Section 22 - Planning Assistance To States Program

Pamet River Investigation
Truro, Massachusetts

April 1998

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6. AUTHOR(S)
John Kedzierski
Heather Sullivan
Catherine Demos

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U.S. Army Corps of Engineers
New England District
696 Virginia Road
Concord, Massachusetts 01742-2751

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The Corps of Engineers was requested by the town of Truro, Massachusetts, to identify and investigate the advantages and disadvantages of introducing daily tidal flows to the present freshwater portion of the Pamet River, and to evaluate the existing configuration of the tide gate, culvert, and dike structure (Wilders Dike) located west of Route 6 and the culvert and embankment at Route 6, in relation to its ability to adequately drain the Pamet River during overtopping events at Ballston Beach. This study has been conducted under the authority contained in the Corps Section 22, Planning Assistance to States Program. The town of Truro is the non-Federal sponsor for this investigation.

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Pamet River Investigation
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Department of The Army
New England District
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EXECUTIVE SUMMARY

The Corps of Engineers was requested by the Town of Truro, Massachusetts to identify and investigate the advantages and disadvantages of introducing daily tidal flows to the present freshwater portion of the Pamet River, and to evaluate the existing configuration of the tide gate, culvert, and dike structure (Wilders Dike) located west of Route 6 and the culvert and embankment at Route 6, in relation to its ability to adequately drain the Pamet River during overtopping events at Ballston Beach. This study has been conducted under the authority contained in the Corps Section 22, Planning Assistance to States Program. The Town of Truro is the non-Federal sponsor for this investigation.

The Pamet River is an estuarine and freshwater river system consisting of three stream branches that meet to form Pamet Harbor before discharging to Cape Cod Bay (see Figure 1). The main branch of the river system is the Pamet River which is about 2.5 miles long extending from Ballston Beach east to Pamet Harbor. The other two branches - Little Pamet River to the north and Eagles Neck Creek to the south - are smaller than the Pamet River. This study focuses on the main branch of the Pamet River system. The Pamet River is divided into two hydrologically separate sections by a dike and tide gate - the upper (freshwater) Pamet east of Wilders Dike, and the lower (saltwater) Pamet west of Wilders Dike. The dike was constructed in 1869 and the tide gate and Route 6 embankment was constructed in the mid-1950's. At present a 3.5 foot diameter culvert with a tide gate allows flow through the dike and a 4.0 foot diameter culvert allows flow through the Route 6 embankment. The tide gate remains open during periods of low tide and closes during high tide, essentially preventing saltwater intrusion east of the dike to the upper Pamet. East of the dike and tide gate the river is a freshwater system fed primarily through groundwater and surface runoff.

The freshwater head of the Pamet River is located directly behind Ballston Beach. There have been numerous instances of overtopping at Ballston Beach leading to saltwater intrusion at the head of the Pamet. This has occurred in 1978, 1991, and 1992. Due to the restriction of tidal action from the tide gate, the portion of the river from Wilders Dike to Ballston Beach has become a freshwater environment which is almost entirely contained within the Cape Cod National Seashore. The portion west of Wilders Dike is still tidally influenced and contains salt marsh characteristics.

Problems on the Pamet River include flooding of the upper Pamet from overtopping at Ballston Beach. Flooding of the upper Pamet during severe storm events is due primarily to overtopping at Ballston Beach and results in the subsequent loss or degradation of vegetation due to saltwater intrusion. As stated above, Ballston Beach has been overtopped on at least three prior occasions - 1978, 1991, and 1992. The storm of December 1992 resulted in the upper Pamet River valley being flooded with four feet of saltwater from the Atlantic Ocean. This large inflow of saltwater drained slowly due to the tide gate and Route 6 culvert constrictions. These constrictions did not allow a significant volume of water to leave the upper river system.

The study determined the optimum plan to address the overtopping problem to be replacement of the existing 4.0 foot diameter culvert under Route 6 and the 3.5 foot diameter culvert under Wilders Dike with 4 foot by 12 foot (height x width) precast reinforced concrete box culverts. The proposed culvert system would continue to employ a tide gate to restrict the flow of saltwater into the upper Pamet River. The plan was selected based on an estimated reduction in the retention time from 6 days to 1.8 days for a 50-year frequency overtopping event. Based on similar work performed by the Corps, the study estimated the total cost of replacing the culverts to be in the order of $1 million.

The Corps was also requested to investigate the advantages and disadvantages of creating salt marsh through the introduction of saltwater to the present freshwater system in the upper Pamet River. Since construction of Wilders Dike and Route 6, the tidal flow in the upstream portion of Pamet River has been interrupted and the vegetation in this area has undergone several successional stages. The stages have succeeded from cattail marsh, to shrub swamp vegetation, and is presently being rapidly replaced by upland shrub species of cherry, shadbush, and bayberry. Introduction of tidal flows into the upper portion of the Pamet River would result in salt marsh vegetation replacing the freshwater vegetation upstream of Route 6 to the level of the spring high water elevation. The replacement of freshwater species with salt marsh species would diminish the farther one traveled upstream. Possible impacts of introducing saltwater into the present freshwater environment include saltwater intrusion into drinking water wells, flooding due to tidal influences, and the degradation of the present freshwater environment.

The study investigated numerous culvert configurations to establish tidal flows to the upper Pamet River. Hydraulic modeling studies of the 4 foot by 12 foot culverts discussed above indicated that some areas of the flood plain would remain flooded. Based on the need to minimize ponding in the flood plain, the study concluded that a 6 foot by 16 foot box culvert would be more appropriate to restore tidal flow to the upper portion of the river. The total cost for this project would be similar to the $1 million estimate previously discussed.

Consideration should also be given to constructing the larger sized (6 foot by 16 foot) box culverts with a tide gate. This would allow for adequate drainage of overtopping while providing the potential for future salt marsh restoration, if desired. It is estimated that providing the larger culvert size with a tide gate would increase the overall implementation costs about 10%.

One of the concerns expressed by the town concerning establishing tidal flow was the potential impact on local wells and septic systems. As part of this investigation, the Corps contracted with the Cape Cod Commission to conduct a groundwater assessment of the upper Pamet River.

The Commission's report estimated that the freshwater/saltwater interface was between 120 and 200 beet below the water table and stated that typical wells penetrating 20 to 30 feet into the aquifer were well separated from the saltwater interface. Groundwater modeling suggested that local wells and septic systems would not be impacted as a result of the introduction of tidal flow beyond Wilders Dike.

Advantages to restoration of a saltwater ecosystem east of Wilders Dike include the introduction of estuarine species and the return of tidal energy to the freshwater marsh. Increased tidal range might help offset encroachment of upland vegetation and increase the amount of wetlands. Increased tidal flows and flushing would help remove contaminants, increase the biological productivity of the Pamet River watershed, increase the exchange of particulate and dissolved nutrients to the estuarine environment, and deposit inorganic material which may eventually elevate the marsh.

The disadvantages of restoring tidal flow to the upper portion of the Pamet River include the decay and death of freshwater species which are not tolerant of saline waters, and the loss of primary production during this transition phase. The changes from a freshwater to saltwater environment will decrease from Route 6 east to Ballston Beach. This is due to the expected dilution of seawater because of freshwater inflow from the river. Therefore, the greatest changes to the present environment would occur closest to Route 6. Changes in vegetation during the restoration of restricted marshes generally begins by the end of the first year. However, this is for a restricted marsh, not a freshwater marsh reverting to a salt marsh. Therefore, the transition phase from a freshwater to saltwater ecosystem would be expected to take at least a few years. Other disadvantages include the invasion of *Phragmites australis* which may occur in areas where there is a transition from high salinity to freshwater.

Additionally, the introduction of saline water to the freshwater portion of the Pamet River may initially cause subsidence which would likely result from the death and decomposition of plant roots and rhizomes under salt stress. Due to the existing subsidence east of Route 6 and the potential for additional subsidence with the introduction of saltwater to the upper portion of the Pamet River, ponding is a concern for any alternative selected. For example, the alternative to keep the existing culverts in place and keep the tide gate permanently open would create a pond immediately east of Route 6 and some minor ponding would occur closer to Ballston Beach.

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I. INTRODUCTION

1. Study Authority

The Corps of Engineers was requested by the Town of Truro, Massachusetts to conduct an investigation into the impacts of altering the present configuration of the tide gate, culvert, and dike structure (Wilders Dike) located west of Route 6 and the culvert and embankment at Route 6 on the Pamet River. This study has been conducted under the authority contained in the Corps Section 22, Planning Assistance to States Program. The Town of Truro is the non-Federal sponsor for this investigation.

2. Study Purpose and Scope

The purpose of this study is to identify and investigate the advantages and disadvantages of introducing daily tidal flows to the present freshwater portion of the Pamet River, and to evaluate the ability of the existing culvert/tide gate structure at Wilders Dike and the culvert at Route 6 to adequately drain the Pamet River during overtopping events at Ballston Beach. Alternative culvert/tide gate configurations were evaluated to provide adequate drainage of the Pamet River and to establish a new hydraulic regime for the purpose of creating a salt marsh environment. A groundwater investigation was also conducted to assess potential impacts on private wells and septic systems as a result of removing the tide gate and allowing tidal flow east of Wilders Dike. The groundwater assessment was conducted by the Cape Cod Commission and is contained in Appendix C. This study effort focuses on the main stem of the Pamet River and the impacts of the introduction of saltwater to the existing freshwater system through the removal or reconfiguration of the Wilders Dike tide gate/culvert and dike structure or the Route 6 culvert and embankment structure.

3. Other Pertinent Studies

Pamet River & Estuary Assessment; May 1995; Burns, Schafer, Waite; Worcester Polytechnic Institute.

Water Resources Protection Plan; December 1985; IEP, Inc.

Pamet River Greenway Management Plan; 1986; Truro Conservation Trust.

Pamet Harbor Management Plan; September 1993; Horsley & Witten, Inc.

The Pamet River Study; 1989; Richard Lewis (MIT); Vol. III of Pamet Harbor Studies.

Application & Assessment of a Shallow-Water Tide Model to Pamet River;

1990; Geise, Freidrichs, Aubrey, and Lewis; Vol. III of Pamet Harbor Studies.

A Brief History of the Pamet River System with Recommendations for Environmental Studies; 1985; Geise, Mello; Vol. II of Pamet Harbor Studies.

Hydraulics, Morphology, and Sediment Transport Patterns at Pamet River Inlet; 1981; Fitzgerald and Levin; Northeastern Geology, v.3, no.3/4, pp.216-224.

Pamet Inlet - Study of Shoaling and Erosion Problems; 1980; Provincetown Center for Coastal Studies; Vol. II of Pamet Harbor Studies.

Hydrologic Modeling as a Predictive Basis for Ecological Restoration of Salt Marshes; Roman, Garvine, and Portnoy; 1995.

Pamet River Study; Sebastian Snow; Truro Harbor Commission and Truro Conservation Trust; November 1991.

II. EXISTING CONDITIONS

1. Study Area Description

The Pamet River is an estuarine and freshwater river system consisting of three stream branches that meet to form Pamet Harbor before discharging to Cape Cod Bay (see Figure 1). The total freshwater drainage area of the Pamet River east of Wilders Dike is approximately 5.3 square miles. The Pamet River estuary occupies about one square mile, with minimum elevations ranging from two to four feet above National Geodetic Vertical Datum (NGVD). The intertidal marsh area west of Wilders Dike, including the river, covers approximately 229 acres, while the freshwater marsh area east of Wilders Dike covers approximately 159 acres. The Pamet River has been recognized by Federal agencies, the Commonwealth of Massachusetts, and local agencies as an important natural resource. As such, the Pamet River east of Wilders Dike was included as part of the Cape Cod National Seashore in 1961. In 1975, the Pamet River and other Truro shore areas became the first wetlands in the State to be protected by deed restrictions under the Coastal Wetlands Restriction Act, and in 1978 was designated a Scenic River.

The main branch of the ecosystem is the Pamet River which is about 2.5 miles long extending from Pamet Harbor east to Ballston Beach. The other two branches, Little Pamet River to the north and Eagles Neck Creek to the south, are smaller than the Pamet River. This study focuses on the main branch of the Pamet River system.

The Pamet River is divided into two hydrologically separate sections by a dike and tide gate - the upper (freshwater) Pamet from Ballston Beach to Wilders Dike, and the lower (saltwater) Pamet from Wilders Dike to the harbor. Wilders Dike was constructed in 1869 to replace a rotting timber bridge at this same location and to develop agriculture (e.g., cranberry bogs). At present a 3.5 foot diameter culvert with a tide gate allows flow through the dike. The tide gate at Wilders Dike and the Route 6 embankment were constructed in the mid-1950's. A 4.0 foot diameter culvert allows flow through the Route 6 embankment. The tide gate remains open during periods of low tide and closes during high tide, essentially preventing saltwater intrusion east of the dike to the upper Pamet. The freshwater portion of the Pamet River, which is almost entirely contained within the Cape Cod National Seashore, extends from Ballston Beach barrier to Wilders Dike and is fed by groundwater and rainfall runoff. The Cape Cod Commission's groundwater assessment report (Appendix C) indicates that 85 percent of the river discharge comes from surface water drainage and runoff. Field observations combined with the groundwater modeling results suggest that the remaining 15 percent of the river flow comes from direct groundwater discharge through highly conductive portions of the river bottom.

The tide gate at Wilders Dike prevents saltwater and tidal influences from moving east of the dike. The tide gate pivots based on fluctuations in freshwater and saltwater elevations. As currently configured, the tide gate is forced closed by tidal saltwater approximately two hours before high tide. The tide gate remains closed for four to six hours. While the gate is closed, freshwater from the upper Pamet fills the area to the east of Wilders Dike, rising about 0.75 feet above saltwater levels on the west side of the tide gate. Approximately three hours after high tide, the tide gate gradually opens allowing freshwater to drain from the upper Pamet.

According to surveys conducted in October and November 1995, the river begins approximately 480 feet west of the dune at Ballston Beach. It is believed that before Wilders Dike was put in place, the Pamet River remained tidal for as much as three quarters of its length. Due to the restriction of tidal action from the tide gate, the portion of the river from Wilders Dike to Ballston Beach has become a freshwater environment which is almost entirely contained within the Cape Cod National Seashore. The portion west of Wilders Dike is still tidally influenced and contains salt marsh characteristics. In addition, there have been other modifications made to the river including numerous ditches to drain portions of the marsh and control mosquitos, and the construction of a railroad embankment in the 1870's.

Three transects taken by the U.S. Army Corps of Engineers east of Route 6 (see Figure 1) show the river bottom to be slightly higher than 0.0 feet NGVD (.20 to .96 feet). The fourth transect across Ballston Beach shows that the head of the Pamet River is approximately 3.0 feet NGVD. The tops of the river banks and the flood plain adjacent to the river east of Route 6 are at elevation 3.0 feet NGVD. Survey transects did not extend to include the slopes of the north or south banks at the edge of the flood plain.

2. Problems and Issues

There are a number of problems and issues at the Pamet River including flooding of the upper Pamet from overtopping at Ballston Beach and the desire to introduce saltwater flow into the present freshwater system. The purpose of this study is to evaluate the present conditions and determine the necessary culvert configurations to reduce flooding impacts from overtopping events and to determine the advantages and disadvantages of introducing saltwater flow to the upper Pamet. Possible impacts of introducing saltwater into the present freshwater environment include saltwater intrusion into drinking water wells and septic systems, increased flooding due to tidal influences, and the degradation of

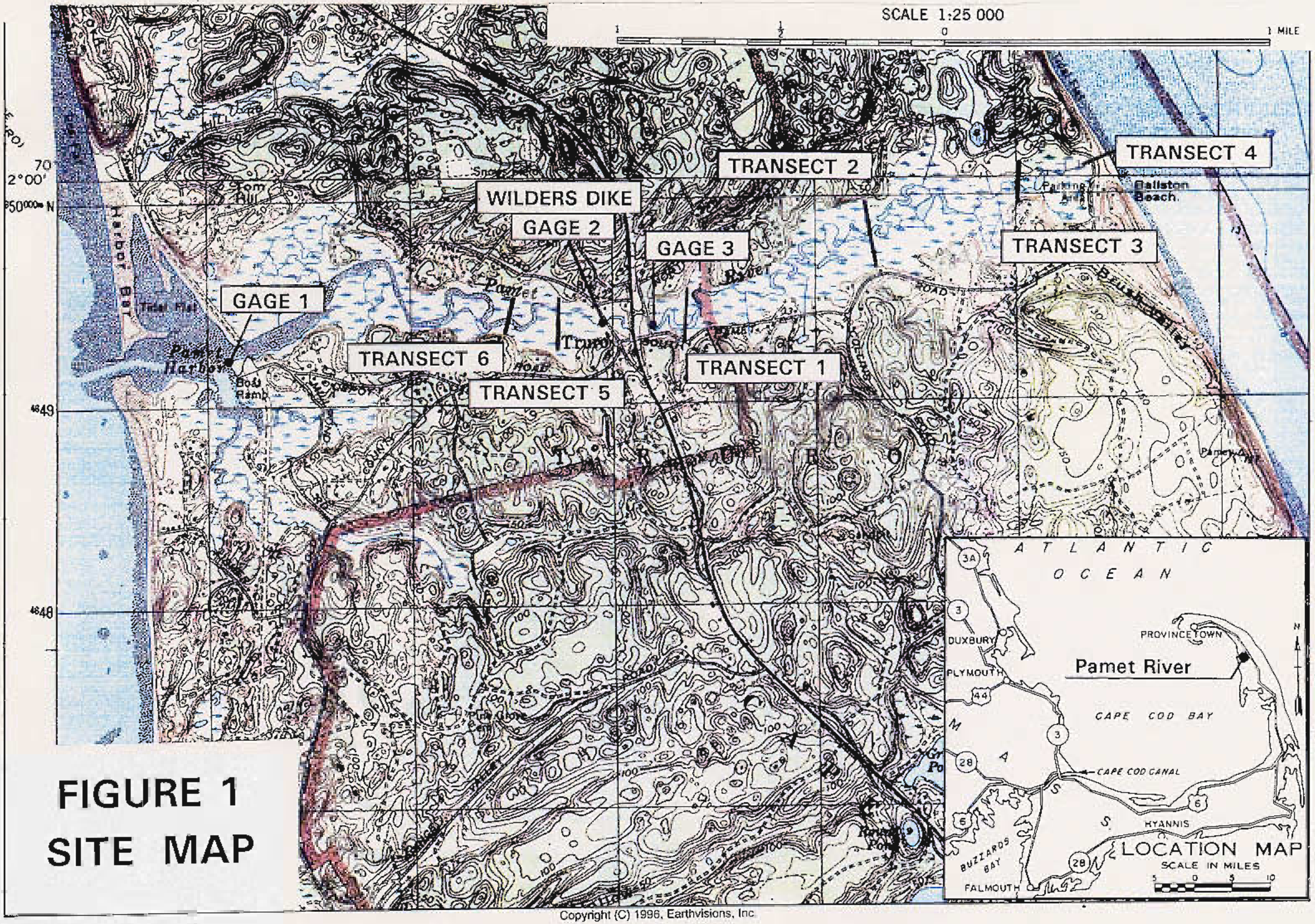

FIGURE 1
SITE MAP

the present freshwater environment. It has been suggested that tidal flow throughout the Pamet River will improve water quality and shellfishing and finfishing opportunities in the river, however, the evaluation of these issues are not within the scope of this study. Physical alterations to the area such as the installation of the tide gate have subsequently led to significant changes in the local environment - most notably from a salt marsh to a freshwater marsh east of Wilders Dike. Eutrophication is also a water quality concern in the upper Pamet River. Currently, pondweed and water lilies strangle freshwater portions of the Pamet River.

The most apparent concern with the Pamet River system appears to be the need to provide adequate hydraulic capacity of the culverts at Route 6 and Wilders Dike to drain the freshwater portion of the Pamet River during overtopping events. Flooding of the upper Pamet during severe storm events is due primarily to saltwater overtopping at Ballston Beach and results in the subsequent loss or degradation of vegetation. Ballston Beach has been overtopped on at least three prior occasions - 1978, 1991, and 1992. The storm of December 1992 resulted in the upper Pamet River valley being flooded with four feet of saltwater from the Atlantic Ocean. This large inflow of saltwater drained slowly due to the Wilders Dike tide gate and Route 6 culvert constrictions.

III. HYDROLOGIC & HYDRAULIC ANALYSIS

1. Introduction

The purpose of this hydrologic and hydraulic analysis was to evaluate the ability of the existing culverts and tide gate to adequately drain the Pamet River during overtopping events at Ballston Beach and to identify alternative culvert/tide gate configurations. This was accomplished by estimating the frequency and volume of overtopping events at Ballston Beach and developing a computer model to evaluate existing and proposed culvert configurations in relation to both improved drainage and the introduction of tidal flooding. The full hydrologic and hydraulic analysis report is contained in Appendix A and includes climatology, rainfall analysis, and tidal investigations.

2. Tidal Hydrology & Hydraulics

a. General

The estimated tide levels in Cape Cod Bay are provided in Table 1. These levels were developed from National Ocean Survey (NOS) tide gage data and from Corps of Engineers tidal flood profiles, dated September 1988.

Tidal flow is generally restricted from the east side of the Pamet River by a tide gate at the Wilders Dike culvert. However, during certain storm events, Ballston Beach is overtopped allowing saltwater into the eastern portion of the Pamet River. The culverts under Route 6 and Wilders Dike are too small to drain floodwaters overtopping Ballston Beach. During the December 1992 storm, the eastern Pamet River valley was flooded with about four feet of saltwater. To evaluate the existing drainage during storms, an overtopping analysis was performed on Ballston Beach. Flows obtained from this analysis were then input into UNET, a one-dimensional hydrodynamic model used to evaluate the drainage and tidal effects on the Pamet River with existing culvert configurations. UNET is more fully described in Appendix A.

The UNET model was then used to evaluate proposed alternatives for improving drainage and introducing tidal flow into the eastern portion of the Pamet River.

Table 1

Estimated Tidal Levels in Cape Cod Bay
Truro, Massachusetts

	Tide Level (ft., NGVD)
100-Year Frequency Flood Event	10.1
50-Year Frequency Flood Event	9.8
10-Year Frequency Flood Event	9.1
Mean Spring High Water	6.4
Mean High Water	5.3
Mean Tide Level	0.6
National Geodetic Vertical Datum	0.0
Mean Low Water	-4.2

b. Overtopping

Peak rates of overtopping were used to determine the frequency event when overtopping begins and saltwater intrusion of the Pamet River east of Wilders Dike occurs. A survey of the beach in November 1995 revealed that Ballston Beach has an approximate beach slope of one vertical on eight horizontal and a crest elevation of 16 feet NGVD. Wave heights and periods were computed for 1-, 10-, 25-, 50, and 100-year return periods. Table 2 shows data computed for a worst case scenario for winds from the east-northeast.

Peak overtopping rates were computed from the information developed for wave characteristics. Peak overtopping rates per linear foot of beach are presented in Table 3. Ballston Beach begins to experience overtopping during events with frequencies of 10 years or greater. The estimated volumes of overtopping were used as input to the UNET model to assess drainage through the existing culverts under Route 6 and Wilders Dike.

c. Computer Model

The hydraulic analysis of the Pamet River was performed using UNET. The objective of the modeling was to evaluate existing conditions of the Pamet River

Table 2

Wave Height & Period

Frequency (yrs.)	Still Water Level (ft., NGVD)	Wind Speed (mph)	Wave Height (ft.)	Period (sec.)
1	7.6	14	2.6	3.8
10	9.1	35	11.1	7.5
25	9.3	40	13.8	8.3
50	9.8	44	16.3	8.9
100	10.1	47	18.3	9.4

Table 3

Peak Overtopping Rates

Frequency (yrs.)	Still Water Level (ft., NGVD)	Overtopping Rate (cfs/lf)
1	7.6	-----
10	9.1	0.1
25	9.3	1.8
50	9.8	4.5
100	10.1	5.8

in terms of drainage and flooding and to evaluate several alternatives for introduction of saltwater into the upper Pamet east of Wilders Dike.

Marsh geometry and tidal measurements were used to calibrate and verify the model's results. Overall, the model's results matched very favorably to the observed data, with computed levels only a few tenths of a foot or less different from the observed levels. Results of the verification process are shown in plate A-7, Appendix A. As can be seen, the computed high and low elevations match those measured within two-tenths of a foot. This verifies the accuracy of the model indicated by calibration. Model calibration and verification are described in Appendix A.

d. Hydraulic Analysis

The intent of the modeling was to evaluate the existing culvert and dike configuration at Wilders Dike and the culvert at Route 6 in terms of drainage of overtopping volume from Ballston Beach and to analyze alternatives to introduce tidal flow to the Pamet River east of Wilders Dike.

Under existing conditions, tidal flows in the Pamet River are unrestricted up to Wilders Dike. At the dike is a 3.5 foot diameter culvert with a tide gate which prevents tidal flows from passing through. The tide gate is forced closed by tidal saltwater approximately two hours before high tide and then remains closed for between four and six hours. During periods that the tide gate is not closed, freshwater flows from the Pamet through the culvert at Route 6 and then through the culvert and tide gate at Wilders Dike.

At present, the existing culvert configuration is capable of draining the freshwater Pamet. Water levels at Ballston Beach are about 3.0 feet NGVD and the water levels east of Route 6 are between 1.6 and 2.2 feet NGVD. However, the culverts are not large enough to handle the volume of overtopping which occurs during certain storm events at Ballston Beach.

The UNET model was run using an estimated water elevation of 3.0 feet NGVD at the head of the Pamet near Ballston Beach. An increase in water elevation due to overtopping was evaluated by inputting the overtopping volume into the UNET model. The December 1992 storm, estimated as a 25-year event, was used to check the overtopping analysis. Interior water levels were predicted to be about 6.8 feet NGVD and interior water levels estimated by the Cape Cod Commission after this storm were less than 7.0 feet NGVD, correlating the UNET model predictions. The time required, after storm events, for the existing culverts to drain the flood water in the upper Pamet back to 3.0 feet NGVD was then evaluated. Table 4 presents the results for various frequency events.

