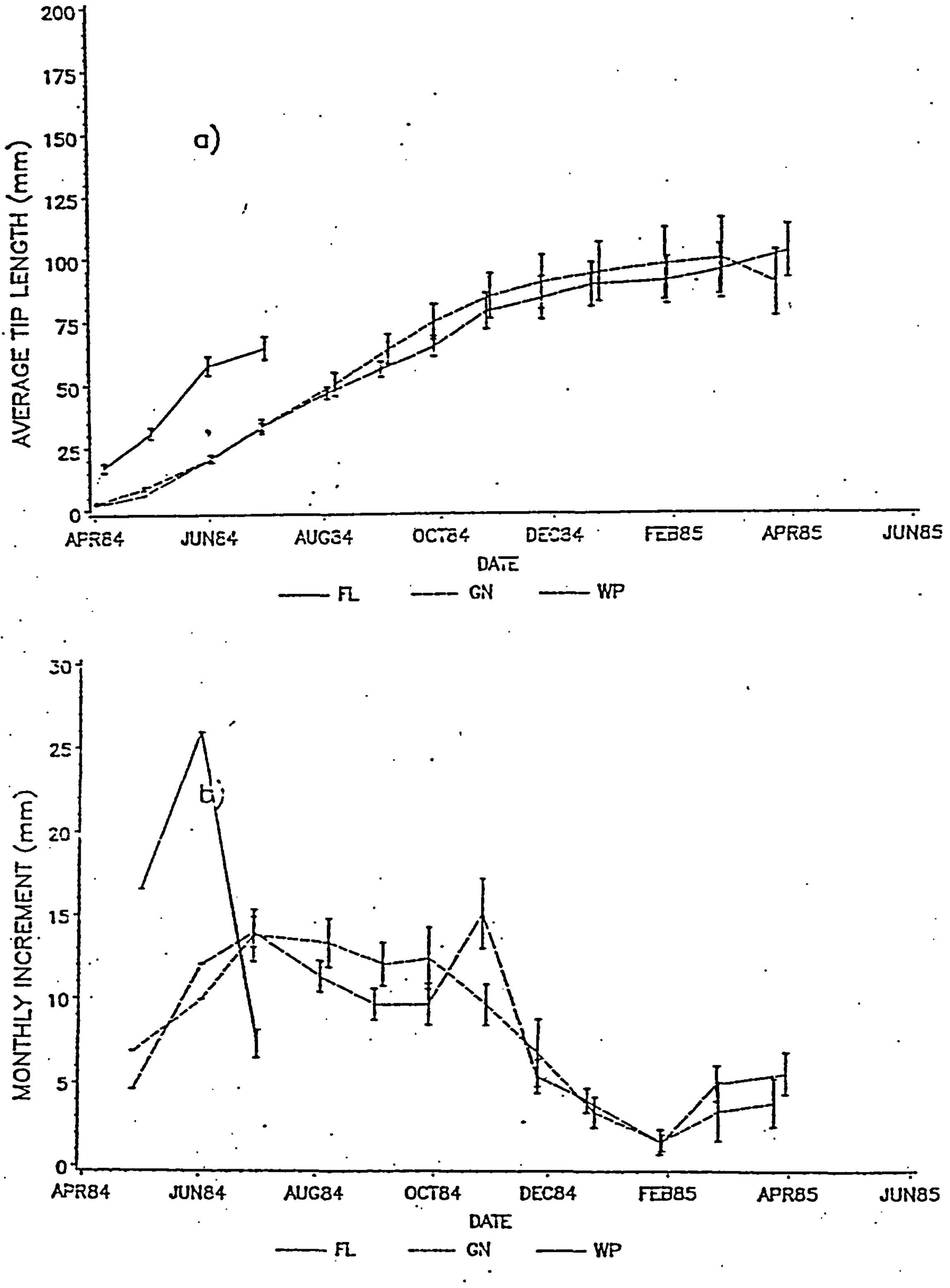

Figure 13. Ascophyllum growth, 1984-85: a) as average tip length, and b) as average monthly increments. Data are plotted as means ±2 standard errors.

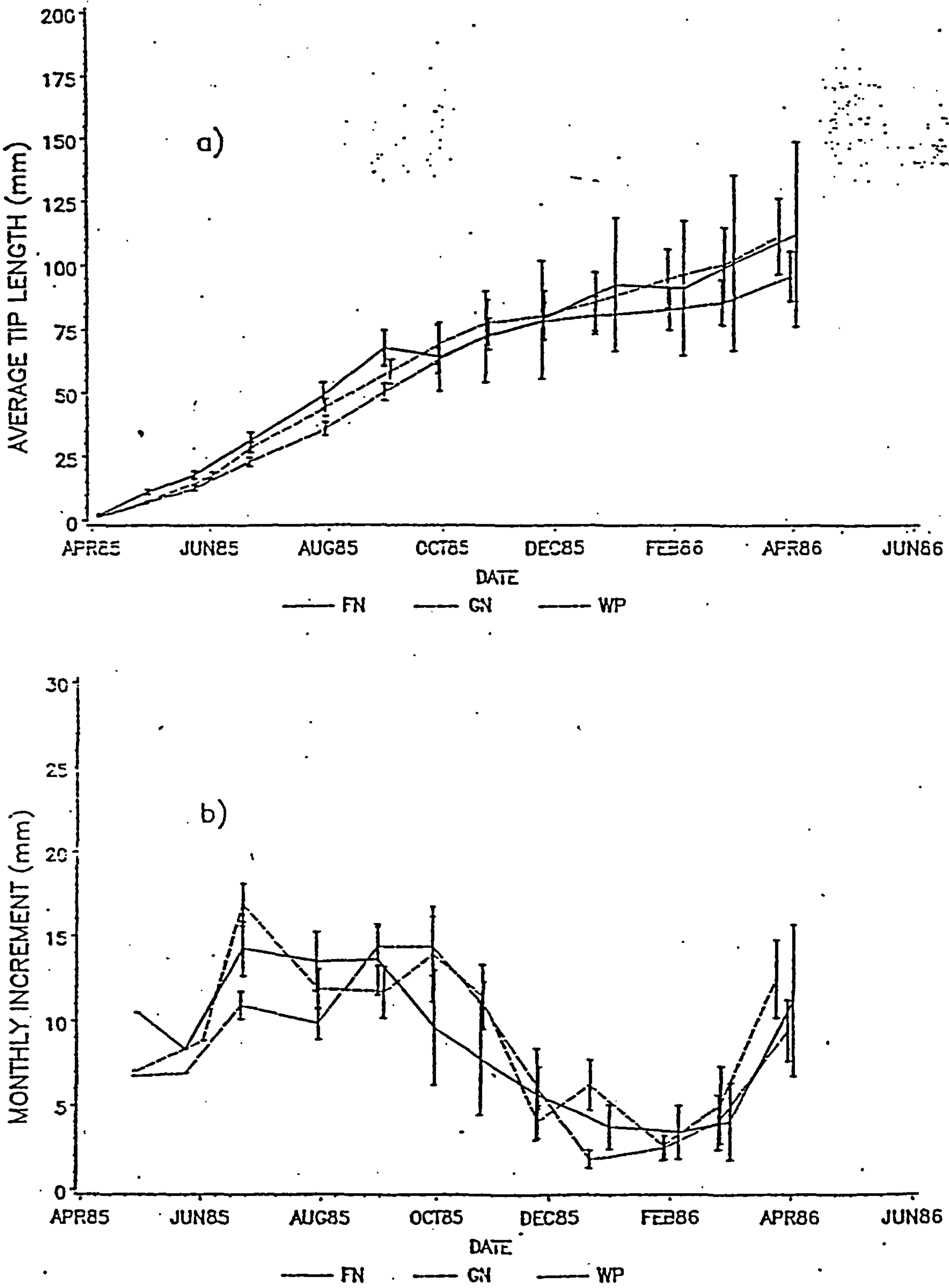

Figure 14. Ascophyllum growth, 1985-86: a) as average tip length, and b) as average monthly increments. Data are plotted as means ±2 standard errors.

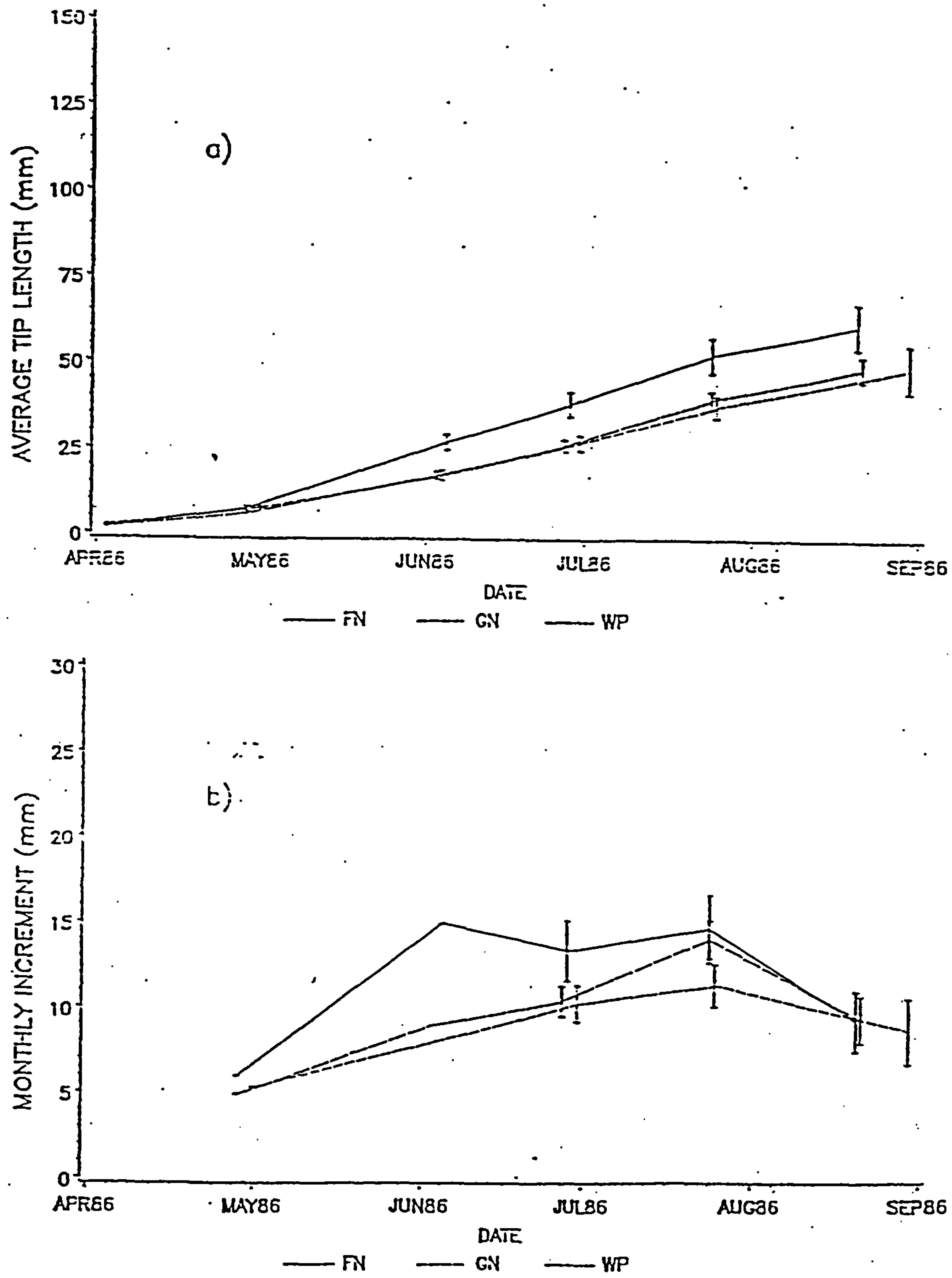

Figure 15. *Ascophyllum* growth, April-September 1986: a) as average tip length, and b) as average monthly increments. Data are plotted as means ±2 standard errors.

Table 1. Qualitative algal collections (March 1979 - Sept. 1986) at Fox Island-Exposed: before, during, and after 2nd cut opening.

