

MASSACHUSETTS DIVISION OF MARINE FISHERIES
SPORTFISHERIES TECHNICAL ASSISTANCE PROGRAM

MASSACHUSETTS BAY SMELT SPAWNING HABITAT MONITORING PROGRAM

Preliminary Report on Manchester Bay

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ABSTRACT

The freshwater streams flowing into Manchester Bay, located in the North Coastal Basin of Massachusetts, were monitored from 1988-1990 for the purpose of documenting the occurrence of anadromous rainbow smelt and the locations of spawning habitats. Ten streams were surveyed in 1988 for potential spawning habitat and three were selected for routine monitoring during spring spawning runs. The monitoring was conducted within the Massachusetts Bay Smelt Spawning Habitat Monitoring Program of the Massachusetts Division of Marine Fisheries. The primary objective of the program is to document spatial, temporal and biological characteristics of all smelt spawning habitats along Massachusetts Bay.

Relatively small populations of smelt were found to spawn in Chubb Creek, Bennett Brook, and Sawmill Brook. Less than 75 m² of substrate suitable for spawning was found in Chubb Creek, probably the least amount of available spawning habitat for an individual smelt spawning run along Massachusetts Bay. Bennett Brook is a narrow stream that provides nearly 300 m² of spawning habitat. Sawmill Brook was not a known smelt run prior to this study. Sawmill Brook contains better water flow and substrate conditions for smelt spawning than the other two locations, and has approximately 450 m² of available spawning habitat.

Consistent with most Massachusetts Bay smelt runs monitored during this period, the Manchester Bay runs have declined greatly from the levels of abundance reported 10-20 years ago. It was apparent during the study period that smelt egg deposition was well below the habitat capacity, but causal factors for the population decline are not well understood. Sedimentation from road run-off was observed at the spawning habitats of Chubb Creek and Bennett Brook. Recommendations are made to prevent further substrate degradation due to sediment and pollutant loadings that enter the spawning habitat from stormwater off nearby roadways.

ACKNOWLEDGEMENTS

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INTRODUCTION

The freshwater streams of Manchester Bay were monitored from 1988-1990 to document characteristics of rainbow smelt, Osmerus mordax, spawning runs. All freshwater drainages into Manchester Bay were surveyed in 1988 and three streams were selected for monitoring based on knowledge of existing smelt runs and the presence of suitable spawning habitat. Chubb Creek, Bennett Brook, and Sawmill Creek were routinely sampled under the Massachusetts Bay Smelt Spawning Habitat Monitoring Program. The primary objective of the program is to document temporal, spatial and biological characteristics of smelt spawning in Massachusetts Bay river systems. The resulting baseline data can be applied to resource management goals of protecting valuable estuarine and river habitats and sustaining the Commonwealth's smelt fisheries.

A valuable fall and winter fishery for smelt exists in many communities along the coast of Massachusetts. Smelt migrate from coastal waters into estuaries in the fall and are fished by hook and line until the fishery is closed from March 15th to June 15th to protect spawning fish. Massachusetts Bay smelt populations are suspected to be well below historical levels of abundance. Consequently, sportfishing catch and effort has sharply declined in the past decade. Smelt fishing in Manchester Harbor has also declined in recent years. As recently as 10-15 years ago, a traditional fishery produced routine catches of smelt from structures along Manchester Harbor during the fall and winter. Fishing effort in the past five years has involved very few individuals with sporadic catches.

Smelt are anadromous, maturing in coastal waters and the lower reaches of estuaries, then ascending into freshwater zones to spawn in the increased flow of shallow riffles during springtime spawning runs. Eggs adhere to the substrate and aquatic vegetation. Upon hatching, larvae immediately move downstream into the tidal zone where feeding on zooplankton begins. Observations of deposited eggs form the basis for delineating smelt spawning habitat.

Smelt populations exhibit much variability between river systems in the timing of spawning and selection of spawning habitat, using a range of water temperature, salinity and substrate type (Kendall 1927; Bigelow and Schroeder 1953; Rupp 1959, Hurlbert 1974). Past investigations of Massachusetts smelt runs found that spawning typically initiates in early to mid-March when water temperatures reach 4-6 C°, and concludes in May (Crestin 1973; Lawton et al. 1990). Spawning smelt concentrate at suitable habitat beyond the interface of fresh and brackish water at night during flood tides (Clayton 1976; Murawski et al. 1980). After spawning, smelt usually leave the spawning habitat to inhabit deeper downstream areas during daylight. Spatial and seasonal variability in spawning, nocturnal spawning, and a closed season for fishing all contribute to a lack of familiarity and documentation of smelt spawning habitat in many coastal river systems.

Secondary objectives of the program include the characterization of river systems through the collection of baseline water chemistry, stream flow, and ichthyoplankton data, and documenting

the occurrence of other anadromous species. This report documents sampling in Manchester Bay, which is one of over thirty Massachusetts Bay river systems chosen for study since the program was initiated in 1988.

STUDY AREA

Manchester Bay is located in the North Coastal Basin of Massachusetts (Halliwell et al. 1982), between Boston Harbor and Cape Ann (Figure 1). There are numerous small creeks that flow into the coastal waters of Beverly and Manchester. Most of these creeks are unnamed and drain freshwater wetlands within a few miles of the coast. In 1988, ten streams were surveyed for the presence of potential smelt spawning habitat. Only three locations were found to possess suitable freshwater flow and substrate. The following five locations were not selected for monitoring because suitable flow and substrate conditions were completely absent: an unnamed creek at Kettle Cove, Manchester, that flows across Rt. 127 into Clark Pond; Wolftrap Creek that flows across Rt. 127 and through the salt marsh into Kettle Cove; an unnamed creek that flows across Rt. 127 to the western side of Manchester Harbor; an unnamed creek at Plum Cove, Beverly; and an unnamed creek at Beverly Cove, Beverly. Two additional streams were not selected for monitoring because adequate spawning conditions were lacking, but visits were made during the spawning season to be certain no spawning was occurring. These locations were the western branch of Chubb Creek, and Days Creek that crosses Beach Street at the eastern side of Manchester Harbor.

Chubb Creek and Bennett Brook (Figure 2) were selected for monitoring because they were known spawning locations (H.R. Iwanowicz, pers. comm.)¹. Sawmill Brook was not a known smelt run, but was added to the monitoring program because suitable spawning habitat was found. The main branch of Chubb Creek is the border between the towns of Beverly and Manchester from Rt. 127 to the coast. The two branches of Chubb Creek drain freshwater wetlands in Beverly and Manchester. Bennett Brook flows from wetlands in Manchester into Manchester Harbor. Sawmill Brook flows from Cedar Swamp in northern Manchester into Manchester Harbor. The known spawning locations of Chubb Creek (CC-1) and Bennett Brook (BB-1) were monitored during each of the study years of 1988-1990. Ichthyoplankton and water chemistry samples were taken from the wood walk bridge at the western branch of Chubb Creek (CC-2) and the railroad bridge at the mouth (CC-3) in 1988 and 1989. The third spawning habitat location was Sawmill Brook (SB-1), which was visited in 1989 to confirm spawning and routinely monitored in 1990.

No previous studies have been conducted on the fishery resources of these Manchester Bay tidal creeks. Chubb Creek was listed as a smelt run in the DMF anadromous fish survey of 1970 (Reback and DeCarlo 1970). The Chubb Creek salt marsh was recognized as the largest salt marsh (44 acres) in the study area of the DMF estuarine report for Salem Sound (Jerome et al. 1967).

¹ H.R. Iwanowicz, Sr. Marine Fisheries Biologist, MDMF, Salem, MA

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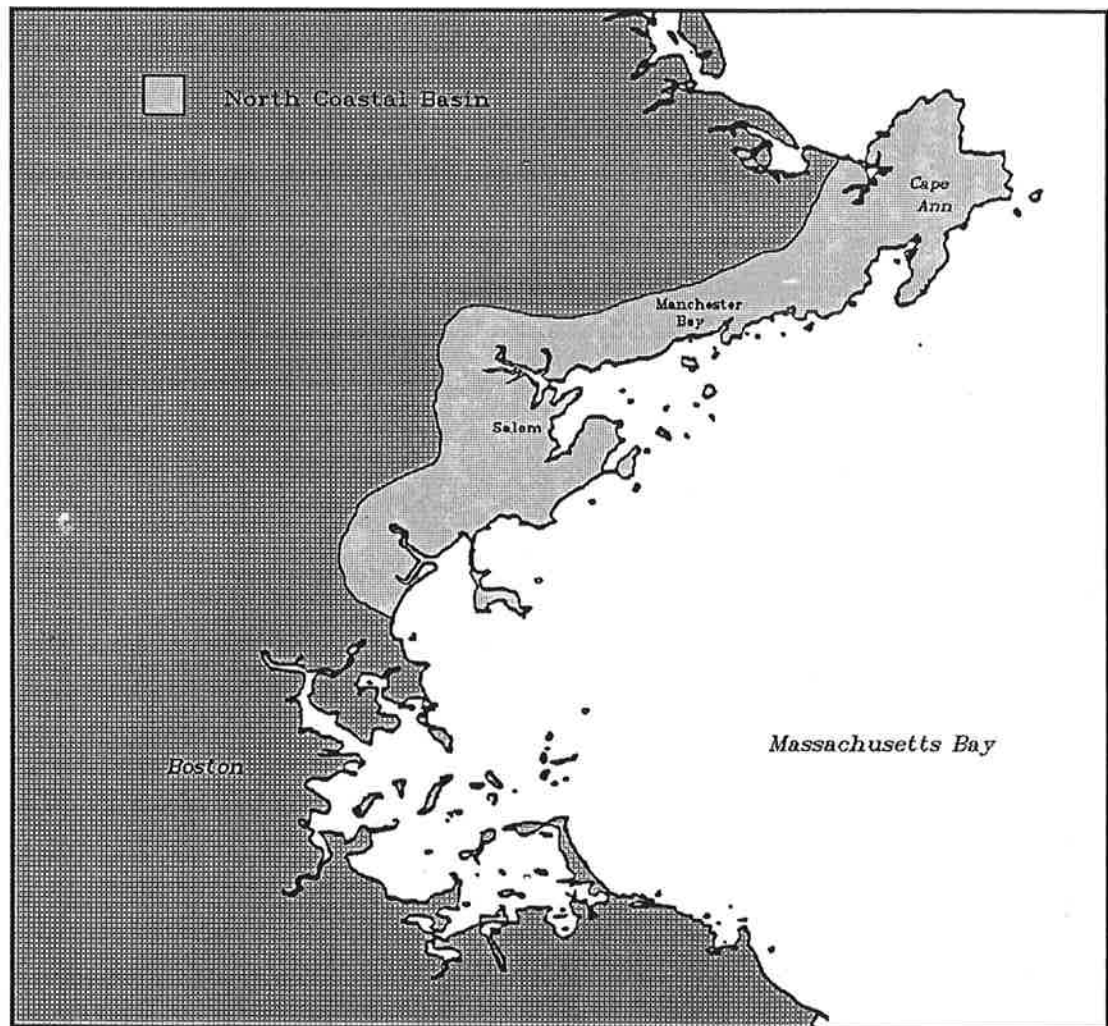