Table 4

Drainage Analysis of Existing Culverts
For Storm Events

Event	Water Level @ Ballston Beach (ft., NGVD)	Time to Drain to Normal Water Levels (3.0' NGVD)
mean tide range	3.0	-----
10-year	3.3	1 day
25-year	6.8	4 days
50-year	9.6	6 days
100-year	10.6	7 days

The model was then used to predict drainage times for several alternative culvert configurations. For example, a 4 foot by 12 foot box culvert under both Route 6 and Wilders Dike would reduce drainage of a 50-year event from about 6 days to 1.8 days. Reducing the time necessary to drain overtopped water lessens the impacts saltwater has on freshwater vegetation. Table 5 shows the time to drain for the various culvert sizes. All alternatives were evaluated using a 50-year storm event and assuming that a tide gate would be maintained at Wilders Dike. It was also determined that replacement of only the culvert at Wilders Dike without replacing the culvert at Route 6, would have minimal impact on the detention time of the flood waters from overtopping at Ballston Beach. The minimum drainage time attained (using a 10 foot by 20 foot box culvert) was 1.7 days. There appears to be little benefit to significantly increase the culvert size from a 4 foot by 12 foot box culvert to a 10 foot by 20 foot box culvert. Therefore, it is recommended that a 4 foot by 12 foot box culvert be placed under both Route 6 and Wilders Dike to alleviate flooding as a result of overtopping at Ballston Beach.

TABLE 5

Drainage Analysis of a 50-Year Event for Various Culvert Configurations With Tide Gates

CONFIGURATION AT EACH CROSSING (FEET, HT. X WIDTH)	WATER LEVEL AT BALLSTON BEACH (FEET NGVD)	TIME TO DRAIN TO 3.0 FEET NGVD (DAYS)
EXISTING	9.6	6.0
4 x 6	9.6	4.0
4 x 8	9.6	2.3
4 x 10	9.6	2.0
4 x 12	9.6	1.8
4 x 16	9.6	1.8
4 x 20	9.6	1.7
6 x 6	9.6	2.7
6 x 8	9.6	1.9
6 x 10	9.6	1.8
6 x 12	9.6	1.7
6 x 16	9.6	1.7
6 x 20	9.6	1.7
8 x 8	9.6	1.85
8 x 10	9.6	1.75
8 x 12	9.6	1.7
8 x 16	9.6	1.7
8 x 20	9.6	1.7
10 x 10	9.6	1.7
10 x 12	9.6	1.7
10 x 16	9.6	1.7
10 x 20	9.6	1.7

Modeling was also performed to predict the effect of various culvert sizes on the introduction of tidal flow to the Pamet River east of Wilders Dike. Alternatives evaluated included lowering the culvert inverts to improve drainage and increasing existing culvert opening and channel widths to introduce tidal flow to the east of Route 6. The desired configuration would be a balance of flooding to maximize salt marsh development without causing permanent ponding. A tide range occurring about eight times per month was used (frequency necessary to restore a salt marsh) to develop the water surface elevations at various areas of the upper Pamet River associated with various culvert sizes. These water surface elevations are shown in Table 6. This table shows that the various culvert configurations would produce high tide levels ranging from 3.4 to 4.6 feet NGVD at Ballston Beach from an estimated high tide of 6.4 feet NGVD in Pamet Harbor. This is about 0.4 to 1.6 feet higher than the present water surface elevation at the head of the Pamet near Ballston Beach. Table 7 displays the mean tide range water levels at various locations along the Pamet River for existing conditions, with the tide gate open, and with various culvert configurations constructed at Wilders Dike and Route 6.

In order to achieve the water surface elevations necessary for salt marsh development, the invert of the proposed culverts and channel between Route 6 and Wilders Dike would have to be dredged approximately 0.5 foot to a new invert of -1.0 feet NGVD. The channel width would equal either the existing channel width or the proposed culvert width, whichever is greater.

3. New Hydraulic Regime Needed

To return a freshwater marsh to salt marsh, the freshwater area must be flooded at about eight times per month with saltwater. Salt marsh species occur between mean tide level and spring high tide levels, depending on site specific conditions. A survey of the salt marsh was used for comparison to determine the hydrologic regime required to establish a salt marsh environment east of Wilders Dike.

Alternatives to increase tidal flow through Wilders Dike and Route 6 include replacing the culverts under Route 6 and Wilders Dike with larger culverts to drain overwash flooding from Ballston Beach and increase tidal flows. This would increase tidal flows to the freshwater portion of the Pamet River. Both structures could be removed and replaced with bridges to achieve maximum tidal flow.

TABLE 6

Water Surface Elevations for Various Culvert Sizes at Each Crossing (for Spring Tide in Feet NGVD)

CULVERT SIZE (FEET) HT. X WIDTH	PAMET HARBOR (high)	WEST OF WILDERS DIKE (high, low)	EAST OF ROUTE 6 (high, low)	BETWEEN RT. 6 & BALLSTON (high, low)	BALLSTON BEACH (high)
Existing Gate Open	6.40	6.10 2.70	3.35 2.80	3.30 2.90	3.30
4 x 6	6.40	6.10 1.90	3.60 2.60	3.50 2.70	3.40
4 x 8	6.40	6.10 2.10	4.00 2.60	3.80 2.70	3.50
4 x 10	6.40	6.00 2.30	4.40 2.60	4.00 2.70	3.80
4 x 12	6.40	6.00 2.40	4.50 2.60	4.10 2.75	3.90
4 x 16	6.40	5.90 2.50	4.70 2.60	4.30 2.80	4.10
4 x 20	6.40	5.80 2.50	4.90 2.65	4.40 2.80	4.10
6 x 6	6.40	6.10 2.00	4.20 2.80	3.90 2.90	3.80
6 x 8	6.40	6.00 2.20	4.60 2.70	4.10 2.85	4.00
6 x 10	6.40	5.90 2.30	4.75 2.60	4.30 2.85	4.10
6 x 12	6.40	5.90 2.30	4.90 2.60	4.40 2.85	4.20
6 x 16	6.40	5.90 2.30	5.00 2.50	4.60 2.85	4.20
6 x 20	6.40	5.70 2.40	5.10 2.60	4.65 2.85	4.30
8 x 8	6.40	6.00 2.20	4.60 2.70	4.20 2.85	4.00
8 x 10	6.40	5.90 2.30	4.80 2.60	4.40 2.85	4.10
8 x 12	6.40	5.80 2.30	4.90 2.60	4.50 2.85	4.20
8 x 16	6.40	5.70 2.40	5.00 2.60	4.60 2.85	4.20
8 x 20	6.40	5.70 2.40	5.10 2.60	4.65 2.85	4.30
10 x 10	6.40	5.70 2.40	5.00 2.50	4.50 2.80	4.20
10 x 12	6.40	5.60 2.40	5.10 2.55	4.65 2.85	4.30
10 x 16	6.40	5.50 2.40	5.20 2.50	4.70 2.85	4.30
10 x 20	6.40	5.50 2.40	5.30 2.50	4.75 2.80	4.30
Bridge	6.40	5.55 2.60	5.40 2.60	5.00 2.85	4.60

Note: The low water surface elevation at Ballston Beach is consistent with the existing elevation of about 3.0 feet NGVD and will not change.

TABLE 7

Water Surface Elevations Within the Pamet River
(at Mean Tide Range in feet NGVD)

CULVERT SIZE (FEET) HT. X WIDTH	PAMET HARBOR (high)	WEST OF WILDERS DIKE (high, low)	EAST OF ROUTE 6 (high, low)	BETWEEN RT. 6 & BALLSTON (high, low)	BALLSTON BEACH (high)
Existing	5.30	5.20 ***	2.20 ***	*** ***	3.00
Existing Gate Open	5.30	5.20 1.20	2.70 2.40	3.00 2.50	3.20
4 x 6	5.30	5.10 1.70	3.30 2.35	3.20 2.45	3.20
4 x 8	5.30	4.90 1.80	3.55 2.20	3.30 2.40	3.30
4 x 10	5.30	4.80 1.90	3.70 2.20	3.40 2.40	3.40
4 x 12	5.30	4.80 1.90	3.80 2.20	3.50 2.40	3.50
4 x 16	5.30	4.70 1.90	3.90 2.10	3.50 2.40	3.50
4 x 20	5.30	4.70 1.90	3.95 2.10	3.60 2.40	3.50
6 x 6	5.30	5.00 1.90	3.50 2.40	3.30 2.50	3.30
6 x 8	5.30	4.80 1.90	3.70 2.30	3.40 2.45	3.40
6 x 10	5.30	4.70 1.90	3.85 2.20	3.50 2.40	3.50
6 x 12	5.30	4.70 1.90	3.90 2.20	3.50 2.40	3.50
6 x 16	5.30	4.70 1.90	4.00 2.10	3.60 2.40	3.55
6 x 20	5.30	4.60 1.90	4.00 2.10	3.60 2.40	3.55
8 x 8	5.30	4.80 1.90	3.70 2.30	3.40 2.50	3.40
8 x 10	5.30	4.70 1.90	3.80 2.20	3.50 2.40	3.50
8 x 12	5.30	4.70 1.90	3.90 2.20	3.55 2.40	3.50
8 x 16	5.30	4.65 1.90	4.00 2.10	3.60 2.40	3.55
8 x 20	5.30	4.60 1.90	4.00 2.00	3.60 2.40	3.60
10 x 10	5.30	4.60 1.90	4.00 2.10	3.60 2.40	3.55
10 x 12	5.30	4.60 1.90	4.00 2.10	3.60 2.40	3.60
10 x 16	5.30	4.60 1.90	4.10 2.10	3.60 2.40	3.60
10 x 20	5.30	4.60 1.90	4.10 2.10	3.60 2.40	3.60
Bridge	5.30	4.80 2.30	4.60 2.40	4.00 2.60	3.90

*Note: *** means readings not obtained.*
The low water surface elevation at Ballston Beach is consistent with the existing elevation of about 3.0 feet NGVD and will not change.

Based on hydrologic modeling performed by the Corps, opening Wilders Dike and Route 6 to full tidal flow would increase the tide levels east of Route 6 to a spring low tide of 2.6 and a spring high tide of (eight flooding tides/month) 5.4 feet NGVD. The present culvert configurations at Wilders Dike and Route 6 would need to be replaced with bridges to obtain this tidal flow.

4. Sea Level Rise

The impacts of sea level rise on the Pamet River are discussed below using Mean Sea Level (MSL) as a reference datum. MSL is the average height of the ocean surface for all stages of the tide over a 19 year period. MSL for Boston is approximately 0.3 feet NGVD and this is used for comparison purposes in the following discussion. The estimated existing freshwater surface elevation at the head of the Pamet River is approximately 3.0 feet NGVD. The elevation of the river bottom is at about 0.9 feet NGVD. Therefore, at present, it appears that MSL (0.3 feet NGVD) is below the current freshwater surface elevation (3.0 feet NGVD) behind Ballston Beach.

Current estimates of sea level rise [1] are about 4 inches per one hundred years for the Boston area and 9 inches per one hundred years for Woods Hole, Massachusetts. Assuming the greater rate of sea level rise, MSL will still not exceed the present freshwater surface elevation until after the year 2300. It is uncertain what effect sea level rise could have on the frequency of overtopping of Ballston Beach. The frequency of overtopping is dependent on numerous variables. These include the characteristics and parameters of storms such as wind speed, direction and duration, wave heights, and wave periods. Other issues such as local shoreline recession and beach erosion will undoubtedly be contributing factors to future overtopping and flooding of the Pamet River.

5. Findings

Existing culverts at Wilders Dike and Route 6 are not capable of draining flood waters quickly; a 50-year storm event takes approximately 6 days to drain. Analysis of various culvert configurations suggests that optimal drainage time of a 50-year event could be obtained with 4 foot by 12 foot box culverts under both Wilders Dike and Route 6. This analysis assumes a tide gate would be maintained at Wilders Dike.

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[1] Responding to Changes in Sea Level - Engineering Implications; National Research Council; 1987.

Various alternatives were also evaluated for restoring tidal flows to the eastern Pamet River. Configurations, ranging from existing culverts to open bridges could obtain water surface elevations at Transect 2 ranging from 3.3 to 5.0 feet NGVD. These elevations correspond to a mean spring high tide elevation of 6.4 feet NGVD in Pamet Harbor. A mean high tide elevation of 5.3 feet NGVD in Pamet Harbor could produce water surface elevations at Transect 2 ranging from 3.0 to 4.0 feet NGVD.

Other potential impacts which need to be addressed, as a result of introducing tidal flows east of Wilders Dike, include the potential flooding of both the public park located between Wilders Dike and Route 6 and the Ballston Beach parking lot. The park, just east of Wilders Dike, appears to have an elevation of at least 3.0 feet NGVD. This information was obtained from cross-sections accomplished for a previous study of the river by Graham Geise. The Ballston Beach parking lot appears to have an elevation of approximately 6.0 feet NGVD. However, these are only estimated elevations as neither of these areas was specifically surveyed during this study.

IV. GROUNDWATER IMPACTS

1. Introduction

The introduction of tidal flow to the upper Pamet River east of Wilders Dike could result in potential groundwater impacts on private wells and septic systems in the Pamet River's flood plain. This potential is due to saltwater intrusion into the groundwater associated with the possible reintroduction of saltwater to the freshwater Pamet. The Cape Cod Commission Water Resources Office has completed a groundwater assessment of this issue under a contract with the New England District. The full report is included in Appendix C.

This groundwater investigation was conducted to assess the potential impacts of removing the tide gate and allowing tidal actions within the upper Pamet River. Previous investigations in other areas of Cape Cod suggest that aquifer thicknesses of 43 to 95 feet would prevent saltwater intrusion on private wells and that adverse impacts would be limited to changes in the plant community as a result of the introduction of saltwater.

Specific concerns with the introduction of saltwater to the freshwater Pamet include the possible degradation in drinking water quality of wells adjacent to or in the Pamet River floodplain and flooding of existing septic systems due to an expected rise in groundwater levels throughout the upper Pamet River valley. There are approximately thirty residential houses bordering the upper Pamet River. The majority (26) of these houses are located above the 10 foot NGVD elevation. The minimum distance between the houses and the river channel is approximately 500 feet.

2. Hydrogeology of The Upper Pamet River

The Pamet River is at the margin of two groundwater lenses, the Pamet lens to the north, and the Chequesset lens to the south. Water table maps of the area indicate that the Pamet River is the discharge area for both lenses. Observations of the marsh ecosystem indicate that freshwater vegetation overlays freshwater marsh peat, which in turn overlays about 3 feet of salt marsh peat. In certain sections, the peat extends to a depth of 15 feet below the land surface. Since peat layers conduct little groundwater movement, the thick deposits of marsh peat in the upper Pamet, if continuous, would tend to isolate the river from the underlying aquifer. Pamet River streamflow is primarily the result of surface runoff and the horizontal seepage component of groundwater which drains off the aquifer along the entire perimeter of the marsh. The river receives little vertical groundwater flow due to the low permeable sediments throughout the marsh and beneath the river (e.g., peat). In fact, groundwater modeling suggests that the marsh surrounding the Pamet River serves to isolate the river from all but limited direct contact with the aquifer underlying the marsh.

3. Data Acquisition & Groundwater Flow Model

The data necessary to conduct this groundwater assessment and groundwater flow modeling process was obtained by installing twenty-four monitoring wells, two stream gauges and also using eleven pre-existing wells for the monitoring network. The wells are shown in Figure 2 and Appendix C - Figure 4. The physical characteristics of the monitoring wells are given in Appendix C - Table 1.

A groundwater flow model was prepared to assist in characterizing the system and to explore hypotheses about its functions. However, this model was not intended to be used for the evaluation of various tide gate or culvert configurations. Additional data collection and model enhancements would be necessary to evaluate tidal scenarios. The model for the Pamet River stream-aquifer system extends from Great Pond in Truro to Pilgrim Lake in Truro and is bounded by Cape Cod Bay and the Atlantic Ocean. The lateral extent of the model was chosen to include the entire watershed of the Pamet River and to incorporate current pumping stresses in the Pamet Lens.

Appendix C, section "IV. Assessment Findings and Discussion (page 24)" details the model structure, hydraulic parameters, existing pumping conditions, boundary conditions, model calibration, sensitivity analysis, and future data collection needs.

4. Findings

The specific findings associated with the well monitoring and groundwater modeling conducted by the Cape Cod Commission are detailed in Appendix C - "IV. Assessment Findings and Discussion". These include discussions on specific conductance, regional water levels, vertical groundwater gradients, streamflow measurements, the influence of tides on water levels, and an analytical tidal rise model. A brief summary of these findings is given below.

Specific conductance is a measure of the concentration of dissolved substances in a sample of groundwater. This can be an indicator of saltwater content in the groundwater. Saltwater from the Atlantic Ocean has a specific conductance of approximately 50,000 mhos/cm (micro ohms per centimeter). At well PW-2 in the Ballston Beach parking lot, specific conductance measured up to 37,000 mhos/cm. A U.S. Geological (USGS) monitoring well installed near this location in 1975 found lower specific conductance readings. Higher specific

Study Area and Data Point Map–Upper Pamet River

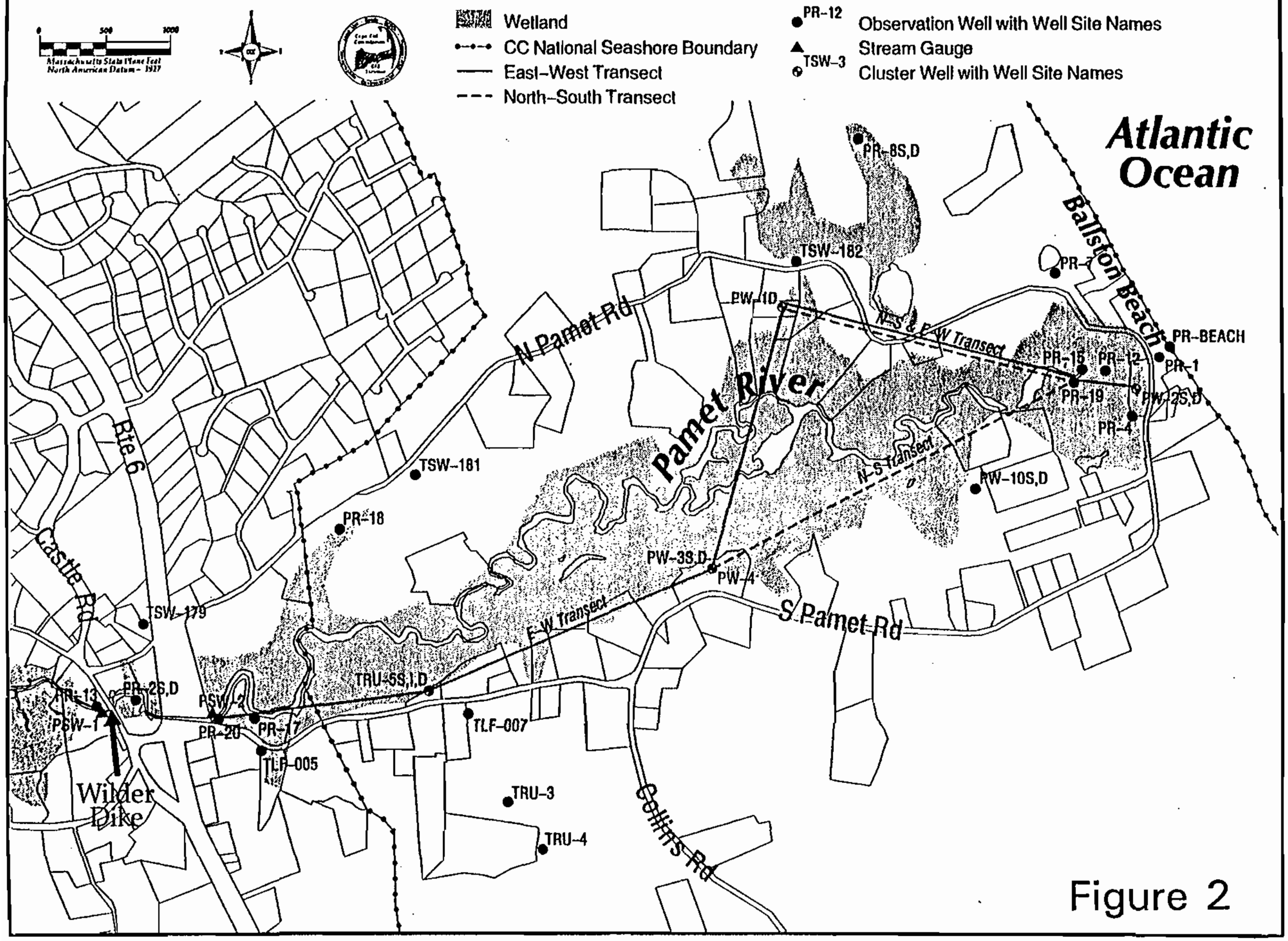

Figure 2

conductance readings at PW-2 compared to the earlier USGS well readings seems to indicate an increase in salt groundwater at the eastern end of the Pamet River. This increase may be the result of overwash events in 1991 and 1992 at Ballston Beach. In contrast, groundwater samples from well PW-3 located about half-way between Ballston Beach and Route 6 had low specific conductivity (80 mhos/cm). PW-3 was drilled to a depth of 150 feet and the water table elevation at this site is between 3 and 5 feet NGVD. The saltwater interface is estimated to be between 120 and 200 feet below the water table. Because there was no saltwater detected at the bottom of the well, the saltwater interface is deeper than 150 feet at this location. The significant thickness of the groundwater lens in this area suggests that typical private wells penetrating 20 to 30 feet into the aquifer are well separated from the saltwater interface.

Regional water levels were determined based on the water table elevation. Groundwater levels collected from the top of the aquifers generally show a decrease in elevation from either the north or south towards the Pamet River. These decreases in elevation indicate that groundwater in the northern and southern portions of the study area is flowing toward the Pamet River.

Water levels in wells below the water table indicate the direction of flow at particular depths. The vertical groundwater gradient along a longitudinal cross-section and a perpendicular cross-section indicate regional horizontal and local vertical flow toward the Pamet River. At well cluster PW-3, groundwater levels indicate that there is an upward component of groundwater flow towards the river. Thick layers of peat were encountered at various well locations which act as a confining layer restricting groundwater flow into the river.

Streamflow measurements were obtained over a 2.5 hour period after the tide gate was opened in order to establish base flow within the river. Base flow is the sustained rate of groundwater discharge in a stream after accounting for precipitation events, stream bank storage, and tidal effects. Base flow for the river was found to about 5.65 cubic feet per second (cfs).

The influence of tides on water levels at various monitoring wells was also observed. A simplified hydraulic cross-section of the Pamet River is provided in Appendix C - Figure 13. It shows the observed fluctuations in surface water levels collected during this study. The cross-section shows the relatively constant water level at PW-2 maintaining a gradient of surface water flow at high and low water levels towards Route 6 and the tide gate.

The potential impacts on groundwater levels resulting from an increase in tidal flow were assessed using an analytical model and a known range of surface water levels to predict a range of groundwater levels at a specified distance from the tidal channel. In this instance, the results of the UNET model (e.g., the range of surface water levels) were used as input to the analytical tidal rise model in order to assess the potential impacts on groundwater levels resulting from an increase in tidal flow. The analytical model equation and a discussion of its parameters can be found in Appendix C, Analytical Tidal Rise Model (page 33). The analytical model equation provides the range of groundwater levels in an observation well. Input to obtain this range includes the range of surface water levels (obtained from UNET model), the distance of the observation well from the tidal channel, the period of the tidal cycle, and the aquifers diffusivity. Aquifer diffusivity is defined as the transmissivity divided by the storage coefficient and was calculated to be 654 ft.^{2}/day for the freshwater marsh east of Route 6.

The analytical model was used to determine the predicted rise in groundwater levels at various distances from the river channel based on the UNET results. For the scenario of removing the tide gate and dike structure at Wilders Dike and creating an open channel through the Route 6 embankment, UNET predicts a 0.9 foot increase in the surface water level at Ballston Beach and a 2.4 feet surface water level increase at the Route 6 culvert. This scenario was used because it produced the greatest change in water levels as a result of tidal inflow (a worst-case scenario).

These results show that at a distance of 46 feet from the river channel at Ballston Beach and 56 feet from the river channel at Route 6, the range of groundwater fluctuations would be only 0.01 foot. The expected rise in river water elevations should have a decreasing impact on groundwater fluctuations as one moves away from the river and as one travels towards the east from Route 6 along the Pamet River. Therefore, since the minimum distance between a house and the river channel is about 500 feet, the maximum predicted tidal range of 2.4 feet should have no measurable impact at this distance. The attenuation of the tidal range on groundwater fluctuations is due to the low permeability peat layer within the marsh, which acts as a buffer to the tidal fluctuations occurring in the river.

These results indicate that the limited flow characteristics of the peat in the marsh system surrounding the upper Pamet River cause tidal ranges within the river to have minimal effect on groundwater levels in the upper Pamet River valley. In addition, the significant thickness of the aquifer system (>150 feet in the middle portion of the upper Pamet River valley) and upward groundwater gradients suggest that saltwater flow from the river into the surrounding groundwater lenses will be prevented.

V. Environmental Assessment

A discussion of the existing environmental conditions and a qualitative assessment of the advantages and disadvantages of the impacts related to the introduction of tidal flow beyond Wilders Dike has been accomplished and is presented in Appendix B.

1. Existing Freshwater Marsh Environment

The existing freshwater marsh environment was created by tidal restrictions on the Pamet River. Wilders Dike has restricted any tidal flow east of it since it was constructed in the late 1800's, and the tide gate has since prevented tidal flow since it was constructed in the mid-1950's. These changes have resulted in the conversion of an estuarine habitat to a freshwater environment. A 1985 study conducted by the Center for Coastal Studies indicates the various types of vegetation which now form this freshwater environment. The vegetation classes in the freshwater portion of the Pamet River include:

Cattail/Rush - Cattails *Typha* sp. and reeds *Phragmites australis* predominate in most of this habitat. However, freshwater rushes and sedges can also be found. *Phragmites australis* are found immediately west of Wilders Dike near the Post Office, between Wilders Dike and Route 6, and east of Route 6 in a few patches along North and South Pamet Road.

