

DISSOLVED OXYGEN, TEMPERATURE, AND DENSITY PROFILES

IN

SALEM SOUND AND MASSACHUSETTS BAY

1990

Prepared by:

Thomas R. Dallaire

Steven G. Halterman

DEPARTMENT OF ENVIRONMENTAL PROTECTION
MASSACHUSETTS DIVISION OF WATER POLLUTION CONTROL
TECHNICAL SERVICES BRANCH
WESTBOROUGH, MASSACHUSETTS

July, 1991

EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS
Susan Tierney, Secretary

DEPARTMENT OF ENVIRONMENTAL PROTECTION
Daniel S. Greenbaum, Commissioner

DIVISION OF WATER POLLUTION CONTROL
Brian M. Donahoe, Director

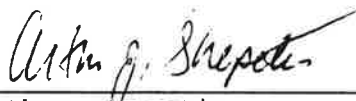
TITLE: Dissolved Oxygen, Temperature, and Density Profiles in Salem Sound
and Massachusetts Bay, 1990

DATE: July 1991

AUTHORS: T.R. Dallaire, S.G. Halterman

REVIEWED BY:

APPROVED BY:



Arthur Scirepetis,
Aquatic Biologist



Alan N. Cooperman, M.S. P.E.
Supervisor, T&B

FOREWORD

The Massachusetts Division of Water Pollution Control was established by the Massachusetts Clean Water Act, Chapter 21 of the General Laws as amended by Chapter 685 of the Acts of 1966. Included in the duties and responsibilities of the Division is the periodic examination of the water quality of various coastal waters, rivers, streams and ponds of the Commonwealth, as stated in section 27, Paragraph 5 of the Acts. This section further directs the Division to publish the results of such examination together with the standards of water quality established for the various waters. The Technical Services Branch of the Division of Water Pollution Control has, among its responsibilities, the execution of this directive. This report is published under the Authority of the Acts and is among a continuing series of reports issued by the Division presenting water quality data and analyses, water quality management plans, baseline and intensive limnological studies and various special studies.

ACKNOWLEDGMENTS

This study was conducted under the direction of Russell Isaac, Director of the Technical Services Branch (TSB), and Alan Cooperman, head of the TSB Water Quality Section. The authors wish to thank Leslie O'Shea, Drew Phinney, and Xiaoning Chen for their assistance in the field, and Arthur Screpetis for his detailed review of the manuscript.

TABLE OF CONTENTS

<u>TITLE</u>	<u>PAGE</u>
Foreword	iii
Acknowledgments	iv
Abstract	vi
List of Tables	vii
List of Figures	vii
Introduction	1
Materials and Methods	1
Water Quality Standards, Dissolved Oxygen	7
Results	9
Discussion	31
Conclusion (Implications for outfall siting)	37
References	42

ABSTRACT

Detailed water column profiles of dissolved oxygen (DO), % DO saturation, density, temperature, and salinity were obtained at fifteen sites in Massachusetts Bay and Salem Sound on July 19, and August 28, 1990, using a Seabird CTD profiler modified with a DO sensor. The Salem Sound sites were located in the vicinity of the South Essex Sewage District (SESD) outfall and in Marblehead Channel at varying distances from the outfall. Measurements in the Bay were made in the vicinities of two sites being considered (by SESD) for relocation of the SESD outfall.

In July the DO concentrations ranged from 8.5 to 10.1 mg/l, with no significant differences between the Sound and the Bay. Dissolved oxygen saturation was around 100% in the entire water column in both the Sound and the Bay. In August, however, the DO concentrations ranged from 5.2 to 9.0 mg/l in the Sound and from 6.8 to 9.0 mg/l in the Bay. The lowest DO concentrations (and the highest "apparent oxygen utilization" values) occurred in the deepest waters of Marblehead Channel, down-current of the existing SESD sewage outfall. The DO saturation in August was about 75% (minimum of 73%) in the deepest waters of the Bay, and ranged from only 62.5% to 71.3% at the Marblehead Channel sites.

Although this study has extremely limited temporal coverage, it does indicate that combinations of certain conditions, including stratification, temperature, and density, can exist, which result in reduced dissolved oxygen in both the Bay and the Sound. The study also raises questions about how a future modified sewage discharge may affect dissolved oxygen in Salem Sound, and how a relocated sewage discharge might impact the dissolved oxygen in Massachusetts Bay.

LIST OF TABLES

<u>NUMBER</u>	<u>TITLE</u>	<u>PAGE</u>
1	July 19, August 28 1990, Salem Sound, Massachusetts Bay Sampling Station Locations	4
2	Salem Sound/Mass Bay, Profile Data, Summer 1990	10

LIST OF FIGURES

<u>NUMBER</u>	<u>TITLE</u>	<u>PAGE</u>
1	Salem Sound Station Locations	5
2	Massachusetts Bay Station Locations and Candidate Outfall Sites	6
3	Waterbody Classifications	8
4	Annual Cycle of Temperature/Salinity Relation at Boston Lightship, 1956-1970	32
5	Merrimack River Flow, Average Daily Mean Flow by Month	35
6	Salem Sound Prevailing Net Flow and Prevailing Winds	36
7	Salem Sound Droque Tracks	38
8	Ocean Surveys Inc., Location of Profile Stations	40

INTRODUCTION

Facilities Planning activities are currently underway for the South Essex Sewer District (SESD) facility located in Salem, Massachusetts. Issues being addressed include upgrading from primary to secondary treatment, selecting a site for locating the plant, and selecting a location for the outfall. The study reported here pertains to selecting a site for the sewage outfall.

A critical factor being considered when selecting the outfall site is the level to which oxygen-demanding substances in the effluent will reduce dissolved oxygen concentrations in the water column (and sediments), and the temporal and spatial extent of the impacted area. Because of the potential for adverse impacts to aquatic organisms, resulting from low dissolved oxygen concentrations, Massachusetts Water Quality Standards provide strict regulations on the DO concentrations allowed in the surface waters of the Commonwealth. Therefore, as part of the outfall siting effort, changes in DO, due to the relocation of the outfall (or from a modified effluent discharged at the existing outfall site), will be predicted. Predictions will be based on several factors, including: effluent chemistry (nutrients, BOD, etc), and receiving water body characteristics such as nutrients, sediment oxygen demand, dissolved oxygen concentrations, primary production (or standing crop of plant matter), water column density and temperature profiles, and current speed and direction.

Although some DO data have been collected in Salem Sound in the vicinity of the existing SESD outfall and in Mass Bay in the vicinity of candidate outfall sites, very little of the data included detailed depth profiles of the critical variables DO, % DO saturation, density, temperature, and salinity. It is for this reason that the Technical Services Branch Marine Section conducted surveys on July 19, and August 28, 1990, producing detailed water column profiles during this potentially critical period.

The tables in this report only present summaries of the extensive data collected in each profile. The entire data record of 5155 measurements (of each variable) are available upon request if the reader requires a greater level of precision of the changes in the reported variables as a function of depth in the water column.

MATERIALS AND METHODS

Cruises were conducted on the Division of Water Pollution Control's 21-foot Privateer, equipped with a Loran C navigational system and depth meter for accurately determining station locations. The 15 stations visited during the study are listed, along with a description of their locations, in Table 1. The maps in Figures 1 and 2 provide the approximate position of each station.

Depth, density, salinity, temperature, and dissolved oxygen concentrations were measured with a Seacat SBE-19 Profiler (Sea-Bird Electronics Inc., Bellevue, Washington).

The Seacat SBE-19 Profiler measures electrical conductivity, temperature,

pressure, dissolved oxygen and pH in marine environments. The responses of the sensors are stored internally at a sampling rate of twice per second with a maximum number of samples (scans) = 21,600 or up to six hours of continuous sampling. Data are extracted by personal computer using software provided by Sea-Bird Electronics Inc. (Seasoft Version 3.2B). The software is also used to calculate salinity, depth, density, and sound velocity.

Seacat calibration:

Prior to surveys the dissolved oxygen sensor was calibrated according to the procedures outlined in the documentation provided with the sensor. Saturated Oxygen Current (SOC) was determined by submerging the entire profiler into a cooler full of water that had been aerated for a minimum of two hours. Zero Oxygen Current (ZOC) was determined by flushing the dissolved oxygen sensor with a 5% solution of Na_2SO_3 (Sodium Sulfite). SOC and ZOC were then processed through the software module "Oxfit" to get the calibration coefficients. Calibration coefficients were placed into the software prior to data reduction.

Outline of Seacat deployment procedures:

- 1) Profiler is deployed with sensors facing upward; therefore, only the upcast data is considered during data reduction.
- 2) Profiler is turned on, time and position are recorded in field log.
- 3) Profiler is placed in the water to a depth of approximately 1 meter for a 1 minute equilibrium period. Bilge pump attached to dissolved oxygen sensor is turned on upon submersion.
- 4) After completion of equilibrium period, profiler is lowered to the bottom.
- 5) After ten seconds on the bottom, the profiler is raised at a constant rate until it reaches the surface.
- 6) After ten seconds on the surface, the pump is turned off and profiler is retrieved.
- 7) Profiler is then turned off.

Data Management:

After a survey has been conducted, data are downloaded to a computer in hexadecimal format using the Sea-Bird software. Data are then processed through the software to produce ascii text files for each profile. The individual ascii files are consolidated into one file, then "Brief" (ascii text editor) is used to edit the data. Data are maintained and manipulated using dBase IV in the TSB/Marine data management system.

Reduction of Data:

The surveys conducted in the summer of 1990 generated 5155 records of data. It was necessary, for the purpose of this memo, to summarize the data so that it could be made available to other users as well as facilitate general conclusions and comments. The data were processed using dBase IV to give:

- 1) the first (lowest depth) record
- 2) each subsequent record of the upcast profile that accompanied a depth change of 1 meter over the previous record
- 3) the last record (water surface) of the upcast profile.

TABLE 1

JULY 19, AUGUST 28 1990

SALEM SOUND, MASSACHUSETTS BAY SAMPLING STATION LOCATIONS

(Compass bearings are in Degrees True)

<u>Station:</u>	<u>Location:</u>
SS01	Salem Sound, midway between the SESD outfall and buoy # C"7"
SS02	Salem Sound, 450 m North West of Great Haste Island (on a bearing of 290°)
SS03	Salem Sound, 600 m North of Great Haste Island (on a bearing of 5°)
SS04	Salem Sound, 250 m East of buoy # N"8" (on a bearing of 80°), between Eagle Bar to the south and Bowditch Ledge to the north
SS05	Salem Sound, 275 m South East of buoy # "13" flashing 4 seconds (on a bearing of 132°)
SS06	Salem Sound, 675 m East of buoy # C "7" (on a bearing of 70°)
SS07	Salem Sound, 650 m East of buoy # C "7" (on a bearing of 100°)
SS08	Marblehead Channel, 200 m South West of buoy # N "6" (on a bearing of 232°)
SS09	South Marblehead Channel, 200 m South of buoy # N "2" (on a bearing of 180°)
MB01	Mass Bay, 301 (h) Waiver site, 3.3 N miles South East by South of Marblehead Rock (on a bearing of 145°) at 42°28'4" N, 70°46'4" W
MB02	Mass Bay, 0.5 N miles South East of MB01 (on a bearing of 140°)
MB03	Mass Bay, 0.5 N miles North West of MB01 (on a bearing of 320°)
MB04	Mass Bay, 3 N miles East of Bakers Island, at 42°32'00" N, 70°43'00"W
MB05	Mass Bay, 0.5 N miles South East of MB04 (on a bearing of 104°)
MB06	Mass Bay, 0.5 N miles North West of MB04 (on a bearing of 275°)