SPECIES NAME	MAR79-AUG83 PRIOR TO 2ND CUT OPENING		SEP83-AUG84 1ST YEAR AFTER CUT OPENING		SEP84-SEP86 1 YEAR AFTER CUT TO PRESENT	
Rhodophyta						
Chondrus crispus	54[1]	(100)[2]	12	(100)	0	(0)
Ceramium rubrum	54	(100)	12	(100)	11	(44)
Corallina officinalis	52	(96)	12	(100)	22	(88)
Ahnfeltia plicata	51	(94)	10	(83)	0	(0)
Cystoclonium purpureum	43	(80)	4	(33)	3	(12)
Porphyra umbilicalis	37	(69)	4	(33)	6	(24)
Polysiphonia harveyi	37	(69)	12	(100)	13	(52)
Polysiphonia lanosa	36	(67)	3	(25)	0	(0)
Callithamnion tetragonum	34	(63)	6	(50)	2	(8)
Bangia atropurpurea	24	(44)	4	(33)	11	(44)
Antithamnion cruciatum	21	(39)	5	(42)	5	(20)
Dumontia contorta	20	(37)	2	(17)	0	(0)
Polysiphonia urceolata	19	(35)	1	(8)	0	(0)
Porphyra leucosticta	17	(31)	4	(33)	8	(32)
Champia parvula	14	(26)	6	(50)	8	(32)
Spermothamnion repens	14	(26)	4	(33)	1	(4)
Callithamnion roseum	13	(24)	1	(8)	1	(4)
Polysiphonia nigrescens	13	(24)	0	(0)	0	(0)
Audouinella purpurea	12	(22)	0	(0)	0	(0)
Gigartina stellata	12	(22)	2	(17)	0	(0)
Audouinella secundata	11	(20)	5	(42)	4	(16)
Phyllophora truncata	9	(17)	0	(0)	0	(0)
Phyllophora pseudoceranoides	8	(15)	0	(0)	0	(0)
Agardhiella subulata	7	(13)	0	(0)	17	(68)
Polysiphonia novae-angliae	7	(13)	9	(75)	22	(88)
Erythrotrichia ciliaris	6	(11)	8	(67)	11	(44)
Palmaria palmata	6	(11)	1	(8)	0	(0)
Ceramium diaphanum	6	(11)	0	(0)	2	(0)
Lomentaria baileyana	5	(9)	3	(25)	7	(28)
Polyides rotundus	4	(7)	0	(0)	0	(0)
Rhodomela confervoides	4	(7)	0	(0)	0	(0)
Polysiphonia denudata	3	(6)	0	(0)	1	(4)
Polysiphonia nigra	3	(6)	0	(0)	0	(0)
Polysiphonia fibrillosa	3	(6)	0	(0)	0	(0)
Choreocolax polysiphoniae	2	(4)	0	(0)	0	(0)
Callithamnion corymbosum	2	(4)	0	(0)	0	(0)
Dasya baillouviana	2	(4)	1	(8)	7	(28)
Audouinella daviesii	1	(2)	1	(8)	0	(0)
Audouinella saviana	1	(2)	4	(33)	5	(20)
Gelidium crinale	1	(2)	0	(0)	0	(0)
Gloisiphonia capillaris	1	(2)	0	(0)	0	(0)
Lomentaria clavellosa	1	(2)	1	(8)	0	(0)
Grinnellia americanum	1	(2)	0	(0)	1	(4)
Phycodrys rubens	1	(2)	0	(0)	0	(0)
Chondria tenuissima	1	(2)	0	(0)	0	(0)
Goniotrichum alsidii	0	(0)	5	(42)	5	(20)
Erythrotrichia carnea	0	(0)	0	(0)	1	(4)
Erythrocladia subintegra	0	(0)	2	(17)	1	(17)
Erythropeltis discigera	0	(0)	0	(0)	4	(16)
Gracilaria tikvahiae	0	(0)	0	(0)	1	(4)
Total	45		29		27	

---

[1] Number of monthly collections that included each species.

[2] Percentage of monthly collections that included each species.

SPECIES NAME	MAR79-AUG83 PRIOR TO 2ND CUT OPENING		SEP83-AUG84 1ST YEAR AFTER CUT OPENING		SEP84-SEP86 1 YEAR AFTER CUT TO PRESENT	
<u>Phaeophyta</u>						
Ascophyllum nodosum	54	(100)	12	(100)	0	(0)
Fucus vesiculosus	54	(100)	12	(100)	10	(40)
Elachista fucicola	45	(83)	6	(50)	0	(0)
Laminaria saccharina	40	(74)	5	(42)	6	(24)
Sphacelaria cirrosa	37	(69)	1	(8)	5	(20)
Ralfsia verrucosa	35	(65)	7	(58)	10	(40)
Ectocarpus siliculosis	33	(61)	4	(33)	1	(4)
Petalonia fascia	32	(59)	6	(50)	11	(44)
Scytosiphon lomentaria	31	(57)	4	(33)	11	(44)
Ectocarpus fasciculatus	13	(24)	6	(50)	4	(16)
Leathesia difformis	12	(22)	0	(0)	2	(8)
Ciffordia mitchelliae	10	(19)	11	(92)	10	(40)
Spongonema tomentosum	9	(17)	1	(8)	0	(0)
Fucus distichus s edentatus	9	(17)	0	(0)	0	(0)
Desmarestia virdis	6	(11)	1	(8)	0	(0)
Pilayella littoralis	4	(7)	0	(0)	2	(8)
Chordaria flagelliformis	4	(7)	0	(0)	0	(0)
Fucus distichus s evanescens	4	(7)	1	(8)	0	(0)
Desmarestia aculeata	3	(6)	1	(8)	0	(0)
Chorda tomentosum	2	(4)	0	(0)	0	(0)
Ectocarpus sp.	1	(2)	1	(8)	0	(0)
Giffordia granulosa	1	(2)	1	(8)	3	(12)
Feldmannia sp.	1	(2)	0	(0)	0	(0)
Punctaria latifolia	1	(2)	1	(8)	1	(4)
Chorda filum	1	(2)	0	(0)	0	(0)
Laminaria longicruris	1	(2)	0	(0)	0	(0)
Asperococcus fistulosus	0	(0)	0	(0)	1	(4)
Desmotrichum undulatum	0	(0)	0	(0)	1	(4)
Total	26		18		15	
<u>Chlorophyta</u>						
Ulva lactuca	54	(100)	12	(100)	20	(80)
Codium fragile	54	(100)	12	(100)	25	(100)
Chaetomorpha linum	47	(87)	8	(67)	4	(16)
Blidingia minima	41	(76)	9	(75)	14	(56)
Enteromorpha linza	40	(74)	8	(67)	17	(68)
Chaetomorpha aerea	36	(67)	10	(83)	19	(76)
Enteromorpha flexuosa	33	(61)	8	(67)	17	(68)
Cladophora sericea	25	(46)	2	(17)	8	(32)
Ulothrix flacca	24	(44)	1	(8)	3	(12)
Monostroma pulchrum	19	(35)	1	(8)	0	(0)
Urospora penicilliformis	18	(33)	2	(17)	9	(36)
Enteromorpha intestinalis	16	(30)	4	(33)	11	(44)
Derbesia marina	16	(30)	3	(25)	2	(8)
Monostroma grevillei	15	(28)	2	(17)	2	(8)
Spongomorpha arcta	15	(28)	0	(0)	0	(0)
Rhizoclonium riparium	15	(28)	1	(8)	1	(4)
Cladophora refracta	13	(24)	2	(17)	1	(4)
Enteromorpha clathrata	12	(22)	3	(25)	8	(32)
Enteromorpha prolifera	12	(22)	7	(58)	11	(44)
Bryopsis plumosa	10	(19)	1	(8)	6	(24)
Cladophora hutchinsiae	7	(13)	4	(33)	0	(0)
Urospora wormskjoldii	5	(9)	0	(0)	1	(4)
Spongomorpha aeruginosa	5	(9)	0	(0)	1	(4)
Cladophora albida	5	(9)	0	(0)	1	(4)
Blidingia marginata	3	(6)	0	(0)	0	(0)
Enteromorpha ralfsii	3	(6)	0	(0)	0	(0)
Cladophora flexuosa	3	(6)	2	(17)	9	(36)
Enteromorpha groenlandica	2	(4)	0	(0)	0	(0)
Cladophora rupestris	2	(4)	0	(0)	0	(0)
Rhizoclonium tortuosum	2	(4)	0	(0)	0	(0)
Enteromorpha torta	1	(2)	0	(0)	0	(0)
Percursaria percursa	1	(2)	0	(0)	0	(0)
Prasiola stipitata	1	(2)	0	(0)	0	(0)
Bryopsis hypnoides	1	(2)	2	(17)	1	(4)
'Urospora collabens'	0	(0)	1	(8)	3	(12)
Cladophora ruchingeri	0	(0)	0	(0)	3	(12)
Total	34		23		25	

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EVALUATION OF SHORELINE STRUCTURES DESIGNED TO MINIMIZE THE ENTRAINMENT OF ORGANISMS INTO THE COOLING WATER INTAKES AT THE MILLSTONE POWER STATION

By

John E. Richardson, Ph.D., P.E.

Submitted to

MILLSTONE POWER STATION

ENVIRONMENTAL SERVICES

Waterford, CT 06385

August 2002

ALDEN RESEARCH LABORATORY, INC.
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EXECUTIVE SUMMARY

At the request of the Millstone Environmental Laboratory, Alden Research Laboratory, Inc. (Alden) was asked to evaluate the performance of shoreline structures (*e.g.*, jetties or groins) that might act to reduce the entrainment of organisms from the Niantic River into the cooling water intakes at the Millstone Power Station.

A two-dimensional, depth averaged, hydrodynamic model was constructed and used to calculate tidally driven flows within Niantic Bay and surrounding waters for five different conditions. This effort included the calculation of flows with and without shoreline structures in place.

Scalar source elements were placed in the mouth of the Niantic River and at the location of heated water discharge at the end of Millstone Point (in the computer model). The concentration of quantities released from these source elements was calculated in the model area. The computed results were then used to visualize and quantify the movement of water from the Niantic River towards the Millstone Power Station and the movement of heated water from the discharge area.

The results of this analysis indicate that shoreline perpendicular structures (*i.e.*, jetties or groins) are <u>not</u> capable of changing the amount of source water that enters the plant intakes from the Niantic River. However, the analysis does show that a continuous barrier with a single opening near Millstone Point could be used to reduce the amount of source water entering the plant from the Niantic River, but that this design could increase the amount of heated discharge water re-circulated into the intakes.

1.0 INTRODUCTION

At the request of the Millstone Environmental Laboratory, Alden Research Laboratory, Inc. (Alden) was asked to evaluate the performance of shoreline structures (*e.g.*, jetties or groins) that might act to reduce the entrainment of organisms from the Niantic River into the cooling water intakes at the Millstone Power Station.

The cooling water intakes at Millstone are located on the Eastern shore of Niantic Bay. Two of the three intakes are currently operating (Intake #1 was shutdown after Unit #1 was decommissioned) and together they withdraw cooling water from Niantic Bay at a rate of about 1.5 million gallons per minute (gpm). After this water is used to cool the operating units at Millstone, it is returned back into Long Island Sound from a shoreline location near the tip of Millstone Point. The location of the intakes and discharge area are identified as locations (a) and (b) on the aerial photograph shown in Figure 1.

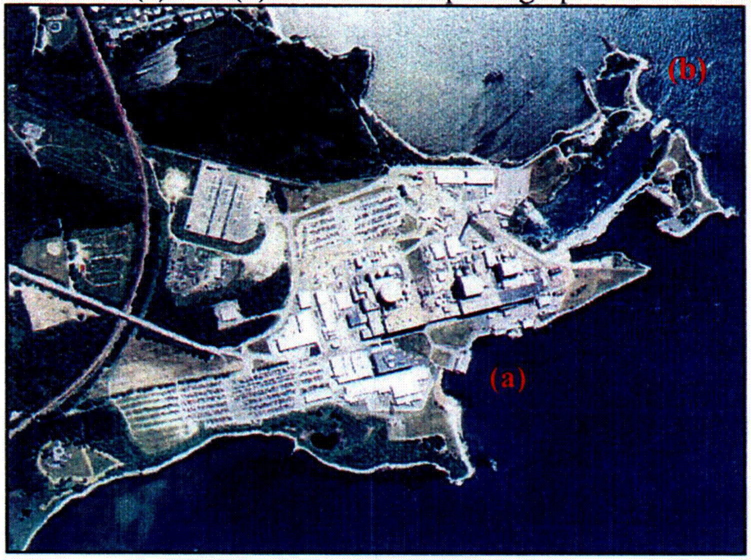

Figure 1: Millstone Nuclear Power Station
(a) intake area, (b) discharge location

Organisms that enter the cooling water intakes can originate from far-field locations in Long Island Sound or from near-field locations in the vicinity of Niantic Bay. Of particular interest, at this location, is the fate of winter flounder larvae that are hatched in the Niantic River and enter Niantic Bay, North of the Millstone Power Station (see Figure 2). Previous studies (Dimou and Adams, 1989) indicate that some of the winter flounder larvae hatched in the Niantic River are entrained by the intakes at Millstone.

The primary objective of this study is to determine whether or not shoreline structures can be used to reduce the entrainment of organisms originating in the Niantic River.[1]

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[1] An evaluation of the entrainment of organisms that come from far-field locations was not part of this analysis. Although, the techniques developed in this study could be used address the fate organisms coming from other locations.

C01

The approach used to estimate the effects of shoreline structures on the entrainment of organisms coming from the Niantic River is discussed in the next section. The results of the analysis are provided in Section 3. Conclusions are made in Section 4 and recommendations for future study are made in Section 5. A Compact Disc (CD) inside the cover contains animations of the model results presented in this report.

2.0 METHODOLOGY

A two-dimensional, depth averaged flow model of Niantic Bay was used to study the effect of shoreline structures intended to reduce the entrainment of organisms into the intakes at Millstone. The model was developed within the framework of the MIKE21 software system, developed by the Danish Hydraulic Institute (DHI). As input to this model, a user must specify the bathymetry (*i.e.,* underwater topography) in the area to be studied and boundary conditions that force the flow through the modeled region. As output, the model provides estimates of water surface elevation and depth averaged velocity. A total of five different computations were performed with the Niantic Bay model. In each computation, a different shoreline structure was added and the ability of the structure to limit the number of organisms entering the intakes from the Niantic River was determined.