Shrub Swamp - Sweet pepperbush *Clethra alnifolia*, winterberry *Ilex verticillata*, swamp honeysuckle *Rhododendron viscosum*, leatherleaf *Chamaedaphne calyculata*, highbush blueberry *Vaccinium corymbosum*, and sweet gale *Myrica gale* are the dominant plants of this area as well as the margins of the marshes and woody bogs, and shrub swamps.

Beech/Maple - This habitat is characterized by mesic (moderate moisture) species. In particular the beech *Fagus grandifolia*, and red maple *Acer rubrum* are dominant. Historically, hickory *Carya* and chestnut *Castanea dentata* were probably present and birches *Betula* may have been more common.

Upland Shrub - This habitat includes cherry *Prunus* spp., shadbush *Amelanchier* spp., beach plum *Prunus maritima*, *Viburnum* spp., blueberry *Vaccinium* spp., huckleberry *Gaylussacia* spp., bayberry *Myrica pensylvanica* and wild rose *Rosa* spp.

Eutrophication is also a water quality concern in the upper Pamet River. Currently, pondweed and water lilies strangle some of the freshwater portions of the Pamet River, making navigation such as canoeing difficult.

During the storm of December 1992, the eastern Pamet River valley was flooded with approximately four feet of sea water. Immediate impacts included plant and algae mortality, oxygen depletion and fish die-offs. However, this portion of the Pamet River appears to have recovered from the overwash event and the effects of saltwater intrusion of the freshwater upper Pamet.

The existing sodium and specific conductance characteristics of the freshwater portion of the Pamet River are somewhat lower than Truro as a whole. Although the Pamet River east of Wilders Dike has no salinity, the head of the Pamet near Ballston Beach has relatively high salinity readings. This is due to ocean water seeping through the dunes at high tide. This information indicates that, except for the head of the river near Ballston Beach, saltwater intrusion is not a concern.

Tidal restrictions on the Pamet River have not only resulted in the conversion of an estuarine habitat to a freshwater environment, but have also resulted in the submergence of the wetlands upstream of Wilders Dike. Tidal flows carry sediment which is deposited on the marsh surface. Surveys by Geise, et.al. (1990) show that the marsh elevation east of Route 6 has dropped approximately two feet below the marsh west from Wilders Dike. Surveys by the U.S. Army Corps of Engineers (November 1995) also show a drop in elevation upstream of Wilders Dike.

The Pamet River Greenway Management study conducted in 1987 indicated that the fish population of the freshwater portion of the Pamet River is quite different east of Route 6. Due to the Pamet's poor flow, obstacles (tide gate at the dike), and the lack of a pond at the headwaters, there is no active anadromous fish run. However, freshwater fish species spawn in the upper Pamet River such as yellow perch *Perca flavescens*, white perch *Morone americana*, smallmouth bass *Micropterus dolomieui*, bluegills *Lepomis macrochirus*, and tessellated darters *Etheostoma olmstedi*. Pumpkin- seed sunfish *Lepomis gibbosus* make numerous spawning depressions throughout the streambed. The upper Pamet River has been stocked in the past with salter brook trout and sea-run brown trout by State Officials.

2. Existing Salt Marsh Environment

The salt marsh west of Wilders Dike is dominated by typical salt marsh species, the cordgrass *Spartina alterniflora* and salt hay *S. patens.* Glasswort *Salicornia* spp. and other typical marsh vegetation are also included in this category.

Tidal sections of the Pamet support most Cape Cod Bay estuarine species. Particular species include winter *Pseudopleuronectes americanus* and summer flounder *Parlichthys dentatus*, bluefish *Pomatomus saltatrix*, menhaden *Brevoortia tyrannus*, eels, and occasionally striped bass *Morone saxatilis*.

3. Threatened or Endangered Species

Except for the occasional transient bald eagle or peregrine falcon, no Federally listed or proposed threatened and endangered species under the jurisdiction of the U.S. Fish and Wildlife Service and the National Marine Fisheries Service are known to occur in the project area. Also, no State-listed rare species are known to occur in the vicinity of the project.

4. Change From Freshwater Wetlands to an Estuarine Environment

Increasing the culvert opening at Wilders Dike will create a tidal range where one does not currently exist, resulting in an increase in the salinity level upstream of the dike. Because of the expected dilution of seawater in this portion of the Pamet River, salinity levels would be expected to be lower than the downstream levels. Salinity levels above the dike would show a gradient from more marine to freshwater conditions the farther one travels upstream.

With the new tidal energy in the freshwater portion of Pamet River, changes to the physical, as well as the biological community, would occur. Changes that might occur to the substrate include the introduction of more sand, lower organic content, higher peat and root content, and higher dissolved oxygen. In addition, the higher water surface levels created with a larger culvert, may have a minor effect on the amount of ocean water seeping through the dunes at Ballston Beach. Because the high tide level on the ocean side would still be higher than the water level at the head of the Pamet River, a gradient would still be created which would cause some ocean water to seep through the dunes.

Species composition of a marsh is partly dependent on the salinity regime of the habitat. The variability and complexity of wetland plant communities increases with decreasing salinity (Odum, et.al., 1984). Tidal freshwater habitat should not encounter average water salinities greater than 0.5 parts per thousand (ppt), as marshes which intermittently come into contact with elevated water salinities may contain slightly less diverse plant communities which are dominated by facultative halophytes (Odum, et.al., 1984). Regular inundation in tidal freshwater regimes extends the lateral boundaries of this habitat. Salt marsh species would be expected to occur up to the highest astronomic tide levels or mean spring high water, where salinity levels are highest. *Spartina alterniflora* is known to occur 98 percent of the time at or below the mean high water level, while over 70 percent of the time *S. patens* is found above mean high water.

Some of the freshwater vegetation along the banks of the Pamet River may become submerged with the opening of the tidal restrictions. Transects taken upstream show the top of the river bank at elevations 2.41, 3.08, and 2.99 feet NGVD for transects 1, 2, and 3, respectively. Predicted low spring water elevations for the installation of a 4 foot by 12 foot box culvert are 2.6, 2.7 and 3.5 feet NGVD for transects 1, 2 and 3 respectively (Table 6). This indicates that those areas with predicted low spring water elevations greater than the river bank elevations would stay submerged with a 4 foot by 12 foot box culvert in place. Therefore, in order to minimize ponding within the flood plain, the chosen culvert must allow a tide range with the lowest low tide levels (associated with spring tides) below the elevation of the flood plain. The smallest culvert size which accomplishes this is a 6 foot by 16 foot box culvert (see Table 6).

Tidal freshwater wetlands are located upstream from tidal saline wetlands (salt marshes) and downstream from nontidal freshwater wetlands. They are characterized by near freshwater conditions (average annual salinity of 0.5 ppt or below except during periods of drought), freshwater species, and daily lunar tidal fluctuation (Odum, et.al., 1984). It is probable that the upper limit of Pamet River may experience characteristics of a tidal freshwater wetlands if the culverts are significantly enlarged.

Opening Wilders Dike and Route 6 to tidal flow would displace much of the freshwater wetlands currently existing in the upper portion of the Pamet River. The degree of displacement will depend on the culvert size selected. However, some comparison between salt marsh, tidal freshwater, and freshwater biological communities can be made to assist in determining the best course of action. It should be noted that the characteristics at a particular location, for estuarine and tidal freshwater systems, can vary and fluctuate on a daily, seasonal, and yearly basis. Estuarine flora is generally less diverse, has a more pronounced macrophyte zonation, moderate level of estuarine and marine invertebrate (other than insects) diversity, and slightly higher decomposition rate for intertidal vascular plants. Annual primary productivity is suspected to be comparable between salt marshes and tidal freshwater systems, while nontidal freshwater systems (the existing condition of the upper Pamet River) may have reduced primary productivity. It is probable that the upper Pamet River will experience characteristics of a tidal freshwater wetland if the culverts are significantly increased in size. Salt marshes are generally known to produce and export high organic material important to estuarine systems and the presence of tidal energy might encourage higher primary productivity in tidal freshwater marshes than in nontidal freshwater marshes.

5. Findings

Significant changes to any ecosystem can have a variety of benefits and impacts. Since the construction of Wilders Dike and Route 6, the tidal flow in the upstream portion of Pamet River has been interrupted. The vegetation in this area has succeeded from cattail marsh, to shrub swamp vegetation, and is presently being rapidly replaced by upland shrub species of cherry, shadbush, and bayberry.

Recovery of the upper Pamet River will depend on seed source, changes in surface elevations, tidal amplitude and duration of disturbance. The decision to restore Pamet River may depend on the amount of change the municipality is willing to accept. In general, the larger the culvert size and associated tidal exchange, the greater the potential for salt marsh restoration. This assumes that issues concerning the invasion of *Phragmites australis* and potential ponding associated with subsidence are resolved.

Based on the water surface elevations predicted from the hydrologic model and the transects taken upstream, salt marsh vegetation would be expected to replace the freshwater vegetation upstream of Route 6 to the level of the spring high water surface elevation as shown in Table 6. The advantages and disadvantages of the introduction of tidal flow east of Wilders Dike are described in Section VI.

VI. CONCLUSIONS & RECOMMENDATIONS

The Corps of Engineers was requested by the town of Truro to investigate options to increase the capacity of the culverts under Wilders Dike and Route 6 to improve their ability to drain saltwater from the upper Pamet River resulting from tidal overtopping events. Recent overtopping events have significantly impacted the surrounding freshwater wetlands vegetation. The study determined the optimum plan to address the overtopping problem to be the replacement of the existing 4.0 foot diameter culvert under Route 6 and the 3.5 foot diameter culvert under Wilders Dike with 4 foot by 12 foot precast reinforced concrete box culverts. The culvert system would continue to employ a tide gate to restrict the flow of saltwater into the upper Pamet River. The plan was selected based on an estimated reduction in the retention time from 6 days to 1.8 days for a 50-year frequency overtopping event. The analysis showed that culvert configurations larger than the selected plan provided only small incremental reductions in retention times. Based on similar wetlands restoration work performed by the Corps, the study estimated the total cost of replacing the culverts to be in the order of $1 million.

The Corps was also requested to investigate the potential of establishing tidal flows to the upper Pamet River. Since the construction of Wilders Dike and Route 6, the tidal flow in the upstream portion of Pamet River has been interrupted and the vegetation in this area has undergone several successional stages. The stages have succeeded from cattail marsh, to shrub swamp vegetation, and is presently being rapidly replaced by upland shrub species of black cherry, shadbush, and bayberry. The introduction of tidal flows into the upper portion of the Pamet River would produce conditions which existed prior to the placement of the tidal restrictions. Salt marsh vegetation would be expected to replace the freshwater vegetation upstream of Route 6 to the level of the spring high water surface elevation. *Spartina alterniflora* would be expected to dominant the lower portion of the Upper Pamet River from mean high water to the mean tide level and below. *Spartina patens* and other salt marsh species would succeed the freshwater species between about the mean high water level and the spring high tide. The replacement of freshwater species with salt marsh species would diminish the farther one traveled upstream.

The study investigated numerous culvert configurations to establish tidal flows to the upper Pamet River. Hydraulic modeling studies of the 4 foot by 12 foot culvert discussed above indicated that some areas of the freshwater marsh will stay submerged, even during a low spring tide. Predicted low spring water elevations associated with this alternative are above the elevation of the river banks. This indicates that some areas of the flood plain will remain flooded. Based on the need to minimize ponding above the river bank elevation, the study concluded that a 6 foot by 16 foot box culvert would be more appropriate to restore tidal flow to the upper portion of the river. The total cost for this project would be similar to the $1 million estimate previously discussed.

Consideration should also be given to constructing the larger sized (6 foot by 16 foot) box culverts with a tide gate. This would allow for adequate drainage of overtopping while providing the potential for future salt marsh restoration, if desired. It is estimated that providing the larger culvert size with a tide gate would increase the overall implementation costs about 10%.

One of the concerns expressed by the town concerning establishing tidal flow was the potential impact on local wells and septic systems. As part of this investigation, the Corps contracted with the Cape Cod Commission to conduct a groundwater assessment of the upper Pamet River.

The Commission's report estimated that the freshwater/saltwater interface was between 120 and 200 beet below the water table and stated that typical wells penetrating 20 to 30 feet into the aquifer were well separated from the saltwater interface. The limited flow characteristics of the peat in the marsh system surrounding the upper Pamet River cause tidal ranges within the river to have minimal effect on groundwater levels in the upper Pamet River valley. In addition, the significant thickness of the aquifer system and upward groundwater gradients suggest that saltwater flow from the river into the surrounding groundwater lenses will be prevented. Groundwater modeling performed by the Commission suggested that local wells and septic systems would not be in danger as a result of the introduction of tidal flow beyond Wilders Dike.

Advantages to restoration of a saltwater ecosystem east of Wilders Dike include the introduction of estuarine species and the return of tidal energy to the freshwater marsh. If upland vegetation is rapidly overtaking the shrub swamp community, then the increased tidal range might help offset this encroachment and increase the amount of wetlands. Increased tidal flows and flushing would help remove contaminants, increase the biological productivity of the Pamet River watershed, increase the exchange of particulate and dissolved nutrients to the estuarine environment, and deposit inorganic material which may eventually elevate the marsh. In addition, concerns about overwash from Ballston Beach would be reduced. Seawater from the overwash events would drain more quickly (in a few days) from the area.

The disadvantages of restoring the tidal flow to the upper portion of Pamet River include the decay and death of freshwater species which are not tolerant of saline waters, and the loss of primary production during this transition phase. The greatest change would occur closest to Route 6. The transition phase from a freshwater to saltwater ecosystem would be expected to take at least a few years. Other disadvantages include the invasion of *Phragmites australis* which may occur in areas where there is a transition from high salinity to freshwater. Other studies may be needed to determine the salinity levels at various locations in the upper part of the Pamet River for selected culvert sizes.

Additionally, the introduction of saline water to the freshwater portion of the Pamet River may initially cause subsidence. Sediment subsidence is likely the result of the death and decomposition of plant roots and rhizomes under salt stress. Due to the existing subsidence east of Route 6 and the potential for additional subsidence with the introduction of saltwater to the upper portion of the Pamet River, ponding is a concern for any alternative selected. For example, the alternative to keep the existing culverts in place and keep the tide gate permanently open would create a pond immediately east of Route 6. There would be minimal or no ponding between Route 6 and Ballston Beach, but some minor ponding would occur closer to Ballston Beach.

Other potential impacts which need to be addressed as a result of introducing tidal flows east of Wilders Dike include the potential flooding of both the public park located between Wilders Dike and Route 6 and the Ballston Beach parking lot. The park, just east of Wilders Dike, appears to have an elevation of at least 3.0 feet NGVD. This information was obtained from cross-sections accomplished for a previous study of the river by Graham Geise. The Ballston Beach parking lot appears to have an elevation of approximately 6.0 feet NGVD. However, these are only estimated elevations as neither of these areas was specifically surveyed during this study.

APPENDIX A

HYDRAULIC ANALYSIS

APPENDIX A

HYDROLOGY AND HYDRAULICS APPENDIX
PAMET RIVER INVESTIGATION
TRURO, MASSACHUSETTS

PREPARED BY
WATER MANAGEMENT SECTION
GEOTECHNICAL AND WATER MANAGEMENT BRANCH
ENGINEERING/PLANNING DIVISION

DEPARTMENT OF THE ARMY
NEW ENGLAND DISTRICT, CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS 02254

SEPTEMBER 1997

APPENDIX A

HYDROLOGY AND HYDRAULICS

PAMET RIVER INVESTIGATION
TRURO, MASSACHUSETTS

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HYDROLOGY AND HYDRAULICS

PAMET RIVER INVESTIGATION
TRURO, MASSACHUSETTS

1. SUMMARY

This reconnaissance report presents the results of studies concerning the Pamet River in Truro, Massachusetts. Pamet River is bounded by Pamet Harbor and Cape Cod Bay on the west and Ballston Beach on the east. The system has two culverts located midway up the river; at Wilder's Dike and Route 6. Tidal waters are prevented from entering the eastern Pamet River by a flap gate on the Wilder's Dike culvert. According to town officials and area residents, flooding of the eastern Pamet occurs during large storms which overtop Ballston Beach. The primary concern is that the two culverts in the system do not have the capacity to drain these floodwaters. The purpose of the study was to evaluate flooding from overtopping of Ballston Beach and to evaluate the capacity of the existing culverts to drain this flooding. The study also evaluated re-introducing tidal flow into the eastern Pamet by removing the flap gate and using the existing or larger culverts. The study, which includes climatology, rainfall analysis, and tidal investigations, concludes that storms with frequencies of 10-years or greater overtop Ballston Beach. The existing culverts cannot drain large overtopping events quickly; larger culverts would be required to reduce drainage time.

2. DESCRIPTION

Pamet River is a shallow estuary that runs east from Cape Cod Bay to Ballston Beach, on the outer coast of Cape Cod (see Figure A-1). Earlier studies by the Truro Conservation Trust concluded that a number of environmental problems related to the Pamet River could be attributed to the construction of dikes for roads and railroads that reduced tidal circulation within the system. The major barrier, Wilder's Dike, was constructed in 1869 to replace a rotting bridge across the mid-section of Great Pamet, and in the mid-1950s, fill for a new state highway (Route 6) was placed across the Pamet valley just east of Wilder's Dike. These dikes have resulted in various water quality problems due to constricted stream flow, increased sedimentation, less oxygen, reduced flushing capabilities, increased sensitivity to acidity and more mobilization of toxic metals and sulfides in sediment. Harbor management problems have

PAMET RIVER SITE MAP

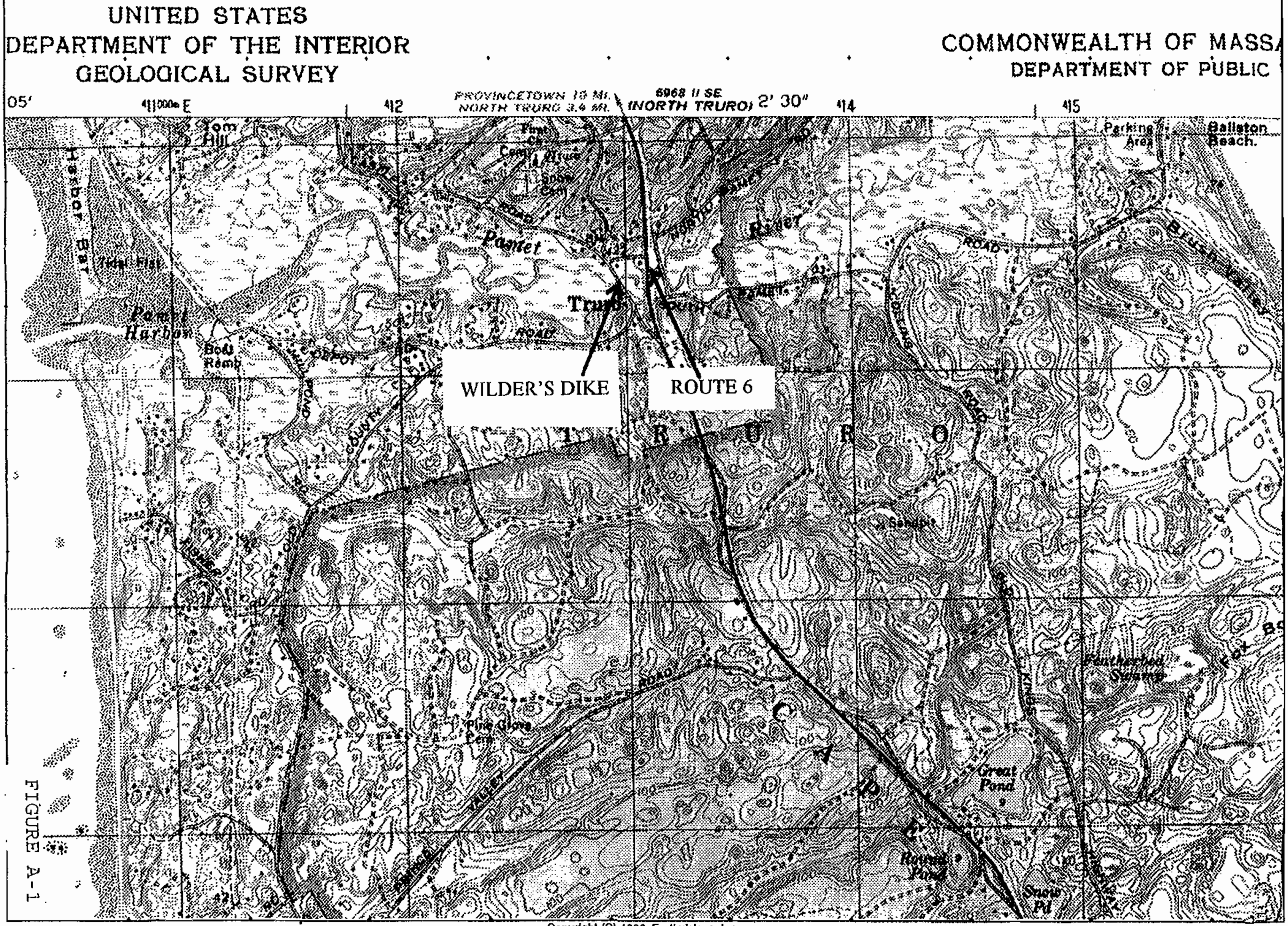


FIGURE A-1

also risen due to a smaller tidal prism, lower current velocities, increases in shoaling, and less flushing capability. Many of the reports have suggested that the return of tidal flow throughout the Pamet River system may improve the water quality and shellfishing and finfishing opportunities within the river. These benefits have been countered by concerns about the potential adverse effects on private wells, septic systems, and the freshwater biota in and around the Upper Pamet River.

After the release of these studies, the Town of Truro requested the Corps of Engineers conduct an investigation into the impacts of removing the tide gate and dike structures located at Wilder's Dike and Route 6 on the Pamet River. The purpose of this appendix was to evaluate the existing culvert/tide gate configurations in relation to their ability to adequately drain the Pamet River during overtopping events at Ballston Beach and to identify alternative culvert/tide gate configurations. This was accomplished by estimating the frequency and volume of overtopping events at Ballston Beach and developing a computer model to evaluate existing and proposed culvert configurations in relation to draining and re-introducing tidal flooding.

3. TIDAL HYDROLOGY

a. Tidal Regime. In the study area, tides are semi-diurnal, with two high and low waters occurring during each lunar day (approximately 24 hours and 50 minutes). The resulting astronomic tide range varies constantly in response to relative positions of the earth, moon, and sun, with the moon having the primary tide producing effect. Maximum tide ranges occur when orbital cycles of these bodies are in phase. A complete sequence of astronomic tide ranges, known as a tidal epoch, is approximately repeated over an interval of 19 years. Because of continual variation in water level due to tides, several reference planes, called tidal datums, have been defined to serve as reference points for measuring elevations of both land and water. The most recent epoch for which the National Ocean Survey (NOS) has published tidal datum information is 1960 thru 1978. Tidal datums are referenced periodically to the National Geodetic Vertical Datum of 1929 to account for apparent sea level rise, a phenomenon observed through tide gaging and tidal benchmark measurements along most of the U.S. coast.

Although long term tidal measurements are not available at the site, an approximation can be developed from correlation to historical tide data at the Boston, Massachusetts, National Ocean Survey (NOS) gage, located 60 miles north of the site. Also, tidal flood profiles developed by the Corps for the open ocean along the New England coastline, were used to estimate tidal flood frequencies at the Pamet River (see Plates A-1 and A-2). A summary of estimated tidal datums in Cape Cod Bay at Truro is shown in Table A-1.

TABLE A-1

ESTIMATED TIDAL LEVELS IN CAPE COD BAY, TRURO

(Estimated from Boston, Massachusetts NOS Tide Gage Data and Corps of Engineers Tidal Flood Profiles, New England Coastline, dated September 1988)

	Tide Level (ft, NGVD)
100-year Frequency Flood Event	10.1
50-year Frequency Flood Event	9.8
10-year Frequency Flood Event	9.1
Maximum Predicted Astronomical High Water	7.5
Mean High Water Spring (MHWS)	6.0
Mean High Water (MHW)	5.3
Mean Tide Level (MTL)	0.6
National Geodetic Vertical Datum (NGVD)	0.0
Mean Low Water (MLW)	-4.2
Mean Lower Low Water (MLLW)	-4.5
Mean Low Water Spring (MLWS)	-4.8
Minimum Predicted Astronomical Low Water	-6.7

b. Freshwater Drainage Area. Based on 1:25,000 U.S. Geological Survey (USGS) quadrangle sheets (photo revised 1979), and recent survey information, the total drainage area is approximated as 5.3 square miles. Of this area, the Pamet River estuary occupies 1 square mile, with minimum elevations ranging between 2 and 4 feet NGVD.

4. CLIMATOLOGY

a. General. The Pamet River area and Cape Cod have a temperate climate. Due to direct coastal exposure, periods of intense precipitation, produced by local thunderstorms and large weather systems of tropical or extratropical origin, are frequently experienced. In the winter coastal storms frequently bring rainfall instead of snow due to the moderating influence of the Atlantic Ocean. In the summer cooling is provided by easterly and southerly sea breezes, thunderstorms from the west, and cool air from the north. Prevailing winds are northwesterly in winter and southwesterly in summer.

b. Temperature and Precipitation. Climatological records, approximately 8 miles northwest of Truro, at Provincetown, MA, U.S. Weather Bureau gage, dating back to 1958, are available. These records are considered representative of the area. Average annual temperature based on these gage readings is 49 degrees Fahrenheit. Average annual precipitation at Provincetown is 40.30 inches. Average precipitation, temperature, and snowfall values recorded at Provincetown, MA are listed in Table A-2. Peak storm rainfall frequency-duration data, as reported in U.S. Weather Bureau Technical Paper 40 (TP-40), are summarized in Table A-3.

c. Runoff. The Pamet River drainage area is about 5.3 square miles, with maximum elevation at approximately 150 feet NGVD in many locations (see Plate A-3). As shown in Table A-2, precipitation is fairly uniform throughout the year; therefore, statistical analysis of annual precipitation can be used. Average annual runoff in the study area from U.S. Weather Bureau Hydrologic Atlas HA 7 is about 24 inches (2 csm based on the drainage area). This amounts to about 60 percent of the average annual precipitation, or an average annual flow rate of 10 cfs. Table A-2 shows that coastal weather keeps a small snowpack resulting in little snow melt in the spring. For this reason, the principal runoff producing events are rainstorms.