Figure 1. North Coastal Basin

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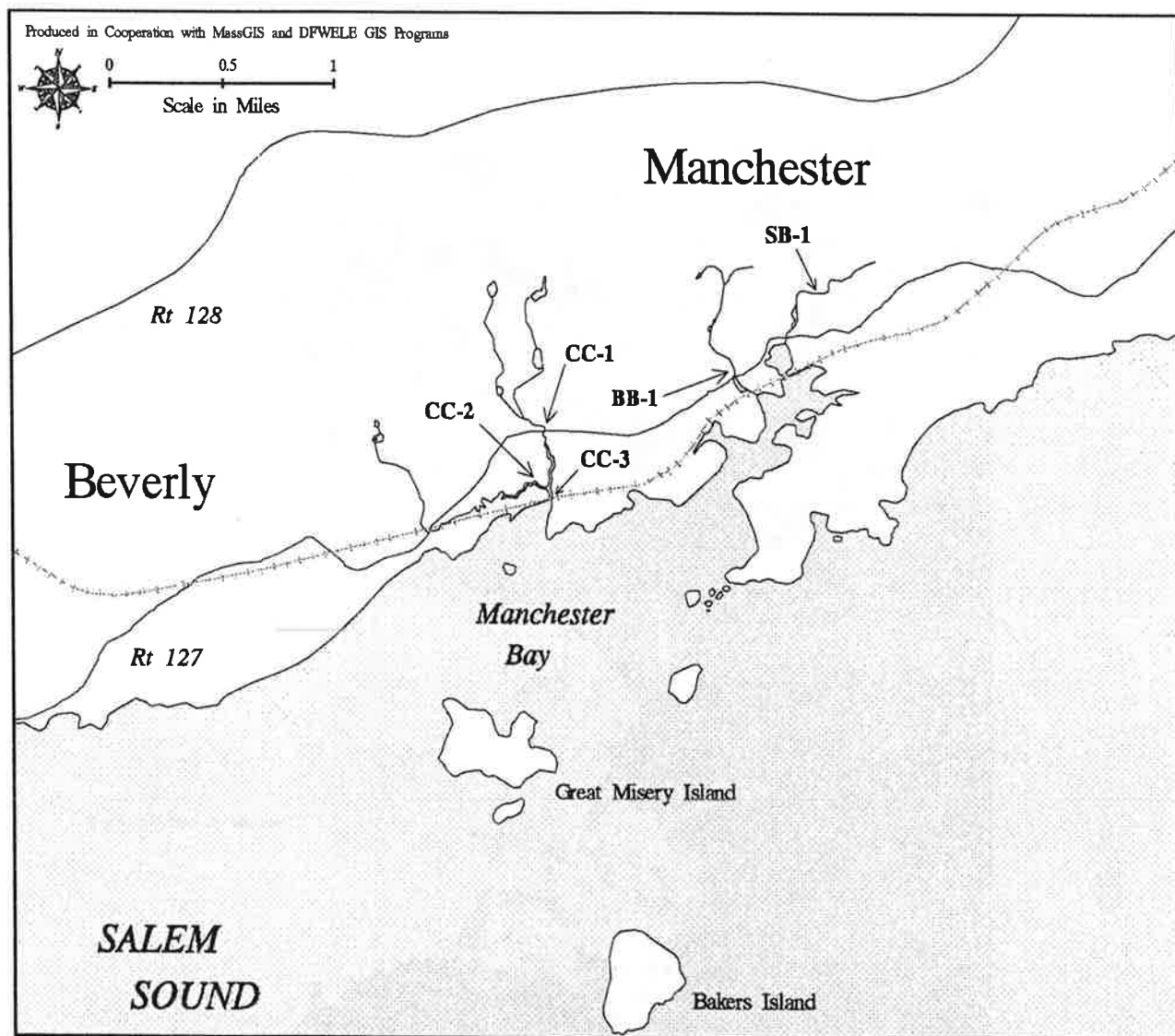


Figure 2. Manchester Bay

Sample Locations:

CC - 1	Chubb Creek Spawning Site
CC - 2	Chubb Creek Water Chemistry
CC - 3	Chubb Creek Ichthyoplankton
BB - 1	Bennett Brook Spawning Site
SB - 1	Sawmill Brook Spawning Site

METHODS

Spawning sites were surveyed twice each week from March 1st through May 31st. During each visit, the substrate was inspected for smelt eggs and water chemistry was sampled. Eggs were identified on the basis of size, oil globule, and seasonal comparison with other species (Cooper 1978; and Elliot and Jimenez 1981). Site visits were not fixed to a targeted time of day or tide stage, but cannot be described as random due to travel logistics and constraints within the sampling schedule.

Water chemistry, weather, and tidal influence data were recorded at all sample sites. Air and water temperature measurements were taken with stem thermometers ($\pm 0.5^\circ\text{C}$). Salinity was measured using a Reichart temperature compensated salinity refractometer (± 1.0 ppt). Water pH was measured with an Orion SA 250 pH meter (± 0.1 pH). Dissolved oxygen was measured with a YSI model 51B meter (± 0.2 mg/l). Weather conditions were noted using a descriptive index (Appendix). Tidal conditions for Boston Harbor (White 1988, 1989 and 1990) were used along with on-site observations to determine tidal influence and tide stage (± 0.5 hour). Bottom water samples were collected with a Van-Dorn style horizontal water sampler. Prior to sampling, and at three hour intervals, the pH meter was calibrated using standard pH buffers, and the D.O. meter was calibrated to the ambient oxygen level. The salinity refractometer was zeroed each week with distilled water. Stem thermometers were checked with a certified thermometer before each season (acceptable range of $\pm 0.5^\circ\text{C}$).

Ichthyoplankton were collected from locations CC-2 and CC-3 for the purpose of confirming smelt larvae presence and characterizing the spring ichthyoplankton community in Chubb Creek. A 0.14 m^2 rectangular plankton net with 0.505 mm mesh, was used to sample the ebb flow of surface water, within 2 hours of high tide. A 2030-R General Dynamics flowmeter attached to the net frame was used to measure stream flow rates (m/sec) and water volume sampled (m^3). Samples were preserved in 5% phosphate buffered formalin and returned to the laboratory for sorting and microscopic analysis. All finfish eggs and larvae were measured to the nearest 0.1 mm and identified with the aid of manuals by Colton and Marak (1969), Scotton et al. (1973), Lippson and Moran (1974), and Elliot and Jimenez (1981).

After the completion of two sampling seasons, stream measurements were made of habitat where smelt egg deposition was found. The area of streambed where spawning occurred was measured using a tape measure to the nearest 0.1 m . The spawning habitat was divided into easily measured segments and the area was determined with mid-stream length measurements and at least three width measurements per segment. Spawning period was estimated for each smelt run. Spawning period is defined as the time between the date of first egg deposition and the date when hatching is complete. Spawning period dates were estimated as the mid-point between the sample visit when viable eggs were first (or last) observed and the nearest sample visit when no eggs were observed.

RESULTS

Smelt were found to spawn in three locations within the Manchester Bay region during the study period of 1988-1990. Smelt spawning was found each year at the known spawning sites in Chubb Creek and Bennett Brook. Smelt egg deposition was observed at Sawmill Brook in 1989 and again during routine monitoring in 1990. The following sections describe results for each spawning habitat. No other anadromous fish were observed during the three years of monitoring. This finding is consistent with the 1970 DMF anadromous fish survey which found no evidence of river herring runs in Manchester Bay streams (Reback and DeCarlo 1970).

Chubb Creek

Smelt spawning in Chubb Creek is limited to a very small area downstream of the Route 127 culvert. Smelt egg deposition was found over a 58 m stretch of the creek downstream of the culvert opening. Egg deposition was not found upstream of the culvert, and ended less than a half meter inside the downstream culvert opening. The highest concentration of eggs were found over the 10 m of substrate directly downstream of the culvert. The average width of the stream containing spawning habitat was 1.25 m (N = 11), and the area of spawning habitat measured was 70.8 m². This narrow stretch of spawning habitat is probably the smallest area available for an individual smelt spawning run in Massachusetts Bay.