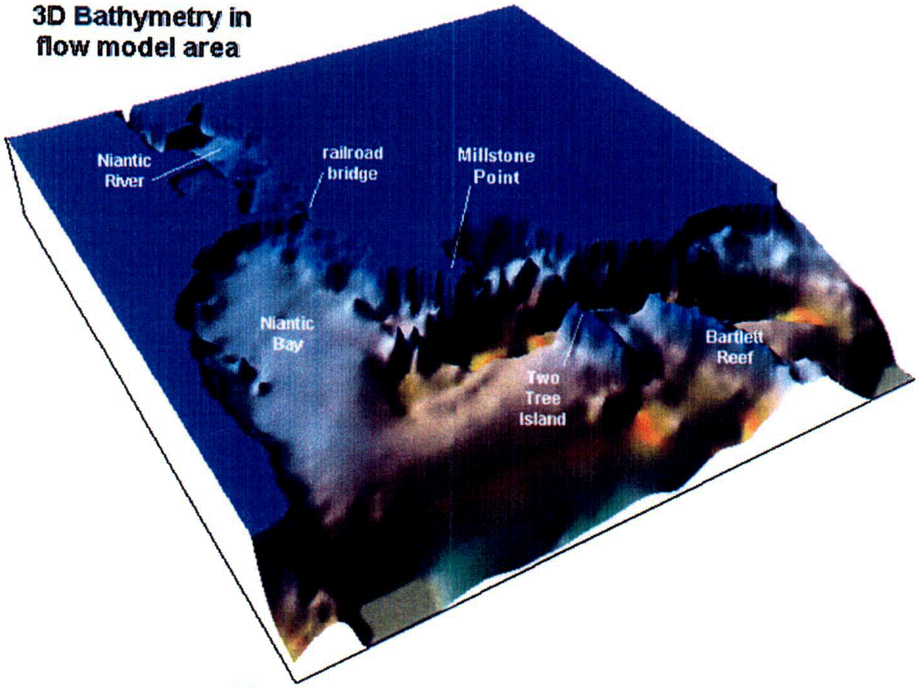

Figure 2: Flow Model Bathymetry
(Exaggerated Vertical Scale)

C02

2.1 Model Setup

The numerical model used for the study extends from a Western limit at Black Point to an Eastern limit at Goshen Point. The Northern limit of the model is located in the Niantic River and the Southern limit of the model is located in Long Island Sound. Significant features in the modeled area include Two Tree Island Sound and Bartlett Reef. NOAA navigational charts were the source of the bathymetric information used for the study.

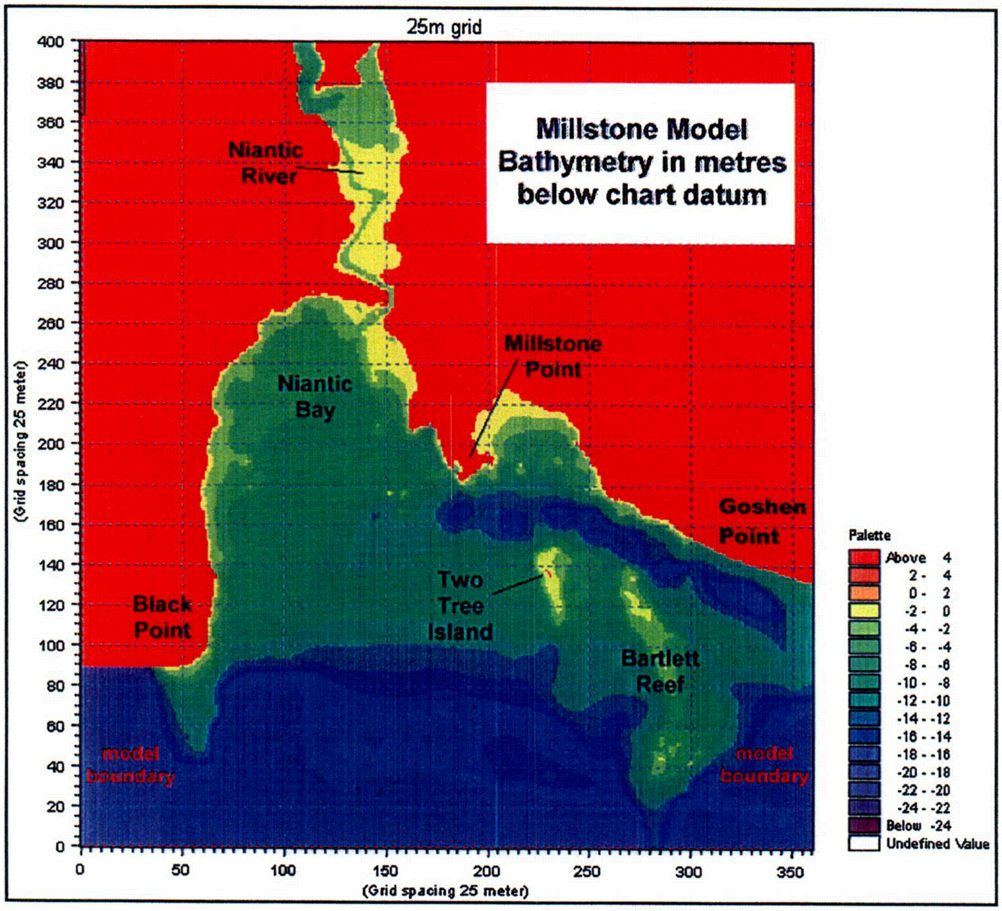

Figure 3: Model Domain
(Bathymetric Map)

The bathymetric information was used to construct the numerical model on a 25 meter uniform grid. This provided adequate resolution for the definition of the shoreline structures and produced an overall model consisting of 75,000 active control volumes.

C03

2.2 Boundary Conditions

Numerical models of the kind used in this study require the specification of boundary conditions at locations where flow enters and exits the modeled region. In this study boundary conditions were specified in Long Island Sound (water surface elevations), at the cooling water intake locations (flow rates), at the heated water discharge location (flow rate), and at the upstream limit of the Niantic River (flow rate).

2.2.1 Tidal Forcing

Water surface elevations as a function of time were specified along the open model boundaries located in Long Island Sound. The boundary conditions were derived from tide gage data reported for Millstone Point, CT (note: this information can be accessed on the internet at: http://tbone.biol.sc.edu/tide/sitesel.html). Figure 4 shows a portion of the tidal record used to force flow through the model domain in this study.

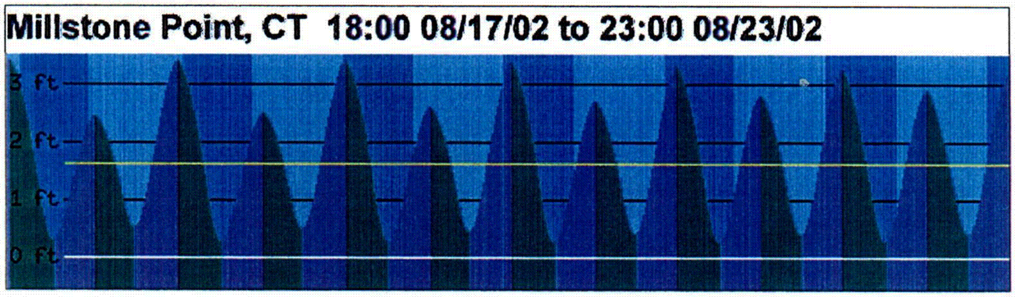

Figure 4: Tidal Predictions for Millstone Point
(August 17, 2002 to August 23, 2002)

In all of the simulations, the tidal record at the eastern and western boundaries was (phase) shifted by 20 minutes and the resulting calculated velocities agreed closely with tidal velocities reported for locations at Two Tree Island Channel, Bartlett Reef, Black Point and at the Niantic River Bridge.

2.2.2 Cooling Water Withdrawal and Heated Water Discharge

"Source" and "sink" elements were defined at the locations of intake numbers 2 and 3 and at the location of the heated water discharge at the end of Millstone Point. These elements account for the (volumetric) loss of cooling water drawn into the intakes and the (volumetric) gain of heated water released by the plant. The flow rates specified at each source and sink location were provided by the Millstone Environmental Laboratory and are given in Table 1.

C04

Table 1: Specified Flow Rates at Source/Sink Locations
(withdraws shown with a minus)

Source/Sink Location	Specified Flow Rate
Intake #2	(-) 572800 US gpm
Intake #3	(-) 948000 US gpm
Discharge Area	1520800 US gpm

2.2.3 Niantic River Discharge

Mean flows in the Niantic River were neglected (*i.e.*, a flow rate of 0.0 cfs was specified at the upstream limit of the Niantic River). However, tidal velocities calculated at the Niantic River Bridge compare closely with published values since the flow is dominated by the tide at this location.

2.3 Computations

The model computations covered a period of about 150 hours in total and ran with a time-step of 6.0 seconds to satisfy the required stability criteria. The model results presented in this report cover the period 18:00 hrs on 17-Aug-2002 to 23:00 hrs on 23-Aug-2002 with a short run-in period for the 12 hours before this start time. A time stamp appearing in the lower left corner of figures produced from the simulations provides a convenient way to match results from different calculations at comparable times in the calculations. Most simulation results are shown for 04:00 hours on 23-Aug-2002 during an ebb tide. The animations, contained on CD, were generated from the entire time series of calculated data.

2.4 Analysis Procedure

To determine the ability of shoreline structures to reduce the entrainment of organisms hatched in the Niantic River and to visualize the movement of heated water discharged from the Millstone Power Station; scalar sources were located in the mouth of the Niantic River and at the location of heated water discharge at the end of Millstone Point. The movement of these scalar quantities was computed in tandem with the calculation of tidally driven flows in Niantic Bay and the results were used to estimate the fate of organisms coming from the Niantic River and the amount of heated water re-circulated to the intake area for the continuous barrier design option. Details regarding these aspects of the analysis are given in the following two sections.

2.4.1 Larvae Source Concentrations

A scalar source was located in the mouth of the Niantic River to represent the origin of winter flounder larvae. To define the source, a small amount of carrier flow (1.0 m^3/sec) was specified at the source location and an arbitrary concentration of release material was added to the flow (*e.g.*, 10,000 release units/m^3). With a carrier flow equal to 1.0 m^3/sec; 10,000 units of larvae are injected into the flow each second. In these calculations it was necessary to specify a high scalar source concentration for the larvae since the flow is rapidly diluted as the tide flushes into and out of the Niantic River. Subsequent tides cause the plume to be moved into deeper water and therefore the concentrations at each model node reduce accordingly. By the time the material gets to Millstone the concentration of the scalar quantity is calculated to be around 100 units/m^3 during the seven day calculations.

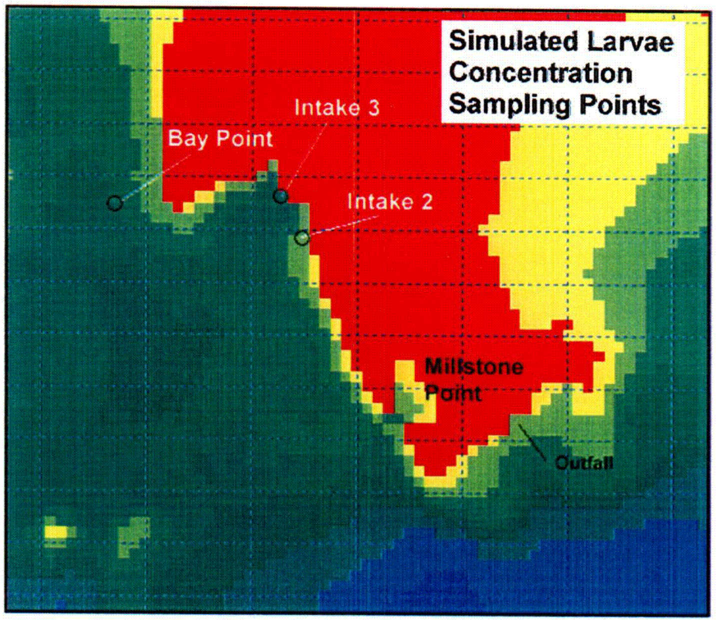

Figure 5: Sampling Locations

Larvae concentrations were output continuously from sampling locations at Intake #2, Intake #3, and just off Bay Point during the calculations. Time series of these data provide a record of larvae concentrations at the intakes and at Bay Point (see Figure 6).

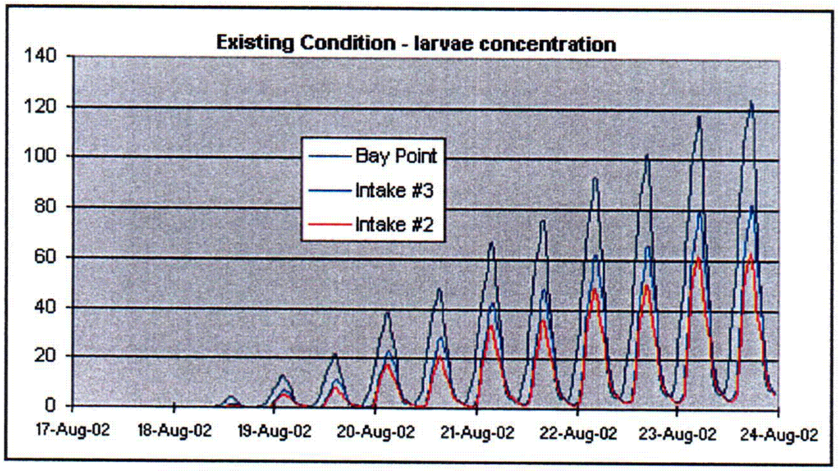

Figure 6: Instantaneous Concentration of Larvae vs. Time (Calculated)

C05

These data can also be integrated to provide an estimate of the total number of larvae passing the intake structures for the duration of a simulation. Figure 7 shows this quantity calculated per unit flow rate for each of the intake structures.

