J. KEDZIERSKI

PAMET RIVER STUDY

* hide on east side of Route 6 = 1.5

A Presentation of Data Collected

during the Summer of 1988

concerning

Tidal Characteristics and Pollution

in

the Pamet River Basin

Submitted to the

Truro Conservation Trust

Truro, MA

by

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February 1989

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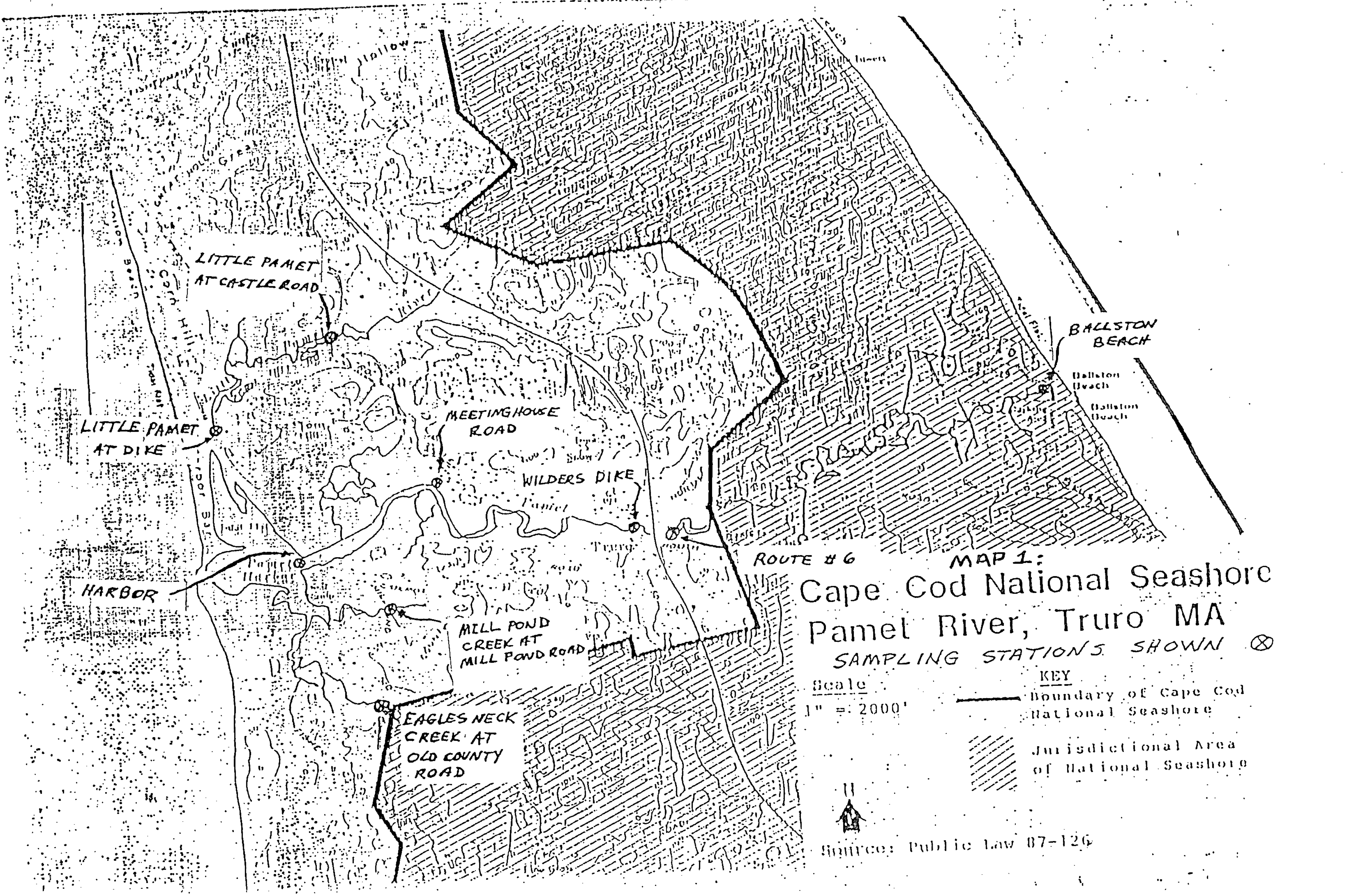
INTRODUCTION

The data collection performed during the summer of 1988 was the first phase of a two year project to study tidal characteristics, transport processes and pollution within the Pamet River basin, which is located in Truro, Massachusetts on Cape Cod. The data to be presented concern the measurements of temperature, salinity and conductivity as well as fecal coliform and *Streptococcus faecalis* counts made throughout the tidal cycle at sampling stations on the Pamet River, Little Pamet River and Eagles Neck Creek. Map 1 shows the Pamet Basin as well as the sampling stations used. Other field measurements, such as river elevations, freshwater flow, rainfall and chemistry data are tabulated in the appendices.

I wish to acknowledge the help and encouragement I received from Dr. Charles Davidson. This project was funded by the Truro Conservation Trust, the Truro Board of Health and the Pamet Harbor Commission. I wish to thank John Portnoy of the National Park Service, Graham Giese of WHOI, the Eastham Department of Natural Resources and the many people of Truro, who aided me with the research. The project is funded for the 1988-89 academic year by the Parsons Fellowship at Parsons Laboratory at the Massachusetts Institute of Technology.

PAMET RIVER STUDY: PHASE ONE

The first phase of the Pamet River study, which concerned data collection during the summer of 1988, is now complete. The data collected include information about tidal characteristics, flow data, elevations in the Pamet basin, microbial pollution, rainfall data and the inorganic chemistry of the Pamet River. This information will be used as a data base for the next phase



LITTLE PAMET AT CASTLE ROAD
LITTLE PAMET AT DIKE
HARBOR
MEETINGHOUSE ROAD
WILDERS DIKE
MILL POND CREEK AT MILL POND ROAD
EAGLES NECK CREEK AT OLD COUNTY ROAD
BALLSTON BEACH
ROUTE # 6
MAP 1:
Cape Cod National Seashore
Pamet River, Truro MA
SAMPLING STATIONS SHOWN ⊗
Scale
1" = 2000'
KEY
Boundary of Cape Cod National Seashore
Jurisdictional Area of National Seashore
N
Source: Public Law 87-126

of the project to be conducted under the auspices of the Massachusetts Institute of Technology Parsons Laboratory and the Truro Conservation Commission.

The initial phase of the study also involved a preliminary survey of the point sources as well as non-point sources of pollutants in the river. This survey and further data collection need to be completed, and both will be continued in the next phase of the project.

THE PAMET RIVER STUDY: SUMMER DATA (1988)

Physical Characteristics

The Pamet River is divided into two sections by a "clapper valve" at Wilders Dike. This valve separates the tidal saltwater estuary of the lower Pamet from the fresh water of the upper Pamet. The freshwater Pamet, which is almost entirely contained within the National Seashore, extends from the Ballston Beach barrier dune on the Atlantic Ocean to Wilders Dike at the post office and is fed by groundwater and rainfall runoff. to what extent?

Tidal Characteristics

The first portion of the summer was spent examining the river in Mr. Ansel Chaplin's canoe and gathering temperature, salinity and conductivity measurements (given in Appendix A) along the Pamet with the aid of the Park Service's salinity meter. On three occasions the salinities and water elevations at Wilders Dike were taken over parts of the tidal cycle. One of these occasions, which is particularly revealing, is given as Graph 1.

Graph 1 shows the NGVD elevation of the tide versus time. This graph was chosen because it shows the "non-sinusoidal" nature of the tide at Wilders Dike. Because the Pamet at Wilders Dike is at a higher elevation than the bay, the amplitude of the tide is "damped out" at low tide, and at this time, the Pamet behaves as a non-tidal river. The elevation difference and energy loss to friction between the bay and Wilders Dike accounts for the the long low tide period in the Pamet basin. Graph 1 shows that the Pamet River at Wilders Dike becomes stratified at high tide. Vertical stratification occurs when there is a large difference in the salinity between the water at the top and the water at the bottom of the river. This phenomenon is discussed below.

Graphs 2 and 3 show salinity vs. time. In these graphs, salinity is expressed in unitless form as concentration as a function of time divided by the maximum salinity encountered in that tidal period. Time is also expressed as a unitless quanitity as time within the tidal period divided by the tidal period. The tidal period is the time between high tides.

Graph 2 shows that although the maximum salinity encountered during any tidal period varies significantly, the pattern of the periods of high and low concentrations of salinity is quite stable. The highest salinities occur at Wilders Dike about one to two hours after high tide. About three hours after high tide, the clapper valve opens and the salinity concentration drops markedly due to dilution by fresh water. Graph 3 shows a comparison of salinity changes over the tidal cycle between the harbor and Wilders Dike. This graph shows that the concentration of salinity in the Pamet at Wilders Dike is about 60% of that at the harbor.

Information about the heights of tide and differences in tidal heights over time at Wilders Dike can be seen in Graph 4. From an examination of the three tidal periods recorded in Graph 4, it can be seen the general tidal shape and duration remain constant although the ultimate height of tide varies in accordance with the spring/neap cycle. Graph 5 shows a difference in height and duration between the tide at Wilders Dike and the harbor. From Graph 5, it can be determined that the harbor has a much more, although not perfect, sinusoidal shape and a shorter period of low tide than have Wilders Dike. This situtation occurs because the harbor, unlike the Pamet at Wilders Dike discussed earlier, has an elevation much closer to that of the bay and the head loss between the two is much less.