5. HYDROLOGIC ANALYSIS

Runoff values for Pamet River were estimated by comparison with a nearby gaged river. The closest river gage was located on the Herring River at North Harwich, MA, approximately 20 miles south of Truro on Cape Cod. It had a period of record of 21 years ranging from 1967 to 1988, and a drainage area of 9.4 square miles. Records from this gage are reportedly poor. Flow is regulated by many ponds upstream, and surface flow may be affected by ground water that enters from or moves into adjacent basins. Although the ground water characteristics may be typical for drainage basins on Cape Cod, the Pamet River basin does not contain as many ponds as the Herring River system. This difference in hydrologic characteristics may produce low discharge estimates for the Pamet River basin.

Peak annual discharge data was input into the Hydrologic Engineering Center Flood Frequency Analysis program (FFA) to estimate a flood flow frequency curve for the Herring River basin. The discharges obtained from this frequency curve were then reduced by comparing the Herring River drainage area to the 5.3 square mile drainage area of the Pamet River. Table A-3 shows estimated peak discharges in the Pamet River for various selected frequencies.

TABLE A-2

MONTHLY CLIMATOLOGICAL DATA
PROVINCETOWN, MA
(Period of Record - 1958-1992)

	Precipitation	Temperature			Snowfall
Month	Average Mean	Maximum	Average	Minimum	Mean
	(inches)		(°F)		(inches)
January	3.82	42	29	15	5.45
February	3.24	44	30	15	7.21
March	3.87	49	37	25	3.56
April	3.55	60	46	32	0.42
May	3.25	69	55	40	0.00
June	3.10	77	65	53	0.00
July	2.44	83	71	58	0.00
August	3.38	82	69	56	0.00
September	3.47	76	63	50	0.00
October	3.64	67	54	41	0.03
November	4.48	56	45	33	0.06
December	4.12	48	34	20	2.95
Annual	40.30	83	49	15	20.40

TABLE A-3

RAINFALL - FREQUENCY - DURATION
USWB TECHNICAL PAPER 40
(Rainfall in Inches)

Annual Frequency		Duration in Hours				
		1	2	6	12	24
Percent	Year					
50	2	1.2	1.6	2.3	2.7	3.3
20	5	1.6	2.0	2.7	3.4	4.0
10	10	2.0	2.4	3.3	4.0	4.6
2	50	2.5	3.0	4.1	5.1	6.0
1	100	2.9	3.4	4.7	6.0	7.0

TABLE A-4

ESTIMATED PEAK INFLOW TO PAMET RIVER FROM FRESHWATER RUNOFF

Frequency Event	Peak Inflow (cfs)
2	24
5	33
10	39
20	46
50	57
100	65

6. TIDAL HYDRAULICS

a. General. The Pamet River is divided in the middle by Wilder's Dike. The west side of the Pamet River is open to Cape Cod Bay, the east side is separated from the Atlantic Ocean by Ballston Beach. Tidal flow is generally restricted from the east side of the Pamet River by a flap gate on the Wilder's Dike culvert. However, during some storm events, Ballston Beach is overtopped, allowing saltwater into the eastern portion of the Pamet. The culverts under Wilder's Dike and Route 6 are too small to drain floodwaters overtopping Ballston Beach. During the December 1992 storm, the eastern Pamet valley was flooded with four feet of saltwater. To evaluate the existing drainage of storms, overtopping analyses were performed on Ballston Beach. Flows obtained from this analysis were then input into UNET, a one-dimensional hydrodynamic model to evaluate drainage under existing conditions.

UNET was then used to evaluate proposed alternatives, selected for improving drainage and re-introducing tidal flow into the eastern portion of the Pamet River.

b. Overtopping Analysis. As part of the Pamet River Investigation, peak rates of overtopping of Ballston Beach were computed. These numbers were used to determine the frequency where overtopping begins and saltwater flooding of the Pamet River east of Wilder's Dike occurs. This analysis required information on the physical geometry of the beach, winds, wave heights, and runup values.

(1) Beach Profile. An average beach profile and crest elevation were taken as part of the survey performed by New England Division in November 1995. Ballston Beach has an approximate slope of 1V on 8H, and a crest elevation of 16 feet NGVD.

(2) Design Wave Heights, Periods, and Runup. Wave heights, periods, and runup were computed using the Automated Coastal Engineering System (ACES). Wave heights were based on fully developed open water waves generated on the Atlantic Ocean, by winds sustained from various directions and durations, using previously analyzed National Weather Service data at Logan International Airport (Shore Protection and Flood Damage Reduction Study, Winthrop, Massachusetts, NED 1994). Design wave heights and periods for 1-, 10-, 25-, 50-, and 100-year return periods were determined, using fetch lengths for each wind direction. This information was used to estimate overtopping volumes. Table A-5 presents data computed for the worst case scenario- winds from the east-northeast.

TABLE A-5

WAVE HEIGHT, PERIOD, AND RUNUP

Frequency (yrs)	SWL (ft NGVD)	Wind-Speed (mph)	Wave Height (ft)	T (sec)
1	7.6	14	2.6	3.8
10	9.1	35	11.1	7.5
25	9.3	40	13.8	8.3
50	9.8	44	16.3	8.9
100	10.1	47	18.3	9.4

- Average height from Rayleigh distribution
- Existing beach slope 1:8
- Unlimited fetch, winds from ENE

(3) Peak Overtopping Rate

(a) General. The Automated Coastal Engineering System (ACES), version 1.07e "Wave Runup and Overtopping on Impermeable Structures" was used to estimate peak rates of overtopping along the existing beach. For each particular return period, a local windspeed from the east-northeast direction was assumed to be occurring during the overtopping period. Overtopping coefficients were estimated, using the 1984 Shore Protection Manual and best engineering judgement; see following section.

The condition when waves break at the structure toe was assumed to be critical, producing the maximum wave runup and peak rates of overtopping of the existing conditions. The structure toe is defined at the base of the beach, or the point where the structure slope intersects the near shore slope. Depth at the structure/beach toe was assumed to be the difference between tidal stillwater level for the particular return period, and elevation of the intersection of the structure and near shore slope.

(b) Overtopping Coefficients. There are two coefficients which need to be estimated for calculating overtopping using ACES- Q^*_0 and alpha. These are empirically determined, and depend on incident wave characteristics and structure geometry. Initial estimates of Q^*_0 were made using figure 7-27 (Overtopping Parameters þ and Q^*_0, on a 1:6 slope) in the Shore Protection Manual. This requires computing H_0/gT^2 and d_s/H_o; where H_0 is the equivalent deepwater wave height, "g" is the gravitational coefficient, "T" is the wave period, and d_s is the ocean stillwater depth at the structure toe. For the 100-year condition with the 18.3-foot, 9.4-second wave, H_0/gT^2 equals 0.0064 and d_s/H_o equals 0.83. The corresponding Q^*_0 from figure 7-27 is 0.0045. These calculations were repeated for 50-, 25-, 10-, and 1-year events. An option available in ACES was used to make initial estimates of alpha. For all events, the ACES-calculated alpha is 0.09 for the existing beach slope of 1 vertical to 8 horizontal.

Table A-6 presents results of the overtopping analysis along Ballston Beach for existing conditions. Ballston Beach begins to experience overtopping during events with frequencies of 10 years or greater. The estimated volumes of overtopping were used as input to the UNET model to assess drainage of the existing culverts under Route 6 and Wilder's Dike.

TABLE A-6

PEAK OVERTOPPING RATES

Freq (yrs)	SWL (ft, NGVD)	Existing Beach (cfs/lf)
1	7.6	negligible
10	9.1	0.1
25	9.3	1.8
50	9.8	4.5
100	10.1	5.8

- Existing beach slope 1:8
- Unlimited fetch, winds from ENE

c. Computer Model. The hydraulic analysis of Pamet River from Cape Cod Bay to Ballston Beach was performed using UNET, a one dimensional hydrodynamic model. UNET, the latest most advanced model readily available, provides reasonable results without the significant difficulties of a two-dimensional model. UNET also has the capability to more accurately model culverts since it is able to use the Federal Highway Administration procedures for determining hydraulic capacities of culverts. This model became available for Corps use through the Hydrologic Engineering Center in September 1992, and was updated in March 1993 and September 1995. Two culverts were simulated in this analysis; one at Wilder's Dike and one under Route 6.

UNET, using the properties of continuity and momentum, applies a linearized, implicit finite difference scheme to solve a set of linear equations. The equations are linearized, using the first order Taylor approximation. The program can simulate one-dimensional unsteady flow through a full network of open channels. For subcritical flow, stages are a function of channel geometry, and downstream backwater effects. UNET provides the user with the ability to apply flow and stage hydrographs, bridges, spillways, levee systems, and culverts. Cross sections are input in a modified HEC-2 forewater format.

The objective of modelling was to evaluate existing conditions of the Pamet River in terms of drainage and flooding of the river east of Wilder's Dike, and to evaluate several alternatives allowing saltwater back into the Pamet River east of Wilder's Dike. Input required to set up the model includes marsh geometry and tide information.

(1) Marsh Geometry. 1985 surveys of the Pamet River west of Route 6 were available for use as model input. Detailed surveying was performed by NED during November 1995 to provide additional information on the topography east of Route 6. Detailed surveys, performed around the culverts, obtained culvert inverts and road elevations. East of Route 6, three transects were surveyed across the marsh.

As part of the survey effort, three staff gages were installed. Gage 1 was located in Pamet Harbor, Gage 2 just west of Wilder's Dike, and Gage 3 just east of Route 6. Transect and gage locations are shown on Plate A-4.

(2) Tide Measurements. Tidal monitoring data was collected to describe the existing salt marsh tidal regime, and to obtain information to calibrate a model of one dimensional flow. NED personnel collected tide data at the three gages on 21 November 1995. The flap gate at Wilder's Dike was kept open that day to observe tidal flows east of

Route 6 which would provide information on the hydraulic capacity of the existing culverts under Wilder's Dike and Route 6. Tide data were also obtained on 18 March 1996 at the three gages with the flap gate closed. Tidal data collected were referenced to National Geodetic Vertical Datum (NGVD) to allow correlation with the nearest NOS gage in Boston, Massachusetts. The correlation allows NED to assign important statistical tidal datum planes to the Pamet River, based on historic data collected at the Boston gage (see Table A-1). These relationships are the basis for predictive analysis completed for the Pamet River. Collected tidal data was used to document movement of the tidal prism into and out of the marsh, and provide background information for the numerical model representation of the marsh.

(3) Model Calibration. Water surface elevations, measured on 21 November 1995, were used to calibrate the UNET model which was used to analyze existing and proposed culverts. These measurements were completed over a 8-hour period to ensure that both incoming and outgoing tidal characteristics would be represented and compared.

On 21 November 1995, the tide in Pamet Harbor ranged from -1.1 to 7.4 feet NGVD. The 7.4 feet NGVD high tide elevation is greater than the mean spring high water (6.0) and almost equal to the maximum astronomical high water predicted for the site (7.5 feet NGVD).

Tidal measurements from Pamet Harbor (Gage 1) were used as boundary conditions for the calibration simulation. In addition, tidal water surface levels for the preceding two days, estimated from tidal conditions at Boston, were used to provide data for startup of the finite difference model. Measurements by the Cape Cod Commission in 1996 of upstream freshwater elevations were used as an upstream boundary condition.

Cross sectional information input to the model was obtained from 1985 and 1995 surveys and from 2-foot contour maps of the marsh. Manning's frictional "n" values (ranging from 0.06 in the channel to 0.12 in the overbanks), estimated by comparing vegetation and topography of the site with "n" values associated with Chow's Open Channel Hydraulics, were adjusted and minor changes made to the cross sections so results more closely matched observed tide level measurements. Minor changes to the estimated cross section overbank areas are justified since changes affected less than 10 percent of the wetted ditch area.

Results of the calibration run for 21 November 1995 are shown on Plates A-5 and A-6. As can be seen, computed results match very favorably to the observed data, with computed levels only a few tenths of a foot or less different from the observed at all times. Based on the good fit to observed data, the model was considered to be calibrated to the degree needed for accurate predictive results.

(4) Model Verification. Tidal measurements were measured again at Gages 1, 2, and 3 on 18 March 1996 with the flap gate in its normal position (closed during flood tide). The tide in Pamet Harbor ranged from -1 to 7.3 feet NGVD. The high tide of 7.3 feet NGVD is close to the maximum astronomical high water predicted for the area (7.5 feet NGVD).

Water surface elevations, measured over a full cycle at Gages 1 and 2 were used for verification of the computer model. Tides observed at Gage 1 were input as the boundary condition into the UNET model. Observed values at Gage 2 were then compared with computed values. Results of the verification run are shown in Plate A-7. As can be seen, computed high and low elevations match those measured within two-tenths, which verify the accuracy of the model indicated by calibration.

Elevations at Gage 3 were measured to obtain an estimation of freshwater elevation on the east side of Wilder's Dike. The freshwater elevation at the east end of the Route 6 culvert ranged from 1.5 to 2.1 feet NGVD on 18 March. A report prepared by the Cape Cod Commission in 1996 stated that surface water levels at Ballston Beach are fairly stable, around 3 feet NGVD. Levels decline to Route 6, where levels ranged from 2.2 to 1.6 feet NGVD, which correlates with measurements on 18 March.

d. Hydraulic Analysis

(1) General. The intent of modeling was to evaluate existing culvert and dike configurations at Wilder's Dike and Route 6 in terms of drainage of storm volume from Ballston Beach and to analyze alternatives of restoring tidal flow to the Pamet River east of Wilder's Dike.

One of the primary concerns about removal of the flap gate is the potential impact on private wells and septic systems in the Upper Pamet River Study area. The Cape Cod Commission assessed the effect of removing the tidal gate on groundwater fluctuations in the river valley. Their evaluation used the maximum predicted increases in surface water for a mean tide range (0.9 ft at Ballston Beach and 2.4 feet at Route 6). The evaluation, presented in Pamet River Investigation Groundwater Assessment Study, 1996, suggested only minimal increases (<0.3 foot) in the range of groundwater fluctuations 500 feet from the river.

(2) Existing Conditions. The Pamet River flows unrestricted from Pamet Harbor to Wilder's Dike. At Wilder's Dike there is a 3.5-foot culvert with a flap gate to prevent tidal flows from passing through. As currently configured, the flap gate is forced closed by tidal saltwater approximately two hours before high tide and remains closed for four to six hours. Freshwater flows west from Ballston Beach and drains through the Route 6 and Wilder's Dike culverts.

Water surface elevations east of Route 6 are estimated at 1.6 to 2.2 feet NGVD. Water levels at Ballston Beach are constant around 3.0 feet NGVD. The existing culverts are capable of draining this flow. Storm events, overtopping Ballston Beach, however, have caused flooding of the freshwater portion of the Pamet. The culverts do not appear to be large enough to drain the saltwater quickly.

(3) Drainage of Overtopping. The model was run using an estimated interior elevation of 3.0 feet NGVD on the west side of Ballston beach. The increase in water elevation from beach overtopping was evaluated by inputting the overtopping volume as a flow hydrograph into the UNET model. The December 1992 storm was estimated at approximately a 25-year storm. Interior levels for a 25-year event were predicted by the model to be 6.8 feet NGVD. Interior levels estimated by the Cape Cod Commission after this storm were just under 7.0 feet NGVD, correlating with model predictions. Time required after storm events to drain the Upper Pamet back to 3.0 feet NGVD was evaluated for the existing culverts. Results are presented in Table A-7.

TABLE A-7

DRAINAGE ANALYSIS OF EXISTING CULVERTS FOR STORM EVENTS

Event	Water Level at Ballston Beach (feet NGVD)	Time to Drain
mean tide range	3.0	N/A
10-year	3.3	1 day
25-year	6.8	4 days
50-year	9.6	6 days
100-year	10.6	7 days

The model was then used to predict drainage times for several alternative culvert configurations. This analysis assumed a flap gate would be maintained at Wilder's Dike. A 50-year storm event was chosen for evaluation purposes. The first set of alternatives analyzed whether faster drainage times could be obtained by replacing only one culvert. A large culvert (10- by 20- feet) under Wilder's Dike with the existing Route 6 culvert would only reduce drainage time of a 50-year event to 4.5 days. From this analysis it was determined that reduction of flooding impacts would require replacement of both culverts.

The second set of alternatives included replacing both Wilder's Dike and Route 6 culverts with box culverts ranging in size from 4-feet by 6-feet to 10-feet by 20-feet. Inverts used for the culverts were -1.22 feet NGVD downstream side of Wilder's Dike culvert and -1.0 feet NGVD for the upstream side of Wilder's Dike and upstream and downstream sides of Route 6. This would also require dredging the channel between the culverts to -1.0 feet NGVD. Inverts lower than -1.0 feet NGVD would be much lower than existing channel inverts and would require extensive channel dredging. Criteria for evaluation was time required to reduce floodwaters back to normal water elevations east of Route 6. Results are presented in Table A-8.

Replacing the culverts under Wilder's Dike and Route 6 with anything larger than a 4- by 12- foot or 6- by 12- foot culvert would not reduce drainage time any further. A 4- by 12- foot box culvert under each crossing would reduce drainage of a 50-year storm from approximately 6 to 1.8 days. The minimum likely drainage time, 1.7 days, could be obtained with a 6- by 12- foot box culvert under each crossing.

(4) <u>Restoration of Tidal Flows to Upper Pamet.</u> Modelling was performed to predict the effect of various culvert sizes on re-introducing tidal flow to the Pamet River east of Route 6. The existing 3.5-foot diameter culvert under Wilder's Dike has downstream and upstream inverts of -1.22 and -0.28 feet NGVD, respectively. The existing 4-foot diameter culvert under Route 6 has downstream and upstream inverts of -0.58 and -0.2 feet NGVD, respectively. The channel invert downstream of Wilder's Dike is approximately -0.4 feet NGVD; the invert upstream of Route 6 is approximately 0.0 feet NGVD.

The analysis was performed to evaluate alternatives including a) lowering culvert inverts to improve drainage, and b) increasing the existing culvert opening and channel

TABLE A-8

DRAINAGE ANALYSIS OF A 50-YEAR EVENT FOR VARIOUS CULVERT CONFIGURATIONS WITH TIDE GATES

CONFIGURATION AT EACH CROSSING	WATER LEVEL AT BALLSTON BEACH (FEET NGVD)	TIME TO DRAIN TO 3.0 FEET NGVD (DAYS)
EXISTING	9.6	6.0
4 x 6	9.6	4.0
4 x 8	9.6	2.3
4 x 10	9.6	2.0
4 x 12	9.6	1.8
4 x 16	9.6	1.8
4 x 20	9.6	1.7
6 x 6	9.6	2.7
6 x 8	9.6	1.9
6 x 10	9.6	1.8
6 x 12	9.6	1.7
6 x 16	9.6	1.7
6 x 20	9.6	1.7
8 x 8	9.6	1.85
8 x 10	9.6	1.75
8 x 12	9.6	1.7
8 x 16	9.6	1.7
8 x 20	9.6	1.7
10 x 10	9.6	1.7
10 x 12	9.6	1.7
10 x 16	9.6	1.7
10 x 20	9.6	1.7

width to re-introduce tidal flow to the east of Route 6. The desired configuration would be a balance of flooding to maximize salt marsh restoration, enough drainage to allow for the restoration without causing permanent flooding, and economic reasonableness.

The first set of alternatives used larger than existing culverts, and analyzed the effect of lowering the culvert and channel inverts. The existing downstream invert of Wilder's Dike culvert was maintained; the upstream invert of Wilder's Dike, downstream and upstream inverts of Route 6, and the channel invert in between the two culverts was lowered to -1.0 feet NGVD. An arbitrarily sized 6- by 12-foot box culvert at each crossing, and a tide range occurring approximately 8 times per month, were used to compare impacts of change in inverts. Results, computed at Transect 2, are shown in Plate A-8. As can be seen, height of the water during high tide conditions is increased approximately 0.10 foot for the lowered inverts and height of water during low tide conditions is decreased approximately 0.20 foot. Due to concerns about drainage of floodwaters overtopping Ballston Beach, the lowered culvert and channel inverts were selected for further analysis.

After establishing the channel and culvert invert elevations, numerous culvert and bridge alternatives were analyzed in detail. For each configuration, the bottom channel width used was equal to the greater of the existing channel or proposed culvert width. The alternatives, shown in Tables A-9 and A-10, were simulated using two tide ranges - a frequency of occurrence of approximately eight times per month (frequency necessary to restore salt marsh), and a mean tide range. As can be seen, the estimated high tide of 6.4 feet NGVD in Pamet Harbor during a larger tide event produced high tide levels ranging from approximately 3.5 to 5.0 feet NGVD at Transect 2. Mean high water of 5.3 feet NGVD in Pamet Harbor produced high tide levels ranging from approximately 3.0 to 4.0 feet NGVD at Transect 2.

An analysis was performed on three of the alternatives with no tide gate at Wilder's Dike to see how they would perform during overtopping events. Alternatives evaluated include existing culverts and 4-feet by 12-feet and 10-feet by 20-feet box culverts under each crossing,

Interior water levels were obtained by inputting the 50-year overtopping as a flow hydrograph into the UNET model developed for each alternative. Water levels increase only slightly above the 9.6 feet NGVD presented in Table A-8 due to larger storage volumes at higher elevations. Estimated drainage times of a 50-year overtopping event are presented in Table A-11. As can be seen from the Table, drainage

TABLE A-9

Water Surface Elevations for Various Culvert Sizes at Each Crossing (for Spring Tide in Feet NGVD) - TIDE FREQUENCY = 8 TIMES PER MONTH

CONFIG AT EACH CROSSING	PAMET HBR (high)	WEST OF WILDERS DIKE (high,low)	EAST OF ROUTE 6 (high,low)	BETWEEN 6 AND BALLSTON BEACH (high,low)	BALLSTON BEACH (high)
EXISTING gate open	6.4	6.1, 2.7	3.35, 2.8	3.3, 2.9	3.3
4 x 6	6.4	6.1, 1.9	3.6, 2.6	3.5, 2.7	3.4
4 x 8	6.4	6.1, 2.1	4.0, 2.6	3.8, 2.7	3.5
4 x 10	6.4	6.0, 2.3	4.4, 2.6	4.0, 2.7	3.8
4 x 12	6.4	6.0, 2.4	4.5, 2.6	4.1, 2.75	3.9
4 x 16	6.4	5.9, 2.5	4.7, 2.6	4.3, 2.8	4.1
4 x 20	6.4	5.8, 2.5	4.9, 2.65	4.4, 2.8	4.1
6 x 6	6.4	6.1, 2.0	4.2, 2.8	3.9, 2.9	3.8
6 x 8	6.4	6.0, 2.2	4.6, 2.7	4.1, 2.85	4.0
6 x 10	6.4	5.9, 2.3	4.75, 2.6	4.3, 2.85	4.1
6 x 12	6.4	5.9, 2.3	4.9, 2.6	4.4, 2.85	4.2
6 x 16	6.4	5.9, 2.3	5.0, 2.5	4.6, 2.85	4.2
6 x 20	6.4	5.7, 2.4	5.1, 2.6	4.65, 2.85	4.3
8 x 8	6.4	6.0, 2.2	4.6, 2.7	4.2, 2.85	4.0
8 x 10	6.4	5.9, 2.3	4.8, 2.6	4.4, 2.85	4.1
8 x 12	6.4	5.8, 2.3	4.9, 2.6	4.5, 2.85	4.2
8 x 16	6.4	5.7, 2.4	5.0, 2.6	4.6, 2.85	4.2
8 x 20	6.4	5.7, 2.4	5.1, 2.6	4.65, 2.85	4.3
10 x 10	6.4	5.7, 2.4	5.0, 2.5	4.5, 2.8	4.2
10 x 12	6.4	5.6, 2.4	5.1, 2.55	4.65, 2.85	4.3
10 x 16	6.4	5.5, 2.4	5.2, 2.5	4.7, 2.85	4.3
10 x 20	6.4	5.5, 2.4	5.3, 2.5	4.75, 2.8	4.3
Bridge	6.4	5.55, 2.6	5.4, 2.6	5.0, 2.85	4.6

TABLE A-10

WATER SURFACE ELEVATIONS FOR VARIOUS CULVERT CONFIGURATIONS (FEET NGVD) - TIDE FREQUENCY = MEAN TIDE RANGE

CONFIG AT EACH CROSSING	PAMET HBR (high)	WEST OF WILDERS DIKE (high, low)	EAST OF ROUTE 6 (high, low)	BETWEEN 6 AND BALLSTON BEACH (high, low)	BALLSTON BEACH (high)
EXISTING GATE OPEN	5.3	5.2, 1.2	2.7, 2.4	3.0, 2.5	3.2
4 x 6	5.3	5.1, 1.7	3.3, 2.35	3.2, 2.45	3.2
4 x 8	5.3	4.9, 1.8	3.55, 2.2	3.3, 2.4	3.3
4 x 10	5.3	4.8, 1.9	3.7, 2.2	3.4, 2.4	3.4
4 x 12	5.3	4.8, 1.9	3.8, 2.2	3.5, 2.4	3.5
4 x 16	5.3	4.7, 1.9	3.9, 2.1	3.5, 2.4	3.5
4 x 20	5.3	4.7, 1.9	3.95, 2.1	3.6, 2.4	3.5
6 x 6	5.3	5.0, 1.8	3.5, 2.4	3.3, 2.5	3.3
6 x 8	5.3	4.8, 1.9	3.7, 2.3	3.4, 2.45	3.4
6 x 10	5.3	4.7, 1.9	3.85, 2.2	3.5, 2.4	3.5
6 x 12	5.3	4.7, 1.9	3.9, 2.2	3.5, 2.4	3.5
6 x 16	5.3	4.7, 1.9	4.0, 2.1	3.6, 2.4	3.55
6 x 20	5.3	4.6, 1.9	4.0, 2.1	3.6, 2.4	3.55
8 x 8	5.3	4.8, 1.9	3.7, 2.3	3.4, 2.5	3.4
8 x 10	5.3	4.7, 1.9	3.8, 2.2	3.5, 2.4	3.5
8 x 12	5.3	4.7, 1.9	3.9, 2.2	3.55, 2.4	3.5
8 x 16	5.3	4.65, 1.9	4.0, 2.1	3.6, 2.4	3.55
8 x 20	5.3	4.6, 1.9	4.0, 2.1	3.6, 2.4	3.6
10 x 10	5.3	4.6, 1.9	4.0, 2.1	3.6, 2.4	3.55
10 x 12	5.3	4.6, 1.9	4.0, 2.1	3.6, 2.4	3.6
10 x 16	5.3	4.6, 1.9	4.1, 2.1	3.6, 2.4	3.6
10 x 20	5.3	4.6, 1.9	4.1, 2.1	3.6, 2.4	3.6
BRIDGE	5.3	4.8, 2.3	4.6, 2.4	4.0, 2.6	3.9

times are similar to or slightly less than those presented in Table A-8 for culvert alternatives with tide gates (for drainage only). This is due to only slightly higher interior water levels after the overtopping is added and having to drain them to the predicted high water for each alternative instead of 3.0 feet NGVD with the gate closed.