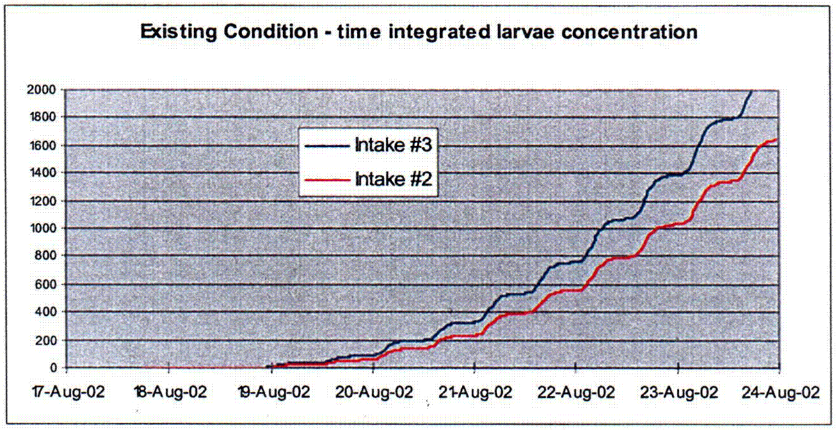

Figure 7: Time Integrated Larvae Concentration per Unit Flow Rate (Calculated)

In this analysis, a comparison of time integrated larvae concentrations for each intake was used to determine the effectiveness of a given shoreline structure intended to reduce the entrainment of organisms coming from the Niantic River. Therefore, the shoreline structure that minimized the value of the time integrated larvae concentration was said to be the "best."

All of the figures and animations showing larvae concentration in this report use the same scale (Figure 8). The maximum value of the color on the scale is 100 release units/m^3 (*i.e.*, the deepest blue on the color scale, although concentrations considerably in excess of this value exist in the North of Niantic Bay).

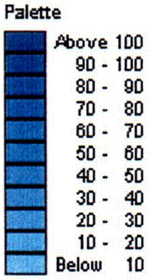

Figure 8: Larvae Concentration Scale for Graphics

2.4.2 Outfall Source Concentrations

To represent the outfall, a conservative scalar quantity at a concentration of 1.0 release units/m^3 was added to the flow. Local estimates of this quantity were then used to estimate the local concentration of the outfall water in the tidal stream (based on the local cell depth at each model node). For example, a value of 0.1 on a contour plot indicates that approximately 10% of the water volume in that model node originated at the outfall location. This type of analysis was used to assess the likely re-circulation of outfall water to the intakes. Figure 9 shows the outfall concentration scale used in the graphics that are part of this report.

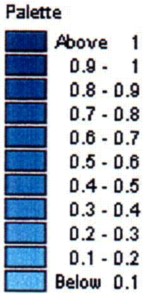

Figure 9: Outfall Concentration Scale for Graphics

2.5 Limitations

Numerical studies of tidal hydraulics, biological processes, and thermal mixing inevitably involve some degree of approximation and limitation. This study is no exception. In reviewing these results it is important to consider the basis of the analysis and the limits of the study.

The numerical model used in this analysis was designed to evaluate the ability of shoreline structures to reduce the entrainment of organisms coming from the Niantic River. The hydraulic analysis was done in two-dimensions to limit the complexity of the computations (and the time required for the analysis). The biological component of the study does not account for the behavioral response of organisms coming from the Niantic River, nor are issues related to the mortality of these organisms addressed by the analysis. Finally, the thermal aspects of the problem are handled in the most rudimentary of ways (*e.g.*, thermal stratification is not accounted for in the two-dimensional hydraulic calculation, nor is the loss of heat to the atmosphere is addressed by the analysis, etc.).

Given these limitations, however, the model does successfully calculate depth averaged velocities similar to those measured in the model area, reproduce the movement of water from the Niantic River to the Millstone Power Station properly, and determines movement of the thermal plume similar to that measured in earlier survey work. Used as a tool to estimate the effect of different shoreline structures designed to reduce the entrainment of organisms – the model is efficient and economical.

3 RESULTS

The numerical model and analysis procedure described in the previous section was used to estimate the entrainment of organisms coming from the Niantic River. In all, five different scenarios were studied. In the first scenario, the entrainment associated with the existing intake design (without shoreline structures) was estimated. In the following simulations, different shoreline structures were placed near the intakes and the entrainment of organisms from the Niantic River was calculated (note: the design options are presented in the order that they were proposed).

3.1 Existing Configuration

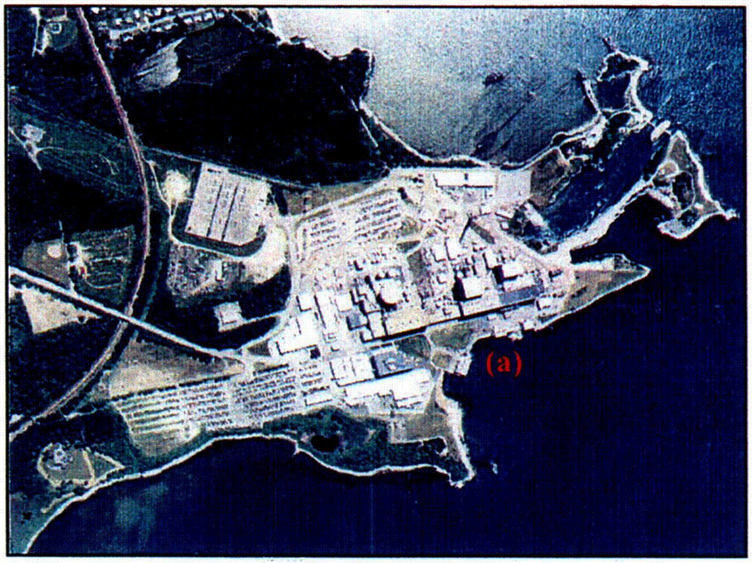

Figure 10: Existing Configuration

The cooling water intakes that service Millstone are located in a shallow embayment on the Eastern shore of Niantic Bay (Figure 10, location [a]). On a flood tide, the majority of water entering the intakes comes from Long Island Sound (*i.e.,* on a flood tide the direction of flow would be from the right to the left in Figure 10). When the tide ebbs, the direction of flow changes and water originating in the Niantic River is brought to the intakes in a greater proportion.

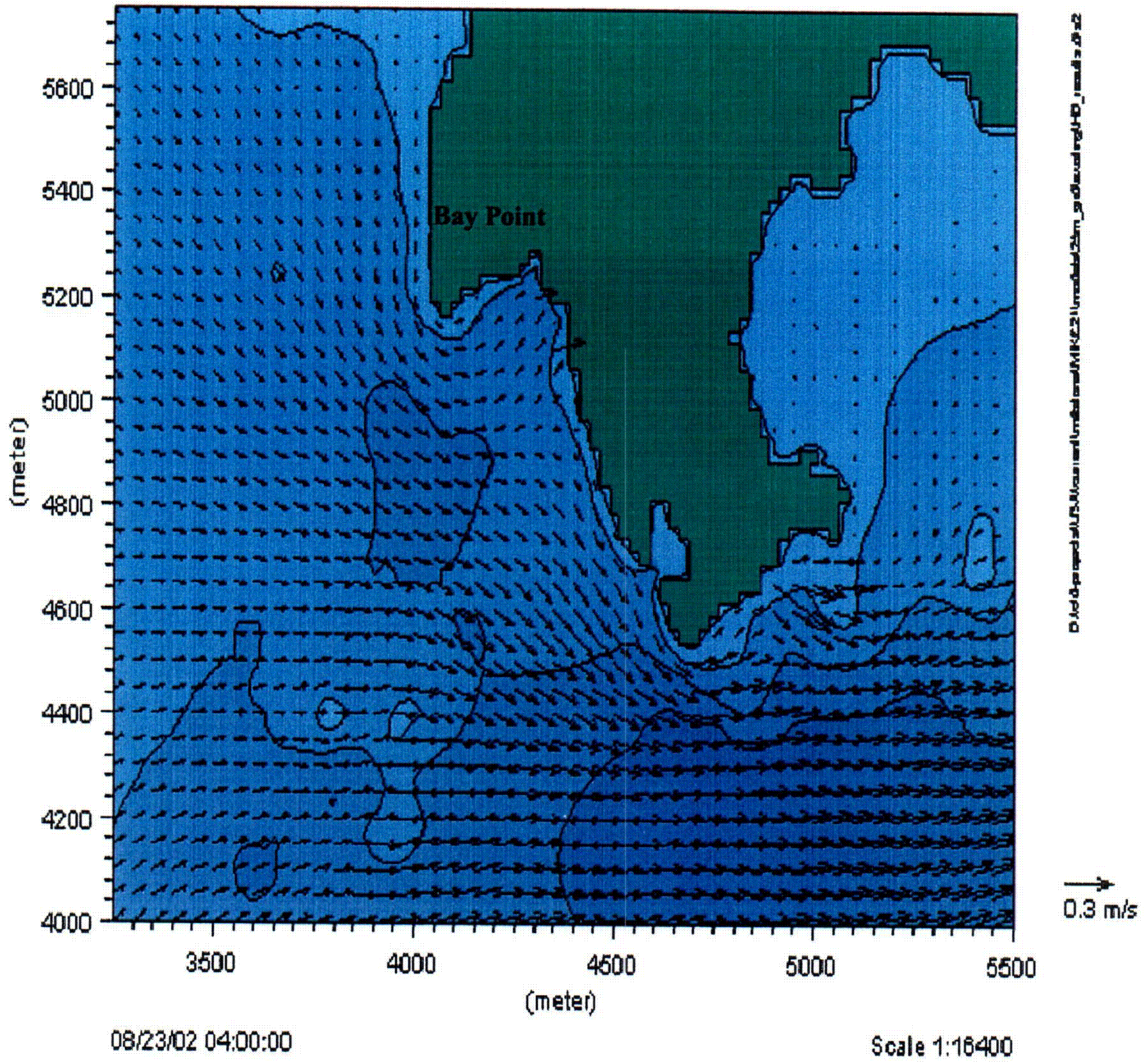

Figure 11: Flow Field, Existing Configuration

Figure 11 shows the calculated flow pattern in front of the intakes during an ebb tide. The waters of Long Island sound appear at the bottom of the figure and water entering from the top of the figure comes from the interior of Niantic Bay and the Niantic River. The velocity vectors show flow moving South, around Bay Point, into the active cooling water intakes. It is this flow pattern that is responsible for the transport of organisms coming from the Niantic River into the cooling water intakes.

C09

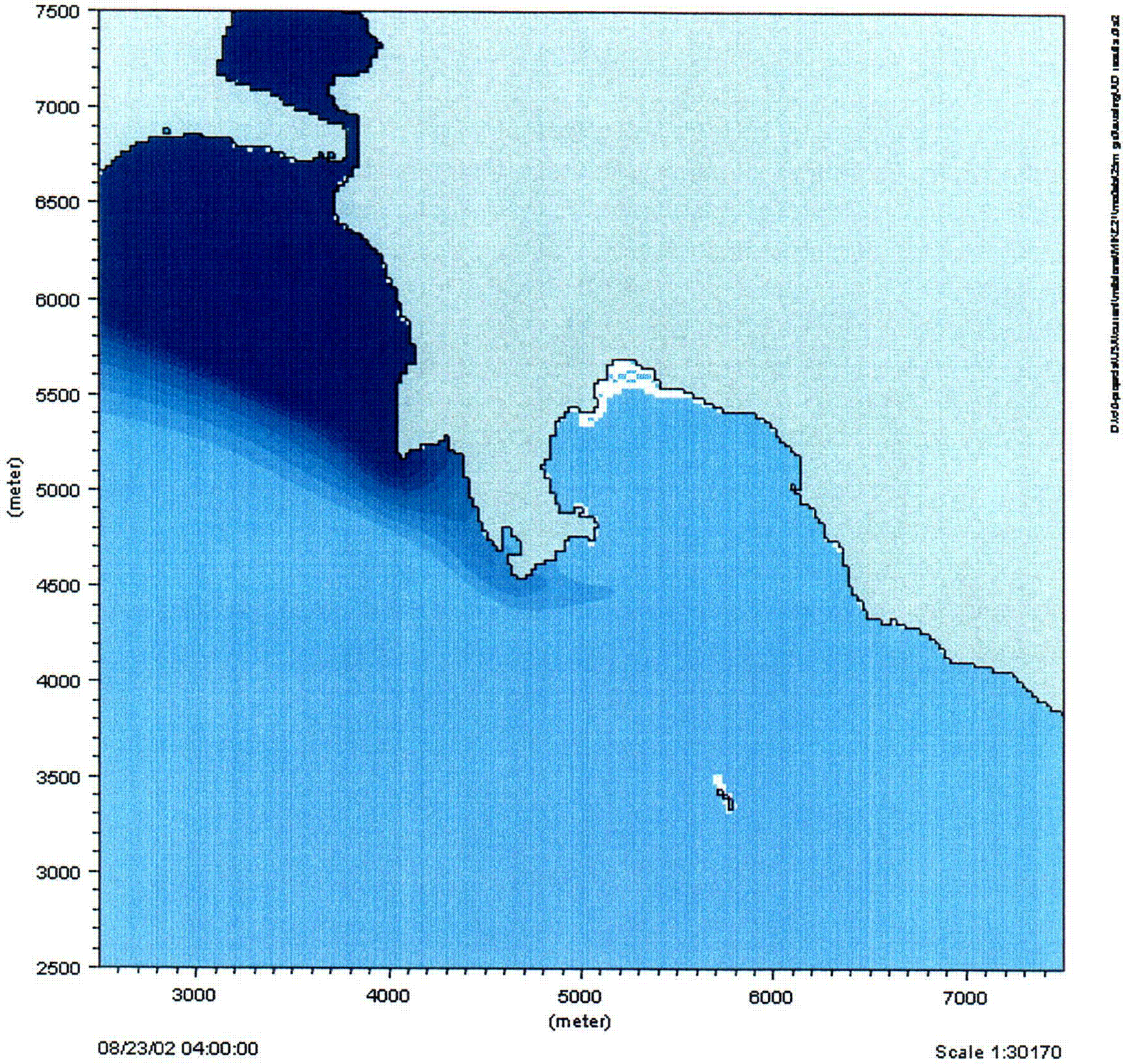

Figure 12: Larvae Distribution, Existing Configuration

Figure 12 shows the distribution of organisms (coming from the Niantic River) in Niantic Bay. The data, used to render the figure, is taken six days into a seven day flow simulation (see sections 2.2.1 and section 2.3 for details). The time stamp, in the lower left corner of the figure, identifies what simulation day and time the image corresponds to (note: this is the same day and time used to render Figure 11). Figure 12 shows water containing relatively high concentrations of organisms (dark blue areas) moving around the tip of Bay Point and into the area where the cooling water intakes are located.