From the graphs, it can be seen that the estuary is flood dominant, meaning the tide comes in quickly and goes out slowly, and due to friction effects low tide lasts longer in the harbor, and longer sill at Wilders Dike, than in the bay. However, very little difference exists between high tides at any point along the river, in fact, only a 15-minute interval exists between high tide at the harbor and high tide at Wilders Dike. The NGVD elevations from the graphs can be used to predict how far tidal water would intrude up the river if Wilders Dike were not in place. All of the above information will be used in calibrating a mathematical model. (See below.)

Along with information gathered for the previous graphs, measurements concerning salinity were obtained and incorporated into these graphs. An interesting "salt wedge" effect at high tide was discovered and is shown in Graph 6. A salt wedge effect occurs when fresh water is "wedged" upward by the denser, and thus heavier, salt water and carried back upstream, in this case, to Wilders Dike with the incoming tide. Thus the fresh water "floats" on the salt water, and in this way the Pamet River becomes a stratified system at Wilders Dike from about an hour before high tide to three hours after high tide (Graph 6). This is important because pollution, as indicated be fecal coliform counts, is concentrated at Wilders Dike during this time period. (See Appendix A.)

Low salinities were encountered near Wilders Dike in the lower Pamet at low tide (Graph 6). This may account for the low number of shellfish found in the upper reaches of the lower Pamet. Shellfish require saline water, and the salinities in the Pamet reach to about 1 ppt (sea water is 30 ppt) for about 6 hours a day, twice a day. This is too fresh for most shellfish.

The final work completed on the saltwater portion of the river involved a land survey of the lower basin. Elevation information concerning the freshwater Pamet was also obtained in this survey. With the help of WHOI, benchmark elevations were set throughout the lower Pamet from which cross-sectional areas of the basin can be determined. All of this information will be used for the boundary conditions for a mathematical model of water quality parameters in the basin.

Freshwater Pamet

The next portion of the river to be studied was the upper Pamet. Whereas the lower Pamet is a wide, deep tidal river with the marsh grasses, *Spartina patens* and *Spartina alterniflora*, on its banks, the upper Pamet is a narrow, shallow stream with dense upland vegetation inhabiting its banks. The upper Pamet has no salinity upstream from Route 6 (excluding the Pamet River near Ballston Beach), indicating the clapper valve at Wilders dike works as designed. The river at the Ballston Beach dune has very high salinity readings, indicating salinity intrusion from some source. Readings of 20 ppt were found at the head of the Pamet, but the salinity concentration is diluted to 0 ppt at about 1000 feet downstream. These measurements could indicate a thinning barrier dune allowing saltwater intrusion from the ocean into the Pamet.

The water level in the ocean at high tide is approximately two feet higher than the water level in the Pamet. Thus a hydraulic gradient is formed between the Pamet and the ocean. Although the NGVD elevation of the water surface of the Pamet river at Ballston Beach was constant through the tidal cycle, observation wells along the Ballston Beach dune showed areas of high salinity in the groundwater. These points were localized where the beach dune was thinnest. More testing must be done, however, as sulphides from decaying peat can affect the readings. Thus, an area of interest in the next phase of the study will be to determine if there is actually saltwater intrusion occuring through the barrier dunes.

In both Graphs 7 and 8, the effect of the clapper valve in stopping flow for about 4 - 6 hours a day, twice a day, can be observed. Characteristics of the flow patterns of the freshwater Pamet were the final area of interest for summer data collection to be used in the mathematical model. This information was collected throughout the upper basin with a Marsh-McBirney current meter and at Route 6 using fluorescein dye, both provided by the Park Service. The freshwater flow and velocity of the river were obtained over the tidal cycle and are recorded in Graph 7, Graph 8 and Appendix B.

The velocity of the freshwater flow was obtained by putting fluorescein dye in the river on the east side of Route 6 and measuring the travel time to the west side of Route 6. The distance traveled is 360 feet, and the cross-section of the pipe under Route 6 is known, so that the volume flow can be calculated. Also given in Appendix B is the NGVD elevation of the water surface at the time the tests were performed.

Combined with rain data from the Park Service, flow data can be used to understand certain hydrologic features of the basin. These features include determination of the percent of rain runoff to groundwater as a source for the Pamet, times of concentration for runoff, and maximum expected water elevations. The Park Service is also interested in these freshwater flow data for use in other studies.

Microbial Characteristics of the River

The other area of summer research concerned microbial pollution. The Massachusetts Division of Marine Fisheries uses the MPN test (Most Probable Number) with 14 cultured fecal coliform colonies per 100 ml of water as the closure limit for shellfish beds. Water containing counts above this number is considered unsafe. In order to understand the method used in this study, one must first understand how the method works and what the results mean.

Many microorganisms exist naturally in marine waters; however, the presence of certain microorganisms indicates the possibility that pollution is also present. The existence of fecal coliform in a water sample is an indication that the water has been contaminated with septic material from a warm-blooded animal; and thus cultured colony counts of these microorganisms are used to regulate the closure of swimming areas and shellfishing beds. Recent studies have found that "fecal" coliform bacteria can grow in the natural environment, and for this reason alone, they are considered a poor indicator organism.

Shellfish filter water for food, and in this way, they concentrate bacteria. By concentrating bacteria, they also may concentrate pathogens (disease causing bacteria), and when man eats the shellfish, he may become infected. It should be noted that fecal coliform itself is usually not a pathogen as it does not cause disease, but it does indicate the presence of mammalian or avian wastes, which might contain pathogens.

For the most part, only a limited number of waterborne diseases can be exchanged from animals to man. This means that if the fecal coliform can be traced to non-human sources, a lesser chance of infection from microbial disease could occur in man, and thus another standard should be used. If the pollution is traced to human sources, serious diseases, such as heptatis, typhoid, cholera, etc., could be transmitted in the water.

The fecal coliform counts in the river and the harbor were found to exceed the limit for shellfishing throughout the entire summer (except in the harbor on an incoming tide without rain, and even then the counts are close to the limits). The limit for swimming closure was frequently exceeded at (1) low tide in the river, (2) all the time in the creeks, and (3) everywhere in the basin after a rain event. By strict evaluation of the coliform test the Pamet would be closed continually to shellfishing and often to swimming. This strict interpretation of the results may not be warranted.

In the summer of 1988, fecal streptococcus and fecal coliform testing was done. The ratios of coliform to streptococcus in the water samples may give insight into the sources of the pollution (man versus animal). Man has a coliform to strep ratio of greater than four and many animals, including sea birds, have a ratio less than one. The ratios found in this summer's research show animals wastes, except in limited areas of Eagles Neck Creek. Because the completed testing was limited, a great deal of uncertainty is associated with the results. Moreover, differential die-off rates of the two organisms in the natural environment, especially in saline waters, could drastically affect the results, so research in this area must be continued. (See Appendix A.)

Other Data

Rainfall data and inorganic chemistry data were received from the Park Service. These data along with other miscellaneous data are tabulated in Appendix C.

PAMET RIVER STUDY: THE FUTURE

This study will continue over the next two years, hopefully culminating in a master's degree thesis, and will coincide with the third year of a three-year study by Graham Giese of the Woods Hole Oceanographic Institution (WHOI). Several goals have been set for the project that involve practical applications for research that is to be done. With the data that have been collected, a mathematical model will be modified to be site-specific for the Pamet River so that it can be used to predict flow patterns, transport mechanisms, and concentration distributions of chemicals or organisms in the Pamet River under various pollution control scenarios.