TABLE A-11

DRAINAGE ANALYSIS OF A 50-YEAR EVENT FOR PROPOSED ALTERNATIVES WITHOUT TIDE GATES

CONFIG AT EACH CROSSING	MEAN HIGH WATER AT BALLSTON BEACH (FEET NGVD)	WATER LEVEL AFTER ADDITION OF 50-YEAR EVENT (FEET NGVD)	DRAINAGE TIME BACK TO MHW AT BALLSTON BEACH (DAYS)
EXISTING - NO GATE	3.2	9.65	6.0
4 X 12	3.5	9.7	1.7
10 X 20	3.6	9.85	1.6

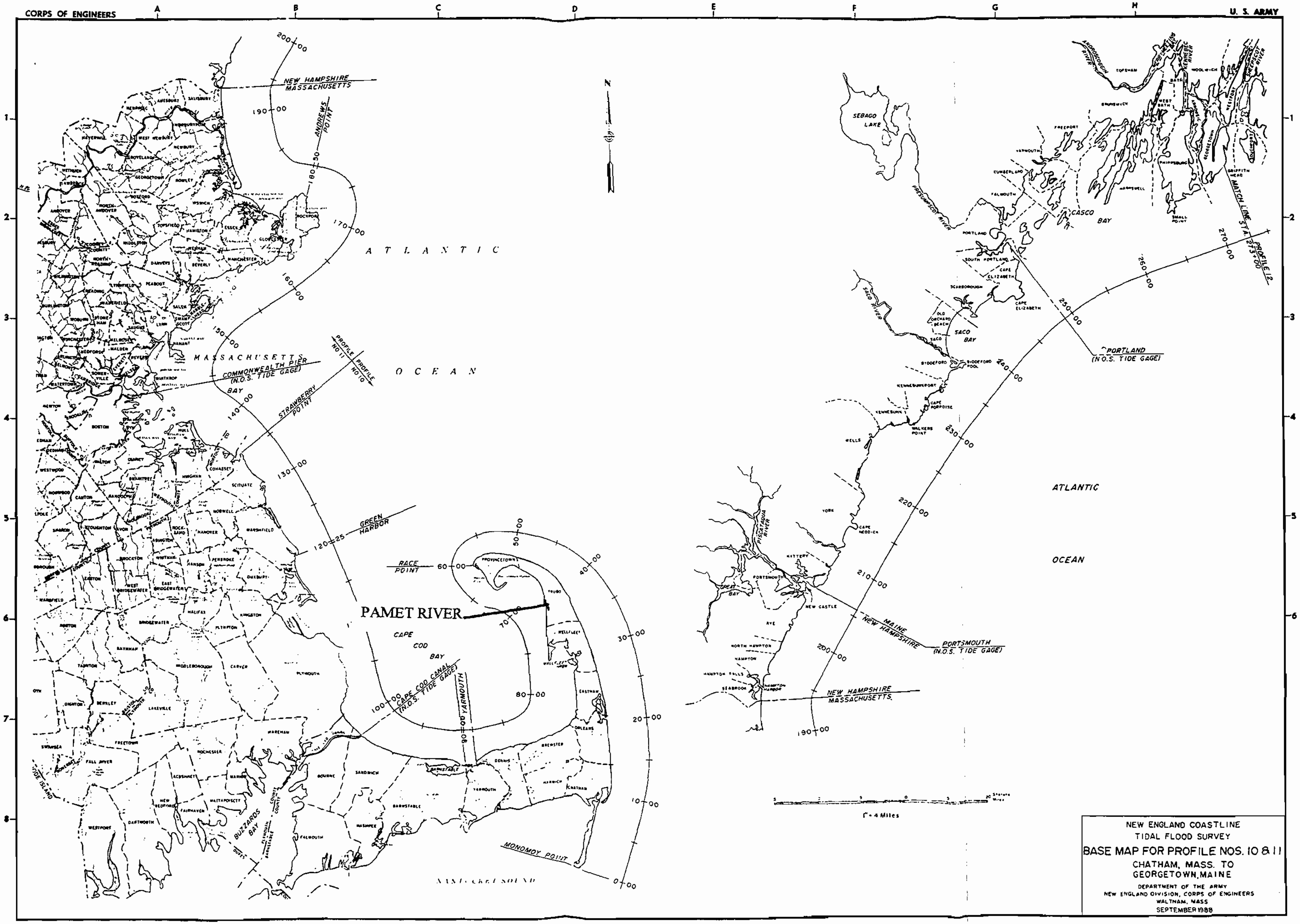
7. CONCLUSIONS

The purpose of this study was to determine the amount of flooding caused by overtopping from Ballston Beach and to evaluate the capacity of existing and alternative culverts in draining this overtopping as well as re-introducing tidal waters east of Route 6.

Wave height, runup, and overtopping analyses using ACES generated volumes of water flooding the eastern Pamet River. Existing culverts under Wilder's Dike and Route 6 are not capable of draining these flood waters quickly; a 50 year storm takes approximately 6 days to drain. Analysis of various culvert configurations suggests that optimal drainage time of a 50-year event could be obtained with a 4- by 12- foot or 6- by 12-foot culvert under both Wilder's Dike and Route 6. This analysis assumed that a flap gate would be maintained at Wilder's Dike.

Various alternatives were also evaluated for restoring tidal flows to the eastern Pamet River. Configurations, ranging from existing culverts to open bridges could obtain water surface elevations at Transect 2 ranging from 3.3 to 5.0 feet NGVD. These elevations correspond to a high tide elevation of 6.4 feet NGVD in Pamet Harbor. A mean high tide elevation of 5.3 feet NGVD in Pamet Harbor could produce water surface elevations at Transect 2 ranging from 3.0 to 4.0 feet NGVD at Transect 2.

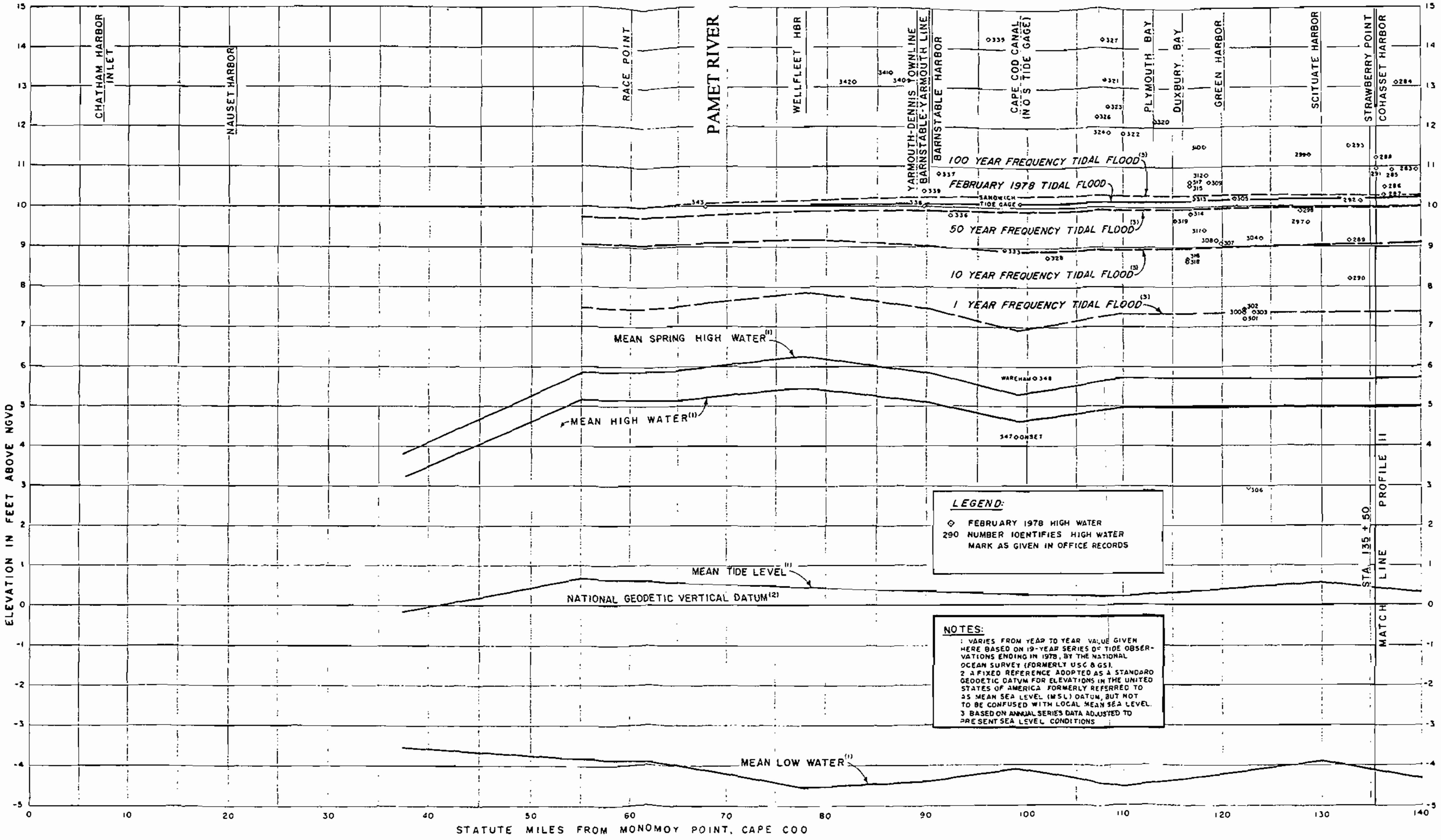
One of the primary concerns about the removal of the flap gate is the potential impact on private wells and septic systems in the Upper Pamet River study area. An evaluation by the Cape Cod Commission suggested only minimal increases in groundwater fluctuations due to maximum predicted increases in surface water levels. Other potential impacts which need to be addressed before proceeding with any alterative include the potential flooding of both the public park located between Wilder's Dike and Route 6 and the Ballston Beach parking lot.



NEW ENGLAND COASTLINE
TIDAL FLOOD SURVEY
BASE MAP FOR PROFILE NOS. 10 & 11
CHATHAM, MASS. TO
GEORGETOWN, MAINE
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS
SEPTEMBER 1988

PLATE A-1

CORPS OF ENGINEERS U. S. ARMY



LEGEND:

◇ FEBRUARY 1978 HIGH WATER

290 NUMBER IDENTIFIES HIGH WATER MARK AS GIVEN IN OFFICE RECORDS

NOTES:

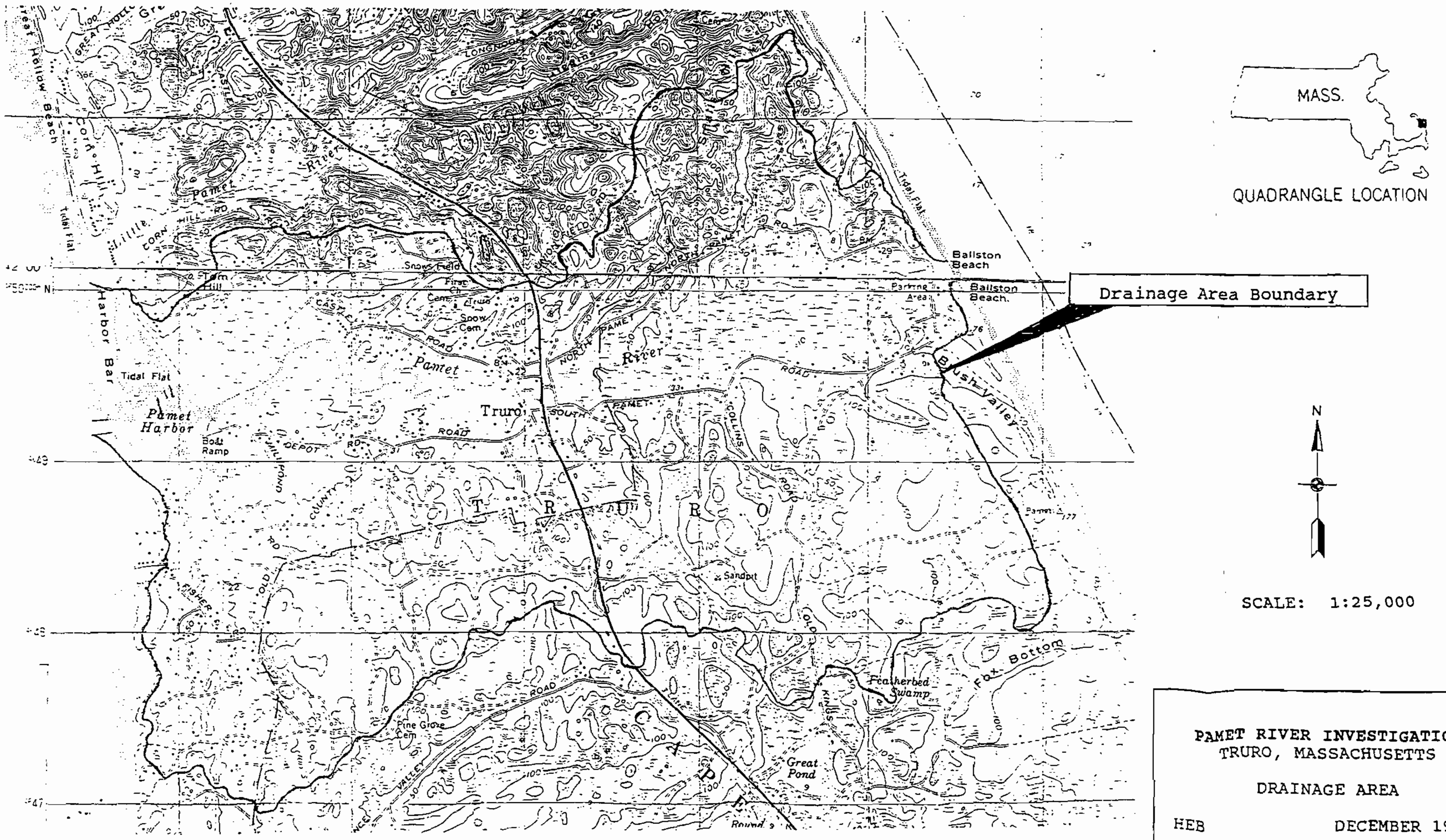
1 VARIES FROM YEAR TO YEAR VALUE GIVEN HERE BASED ON 19-YEAR SERIES OF TIDE OBSERVATIONS ENDING IN 1978, BY THE NATIONAL OCEAN SURVEY (FORMERLY USC & GS).

2 A FIXED REFERENCE ADOPTED AS A STANDARD GEODETIC DATUM FOR ELEVATIONS IN THE UNITED STATES OF AMERICA FORMERLY REFERRED TO AS MEAN SEA LEVEL (MSL) DATUM, BUT NOT TO BE CONFUSED WITH LOCAL MEAN SEA LEVEL.

3 BASED ON ANNUAL SERIES DATA ADJUSTED TO PRESENT SEA LEVEL CONDITIONS

20 STATUTE MILES

NEW ENGLAND COASTLINE
TIDAL FLOOD SURVEY
TIDAL FLOOD PROFILE NO. 10
CHATHAM, MASS.
TO COHASSET, MASS.
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.
SEPTEMBER 1988



PAMET RIVER INVESTIGATION
TRURO, MASSACHUSETTS

DRAINAGE AREA

HEB DECEMBER 1995

PLATE A-3

TRANSECT AND GAGE LOCATIONS

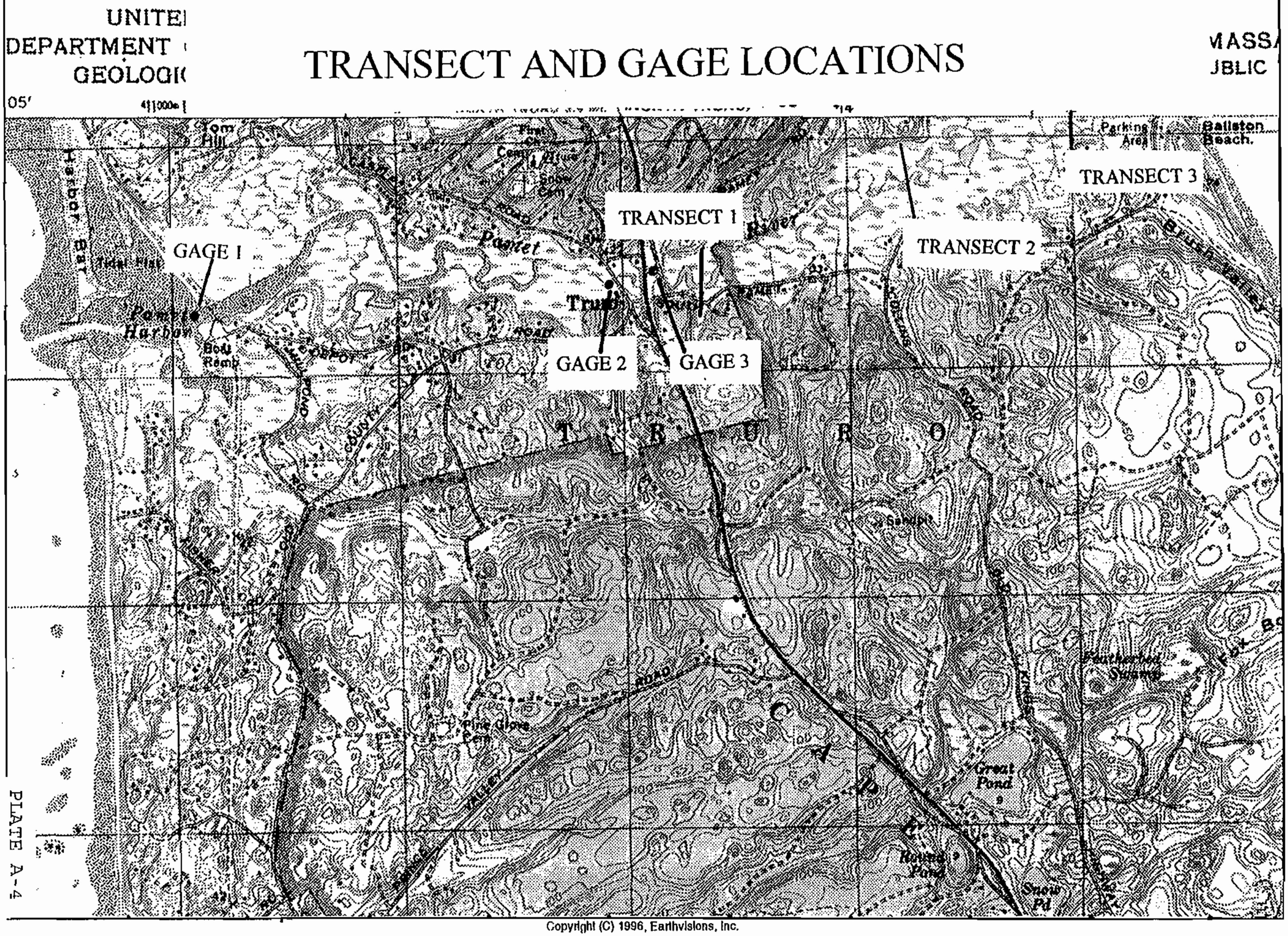


PLATE A-4

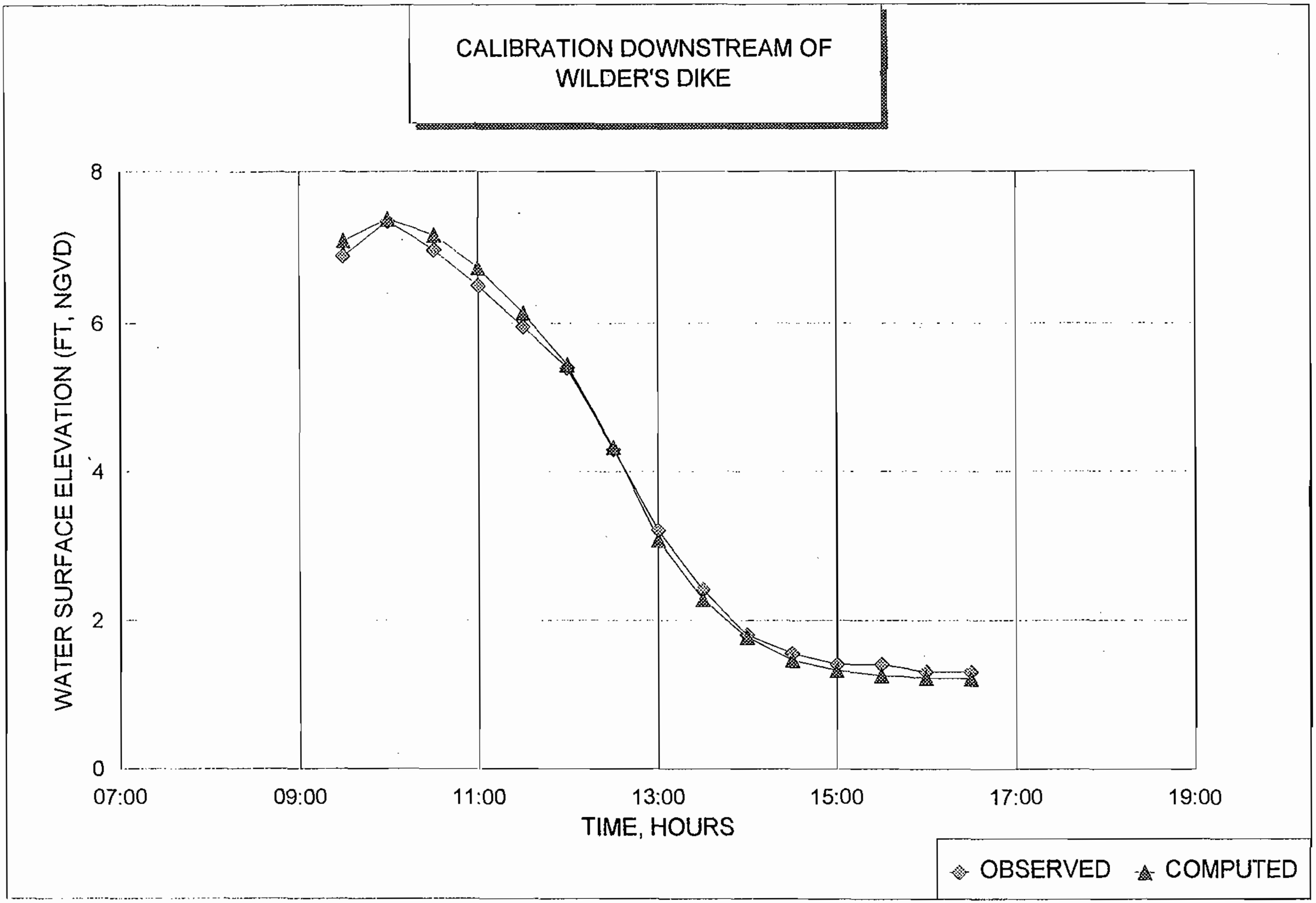

CALIBRATION DOWNSTREAM OF WILDER'S DIKE
WATER SURFACE ELEVATION (FT, NGVD)
8
6
4
2
0
07:00
09:00
11:00
13:00
15:00
17:00
19:00
TIME, HOURS
OBSERVED
COMPUTED