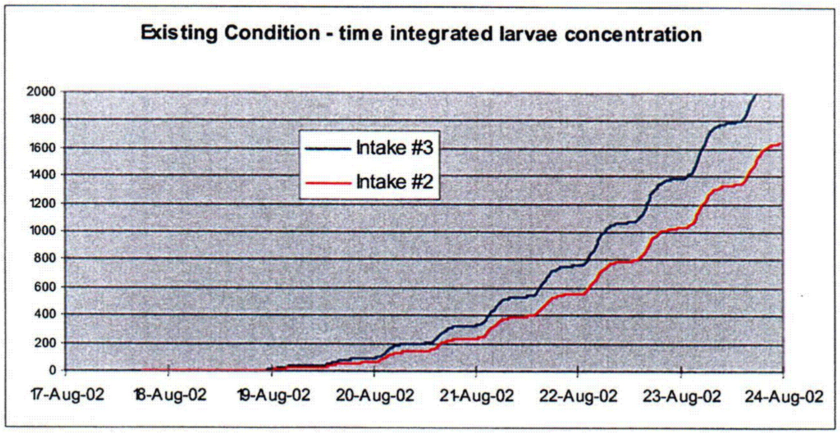

Figure 13: Time Integrated Larvae Concentration per Unit Flow Rate

Figure 13 contains a plot of time integrated larvae concentration. As previously discussed, instantaneous measures of larvae concentration were recorded at the intakes during the flow simulations. The instantaneous concentrations were integrated and an estimate of the total amount of larvae passing through the intakes was made. Figure 13, therefore, shows the amount of larvae passing through the intakes increasing during the course of a seven day calculation (*i.e.,* as more larvae are transported from the Niantic River to the cooling water intakes). This analysis was repeated for each scenario studied and the shoreline structure that minimized the value of the time integrated larvae concentration was said to be the "best."[2]

The following parts of this section contain the results of simulations where shoreline structures have been placed near the cooling water intakes. The presentation of the results is similar to that used for this "benchmark" case. That is to say, the figures are similar to the ones appearing in this section (*i.e.,* the time stamps and the scales are same so the figures can be compared side-by-side) and the calculation of time integrated larvae concentration is the same. Animations of these results can also be found on the CD located inside the cover of this report.

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[2] Note: the concentrations of "larvae" used in this analysis are arbitrary and have no biological relevance.

3.2 Option #1: Large Groins

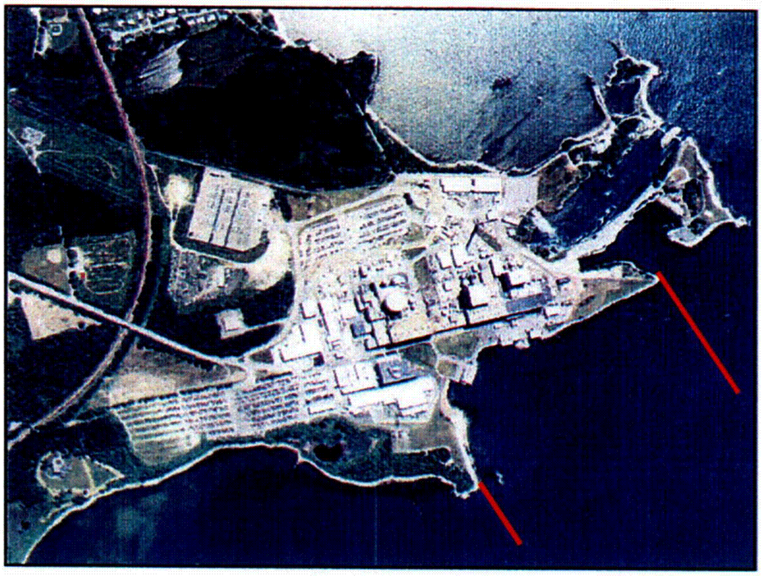


Figure 14: Large Groins

The ability of two large shoreline perpendicular structures (*i.e.,* groins) to reduce the entrainment of organisms coming from the Niantic River was the focus of the first comparative analysis. Figure 14 shows the location of the two shoreline structures placed to either side of the cooling water intakes. The nominal length of these structures is 700 feet.

C12

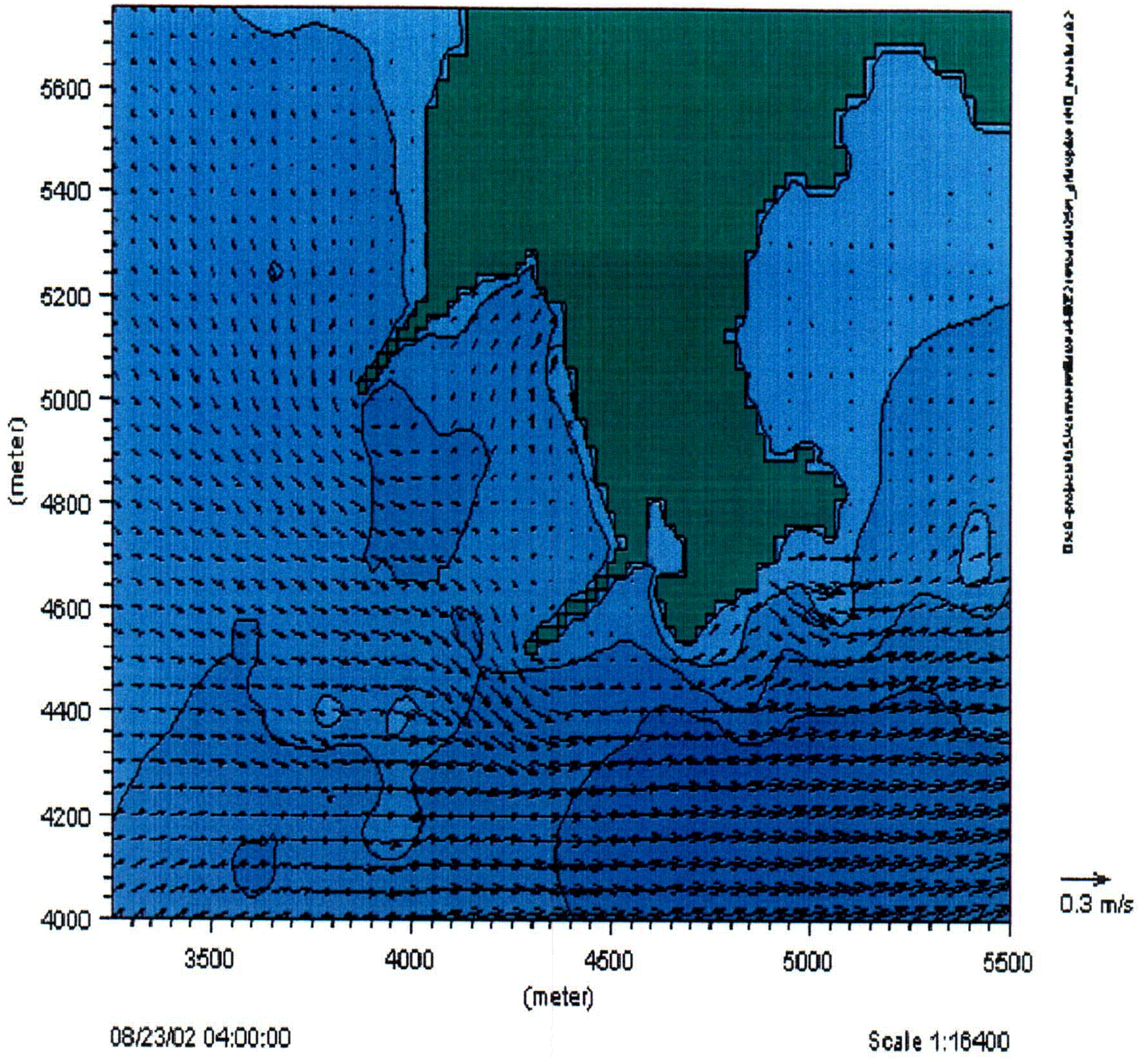


Figure 15: Flow Field, Large Groins

Figure 15 shows the calculated flow pattern in front of the intakes during an ebb tide. The waters of Long Island sound appear at the bottom of the figure and water entering from the top of the figure comes from the interior of Niantic Bay and the Niantic River. The velocity vectors show flow moving South, around one of the shoreline structures, into the area occupied by the cooling water intakes. This flow pattern is similar to that appearing in Figure 11 except that the flow must pass around the shoreline structure before it moves into the intake area.

C13

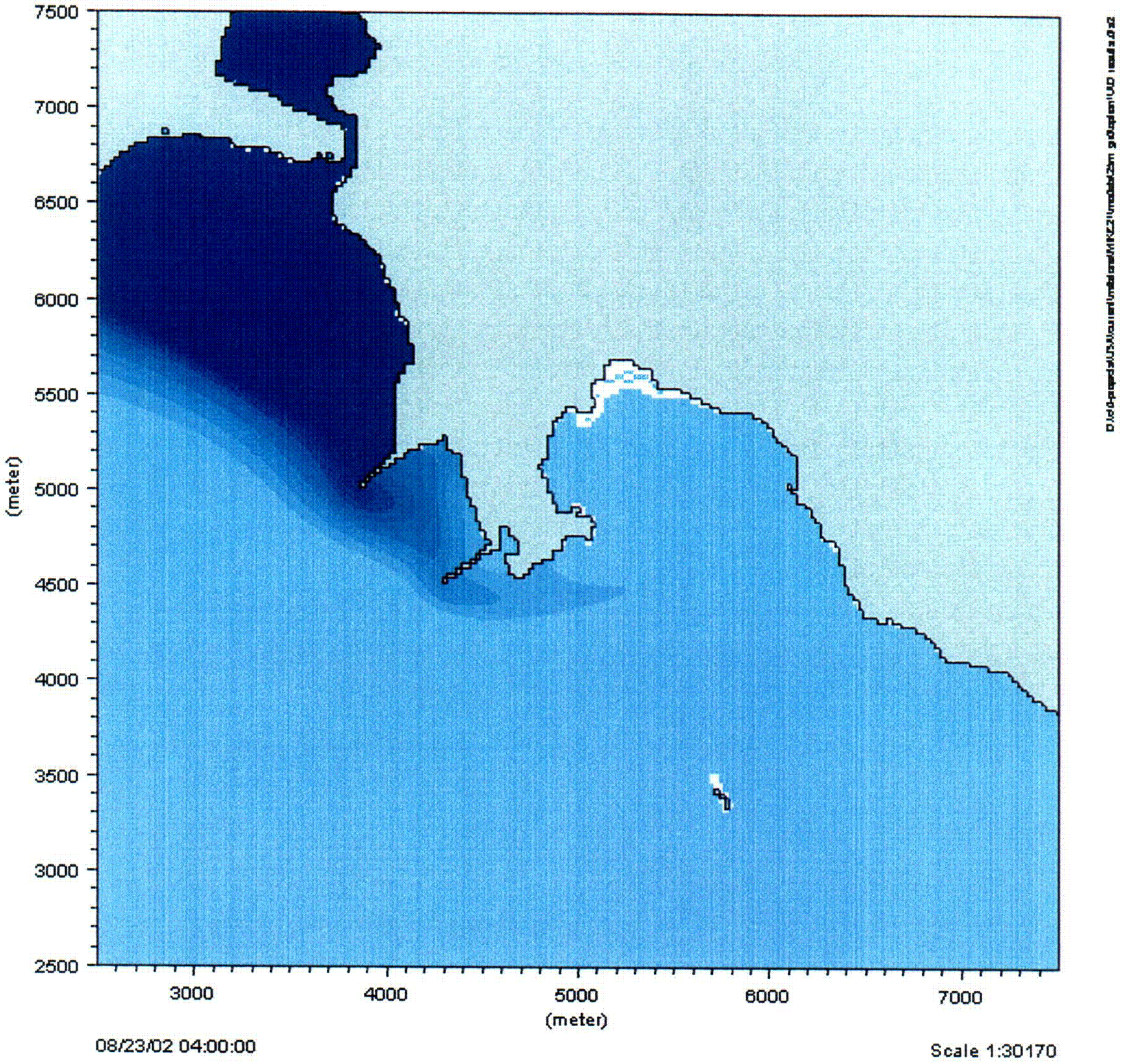


Figure 16: Larvae Distribution, Large Groins

Figure 16 shows the distribution of organisms (coming from the Niantic River) in Niantic Bay. The data, used to render the figure, is taken six days into a seven day flow simulation. The time stamp, in the lower left corner of the figure, identifies what simulation day and time the image corresponds to (note: this is the same day and time used to render Figure 12). The figure shows water containing relatively high concentrations of organisms (dark blue areas) moving around the tip one of the shoreline structures and into the area where the cooling water intakes are located.