Figure 1. Salem Sound Station Locations

Scale: 1"=0.97 Nautical Miles

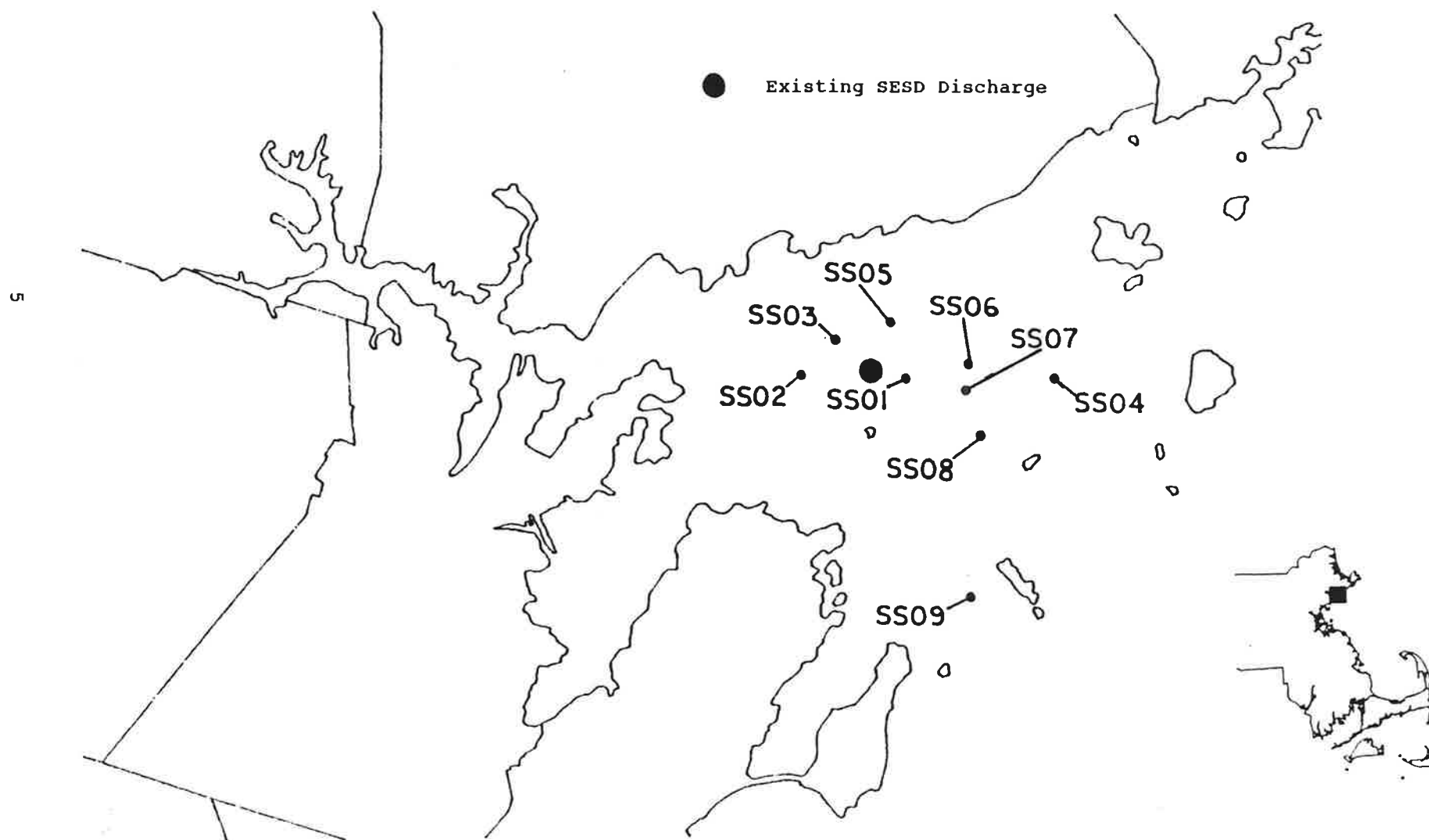
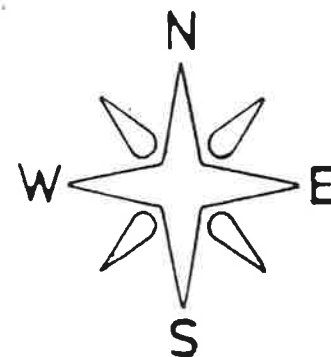
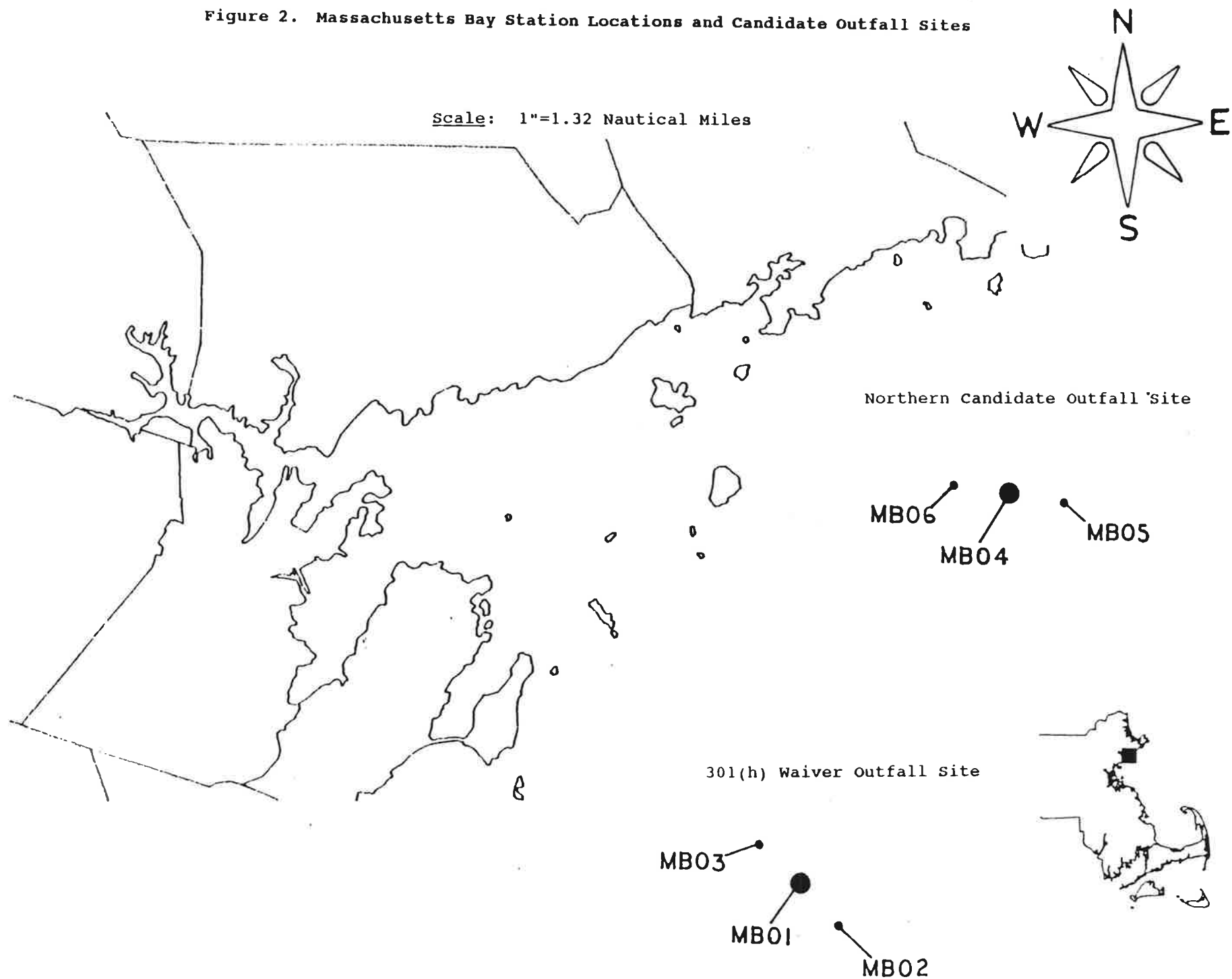


Figure 2. Massachusetts Bay Station Locations and Candidate Outfall Sites



Water Quality Standards, Dissolved Oxygen

The following is taken from the 1990 Massachusetts Surface Water Quality Standards: (Massachusetts Division of Water Pollution Control, 1990)

Class SA:

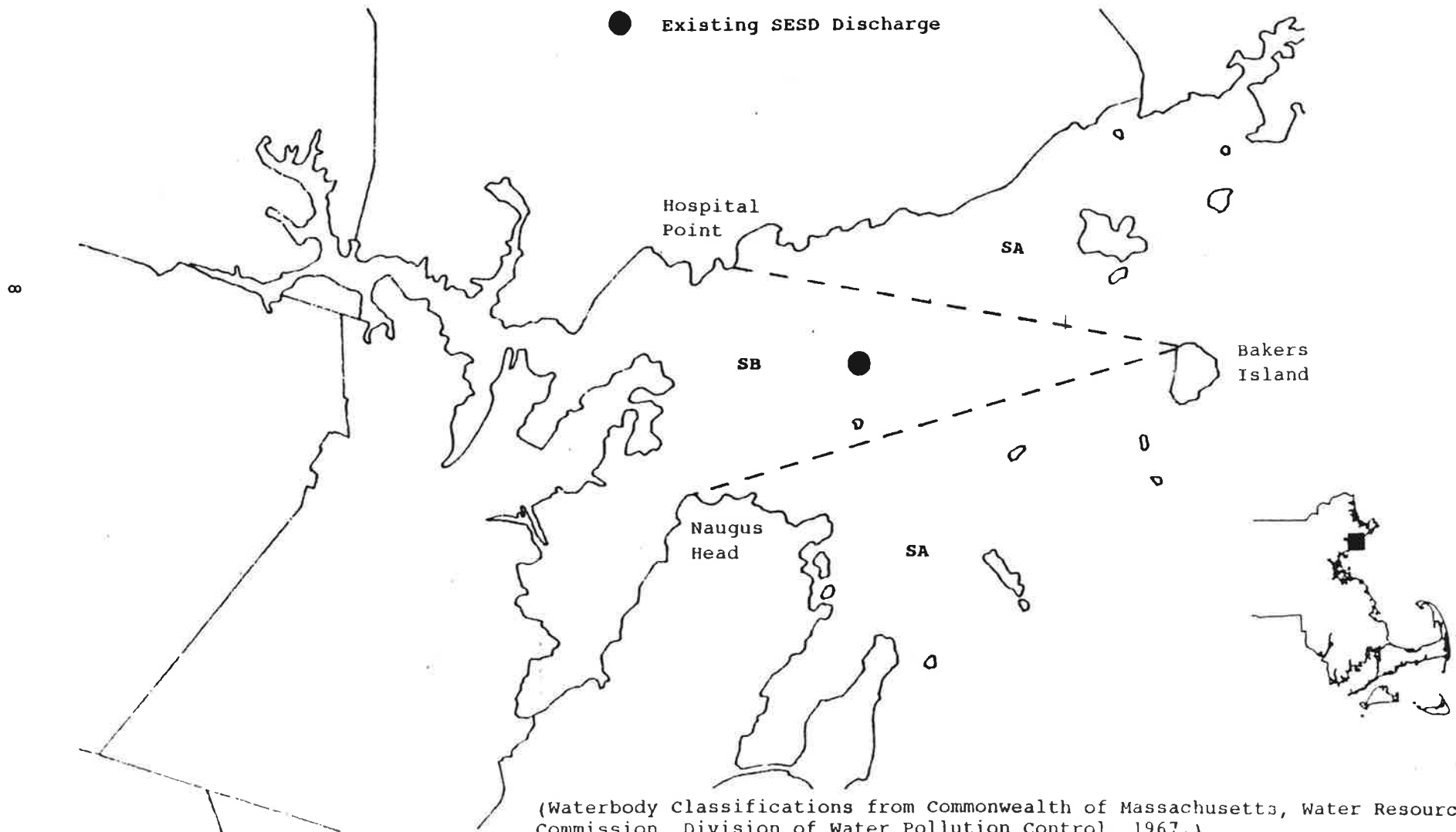
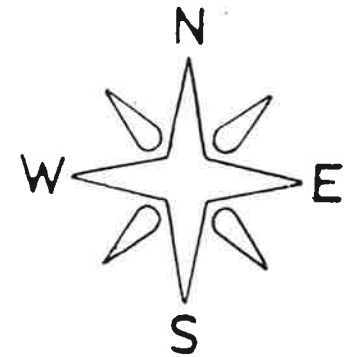
Dissolved Oxygen - (a) shall not be less than 6.0 mg/l unless background conditions are lower; (b) natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 75 percent of saturation due to a discharge; and (c) site-specific criteria may apply where background conditions are lower than specified levels or to the bottom stratified layer where the Director determines that designated uses are not impaired.

Class SB:

Dissolved Oxygen - (a) shall not be less than 5.0 mg/l unless background conditions are lower; (b) natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 60 percent of saturation due to a discharge; and (c) site-specific criteria may apply where background conditions are lower than specified levels or to the bottom stratified layer where the Director determines that designated uses are not impaired.

Figure 3. Waterbody Classifications

Scale: 1"=0.97 Nautical Miles



(Waterbody Classifications from Commonwealth of Massachusetts, Water Resources Commission, Division of Water Pollution Control, 1967.)

RESULTS

The water column depth, density, salinity, temperature, DO, and percent DO saturation data, generated during the two cruises, are summarized in Table 2.

Cruise 1 (July 19, 1990)

Dissolved oxygen ranged from 8.5 to 10.1 mg/l with no significant difference between the Salem Sound stations and those located in Mass Bay, or between the surface and the bottom waters. Dissolved oxygen saturation was around 100 % in the surface and the bottom waters of the Sound and the Bay. There were no violations of the current water quality standards for dissolved oxygen.

Temperatures throughout the study area ranged from 6.4°C to 15.1°C, with only slight differences between Salem Sound and Mass Bay (8.1°C to 15.1°C in the Sound and 6.4°C to 14.8°C in the Bay). Temperature differences between top and bottom ranged from 4.3 to 6.8°C in Salem Sound and 7.6 to 8.4°C in Mass Bay.

Salinity ranged from 29.6 ppt to 33.2 ppt with no significant differences between the Sound and the Bay. Density, reported as sigma-t, ranged from 21.9 to 25.8, with only slight differences between the Sound and the Bay. Density differences between top and bottom ranged from 1.8 to 3.2 in the sound and 1.9-2.3 in Mass Bay.

Cruise 2 (August 28, 1990)

The results of this cruise indicated important differences between Salem Sound and Mass Bay, as well as differences within regions of Salem Sound.

Dissolved oxygen concentrations ranged from 5.2 to 9.0 mg/l in the Sound and 6.8 to 9.0 mg/l in the Bay, with the lowest concentrations occurring in the bottom waters of Marblehead Channel (Stations SS06 through SS09). Violations of the SA standard of 6.0 mg/l were measured in the bottom of the water column at station SS08. Dissolved oxygen gradients between top and bottom were more pronounced at Marblehead Channel stations than at all other stations sampled. Top to bottom gradients ranged from 1.9 to 3.1 mg/l at Marblehead Channel stations, 1.4 to 2.2 mg/l at stations SS01 through SS05, and 1.2 to 1.9 mg/l in Mass Bay. The greatest top to bottom gradient was measured at station SS07.

Temperatures were considerably warmer in the Sound than in the Bay, ranging from 14.3°C to 21.2°C in the Sound and 7.5°C to 20.3°C in the Bay. Top to bottom gradients ranged from 11.8°C to 12.6°C in Mass Bay and 2.3°C to 5.6°C in the Sound. Temperature gradients within Salem Sound were greater at stations south and west of the present outfall.

Salinity ranged from 29.3 to 32.5 ppt in the entire study area. Significant differences between Salem Sound and Mass Bay were noted. Top to bottom salinity gradients ranged from 0.9 to 1.9 ppt in the Sound and 1.9 to 2.8 ppt in Mass Bay.