Because of the limited available spawning habitat, smelt eggs were easily found and the start dates of the spawning period were readily determined for all three years (Table 1). All start dates are expected to be within 1-2 days of the actual date when spawning began. For all three years, spawning began in April and egg hatching was complete in the latter half of May. Spawning appeared to commence late in 1988. The start of the spawning period was estimated as April 24th, more than two weeks later than found in 1989 and 1990. The amount of eggs deposited in 1989 greatly exceeded that found in 1988 and 1990. This trend was observed in other Massachusetts Bay smelt runs monitored during this period.

Water chemistry measurements were made at the downstream side of a wood walk bridge located 20 m downstream of the Route 127 culvert (CC-1). The average water temperature was 10-12° C for the spawning period. Tidal influence was commonly observed at the walk bridge during high tides. The extent of the salt wedge at this location depended on the weather conditions and tidal elevation. Bottom salinity of 17-27 ‰ was found on five occasions during high tides. Surface salinity was found only once; 10 ‰ during a 11.6 ft high tide. The salt wedge was observed to continue into the Route 127 culvert during the highest tides, with bottom water of low salinity. Water pH was found to be more acidic than most other smelt runs in the North Coastal Basin, averaging less than 6.5. Water pH would pulse down after large rainfalls due to the low volume of freshwater flow in Chubb Creek (0.013 m³/sec, N = 2). Dissolved oxygen was measured during 1989 and 1990 and found to be at least saturated throughout the spawning period.

Table 1. Spawning Period and Water Chemistry Summary: Chubb Creek

Year	Spawning Period	Days	WATER TEMPERATURE (C)				Mean
			Start	End	Range		
1988	April 24th – May 21st	28	11.5	14.5	8.0 – 18.0		12.1
1989	April 8th – May 27th	50	7.5	15.0	7.0 – 15.0		10.9
1990	April 5th – May 19th	45	5.5	10.0	5.0 – 16.0		10.0

		On Site Visits (#)	On Site Air Temp (C)	NOAA Air Temp (C)	NOAA Rainfall (in.)	SURFACE WATER CHEMISTRY			
						Temp (C)	Salinity (ppt)	pH	D.O. (ppm)
1988	March	9	4.1	3.6	3.7	3.4	0	6.5	-
	April	8	9.1	7.8	2.9	9.1	0	6.6	-
	May	8	12.8	14.0	4.4	12.5	0	6.6	-
	Season	25	8.5	8.5	11.0	8.1	0	6.5	-
1989	March	9	2.5	2.8	3.0	3.8	1.1	6.5	12.5
	April	8	9.6	7.2	4.3	8.8	0	6.1	11.2
	May	6	12.2	15.0	4.0	12.2	0	6.3	10.5
	Season	23	7.5	8.3	11.3	7.7	0.4	6.3	11.5
1990	March	8	5.4	3.7	1.9	4.1	0	6.2	13.4
	April	9	10.0	8.8	6.2	8.9	0	6.2	11.8
	May	7	11.2	12.2	6.5	12.4	0	6.3	10.2
	Season	24	8.8	8.2	14.6	8.3	0	6.2	11.9

Notes: NOAA air temperature and rainfall data are from Peabody, MA, station (NOAA 1988–1990). Monthly and seasonal data are averages of samples reported in the appendix, tables 9–11.

Bennett Brook

Smelt egg deposition in Bennett Brook was found over a 172 m stretch of the brook that begins 12 m below Bennett Street and continues upstream until passage is blocked by the remnants of a mill dam. Measurements made in eight segments of this stretch produced an area of 296 m² of available spawning habitat. The average width for this stretch was 1.7 m (N = 22). Egg deposition was found to be continuous throughout the stretch, but was heaviest directly below the old dam footing and lightest below Bennett Street. Similar to Chubb Creek, this narrow tidal brook supports a relatively small population of smelt.

Accurate start and end dates for the spawning period were determined with the exception of the 1988 end date (Table 2). The three start dates are expected to be accurate within a day of the actual commencement of spawning. Spawning was found to begin during the third week of March in both 1989 and 1990, and more than two weeks later in 1988. For all three seasons the first eggs were found in the riffles 10-12 m below Bennett Street. As the season progressed, egg deposition would advance upstream towards the old dam, and egg density would increase as the smelt approached the upstream limit of the spawning habitat. The egg density observed in 1989 greatly exceeded the scant deposition seen in 1988 and 1990. The thick egg concentration observed in 1989 in the 5 m of substrate below the old dam was among the highest densities seen during monitoring of the eight smelt runs in the North Coastal Basin during the study period.

Water chemistry and flow measurements were made at the downstream mouth of the Bennett Street culvert (BB-1). The average water temperature during the spawning period ranged between 9-10° C for the three seasons. Tidal influence approached the sample site with each flood tide. The highest encroachment of tidal influence was observed during a 11.6 ft high tide on March 3, 1989, when water flow was backed up 25 m above Bennett Street. On this occasion, the surface water salinity was 1 ‰ and the bottom water was 28 ‰ at the sample site. Under most flood tide conditions the salt wedge did not reach Bennett Street, although tidal influence was observed. Water pH was acidic during most samples, with the seasonal average ranging between 6.4 and 6.7. Fluctuations in water pH to as low as 5.9 were seen during heavy rainfall. Dissolved oxygen was found to be at least saturated for all measurements made during the spawning period.

Three stream flow measurements were made in 1991, producing an average of 0.045 m³/second (Table 7, Appendix). A reduced stream flow of 0.017 m³/sec on April 19, 1991 resulted in the exposure of small amounts of substrate where eggs were deposited.

Table 2. Spawning Period and Water Chemistry Summary: Bennett Brook

Year	Spawning Period	Days	WATER TEMPERATURE (C)				Mean
			Start	End	Range		
1988	April 7th - ?	-	11.5	-	-		-
1989	March 21st - May 16th	57	5.0	14.0	4.5 - 15.5		9.6
1990	March 22nd - May 9th	49	7.0	13.0	5.0 - 15.0		8.9

		On Site Visits (#)	On Site Air Temp (C)	NOAA Air Temp (C)	NOAA Rainfall (in.)	SURFACE WATER CHEMISTRY			
						Temp (C)	Salinity (ppt)	pH	D.O. (ppm)
1988	March	9	4.4	3.6	3.7	4.8	0	6.4	-
	April	8	9.4	7.8	2.9	9.3	0	6.8	-
	May	8	13.1	14.0	4.4	13.2	0	6.8	-
	Season	25	8.8	8.5	11.0	8.9	0	6.7	-
1989	March	9	2.9	2.8	3.0	4.4	0.1	6.7	13.1
	April	8	9.3	7.2	4.3	9.3	0	6.4	11.8
	May	6	12.4	15.0	4.0	12.3	0	6.4	10.9
	Season	23	7.6	8.3	11.3	8.2	0	6.5	12.0
1990	March	8	5.6	3.7	1.9	4.8	0	6.4	13.8
	April	9	10.3	8.8	6.2	9.2	0	6.4	12.3
	May	7	11.4	12.2	6.5	12.9	0	6.4	10.8
	Season	24	9.0	8.2	14.6	8.8	0	6.4	12.4

Notes: NOAA air temperature and rainfall data are from Peabody, MA, station (NOAA 1988-1990). Monthly and seasonal data are averages of samples reported in the appendix, tables 12-14. The end date of the 1988 spawning period was not accurately estimated.

Sawmill Brook

Sawmill Brook was not a known smelt run prior to this study. Smelt eggs were first found in April 1989 and the following season the brook was routinely monitored. Sawmill Brook has a greater capacity to support a smelt population than the other two smelt runs of Manchester Bay. It is a much larger freshwater brook with suitable substrate of cobble and attached vegetation. In 1990, egg deposition was found over a 98 m stretch with an average width of 3.2 m ($N = 15$), that contained 338.8 m² of spawning habitat.

Sawmill Brook flows into Manchester Harbor after crossing Central Street. A flood control dam at Central Street allows smelt passage into Sawmill Brook only during above average high tides. A small pond exists between Central Street and School Street that smelt must pass through to reach suitable spawning habitat. Smelt eggs were first found 60 m below the School Street bridge. The highest densities of eggs were found in the swift, channelized flow 20 m upstream of School Street. Nothing impedes smelt from passing above the upper limit of egg deposition for 1990. There is an additional 43 m stretch of suitable habitat (114.4 m²) above the 1990 upper limit. Passage is still possible above that stretch, but the brook slows down over deeper, silt laden pools, which offer no attraction to smelt for spawning. Therefore, the total available spawning habitat was 453.2 m² over a 141 m stretch. Egg deposition observed in 1990 was lightly scattered and well below habitat capacity, but still exceeded that observed in Chubb Creek and Bennett Brook.

The start date of the spawning period was estimated to be March 28th in 1990 and the end date was May 12th. Water chemistry was measured at the upstream opening of the School Street bridge (SB-1). The water chemistry results were consistent with that found for the other two Manchester Bay smelt runs (Table 3). Tidal influence was not observed to reach up to the spawning habitat, and probably could not go farther than the pond above Central Street. The stream flow was measured on three occasions, producing an average of 0.415 m³/second (Table 7). Overall, the relative habitat quality of Sawmill Brook is better suited for egg survival than that found at Chubb Creek or Bennett Brook. The stretch above School Street has excellent flow conditions and a fair amount of attached vegetation.

Other Potential Spawning Locations

Two additional freshwater sources were visited occasionally during the peak spawning seasons to be certain there was no spawning activity. The western branch of Chubb Creek was visited several times and no evidence of spawning was found. Most of this branch is tidal with a minor amount of freshwater draining over silt covered substrate above the tidal influence. Days Creek, that crosses Beach Street at the eastern side of Manchester Harbor, was also visited. No evidence of spawning was found in the sandy substrate of this tiny creek.