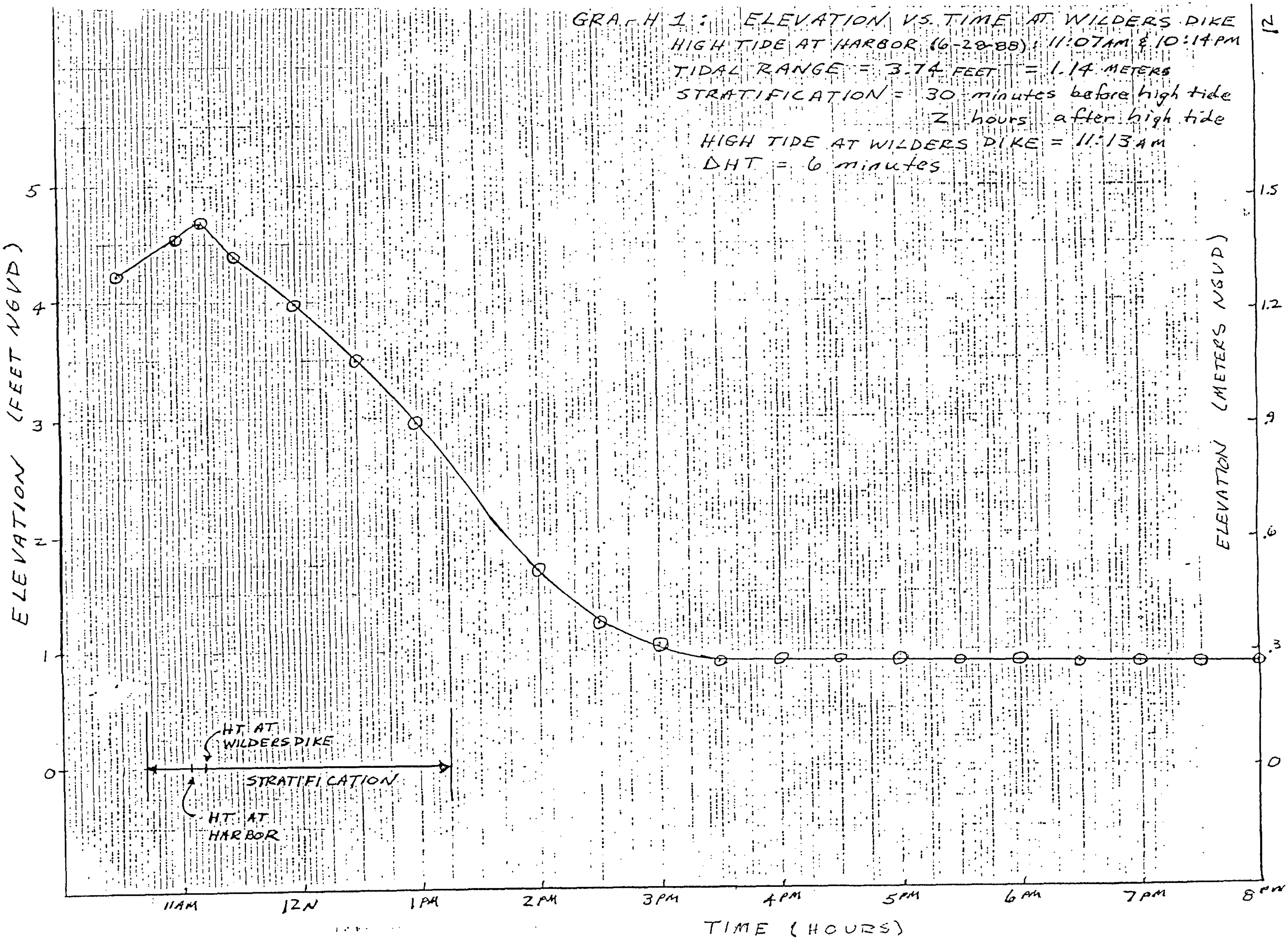
Use of results

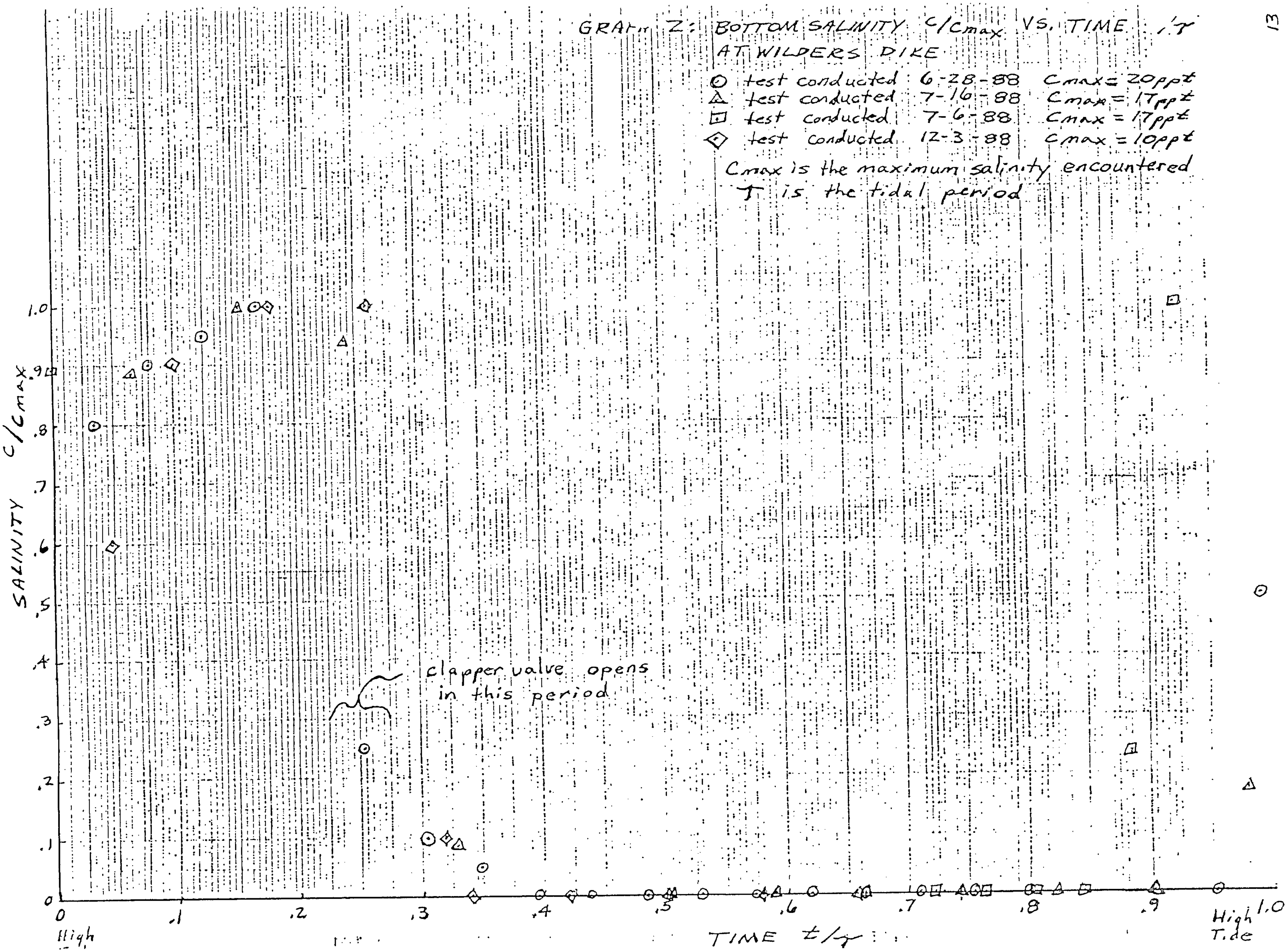
A calibrated mathematical model can be used to understand sediment transport. With the information gained by using this model, dredging operations can be maximized and the frequency of required dredging can be reduced. Understanding the sediment transport and flow patterns within the basin allows for knowledgeable management plans to be developed for the basin.

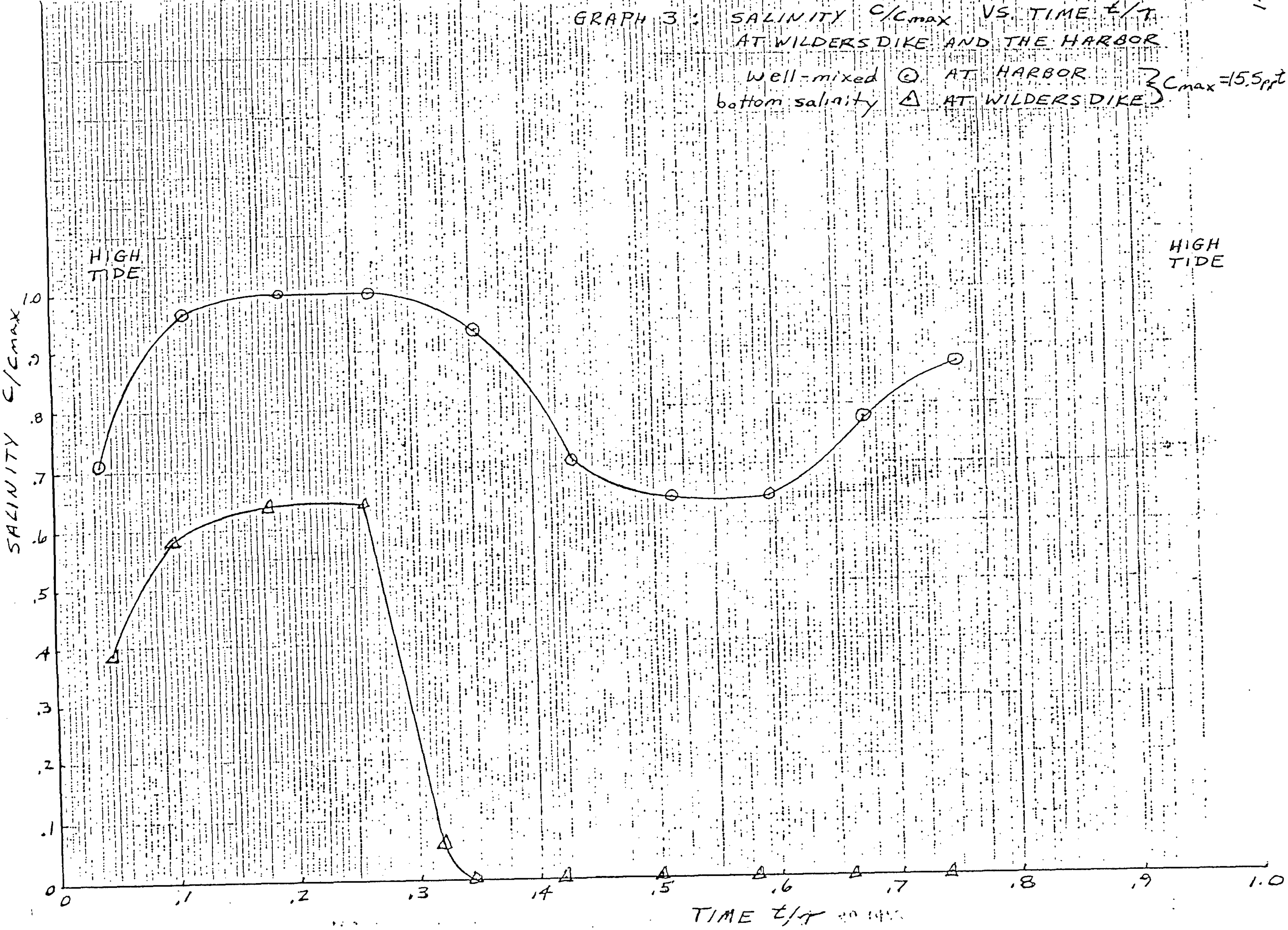
This portion of the project will be coordinated by WHOI.