PLATE A-5

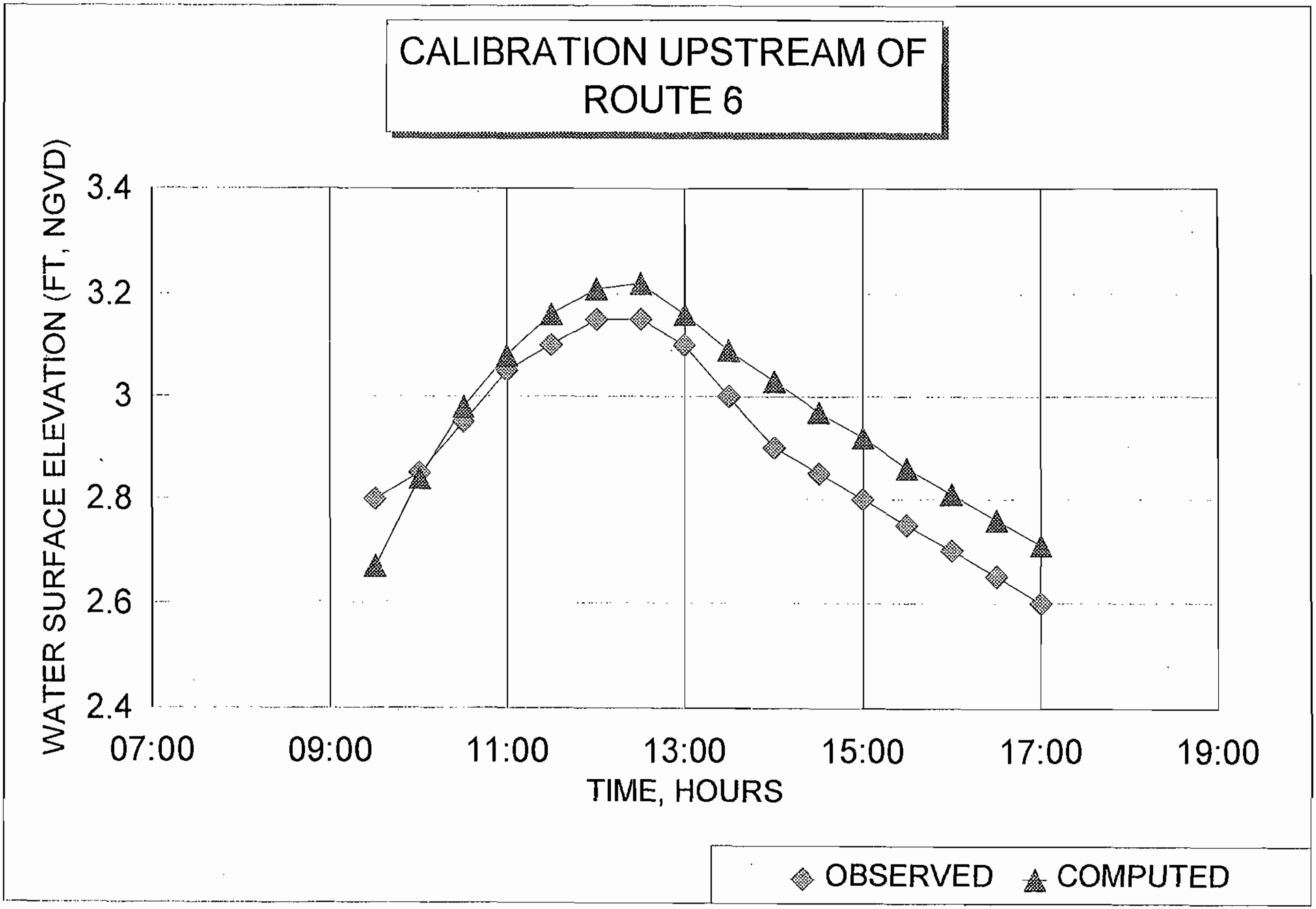
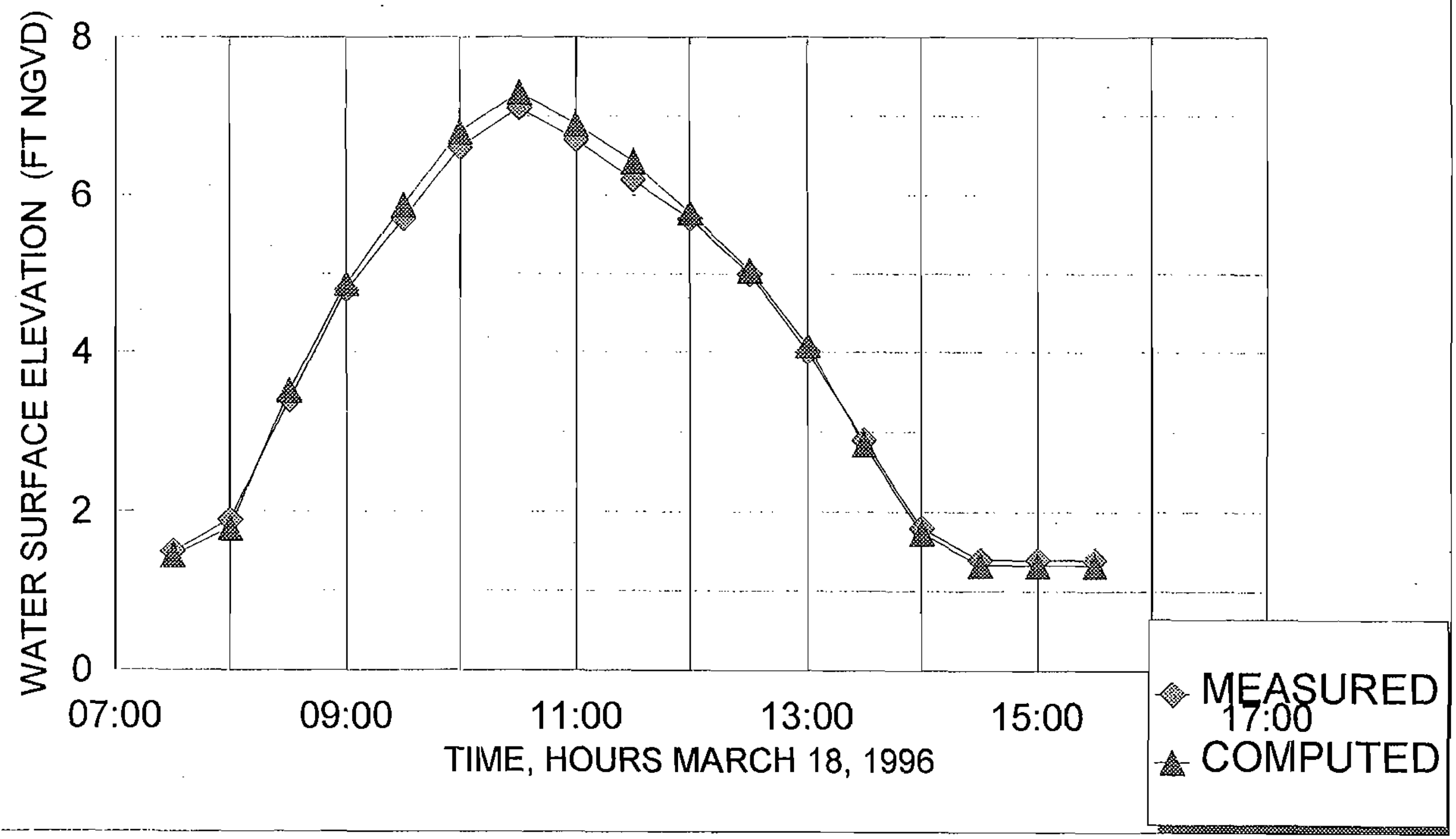

CALIBRATION UPSTREAM OF ROUTE 6
WATER SURFACE ELEVATION (FT, NGVD)
3.4
3.2
3
2.8
2.6
2.4
07:00
09:00
11:00
13:00
15:00
17:00
19:00
TIME, HOURS
OBSERVED
COMPUTED

PLATE A-6

VERIFICATION WEST OF WILDERS DIKE

MARCH 18, 1996



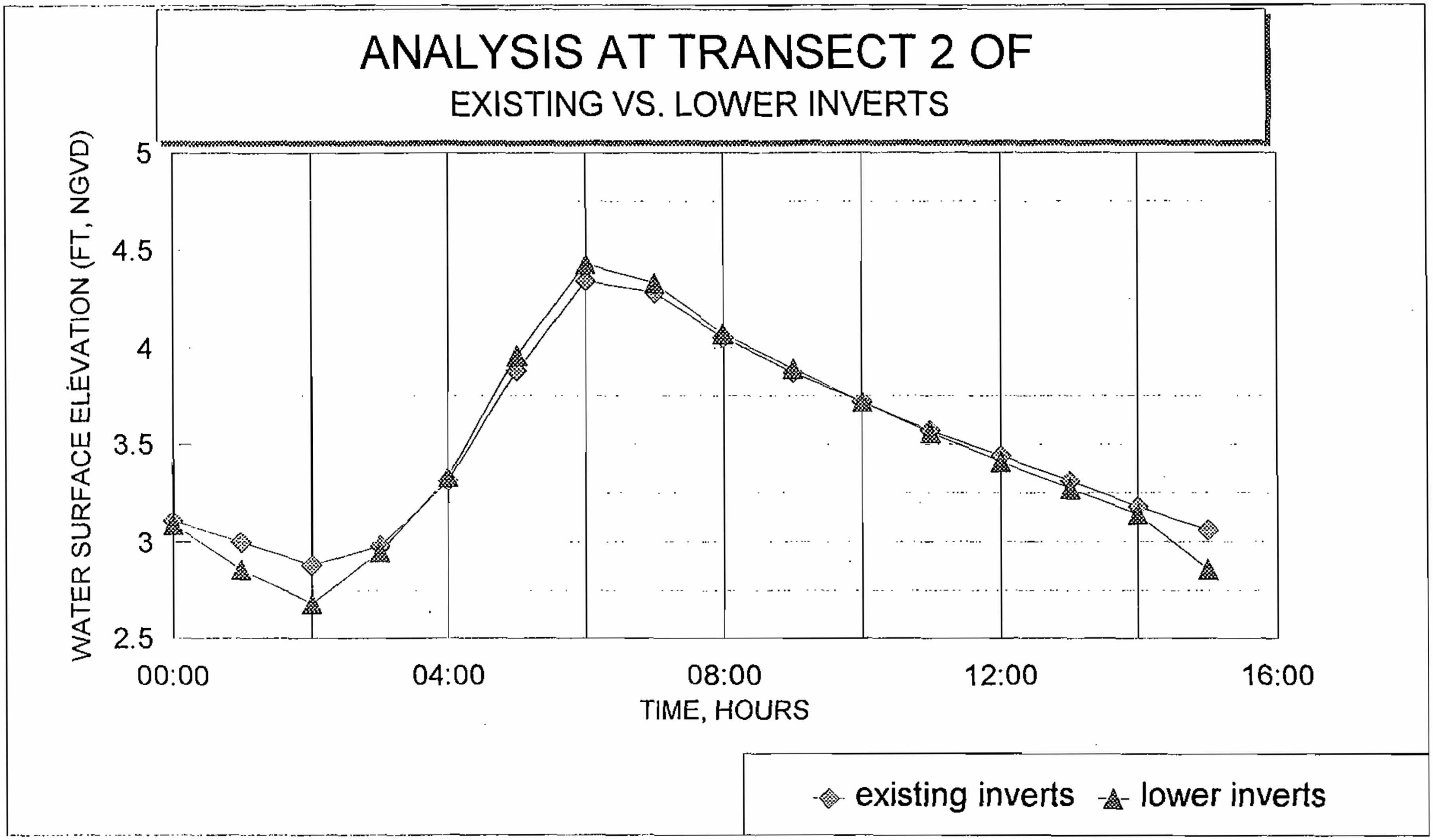

ANALYSIS AT TRANSECT 2 OF
EXISTING VS. LOWER INVERTS
WATER SURFACE ELEVATION (FT, NGVD)
5
4.5
4
3.5
3
2.5
00:00
04:00
08:00
12:00
16:00
TIME, HOURS
existing inverts
lower inverts

PLATE A-8

See Figure 1 of the *Main Report* for the approximate location of Transects.
All Station distances are from south to north.

Transect 1:

Description	Station	Elevation (Ft., NGVD)
Dirt Ground	-9	3.28
Top Edge of South Bank	0	2.41
Toe of South Bank	3	1.06
Centerline of River	22	0.20

Approximate Width of river = 50'

Transect 2:

Description	Station	Elevation (Ft., NGVD)
Dirt Ground	-8	2.98
Top Edge of South Bank	0	3.08
Toe of South Bank	5	1.08
Centerline of River	17	0.96
3/4 of Way Across River	25	0.96

Approximate Width of river = 37'

Transect 3:

Description	Station	Elevation (Ft., NGVD)
Dirt Ground	-10	2.88
Top Edge of South Bank	0	2.99
Toe of South Bank	2	1.30
Soft Bottom of River	21	0.87

Approximate Width of river = 92'

Transect 4:

Description	Station	Elevation (Ft., NGVD)
Top of Dune @ Fence	0	15.96
Top of Dune	-10	15.59
Toe of Dune	-27	12.15
Sand	-45	10.70
Sand	-75	9.09
Sand	-100	7.89
Sand	-150	6.43

Transect 4: (cont.)

Description	Station	Elevation (Ft., NGVD)
Sand	-200	5.18
Sand	-250	4.07
Sand	-300	3.54
Sand	-350	3.33
Sand	-400	3.54
Sand & Dune Grass	-450	3.66
Edge of River	-479	3.14
Slope	15	15.22
Sand	50	14.39
Sand	100	14.28
Top of Beach	133	14.18
Sand	150	12.34
Sand	200	7.42
Sand	251	-0.08

Transect 5:

Description	Station	Elevation (Ft., NGVD)
Marsh	0	5.81
Marsh	162	4.38
Marsh	195	4.48
South edge of River	289	2.68
Centerline of River	302	0.16
North edge of River	314	2.26
Marsh	324	4.68

Approximate Width of river = 25'

Transect 6:

Description	Station	Elevation (Ft., NGVD)
S. Edge of Salt Marsh	0	5.71
Marsh	300	5.18
Marsh	703	5.36
Top of bank, S. Side	743	4.21
Bottom of bank, S. Side	744	2.71
Centerline of River	760	-0.39
Bottom of bank, N. Side	770	2.51
Top of bank, N. Side	777	4.11
N. Edge of Salt Marsh	945	5.81

Approximate Width of river = 26'

APPENDIX B

ENVIRONMENTAL REPORT

Pamet River
Truro, Massachusetts

APPENDIX - B

ENVIRONMENTAL REPORT

Prepared by:

Catherine J. Demos
Marine Ecologist

September 1997

TABLE OF CONTENTS

PAMET RIVER ENVIRONMENTAL REPORT

I. Introduction

The U.S. Army Corps of Engineers was requested by the Town of Truro, Massachusetts to conduct an investigation into the impacts of altering the present configuration of the tide gate, culvert, and dike structure (Wilders Dike) located west of Route 6 and the culvert and embankment at Route 6 on the Pamet River. One purpose of the study is to identify and investigate the advantages and disadvantages of reintroducing daily tidal flows to the present freshwater portion of the Pamet River. This particular study effort involves four phases: a) the documentation of the existing freshwater marsh hydrology, vegetation, and functions; b) define a new hydrologic regime which will establish the salt marsh surface area; c) document qualitative changes in or loss of fresh water wetlands environment, including types of vegetation and wildlife which will be displaced or destroyed; and d) qualitatively identify advantages of establishing a saltwater environment. This study is conducted under the authority contained in Section 22, Planning Assistance to States Program.

2. General Environment

The Pamet River is located in the town of Truro at the tip of Cape Cod. The Pamet River is an altered estuarine system composed of three branches (Center for Coastal Studies, 1985). The main stem, Pamet River, extends completely across Cape Cod, approximately 2.5 miles, from Ballston Beach along the Atlantic Ocean to Pamet Harbor in Cape Cod Bay. The Pamet River is flanked by two smaller branches: Little Pamet to the north, and the south branch which forks first to Mill Creek and then continues to Bangs Creek. The system is isolated from ocean waters at its eastern limit by an unbroken barrier beach, but opens to the Cape Cod Bay through a tidal inlet between barrier beaches. Pamet Harbor lies just inside these Cape Cod Bay barrier beaches, where the three branches of the Pamet system join together.

The Pamet River system remained essentially unaltered until the mid-nineteenth century (Center for Coastal Studies, 1985). When the rotting timbers of Wilders Bridge was replaced with solid fill in 1869, the entire eastern portion of the Pamet River was changed from an estuarine to a freshwater environment. Solid fill dikes were used to cross the mouths of Little Pamet, Mill Pond Creek and Bang's Creek for expansion of the railroad in the 1870's. The result of the dikes was to cut off greater portions of the Pamet River to tidal flow. In addition, mosquito control ditches were built in all three branches of the Pamet system to reduce standing pools of water which has resulted in the Pamet River system being separated into 16 different areas with hydraulic alterations (Burns, Schafer, and Waite, 1995). The drainage produced by the ditches and the elevated ridges of rich soil produced a significant reduction in water level and conditions which favored the invasion of upland species.

The Pamet River is considered to be a significant surface water resource to the Town of Truro. Currently, the freshwater head of Pamet River is located approximately 100 yards from the coast at Ballston Beach. From here the Pamet River flows west towards Pamet Harbor. The river does not become tidal until west of Wilders Dike, where a clapper valve prohibits further eastward flow. It is estimated that before Wilders Dike was put in place, the Pamet River remained tidal for as much as three quarters of its length (Burns, Schafer, and Waite, 1995). The freshwater portion of the Pamet River, which is almost entirely contained within the Cape Cod National Seashore, extends from Ballston Beach barrier dune on the Atlantic Ocean to Wilders Dike and is fed by ground water and rainfall runoff (Lewis, 1989). The Cape Cod Commission's (1997) report indicates that 85 percent of the river discharge comes from surface water drains (i.e. mosquito ditches) which carries water across the top of the marsh and discharges it into the river. Field observations combined with the modeling results suggest that the remaining 15 percent of the river flow comes from direct groundwater discharge through highly conductive portions of the river bottom.

The Pamet River system is complex because of its freshwater and marine environments. The intertidal marsh area downstream of Wilders Dike, including the river, covers approximately 229 acres, while the freshwater marsh area upstream of Wilders Dike covers approximately 159 acres (Cape Cod Commission - GIS Dept., in Cape Cod Commission, 1997). The Pamet River has been recognized by Federal agencies, the Commonwealth of Massachusetts, and local agencies as an important natural resource. As such, the upper Pamet River was included as part of the Cape Cod National Seashore in 1961. In 1975, the Pamet River and other Truro shore areas became the first wetlands in the State to be protected by deed restrictions under the Coastal Wetlands Restriction Act, and in 1978 was designated a Scenic River (Pamet River Greenway Committee, 1987). The Cape Cod National Seashore policy is to restore altered habitats to their original state (Reynolds, pers. comm.).

Although the Pamet River appears to be relatively pristine, there are some water quality concerns. A study conducted by Richard G. Lewis, in the summer of 1988, indicated that fecal coliform bacteria counts exceeded the limit for shellfishing throughout the entire summer. Although data collected in the harbor during incoming tide periods was slightly below the shellfishing limits established by the Massachusetts Division of Marine Fisheries, the limit for swimming closure was frequently exceeded at low tide in the river, at all times in the creeks and the entire basin after rain events. Since the levels of fecal coliform were higher during a rain event, it is common to assume that the main source of contamination is due to non-point discharges (Burns, Schafer, and Waite, 1995).

Sources of contamination within the recharge area which potentially threaten this resource include septic systems, road runoff, underground fuel storage tanks, a small "General Business" zone adjacent to Route 6, the sanitary landfill and seepage pits (IEP, Inc., 1985).

Except for the occasional transient bald eagle or peregrine falcon, no Federally-listed or proposed threatened and endangered species under the jurisdiction of the U.S. Fish and Wildlife Service and the National Marine Fisheries Service are known to occur in the project area. Also, no State-listed rare species are known to occur in the vicinity of the project. See the Coordination Appendix.

a. Existing Freshwater Marsh Environment

Eutrophication is a water quality concern within the existing freshwater environment of the Pamet River. The acceleration of eutrophication occurs in the freshwater portions of the Pamet River because of anthropogenic nutrient sources, as well as stagnation of many freshwater areas due to extensive diking and ditching (Burns, Schafer, and Waite, 1995). Currently, pondweed and water lilies strangle some of the freshwater portions of the Pamet River, making navigation, such as canoeing difficult.

During the storm of December 1992, the eastern Pamet River valley was flooded with four feet of sea water. Immediate impacts included plant and algae mortality, oxygen depletion and fish die-offs. However, this portion of the Pamet River appears to have recovered from the overwash event.

Previous studies on Pamet River (Burns, Schafer, and Waite, 1995; Lewis, 1989) indicated possible water quality concerns about high sodium levels in the groundwater above Wilders Dike. The Cape Cod Commission (1997) ground water assessment study documents that the sodium and specific conductance levels within private wells are higher in the downstream portion, where tidal influences occur, than the upstream portion, freshwater area, of Pamet River. The existing sodium and specific conductance characteristics of the upstream, or freshwater portion of the Pamet River, are somewhat lower than Truro as a whole. This indicates that, except for the head of the river near Ballston Beach, saltwater intrusion is not a concern.

During placement of the monitoring wells for the groundwater assessment study, a layer of peat approximately 18 feet below the ground at Ballston Beach and 16 feet below the surface near Route 6 was encountered. The existence of a relatively thick layer of peat (three to five feet) was encountered at numerous sites surrounding the river. Observations of the marsh ecosystem by National Park Service personnel, have indicated that freshwater vegetation overlays freshwater marsh peat, which in turn overlays approximately three feet of salt marsh peat. The peat extends to a depth of 15 feet below the land surface in certain areas, seeming to indicate the result of more than 1,000 years of salt marsh growth prior to the construction of the dike and tide gate structures (Cape Cod Commission, 1997).

Tidal restriction on the Pamet River has not only resulted in the conversion of an estuarine habitat to a freshwater environment, but has also resulted in the submergence of the wetlands upstream of Wilders Dike. Tidal flows also carry sediment which is deposited on the marsh surface. Surveys by Giese, et.al. (1990) show that the marsh elevation upstream of Route 6 has dropped approximately two feet below the marsh downstream Wilders Dike. Surveys by the U.S. Army Corps of Engineers show a drop in elevation upstream of Wilders Dike, but not as extreme.

The Pamet River Greenway Management study conducted in 1987 indicated that the fish population of the freshwater portion of the Pamet River is quite different east of Route 6. Due to the Pamet's poor flow, obstacles (clapper valves at the dikes), and the lack of a pond at the headwaters, there is no active anadromous fish run. However, freshwater fish species spawn in the upper Pamet River such as yellow perch *Perca flavescens*, white perch *Morone americana*, smallmouth bass *Micropterus dolomieui*, bluegills *Lepomis macrochirus*, and tessellated darters *Etheostoma olmstedi*. Pumpkinseed sunfish *Lepomis gibbosus* make numerous spawning depressions throughout the streambed. The upper Pamet River has been stocked with salter brook trout and sea-run brown trout by State Officials.

Wildlife in the study area include snapping turtles and black snakes. Pheasant, bobwhite quail, woodcock, and other game birds are found near the Pamet River. Rabbits, muskrats, raccoons, skunks and fox are still plentiful (Pamet Greenway Management Committee, 1987). Deer find the open woods and plentiful bearberry fruit attractive.

Birds commonly found in the Pamet are green herons *Butorides virescens*, great blue herons *Ardea herodias*, kingfishers *Megaceryle alcyon*, marsh hawks *Circus cyaneus hudsonius*, snowy egrets *Leucophoyx thula*, laughing gulls *Larus atricilla*, black ducks *Anas rubripes*, buffleheads *Glaucionetta albeola*, scoters and yellowlegs *Totanus* spp. (Pamet Greenway Management Committee, 1987). Ospreys frequently migrate through the area and are observed fishing in the marsh (Pamet Greenway Management Committee, 1987).

The diked wetland upstream includes mostly cattails *Typha angustifolia*, *Rhus vernix*, and *Rubus* sp. (Portnoy and Giblin, 1997a). A study conducted by the Center for Coastal Studies in 1985 indicates that there are ten vegetation classes in the Pamet River system. Vegetation classes in the freshwater portion of the Pamet River include:

Cattail/Rush - Cattails *Typha* sp. and reeds *Phragmites australis* predominate in most of this habitat. However, freshwater rushes and sedges can also be found. *Phragmites australis* is found immediately west of Wilders Dike near the Post Office, in-between Wilders Dike and Route 6, and east of Route 6 in a few patches along North and South Pamet Road (Portnoy, pers. comm. 1997).

Shrub Swamp - Sweet pepperbush *Clethra alnifolia,* winterberry *Ilex verticillata,* swamp honeysuckle *Rhododendron viscosum,* leatherleaf *Chamaedaphne calyculata,* highbush blueberry *Vaccinium corymbosum,* and sweet gale *Myrica gale* are the dominant plants of this area as well as the margins of the marshes and woody bogs, and shrub swamps.

Beech/Maple - This habitat is characterized by mesic (moderate moisture) species. In particular the beech *Fagus grandifolia,* and red maple *Acer rubrum* are dominant. Historically, hickory *Carya* and chestnut *Castanea dentata* were probably present and birches *Betula* may have been more common.

Upland Shrub - This habitat includes cherry *Prunus* spp., shadbush *Amelanchier* spp., beach plum *Prunus maritima, Viburnum* spp., blueberry *Vaccinium* spp., huckleberry *Gaylussacia* spp., bayberry *Myrica pensylvanica* and wild rose *Rosa* spp.

b. Existing Salt Marsh Environment

The salt marsh west of Wilders Dike is dominated by typical salt marsh species, the cordgrass *Spartina alterniflora* and salt hay *S. patens.* Glasswort *Salicornia* spp. and other typical marsh vegetation are also included in this category.

The mean tidal range for Pamet River west of Wilders Dike is approximately four feet, according to the tide gage readings obtained for the hydrodynamic model. Salinity ranges from a high of about 26 parts per thousand (ppt) in the harbor to 0 ppt just east of Wilders Dike. The highest salinity levels at Wilders Dike occur one to two hours after high tide, then drops significantly when the clapper valve under Wilders Dike opens about three hours after high tide to allow for the flow of freshwater (Lewis, 1989). Salinity levels at Wilders Dike during high tide are approximately 60 percent or more of the salinity levels in Pamet Harbor (Lewis, 1989). At low tide, the salinity level drops to about one ppt at Wilders Dike for about six hours a day, twice a day. The Pamet River east of Wilders Dike, has no salinity, while, the head of the Pamet River near Ballston Beach has very high salinity readings of 20 ppt (Lewis, 1989). The most likely source of this salinity is from ocean water seeping through the dunes of Ballston Beach at high tide (Cambareri, pers. comm., 1997). However, the salinity levels drop to 0 ppt about 1,000 feet downstream. The Pamet system is sealed off from the sea except for the occasional overwash episodes (1978, 1991, 1992) (Center for Coastal Studies, 1985). The National

Park Service has been using sand fencing to build the dunes along this section of Ballston Beach to reduce these overwash episodes.