Table 3. Spawning Period and Water Chemistry Summary: Sawmill Brook

Year	Spawning Period	Days	WATER TEMPERATURE (C)			
			Start	End	Range	Mean
1990	March 28th - May 12th	46	5.0	14.5	4.0 - 16.0	9.3

		On Site Visits (#)	On Site Air Temp (C)	NOAA Air Temp (C)	NOAA Rainfall (in.)	SURFACE WATER CHEMISTRY			
						Temp (C)	Salinity (ppt)	pH	D.O. (ppm)
1990	March	8	5.4	3.7	1.9	3.9	0	6.4	13.8
	April	9	10.8	8.8	6.2	8.8	0	6.3	12.2
	May	7	12.5	12.2	6.5	12.9	0	6.4	10.4
	Season	24	9.5	8.2	14.6	8.4	0	6.4	12.2

Notes: NOAA air temperature and rainfall data are from Peabody, MA, station (NOAA 1988-1990). Monthly and seasonal data are averages of samples reported in appendix, table 15.

Chubb Creek Ichthyoplankton

Seventeen ichthyoplankton samples were collected from two locations in Chubb Creek during the 1988 and 1989 seasons (Tables 4-6). The primary location was the railroad bridge at the mouth of Chubb Creek (CC-3). Six samples were also collected from the wood walk bridge at the confluence of the west branch and mainstem of Chubb Creek (CC-2) for the purpose of determining if smelt larvae were found in the west branch.

At least twelve species of finfish were represented by eggs and larvae captured in the 17 samples. Rainbow smelt were the most frequently caught and most abundant ichthyoplankton found in these springtime samples from Chubb Creek. Smelt larvae were captured on four occasions, all occurring in May. The density of smelt larvae was 71.6/100 m³ for all samples combined and 301.9/100 m³ for the four samples in which smelt larvae were caught. These high densities are largely due to a single sample on May 15, 1989 that captured 710 yolk-sac smelt larvae. Smelt larvae were caught at location CC-2 on two occasions. With the absence of spawning habitat in the west branch, the occurrence of larvae there must result from tidal advection of larvae hatched out at the Rt. 127 spawning location.

All other species of larvae occurred incidentally and in low densities. The most common fish egg was from the Paralichthyes-Scopthalmus egg group, occurring in four samples at an overall density of 20.3/100 m³. It was not possible to identify these eggs to the species level, however, given the season and local abundance of adults, it is expected that the eggs are windowpane flounder. The following species of local commercial and recreational importance were captured on one occasion each: Atlantic cod, winter flounder, and Atlantic mackerel.

DISCUSSION

Preliminary results of the Massachusetts Bay Smelt Spawning Habitat Program indicate there are approximately 35 individual spawning locations for smelt along Massachusetts Bay. In terms of available spawning habitat and population size, the three Manchester Bay runs are relatively small, and Chubb Creek is one of the smallest in Massachusetts Bay. All three Manchester Bay smelt runs appear to be well below historical levels of abundance. Numerous comments were received from local residents on recent changes in smelt populations. In summary, residents report that 10-20 years ago, a robust smelt fishery existed and large numbers of smelt were often observed at the Bennett Brook smelt run; and presently, some residents were unaware that the smelt runs were still active. Without baseline data on spawning habitat conditions it is difficult to identify factors causing the declining populations. The following sections discuss conditions unique to each run and offer recommendations for habitat improvement and protection.

Table 4.

Summary of Chubb Creek ichthyoplankton samples: 1988-1989

<u>Pooled Samples</u>			
Sample number:	17	Railroad bridge volume:	823.3 m ³
Sampling period:	March 9th - June 6th	Wood bridge volume:	312.6 m ³
Ave. tide cycle:	high + 0.5 hrs.	Total volume:	1,135.9 m ³
Average velocity:	0.606 m/sec		
Velocity range:	0.376 - 0.986 m/sec		

SPECIES LIST

<u>Larvae</u>		Occurrence	Number	Ave. Size	Density (100 m ³)
rainbow smelt	<i>Osmerus mordax</i>	4	813	6.2	71.6
sand lance	<i>Ammodytes americanus</i>	2	2	6.7	0.2
grubby	<i>Myoxocephalus aenaeus</i>	2	3	11.2	0.3
Myoxocephalus sp.	<i>Myoxocephalus sp.</i>	1	1	5.3	0.1
three-spine stickleback	<i>Gasterosteus aculeatus</i>	2	2	41.5	0.2
winter flounder	<i>Pleuronectes americanus</i>	1	1	6.4	0.1
Atlantic cod	<i>Gadus morhua</i>	1	1	22.0	0.1
striped seasnail	<i>Liparis gibbus</i>	1	1	4.0	0.1
unidentified fish	<i>Teleostei</i>	2	3	-	0.3

Eggs

American plaice	<i>Hippoglossoides platessoides</i>	3	10	2.4	0.9
Atlantic mackerel	<i>Scomber scombrus</i>	1	7	1.4	0.6
Paralichthyes-Scophthalmus group		4	231	1.1	20.3
Labridae-Limanda group		1	82	1.0	7.2
Gadidae-Glyptocephalus group		1	1	1.4	0.1
unidentified fish		2	4	-	0.4

notes:

Labridae-Limanda group eggs are most likely cunner, *Tautoglabrus adspersus*

Paralichthyes-Scophthalmus group eggs are most likely windowpane flounder, ³ *Scophthalmus aquosus*

Density column is for absolute density of larvae found in total volume of 1,135.9 m³.

Chubb Creek

Chubb Creek contributes a very low volume of freshwater to a relatively small estuary. With each low tide, the entire estuary drains out of a narrow opening into Manchester Bay, typically leaving only freshwater in shallow channels throughout the estuary. Many larger estuaries with smelt runs have deeper channels that the smelt rest in prior to moving up into the freshwater zone to spawn at night. No such resting pools were found in Chubb Creek, indicating that smelt probably leave the estuary after each night of spawning. The flood tide brings saline water to the lower limits of the spawning habitat below Route 127. Presumably, the smelt arrive to the spawning habitat with the flood tide and vacate the estuary as the tide ebbs. The daily exodus of smelt from Chubb Creek brings up the question over the spawning fidelity of Manchester Bay smelt to specific spawning habitats. With the close proximity of Bennett and Sawmill brooks, and limited attraction of Chubb Creek freshwater flow, it is possible that Manchester Bay smelt do not have discrete fidelity to one spawning habitat.

The diurnal draining of Chubb Creek may also contribute to the late start of the spawning period. Very few smelt runs monitored in this program have been found to commence in April. Chubb Creek spawning commenced in April each of the three seasons monitored. Because the smelt do not take up residence in the estuary prior to spawning, they may not be exposed to conditions (water chemistry and temperature) that prompt most smelt runs to begin in March.

The reasons for the low population of smelt in Chubb Creek are not obvious. The small area of spawning habitat limits the population size, but the egg deposition observed was well below the capacity for the spawning habitat. Water run-off from Route 127 is a potential source of negative impacts, and the low freshwater flow offers little buffering capacity. Trash and petroleum residues from automobile traffic and sediments are carried by stormwater into Chubb Creek and can degrade spawning habitat. Chubb Creek is also subject to sharp downward pulses in water pH in response to rain events. In the interest of protecting the smelt spawning habitat and surrounding estuarine resources, it is recommended that the Route 127 catch basins along Chubb Creek are evaluated for efficient removal of sediments and stormwater pollutants, and are maintained annually.

Smelt do not pass through the Route 127 culvert to spawn on the upstream side. Passage is not obstructed, but there is little attraction due to the slow flow over substrate covered with silt and organic debris. It is possible that the upstream habitat can be restored to conditions that will expand existing smelt spawning habitat through annual efforts to remove excessive debris and trash. The success of such cleaning efforts is not certain because weak flows may allow a quick return of silt and debris. It is recommended that a stream clean-up is conducted of Chubb Creek above Route 127 by interested community groups. The cleaning may assist the smelt populations and provide education benefits.

Bennett Brook

With nearly 300 m² of spawning habitat, Bennett Brook has the potential for a larger population of smelt than Chubb Creek. Bennett Brook egg deposition in 1989 was much greater than observed in 1988 and 1990, yet was still well below habitat capacity. The drop in egg production from 1989 to 1990 was remarkable. Spawning was continuous in the month of April in 1989, and egg densities below the old mill dam were some of the highest seen north of Boston during the time period. In 1990 the egg deposition peaked in early April and eggs were difficult to locate by the beginning of May. The population has clearly declined from conditions of 15-20 years ago when local residents reported observing schools of smelt filling the brook channel in the daytime. The causal factors behind the decline in population size are not known.

The low volume of freshwater flow in Bennett Brook could make the spawning habitat susceptible to run-off impacts from Bennett Street. The potential impact is probably less relative to Chubb Creek given the lighter traffic on Bennett Street. The substrate does contain a large amount of sand in the vicinity of Bennett Street. The amount of sand was observed to increase greatly during the 1990 season, reducing the quality of that substrate for attracting spawning smelt and for egg survival.

The only recommendation offered for Bennett Brook is that local efforts are made to minimize sediment loadings from street run-off. The spawning habitat is bordered by woodland and only two residential properties, minimizing exposure to land-use impacts. Consideration was given to removing the footing of the old dam, for the purpose of expanding the upper limit of smelt spawning. This recommendation was not made because the quality of the substrate upstream is questionable and the wood footing will eventually rot out, allowing for gradual changes to the surrounding substrate.