The question of dike removal or repair will be addressed. Many problems are associated with some of the dilapidated dikes. Since either repair or removal of the dike systems would be expensive, an understanding of the consequences of either action should be examined. This can be done satisfactorially with the mathematical model.

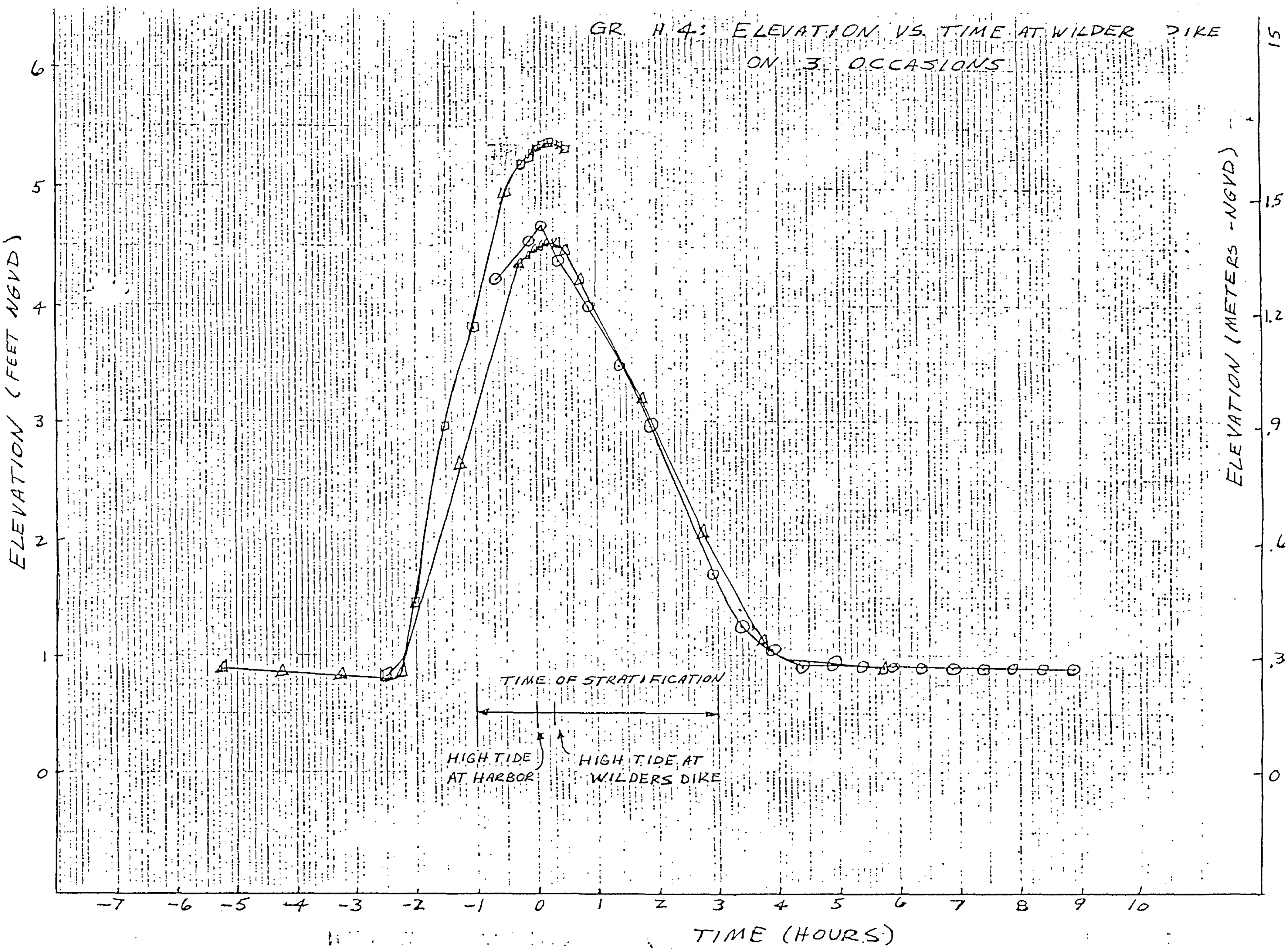
Other problems to be addressed by the research include finding and limiting the sources of microbial and chemical pollution on the Pamet. Currently the method of pollution determination is somewhat arbitrary and is actually a poor indication of hazard from pathogenic disease. Either a method of determining the actual level of pollution will be found or a better way of interpreting the results of current methods will be examined. This goal will be accomplished by using a DNA amplication technique to identify certain animal-specific DNA sequences. These sequences can be detected at high dilution and can, hopefully, be used to identify the source of pollution in the Pamet. Thus a better understanding of health risks assciated with shellishing and swimming in the Pamet can be developed.

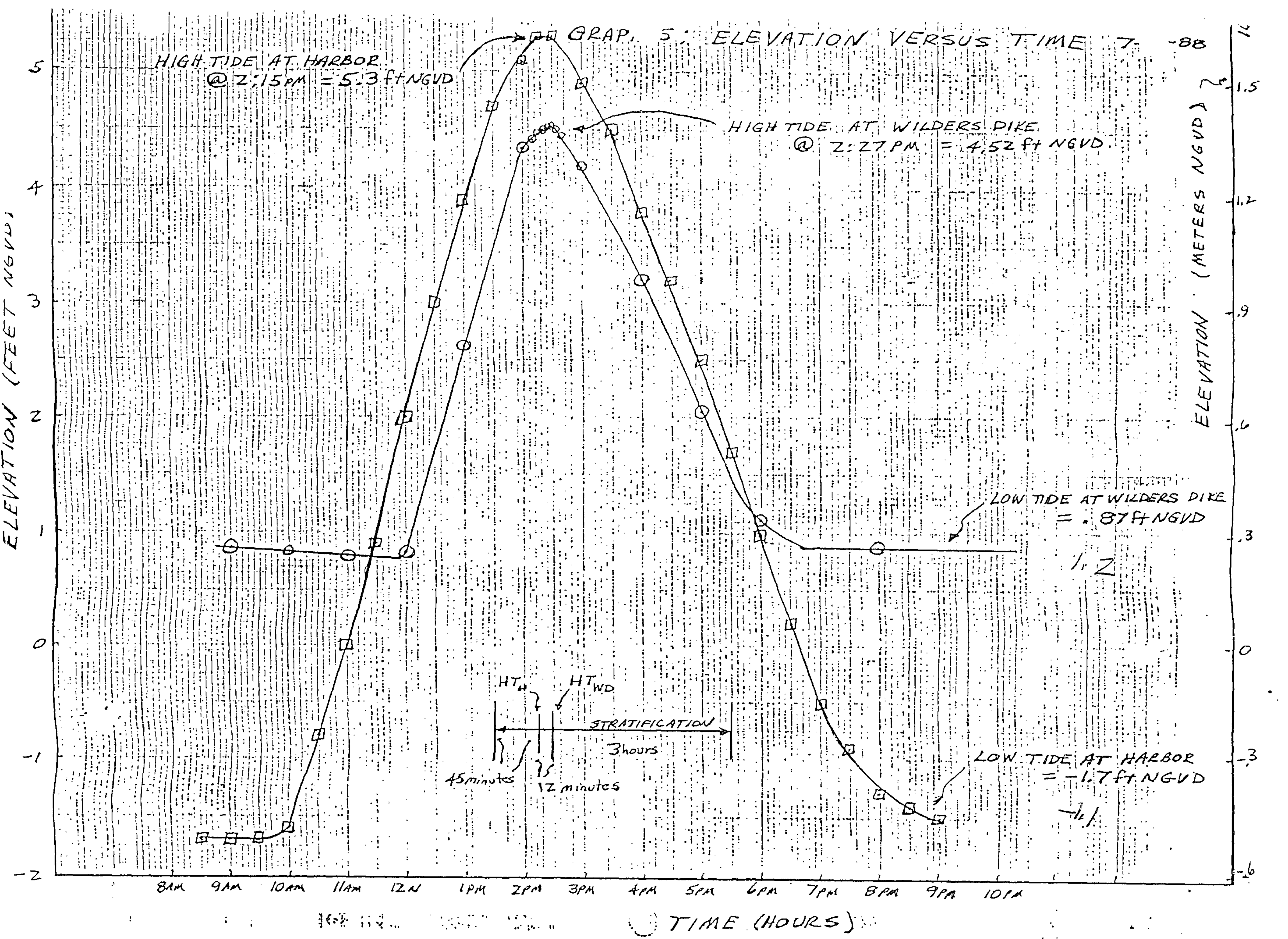

GRAPH 1: ELEVATION VS. TIME AT WILDERS DIKE
HIGH TIDE AT HARBOR (6-28-88): 11:07AM & 10:14PM
TIDAL RANGE = 3.74 FEET = 1.14 METERS
STRATIFICATION = 30 minutes before high tide
2 hours after high tide
HIGH TIDE AT WILDERS DIKE = 11:13 AM
DHT = 6 minutes
ELEVATION (FEET NGVD)
ELEVATION (METERS NGVD)
5
4
3
2
1
0
1.5
1.2
.9
.6
.3
0
HT AT WILDERS DIKE
STRATIFICATION
HT AT HARBOR
11AM
12N
1PM
2PM
3PM
4PM
5PM
6PM
7PM
8PM
TIME (HOURS)
12