Tidal sections of the Pamet support most Cape Cod Bay estuarine species (Pamet River Greenway Committee, 1987). Particular species include winter *Pseudopleuronectes americanus* and summer flounder *Parlichthys dentatus*, bluefish *Pomatomus saltatrix*, menhaden *Brevoortia tyrannus*, eels, and occasionally striped bass *Morone saxatilis*.

3. New Hydrologic Regime Needed

To return a freshwater marsh to salt marsh, the freshwater area must be flooded about eight times per month with seawater. Flooding at eight times per month has been previously considered by the U.S. Army Corps of Engineers as a method to completely eliminate common reed from salt marsh at other project sites such as the Sagamore Marsh (Bourne and Sandwich, Massachusetts), and Galilee Marsh (Narragansett, Rhode Island). Soil salinity of approximately 20 ppt or more is needed to eliminate or prevent the invasion of the common reed *Phragmites australis*. Salt marsh species occur between mean tide level and spring high tide levels, depending on site specific conditions. A survey of the salt marsh was used for comparison to determine what hydrologic regime should occur to establish a salt marsh environment east of Wilders Dike.

Pamet River is restricted midway by a tide gate culvert under Wilders Dike and a culvert under Route 6. To determine tide levels and ranges along the Pamet River, tide gages were installed at: 1) Pamet Harbor, 2) west of Wilders Dike, and 3) east of Route 6. Tide monitoring data was collected on November 21, 1995 and March 18, 1996 for almost 12 hours during spring tides. Readings collected in November 1995 were taken with the tide gate open to provide information on the hydraulic capacity of the existing culverts under Wilders Dike and Route 6.

The tide gage readings on November 21, 1995, show a delay of about an ½ hour in the tidal peak from Pamet Harbor to Wilders Dike, with another two hour delay upstream of Route 6. The tidal range is reduced by 4.2 feet upstream of Wilders Dike as compared to downstream. See Table 1. This data shows that, even with the tide gate open, Wilders Dike and Route 6 are still a major tidal restriction.

The tide gate under Wilders Dike was left closed (normal condition) during the March 1996 tidal readings. Tide range readings ranged from about -1.0 to 7.3 feet NGVD for Pamet Harbor, 1.4 to 7.1 feet NGVD west of Wilders Dike, and 1.5 to 2.1 feet NGVD east of Route 6. Results between the November 1995 readings (Table 1) and the March 1996 readings show similar tide range readings west of Wilders Dike and in Pamet

Harbor. With the tide gate open, the tide levels rose to 3.15 feet NGVD east of Route 6, compared to 2.1 feet NGVD with the gates closed. Therefore, the dike and Route 6 culverts account for at least a 1.05 feet of reduction in tidal range.

Four elevation surveys were also taken in November 1995 by the U.S. Army Corps of Engineers east of Route 6. On May 28, 1997, staff from U.S. Army Corps of Engineers took additional elevations along two transects on the west side of Wilders Dike across the salt marsh. The transects ran from north to south and crossed the Pamet River. Elevation changes were noted at salt marsh vegetation transition zones and tidal creeks. Refer to Figure 1 for location of transects sampled by the U.S. Army Corps of Engineers.

Figures 2 and 3 show salt marsh vegetation west of Wilders Dike occurring between elevations 2.26 feet NGVD (the lower limit of salt marsh cordgrass) and 5.81 feet NGVD (the upper limit of high marsh vegetation). Based on the tide gage readings at Wilders Dike, it appears that the salt marsh vegetation west of Wilders Dike would extend further laterally, and vertically, if the boundary of the high landforms surrounding the marsh did not prevent encroachment. This means that the maximum lateral extent of tidal flow on vegetation is unknown.

In general, the three transects taken by the U.S. Army Corps of Engineers east of Route 6 show the river bottom to be slightly higher than 0 feet NGVD (.20 to .96 feet). The fourth transect taken across Ballston Beach to the mouth of Pamet River show that the head of Pamet River is higher at 3.14 feet NGVD. The top of the river banks and the level ground adjacent to the river east of Route 6 are located at about 3 feet NGVD. Survey transects did not extend to the slope of the bank. Marsh and river bottom elevation surveys were taken along the tidal portion of Pamet River in 1990 by Geise, et.al. A difference of about two feet was found in the elevation between the downstream and upstream portions of the Pamet River. Two reasons are given for the subsidence of the freshwater marsh upstream of Route 6 (Geise, et.al., 1990). The first reason is the lack of access to a supply of sediment from tides which could allow the marsh to keep pace with sea level rise. The second reason is that drainage of interstitial water from salt marsh peat that is no longer flooded by spring tides can cause compaction.

Alternatives to increase tidal flow through Wilders Dike and Route 6 include replacing the culverts under Route 6 and Wilders Dike with larger-sized culverts to drain overwash flooding from Ballston Beach and increase tidal flows. This would increase tidal flows to the freshwater portion of the Pamet River. Or for maximum tidal flow, both structures could be removed and replaced with bridges.

TABLE 1

Tide Gage Readings From Pamet River with Wilders Dike Tide Gate Open For Spring Tide (in feet NGVD)

November 21, 1995

TIME	PAMET HARBOR	WEST OF WILDERS DIKE	EAST OF ROUTE 6
0930	7.40	6.90	2.80
1000	7.15	7.35	2.85
1030	6.60	6.97	2.95
1100	5.85	6.50	3.05
1130	4.90	5.95	3.10
1200	3.90	5.40	3.15
1230	2.80	4.30	3.15
1300	1.90	3.20	3.10
1330	1.20	2.40	3.00
1400	0.60	1.80	2.90
1430	0 .00	1.55	2.85
1500	-0.40	1.40	2.80
1530	-0.65	1.40	2.75
1600	-0.82	1.30	2.70
1630	-1.00	1.30	2.65
1700	-1.10	1.30	2.60

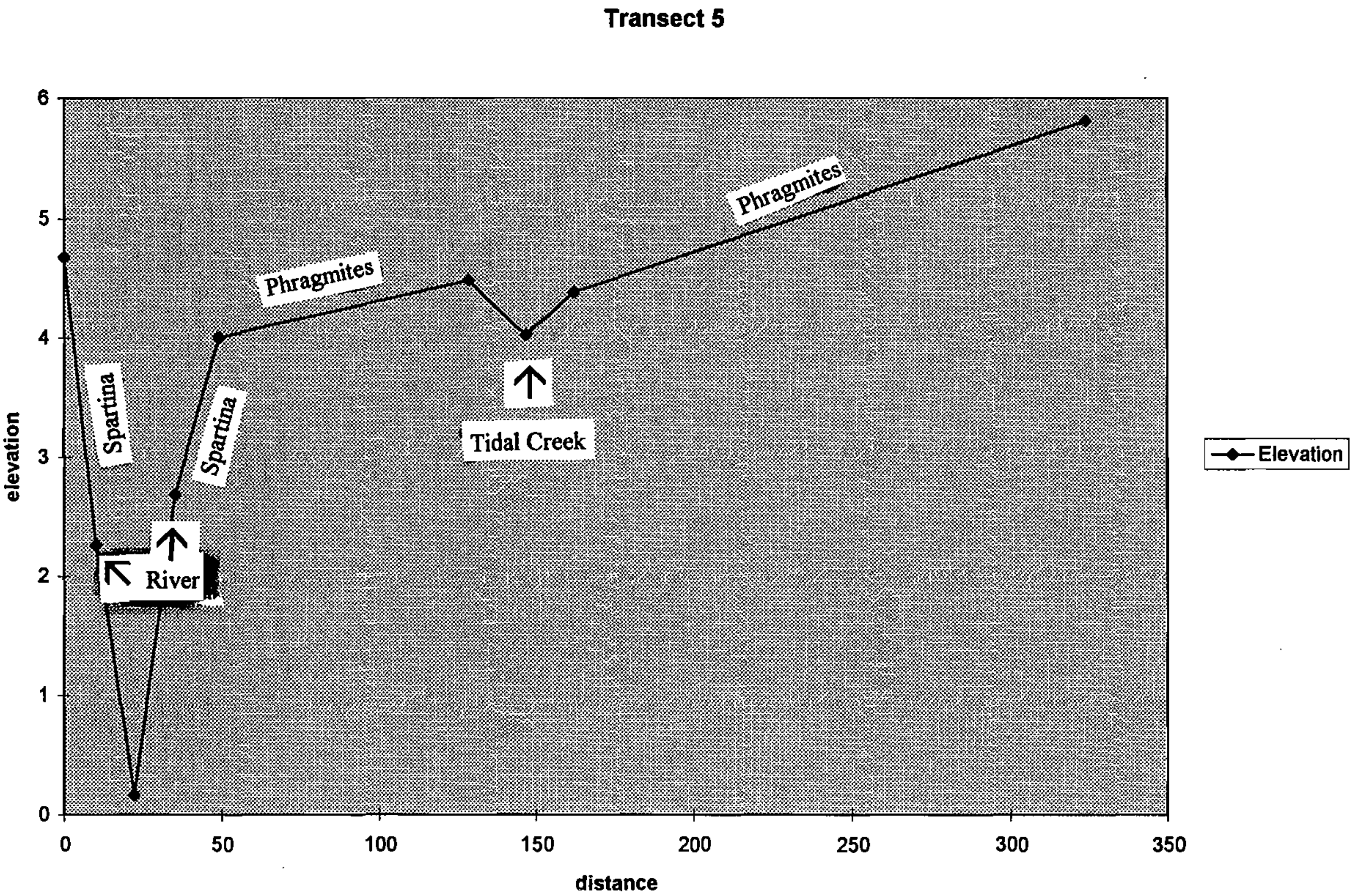


FIGURE 2

Transect 5 - Elevation in Feet

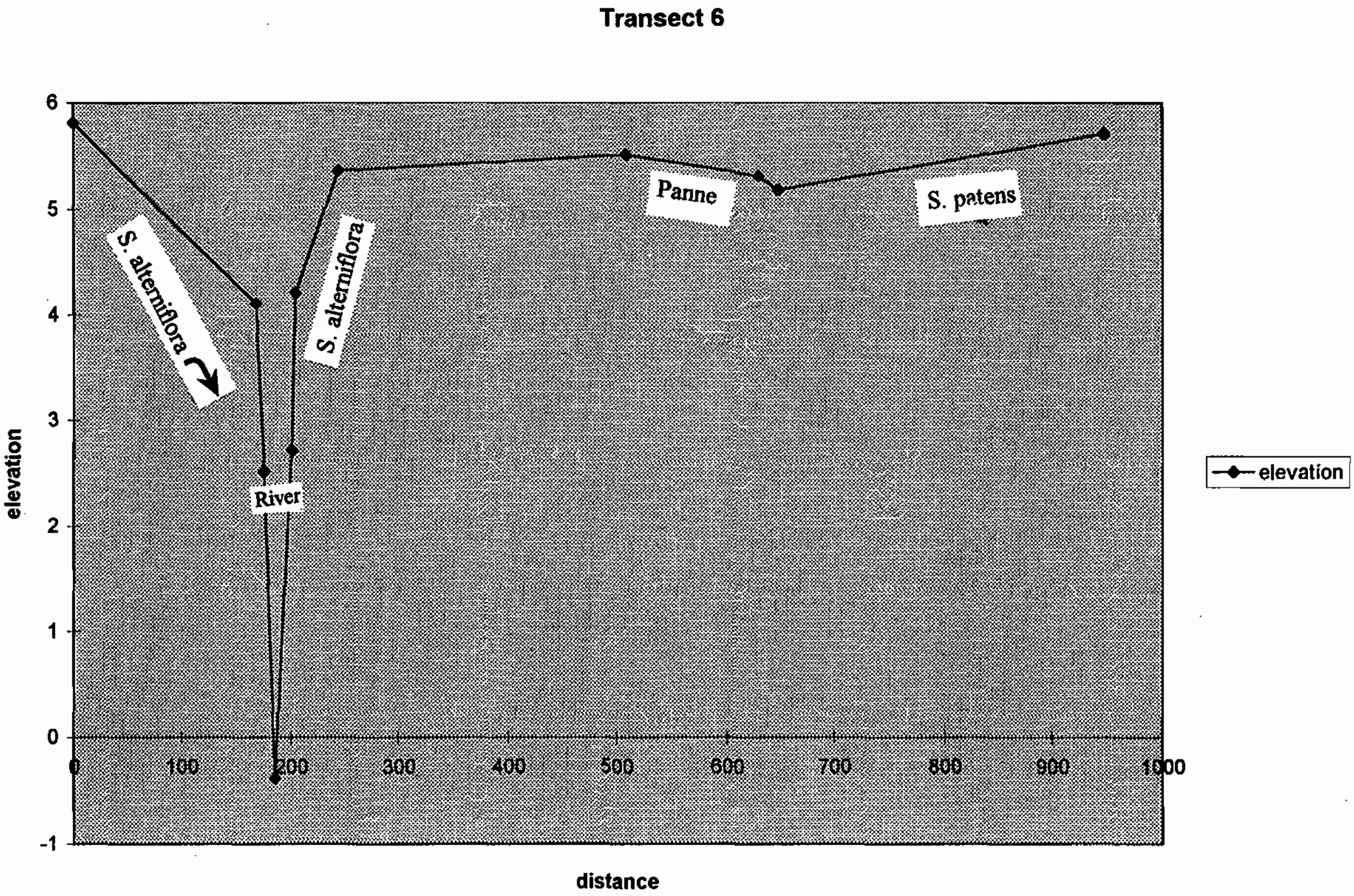


FIGURE 3

Transect 6 - Elevation in Feet

Table 2 displays the spring tide water surface elevations at various locations for each culvert and bridge design for flooding eight times per month. Based on hydrologic modeling performed by the Corps, opening Wilders Dike and Route 6 to full tidal flow would increase the tide levels east of Route 6 to a spring low tide of 2.6 and a spring high tide of 5.4 feet NGVD. Bridges would need to be constructed to replace Wilders Dike and Route 6 to obtain this tidal flow.

4. Change From Freshwater Wetlands to an Estuarine Environment

Pamet River begins 100 yards from the ocean as a freshwater stream and flows towards the bay. As mentioned above, the river becomes tidal west of Wilders Dike, and was probably tidal for as much as three-quarters of its length before Wilders Dike was built. Plant diversity is much higher in tidal freshwater marshes than in higher salinity estuarine marshes (Odum, et.al., 1984).

The obvious physical changes to increasing the dike opening is to create a tidal range where one does not currently exist, and to increase the salinity level upstream of the dike. The tide range would increase over 1.1 feet if a 4 foot by 12 foot (height x width) box culvert is installed and by over two feet if a bridge is constructed (refer to Tables 1 and 2). Because of the expected dilution of seawater in this portion of the Pamet River, salinity levels would be expected to be lower than the downstream levels. Salinity levels above the dike would show a gradient from more marine to freshwater conditions the farther one travels upstream.

With the new tidal energy in the freshwater portion of Pamet River, changes to the physical, as well as the biological community, would occur. Changes that might occur to the substrate include the introduction of more sand, lower organic content, higher peat and root content, and higher dissolved oxygen (Odum, et.al., 1984). In addition, the higher water surface levels created with a larger culvert, may have a minor effect on the amount of ocean water seeping through the dunes at Ballston Beach. Because the high tide level on the ocean side would still be higher than the water level at the head of the Pamet River, a gradient would still be created which would cause some ocean water to still seep through the dunes.

Species composition of a marsh is partly dependent on the salinity regime of the habitat. The variability and complexity of wetland plant communities increases with decreasing salinity (Odum, et.al., 1984). Tidal freshwater habitat should not encounter average water salinities greater than 0.5 ppt, as marshes which intermittently come into contact with elevated water salinities may contain slightly less diverse plant communities which are dominated by facultative halophytes (Odum, et.al., 1984). Regular inundation in tidal freshwater regimes extends the lateral boundaries of this habitat, unlike nontidal riverine wetlands (Odum, et.al., 1984). Salinity regime for typical salt marsh species such as *Spartina alterniflora* and *Spartina patens* range from about 10 ppt and higher.

TABLE 2

Water Surface Elevations for Various Culvert Sizes at Each Crossing (for Spring Tide in Feet NGVD)

CULVERT SIZE (FT) (Height x Width)	PAMET HARBOR (high)	WEST OF WILDERS DIKE (high, low)	EAST OF ROUTE 6 (high, low)	BETWEEN RT. 6 & BALLSTON (high, low)	BALLSTON BEACH
Existing Gate Open	6.40	6.10 2.70	3.35 2.80	3.30 2.90	3.30
4 x 6	6.40	6.10 1.90	3.60 2.60	3.50 2.70	3.40
4 x 8	6.40	6.10 2.10	4.00 2.60	3.80 2.70	3.50
4 x 10	6.40	6.00 2.30	4.40 2.60	4.00 2.70	3.80
4 x 12	6.40	6.00 2.40	4.50 2.60	4.10 2.75	3.90
4 x 16	6.40	5.90 2.50	4.70 2.60	4.30 2.80	4.10
4 x 20	6.40	5.80 2.50	4.90 2.65	4.40 2.80	4.10
6 x 6	6.40	6.10 2.00	4.20 2.80	3.90 2.90	3.80
6 x 8	6.40	6.00 2.20	4.60 2.70	4.10 2.85	4.00
6 x 10	6.40	5.90 2.30	4.75 2.60	4.30 2.85	4.10
6 x 12	6.40	5.90 2.30	4.90 2.60	4.40 2.85	4.20
6 x 16	6.40	5.90 2.30	5.00 2.50	4.60 2.85	4.20
6 x 20	6.40	5.70 2.40	5.10 2.60	4.65 2.85	4.30
8 x 8	6.40	6.00 2.20	4.60 2.70	4.20 2.85	4.00
8 x 10	6.40	5.90 2.30	4.80 2.60	4.40 2.85	4.10
8 x 12	6.40	5.80 2.30	4.90 2.60	4.50 2.85	4.20
8 x 16	6.40	5.70 2.40	5.00 2.60	4.60 2.85	4.20
8 x 20	6.40	5.70 2.40	5.10 2.60	4.65 2.85	4.30
10 x 10	6.40	5.70 2.40	5.00 2.50	4.50 2.80	4.20
10 x 12	6.40	5.60 2.40	5.10 2.55	4.65 2.85	4.30
10 x 16	6.40	5.50 2.40	5.20 2.50	4.70 2.85	4.30
10 x 20	6.40	5.50 2.40	5.30 2.50	4.75 2.80	4.30
Bridge	6.40	5.55 2.60	5.40 2.60	5.00 2.85	4.60

Table 3 displays the mean high water levels at various locations along Pamet River for existing conditions, with the tide gate open, and with various culvert configurations constructed through Wilders Dike and Route 6. Salt marsh species would be expected to occur up to the highest astronomic tide levels or mean spring high water, where salinity levels are highest. *Spartina alterniflora* is known to occur 98 percent of the time at or below the mean high water level, while over 70 percent of the time *S. patens* is found above mean high water (Kennard, et.al., 1983). The hydrodynamic model performed by the Corps shows a small tidal range, even at the head of the Pamet River. The spring tide level for Ballston Beach with the existing gate open would be 3.3 feet NGVD, but would increase to 4.6 feet NGVD with the construction of bridges. See Table 2 for various spring high tide levels at Ballston Beach.

Some of the freshwater vegetation along the banks of the Pamet River may become submerged with the opening of the tidal restrictions. Transects taken upstream show the top of the river bank at elevations 2.41, 3.08, and 2.99 feet NGVD for transects 1, 2, and 3, respectively (see transects (Profiles) 1 - 4). Predicted low spring water elevations for the installation of 4 foot by 12 foot box culvert is 2.6, 2.7 and 3.5 feet NGVD for transects 1, 2 and 3 respectively (Table 2). This indicates that some areas will stay submerged, even during a low spring tide.

Based on the fact that some of the area above the river bank may stay flooded, it is advisable to construct a culvert opening that would minimize ponding. Box culvert sizes with the lowest low tide levels are the 6 foot by 16 foot, 10 foot by 10 foot, 10 foot by 16 foot, and 10 foot by 20 foot (see Table 2). However, these same culverts also provide some of the highest high tide levels, thereby creating a larger tide range.

Tidal freshwater wetlands are located upstream from tidal saline wetlands (salt marshes) and downstream from nontidal freshwater wetlands. They are characterized by near freshwater conditions (average annual salinity of 0.5 ppt or below except during periods of a drought), freshwater species, and daily lunar tidal fluctuation (Odum, et.al., 1984). It is probable that the upper limit of Pamet River may experience characteristics of a tidal freshwater wetlands if the culverts are significantly enlarged. Organisms in the tidal freshwater marsh include freshwater snakes, turtles, adult and larval insects, ducks, geese, and muskrats. Fauna of the tidal freshwater marsh reveals few bivalves, crustaceans or polychaetes, organisms which dominate the higher salinity marshes in the lower estuary (Odum, et.al., 1984). Tidal freshwater marshes in New England contain conspicuous perennial sedges and grasses, with reed bentgrass, various rushes and sedges, arrowheads, cattails, and spiked loosestrife evident (Odum, et.al., 1984). Subtidal species could include pondweeds, waterweed, and hornwort; lower intertidal species include arrowheads, seedbox, and bulrushes; mid-tidal marsh border species contain bulrushes,

TABLE 3

Water Surface Elevations Within the Pamet River (at Mean Tide Range in feet NGVD)

CULVERT SIZE (FT) (Height x Width)	PAMET HARBOR (high)	WEST OF WILDERS DIKE (high, low)		EAST OF ROUTE 6 (high, low)		BETWEEN RT. 6 AND BALLSTON (high, low)		BALLSTON BEACH
Existing	5.30	5.20	*	2.20	*	*	*	3.00
Existing with Gate Open	5.30	5.20	1.20	2.70	2.40	3.00	2.50	3.20
4 x 6	5.30	5.10	1.70	3.30	2.35	3.20	2.45	3.20
4 x 8	5.30	4.90	1.80	3.55	2.20	3.30	2.40	3.30
4 x 10	5.30	4.80	1.90	3.70	2.20	3.40	2.40	3.40
4 x 12	5.30	4.80	1.90	3.80	2.20	3.50	2.40	3.50
4 x 16	5.30	4.70	1.90	3.90	2.10	3.50	2.40	3.50
4 x 20	5.30	4.70	1.90	3.95	2.10	3.60	2.40	3.50
6 x 6	5.30	5.00	1.80	3.50	2.40	3.30	2.50	3.30
6 x 8	5.30	4.80	1.90	3.70	2.30	3.40	2.45	3.40
6 x 10	5.30	4.70	1.90	3.85	2.20	3.50	2.40	3.50
6 x 12	5.30	4.70	1.90	3.90	2.20	3.50	2.40	3.50
6 x 16	5.30	4.70	1.90	4.00	2.10	3.60	2.40	3.55
6 x 20	5.30	4.60	1.90	4.00	2.10	3.60	2.40	3.55
8 x 8	5.30	4.80	1.90	3.70	2.30	3.40	2.50	3.40
8 x 10	5.30	4.70	1.90	3.80	2.20	3.50	2.40	3.50
8 x 12	5.30	4.70	1.90	3.90	2.20	3.55	2.40	3.50
8 x 16	5.30	4.65	1.90	4.00	2.10	3.60	2.40	3.55
8 x 20	5.30	4.60	1.90	4.00	2.00	3.60	2.40	3.60
10 x 10	5.30	4.60	1.90	4.00	2.10	3.60	2.40	3.55
10 x 12	5.30	4.60	1.90	4.00	2.10	3.60	2.40	3.60
10 x 16	5.30	4.60	1.90	4.10	2.10	3.60	2.40	3.60
10 x 20	5.30	4.60	1.90	4.10	2.10	3.60	2.40	3.60
Bridge	5.30	4.80	2.30	4.60	2.40	4.00	2.60	3.90

* Readings not applicable or available

water hemp, water parsnip, sneezeweed, smooth burmarigold, wild rice, pickerelweed, and arrowheads; the high marsh would be comprised of sweetflag, cattail, swamp rose, reed bentgrass; and the upland may contain red maple, water willow, and arrow-wood.

Opening Wilders Dike and Route 6 to tidal flow would displace much of the freshwater wetlands currently existing in the upper portion of the Pamet River. The degree of displacement will depend on the culvert size selected. However, some comparison between salt marsh, tidal freshwater, and freshwater biological communities can be made to assist in determining the best course of action. It should be noted that the characteristics at a particular location, for estuarine and tidal freshwater systems, can vary and fluctuate on a daily, seasonal, and yearly basis. Estuarine flora is generally less diverse, has a more pronounced macrophyte zonation, moderate level of estuarine and marine invertebrate (other than insects) diversity, and slightly higher decomposition rate for intertidal vascular plants (Odum, et.al., 1984). Annual primary productivity is suspected to be comparable between salt marshes and tidal freshwater systems, while nontidal freshwater systems may have reduced primary productivity. Salt marshes are generally known to produce and export high organic material important to estuarine systems. Odum, et.al., 1984, hypothesizes that the presence of tidal energy might encourage higher primary productivity in tidal freshwater marshes than in nontidal freshwater marshes.

5. Conclusions

Significant changes to any ecosystem can have a variety of benefits and impacts. The purpose of a restoration project is to provide significantly more ecological benefits than costs. Since the construction of Wilders Dike and Route 6, the tidal flow in the upstream portion of Pamet River has been interrupted. The vegetation in this area has undergone several successional stages since that time. The stages have succeeded from cattail marsh, to shrub swamp vegetation, and is presently being rapidly replaced by upland shrub species of cherry, shadbush, and bayberry (Center for Coastal Studies, 1985).