Density gradients were more pronounced in Mass Bay than Salem Sound. Top to bottom gradients ranged from 1.3 to 2.8 sigma-t units in Salem Sound and 4.0 to 4.6 sigma-t units in Mass Bay.

Table 2.

Density, salinity, temperature, dissolved oxygen, % oxygen saturation and apparent oxygen utilization (AOU) profile data collected in Salem Sound and Massachusetts Bay, summer 1990. (See text for explanation of AOU)

Table 2
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
MB01	07/19/90	1027	0.8	23.04	31.08	14.58	9.9	117.2	-1.4
			1.0	23.07	31.12	14.59	9.8	116.7	-1.4
			2.2	23.23	31.25	14.28	9.5	112.4	-1.0
			3.0	23.11	31.00	13.96	9.5	111.7	-1.0
			4.2	23.58	31.41	13.18	9.4	109.1	-0.8
			5.1	23.74	31.37	12.17	9.4	107.0	-0.6
			6.1	24.16	31.65	11.04	9.3	102.8	-0.3
			7.0	24.50	31.79	9.69	9.4	101.2	-0.1
			8.3	24.84	32.03	8.73	9.4	98.9	0.1
			9.0	24.82	31.91	8.24	9.4	98.4	0.2
			10.1	24.80	31.88	8.12	9.3	96.8	0.3
			11.1	24.89	31.95	7.91	9.2	95.9	0.4
			12.1	24.93	31.97	7.76	9.2	95.0	0.5
			13.1	24.94	31.97	7.69	9.2	94.6	0.5
			14.3	25.02	32.04	7.48	9.2	94.4	0.5
			15.3	24.99	32.00	7.45	9.2	94.1	0.6
			16.2	25.00	32.00	7.42	9.1	93.6	0.6
			17.1	25.03	32.03	7.34	9.1	93.3	0.7
			18.1	25.03	32.01	7.29	9.1	92.9	0.7
			19.2	25.03	32.01	7.23	9.1	92.7	0.7
			20.1	25.05	32.02	7.17	9.0	92.3	0.8
			21.2	25.06	32.02	7.11	9.0	92.0	0.8
			22.1	25.06	32.03	7.09	9.0	91.9	0.8
			23.1	25.05	32.00	7.08	9.0	91.4	0.8
			24.1	25.09	32.04	7.02	9.0	91.3	0.9
			25.0	25.09	32.03	6.97	9.0	91.6	0.8
			26.0	25.11	32.05	6.93	9.0	91.4	0.8
			27.0	25.13	32.07	6.88	8.9	90.7	0.9
			28.0	25.13	32.07	6.85	8.9	90.5	0.9
			29.1	25.13	32.06	6.83	8.9	90.0	1.0
			30.3	25.17	32.10	6.74	8.9	90.0	1.0
			31.1	25.17	32.10	6.71	8.9	90.0	1.0
			32.1	25.20	32.12	6.66	8.9	89.5	1.0
			33.1	25.21	32.13	6.64	8.8	89.2	1.1
			34.1	25.23	32.15	6.59	8.9	89.4	1.0
			35.0	25.25	32.17	6.53	8.9	89.2	1.1
			36.0	25.28	32.19	6.47	8.8	88.0	1.2
			37.1	25.30	32.22	6.43	8.8	88.1	1.2
			38.0	25.33	32.25	6.40	8.8	88.2	1.2
			39.0	25.34	32.26	6.40	8.8	88.3	1.2
			40.1	25.36	32.28	6.40	8.8	88.7	1.1
			41.1	25.35	32.27	6.40	9.0	90.5	1.0
			41.3	25.38	32.31	6.40	9.0	90.9	0.9

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
MB01	08/28/90	1310	0.2	20.83	29.88	20.15	8.9	117.3	-1.3
			1.1	21.60	30.55	19.09	8.5	110.1	-0.8
			2.1	21.65	30.50	18.75	8.5	109.8	-0.8
			3.2	21.82	30.60	18.35	8.3	106.3	-0.5
			4.2	22.08	30.68	17.52	8.3	104.9	-0.4
			5.2	22.15	30.73	17.41	8.3	104.1	-0.3
			6.2	22.17	30.71	17.24	8.2	102.2	-0.2
			7.2	22.30	30.79	16.94	8.1	100.5	0.0
			8.2	22.39	30.80	16.57	8.0	98.9	0.1
			9.1	22.52	30.88	16.29	8.0	98.2	0.1
			10.2	22.55	30.89	16.19	7.9	97.5	0.2
			11.0	22.63	30.93	15.96	7.9	96.2	0.3
			12.0	22.49	30.72	15.87	7.7	94.0	0.5
			13.0	22.81	31.02	15.47	7.6	91.6	0.7
			14.1	22.83	30.91	14.95	7.6	90.6	0.8
			15.1	23.12	31.16	14.50	7.5	89.6	0.9
			16.2	23.25	31.20	14.02	7.6	89.0	0.9
			17.0	23.57	31.44	13.34	7.3	84.6	1.3
			18.1	23.75	31.43	12.38	7.5	85.0	1.3
			19.3	23.98	31.58	11.79	7.6	85.4	1.3
			20.0	23.94	31.50	11.64	7.6	85.4	1.3
			21.2	24.14	31.62	11.02	7.5	83.5	1.5
			22.1	24.34	31.73	10.40	7.6	83.0	1.5
			23.1	24.39	31.73	10.09	7.7	83.6	1.5
			24.0	24.53	31.87	9.89	7.7	83.6	1.5
			25.0	24.54	31.86	9.76	7.7	83.2	1.6
			26.0	24.57	31.88	9.66	7.6	82.0	1.7
			27.2	24.61	31.90	9.49	7.6	81.1	1.8
			28.2	24.63	31.91	9.41	7.4	79.1	1.9
			29.0	24.60	31.85	9.33	7.3	78.2	2.0
			30.0	24.64	31.88	9.26	7.2	77.1	2.1
			31.1	24.67	31.90	9.15	7.1	75.4	2.3
			32.2	24.79	31.99	8.81	7.1	75.2	2.3
			33.1	24.93	32.10	8.47	7.2	75.5	2.3
			34.0	24.95	32.09	8.25	7.2	75.8	2.3
			35.2	25.00	32.13	8.15	7.2	75.0	2.4
			36.1	25.04	32.16	8.06	7.3	75.7	2.3
			37.0	25.04	32.16	8.01	7.2	75.3	2.4
			38.0	25.11	32.22	7.89	7.2	75.0	2.4
			39.2	25.14	32.25	7.83	7.2	74.6	2.5
			40.1	25.18	32.28	7.74	7.2	74.9	2.4
			41.2	25.18	32.28	7.74	7.3	75.8	2.3
			42.1	25.20	32.31	7.74	7.4	76.7	2.2
			43.1	25.25	32.37	7.76	7.4	76.5	2.3
			43.1	25.27	32.40	7.75	7.4	76.7	2.2

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
MB02	07/19/90	1043	0.5	23.32	31.49	14.77	10.0	119.4	-1.6
			1.0	23.06	31.16	14.79	9.8	116.7	-1.4
			2.0	23.29	31.42	14.66	9.5	113.7	-1.1
			3.1	23.67	31.69	13.80	9.5	111.4	-1.0
			4.0	23.81	31.56	12.56	9.6	109.4	-0.8
			5.2	23.68	31.17	11.69	9.3	104.3	-0.4
			6.0	24.34	31.61	9.81	9.5	102.9	-0.3
			7.3	24.52	31.75	9.36	9.3	99.3	0.1
			8.0	24.89	32.06	8.51	9.3	98.4	0.2
			9.3	24.84	31.92	8.11	9.3	96.9	0.3
			10.0	24.81	31.86	7.99	9.2	95.7	0.4
			11.1	24.95	31.99	7.73	9.2	94.7	0.5
			12.1	25.01	32.03	7.54	9.2	94.5	0.5
			13.0	24.95	31.93	7.44	9.2	94.1	0.6
			14.2	25.02	32.00	7.33	9.2	93.8	0.6
			15.2	25.03	32.01	7.29	9.1	93.4	0.6
			16.2	25.06	32.04	7.20	9.1	93.0	0.7
			17.2	25.05	32.02	7.18	9.1	92.9	0.7
			18.0	25.05	32.02	7.16	9.1	92.8	0.7
			19.2	25.06	32.02	7.10	9.1	92.6	0.7
			20.0	25.07	32.03	7.09	9.1	92.5	0.7
			21.3	25.07	32.03	7.07	9.1	92.2	0.8
			22.1	25.09	32.04	7.04	9.0	92.1	0.8
			23.3	25.09	32.04	6.99	9.1	92.1	0.8
			24.1	25.11	32.06	6.94	9.1	91.9	0.8
			25.2	25.12	32.07	6.89	9.0	91.5	0.8
			26.0	25.13	32.07	6.87	9.0	91.6	0.8
			27.1	25.13	32.07	6.84	8.9	90.5	0.9
			28.0	25.17	32.10	6.77	9.0	91.0	0.9
			29.2	25.18	32.11	6.71	9.0	91.1	0.9
			30.3	25.19	32.11	6.68	9.0	90.6	0.9
			31.3	25.20	32.13	6.65	9.0	90.6	0.9
			32.1	25.21	32.13	6.61	9.0	90.5	0.9
			33.4	25.21	32.12	6.58	8.9	89.9	1.0
			34.1	25.21	32.13	6.57	8.8	88.8	1.1
			35.3	25.24	32.15	6.53	8.8	88.5	1.1
			36.1	25.30	32.21	6.42	8.8	88.2	1.2
			37.2	25.29	32.20	6.41	8.7	87.7	1.2
			38.2	25.30	32.21	6.42	8.8	87.9	1.2
			39.3	25.31	32.22	6.41	8.7	87.5	1.2
			40.2	25.32	32.23	6.38	8.7	87.5	1.2
			41.4	25.32	32.23	6.37	8.8	87.8	1.2
			42.2	25.32	32.24	6.37	8.8	88.2	1.2
			43.2	25.33	32.24	6.37	8.8	88.5	1.1
			44.0	25.33	32.24	6.37	8.8	88.3	1.2
			44.7	25.35	32.26	6.37	8.9	89.8	1.0

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
MB02	08/28/90	1338	0.2	20.71	29.75	20.20	8.9	116.7	-1.3
			1.0	21.44	30.35	19.11	8.4	109.2	-0.7
			2.1	21.61	30.46	18.80	8.5	108.9	-0.7
			3.1	21.67	30.44	18.50	8.2	104.9	-0.4
			4.2	22.06	30.66	17.57	8.3	103.9	-0.3
			5.0	22.12	30.69	17.43	8.2	102.7	-0.2
			6.2	22.23	30.77	17.18	8.0	100.6	-0.1
			7.3	22.39	30.87	16.85	7.9	98.8	0.1
			8.2	22.60	31.02	16.39	7.9	98.0	0.2
			9.1	22.48	30.81	16.19	7.9	97.3	0.2
			10.2	22.62	30.95	16.07	7.9	96.4	0.3
			11.1	22.60	30.88	15.91	7.8	95.7	0.4
			12.1	22.62	30.89	15.85	7.8	95.1	0.4
			13.0	22.56	30.80	15.79	7.7	93.6	0.5
			14.1	22.59	30.75	15.50	7.5	90.8	0.8
			15.1	22.58	30.61	15.03	7.5	89.3	0.9
			16.1	23.12	31.12	14.34	7.4	88.0	1.0
			17.3	23.34	31.26	13.80	7.2	84.0	1.4
			18.2	23.52	31.29	13.00	7.1	81.9	1.6
			19.1	23.70	31.35	12.27	7.3	82.8	1.5
			20.1	23.80	31.41	12.02	7.4	83.5	1.5
			21.2	23.90	31.47	11.70	7.5	84.3	1.4
			22.1	23.86	31.37	11.50	7.4	82.8	1.5
			23.1	23.99	31.45	11.11	7.4	82.1	1.6
			24.1	24.25	31.67	10.62	7.3	80.8	1.7
			25.1	24.32	31.70	10.33	7.4	80.6	1.8
			26.3	24.41	31.75	10.03	7.3	79.0	1.9
			27.0	24.51	31.79	9.62	7.3	78.4	2.0
			28.0	24.57	31.84	9.47	7.2	77.8	2.1
			29.2	24.65	31.91	9.31	7.1	76.1	2.2
			30.0	24.52	31.73	9.26	7.0	75.0	2.3
			31.1	24.58	31.77	9.07	6.9	73.3	2.5
			32.3	24.81	31.99	8.70	6.9	73.3	2.5
			33.1	24.84	32.00	8.56	7.0	73.5	2.5
			34.1	24.92	32.05	8.28	7.1	74.0	2.5
			35.0	25.03	32.17	8.13	7.1	74.0	2.5
			36.3	25.04	32.17	8.07	7.1	74.5	2.4
			37.3	25.05	32.17	8.05	7.1	74.4	2.5
			38.1	25.05	32.18	8.03	7.1	74.3	2.5
			39.1	25.05	32.17	8.00	7.1	74.3	2.5
			40.1	25.09	32.20	7.92	7.2	74.4	2.5
			41.0	25.14	32.25	7.80	7.2	74.6	2.4
			42.2	25.19	32.29	7.73	7.2	74.7	2.4
			43.0	25.21	32.32	7.72	7.2	74.6	2.5
			44.0	25.27	32.39	7.73	7.2	75.1	2.4
			44.0	25.27	32.39	7.73	7.2	75.1	2.4