GRAPH Z: BOTTOM SALINITY c/Cmax VS. TIME t/T
AT WILDERS DIKE
test conducted 6-28-88 Cmax = 20ppt
test conducted 7-16-88 Cmax = 17ppt
test conducted 7-6-88 Cmax = 17ppt
test conducted 12-3-88 Cmax = 10ppt
Cmax is the maximum salinity encountered
T is the tidal period
clapper valve opens in this period
SALINITY c/Cmax
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
High
High Tide
TIME t/T

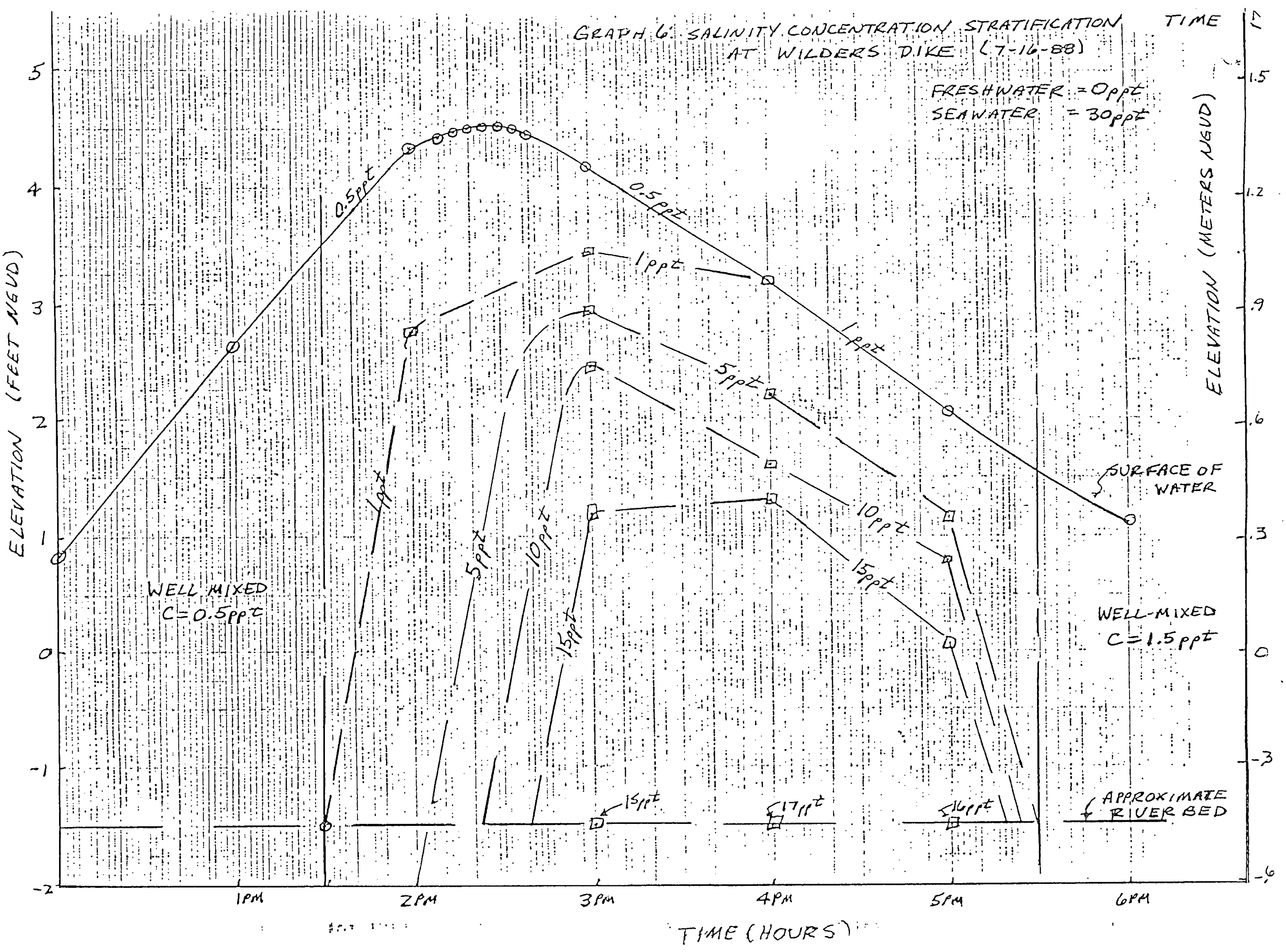


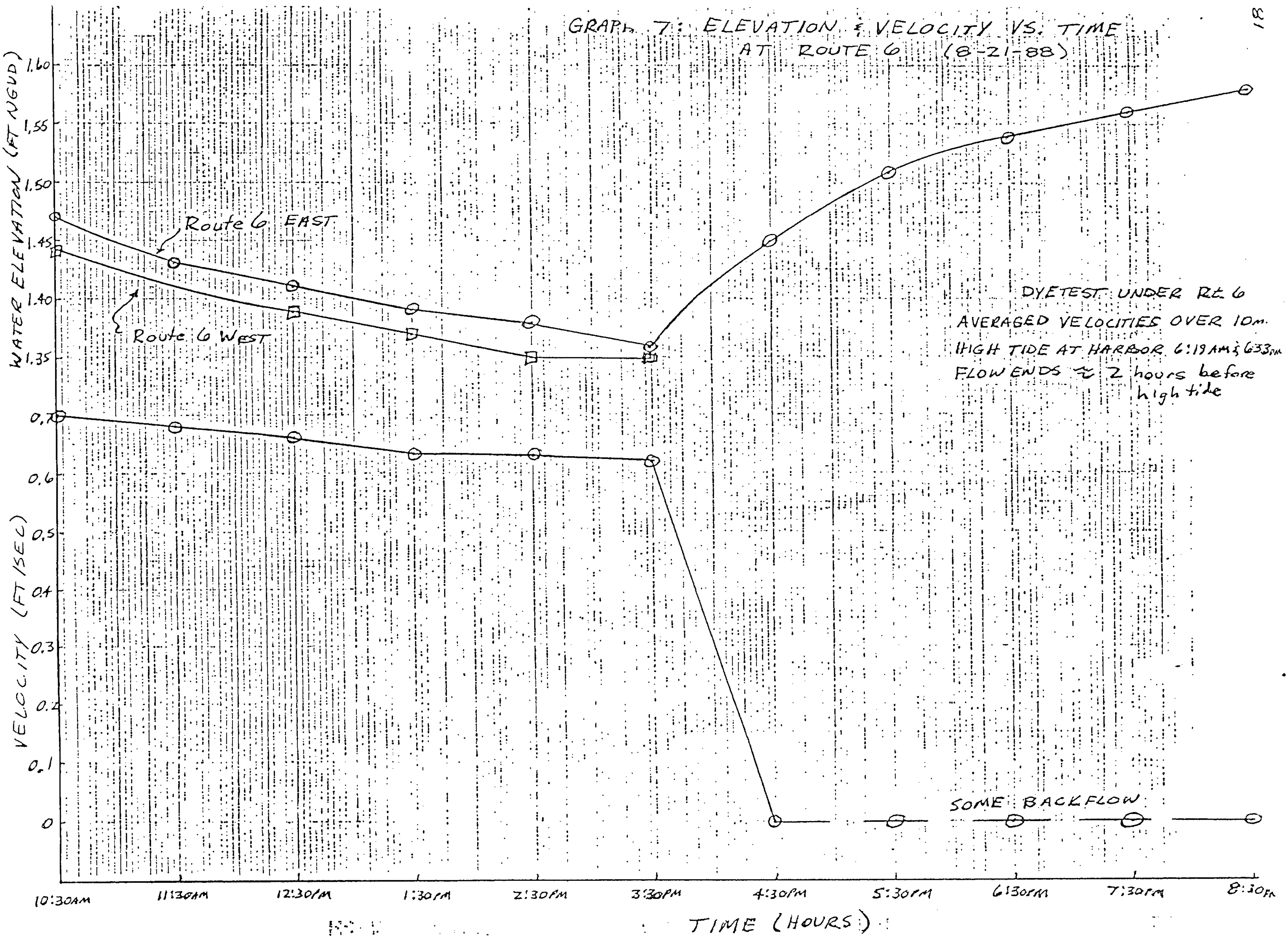
GRAPH 3: SALINITY C/Cmax VS. TIME t/T
AT WILDERSDIKE AND THE HARBOR
Well-mixed ⊙ AT HARBOR
bottom salinity Δ AT WILDERSDIKE
Cmax = 15.5ppt
HIGH TIDE
HIGH TIDE
SALINITY C/Cmax
TIME t/T
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