Sawmill Brook

Of the three Manchester Bay smelt runs, Sawmill Brook possesses the most available spawning habitat and best quality of substrate for egg attachment and survival. Despite the better conditions, the smelt egg deposition observed in 1989 and monitored in 1990 was well below habitat capacity.

Similar to the other two smelt runs, road run-off is a potential source of negative impacts at Sawmill Brook. All local road work and land development should be conducted with consideration to minimize sediment and pollution run-off into Sawmill Brook. The Central Street dam at the mouth of Manchester Harbor acts as an obstruction to smelt passage during average and below average high tides. It is recommended that local officials determine what tidal elevations are required to allow smelt passage over the lip of the dam and consider scheduling flood gate openings at these elevations to facilitate passage during the spawning run.

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APPENDIX

Table 5. Chubb Creek ichthyoplankton samples, railroad bridge: 1988-1989

Date	Velocity (m/sec.)	Sample Volume (m ³)	Species	Type	Number	Average Size (mm)	Number (/100m ³)
4-05-88	0.545	27.5	grubby American plaice	larvae	1	9.5	3.6
				egg	4	2.2	14.5
4-15-88	0.673	50.9	unidentified fish	egg	3	-	5.9
4-27-88	0.781	45.9	American plaice	egg	1	2.4	2.2
5-13-88	0.376	34.7	rainbow smelt	larvae	3	7.0	8.6
			unidentified fish	larvae	1	-	2.9
			Atlantic mackerel	egg	7	1.4	20.2
			P-S group	egg	4	1.0	11.5
5-27-88	0.532	44.7	<i>Myoxocephalus</i> sp. P-S group	larvae	1	5.3	2.2
				egg	13	1.0	29.1
3-09-89	0.986	115.9	sand lance	larvae	1	6.3	0.9
4-03-89	0.881	118.4	sand lance grubby	larvae	7	7.0*	5.9
				larvae	2	12.0	1.7
4-24-89	0.327	41.2	American plaice	egg	2	2.4	4.9
5-08-89	0.791	106.3	three-spine stickleback	juvenile	1	39.0	0.9
5-15-89	0.934	117.7	rainbow smelt	larvae	710	6.1	603.2
6-06-89	0.715	120.1	three-spine stickleback	juvenile	1	44.0	0.8
			winter flounder	larvae	1	6.4	0.8
			P-S group	egg	210	1.1	174.9
			L-L group	egg	82	1.0	68.3

notes: Ave. size: total length for larvae, diameter for eggs; "*" indicates estimated length
P-S group eggs: Paralichthyes-Scophthalmus group (most likely windowpane flounder)
L-L group eggs: Labridae-Limanda egg group (most likely cunner)

APPENDIX

Table 6. Chubb Creek ichthyoplankton samples, wood bridge: 1988-1989

Date	Velocity (m/sec.)	Sample Volume (m ³)	Species	Type	Number	Average Size (mm)	Number (/100m ³)
4-15-88	0.472	35.7	American plaice unidentified fish	egg	5	2.5	14.0
				egg	1	1.5	2.8
4-27-88	0.425	39.3	none				
5-13-88	0.391	42.7	unidentified fish	larvae	2	-	4.7
			P-S group	egg	4	0.9	9.4
			G-G group	egg	1	1.4	2.3
4-03-89	0.580	78.0	none				
5-08-89	0.513	69.0	rainbow smelt	larvae	93	6.5	134.8
			striped sea-snail	larvae	1	4.0	1.5
5-15-89	0.380	47.9	rainbow smelt	larvae	7	6.5	14.6
			Atlantic cod	juvenile	1	22.0	2.1

notes: Average size: total length for larvae, and diameter for eggs.
P-S group eggs: Paralichthyes-Scophthalmus group (most likely windowpane flounder).
G-G group eggs: Gadidae-Glyptocephalus egg group.

APPENDIX

Table 7. Spawning Habitat Stream Flow Measurements

Bennett Brook

DATE	SITE	DEPTH Ave. (m)	WIDTH (m)	AREA (m ²)	VELOCITY (m/sec.)	FLOW m ³ /sec	cfs	RAINFALL (inches)	QUALITATIVE flow	DESCRIPTION Substrate
3-25-91	BB-1	0.18	1.30	0.23	0.453	0.104	3.68	1.17	average	covered
4-19-91	BB-1	0.08	1.30	0.10	0.168	0.017	0.59	0.33	below ave.	minor exp.
5-18-91	BB-1	0.11	1.30	0.14	0.098	0.014	0.48	0.38	below ave.	covered

Sawmill Brook

3-25-91	SB-1	0.36	2.80	1.01	0.793	0.801	28.28	1.17	average	covered
4-19-91	SB-1	0.22	2.80	0.62	0.310	0.192	6.79	0.33	below ave.	covered
5-18-91	SB-1	0.25	2.90	0.73	0.345	0.252	8.89	0.38	below ave.	covered

Chubb Creek

4-19-91	CC-1	0.14	0.75	0.11	0.088	0.010	0.34	0.33	below ave.	minor exp.
5-18-91	CC-1	0.14	0.75	0.11	0.141	0.016	0.55	0.38	below ave.	covered

Notes: Rainfall amounts include day of sampling and previous four days at Peabody station (NOAA 1991).

APPENDIX

Table 8. 1991 Water Chemistry Measurements

LOCATION	SAMPLE SITE	DATE	TIME OF DAY	AIR TEMP. (C)	WATER TEMP (C)	SALINITY (ppt)	pH	D.O. (ppm)	CONDUCT. (mmho/cm)
Bennett Brook	BB-1	3-25-91	1535	3.0	4.2	0.0	6.0	12.6	0.178
Bennett Brook	BB-1	4-19-91	1405	13.0	13.8	0.0	6.7	10.2	0.242
Bennett Brook	BB-1	5-18-91	1350	15.0	19.0	0.0	6.6	7.0	-
Chubb Creek	CC-1	3-25-91	1630	3.0	3.7	0.0	5.8	12.3	0.124
Chubb Creek	CC-1	4-19-91	1425	12.5	12.6	0.0	6.5	10.5	0.215
Chubb Creek	CC-1	5-18-91	1415	10.5	14.5	0.0	6.7	7.6	-
Sawmill Brook	SB-1	3-25-91	1600	3.0	3.5	0.0	5.8	12.5	0.232
Sawmill Brook	SB-1	4-19-91	1440	10.5	11.4	0.0	6.6	11.4	0.273
Sawmill Brook	SB-1	5-18-91	1435	10.5	17.0	0.0	6.6	8.2	-

Notes: Water chemistry measurements were made with a Hydrolab Surveyor II, during stream flow sample visits. Tidal influence was not present during all measurements.

APPENDIX

(CC-1)

Table 9.

Sample Site:

Chubb Creek, Rt. 127, Manchester

Year:

1988

DATE	TIME OF DAY	TIDE STAGE	TIDAL INFLUENCE	TIDE AMP. (ft.)	WEATHER INDEX	AIR TEMP. (C)	WATER TEMP. (C)		SALINITY (ppt)		WATER pH		D.O. (mg/l)	
							Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
3-01-88	1015	low +5.5 hrs.	Yes	9.3	1	1.5	1.5							
3-04-88	1127	low +5.0	Y	9.6	5	1.5	1.0							
3-08-88	1010	low +1.0	No	9.5	1	6.0	2.5				6.3			
3-11-88	1207	low +0.5	N	9.3	1	5.0	3.5				6.2			
3-15-88	1152	high +2.5	Y	10.3	4	2.5	3.0				7.1			
3-18-88	1439	high +2.5	Y	11.2	4	8.0	5.5				6.9			
3-22-88	1044	low +1.5	N	10.8	1	-0.5	1.5				6.3			
3-25-88	1157	low tide	N	9.0	4	8.5	5.5				6.4			
3-29-88	1209	high +2.5	N	8.8	1	4.5	6.5				6.1			
4-01-88	1347	high +2.0	N	9.3	4	12.0	8.0				6.4			
4-06-88	1645	high +2.0	N	8.7	4	5.5	7.0				6.7			
4-08-88	1058	low tide	N	8.2	4	6.0	6.0				6.8			
4-15-88	1250	high +1.0	Y	10.6	4	5.0	7.5				6.4			
4-19-88	1221	low +3.5	N	9.6	3	8.0	9.0				6.8			
4-21-88	1205	low +1.5	N	8.5	3	12.0	10.0				6.6			
4-27-88	1114	high +1.5	N	8.5	2	13.5	13.0				6.9			
4-29-88	1309	high +1.5	Y	8.8	1	11.0	12.0				6.2			
5-03-88	1036	low +2.5	N	9.0	4	7.0	8.0				6.7			
5-06-88	1128	low +1.0	N	8.7	4	11.0	12.0				6.6			
5-10-88	1112	high +3.5	N	9.6	6	8.0	10.0				6.5			
5-13-88	1004	low +5.5	Y	9.8	1	14.0	12.5	11.5	0	17	6.6			
5-17-88	1148	low +4.0	N	9.4	3	16.0	15.0		0		6.7			
5-20-88	1118	low +1.0	N	8.5	5	11.0	10.5		0		6.1			
5-24-88	1314	low +0.5	N	8.5	2	19.0	18.0		0		6.7			
5-27-88	1030	high +0.5	Y	8.3	1	16.0	14.0		0		6.5			
6-01-88	1135	low +4.0	N	9.0	4	17.0	14.0		0		6.6		9.0	
6-07-88	1143	high +6.0	N	9.7	1	16.0	16.0		0		6.8		8.7	
Season Average						9.1	8.6				6.6			

Tide delay: 1 hour from Boston Harbor

APPENDIX

Table 10.