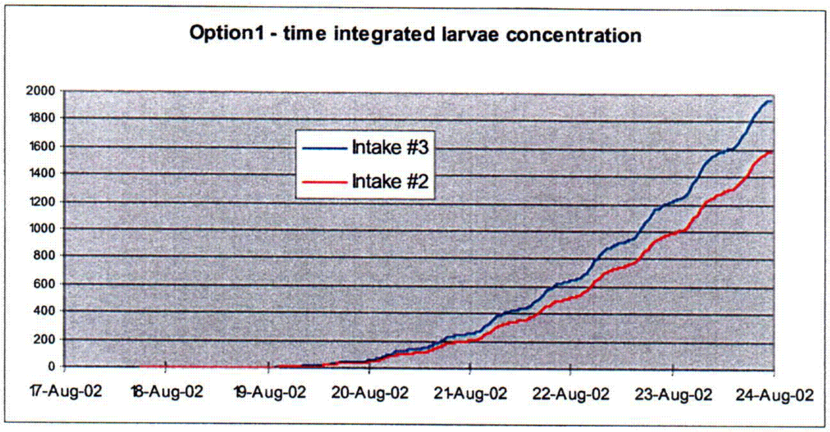


Figure 17: Time Integrated Larvae Concentration per Unit Flow Rate

Figure 17 contains a plot of time integrated larvae concentration. At the end of seven days (24 Aug-02) the total amount of larvae that has entered the intakes is about the same as that calculated for the existing condition (see Figure 13). This means that the shoreline structures modeled in this scenario do <u>not</u> reduce the entrainment of larvae coming from the Niantic River. Stated another way, the proportion of water entering the intakes from the Niantic River is calculated to be similar to that occurring for the existing condition. In this case, flow is forced to move around the shoreline structures, but is otherwise unaffected by their presence.

3.3 Option #2: Continuous Barrier

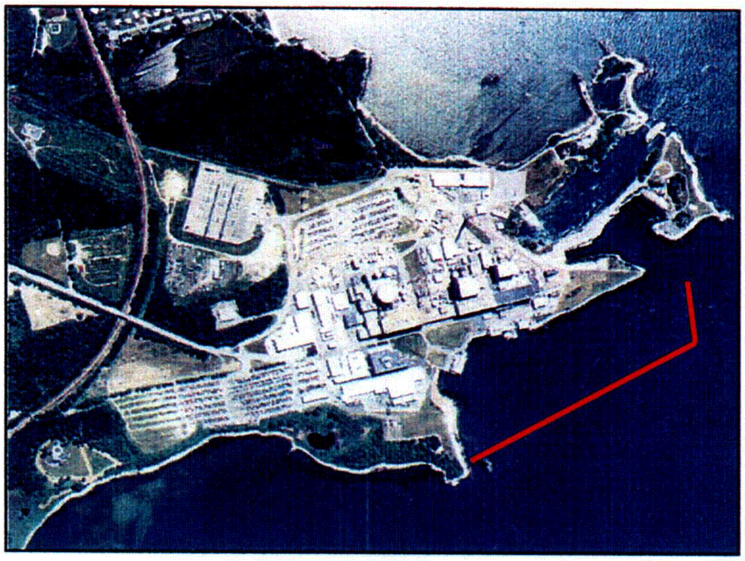


Figure 18: Continuous Barrier

The ability of a continuous barrier to reduce the entrainment of organisms coming from the Niantic River was the focus of the second comparative analysis (Figure 18). This single structure requires water originating in the Niantic River to enter Two Tree Island Channel before moving into the intake area (*i.e.,* the water must move to the end of Millstone Point before it is redirected towards the intakes). The nominal length of this structure is 2300 feet.

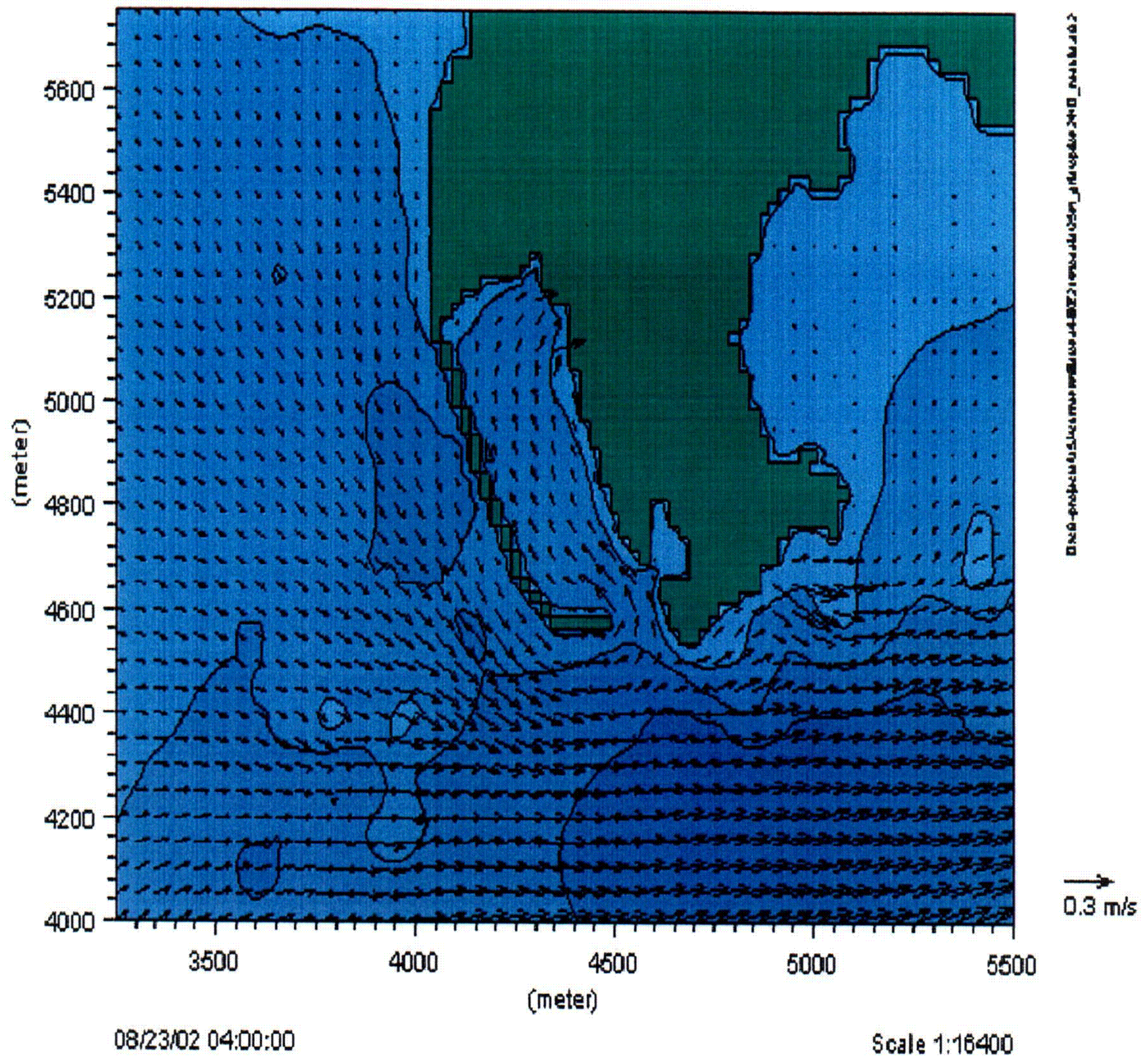


Figure 19: Flow Field, Continuous Barrier

Figure 19 shows the calculated flow pattern in front of the intakes during an ebb tide. The waters of Long Island sound appear at the bottom of the figure and water entering from the top of the figure comes from the interior of Niantic Bay and the Niantic River. The velocity vectors show flow moving South, along the continuous barrier, into relatively deep water at the end of Millstone Point, then turning North and passing into the intake area. This flow pattern is different the flow patterns that appear in Figures 11 and 15 because the water moving South from Niantic bay is forced to into the deeper waters of Long Island Sound before it moves into the intake areas (the background of the Figure 19 is colored by depth – darker shades of blue indicate deeper water).

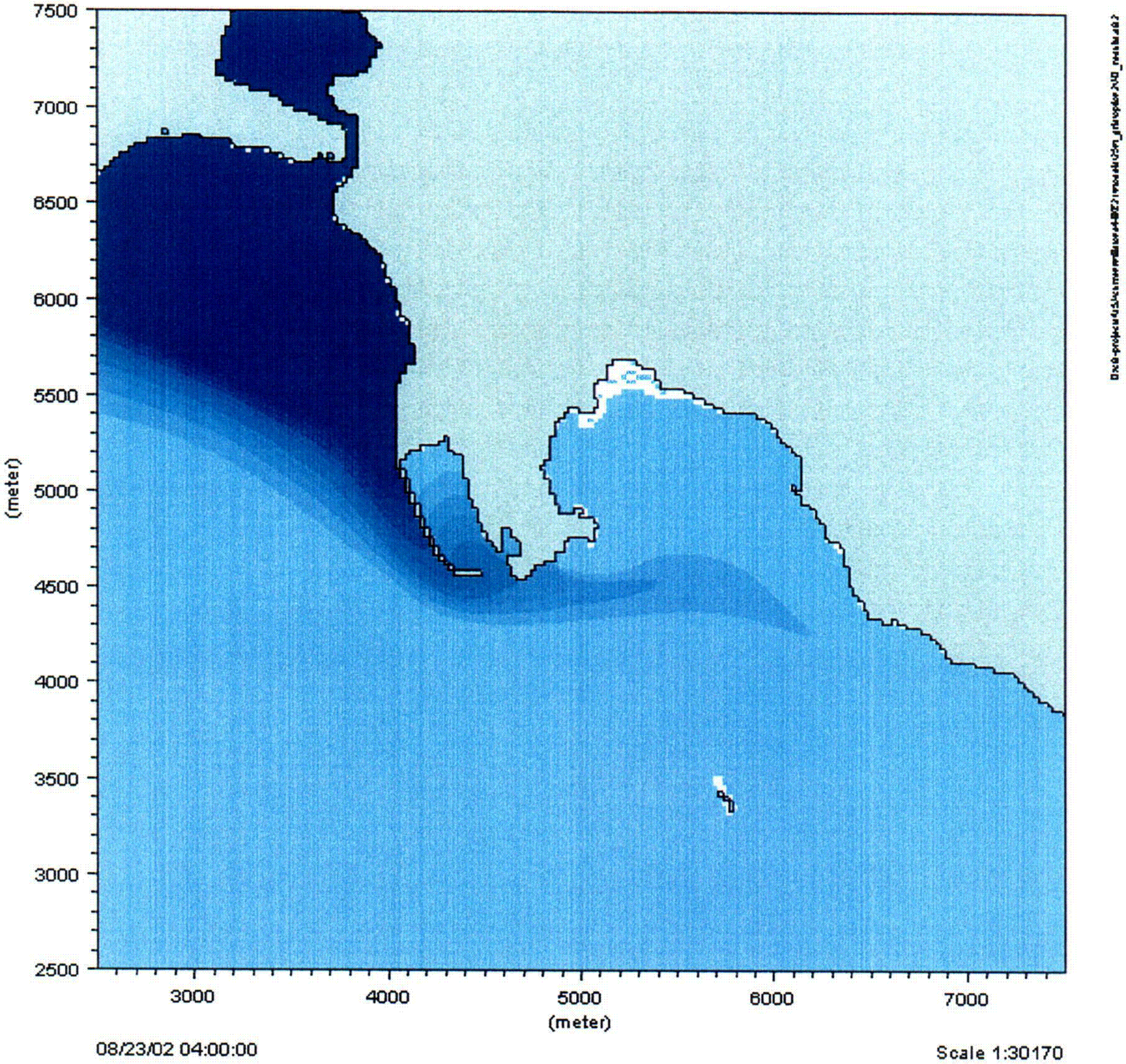


Figure 20: Larvae Distribution, Continuous Barrier

Figure 20 shows the distribution of organisms (coming from the Niantic River) in Niantic Bay. The data, used to render the figure, is taken six days into a seven day flow simulation. The time stamp, in the lower left corner of the figure, identifies what simulation day and time the image corresponds to (note: this is the same day and time used to render Figures 12 and 16). The figure shows water containing relatively high concentrations of organisms (dark blue areas) moving along the continuous barrier towards Two Tree Island Channel (see Figure 2). Near the end of Millstone Point, the water coming from the Niantic River is split and one portion of the flow moves towards the intakes, while the remaining portion is carried away by the relatively high tidal currents present in Two Tree Island Channel.