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
MB03	07/19/90	1056	0.4	23.39	31.45	14.31	10.0	118.7	-1.6
			1.0	23.39	31.45	14.28	9.9	117.2	-1.5
			2.1	23.37	31.42	14.23	9.8	116.1	-1.4
			3.1	23.33	31.34	14.14	9.7	114.9	-1.3
			4.1	23.32	31.30	14.06	9.6	113.6	-1.2
			5.2	23.26	31.19	13.92	9.6	112.3	-1.1
			6.2	23.73	31.65	13.35	9.5	111.1	-0.9
			7.2	23.32	30.99	12.83	9.6	110.2	-0.9
			8.2	23.85	31.49	12.08	9.5	107.5	-0.7
			9.1	23.86	31.38	11.59	9.4	104.9	-0.4
			10.0	23.97	31.31	10.62	9.3	102.2	-0.2
			11.2	24.91	32.16	8.92	9.2	98.1	0.2
			12.2	24.81	31.92	8.33	9.4	98.1	0.2
			13.0	24.78	31.86	8.15	9.3	97.4	0.2
			14.3	24.89	31.95	7.90	9.2	95.8	0.4
			15.3	24.90	31.93	7.79	9.2	94.8	0.5
			16.2	24.95	31.97	7.62	9.0	93.1	0.7
			17.0	25.01	32.01	7.42	9.0	92.3	0.7
			18.2	25.05	32.04	7.29	8.9	91.3	0.9
			19.2	25.06	32.05	7.26	9.0	91.6	0.8
			20.3	25.06	32.04	7.24	8.9	91.0	0.9
			21.2	25.06	32.04	7.23	8.9	90.7	0.9
			22.2	25.07	32.05	7.20	8.8	90.1	1.0
			23.0	25.09	32.06	7.14	8.9	90.3	1.0
			24.1	25.08	32.06	7.13	8.9	90.5	0.9
			25.2	25.06	32.02	7.09	8.8	89.8	1.0
			26.0	25.12	32.07	6.97	8.7	88.7	1.1
			27.0	25.15	32.11	6.93	8.7	88.8	1.1
			28.0	25.15	32.10	6.88	8.7	88.5	1.1
			29.1	25.15	32.09	6.85	8.8	88.7	1.1
			30.1	25.16	32.10	6.83	8.7	88.2	1.2
			31.0	25.18	32.12	6.78	8.7	88.4	1.1
			32.1	25.17	32.11	6.77	8.7	88.3	1.2
			33.2	25.19	32.13	6.75	8.7	88.4	1.1
			34.0	25.19	32.12	6.72	8.7	87.6	1.2
			35.1	25.22	32.14	6.64	8.6	87.2	1.3
			36.0	25.26	32.19	6.57	8.7	87.4	1.2
			37.0	25.26	32.19	6.57	8.7	87.7	1.2
			38.2	25.27	32.19	6.56	8.7	87.4	1.2
			39.2	25.27	32.20	6.55	8.7	87.9	1.2
			40.0	25.27	32.20	6.54	8.7	87.7	1.2
			41.2	25.29	32.22	6.55	8.8	88.7	1.1
			41.2	25.29	32.22	6.55	8.8	88.7	1.1

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ_t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
MB03	08/28/90	1301	0.2	21.00	30.02	19.86	9.0	118.2	-1.4
			1.1	21.40	30.42	19.52	8.7	113.1	-1.0
			2.1	21.51	30.38	18.94	8.6	110.9	-0.8
			3.2	21.70	30.54	18.64	8.4	107.8	-0.6
			4.0	21.66	30.32	18.13	8.2	103.6	-0.3
			5.0	22.07	30.76	17.82	8.1	102.8	-0.2
			6.1	22.08	30.69	17.54	8.1	101.9	-0.2
			7.0	22.15	30.71	17.35	8.1	101.2	-0.1
			8.1	22.01	30.43	17.02	7.9	97.7	0.2
			9.2	22.45	30.89	16.62	7.7	95.4	0.4
			10.1	22.37	30.76	16.51	7.6	93.8	0.5
			11.2	22.50	30.90	16.43	7.5	92.9	0.6
			12.2	22.63	30.90	15.88	7.5	91.8	0.7
			13.1	22.94	31.11	15.18	7.6	91.9	0.7
			14.2	23.06	31.16	14.80	7.6	91.4	0.7
			15.2	22.98	30.99	14.52	7.6	90.2	0.8
			16.2	23.30	31.27	14.01	7.6	89.7	0.9
			17.1	23.12	31.00	13.90	7.6	89.4	0.9
			18.1	23.00	30.81	13.75	7.4	86.7	1.1
			19.2	23.64	31.42	12.93	7.4	85.0	1.3
			20.1	23.85	31.54	12.27	7.4	84.2	1.4
			21.1	23.69	31.20	11.73	7.5	83.9	1.4
			22.1	24.13	31.64	11.19	7.5	84.0	1.4
			23.2	24.06	31.51	10.97	7.5	83.5	1.5
			24.1	24.33	31.71	10.34	7.7	83.8	1.5
			25.1	24.41	31.79	10.23	7.7	83.9	1.5
			26.2	24.50	31.84	9.92	7.7	83.6	1.5
			27.0	24.55	31.85	9.67	7.7	82.8	1.6
			28.0	24.67	31.95	9.39	7.7	82.5	1.6
			29.0	24.64	31.90	9.32	7.7	82.0	1.7
			30.1	24.70	31.95	9.19	7.6	81.4	1.7
			31.1	24.72	31.95	9.07	7.6	80.6	1.8
			32.2	24.83	32.05	8.88	7.6	80.1	1.9
			33.2	24.86	32.07	8.77	7.4	78.7	2.0
			34.2	24.88	32.07	8.68	7.4	78.0	2.1
			35.0	24.88	32.06	8.64	7.3	77.2	2.2
			36.1	24.90	32.08	8.55	7.2	75.6	2.3
			37.2	24.91	32.07	8.44	7.0	73.2	2.6
			38.2	25.12	32.28	8.10	7.1	74.4	2.5
			39.0	25.16	32.31	8.03	7.1	73.5	2.5
			39.8	25.22	32.39	8.03	7.1	74.5	2.4

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
MB04	07/19/90	1123	0.4	23.30	31.38	14.45	9.7	115.4	-1.3
			1.3	23.47	31.57	14.34	9.6	113.7	-1.2
			2.2	23.48	31.44	13.77	9.4	110.0	-0.8
			3.0	23.81	31.56	12.59	9.5	108.4	-0.7
			4.1	24.13	31.59	10.94	9.7	107.8	-0.7
			5.2	24.76	32.18	9.91	9.9	107.3	-0.7
			6.1	24.66	31.94	9.41	10.0	107.3	-0.7
			7.1	24.70	31.92	9.07	10.1	107.4	-0.7
			8.0	24.74	31.95	8.94	10.1	106.8	-0.6
			9.2	24.78	31.98	8.82	10.0	105.8	-0.5
			10.2	24.82	32.01	8.69	10.0	105.2	-0.5
			11.2	24.84	32.01	8.64	9.9	104.6	-0.4
			12.2	24.82	31.99	8.62	9.8	103.1	-0.3
			13.0	24.87	32.04	8.53	9.6	100.6	-0.1
			14.1	24.84	31.97	8.40	9.3	97.6	0.2
			15.1	24.92	32.00	8.01	9.4	98.2	0.2
			16.1	24.95	32.02	7.92	9.5	98.2	0.2
			17.0	24.97	32.05	7.95	9.4	98.2	0.2
			18.0	24.97	32.06	7.94	9.4	97.3	0.3
			19.0	24.97	32.05	7.95	9.2	95.6	0.4
			20.3	24.98	32.05	7.88	8.9	92.8	0.7
			21.2	25.08	32.13	7.60	8.9	91.8	0.8
			22.0	25.03	32.04	7.41	8.9	91.5	0.8
			23.1	25.04	32.04	7.36	8.9	91.0	0.9
			24.1	25.08	32.06	7.22	8.8	90.3	1.0
			25.1	25.12	32.09	7.10	8.8	90.1	1.0
			26.1	25.11	32.08	7.05	8.8	90.0	1.0
			27.0	25.11	32.07	7.03	8.8	89.9	1.0
			28.0	25.11	32.07	7.02	8.7	89.0	1.1
			29.4	25.12	32.08	7.00	8.6	88.0	1.2
			30.2	25.16	32.12	6.93	8.7	88.1	1.2
			31.5	25.17	32.12	6.87	8.6	87.6	1.2
			32.3	25.17	32.12	6.84	8.7	87.7	1.2
			33.0	25.19	32.13	6.77	8.6	87.4	1.2
			34.1	25.21	32.14	6.72	8.6	87.1	1.3
			35.1	25.23	32.17	6.67	8.6	86.9	1.3
			36.1	25.24	32.18	6.63	8.6	86.8	1.3
			37.0	25.26	32.19	6.62	8.6	87.0	1.3
			38.0	25.32	32.26	6.56	8.7	88.1	1.2
			39.1	25.29	32.23	6.56	8.8	88.5	1.1
			39.1	25.29	32.23	6.56	8.8	88.5	1.1

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
MB04	08/28/90	1410	0.3	21.20	30.44	20.34	8.6	114.5	-1.1
			1.2	21.42	30.43	19.44	8.5	111.1	-0.9
			2.1	21.53	30.49	19.19	8.3	107.9	-0.6
			3.2	21.91	30.81	18.66	7.9	102.1	-0.2
			4.1	21.81	30.40	17.77	7.8	98.4	0.1
			5.1	22.28	30.80	17.06	7.8	96.9	0.2
			6.0	22.38	30.76	16.52	7.7	95.6	0.4
			7.2	22.46	30.74	16.08	7.7	94.6	0.4
			8.1	22.77	30.92	15.29	7.7	92.9	0.6
			9.2	22.95	30.93	14.48	7.7	91.5	0.7
			10.2	23.18	31.14	14.16	7.7	90.8	0.8
			11.0	23.35	31.29	13.89	7.7	90.4	0.8
			12.1	23.10	30.90	13.62	7.7	90.1	0.9
			13.2	23.38	31.18	13.30	7.7	89.6	0.9
			14.1	23.59	31.35	12.88	7.7	88.8	1.0
			15.2	23.65	31.34	12.50	7.8	88.6	1.0
			16.1	23.87	31.52	12.10	7.8	88.5	1.0
			17.0	23.74	31.36	12.12	7.8	88.3	1.0
			18.1	23.94	31.54	11.83	7.8	87.7	1.1
			19.1	24.01	31.60	11.67	7.8	87.3	1.1
			20.1	23.95	31.50	11.58	7.7	86.8	1.2
			21.0	23.95	31.45	11.35	7.8	86.6	1.2
			22.2	24.15	31.61	10.90	7.5	82.7	1.6
			23.1	24.11	31.47	10.52	7.5	81.6	1.7
			24.2	24.34	31.67	10.08	7.3	79.4	1.9
			25.0	24.52	31.81	9.65	7.4	79.4	1.9
			26.1	24.65	31.92	9.40	7.4	79.6	1.9
			27.0	24.59	31.82	9.30	7.4	79.3	1.9
			28.2	24.76	32.00	9.08	7.3	78.1	2.1
			29.1	24.68	31.88	8.98	7.3	77.8	2.1
			30.1	24.80	31.99	8.75	7.3	77.0	2.2
			31.1	24.78	31.96	8.72	7.3	76.8	2.2
			32.1	24.86	32.02	8.49	7.2	76.1	2.3
			33.2	24.90	32.04	8.35	7.2	75.3	2.4
			34.1	24.98	32.10	8.14	7.2	75.4	2.4
			35.1	25.11	32.22	7.90	7.3	75.7	2.3
			36.0	25.13	32.24	7.84	7.3	75.8	2.3
			37.1	25.17	32.28	7.83	7.3	76.1	2.3
			38.3	25.14	32.26	7.84	7.3	76.2	2.3
			39.0	25.21	32.34	7.84	7.3	75.8	2.3
			39.2	25.20	32.32	7.84	7.3	76.1	2.3

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
MB05	07/19/90	1143	0.4	23.35	31.39	14.23	9.8	115.7	-1.3
			1.0	23.40	31.44	14.20	9.6	113.1	-1.1
			2.3	23.50	31.52	14.02	9.4	111.2	-1.0
			3.0	23.62	31.60	13.69	9.3	109.5	-0.8
			4.0	24.03	31.57	11.45	9.3	103.9	-0.3
			5.3	24.63	31.88	9.26	9.6	102.5	-0.2
			6.3	24.75	31.90	8.64	9.6	100.8	-0.1
			7.1	24.74	31.87	8.52	9.5	99.8	0.0
			8.0	24.84	31.95	8.31	9.5	99.2	0.1
			9.1	24.78	31.87	8.27	9.4	97.9	0.2
			10.0	24.83	31.91	8.15	9.4	97.6	0.2
			11.1	24.88	31.95	8.02	9.3	97.2	0.3
			12.0	24.89	31.95	7.96	9.3	96.6	0.3
			13.0	24.89	31.96	7.94	9.3	96.4	0.3
			14.0	24.91	31.96	7.86	9.3	96.0	0.4
			15.1	24.94	31.99	7.78	9.2	95.5	0.4
			16.1	24.98	32.01	7.61	9.3	95.9	0.4
			17.2	24.99	32.03	7.63	9.4	96.8	0.3
			18.1	25.00	32.03	7.62	9.5	98.2	0.2
			19.1	24.96	32.00	7.74	9.3	96.4	0.3
			20.1	24.99	32.07	7.89	9.0	93.7	0.6
			21.2	25.07	32.10	7.51	9.0	92.7	0.7
			22.0	25.05	32.05	7.31	9.0	92.5	0.7
			23.2	25.08	32.07	7.21	9.0	92.3	0.8
			24.1	25.07	32.05	7.19	9.0	92.2	0.8
			25.0	25.08	32.06	7.18	9.0	92.0	0.8
			26.2	25.09	32.06	7.12	8.9	90.8	0.9
			27.3	25.12	32.10	7.06	8.8	89.8	1.0
			28.3	25.14	32.10	6.96	8.8	89.3	1.1
			29.2	25.14	32.09	6.90	8.8	89.1	1.1
			30.1	25.16	32.11	6.82	8.6	86.9	1.3
			31.2	25.17	32.11	6.77	8.5	86.0	1.4
			32.2	25.24	32.17	6.63	8.5	85.8	1.4
			33.1	25.25	32.17	6.57	8.5	85.8	1.4
			34.1	25.25	32.17	6.57	8.5	86.0	1.4
			35.0	25.27	32.20	6.56	8.5	85.9	1.4
			36.1	25.26	32.18	6.55	8.5	85.7	1.4
			37.3	25.26	32.18	6.55	8.6	86.4	1.4
			38.3	25.26	32.19	6.54	8.6	86.8	1.3
			39.4	25.27	32.20	6.54	8.7	87.1	1.3
			40.2	25.32	32.26	6.54	8.7	87.6	1.2
			40.3	25.34	32.28	6.54	8.7	87.6	1.2