Sample Site:

Chubb Creek, Rt. 127, Manchester

Year:

1989

DATE	TIME OF DAY	TIDE STAGE	TIDAL INFLUENCE	TIDE AMP. (ft.)	WEATHER INDEX	AIR TEMP. (C)	WATER TEMP. (C)		SALINITY (ppt)		WATER pH		D.O. (mg/l)	
							Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
3-02-89	1313	low tide	No	9.1	2	1.0	2.5		0				14.0	
3-06-89	1245	high +2.0 hrs.	N	11.0	4	-2.0	2.0		0		6.3		13.0	
3-09-89	1230	low +5.5	Yes	11.6	3	-1.0	0.5	1.5	10	27	7.1		12.7	11.6
3-13-89	1316	low +2.5	N	9.2	1	-1.5	3.0		0		6.0		13.1	
3-16-89	1008	high +3.0	N	9.4	2	3.5	3.5		0		6.8		12.3	
3-20-89	1320	high +2.5	N	9.7	2	3.0	4.5		0		6.1		12.5	
3-23-89	1048	low +4.0	N	9.7	2	5.0	4.0		0		6.9		12.9	
3-27-89	1311	low +4.0	N	9.7	1	11.5	8.0		0		6.3		11.0	
3-30-89	1250	low +1.0	N	8.0	1	3.0	6.0		0		6.2		10.6	
4-03-89	1118	high +1.0	N	10.5	5	5.5	6.0		0		6.2		11.2	
4-06-89	1208	low +5.5	Y	11.3	5	9.0	8.0	7.0	0	23	5.9		10.9	
4-10-89	1030	low +1.0	N	9.7	2	7.0	7.0		0		6.0		11.1	
4-13-89	1405	low +2.0	N	9.6	3	8.0	9.5		0		6.1		11.4	
4-17-89	1335	high +3.0	N	9.2	1	14.0	10.0		0		5.6		11.1	
4-20-89	1140	low +5.0	Y	9.4	2	12.0	9.0		0		6.1		11.8	
4-24-89	1535	high tide	N	8.9	3	10.0	10.0		0		6.5		10.9	
4-27-89	1338	low +2.0	N	8.5	2	11.5	10.5		0		6.4		11.4	
5-01-89	1317	high +4.5	N	10.0	4	10.0	10.0		0		6.6		11.0	
5-04-89	1536	high +4.0	N	10.7	2	13.0	14.0		0		6.1		10.1	
5-08-89	1616	high +1.0	N	10.0	3	11.0	12.0		0		6.6		10.0	
5-11-89	1250	low +1.0	N	8.8	5	11.0	9.5		0		6.0		10.2	
5-15-89	1045	high +1.5	N	8.8	1	13.0	12.5		0		6.0		11.2	
5-17-89	1338	high +2.5	N	8.8	3	15.0	15.0		0		6.5		10.6	
6-06-89	1545	high +0.5	N	9.6	4	15.0	15.0		0				8.4	

Season
Average

7.8

8.0

6.3

11.4

Tide delay: 1 hour from Boston Harbor

APPENDIX

Table 11.

Sample Site:

Chubb Creek, Rt. 127, Manchester

Year:

1990

DATE	TIME OF DAY	TIDE STAGE	TIDAL INFLUENCE	TIDE AMP. (ft.)	WEATHER INDEX	AIR TEMP. (C)	WATER TEMP. (C)		SALINITY (ppt)		WATER pH		D.O. (mg/l)	
							Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
3-02-90	1012	low +0.5 hrs.	No	9.8	1	5.0	1.0		0		6.0		15.0	
3-05-90	1341	low +0.5	N	8.4	1	-3.5	1.0				6.2		14.3	
3-09-90	1430	high +4.0	N	10.2	1	1.0	2.0		0		6.4		13.8	
3-15-90	1133	low +3.0	N	9.2	2	11.0	6.0		0		6.2		13.6	
3-21-90	1257	high +5.5	N	8.9	4	4.5	5.0		0		6.3		12.6	
3-23-90	1206	high +3.0	N	9.6	3	15.5	7.0		0		6.1		13.1	
3-26-90	1401	high +2.5	N	10.9	2	9.0	7.0		0		6.3		12.0	
3-30-90	1204	low +3.5	N	10.3	9	1.0	3.5		0		6.4		12.8	
4-02-90	1303	low +0.5	N	10.4	4	4.5	5.0		0		6.3		12.0	
4-06-90	1226	high +2.0	N	9.7	3	8.5	6.0		0		5.9		11.7	
4-09-90	1355	high +1.0	N	9.7	2	8.0	8.0		0		6.1		11.9	
4-13-90	1056	low +2.0	N	9.0	2	5.0	6.5		0		6.1		14.1	
4-16-90	1243	low +1.5	N	8.2	1	12.5	10.0		0		6.1		12.0	
4-20-90	1245	high +4.0	N	9.3	4	11.0	9.0		0		6.3		11.6	
4-23-90	1425	high +3.0	N	10.4	1	13.0	14.0		0		6.2		10.2	
4-27-90	1141	low +3.0	N	10.5	2	20.0	13.5		0		6.2		11.8	
4-30-90	1152	low +0.5	N	9.4	5	7.5	8.5		0		6.3		10.9	
5-07-90	1446	high +3.0	N	9.2	4	8.5	11.0		0		6.4		10.2	
5-10-90	1244	low +5.5	Yes	9.1	3	16.5	16.0		0		6.5		10.3	
5-14-90	1055	low +1.0	N	8.6	2	13.0	12.5		0		6.2		10.5	
5-17-90	1102	high +5.0	N	9.4	5	9.5	11.0		0		6.1		9.8	
5-21-90	1421	high +4.5	N	9.8	4	6.0	8.5		0		6.2		10.2	
5-24-90	1231	high tide	Y	10.4	2	9.0	11.5	11.0	0	22.0	6.3	7.8	10.6	10.4
5-28-90	1351	low +4.0	N	9.9	1	16.0	16.0		0		6.3		10.1	
Season Average						8.8	8.3				6.2		11.9	

Tide delay: 1 hour from Boston Harbor

APPENDIX

(BB-1)

Table 12.

Sample Site:

Bennett Brook, Manchester Bay

Year:

1988

DATE	TIME OF DAY	TIDE STAGE	TIDE AMP. (ft.)	TIDAL INFLUENCE	WEATHER INDEX	AIR TEMP. (C)	WATER TEMP. (C)		SALINITY (ppt)		WATER pH		D.O. (mg/l)	
							Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
3-01-88	1112	high +0.5 hrs.	9.3	No	1	3.0	4.0		0					
3-04-88	1205	high tide	9.6	Yes	5	1.5	2.5		0					
3-08-88	1125	low +2.5	8.7	N	1	6.0	4.0		0		6.2			
3-11-88	1233	low +1.0	7.8	N	1	4.5	4.5		0		6.6			
3-15-88	1215	high +3.0	10.3	N	4	2.0	4.5		0		6.6			
3-18-88	1339	high +2.0	11.2	N	4	7.0	5.5		0		6.5			
3-22-88	1056	low +1.5	9.4	N	1	1.5	4.5		0		6.3			
3-25-88	1117	low tide	9.0	N	4	8.0	7.5		0		6.7			
3-29-88	1217	high +3.0	8.8	N	1	6.0	6.5		0		6.1			
4-01-88	1248	high +1.5	9.3	N	4	9.5	8.0		0		6.5			
4-06-88	1530	high +1.0	8.7	Y	4	5.0	7.5		0		6.5			
4-08-88	1109	low tide	8.2	N	4	6.5	7.0		0		7.0			
4-15-88	1316	high +1.5	10.6	N	4	6.0	8.0		0		6.9			
4-19-88	1139	low +3.0	9.6	N	3	8.0	9.0		0		7.1			
4-21-88	1122	low +1.0	8.5	N	2	14.0	10.0		0		6.7			
4-27-88	1148	high +2.0	8.5	N	2	14.5	13.0		0		6.9			
4-29-88	1327	high +2.0	8.8	N	1	11.5	11.5		0		7.1			
5-03-88	1140	low +4.0	9.0	N	4	8.5	10.0		0		6.6			
5-06-88	1138	low +1.5	8.7	N	4	11.5	12.5		0		7.0			
5-10-88	1123	high +4.0	9.6	N	5	8.0	11.5		0		6.6			
5-13-88	1135	high +1.0	9.8	N	1	15.0	14.0		0		7.1			
5-17-88	1107	low +3.5	9.4	N	3	15.0	15.0		0		6.8			
5-20-88	1134	low +1.5	8.5	N	4	11.0	11.0		0		6.8			
5-24-88	1327	low tide	8.5	N	2	19.0	18.5		0		6.8			
5-27-88	1048	high +1.0	8.3	N	1	17.0	13.0		0		6.6			
6-01-88	1235	low +5.5	9.0	Y	4	15.5	14.5		0		7.0		9.8	
6-07-88	1235	low tide	9.7	N	1	20.5	19.0		0	2.0	7.2		7.8	
Season Average						9.5	9.5		0		6.7			

Tidal Delay:

45 minutes from Boston Harbor

APPENDIX

Table 13.