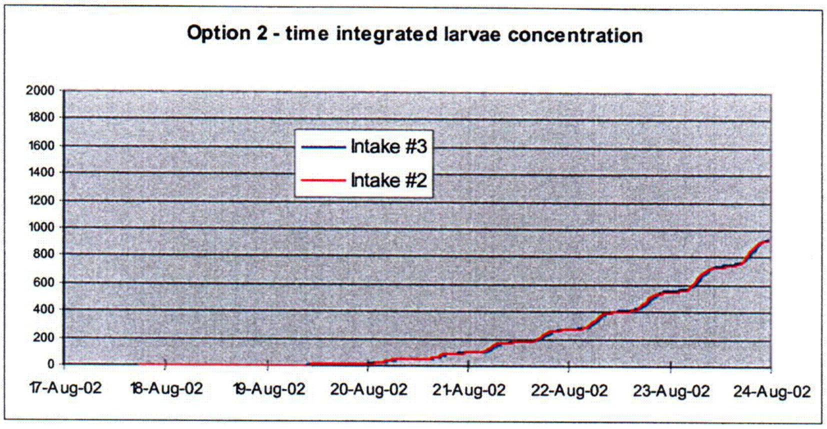
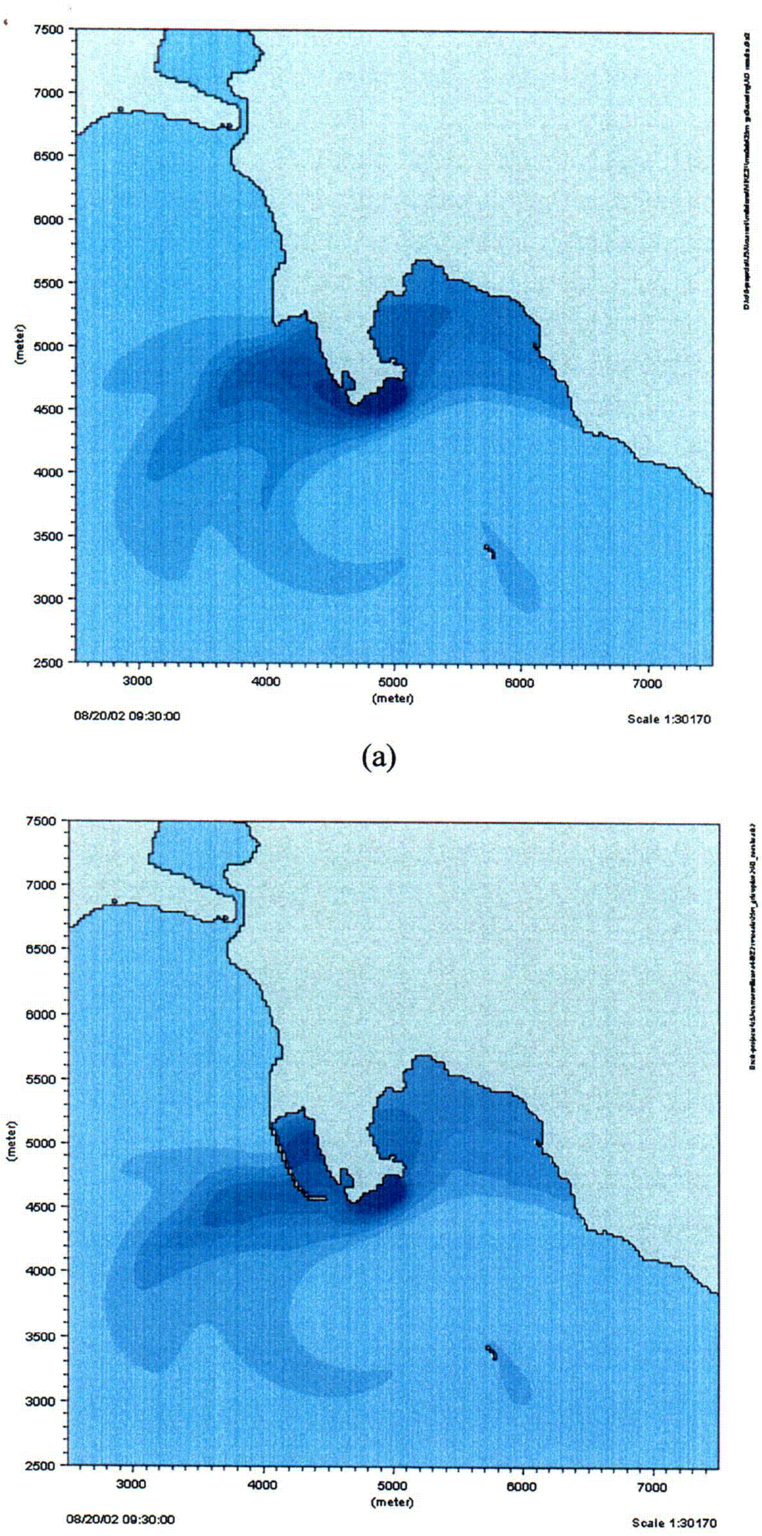


Figure 21: Time Integrated Larvae Concentration per Unit Flow Rate

Figure 21 contains a plot of time integrated larvae concentration. At the end of seven days (24 Aug-02), the total amount of larvae that has entered the intakes is about half of that calculated for the existing condition (see Figure 13). This means that the continuous barrier does reduce the entrainment of larvae coming from the Niantic River. Stated another way, the proportion of water entering the intakes from the Niantic River is calculated to be less than that occurring for the existing condition. In this case, the waters of the Niantic must mix with the waters of Long Island Sound before they enter the intakes. Thus, this mixing process serves to reduce (*i.e.,* dilute) the amount of larvae in a given volume of water that is taken into the intakes.

This analysis indicates that a continuous barrier could be used to reduce the amount of Niantic River water withdrawn by the cooling water intakes at Millstone. However, the mechanisms that cause this reduction may also increase the amount of heated water brought to the intakes when the tide floods. To better understand this phenomenon, a scalar source was placed at the location of heated water discharge and the movement of the "thermal" plume was tracked (see section 3.3.2 for details). The reader should note that the treatment of the thermal plume is rudimentary since the scalar quantity released into the flow was conservative and this analysis was not (at its inception) designed to be a thermal study. Visualizations of the movement of the thermal plume do, however, agree reasonably well with the results of prior studies and the results provide an awareness of a possible shortcoming of the continuous barrier design.

Figure 22 shows the location of the thermal plume during a flood tide with and without the continuous barrier in place. The comparison shows that with the continuous barrier in place a greater quantity of heated water might be re-circulated to the cooling water intakes (*i.e.*, the close proximity of the opening in the continuous barrier and the discharge location works to direct a greater quantity of heated water towards the intakes during a flood tide).



(a)

(b)

Figure 22: Thermal Plume, Continuous Barrier
(a) Existing Condition, (b) with Continuous Barrier

C20

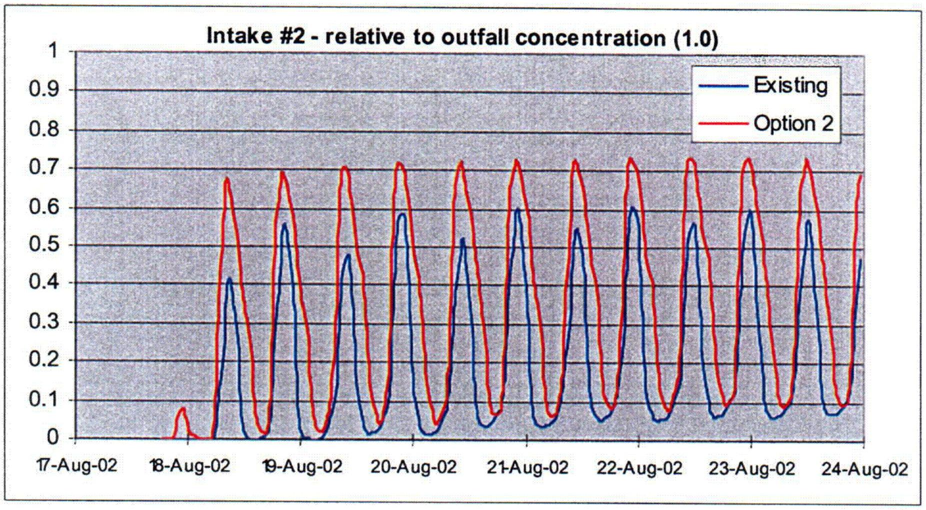


Figure 23: Relative Outfall Concentration
(Existing Condition versus Continuous Barrier [Option 2])

Figure 23 contains time histories of the amount of outfall water contained in the intake volume over the course of a seven day simulation. In this figure, for example, a value of 0.1 (or on the contour plots in Figure 22) indicates that approximately 10% of the local water volume comes from the outfall location. This analysis indicates that the amount of heated discharge water re-circulated to the intake area would increase with the continuous barrier in place (from a time-averaged value of about 19% without the barrier in place to a time-average value of about 35% with the barrier in place).

Since the construction of a continuous barrier might cause more heated water to be entrained by the cooling water intakes, an additional calculation was devised. In this calculation, a second shoreline structure was placed between the opening in the continuous barrier and the heated water discharge location (Figure 24). The purpose of the second structure was to push the heated plume away from Millstone Point and to limit the amount of heated water re-circulated into the intake area. This enhancement did not produce drastically different results compared to the case with the continuous barrier only (*e.g.* compare the location of the thermal plume in Figure 22 (b) to the location of the thermal plume in Figure 24).

C21

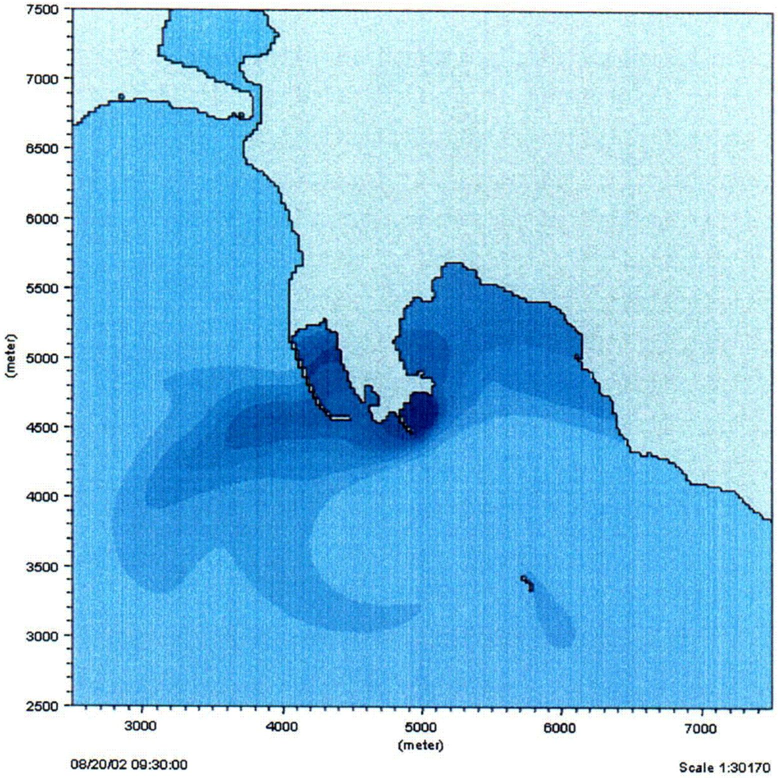


Figure 24: Thermal Plume, Option 2a

c22

3.4 Option #3: Small Groins

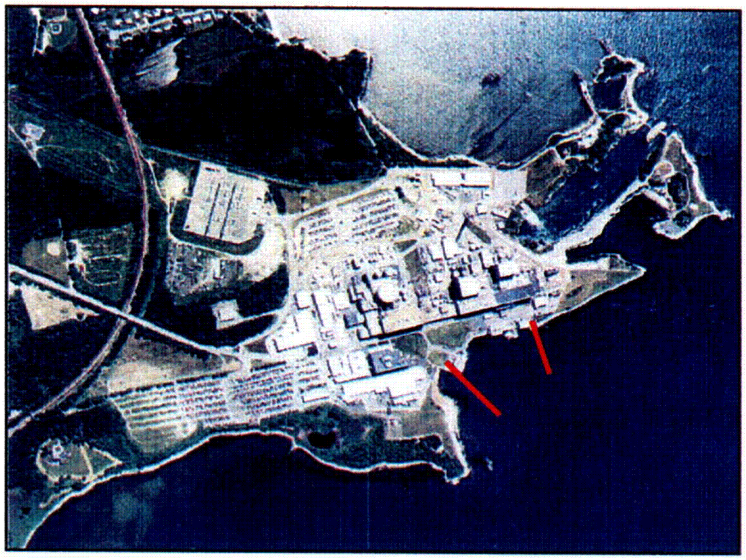
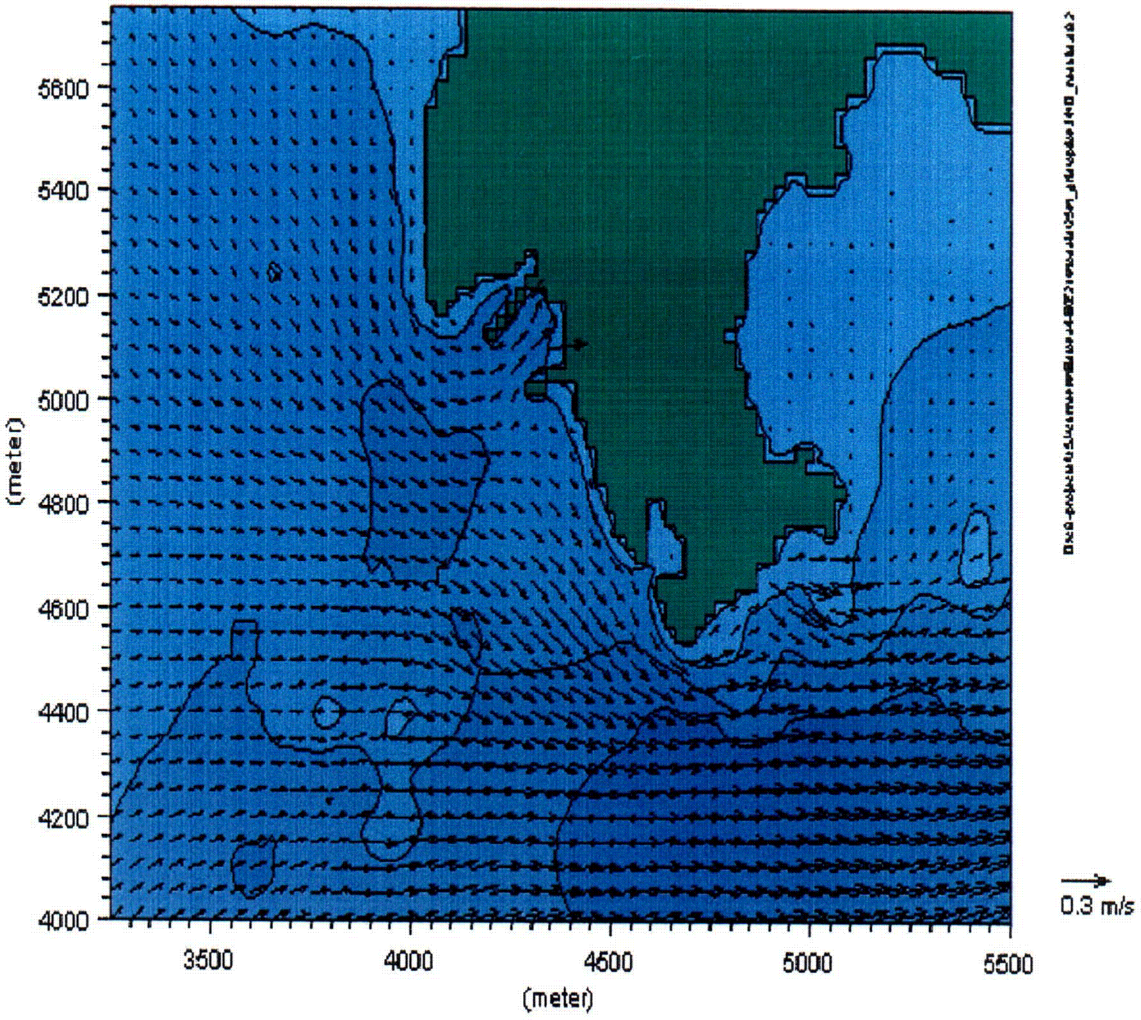


Figure 25: Small Groins

The ability of two small shoreline perpendicular structures to reduce the entrainment of organisms coming from the Niantic River was the focus of the final comparative analysis. Figure 25 shows the location of the two shoreline structures placed besides the cooling water intakes. The nominal length of these structures is 400 feet.