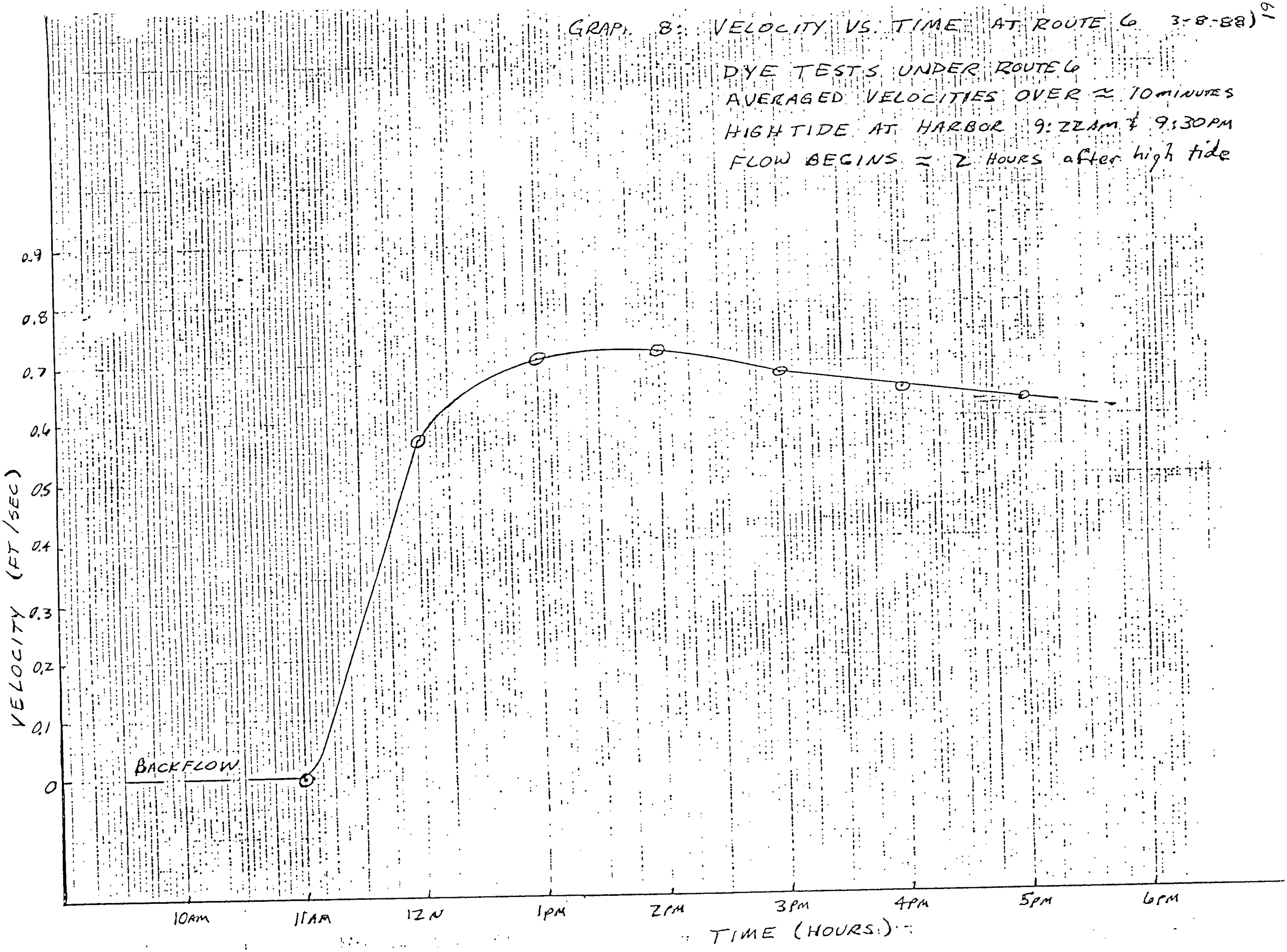

GR. H 4: ELEVATION VS. TIME AT WILDER DIKE
ON 3 OCCASIONS
ELEVATION (FEET NGVD)
ELEVATION (METERS - NGVD)
TIME (HOURS)
TIME OF STRATIFICATION
HIGH TIDE AT HARBOR
HIGH TIDE AT WILDERS DIKE
6
5
4
3
2
1
0
15
1.5
1.2
.9
.6
.3
0
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10



GRAP. 5: ELEVATION VERSUS TIME 7- -88
HIGH TIDE AT HARBOR @ 2:15PM = 5.3 ft NGVD
HIGH TIDE AT WILDERS DIKE @ 2:27PM = 4.52 ft NGVD
LOW TIDE AT WILDERS DIKE = .87 ft NGVD
LOW TIDE AT HARBOR = -1.7 ft NGVD
HT_H
HT_{WD}
STRATIFICATION
3 hours
45 minutes
12 minutes
ELEVATION (FEET NGVD)
ELEVATION (METERS NGVD)
TIME (HOURS)
8AM 9AM 10AM 11AM 12N 1PM 2PM 3PM 4PM 5PM 6PM 7PM 8PM 9PM 10PM
5 4 3 2 1 0 -1 -2
1.5 1.2 .9 .6 .3 0 -.3 -.6
1.2
-1.1


GRAPH 6: SALINITY CONCENTRATION STRATIFICATION
AT WILDERS DIKE (7-16-88)
TIME
FRESHWATER = 0ppt
SEAWATER = 30ppt
ELEVATION (FEET NGVD)
ELEVATION (METERS NGVD)
TIME (HOURS)
1PM
2PM
3PM
4PM
5PM
6PM
0.5ppt
1ppt
5ppt
10ppt
15ppt
15ppt
17ppt
16ppt
WELL MIXED
C=0.5ppt
WELL-MIXED
C=1.5ppt
SURFACE OF WATER
APPROXIMATE RIVER BED


GRAPH 7: ELEVATION & VELOCITY VS. TIME
AT ROUTE 6 (8-21-88)
WATER ELEVATION (FT NGVD)
1.60
1.55
1.50
1.45
1.40
1.35
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
VELOCITY (FT/SEC)
Route 6 EAST
Route 6 WEST
DYETEST UNDER Rt. 6
AVERAGED VELOCITIES OVER 10m.
HIGH TIDE AT HARBOR 6:19AM & 6:33PM
FLOW ENDS ≈ 2 hours before high tide
SOME BACKFLOW
10:30AM
11:30AM
12:30PM
1:30PM
2:30PM
3:30PM
4:30PM
5:30PM
6:30PM
7:30PM
8:30PM
TIME (HOURS)



GRAPH 8: VELOCITY VS. TIME AT ROUTE 6 3-8-88)
DYE TESTS UNDER ROUTE 6
AVERAGED VELOCITIES OVER ≈ 10 minutes
HIGH TIDE AT HARBOR 9:22AM & 9:30PM
FLOW BEGINS ≈ 2 HOURS after high tide
BACKFLOW
VELOCITY (FT/SEC)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
10AM
11AM
12N
1PM
2PM
3PM
4PM
5PM
6PM
TIME (HOURS)

Appendix A

Pollution Data from Ten Sites in the Pamet Basin

Information included in tables:

Location of testing sites (see map 1)

Date and time (EDT) of testing

Temperature of water in Celsius

Salinity of water in ppt (parts per thousand) = gm/L (grams per liter)

Conductivity of water in micromhos (μmhos)

Fecal coliform count/fecal streptococcus counts in colonies per 100 mL

High tide times for testing date (EDT)

Notes:

1. The abbreviation "strat" is used to denote stratification in which case a surface and bottom reading are given for salinity and conductivity.

2. The membrane fiter technique (MF) is used to determine colony counts, which involves filtering 100 ml of sample. Dilutions tests are denoted by asterisks. All tests measured as # of colonies per 100 mL. The asterisk * denotes a test performed at 10 mL dilution.

3. The FC/FS value is not a ratio. The first, and often only, value given is the fecal coliform (FC) count. The second value, after the slash, is the fecal streptococcus (FS) count.

4. ** = test performed by Barnstable County Laboratory.

5. Several testing sites were chosen along Eagles Neck Creek and Mill Pond Creek. To distinguish between these locations, subheadings are used.

   a. Both creeks intersect roads; and these locations, labeled road, were chosen as testing sites.

   b. A testing site was chosen where Eagles Neck Creek intersects Mill Pond Creek and is labeled Creek in the notes.

   c. Another testing site was chosen where Eagles Neck Creek intersects the harbor and this site is labeled Harbor.

   d. The final station along Eagles Neck Creek, midway between the harbor and Old County Road, was labeled Mid.

Date	Temp(C)	Salinity (ppt)	Conductivity µMHOs	MF FC/FS	Time EDT	High Tide
Harbor						
6-24-88	23°	13.8	22,000	-	2:40p	7:38a 8:01p
7-6-88**	-	-	-	9	-	5:26a 6:01p
7-11-88	27°	26	40,000	13	1:55p	10:53a 10:41p
7-29-88	25°	23	-	10	1:45p	12 mid 12:24p
7-31-88	23°	22	33,000	-	2:40p	1:28a 2:05p
8-11-88	28°	23	38,000	97/>2000	10:20a	11:55a 11:59p
8-17-88	25°	16	26,000	71	11:30a	3:11a 3:32p
8-17-88**	25°	16	26,000	36	11:30a	3:11a 3:32p
Route 6						
7-3-88	22°	0	550	-	-	2:37a 3:19p
7-6-88**	-	-	-	145	≈11:00a	5:26a 6:01p
7-7-88	25°	0.2~0	-	118	12:20p	6:28a 6:58p
7-11-88	30°	0.8~0	1,100	72	2:55p	10:33a 10:41p
7-14-88	25°	0.5~0	1,100	158	1:54p	12:15a 12:56p
7-21-88	20°	0.3~0	600	>700	12:20p	5:13a 5:39p
7-23-88	21°	0.2~0	580	378 550*	12:25p	6:55a 7:14p
7-29-88	27°	0	-	0	2:30p	12:00a 12:24p