Sample Site:

Bennett Brook, Manchester Bay

Year:

1989

DATE	TIME OF DAY	TIDE STAGE	TIDE AMP. (ft.)	TIDAL INFLUENCE	WEATHER INDEX	AIR TEMP. (C)	WATER TEMP. (C)		SALINITY (ppt)		WATER pH		D.O. (mg/l)	
							Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
3-02-89	1352	low +0.5 hrs	9.1	No	2	2.0	3.0		0				14.7	
3-06-89	1155	high +1.5	11.0	N	4	-2.5	3.0		0		7.8		12.7	
3-09-89	1208	low +5.5	11.6	Yes	3	-0.5	2.0	2.0	1	28	7.4		14.2	12.6
3-13-89	1150	low +1.5	9.2	N	1	2.0	3.0		0		6.2		13.4	
3-16-89	1025	high +3.5	9.4	N	2	5.0	4.5		0		6.8		12.5	
3-20-89	1331	high +2.5	9.7	N	2	3.5	4.5		0		6.0		12.9	
3-23-89	1105	low +4.5	9.7	N	1	4.0	5.0		0		6.7		12.8	
3-27-89	1335	low +4.5	8.6	N	1	10.0	7.5		0		6.4		12.4	
3-30-89	1158	low +0.5	8.0	N	5	3.0	7.0		0		6.3		12.0	
4-03-89	1139	high +1.5	10.5	N	5	5.5	6.0		0		6.3		12.4	
4-06-89	1230	high tide	11.3	Yes	5	10.0	8.5	8.5	0	3	5.9		11.5	
4-10-89	1100	low +1.0	9.7	N	2	5.0	7.0		0		6.5		11.9	
4-13-89	1328	low +0.5	8.4	N	2	6.5	9.0		0		6.5		12.6	
4-17-89	1355	high +3.5	9.2	N	1	12.5	10.0		0		6.3		11.7	
4-20-89	1155	low +5.5	9.4	N	2	12.0	10.0		0		6.3		11.6	
4-24-89	1442	high tide	8.9	N	3	10.5	10.5		0		6.7		11.6	
4-27-89	1355	low +2.5	8.5	N	2	12.0	13.0		0		6.7		10.8	
5-01-89	1335	high +5.0	10.0	N	4	10.0	10.5		0		6.7		10.8	
5-04-89	1500	high +3.5	10.7	N	2	14.0	13.0		0		6.2		11.4	
5-08-89	1445	high tide	10.0	Yes	4	11.0	12.5		0		6.6		10.0	
5-11-89	1305	low +1.5	8.8	N	5	11.5	10.0		0		6.4		11.2	
5-15-89	1115	high +2.0	8.8	N	1	14.0	12.5		0		5.9		11.3	
5-17-89	1326	high +2.5	8.8	N	2	14.0	15.5		0		6.5		10.6	
6-06-89	1557	high +1.0	9.6	N	4	16.0	17.0		0		6.6		8.4	
Season Average						8.0	8.5		0.0		6.5		11.9	

Tidal Delay: 45 minutes from Boston Harbor

APPENDIX

Table 14.

Sample Site:

Bennett Brook, Manchester Bay

Year:

1990

DATE	TIME OF DAY	TIDE STAGE	TIDAL INFLUENCE	TIDE AMP. (ft.)	WEATHER INDEX	AIR TEMP. (C)	WATER TEMP. (C)		SALINITY (ppt)		WATER pH		D.O. (mg/l)	
							Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
3-02-90	1028	low +1.0 hrs.	No	9.8	1	4.0	2.0		0		6.2		15.0	
3-05-90	1349	low +1.0	N	10.1	1	-3.0	3.0		0		6.3		14.4	
3-09-90	1418	high +4.0	N	10.2	1	3.5	2.5		0		6.4		14.5	
3-15-90	1150	low +3.5	N	9.2	2	12.0	5.5		0		6.4		14.8	
3-21-90	1311	low tide	N	8.9	4	4.5	5.5		0		6.4		13.8	
3-23-90	1220	high +3.5	N	9.6	3	13.0	8.0		0		6.3		13.3	
3-26-90	1414	high +3.0	N	10.9	2	9.5	7.0		0		6.4		12.3	
3-30-90	1214	low +4.0	N	10.3	9	1.0	5.0		0		6.6		12.5	
4-02-90	1316	low +1.0	N	8.8	4	4.5	5.0		0		6.4		12.5	
4-06-90	1242	high +2.5	N	9.7	3	9.0	7.0		0		6.1		12.5	
4-09-90	1409	high +1.5	N	9.7	2	8.5	7.5		0		6.4		12.5	
4-13-90	1110	low +2.5	N	9.0	2	5.0	8.0		0		6.3		13.8	
4-16-90	1257	low +2.0	N	8.2	1	12.5	10.0		0		6.4		13.0	
4-20-90	1300	high +4.5	N	9.3	4	10.5	9.0		0		6.5		12.0	
4-23-90	1419	high +3.5	N	10.4	1	14.0	13.0		0		6.3		11.0	
4-27-90	1153	low +3.5	N	10.5	2	20.5	14.0		0		6.4		12.3	
4-30-90	1202	low +1.0	N	9.4	5	8.0	9.5		0		6.5		11.2	
5-07-90	1459	high +3.5	N	9.2	4	8.5	10.5		0		6.7		11.1	
5-10-90	1256	low +5.5	N	9.1	3	15.5	15.0		0		6.7		10.7	
5-14-90	1111	low +1.5	N	8.6	2	13.0	13.0		0		6.3		10.8	
5-17-90	1117	high +5.5	N	9.4	4	10.0	11.0		0		6.4		10.7	
5-21-90	1432	high +5.0	N	9.8	4	5.5	9.0		0		6.3		10.9	
5-24-90	1247	high +0.5	Yes	10.4	2	10.0	12.5	12.5	0	0	6.3		10.8	
5-28-90	1402	low +4.5	N	9.9	1	17.0	19.0		0		6.4		10.4	
Season Average						9.0	8.8		0		6.4		12.4	

Tide Delay:

45 minutes from Boston Harbor

APPENDIX

Table 15.

Sample Site:

(SB-1)
Sawmill Brook, Manchester Bay

Year:

1990

DATE	TIME OF DAY	TIDAL INFLUENCE	WEATHER INDEX	AIR TEMP. (C)	WATER TEMP. (C)		SALINITY (ppt)		WATER pH		D.O. (mg/l)	
					Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
3-02-90	1040	No	1	4.5	0.5		0		6.1		15.0	
3-05-90	1353	N	1	-3.0	1.5		0		6.4		14.6	
3-09-90	1409	N	1	2.5	2.5		0		6.3		14.7	
3-15-90	1208	N	2	11.0	5.0		0		6.5		14.3	
3-21-90	1331	N	4	4.0	5.0		0		6.5		13.1	
3-23-90	1258	N	2	14.0	7.0		0		6.4		13.0	
3-26-90	1442	N	2	8.0	6.0		0		6.5		12.6	
3-30-90	1224	N	9	2.0	4.0		0		6.5		12.9	
4-02-90	1323	N	4	5.5	5.0		0		6.5		12.5	
4-06-90	1305	N	3	10.0	6.5		0		5.8		11.6	
4-09-90	1422	N	2	7.5	7.5		0		6.4		12.5	
4-13-90	1119	N	2	5.0	6.0		0		6.2		14.6	
4-16-90	1309	N	1	14.0	10.0		0		6.3		12.4	
4-20-90	1316	N	4	12.0	9.0		0		6.5		11.8	
4-23-90	1435	N	1	14.0	13.0		0		6.3		10.9	
4-27-90	1218	N	2	21.0	13.0		0		6.3		12.3	
4-30-90	1209	N	5	8.0	9.0		0		6.5		10.9	
5-07-90	1437	N	3	8.5	11.5		0		6.4		10.8	
5-10-90	1319	N	4	18.0	16.0		0		6.6		10.3	
5-14-90	1134	N	1	14.5	13.0		0		6.4		10.2	
5-17-90	1139	N	5	10.5	12.0		0		6.3		9.6	
5-21-90	1447	N	4	6.5	9.0		0		6.3		10.4	
5-24-90	1259	N	2	12.5	12.0		0		6.1		11.0	
5-28-90	1412	N	1	17.0	17.0		0		6.4		10.4	
Season Average				9.5	8.4		0		6.4		12.2	

Tide delay: not possible for tide to reach sample site.

APPENDIX

(CC-3)

Table 16.

Sample Site:

Chubb Creek Railroad Bridge, Manchester Bay

Year:

1988

DATE	TIME OF DAY	TIDE STAGE	TIDE AMP. (ft.)	WEATHER INDEX	AIR TEMP. (C)	WATER TEMP. (C)		SALINITY (ppt)		WATER pH		D.O. (mg/l)	
						Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
3-01-88	1040	high +0.5 hrs.	9.3	1	2.0	2.5		31					
3-04-88	1145	high tide	9.6	5	0.5	2.5		31					
3-08-88	1055	low +2.5	8.7	1	4.0	3.0				6.6			
3-11-88	1155	low +1.0	7.8	1	4.5	4.5				6.7			
3-15-88	1134	high +3.0	10.3	4	2.0	3.0		28		8.0			
3-18-88	1421	high +3.0	11.2	4	8.0	5.5		27		8.1			
3-22-88	1033	low +2.0	9.4	1	-2.0	2.0				7.0			
3-25-88	1140	low +0.5	9.0	4	8.0	7.5				6.7			
3-29-88	1148	high +3.0	8.8	1	5.0	6.5				6.8			
4-01-88	1325	high +2.5	9.3	4	10.0	8.0		12		7.5			
4-06-88	1600	high +1.0	8.7	4	6.0	5.0		31		7.8			
4-08-88	1045	low tide	8.2	4	6.5	6.0		7		7.1			
4-15-88	1203	high +1.0	10.6	4	5.5	6.0		30		8.1			
4-19-88	1208	low +4.0	9.6	3	6.0	9.5		21		8.0			
4-21-88	1156	low +2.0	8.5	3	11.5	9.0		6		7.2			
4-27-88	1031	high +1.5	8.5	1	10.0	9.0		29		8.0			
4-29-88	1254	high +2.0	8.8	1	10.0	11.0		16		7.6			
5-03-88	1026	high +3.0	9.0	3	7.0	8.0		6		6.8			
5-06-88	1056	low +1.5	8.7	4	10.5	13.0		8		6.9			
5-10-88	1056	high +4.0	9.6	6	8.0	10.5		15		7.5			
5-13-88	1027	high +0.5	9.8	1	15.0	11.0		30		8.1			
5-17-88	1136	low +4.5	9.4	3	14.0	10.0		32		8.2			
5-20-88	1104	low +1.5	8.5	5	11.0	11.0		3		6.1			
5-24-88	1225	low tide	8.5	2	16.5	21.0		6		7.3			
5-27-88	945	high +0.5	8.3	1	14.5	11.0		27		8.2			
6-01-88	1201	low +5.0	9.0	4	14.5	12.0		31		8.2		9.7	
6-07-88	1212	low tide	9.7	1	18.0	17.0		16		7.4		7.8	
Season													
Average						8.4	8.3		20		7.4		

Tidal Delay: 15 minutes from Boston Harbor

APPENDIX

Table 17.