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
MB05	08/28/90	1400	0.2	21.15	30.28	20.08	8.6	113.7	-1.0
			1.1	21.45	30.58	19.82	8.4	110.0	-0.8
			2.1	21.60	30.54	19.05	8.4	108.1	-0.6
			3.0	21.81	30.73	18.81	8.2	106.3	-0.5
			4.1	21.59	30.36	18.57	7.9	101.4	-0.1
			5.1	21.99	30.67	17.89	7.8	98.8	0.1
			6.2	22.03	30.52	17.23	7.5	93.9	0.5
			7.1	22.26	30.66	16.67	7.5	92.4	0.6
			8.2	22.70	30.94	15.64	7.5	91.3	0.7
			9.2	22.74	30.84	15.11	7.5	90.3	0.8
			10.2	23.07	31.12	14.60	7.5	89.9	0.8
			11.0	22.68	30.61	14.56	7.5	88.5	1.0
			12.3	23.31	31.24	13.86	7.5	87.6	1.1
			13.0	23.41	31.28	13.51	7.5	87.4	1.1
			14.1	23.68	31.43	12.75	7.6	87.1	1.1
			15.2	23.86	31.57	12.36	7.6	86.8	1.2
			16.0	23.83	31.50	12.24	7.5	85.5	1.3
			17.0	23.64	31.18	11.92	7.4	83.2	1.5
			18.1	24.00	31.55	11.50	7.4	82.8	1.5
			19.1	24.06	31.55	11.22	7.5	83.4	1.5
			20.2	24.01	31.49	11.22	7.5	83.7	1.5
			21.1	24.09	31.57	11.08	7.5	83.3	1.5
			22.1	24.11	31.57	10.96	7.3	80.8	1.7
			23.0	23.95	31.25	10.46	7.2	79.2	1.9
			24.3	24.60	31.90	9.59	7.2	78.0	2.0
			25.2	24.82	32.06	9.00	7.3	77.3	2.1
			26.1	24.80	31.99	8.73	7.3	77.5	2.1
			27.2	24.80	31.98	8.71	7.3	77.0	2.2
			28.3	24.84	32.03	8.70	7.3	76.7	2.2
			29.0	24.77	31.93	8.64	7.2	76.0	2.3
			30.2	24.93	32.07	8.28	7.2	75.8	2.3
			31.1	25.04	32.17	8.09	7.3	76.0	2.3
			32.1	25.01	32.13	8.06	7.3	75.7	2.3
			33.2	25.00	32.11	8.00	7.3	75.6	2.3
			34.1	25.12	32.22	7.79	7.3	75.9	2.3
			35.0	25.12	32.22	7.77	7.3	75.9	2.3
			36.0	25.12	32.20	7.72	7.3	75.2	2.4
			37.0	25.23	32.32	7.54	7.3	75.1	2.4
			38.0	25.27	32.35	7.51	7.3	75.4	2.4
			39.1	25.29	32.38	7.51	7.3	75.7	2.4
			40.0	25.28	32.38	7.53	7.4	76.1	2.3
			40.0	25.28	32.38	7.53	7.4	76.1	2.3

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
MB06	07/19/90	1206	0.2	23.28	31.33	14.35	9.7	115.2	-1.3
			1.1	23.49	31.56	14.19	9.6	113.7	-1.2
			2.2	23.55	31.52	13.75	9.6	113.0	-1.1
			3.2	23.61	31.50	13.39	9.6	111.8	-1.0
			4.1	23.55	31.26	12.75	9.7	110.9	-1.0
			5.1	23.98	31.68	12.17	9.7	110.1	-0.9
			6.0	23.71	31.24	11.80	9.7	109.0	-0.8
			7.1	24.14	31.68	11.30	9.6	107.0	-0.6
			8.2	24.46	31.79	9.92	9.7	104.9	-0.5
			9.1	24.43	31.68	9.59	9.6	103.7	-0.3
			10.2	24.61	31.81	9.07	9.7	102.9	-0.3
			11.1	24.60	31.77	8.96	9.7	102.7	-0.3
			12.0	24.70	31.87	8.78	9.5	100.7	-0.1
			13.0	24.69	31.81	8.53	9.4	99.2	0.1
			14.1	24.76	31.86	8.32	9.3	97.4	0.3
			15.2	24.86	31.95	8.14	9.2	95.9	0.4
			16.1	24.88	31.95	7.98	9.1	94.5	0.5
			17.4	24.94	31.97	7.72	9.1	93.6	0.6
			18.2	24.94	31.96	7.65	9.0	93.1	0.7
			19.1	24.96	31.97	7.54	9.0	92.6	0.7
			20.2	24.98	31.99	7.47	8.9	91.7	0.8
			21.2	24.98	31.97	7.38	8.9	90.7	0.9
			22.3	25.04	32.03	7.30	8.8	90.3	0.9
			23.1	25.04	32.02	7.28	8.8	89.6	1.0
			24.1	25.07	32.05	7.18	8.7	88.8	1.1
			25.2	25.11	32.08	7.12	8.6	87.7	1.2
			26.1	25.11	32.08	7.03	8.6	87.5	1.2
			27.0	25.14	32.10	6.97	8.5	86.9	1.3
			28.3	25.16	32.12	6.90	8.5	86.4	1.3
			29.3	25.17	32.12	6.90	8.5	86.6	1.3
			30.2	25.19	32.14	6.84	8.5	86.6	1.3
			31.2	25.20	32.15	6.81	8.5	86.5	1.3
			32.2	25.21	32.16	6.79	8.6	87.3	1.3
			33.0	25.25	32.21	6.76	8.6	87.4	1.2
			34.3	25.24	32.20	6.77	8.7	88.1	1.2
			34.6	25.27	32.23	6.77	8.7	88.1	1.2

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
SS01	07/19/90	844	0.3	22.96	30.56	12.96	9.3	106.7	-0.6
			1.3	23.14	31.18	14.47	9.3	110.1	-0.8
			2.1	23.26	31.03	13.29	9.1	105.1	-0.4
			3.0	24.43	31.93	10.76	9.3	102.9	-0.3
			4.1	24.57	31.84	9.50	9.6	103.2	-0.3
			5.1	24.62	31.87	9.30	9.6	102.7	-0.3
			6.2	24.72	31.94	9.02	9.6	102.5	-0.2
			7.0	24.71	31.93	8.98	9.6	102.2	-0.2
			8.1	24.74	31.94	8.91	9.7	102.4	-0.2
			9.1	24.76	31.96	8.90	9.7	102.5	-0.2
			10.1	24.76	31.97	8.87	9.6	102.2	-0.2
			11.0	24.84	32.06	8.83	9.6	102.1	-0.2
			12.1	24.84	32.04	8.76	9.6	101.5	-0.1
			13.0	25.06	32.33	8.78	9.8	103.4	-0.3
			13.0	25.06	32.33	8.78	9.8	103.4	-0.3
	08/28/90	1128	0.3	21.12	29.69	18.40	7.8	99.4	0.0
			1.1	21.64	30.53	18.89	8.0	103.7	-0.3
			2.0	21.54	30.31	18.62	7.9	101.1	-0.1
			3.2	22.02	30.71	17.88	7.4	93.3	0.5
			4.0	21.96	30.60	17.75	7.1	89.6	0.8
			5.1	22.23	30.85	17.47	7.0	87.8	1.0
			6.0	22.22	30.77	17.22	7.0	87.0	1.0
			7.0	22.42	30.95	16.94	6.8	85.0	1.2
			8.0	22.58	31.03	16.53	6.7	82.2	1.4
			9.0	22.72	31.12	16.23	6.5	79.4	1.7
			10.1	22.89	31.24	15.87	6.2	75.4	2.0
			10.7	23.12	31.49	15.68	6.3	77.0	1.9

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
SS02	07/19/90	811	0.3	23.31	31.26	13.95	9.2	107.9	-0.7
			1.2	23.26	31.17	13.82	9.1	106.9	-0.6
			2.1	23.44	31.30	13.45	9.1	106.4	-0.6
			3.2	23.20	30.94	13.27	9.2	106.1	-0.5
			4.0	23.56	31.27	12.75	8.9	102.4	-0.2
			5.2	24.14	31.58	10.86	9.3	102.3	-0.2
			6.2	24.40	31.74	10.05	9.4	102.6	-0.2
			7.2	24.48	31.79	9.76	9.5	102.5	-0.2
			8.1	24.72	31.96	9.15	9.6	102.2	-0.2
			9.1	24.75	31.99	9.08	9.6	101.9	-0.2
			10.1	24.88	32.12	8.94	9.6	102.2	-0.2
			11.1	24.93	32.18	8.87	9.6	102.5	-0.2
			11.6	25.10	32.40	8.88	9.7	102.8	-0.3
	08/28/90	912	0.2	21.24	30.02	18.95	8.3	106.4	-0.5
			1.1	21.47	30.32	18.91	8.0	102.9	-0.2
			2.0	21.53	30.38	18.85	7.2	93.3	0.5
			3.0	21.97	30.71	18.10	7.0	89.4	0.8
			4.1	22.23	30.87	17.51	6.9	87.3	1.0
			5.1	22.35	30.94	17.23	6.8	85.6	1.2
			6.0	22.47	31.02	16.96	6.9	85.8	1.1
			7.2	22.51	31.04	16.88	6.9	85.6	1.2
			8.0	22.53	31.06	16.82	6.8	84.2	1.3
			9.2	22.57	31.08	16.75	6.6	82.4	1.4
			10.0	22.63	31.13	16.64	6.7	83.4	1.3
			10.2	22.67	31.18	16.65	6.7	83.4	1.3

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
SS03	07/19/90	819	0.3	23.17	30.92	13.36	9.3	108.1	-0.7
			1.0	23.15	31.11	14.12	9.5	111.5	-1.0
			2.1	23.62	31.43	13.04	9.2	106.5	-0.6
			3.2	24.24	31.77	11.12	9.5	105.2	-0.5
			4.1	24.29	31.66	10.30	9.7	105.6	-0.5
			5.2	24.40	31.73	9.97	9.6	104.0	-0.4
			6.1	24.58	31.85	9.47	9.6	102.6	-0.2
			7.2	24.72	31.93	8.95	9.6	102.5	-0.2
			8.3	24.75	31.94	8.84	9.6	101.6	-0.2
			9.3	24.78	31.95	8.72	9.6	101.3	-0.1
			10.1	24.83	32.00	8.62	9.6	101.0	-0.1
			11.2	24.86	32.02	8.52	9.6	101.5	-0.1
			12.0	24.89	32.05	8.48	9.6	101.4	-0.1
			13.0	25.15	32.37	8.44	9.7	102.3	-0.2
	08/28/90	938	0.3	21.54	30.44	19.02	8.4	109.1	-0.7
			1.2	21.58	30.49	19.00	8.3	106.6	-0.5
			2.1	21.55	30.43	18.95	8.0	103.7	-0.3
			3.1	21.77	30.61	18.62	7.7	99.3	0.1
			4.2	22.09	30.78	17.79	7.1	90.0	0.8
			5.1	22.20	30.85	17.59	6.9	87.6	1.0
			6.1	22.13	30.73	17.48	6.8	85.3	1.2
			7.1	22.19	30.78	17.37	6.5	81.0	1.5
			8.1	22.37	30.93	17.11	6.4	79.6	1.6
			9.0	22.45	30.97	16.89	6.3	79.0	1.7
			10.1	22.63	31.08	16.48	6.3	77.6	1.8
			11.1	22.84	31.25	16.11	6.1	74.4	2.1
			11.9	23.11	31.56	15.97	6.2	75.7	2.0

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
SS04	07/19/90	922	0.2	22.82	30.88	14.92	9.6	114.4	-1.2
			1.1	23.64	31.61	13.63	9.3	108.3	-0.7
			2.0	23.83	31.54	12.41	9.4	107.7	-0.7
			3.2	24.11	31.74	11.74	9.4	105.9	-0.5
			4.2	24.15	31.64	11.09	9.3	103.6	-0.3
			5.1	24.26	31.66	10.53	9.2	100.7	-0.1
			6.2	24.74	31.96	8.99	9.5	101.4	-0.1
			7.0	24.74	31.92	8.80	9.5	100.9	-0.1
			8.0	24.74	31.92	8.76	9.5	100.6	-0.1
			9.2	24.76	31.93	8.70	9.5	100.7	-0.1
			10.0	24.76	31.93	8.69	9.5	100.2	0.0
			11.2	24.79	31.95	8.62	9.5	99.9	0.0
			12.2	24.81	31.96	8.52	9.5	100.1	0.0
			13.1	24.83	31.97	8.49	9.6	100.5	0.0
			14.1	24.85	31.99	8.45	9.5	100.1	0.0
			15.1	24.87	32.01	8.41	9.6	100.3	0.0
			15.6	24.93	32.08	8.40	9.6	100.8	-0.1
	08/28/90	1039	0.3	21.07	30.13	19.92	8.4	110.8	-0.8
			1.1	21.17	30.19	19.74	8.0	104.4	-0.3
			2.1	21.41	30.26	19.00	7.5	96.3	0.3
			3.1	22.06	30.76	17.86	7.3	92.9	0.6
			4.2	22.18	30.83	17.61	7.2	90.7	0.7
			5.1	22.19	30.78	17.40	6.9	86.2	1.1
			6.0	22.27	30.81	17.16	6.9	86.8	1.1
			7.0	22.36	30.88	16.99	6.8	84.9	1.2
			8.1	22.55	31.02	16.61	7.0	87.0	1.0
			9.1	22.55	30.99	16.53	6.9	85.1	1.2
			10.1	22.59	31.00	16.38	6.7	82.4	1.4
			11.2	22.85	31.14	15.68	6.5	78.6	1.8
			12.1	23.12	31.31	15.02	6.4	77.2	1.9
			13.1	23.25	31.39	14.72	6.4	76.6	2.0
			14.0	23.54	31.66	14.36	6.5	77.4	1.9
			14.5	23.69	31.84	14.28	6.6	78.0	1.8