08/23/02 04:00:00

Scale 1:16400

Figure 26: Flow Field, Small Groins

Figure 26 shows the calculated flow pattern in front of the intakes during an ebb tide. The waters of Long Island sound appear at the bottom of the figure and water entering from the top of the figure comes from the interior of Niantic Bay and the Niantic River. The velocity vectors show flow moving South, around Bay Point and one of the shoreline structures, into the active cooling water intakes. This flow pattern is similar to that appearing in Figure 11 except that the flow must pass around one of the short shoreline structures before it moves into the intake area.

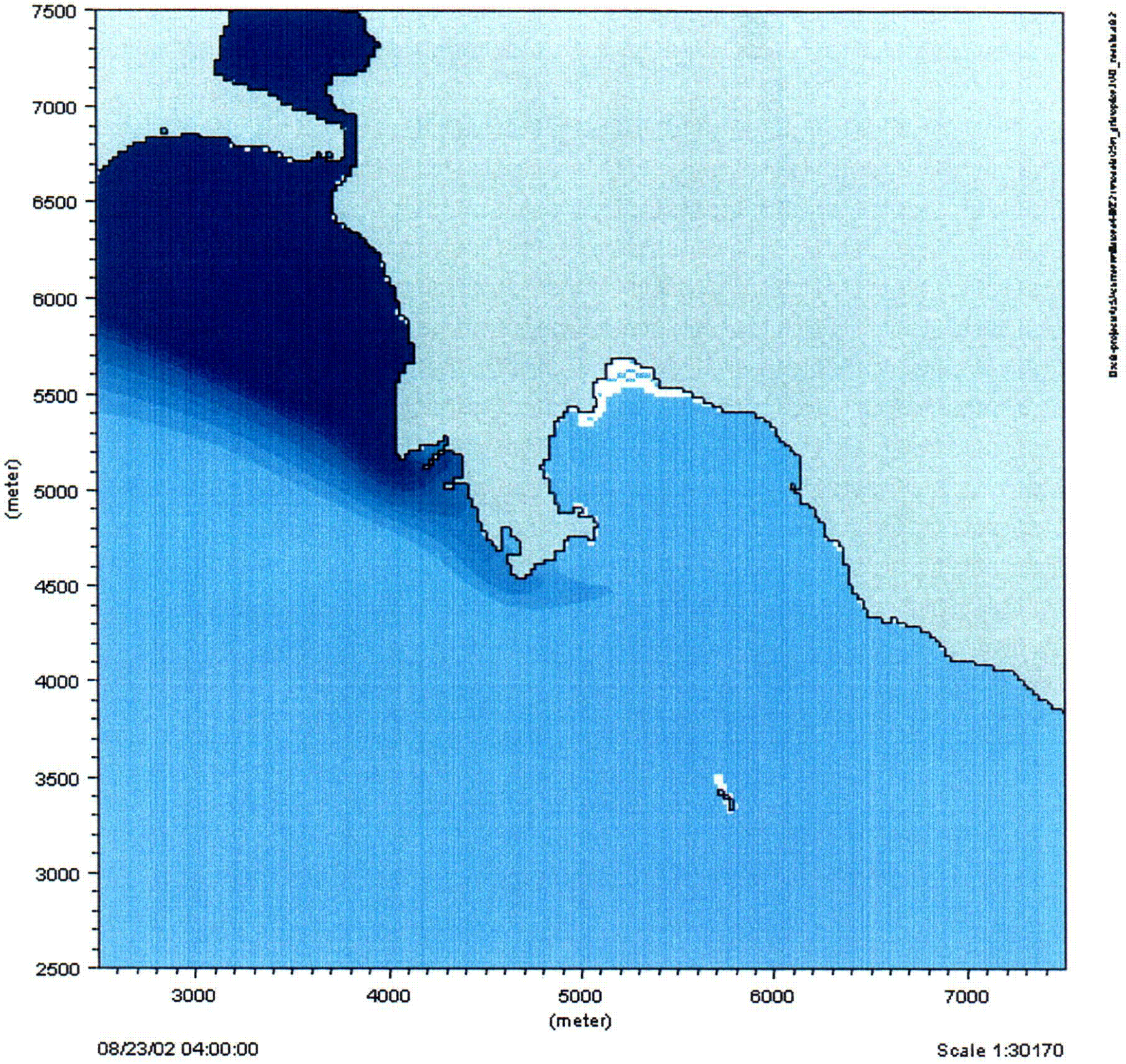


Figure 27: Larvae Distribution, Small Groins

Figure 27 shows the distribution of organisms (coming from the Niantic River) in Niantic Bay. The data, used to render the figure, is taken six days into a seven day flow simulation. The time stamp, in the lower left corner of the figure, identifies what simulation day and time the image corresponds to (note: this is the same day and time used to render Figure 12). Figure 27 shows water containing relatively high concentrations of organisms (dark blue areas) moving around the tip one of the shoreline structures and into the area where the cooling water intakes are located.

C25

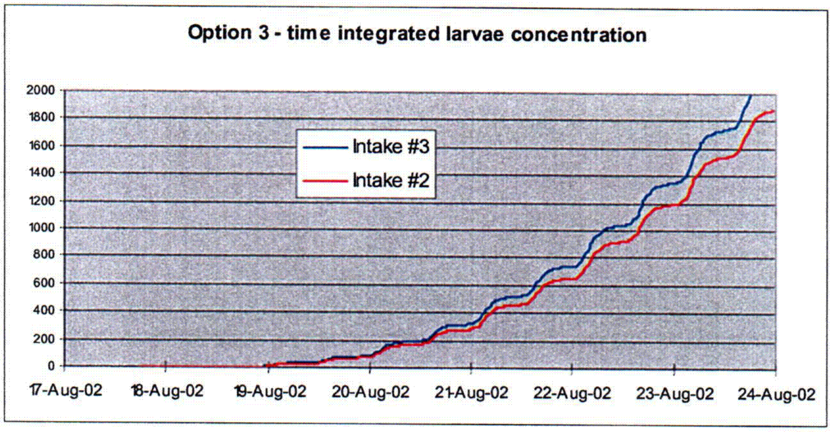


Figure 28: Time Integrated Larvae Concentration per Unit Flow Rate, Small Groins

Figure 28 contains a plot of time integrated larvae concentration. At the end of seven days (24 Aug-02) the total amount of larvae that has entered the intakes is about the same as that calculated for the existing condition (see Figure 13). This means that the shoreline structures modeled in this scenario do <u>not</u> reduce the entrainment of larvae coming from the Niantic River. In this case, flow is forced to move around the shoreline structures, but is otherwise unaffected by their presence.

C26

3 CONCLUSIONS

As a result of this study, the following conclusions can be drawn.

Hydraulic

1. The proportion of water entering the Millstone Power Station from the Niantic River can be altered by the construction of a continuous barrier surrounding the cooling water intakes. When the opening of this barrier is positioned near the end of Millstone Point more water from Long Island Sound is brought into the intake area and proportionally less water originating in the Niantic River is brought into the intake area. If the opening of this barrier was positioned near Bay Point, then the situation would be reversed (*i.e.,* more water originating in the Niantic River would be brought into the intake area and less from Long Island Sound would be brought into the intake area – note: this result is not explicitly shown in this analysis).

2. The construction of shoreline perpendicular structures would not alter the proportion of water entering the cooling water intakes from the Niantic River. While the shoreline perpendicular structures affect flow patterns locally they do not change the overall flow patterns that contribute to the mixing of water from different source locations.

Biological

1. The number of passive organisms entering the Millstone Power Station from the Niantic River would be reduced if a continuous barrier (Option #2) was constructed. This shoreline structure would force water originating in the Niantic River to mix with water moving in Long Island Sound before it was brought to the intake area. Thus, the proportion of water originating in the Niantic River would be reduced as well as the concentration of organisms contained therein.

2. The number of passive organisms entering the Millstone Power Station from far-field locations (*i.e.,* locations other than the Niantic River) would be increased if a continuous barrier (Option #2) was constructed (*i.e.,* if less water is withdrawn from the Niantic River, then more water must be withdrawn from elsewhere).

   Furthermore, the total number of organisms entrained by the cooling water intakes might not be reduced if a continuous barrier is constructed (or any structure for that matter). That is to say, a change in the proportion of water withdrawn from different areas could result in no-net change or even an increase in entrainment numbers if higher populations of a particular organism were present in the "new" water that is brought into the power plant.

3. Organisms that are uniformly distributed in Niantic Bay and vicinity would be entrained in similar numbers with or without Option Numbers 1, 2, or 3 in place.

Thermal

1. The construction of a continuous barrier could increase the amount of heated (discharge) water re-circulated to the intakes. The amount of water re-circulated could be reduced by the addition of a skimmer wall across the opening of the barrier. The addition of this wall would also increase local flow velocities and could contribute to the erosion of sediments near the opening of the barrier. An analysis of this effectiveness of this option is, however, beyond the scope of this initial modeling effort.

Sediment Transport

1. The construction of shoreline perpendicular structures could affect the movement of sediments along the Eastern shore of Niantic Bay. However, since these structures have been shown to be ineffective with respect to their ability to alter the proportions of water entering the cooling water intakes from different locations, their construction would not be recommended.

2. The construction of a continuous barrier could increase local flow velocities in the vicinity of Millstone Point. This change could increase the erosion of sediments in this area; however, the evaluation of this possibility is not part of this study.

4 FINAL REMARKS

This analysis was designed to study the effects of shoreline structures intended to reduce the entrainment of organism into the cooling water intakes at the Millstone Power Station. The study hinges on the application of a 2-D hydrodynamic model used to simulate flows in Niantic Bay with and without shoreline structures placed near the cooling water intakes. While the analysis is capable of answering the basic question; to what effect can shoreline structures be used to reduce entrainment, several important issues related to the potential cost and benefit of such structures are not addressed. Namely,

- Cost of construction: the cost of constructing shoreline structures, such as the ones addressed in this analysis, could be prohibitive due to the large size of the structures.
- Impact on navigation: shoreline structure placed in the vicinity of the cooling water intakes could be viewed as hazards since they would be located in navigable waters.
- Development of new habitat near intakes: the shoreline structures, themselves, would provide new habitat for some species of organisms. These "new" populations of organisms could be prone to entrainment since they would thrive in the near vicinity of the intakes.
- Impact on organisms coming from locations outside of Niantic Bay: it has been shown that a continuous barrier may reduce the amount of water that enters the cooling water intakes from the Niantic River while at the same time increasing the amount of water that enters the intakes from elsewhere (*i.e.*, far-field locations). The likely impact on populations of organisms located in these far-field locations should be assessed.
- Sedimentation and erosion: the movement sediments around Millstone Point could be affected by the construction of any of the shoreline structures considered in this report. The impact of these constructions on the local sediment budget should be determined (*e.g.*, after the startup of Unit #3 the sandbar adjacent to Bay Point began to erode – similar changes could occur if any of these options were pursued).
- The effect of increased re-circulation of heated water: the analysis indicates that increased re-circulation of heated discharge water could occur if the continuous barrier structure was put into place. The extent to which this would occur and the impact on plant efficiency/operation should be assessed more rigorously.
- Safety: the continuous barrier design places the intakes behind a partition with one entrance. If this entrance were to be blocked no cooling water could be pumped through the existing cooling water intakes.
- Permitting/licensing: the level of effort required to permit and license this new construction could be excessive.

We would recommend that additional work, designed to address the concerns listed above, be conducted before a decision to construct any of the options considered in this analysis is made.

REFERENCES

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, Cambridge, MA.

Northeast Utilities Service Company and Ocean Surveys, Inc. (1988), "Monitoring the Marine Environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut: Three-unit Operational Studies 1986-1987," Northeast Utilities Service Company.

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EVALUATION OF SHORELINE STRUCTURES DESIGNED TO MINIMIZE THE ENTRAINMENT OF ORGANISMS INTO THE COOLING WATER INTAKES AT THE MILLSTONE POWER STATION

By
John E. Richardson, Ph.D., P.E.

Submitted to
MILLSTONE POWER STATION
ENVIRONMENTAL SERVICES
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August 2002

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