Sample Site:

Chubb Creek Railroad Bridge, Manchester Bay

Year:

1989

DATE	TIME OF DAY	TIDE STAGE	TIDE AMP. (ft.)	WEATHER INDEX	AIR TEMP. (C)	WATER TEMP. (C)		SALINITY (ppt)		WATER pH		D.O. (mg/l)	
						Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
3-02-89	1255	low +0.5 hrs.	9.1	2	0.0	3.0		1				14.5	
3-06-89	1223	high +2.5	11.0	4	-2.5	1.5		23		7.7		12.5	
3-09-89	1305	high +0.5	11.6	2	0.0	2.0		29		7.9		11.0	
3-13-89	1254	low +3.0	9.2	1	-3.0	6.0		5		7.3		12.3	
3-16-89	950	high +3.5	9.4	2	3.0	4.5		13		7.6		11.6	
3-20-89	1252	high +2.5	9.7	2	3.0	4.0		18		7.6		10.9	
3-23-89	1030	low +4.5	9.7	2	2.0	3.0		20		7.9		10.7	
3-27-89	1251	low +4.5	8.6	1	10.0	10.0		3		6.4		11.2	
3-30-89	1231	low +1.5	8.0	1	2.5	5.5		0		6.8		12.4	
4-03-89	1025	high +1.0	10.5	5	5.5	5.0		21		7.7		9.8	
4-06-89	1146	low +5.5	11.3	4	8.0	5.0	5.5	30	30	7.8		9.9	
4-10-89	1000	low +0.5	9.7	2	4.5	6.0		0		6.5		12.5	
4-13-89	1350	low +1.5	8.4	3	7.0	7.5		1		6.8		12.0	
4-17-89	1307	high +3.0	9.2	1	13.5	9.5		2		6.4		11.7	
4-20-89	1123	low +5.5	9.4	2	10.5	7.5		31		8.4		10.3	
4-24-89	1505	high +0.5	8.9	2	12.0	8.5		32		8.2		9.4	
4-27-89	1310	low +2.5	8.5	2	6.0	11.5		5		7.0		10.8	
5-01-89	1254	high +4.5	10.0	4	10.0	10.0		8		7.0		10.2	
5-04-89	1517	high +4.0	10.7	2	14.0	15.0		9		7.1		9.6	
5-08-89	1520	high +0.5	10.0	4	9.0	11.5		24		8.2		8.8	
5-11-89	1232	low +1.5	8.8	5	11.0	10.0		2		6.5		10.8	
5-15-89	950	high +1.5	8.8	1	14.0	12.0		23		7.8		9.0	
6-06-89	1515	high +1.0	9.6	4	14.0	14.0		30		7.7		8.3	
Season Average					6.7	7.5		14.3		7.4		10.9	

Tidal Delay: 15 minutes from Boston Harbor

APPENDIX

Table 18.

Sample Site:

Chubb Creek wood bridge, Manchester Bay

Year:

1988

DATE	TIME OF DAY	TIDE STAGE	TIDE AMP. (ft.)	WEATHER INDEX	AIR TEMP. (C)	WATER TEMP. (C)		SALINITY (ppt)		WATER pH		D.O. (mg/l)	
						Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
3-04-88	1140	low +5.5 hrs.	9.6	5	0.5	2.5		31					
3-08-88	1047	low +2.0	8.7	1	4.5	3.5				6.4			
3-11-88	1140	low +0.5	7.8	1	2.5	5.0				6.8			
3-15-88	1126	high +2.5	10.3	4	2.0	3.0		23		7.9			
3-18-88	1407	high +2.5	11.2	4	7.5	5.5		25		8.1			
3-22-88	1028	low +1.5	9.4	1	-2.0	2.5				7.1			
3-25-88	1131	low tide	9.0	4	8.0	7.5				6.7			
3-29-88	1135	high +2.5	8.8	1	5.5	6.5				6.5			
4-01-88	1317	high +2.0	9.3	4	10.0	8.0		6		7.2			
4-06-88	1620	high +1.0	8.7	4	5.5	6.5		18		6.6			
4-08-88	1037	low tide	8.2	4	6.5	6.5				7.2			
4-15-88	1223	high +1.0	10.6	4	5.5	7.0		29		8.1			
4-19-88	1200	low +3.5	9.6	3	6.0	8.5		7		6.9			
4-21-88	1147	low +1.5	8.5	3	11.5	9.0				7.1			
4-27-88	1051	high +1.5	8.5	1	10.0	10.0		21		7.9			
4-29-88	1245	high +2.0	8.8	1	10.5	11.5		8		7.3			
5-03-88	1020	low +3.0	9.0	3	7.0	8.0				6.5			
5-06-88	1050	low +1.0	8.7	4	11.0	13.0				6.8			
5-10-88	1050	high +3.5	9.6	6	8.0	10.5		6		7.0			
5-13-88	1050	high +0.5	9.8	1	15.0	12.0		28		7.9			
5-17-88	1127	low +4.0	9.4	3	14.5	14.0		7		7.0			
5-20-88	1058	low +1.0	8.5	5	11.0	11.0		1		6.7			
5-24-88	1218	high +5.5	8.5	2	16.5	21.0		2		7.1			
5-27-88	1008	high +0.5	8.3	1	17.0	12.0		13		7.5			
6-01-88	1153	low +5.0	9.0	4	14.0	12.5		26		8.2		9.2	
6-07-88	1205	low tide	9.7	1	15.5	18.0		7		7.4		8.6	
Season Average					8.6	9.0		15		7.2			

Tidal Delay: 30 minutes from Boston Harbor

APPENDIX

Table 19.

Sample Site:

Chubb Creek wood bridge, Manchester Bay

Year:

1989

DATE	TIME OF DAY	TIDE STAGE	TIDE AMP. (ft.)	WEATHER INDEX	AIR TEMP. (C)	WATER TEMP. (C)		SALINITY (ppt)		WATER pH		D.O. (mg/l)	
						Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
3-02-89	1305	low tide	9.1	2	1.0	3.0		0				14.4	
3-06-89	1230	high +2.5 hrs.	11.0	4	-2.0	1.0		15		7.4		12.5	
3-09-89	1322	high +0.5	11.6	2	0.0	2.0		30		7.9		11.0	
3-13-89	1302	low +3.0	9.2	1	-1.0	7.0		2		7.2		12.3	
3-16-89	957	high +3.0	9.4	2	3.0	4.0		2		7.0		12.8	
3-20-89	1301	high +2.5	9.7	2	2.5	4.0		7		7.6		12.4	
3-23-89	1038	low +4.5	9.7	2	2.0	3.0		0		7.7		13.4	
3-27-89	1300	low +4.0	8.6	1	10.0	10.0		1		6.4		11.4	
3-30-89	1238	low +1.5	8.0	1	2.5	5.5		0		6.7		12.2	
4-03-89	1050	high +1.0	10.5	5	5.5	5.5		12		7.6		11.2	
4-06-89	1155	low +5.5	11.3	4	8.0	5.5	5.5	30	30	7.8		9.9	
4-10-89	1008	low +0.5	9.7	2	4.5	6.0		0		6.4		12.6	
4-13-89	1356	low +1.0	8.4	3	7.0	12.0		0		6.7		11.2	
4-17-89	1315	high +3.0	9.2	1	13.5	10.0		0		6.3		11.7	
4-20-89	1129	low +5.5	9.4	2	10.5	8.5		20		8.2		10.3	
4-24-89	1522	high +0.5	8.9	2	8.5	10.0		13		7.9		10.6	
4-27-89	1317	low +2.5	8.5	2	8.0	12.0		2		7.0		11.1	
5-01-89	1300	high +4.5	10.0	4	10.0	10.5		1		6.7		10.9	
5-04-89	1523	high +4.0	10.7	2	12.0	16.0		2		7.0		10.4	
5-08-89	1550	high +1.0	10.0	4	10.0	13.0		12					
5-11-89	1238	low +1.5	8.8	5	11.0	10.0		0		6.4		10.7	
5-15-89	1015	high +1.5	8.8	1	15.0	13.0		5		7.2		10.4	
Season Average					6.4	7.8		7.0		7.2		11.6	

Tidal Delay:

30 minutes from Boston Harbor

APPENDIX

Table 20. Weather Index

- | | | |
|----|---------------|-----------------------|
| 1. | clear sky | (< 5% clouds) |
| 2. | partly cloudy | (5 to < 25% clouds) |
| 3. | mostly cloudy | (25 to < 75% clouds) |
| 4. | cloud cover | (> 75% clouds) |
| 5. | light rain | |
| 6. | medium rain | |
| 7. | heavy rain | |
| 8. | snow | |
| 9. | other | (ex. hail, fog) |