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
SS05	07/19/90	834	0.3	22.68	30.66	14.74	9.5	112.8	-1.1
			1.0	22.86	30.80	14.43	9.4	111.0	-0.9
			2.1	23.14	31.09	14.13	9.3	109.9	-0.8
			3.0	22.69	30.44	13.88	9.3	109.2	-0.8
			4.1	23.37	30.79	11.74	9.3	104.2	-0.4
			5.1	24.25	31.60	10.28	9.6	104.5	-0.4
			6.1	24.53	31.82	9.65	9.6	103.8	-0.4
			7.0	24.51	31.75	9.42	9.6	103.1	-0.3
			8.0	24.70	31.93	9.06	9.6	101.7	-0.2
			9.1	24.86	32.05	8.66	9.6	101.1	-0.1
			10.2	24.95	32.13	8.52	9.6	100.7	-0.1
			11.0	25.17	32.40	8.41	9.6	100.8	-0.1
			12.2	25.76	33.16	8.48	9.6	101.6	-0.2
			12.2	25.76	33.16	8.46	9.6	101.6	-0.2
	08/28/90	1008	0.2	21.39	30.37	19.38	8.5	111.1	-0.9
			1.2	21.53	30.53	19.33	8.2	106.6	-0.5
			2.1	21.85	30.72	18.58	7.8	100.1	0.0
			3.0	22.20	30.92	17.77	7.7	97.3	0.2
			4.1	22.30	30.96	17.50	7.4	92.9	0.6
			5.1	22.33	30.96	17.38	7.0	88.3	0.9
			6.1	22.37	30.98	17.27	7.0	87.7	1.0
			7.0	22.38	30.98	17.24	7.1	89.2	0.9
			8.0	22.48	31.05	17.03	7.1	88.9	0.9
			9.1	22.60	31.15	16.83	7.2	89.0	0.9
			9.4	22.69	31.27	16.86	7.1	89.0	0.9

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
SS06	07/19/90	853	0.2	22.31	30.25	15.06	9.3	111.3	-0.9
			1.1	23.00	31.08	14.76	9.2	110.1	-0.8
			2.0	22.95	30.86	14.20	9.2	108.8	-0.7
			3.0	23.05	30.51	12.30	9.1	102.6	-0.2
			4.1	24.52	31.86	9.84	9.4	101.9	-0.2
			5.2	24.62	31.86	9.23	9.6	102.2	-0.2
			6.0	24.69	31.91	9.05	9.5	101.6	-0.2
			7.1	24.69	31.89	8.97	9.6	101.6	-0.2
			8.0	24.70	31.90	8.94	9.6	101.5	-0.1
			9.2	24.70	31.89	8.88	9.6	101.6	-0.2
			10.0	24.73	31.90	8.74	9.5	100.8	-0.1
			11.0	24.79	31.94	8.56	9.6	100.6	-0.1
			12.1	24.89	32.01	8.29	9.7	101.1	-0.1
			13.1	24.92	32.05	8.24	9.7	101.2	-0.1
			14.1	24.95	32.09	8.22	9.7	101.0	-0.1
			15.0	24.95	32.09	8.24	9.8	102.6	-0.2
	08/28/90	1028	0.4	20.87	29.74	19.55	8.3	107.6	-0.6
			1.0	21.23	30.21	19.53	8.4	109.8	-0.8
			2.1	21.34	30.29	19.33	8.1	105.3	-0.4
			3.0	21.60	30.34	18.44	7.8	99.1	0.1
			4.0	22.21	30.89	17.66	7.6	96.2	0.3
			5.0	22.13	30.75	17.53	7.3	91.8	0.7
			6.1	22.26	30.84	17.30	7.0	88.2	0.9
			7.2	22.42	30.96	17.00	6.8	85.4	1.2
			8.1	22.47	30.97	16.82	6.6	82.5	1.4
			9.1	22.56	31.03	16.62	6.4	79.3	1.7
			10.2	22.77	31.14	16.07	6.3	77.7	1.8
			11.1	22.89	31.22	15.77	6.3	76.8	1.9
			12.1	22.98	31.29	15.63	5.7	69.6	2.5
			12.9	23.23	31.56	15.44	6.0	73.3	2.2

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
SS07	08/28/90	1111	0.2	20.95	29.83	19.50	8.5	111.0	-0.8
			1.1	21.27	30.19	19.33	8.1	104.8	-0.4
			2.0	21.40	30.30	19.15	7.4	96.0	0.3
			3.0	21.86	30.55	18.05	7.9	100.4	0.0
			4.1	22.12	30.78	17.67	7.4	94.0	0.5
			5.1	22.17	30.79	17.50	7.2	90.9	0.7
			6.1	22.19	30.76	17.33	6.8	85.6	1.2
			7.1	22.27	30.78	17.02	6.5	81.3	1.5
			8.1	22.42	30.90	16.79	6.0	74.0	2.1
			9.1	22.59	30.99	16.38	6.0	73.4	2.2
			10.2	22.85	31.14	15.70	5.9	71.7	2.3
			11.0	22.95	31.22	15.50	5.6	67.8	2.7
			12.1	23.08	31.32	15.25	5.2	62.5	3.1
			13.1	23.38	31.61	14.89	5.4	65.3	2.9
			13.1	23.38	31.61	14.89	5.4	65.3	2.9

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
SS08	07/19/90	934	0.4	22.75	30.77	14.83	9.2	109.9	-0.8
			1.2	23.30	31.25	13.99	9.1	107.1	-0.6
			2.0	23.72	31.52	12.92	9.3	107.3	-0.6
			3.1	23.79	31.40	12.00	9.1	102.6	-0.2
			4.1	24.19	31.59	10.60	9.1	100.0	0.0
			5.2	24.62	31.89	9.41	9.3	99.8	0.0
			6.2	24.60	31.81	9.11	9.3	99.1	0.1
			7.0	24.62	31.81	9.03	9.2	98.0	0.2
			8.0	24.77	31.94	8.70	9.2	97.2	0.3
			9.0	24.78	31.94	8.57	9.2	96.6	0.3
			10.2	24.81	31.95	8.51	8.9	93.4	0.6
			11.1	24.88	32.00	8.30	8.8	92.6	0.7
			12.1	24.92	32.04	8.18	8.9	92.9	0.7
			13.1	24.95	32.07	8.15	8.9	92.9	0.7
			14.0	25.15	32.32	8.16	8.9	93.2	0.6
			14.0	25.15	32.32	8.16	8.9	93.2	0.6
	08/28/90	1157	0.2	20.42	29.43	20.39	7.9	104.5	-0.3
			1.0	20.94	29.85	19.60	7.9	102.9	-0.2
			2.1	21.49	30.33	18.87	8.0	102.6	-0.2
			3.1	21.78	30.55	18.39	7.3	93.0	0.6
			4.1	22.21	30.86	17.58	7.0	88.0	1.0
			5.1	22.23	30.85	17.45	7.0	87.7	1.0
			6.0	22.32	30.92	17.29	6.9	86.2	1.1
			7.2	22.38	30.95	17.11	6.9	85.8	1.1
			8.2	22.40	30.88	16.80	6.6	81.9	1.5
			9.2	22.62	31.08	16.54	6.4	79.7	1.6
			10.1	22.55	30.94	16.35	6.3	78.0	1.8
			11.1	22.57	30.91	16.15	5.6	69.2	2.5
			12.1	23.19	31.39	14.99	5.7	68.8	2.6
			13.0	23.20	31.40	15.00	5.8	69.3	2.6

Table 2 (continued)
Salem Sound/Mass Bay, Summer 1990
Profile Data

Station	Date	Time (h)	Depth (m)	Density (σ -t)	Salinity (0/00)	Temp (°C)	DO (mg/l)	%Sat	AOU (mg/l)
SS09	07/19/90	946	0.4	22.88	30.93	14.81	9.4	112.6	-1.1
			1.0	23.10	31.22	14.79	9.2	110.6	-0.9
			2.1	24.03	31.86	12.64	9.3	107.2	-0.6
			3.1	24.05	31.59	11.43	9.5	106.8	-0.6
			4.2	24.31	31.72	10.47	9.6	105.2	-0.5
			5.0	24.45	31.79	9.99	9.7	105.1	-0.5
			6.1	24.54	31.85	9.73	9.7	104.5	-0.4
			7.2	24.72	31.94	9.03	9.9	104.8	-0.5
			8.0	24.70	31.89	8.90	9.8	104.3	-0.4
			9.1	24.73	31.90	8.79	9.7	102.6	-0.3
			10.2	24.77	31.94	8.69	9.6	101.4	-0.1
			11.2	24.83	31.99	8.53	9.6	101.0	-0.1
			12.0	24.93	32.09	8.44	9.7	101.8	-0.2
			12.2	25.04	32.23	8.43	9.7	102.2	-0.2
	08/28/90	1222	0.1	20.37	29.66	21.22	8.9	119.8	-1.5
			1.0	20.80	29.95	20.45	8.6	113.3	-1.0
			2.1	21.00	29.98	19.78	8.5	110.5	-0.8
			3.0	21.16	30.07	19.41	8.2	107.2	-0.6
			4.1	21.96	30.75	18.27	8.0	102.1	-0.2
			5.0	22.03	30.71	17.83	7.8	99.1	0.1
			6.0	22.11	30.78	17.70	7.2	90.5	0.8
			7.2	22.22	30.84	17.48	6.9	86.7	1.1
			8.1	22.23	30.82	17.34	6.5	81.6	1.5
			9.1	22.44	30.99	16.99	6.7	83.8	1.3
			10.1	22.54	31.06	16.79	6.6	81.7	1.5
			11.0	22.82	31.25	16.21	5.8	71.1	2.3
			11.8	23.17	31.54	15.66	6.0	73.0	2.2

DISCUSSION

While reviewing profiles from the cruises conducted in 1990, as well as profiles collected as part of the 1985 301(h) waiver studies, it became apparent that violations of the dissolved oxygen water quality standards were infrequent. The data indicate, however, that there are seasonal as well as spatial trends in dissolved oxygen and density structure that have not been previously discussed. The primary basis for discussion will be the data collected on the two cruises in the summer of 1990. Data collected as part of the 301(h) Waiver application as well as historical Mass Bay data will be cited to support conclusions and as a basis for comparison.

Massachusetts Bay:

Water column profiles at and near the proposed extended outfall sites in Mass Bay were similar. The data confirmed the seasonal trend towards increased stratification in the warmer summer months. The top to bottom density gradients measured in August were among the highest reported in the literature for Mass Bay. The magnitude of density gradients was not the only thing that was significantly different between cruises. Density profiles measured in July showed a defined pycnocline with most of the top to bottom density gradient achieved in the top 15 meters. In contrast, density profiles measured in August lacked a defined pycnocline with only half the top to bottom gradient in density occurring in the top 15 meters.

The annual cycle of temperature and salinity in Mass Bay (Bumpus 1974), reproduced from the MWRA Facilities Plan (MWRA 1987), is presented in Figure 4. Seasonal fluctuations in temperature and salinity are attributed to the annual solar heating cycle as well as the spring rain season (up to 90 percent of the fresh water input from Massachusetts to Mass Bay is attributed to the Merrimack River). The data presented here do not follow the seasonal trends, described by Bumpus, in which surface salinities would be expected to be higher in August than in July. Observed salinities were in the range of 29.7-30.4 ppt in August, but salinities of 31.1-31.5 ppt were measured in July. Interestingly, surface salinities from the July cruise were in the range reported by Bumpus for July; however, the surface salinities observed in August were in the range of surface salinities reported by Bumpus for the month of May.