Date	Temp(C)	Salinity (ppt)	Conductivity µMHOs	MF FC/FS	Time EDT	High Tide
7-31-88	26°	0.3~0	6,500	45/81	2:00p	11:28a 2:05p
8-11-88	29°	0	700	43/94	1:35p	11:55a 11:59p
8-17-88	23°	0	460	64	10:50p	3:11a 3:32p
**	23°	0	460	18	10:50p	

Wilders Dike

Date	Temp(C)	Salinity (ppt)	Conductivity µMHOs	MF FC/FS	Time EDT	High Tide
6-24-88	-	0	700	-	4:30p	7:38a 8:01p
6-25-88	20	0	-	-	2:15p	8:32a 8:48p
6-26-88	18	13	16,500	-	9:55p	9:25a 9:37p
6-28-88	20	0.4~0	750	-	10:30a	11:07a 10:14p
	20	0.5~0 10	900 16,000 strat	-	11:00a	
	22	0.2~0 16	850 24,000 strat	-	11:30a	
	23	0.8~0 18	1,000 27,000 strat	-	12 noon	
	25	0.5~0 19	1,000 28,000 strat	-	12:30p	
	25	0.5~0 20	1,050 29,000 strat	-	1:00p	
	24	3 5	5,500 7,500 strat	-	2:00p	
	24	2	3,500	-	2:30p	
	23	1	1,500	-	3:00p	

Date	Temp(C)	Salinity (ppt)	Conductivity µMHOs	MF FC/FS	Time EDT	High Tide
	23	0.6~0	1,000	–	3:30p	
	25	0.3~0	–	–	4:00p	
	24	0.2~0	750	–	4:30p	
	24	0.2~0	700	–	5:00p	
	24	0.1~0	600	–	5:30p	
	23	0.1~0	600	–	6:00p	
	23	0.1~0	550	–	6:30p	
	22.5	0.1~0	550	–	7:00p	
	21	0.1~0	550	–	7:30p	
	21	0.1~0	550	–	8:00p	
7-6-88	27.5	0.1~0	800	–	3:30p	6:28a 6:58p
	27	0.1~0	800	–	4:00p	
	27	0.2~0	1,000	–	4:30p	
	25	0.6~0 0.8~0	1,200 1,500 strat	–	5:00p	
	26	0.8~0 4	1,300 8,000 strat	–	5:30p	
	25	0.5~0 17	1,350 29,000 strat	–	6:00p	
7-1-88	20	29	40,000	–	2:00p	12:35a 1:38p

Date	Temp(C)	Salinity (ppt)	Conductivity µMHOs	MF FC/FS	Time EDT	High Tide
	19.5	2 26	3,100 37,000 strat	-	2:35p	
7-14-88	25	17	22,000	217	2:04p	12:15a 12:56p
7-16-88	22	0.5~0	950	-	9:00a	1:38a 2:15p
	23	0.5~0	1,000	-	10:00a	
	24	0.5~0	1,000	-	11:00a	
	25	0.4~0	800	-	12 noon	
	26	0.5~0	1,000	-	1:00p	
	28	0.5~0 3	1,200 5,500 strat	-	2:00p	
	23	0.8~0 15	1,400 23,000 strat	-	3:00p	
	25	1 17	1,800 18,000 strat	-	4:00p	
	27.5	1 16	1,900 28,000 strat	-	5:00p	
	25.5	1.5	2,800	-	6:00p	
	25	0.5~0	1,000	-	8:00p	
7-29-88	23	2 14	- strat	188 166	12:32p	12:00a 12:24p
7-31-88	27	3 15	5,500 26,000 strat	97/>800 96/>800	2:05p	1:28a 2:05p
8-11-88	25	1 10	1,500 17,000 strat	55/508 76/>1000	1:40p	11:55a 11:54p
8-21-88 east	-	0	700	-	4:30p	6:19a 6:38p

Date	Temp(C)	Salinity (ppt)	Conductivity µMHOs	MF FC/FS	Time EDT	High Tide
east	-	0.3~0	950	-	5:30p	
east	-	12	19,000	-	6:30p	
east	-	15	24,000	-	7:30p	
8-17-88	23	0	600	47	10:55a	3:11a 3:32p
**	23	0	600	27	10:55a	
Ballston Beach						
7-3-88	22	1 10	1,450 16,000 strat	-	11:46p	2:37a 3:19p
7-6-88**	-	-	-	<10	-	5:26a 6:01p
7-25-88	28	6 21	- strat	-	1:30p	8:49a 9:00p
7-31-88	28	10	17,000	45/525	1:50p	1:28a 2:05p
8-10-88	32	6 16	- 31,000 strat	-	12:30p	11:09a 11:15p
8-11-88	35	11	21,000	121/>2000	12:35p	11:55a 11:59p
8-17-88	24	10	17,000	23	10:45p	3:11a 3:32p
8-17-88**	24	10	17,000	18	10:45p	3:11a 3:32p
8-21-88	25	5	10,000	-	10:45a	6:19a 6:33p
	26.5	6	10,000	-	11:45a	
	28	13	17,000	-	12:45a	
	29	11	19,000	-	1:45p	
	28	8	15,000	-	2 :45p	
	27	10	19,000	-	3:45p	
	25	12.5	21,000	-	4:45p	

Date	Temp(C)	Salinity (ppt)	Conductivity μMHOs	MF FC/FS	Time EDT	High Tide
	24	10	17,000	-	5:45p	
	24	12	19,500	-	6:45p	
8-21-88	20	11.5	17,000	-	7:45p	6:19a 6:33p
Little Pamet (at dike)						
7-6-88**	-	-	-	290	11:00a	5:26a 6:01p
7-7-88	26	2	-	69	12:10a	6:28a 6:58p
7-11-88	30	13.5	23,000	36	3:00p	10:33a 10:41p
7-21-88	21.5	0.6~0	1,000	>400	12:30p	5:13a 5:39p
7-23-88	22	0.5~0	1,300	161 230*	12:30p	6:55a 7:14p
7-31-88	24	16	25,000	549/508	2:15p	1:28a 2:05p
8-11-88	26	0.3~0	1,000	76/1000	10:50a	11:55a 11:59p
8-17-88	25	10	17,500	69	11:00a	3:11a 3:32p
8-17-88**	25	10	17,500	118	11:00a	3:11a 3:32p
Little Pamet (Castle Road)						
7-6-88**	-	-	-	100	≈12:00	5:26a 6:01p
7-31-88	26	0	260	47/351	2:25p	1:28a 2:05p
8-11-88	27	0	260	93/151	10:55a	11:55a 11:59p
8-17-88	23.5	0	200	>105	11:10a	3:11a 3:32p

Date	Temp(C)	Salinity (ppt)	Conductivity µMHOs	MF FC/FS	Time EDT	High Tide
8-17-88**	23.5	0	200	200	11:10a	3:11a 3:32p
Eagles Neck Creek						
7-6-88 ** Old County Road		–	–	220	≈11:00a	5:26a 6:01p
7-6-88 ** Main Stream near harbor		–	–	45	11:00a	5:26a 6:01p
7-21-88 Road	22	2	3,400	>800	12:10a	5:13a 5:39p
Harbor	21.5	17	26,000	>1,000	11:15a	
Creek	21.5	14	22,000	>500	11:25a	
Mid	21	13	20,000	>500	11:35a	
7-23-88 Road	22	2	2,700	>300 640*	12:15p	6:55a 7:14p
Harbor	22	18.5	28,000	>1,000 1,220*	11:40a	
Creek	22	16	25,000	291 390*	11:50a	
7-31-88 Road	25	20	32,000	203/>800	2:45p	1:28a 2:05p
8-11-88 Road	30	2.5	5,000	–	10:40a	11:55a 11:59p
8-17-88 Road	27	4	7,000	>280	11:40a	3:11a 3:32p
8-17-88** Road	27	4	7,000	1,618	11:40a	3:11a 3:32p
Mill Pond Creek						
7-6-88** Mill Pond Road	–	–	–	260	11:30a	5:26a 6:01p
7-21-88 Creek near Harbor	21.5	19	28,500	>1000	11:20a	5:13a 5:39p

Date	Temp(C)	Salinity (ppt)	Conductivity µMHOs	MF FC/FS	Time EDT	High Tide
7-21-88 Road	16	2.5	3,900	>800	11:55a	5:13a 5:39p
7-23-88 Creek	22	21	31,500	>1,000 3,170*	11:45a	6:55a 7:14p
7-23-88 Road	16	1.5	2,500	>400 >740*	12:05p	6:55a 7:14p
7-31-88 Road	21	16	25,000	386/200	2:50p	1.28a 2.05p
8-11-88 Road	23	3.5	6,000	442/225	10:30a	11:55a 11:59p
8-17-88 Road	24	7	12,000	>180	11:35a	3:11a 3:32p
8-17-88** Road	24	7	12,000	2,464	11:35a	3:11a 3:32p
Meetinghouse Road						
7-6-88**	-	-	-	64	≈12 noon	5:26a 6:01p
7-7-88	26	18	-	69 100*	12:10a	6:28a 6:58p
7-11-88	27	18	30,000	128	3:00p	10:33a 10:41p
7-11-88 Basin	30	25	42,000	125	3:00p	10:37a 10:41p
7-14-88	26	28	44,000	61	2:12p	12:15a 12:56p
7-21-88 Basin	24	20	32,000	-	12:40p	5:13a 5:39p
7-23-88 Basin	27	19	30,000	-	12:40p	6:55a 7:14p
7-23-88	21	7	11,000	241 160*	12:45p	6:55a 7:14p
7-29-88	24	23	-	19	1:16p	12 mid 12:24p