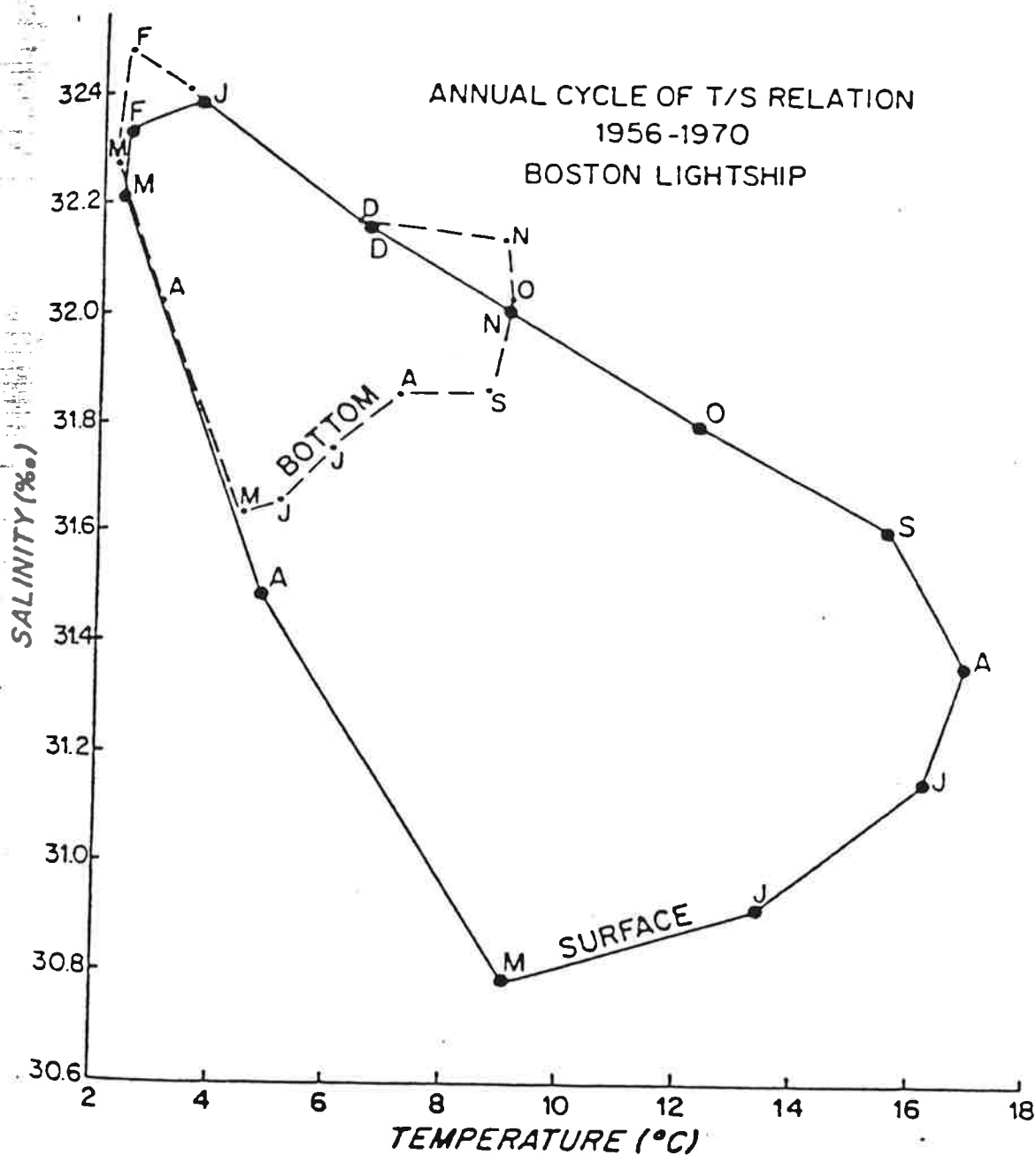
While only two days of profiles are insufficient to conclude that anomalous findings existed for an extended period of time, several significant corollary events suggest that these anomalous findings were not ephemeral:

- The year 1990 was the warmest in the past 34 (Lawrence Eagle Tribune, December 31, 1990) with the average 1990 temperature 2.6 (Fahrenheit) degrees above normal. It was also reported that 1990 precipitation was 9.11 inches above normal. The figures for August precipitation were also record breaking with 8 inches of rain making it the wettest August since 1955.
- The average daily mean flow of the Merrimack River, recorded below the confluence of the Concord River at Lowell Mass., was the highest

Figure 4.

Annual Cycle of Temperature/Salinity Relation at Boston Lightship, 1956-1970

(Reproduced from MWRA, December 11, 1987, Figure 2.2.1-3)



(REPRODUCED FROM BUMPUS, 1974)

MASSACHUSETTS WATER
RESOURCES AUTHORITY

FIGURE 2.2.1-3
ANNUAL CYCLE OF TEMPERATURE/
SALINITY RELATION AT
BOSTON LIGHTSHIP, 1956-1970

daily mean flow for August when compared to the 57 year period between 1924-81 (Wandle et. al. 1984). Figure 5 summarizes Merrimack River flow for 1990 (USGS provisional) and the 57 year record. August 1990 flows were a factor of four above the 57 year August mean and similar to the 57 year mean for the month of May.

The degree of stratification in Mass Bay, and the implied lack of mixing with oxygenated surface waters, was reflected in the dissolved oxygen profiles. Oxygen concentrations were generally lower during the August cruise. Surface dissolved oxygen saturations were similar while bottom saturations were different between the two cruises (July: 87.6-90.9%, August: 74.5-76.7%). The Apparent Oxygen Utilization (AOU), defined as the difference between theoretical 100% saturated DO concentration and measured concentration, were different for bottom waters between cruises (July: 0.9 -1.2 mg/l, August: 2.2-2.4 mg/l). Changes in temperature and stratification conditions could both affect AOU; however, the data indicate that the lack of vertical mixing implied by the observed increase in stratification most likely accounts for the doubling in AOU because the temperature, and therefore temperature mediated biochemical reaction rates, did not change significantly between cruises. Any additional oxygen deficits applied under these conditions would result in concentrations lower than are allowed by the water quality standards.

Salem Sound:

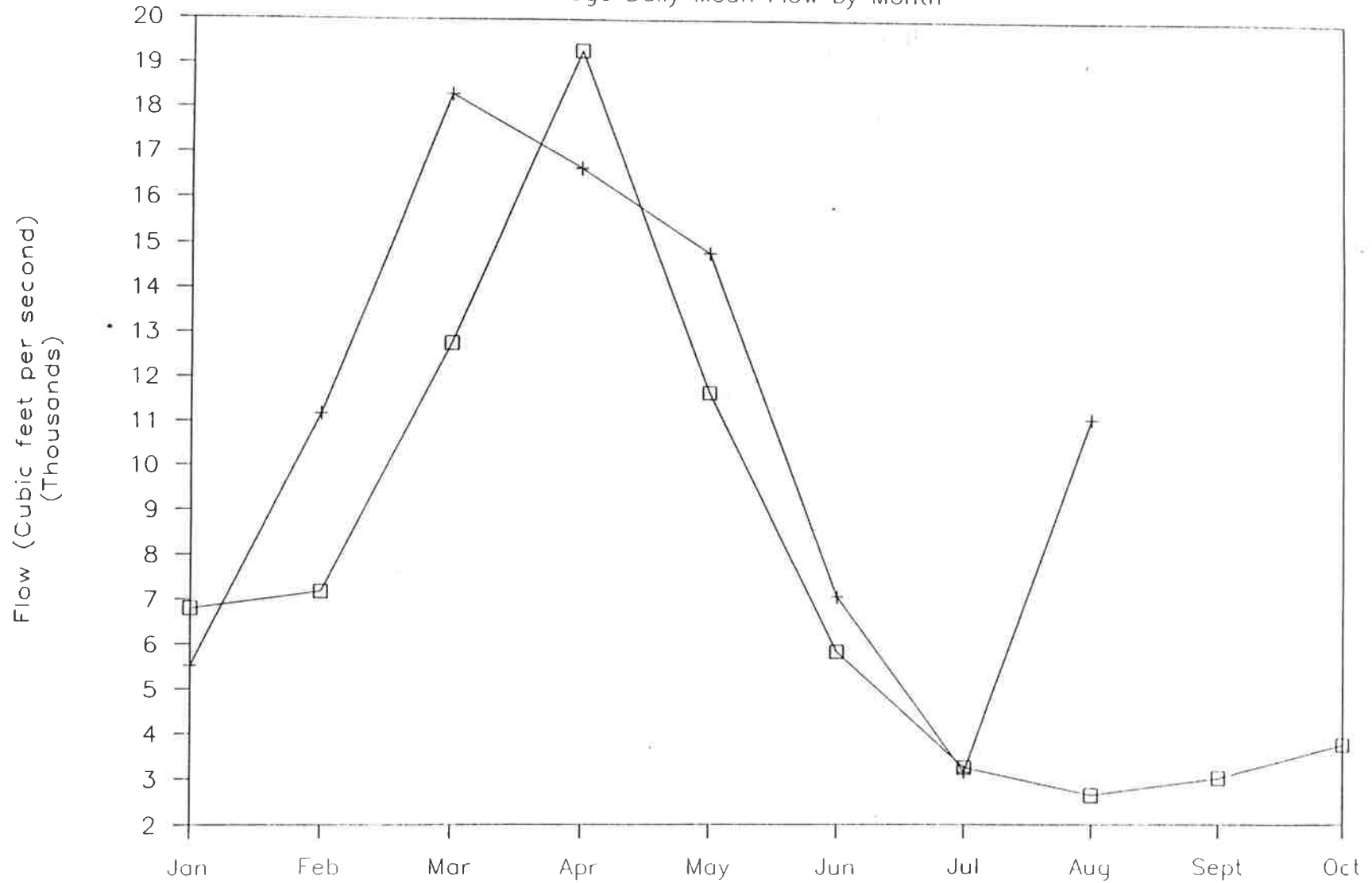
The profiles measured in Salem Sound indicated variable spatial and temporal patterns. With only two days of data it is difficult to account for all factors affecting density structure; however, the data indicate spatial differences within two groupings of the stations. The stations located west and north of the present discharge (SS01, SS02, SS03, SS05, SS06) had the highest degree of stratification in July, while the stations south and east (SS04, SS07, SS08, SS09) were more stratified in August. Generalized circulation patterns from the 301(h) physical oceanographic studies (Figure 6) indicate that currents in Salem Sound exhibit a pattern of prevailing net flow on the order of 350 to 1000 million cu ft from the east to the southwest. This indicates that the areas located south and east of the present discharge are more likely to be directly effected by the prevailing net flow while areas north and west are effected by more complex localized circulation patterns (Figure 7).

Dissolved oxygen concentrations measured in Salem Sound in July were considerably different than the concentrations observed in August. In July dissolved oxygen concentrations were above saturation throughout the water column (with the exception of station SS08), suggesting that in most of the Sound, oxygen producing processes were more important than oxygen demanding processes. Station SS08 was the only Salem Sound station with sub-saturation concentrations of oxygen in July, probably because it is was located close to and down current from the present outfall. Dissolved oxygen concentrations measured in Salem Sound in August suggest that oxygen demanding processes dominated all but the top 1-4 meters of the water column. The average apparent oxygen utilization (AOU) of bottom waters was two times higher in August than July. The highest AOU's were measured at stations near and down current of the present discharge (SS06, SS07, SS08, SS09) in Marblehead Channel. Dissolved oxygen profiles from the 301(h) waiver studies in 1985 (Ocean Surveys Inc. 1985), indicate a similar spatial

Figure 5.

Merrimack River Flow

Average Daily Mean Flow by Month

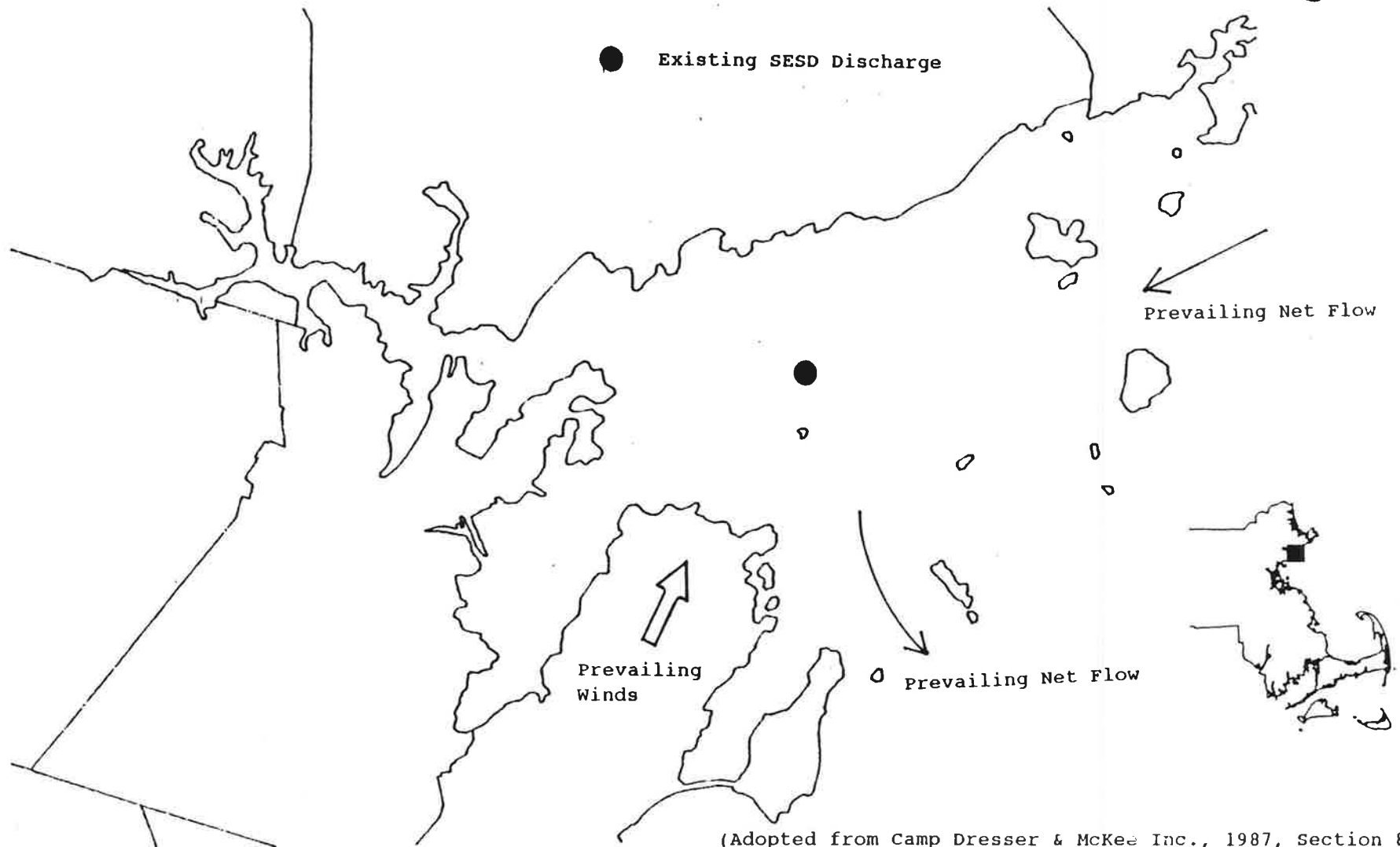
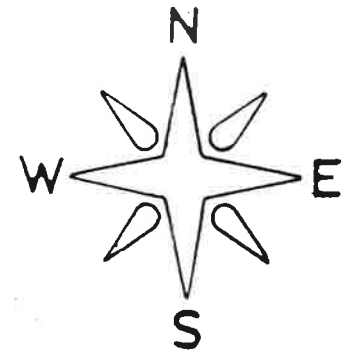


□ 50-year mean
(Wandle et. al., 1984)

× 1990 Mean
(USGS provisional)

Figure 6. Salem Sound Prevailing Net Flow and Prevailing Winds

Scale: 1"=0.97 Nautical Miles



(Adopted from Camp Dresser & McKee Inc., 1987, Section 8.)

trend. Ocean Surveys stations P-7, P-10, and P-16 (Figure 8) located in Marblehead Channel had higher AOU values, in bottom waters, than the other Salem Sound stations that were sampled.

There were only minor differences in stratification conditions between cruises, however, temperatures differed significantly (especially in the lower water column). Bottom temperatures ranged from 8.2 °C to 8.9 °C in July and 14.3 °C to 16.9 °C in August, suggesting that an increase in biochemical reaction rates could account for the differences in DO concentrations discussed above.

CONCLUSION

(Implications for Outfall Siting)

The data collected in 1990 as well as data collected in support of the SEDS 301(h) Waiver studies indicate that while violations of dissolved oxygen water quality standards were measured infrequently, dissolved oxygen concentrations were never measured below 5.0 mg/l. The data indicate, however, that the greatest top to bottom differences in dissolved oxygen, as well as the greatest apparent oxygen utilization, occur in Marblehead Channel. Marblehead Channel is described in the 301(h) Waiver studies as "Downstream" from the existing discharge, suggesting that the oxygen deficits observed are attributable to the existing discharge of primary effluent. Predictions made during Phase I Facilities Planning include a 30% increase in phytoplankton productivity upon completion of secondary facilities and discharge at the existing outfall in Salem Sound. An assumption commonly made when primary is upgraded to secondary is that reduction of BOD and solids loading would reduce the impact to dissolved oxygen concentrations in the receiving body; however, it is unclear how the reduced BOD and solids loading of a secondary effluent would compare to the increased demands on oxygen related to increases in productivity.

Results of outfall siting studies in New Bedford led to the conclusion that the impact to DO concentrations in the immediate area of the existing discharge was slightly reduced with a secondary effluent; however, the area impacted by a modified effluent increased. In addition, results of modeling for the New Bedford project predict that for worst case conditions at the existing discharge, marginal differences in impacts to dissolved oxygen conditions would be realized between primary and secondary treatment. The reasons given for marginal changes in DO conditions include the potential for an increase in phytoplankton-derived sediment oxygen demand (SOD).

The available dissolved oxygen data for Salem Sound do not indicate that the existing discharge is causing significant dissolved oxygen deficits. The increase in phytoplankton productivity, predicted if secondary effluent is discharged at the existing outfall, suggests that there will be an increase in phytoplankton-derived SOD. Because there is a lack of appropriate field data (SOD, direct effluent BOD/COD, nutrient related, continuous measurements of dissolved oxygen, current, and wind) needed to understand the existing dynamics of oxygen deficits in Salem Sound, predictions of how a modified discharge may affect dissolved oxygen concentrations in Salem Sound will be difficult to make.

Figure 7.

Salem Sound Drogue Tracks

(Reproduced from Camp Dresser & McKee Inc., SESD Draft Facilities Plan, Figure 8-13)

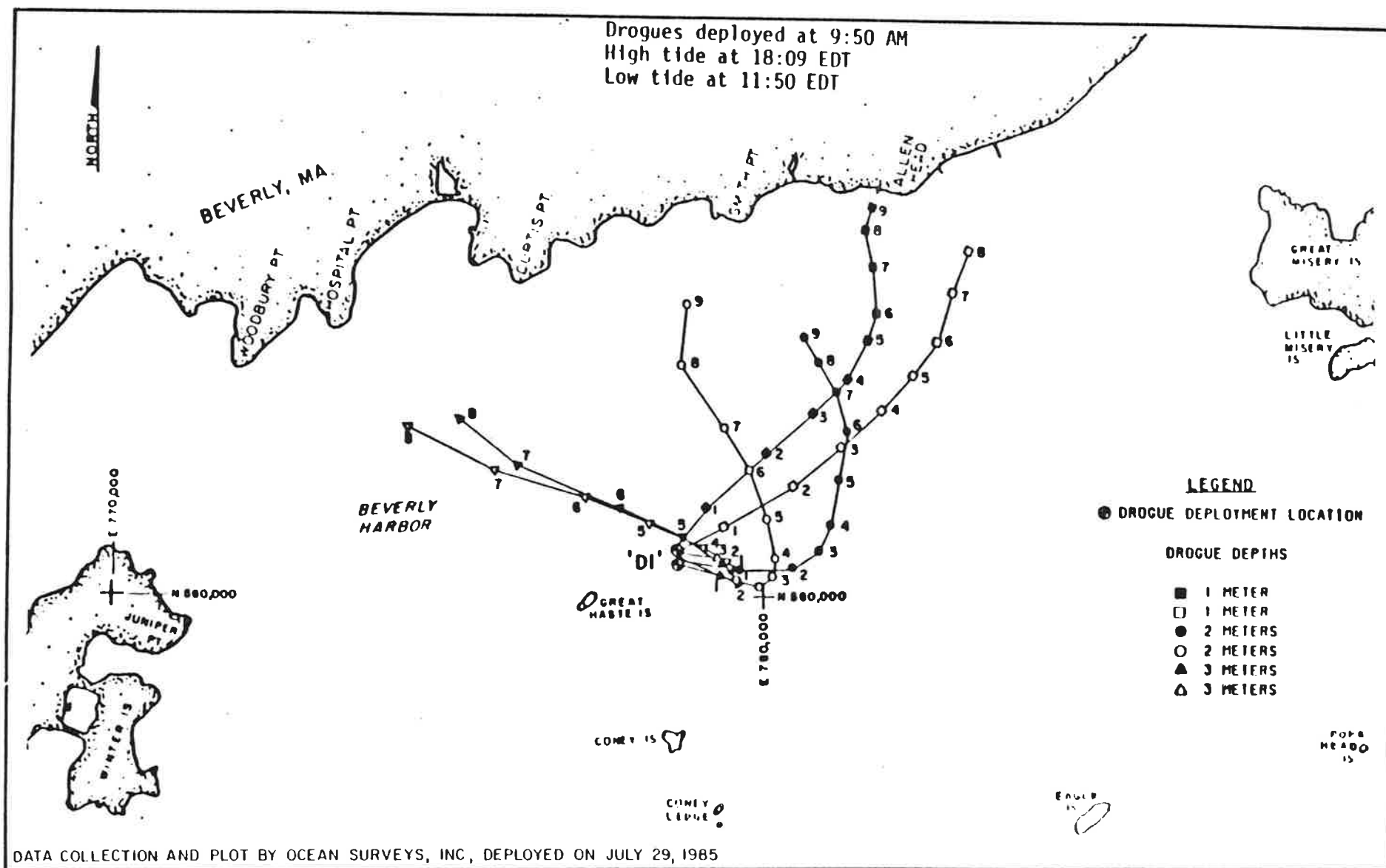


FIGURE 8-13 SALEM SOUND DROGUE TRACK
AT STATION D1

Figure 8.

Ocean Surveys Inc., Location of Profile Stations

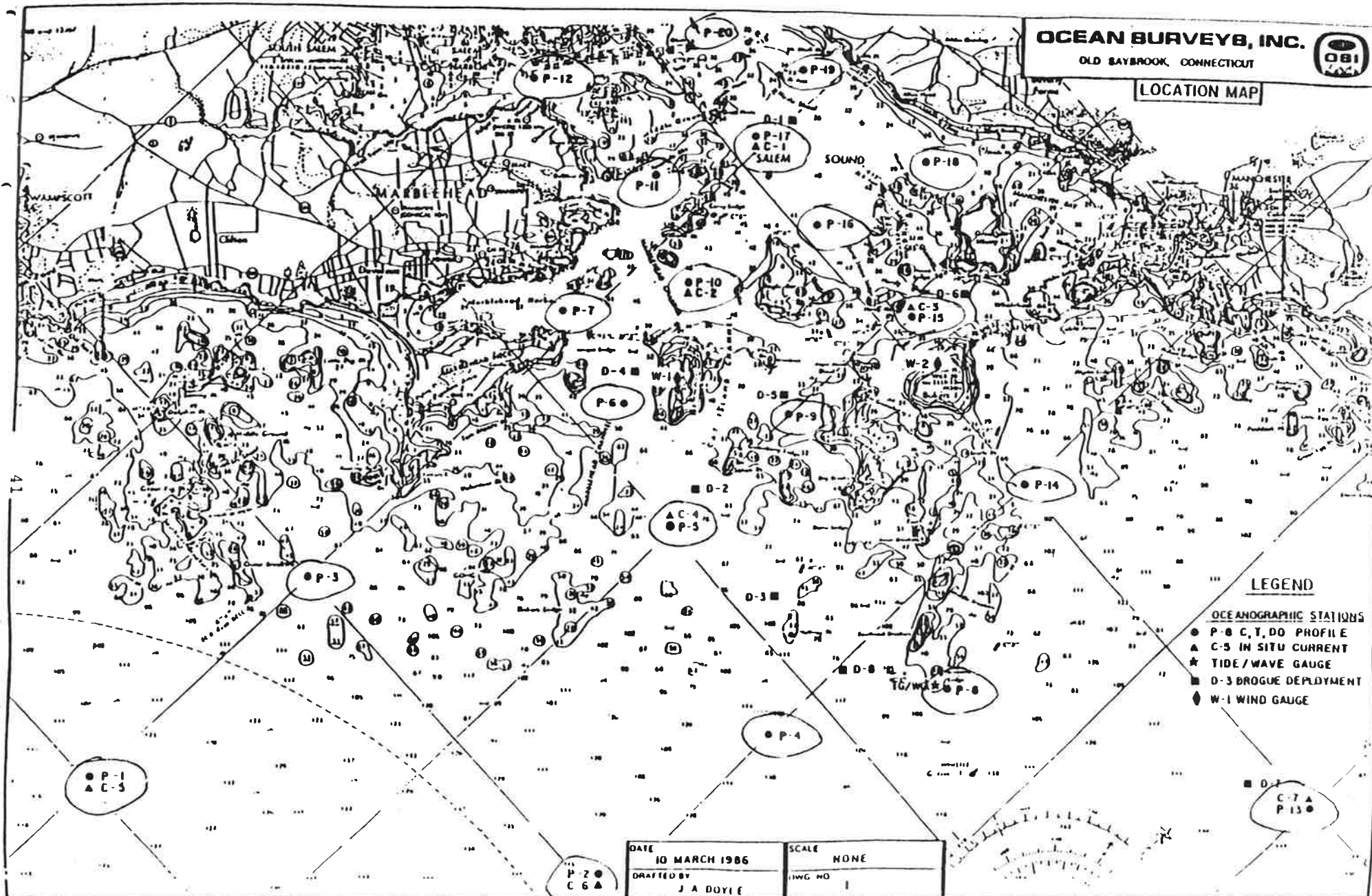
(Reproduced from Ocean Surveys Inc., 1985, Appendix A to SEDS 301(h) Waiver Application, Figure 1.)

OCEAN SURVEYS, INC.

OLD SAYBROOK, CONNECTICUT



LOCATION MAP



REFERENCES

- Bumpus, D.F., 1974. Review of the Physical Oceanography: Massachusetts Bay. Technical Report. WHOI 74-8. Woods Hole, MA: Woods Hole Oceanographic Institution.
- Camp Dresser & McKee Inc., 1987. Draft Facilities Plan for Wastewater Treatment and Disposal: Phase I, Volume I-Report. Prepared for the South Essex Sewerage District, Salem, MA. Boston: Camp Dresser McKee Inc.
- Commonwealth of Massachusetts, Water Resources Commission, Division of Water Pollution Control, 1967. Water Quality Standards: Volume 8, Coastal Waters.
- Massachusetts Division of Water Pollution Control, 1990. Massachusetts Surface Water Quality Standards, 1990. Pub. No. 16,453-114-100-9-90-C.R. Westborough, MA: Department of Environmental Protection, Division of Water Pollution Control, Technical Services Branch.
- Massachusetts Water Resources Authority (MWRA), 1987. Physical Oceanographic Investigations. Draft 3.0, Appendix A to volume V, Secondary Treatment Facilities Plan. Boston: Massachusetts Water Resources Authority.
- Ocean Surveys Inc., 1985. Final Report, SESD/CDM Oceanographic Study, Salem Sound/Massachusetts Bay: (Appendix A to South Essex Sewerage District 301(h) Waiver Application). Prepared for Camp Dresser McKee Inc., Boston, MA. Old Saybrook, CT: Ocean Surveys Inc.
- Wandle, S.W., Jr., and Fontaine, R.A., 1984. Gazetteer of Hydrologic Characteristics of Streams in Massachusetts--Merrimack River Basin: U.S. Geological Survey Water Resources Investigations Report 84-4284.