Date	Temp(C)	Salinity (ppt)	Conductivity µMHOs	MF FC/FS	Time EDT	High Tide
7-31-88	24	21	33,000	-	2:35p	1:28a 2:05p
8-11-88	28	23	38,000	52/>2,000	11:05a	11:55a 11:59p
8-17-88 Basin	29	21	36,500	≈100	11:20a	3:11a 3:32p
** Basin	29	21	36,500	<10	11:20a	
	25	7	13,000	25	11:15a	
**	25	7	13,000	18	11:15a	

Appendix B

Freshwater Flow at Route 6

Information included in tables:

Date and time (EDT) of testing

Method of measuring velocity

Velocity and flow of water under Route 6

Methods of measuring velocity/flow

1. Marsh-McBirney current meter direct reading
2. Dye test

   a) Dye is put into river and the time it takes for the dye to travel a known distance (360 feet) is recorded in "Duration column."

   b) Average velocity = 360ft/duration

   c) Average cross-sectional Area of water in pipe = $\left(\text{area at eastend} + \text{area at westend}\right) / 2$

   The cross-sectional area of water at the east and west end of the pipe is obtained by knowing the NGVD deviations of the bottom of the 48" pipe, (-0.45' east) and (-0.77' west), and the NGVD elevations of the water surface, given in the tables.

   d) flow = velocity x area

Distance = 360 feet under Rt. 6

Diameter = 48 inch pipe

m = minutes

s = seconds

E = elevation at Rt. 6 east

W = elevation at Rt. 6 west

A = area

WD = elevation/salinity (ppt) at Wilders Dike

* = based on approximation of half full pipe

Appendix B

Flow at Route 6

High Tide	Date	Time EDT	Method	Duration	Velocity	Area	Flow
2:19a 2:55p	7-17-88	12 noon	Dye	9m 30s	.63 ft/s	6.62 ft^2	4.2 ft^3/s
2:19a 2:55p	7-17-88	12 noon	Meter	–	30cm/s	6.62 ft^2	6.5 ft^3/s
4:09a 4:38p	8-3-88	≈12:30p	Dye	9m 30s	.63 ft/s	*	4.0 ft^3/s
8:17a 8:33p	8-7-88	11:00a	Dye	Backflow	–	*	0 ft^3/s
		12:20a	Dye	10m 30s	.57 ft/s	*	3.6 ft^3/s
		1:00p	Dye	8m 30s	.71 ft/s	*	4.5 ft^3/s
		2:00p	Dye	8m 20s	.72 ft/s	*	4.5 ft^3/s
		3:00p	Dye	8m 50s	.68 ft/s	*	4.3 ft^3/s
		4:00p	Dye	9m 10s	.65 ft/s	*	4.1 ft^3/s
		5:00p	Dye	9m 30s	.63 ft/s	*	4.0 ft^3/s
2:32a 2:55p	8-16-88	10:40a	Dye	9m 30s	.63 ft/s	*	4.0 ft^3/s
3:11a 3:32p	8-17-88	1:25p	Dye	9m 30s	.63 ft/s	*	4.0 ft^3/s
6:19a 6:33p	8-21-88	10:30a	Dye	8m 30s	.71 ft/s	NGVD E 1.47' W 1.44' A 6.70 ft^2	4.6 ft^3/s
		11:30a	Dye	8m 50s	.68 ft/s	E 1.43' W 1.39' A 6.52 ft^2	4.3 ft^3/s

Appendix B

Flow at Route 6

High Tide	Date	Time EDT	Method	Duration	Velocity	Area	Flow
6:19a 6:33p	8-21-88	12:30p	Dye	9m 05s	.66 ft/s	E 1.41' W 1.39' A 6.30 ft^2	4.1 ft^3/s
		1:30	Dye	9m 25s	.64 ft/s	E 1.39' W 1.37' A 6.22 ft^2	4.0 ft^3/s
		2:30p	Dye	9m 35s	.63 ft/s	E 1.38' W 1.33' A 6.12 ft^2	3.9 ft^3/s
		3:30p	Dye	9m 45s	.62 ft/s	E 1.36' W 1.33' A 6.08 ft^2	3.8 ft^3/s
		4:30p	Dye	No flow	0	E 1.45' WD-/0 A -	0
		5:30p	Dye	Backflow	-	E 1.51' WD1.51'/0 A -	0
		6:30p	Dye	Backflow	-	E 1.54' WD1.55'/12 A -	0
		7:30p	Dye	Strong Backflow	-	E 1.56' WD1.57'/15 A -	0
		8:30p	Dye	No flow	0	E 1.58' A	0
10:16a 10:29p	8-25-988	3:30p	Dye	7m 40s	.78ft/s	E 1.53' W 1.47' A 6.70 ft^2	5.2 ft^3/s

Appendix C

Inorganic Chemistry and Rainfall Data Obtained from the Park Service

Information included in tables:

Date and time (EDT) of testing

Depth in centimeters (cm) and velocity in cm/sec of water at test site

Temperature of the water in Celsius

Dissolved oxygen (DO) in the water in ppm

pH of the water

EPA alkalinity of water in ppm

Conductivity of the water in μMHO/cm

Free carbon dioxide (CO_2) in water in ppm

Iron in the water in ppm

Iron, silicates, and chlorides in filtered water in ppm

Chemical oxygen demand (COD) of water in ppm

Notes:

1. Because odor problems and the death of aerobic organisms are associated with anoxic waters, the dissolved oxygen in water is an indicator of the "health" of the river. Fresh water is saturated at 9.2 ppm of DO at 20°C. At midmorning, the DO is at its lowest concentration in the daily cycle. The data show that around noon, when DO values are expected to be low, the Pamet is half saturated.

2. The pH is a measure of the acidity or basicity of water. A pH of 7.0 is neutral. Most "healthy" natural waters are within a pH unit of 7.0, and this is true of the Pamet.

3. The alkalinity is a measure of a water's ability to resist change in pH.

4. Insight is given into the source of river water by comparing the difference in iron concentrations between filtered and unfiltered samples of water from the river. River water from ground water does not have a large solids content as it has been filtered by the soil. Thus a comparison of the iron in solution (Fe filtered) with the iron adsorbed on particles (Fe total - Fe filtered) can be thought of as a measure of the percent of groundwater to surface runoff and other sources.

5. The soluble silicates represent the amount of material available for diatoms to build cell material.

6. The chloride value gives a measure of salinity from NaCl. It should be noted that other salts are also included in the measurement of salinity, although NaCl is a major component in salinity in sea water.

7. COD is a measure of both the biodegradable (BOD) and non-biodegradable materials in the water which could "use up" oxygen. Because the COD value is quite low in the Pamet, it can be concluded that the water is relatively clean and free of BOD, which could drive down the DO. "Clean" means low levels of algae, other microorganisms, and organic (including septic) materials that might lower the DO.

8. The rainfall data are given to be used in conjunction with Appendix A. Note that the periods of rainall correspond to high coliform counts.

Appendix C

Inorganic Chemistry and Rainfall Data Obtained from the Park Service

Pamet River at west side of Route 6

Data obtained from National Park Service

Date	7-13-88	7-20-88	7-27-88	8-3-88	8-10-88	8-17-88
Time	11:15am	12:30pm	11:48am	11:35am	11:30am	10:38am
Depth(cm)	-	73	-	71	71	47
Velocity (cm/s)	-	24	-	22	backflow	33.5
Temperature (°C)	21.5	20.0	21.8	25.0	23.2	21.5
DO (ppm)	5.4	4.0	4.2	6.4	3.6	4.5
pH	6.6	6.4	6.25	6.58	6.37	6.59
EPA Alkalinity (ppm)	12.7	12.8	7.8	9.5	9.8	9.9
Conductivity (μMHO/cm)	3,666	720	694	666	617	548
Free CO_2 (ppm)	-	-	-	5.0	8.4	-
Fe (Total)	1.83	1.76	2.15	1.69	1.62	1.78
Fe Filtered (ppm)	0.11	0.55	0.53	0.72	0.54	0.70
Si Filtered (ppm)	4.98	5.6	6.1	4.0	5.7	7.2
Cl Filtered (ppm)	1,026	268	218	218	181	172
COD (ppm)	-	18.7	33.4	3.7	19.4	11.3

Appendix C

Rainfall data from the National Park Service

June 14, 1988 to August 16, 1988

Date	Approximate Time	Amount (inches)
6-17-88	Early morning	0.01
6-18-88	Early morning	0.02
6-25-88	Early morning	0.20
6-26-88	Morning to noon	1.10
6-27-88	Noon	0.01
7-2-88	Morning	0.10
7-12-88	Noon	0.07
7-14-88		0.01
7-17-88	Midnight	0.02
7-19-88	Noon	0.03
7-20-88	Early morning	0.35
	Noon	0.36
7-21-88	Early morning	0.24
	Morning	0.30
	Late morning	0.23
	Noon	0.02
7-22-88	Monring	0.07
	Noon	0.04
	Evening to Midnight	0.10
7-23-88	Early morning	0.36
	Late evening	0.06
	Midnight	0.17

Appendix C

Rainfall data from the National Park Service

June 14, 1988 to August 16, 1988

Date	Approximate Time	Amount (inches)
7-24-88	Early morning to noon	0.75
	Early evening	0.10
7-27-88	Noon	0.53
7-28-88	Late morning	0.06
7-31-88	Afternoon	0.05
	Evening	0.03
8-7-88	Noon	0.02
8-13-88	Morning to Noon	0.05