Introduction of tidal flows in the upper portion of the Pamet River would restore previously existing conditions. Based on the water surface elevations predicted from the hydrologic model and the transect surveys taken upstream, salt marsh vegetation would be expected to replace the freshwater vegetation upstream of Route 6 to the level of the spring high water surface elevation. Table 3 gives the expected mean high and mean low levels for each culvert alternative, based on the hydrodynamic model. *Spartina alterniflora* would be expected to dominant the lower portion of the Pamet River from mean high water to the mean tide level and below. *Spartina patens* and other salt marsh species would succeed the freshwater species between about the mean high water level and the spring high tide.

The replacement of freshwater species with salt marsh species would diminish the further one traveled upstream. The head of the Pamet River occurs at Ballston Beach. Freshwater would dilute the salinity of the sea water. Although it was suspected that the tidal influence only reached about 3/4 of the length of the Pamet River before Wilders Dike and Route 6 were constructed, the hydrodynamic model indicates that some tidal influence and possibly saline water (other than the seepage through Ballston Beach dunes) would reach the head of Pamet River.

Advantages to restoration of a salt water ecosystem upstream of Wilders Dike is the introduction of estuarine species and the return of tidal energy to the freshwater marsh. As stated above, this would increase primary productivity in the estuarine system. The lateral extent of salt marsh vegetation would be dependent on the adjacent topography. If upland vegetation is rapidly overtaking the shrub swamp community, then the increased tidal range might help offset this encroachment and increase the amount of wetlands. Increased tidal flows and flushing would help remove contaminants, increase the biological productivity of the Pamet River watershed, increase the exchange of particulate and dissolved nutrients to the estuarine environment, and deposit inorganic material which may eventually elevate the marsh. In addition, concerns about overwash from Ballston Beach would be reduced. Seawater from the overwash events would drain more quickly (in a few days) from the area.

The disadvantages to restoring the tidal flow to the upper portion of Pamet River is the decay and death of freshwater species which are not tolerant of saline waters, and the loss of primary production during this transition phase. The greatest change would occur closest to Route 6. The transition phase from a freshwater to salt water ecosystem would be expected to take a few years. Several studies (Bongiorno, et.al, 1984; Sinicrope, et.al., 1990; Roman, et.al., 1984) document changes in vegetation by the end of the first year or several years later when a restricted marsh was restored. These studies discuss restricted marshes, but not salt marshes that reverted to a freshwater marsh. In this case, it might be expected to take longer for this transition to occur in the Pamet River. In addition, concerns about overwash from Ballston Beach would be reduced if tidal influences reach the head of Pamet River. Plant composition would be expected to change from opening the upper Pamet River to oceanic influences based on the level of salinity in the water and soil. Vegetation accustomed to bracish conditions may be able to sustain the periodic overwash. However, if tidal influences do not reach the head of the Pamet River then these overwash episodes could continue to impact this area.

The invasion of *Phragmites australis* may occur in areas where there is a transition from high salinity to freshwater. (Generally, biologists do not consider *Phragmites australis* to be as biologically productive as salt marsh species). Additional studies may be needed to determine the salinity levels at various locations in the upper part of the Pamet

River for selected culvert sizes. The invasion of *Phragmites* may be limited by reducing impacts from storm events which would carry saline water into the higher elevations which would not normally be inundated.

Besides the concerns regarding invasion of *Phragmites australis,* the introduction of saline water to the freshwater portion of the Pamet River may cause subsidence (Portnoy and Giblin, 1997). Sediment subsidence are likely the result of the death and decomposition of plant roots and rhizomes under salt stress. Due to the existing subsidence east of Route 6 and the potential for additional subsidence with the introduction of salt water to the upper portion of the Pamet River, ponding is a concern for any alternative selected.

If the existing culverts are kept in place with the tide gate permanently open, a pond would be created immediately east of Route 6 (see Tables 3 and 4). Minimal or no ponding would occur between Route 6 and Ballston Beach, but some minor ponding would occur at Ballston Beach. It is important to select an alternative that would minimize ponding to realize the greatest ecological benefit. Culvert sizes that produce the greatest tidal range, also seem to create the largest ponding effect at Ballston Beach. It may take many decades before enough inorganic material is introduced to the system to build the surface elevations to minimize ponding. Additional surveys east of Route 6 which give the topography from the river bank to upland areas may help determine more precisely the amount of ponding that could occur.

Recovery of the upper Pamet River will depend on seed source, changes in surface elevations, tidal amplitude and duration of disturbance (Bongiorno, et.al., 1984). The decision to restore Pamet River may depend on the amount of change the municipality is willing to accept. The larger the culvert size and associated tidal exchange, the greater the potential for restoration; if issues concerning the invasion of *Phragmites australis* and ponding associated with subsidence are resolved.

6. References

Bongiorno, S.F., J.R. Trautman, T.J. Steinke, S. Kawa-Raymond, D. Warner. 1984. A Study of Restoration in Pine Creek Salt Marsh, Fairfield, Connecticut. Proceedings of the Eleventh Annual Conference on Wetlands Restoration and Creation. F.J. Webb, Editor, Hillsborough Community College, Tampa, Florida.

Burns, Antoinette, William Schafer, and Andrew Waite. 1995. Pamet River and Estuary Assessment, a major qualifying project report submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science. Project Number: CE-PPM-9502.

Cambareri, Thomas. September 9, 1997. Personal Communication. Cape Cod Commission.

Cape Cod Commission. 1997. Pamet River Investigation Groundwater Assessment Study, Groundwater Impacts Associated with the Removal of the Tide Gate and Dike Structures, Final Report. Prepared by: E.M. Eichner, T.C. Cambareri, K. Livingston, B. Sobczak, and B. Smith, Cape Cod Commission, Water Resources Office.

Center for Coastal Studies. 1985. A Brief History of the Pamet River System with Recommendations for Environmental Studies and Accompanied by Two Maps. A report submitted to the Truro Conservation Trust and the National Park Service. Center for Coastal Studies, 59 Commercial Street, Provincetown, MA.

Giese, G.S., C.T. Friedrichs, D.G. Aubrey, and R.G. Lewis II. 1990. Application and Assessment of a Shallow-Water Tide Model to Pamet River, Truro, Massachusetts. Woods Hole Oceanographic Institution and Massachusetts Institute of Technology.

IEP, Inc. 1985. Water Resources Protection Plan for the Town of Truro, Massachusetts. Prepared under a Grant from: The Massachusetts Executive Office of Communities and Development for the Town of Truro, MA. Prepared by: IEP, Inc. 3179 Main Street, Box 434, Barnstable, MA.

Kennard, W.C., M.W. Lefor, and D.L. Civco. 1983. Analysis of Coastal Marsh Ecosystems: Effects of Tides on Vegetation Change. Prepared for the U.S. Department of the Interior, Research Project Technical Completion Report B-014 CONN.

Lewis, Richard G. 1989. Pamet River Study - 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.

Odum, W.E., T.J. Smith III, J.K. Hoover, and CC. McIvor. 1984. The Ecology of Tidal Freshwater Marshes of the United States East Coast: A Community Profile. U.S. Fish Wildl. Serv. FWS/OBS-83/17. 177 pp.

Pamet River Greenway Committee. 1987. Final Pamet River Greenway Management Plan. Truro Conservation Trust, North Truro, Massachusetts.

Portnoy, John. September 8, 1997. Personal Communication. Cape Cod National Seashore.

Portnoy, J.W. and A.E. Giblin. 1997. Biogeochemical Effects of Seawater Restoration to Diked Salt Marshes. Ecological Applications, 7(3), pp. 1054-1063.

Portnoy, J.W. and A.E. Giblin. 1997a. Effects of Historic Tidal Restrictions on Salt Marsh Sediment Chemistry. Biogeochemistry, 36, pp. 275-303.

Reynolds, Mike. September 8, 1997. Personal Communication. Cape Cod National Seashore.

Roman, C.T. W.A. Niering, R.S. Warren. 1984. Salt Marsh Vegetation Change in Response to Tidal Restriction. Environmental Management, vol. 8, pp. 141-150.

Sinicrope, T.L., P.G. Hine, R.S. Warren, W.A. Niering. 1990. Restoration of an Impounded Salt Marsh in New England. Estuaries, vol. 13, pp. 25-30.

COORDINATION APPENDIX

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
NORTHEAST REGION
One Blackburn Drive
Gloucester, MA 01930

JUL 3 1996

Mr. Joseph L. Ignazio
Director of Planning
Impact Analysis Division
Army Corps of Engineers. New England Division
424 Trapelo Road
Waltham, MA 02254-9149

Dear Mr. Ignazio:

This letter is in response to the Section 22-Planning Assistance to States Study to investigate the impacts of removing the tide gate and dike structure located at Route 6 on the Pamet River in Truro, Massachusetts. Several alternatives, including removal of the dike and enlargement or addition of new culverts will be evaluated to restore a large area of marsh and estuarine habitat that was converted to a fresh water habitat when the tide gate was installed. At this time the National Marine Fisheries Service (NMFS) does not have adequate information to allow us to provide substantive comments on this study, but we do support restoration of former marine habitat whenever possible.

We conducted a site visit to the Pamet River on April 18. 1996. During this visit we observed a large area of common reed (Phragmites australis) growing just above the tide gate. Presence of common reeds is indicative of a degraded wetland habitat and because of the low ecological value offered by this species. we recommend that your study investigate the opportunity to eradicate this species by allowing the influx of tidal water. However, because this species is relatively salt tolerant, it is equally important to investigate any post-project expansion of common reeds into new sections of the Pamet River due to insufficient tidal flow.

No endangered or threatened species under the jurisdiction of NMFS are present within the project area. Further consultation under Section 7 of the Endangered Species Act will not be necessary. However, should project plans change, or should new information become available which modifies the basis for this determination, consultation should be reinitiated.

We will provide more specific comments and recommendations when the study is complete. If you have any questions pertaining to this letter, please contact Eric W. Hutchins at (508) 281-9313.

Sincerely,

Christopher Mantzaris
Chief, Habitat and Protected
Resources Division

cc: Phil Morrison, USFWS (Concord, NH)
Ed Reiner, USEPA (Boston, MA)

File: 1503-07 (MA) Truro
Pamet River Section 22 Study

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION I
JOHN F. KENNEDY FEDERAL BUILDING
BOSTON, MASSACHUSETTS 02203-0001

June 21, 1996

Mr. Joseph L. Ignazio
Director of Planning, Planning Directorate
Impact Analysis Division
New England Division, Corps of Engineers
424 Trapelo Road
Waltham, MA 02254-9149

Re: Pamet River, Truro, Massachusetts Section 22 - Planning Assistance to States Project

Dear Mr. Ignazio:

Ed Reiner of my staff visited the Pamet River in Truro, Massachusetts in order to provide some comments to your office in regard to the study your office is conducting. At this time EPA does not have sufficient information to base substantive comments on. We understand that several alternatives have been identified to alleviate flooding and/or reintroduce tidal flows to the Pamet River east of the existing tide gate located at Route 6 (Wilder's Dike).

Mr. Reiner noticed that the freshwater wetlands located east of the Wilder's Dike tidegate appeared to have significant ecological value in their present condition. It is important to recognize that the current function and value of these fresh water wetlands east of the tidegate may make it ecologically undesirable to reintroduce tidal flows past the tidegate.

EPA also noticed that a wooden bulkhead on the Pamet River located adjacent to the Truro Post office property west of Wilder's Dike and Route 6 has failed. We would like at this time to indicate our preference for riprap stabilization of the failed bulkhead shoreline or bioengineering vegetative stabilization if practicable in order to restore the Pamet River at this location.

Please send us a copy of your study report when it is available for our review. We will provide additional comments at that time. For further coordination please contact Ed Reiner of my staff at (617) 565-4434.

Sincerely,

Jane Downing

Jane Downing, Director
Massachusetts Office of Ecosystem Protection

CC: Eric Hutchinson, NMFS Gloucester
Phil Morrison, USFWS, Concord, NH

The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
100 Cambridge Street, Boston, 02202

WILLIAM F. WELD
GOVERNOR
ARGEO PAUL CELLUCCI
LIEUTENANT GOVERNOR
TRUDY COXE
SECRETARY

Tel: (617) 727-9800
Fax: (617) 727-2754

April 29, 1996

Mr. Joseph L. Ignazio
Director of Planning
Department of the Army
Corps of Engineers
424 Trapelo Road
Waltham, MA 02254-9149

Re: Section 22 Planning, Tide gate and dike removal at Route 6 on the Pamet River in Truro, MA.

Dear Mr. Ignazio:

By letter dated March 15, 1996 you requested comments on the above referenced project and any information MEPA may have on natural resources in the project area.

In your letter you state that the planning study is to evaluate the advantages and disadvantages of reintroducing daily tidal flows to freshwater wetlands, investigate flooding impacts associated with existing railroad dikes and evaluate the existing tide gate/culvert ability to drain Pamet River overtopping events at Ballston Beach. From your project description and the enclosed figure, it is not possible to estimate the extent of alterations which could be involved in the project. The Massachusetts Environmental Policy Act (MEPA) regulations (301 CMR 11.25) require the preparation of an Environmental Impact Report (EIR) for non-residential projects that would alter: 50 or more acres of land; one or more acres of bordering vegetated wetland or salt marsh; or 10 or more acres of other wetland resource areas. I assume the project may exceed the above project parameters and that several state agencies will have to act on the project. On that basis, it is likely that an EIR will be required.

I do not know of any natural resource information about the project area available through the MEPA files. However, I suggest that you contact the Cape Cod Commission and Mass GIS, as both agencies maintain extensive Geographic Information Systems.

If the current study is to become an Environmental Assessment

Document under NEPA, I urge the initiation of the MEPA process so that any such document may address both the state and federal requirements and undergo joint review. In addition, you should note that the project may be a Development of Regional Impact under the Cape Cod Commission regulations and may require the preparation of a Project Report. If so, the Commission's requirements may also be addressed in the same document.

If you have further questions concerning the MEPA process, please call David Shepardson of my staff at 617-727-5830 x304.

Sincerely,

Jan H. Reitsma,
Assistant Secretary
Environmental Impact Review

cc: Town of Truro (enclosure, ENF package)
Cape Cod National Seashore
Massachusetts Water Resources Commission
Wetlands Restoration Banking Program
Massachusetts Coastal Zone Management

JHR/DES/ds

Commonwealth of Massachusetts

Division of Fisheries & Wildlife

Wayne F. MacCallum, *Director*

19 April 1996

Joseph Ignazio
New England Division, Army Corp. of Engineers
424 Trapelo Rd.
Waltham, MA 02254

Re: Proposed Removal of Tide Gate and Dike Structure; Rte. 6 & Pamet River
Truro, MA
NHESP File No. 96-301

Dear Mr. Ignazio,

Thank you for contacting the Natural Heritage and Endangered Species Program for information regarding state-listed rare species in the vicinity of the project referred to above.

At this time we are not aware of any rare plants or animals or exemplary natural communities that would be adversely affected by the proposed project.

This review concerns only rare species of plants and animals and ecologically significant natural communities for which the Program maintains site-specific records. This review does not rule out the possibility that more common wildlife or vegetation might be adversely affected by the project, especially if it will modify currently undeveloped areas. Should project plans change, or new rare species information become available, this evaluation may have to be reconsidered.

Please call me if you have any questions.

Sincerely,

Hanni Dinkeloo
Environmental Reviewer

Natural Heritage & Endangered Species Program
Route 135, Westborough, MA 01581 **Tel:** (508) 792-7270 x 200 **Fax:** (508) 792-7275
An Agency of the Department of Fisheries, Wildlife & Environmental Law Enforcement

United States Department of the Interior

FISH AND WILDLIFE SERVICE
New England Field Office
22 Bridge Street, Unit #1
Concord, New Hampshire 03301-4986

April 17, 1996

Joseph L. Ignazio
Planning Directorate
New England Division, Corps of Engineers
424 Trapelo Road
Waltham, MA 02254-9149

ATTN: Evaluation Division

Dear Mr. Ignazio:

This responds to your March 15, 1996 letter requesting information on the presence of federally-listed and proposed endangered or threatened species in relation to the removal of tide gates and a dike structure on the Pamet River in Truro, Massachusetts.

Based on information currently available to us, no federally-listed or proposed threatened and endangered species under the jurisdiction of the U.S. Fish and Wildlife Service are known to occur in the project area, with the exception of occasional transient bald eagles (*Haliaeetus leucocephalus*) or peregrine falcons (*Falco peregrinus*). However, we suggest that you contact Hanni Dinkeloo, Natural Heritage and Endangered Species Program, 1 Rabbit Hill Road, Westborough, MA 01581-3337, (508) 792-7270 for information on state-listed species that may be present.

Preparation of a Biological Assessment or further consultation with us under Section 7 of the Endangered Species Act is not required. Should project plans change, or additional information on listed or proposed species becomes available, this determination may be reconsidered. This response relates only to endangered species under our jurisdiction. It does not address other legislation or our responsibilities under the Fish and Wildlife Coordination Act or the Federal Power Act.

Thank you for your cooperation and please contact Susi von Oettingen of this office at (603) 225-1411 if we can be of further assistance.

Sincerely yours,

Michael J. Bartlett
Supervisor
New England Field Office

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENVIRONMENTAL PROTECTION
ONE WINTER STREET, BOSTON MA 02108 (617) 292-5500

WILLIAM F. WELD
Governor

ARGEO PAUL CELLUCCI
Lt. Governor

TRUDY COXE
Secretary

DAVID B. STRUHS
Commissioner

April 16, 1996

Mr. Joseph L. Ignazio
Director of Planning
Planning Directorate, Evaluation Division
Department of the Army
New England Division, Corps of Engineers
424 Trapelo Rd.
Walthan, MA 02254-9149

Dear Mr. Ignazio:

In response to your letter of March 15, 1996 regarding the Section 22 Study of the Pamet River, Route 6 tide gate and dike structure, this project is being followed by Lenore White and Elizabeth Kouloheras of our Southeast Regional Office in Lakeville (508-946-2800), and your office should contact these individuals for input on the project. Also, Truman Henson of the Massachusetts Coastal Zone Managment Office in Boston (617-727-9530) is engaged in this project, as is Christy Foote-Smith of the Massachusetts Executive Office of Environmental Affairs (617-727-9800 ext. 213).

If you have any further questions, please contact Steve Pearlman of my staff (617-556-1190).

Sincerely,

Robert W. Golledge, Jr.
Acting Director
Division of Wetlands
& Waterways

cc: Robert J. Martin, Truro Bd. of Selectmen
Maria Burks, Cape Cod National Seashore
Howard Irwin, Truro Conservation Commission
Catherine Demos, USACOE, NE Division
Lenore White, DWW/SERO
Liz Kouloheras, DWW/SERO
Truman Henson, MCZM
Christy Foote-Smith, EOEA
Steve Pearlman

ignaz

THE COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS
OFFICE OF COASTAL ZONE MANAGEMENT
100 CAMBRIDGE STREET, BOSTON, MA 02202
(617) 727-9530 FAX (617) 727-2754

Joseph L. Ignazio
Director of Planning
Planning Directorate
Army Corps of Engineers
New England Division
424 Trapelo Road
Waltham, MA 02254-9149

11 April 1996

Dear Mr. Ignazio:

This letter response to your correspondence of March 15, 1996 regarding the Corps' initiation of a Section 22 Planning Assistance to States Study to investigate wetlands restoration and flood prevention for the Pamet River in Truro, Massachusetts.

Massachusetts Coastal Zone Management (MCZM) is pleased that the Corps and the Town of Truro have joined in cooperation to explore the alternatives available for this project. MCZM has a strong interest in this project and would like to offer our assistance and coordination. Bruce Carlisle, MCZM wetlands and water quality staff, and Truman Henson, MCZM Cape Cod Regional Coordinator, are available to provide assistance on this project. They have reviewed the August 1994 Draft Scope of Studies and have requested from Catherine Demos, of your staff, a more current scope.

With more specific information about the project investigation and alternatives analysis work. MCZM should be in a position to offer substantive input.

We look forward to continued coordination on this project.

Sincerely,

Peg Brady

Peg Brady, Director
Massachusetts Coastal Zone Management

The Commonwealth of Massachusetts

Division of Marine Fisheries
Leverett Saltonstall State Office Building
100 Cambridge Street
Boston, Massachusetts 02202

PHILIP G. COATES
DIRECTOR

727-3193

April 3, 1996

Ms. Catherine Demos
Department of the Army
New England Division, Corps of Engineers
424 Trapelo Road
Waltham, MA 02254

Dear Ms. Demos,

The following comments are submitted in response to a letter and attachment from Joseph Ignazio dated March 15, 1996, requesting comments on a Section 22 to investigate the impacts of removing the existing tide gate and dike at route 6 on the Pamet River in Truro.

The Division of Marine Fisheries has a limited data base regarding existing fisheries resources within the upper Pamet River system. A previous report on anadramous fisheries resources lists the Pamet as having no known anadramous fisheries resources and having little development potential for those resources, since the river has no headwaters pond or lake.

Regarding potential gains to other marine fisheries resources, if the project returns some of the existing fresh water marshes in the upper river system to salt marsh, a net positive benefit to the marine productivity of the river system and nearby Cape Cod Bay could reasonably be expected.

If you should have any questions regarding the above comments or are in need of additional information, please feel free to contact Paul Caruso at our Sandwich office (508-888-1155 ext.25).

Sincerely,

Phillip G. Coates
Director

cc: Paul G. Caruso

APPENDIX C

GROUNDWATER ASSESSMENT

Pamet River Investigation Groundwater Assessment Study
Truro, Massachusetts

Groundwater Impacts
Associated with the Removal
of the Tide Gate and Dike Structures

FINAL REPORT
(May, 1997)

prepared by

Eduard M. Eichner, Water Resources Scientist
Thomas C. Cambareri, Water Resources Program Manager
Kenneth Livingston, Project Assistant
Bob Sobczak, Project Hydrologist
Ben Smith, GIS Analyst

WATER RESOURCES OFFICE

Cape Cod Commission
Armando Carbonell, Executive Director

Acknowledgement

We gratefully acknowledge the assistance of staff of the Town of Truro, Cape Cod National Seashore, National Park Service, National Biological Survey, and the Army Corps of Engineers for their assistance in the completion of this project. We also gratefully acknowledge the assistance and understanding of Richard Aiken, Mr. and Mrs. George Mooney, and Mr. and Mrs. David Weden for allowing installation of monitoring wells on their property.

This project has been financed in part with federal funds from the National Park Service, Cape Cod National Seashore, and Army Corps of Engineers, county funds from the Cape Cod Commission, and local funds from the Town of Truro. The contents of this report do not necessarily reflect the views and policies of the financing agencies, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Executive Summary

The Pamet River, which is located within the Town of Truro, MA and the Cape Cod National Seashore, is divided into an estuarine and freshwater river system by a clapper valve that prevents Cape Cod Bay salt watertides from reaching upper portions of the river. During significant Atlantic Ocean storms in 1978, 1991, and 1992, Ballston Beach, which is located at the eastern end of the Upper Pamet River system, was overwashed. The 1992 storm resulted in the Upper Pamet River valley being flooded with four feet of saltwater. Discussions among town, county, state, and federal officials in the aftermath of the 1992 storm resulted in a significant number of questions to address regarding the future management of the Pamet River and the increasingly frequent breaches of Ballston Beach. A study of groundwater and tidal actions was proposed to address some of these questions and was funded by the Town of Truro, the Cape Cod Commission, the National Park Service, and the Army Corps of Engineers.

This report details the hydrogeologic investigation of the Pamet River in Truro, MA conducted by the Cape Cod Commission Water Resources Office under contract to the Army Corps of Engineers. This investigation focussed on an evaluation of the groundwater impacts associated with the removal of the clapper valve at Wilder Dike. The investigation included the installation and surveying of 24 monitoring wells and 2 stream gauges; measurement of stream flows, groundwater levels, surface water levels, and tidal fluctuations; identification of private wells; and analysis of potential impacts using numerical and analytical groundwater models.

The Pamet River is at the margin of two groundwater lenses, the Pamet lens to the north, and Chequesset lens to the south. Water level measurements in the Pamet River valley indicate upward gradients toward the river, confirming that the Pamet River is a discharge area for these lenses. A calibrated groundwater model developed for this study and based on the collected hydrogeologic information suggests that the marsh surrounding the Pamet River serves to isolate the river from all but limited direct contact with the aquifer underlying the marsh. Modeling results indicate that 85% of the river discharge comes from surface water drains (*i.e.*, mosquito ditches) from the surrounding aquifer that flow across the top of the marsh and discharge into the river. Field observations combined with modeling results suggest that the remaining 15% of the river flow comes from direct groundwater discharge through highly conductive portions of the river bottom.

One of the primary concerns about removal of the clapper valve is the potential impact on private wells and septic systems in the Upper Pamet River valley. Commission staff used an analytical model to assess the effect of removing the tidal gate on groundwater fluctuations in the river valley. This evaluation of potential groundwater fluctuations used maximum tidal ranges predicted by the removal of constrictions near Wilder Dike and Route 6: 0.9 ft at Ballston Beach and 2.4 ft at

Route 6. The resulting analyses suggests only minimal increases (< 0.01 ft) in the range of groundwater fluctuations 500 ft from the river (the distance to the closest house) and virtually unmeasurable changes in water levels near septic systems and wells greater than 500 ft from the river. The low permeability characteristics of the marsh peat serve to dampen tidal impacts on groundwater levels.

The field data collected and modeling results indicate that the limited flow characteristics of the peat in the marsh system surrounding the Upper Pamet River would cause tidal ranges within the river to have minimal effect on groundwater levels in the Upper Pamet River valley. In addition, the significant thickness of the aquifer system (greater than 150 ft in the middle portion of the Upper Pamet River valley) and upward groundwater gradients suggest that saltwater flow from the river into the surrounding groundwater lenses will be prevented.

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Cape Cod Commission
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May 1997

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I. INTRODUCTION

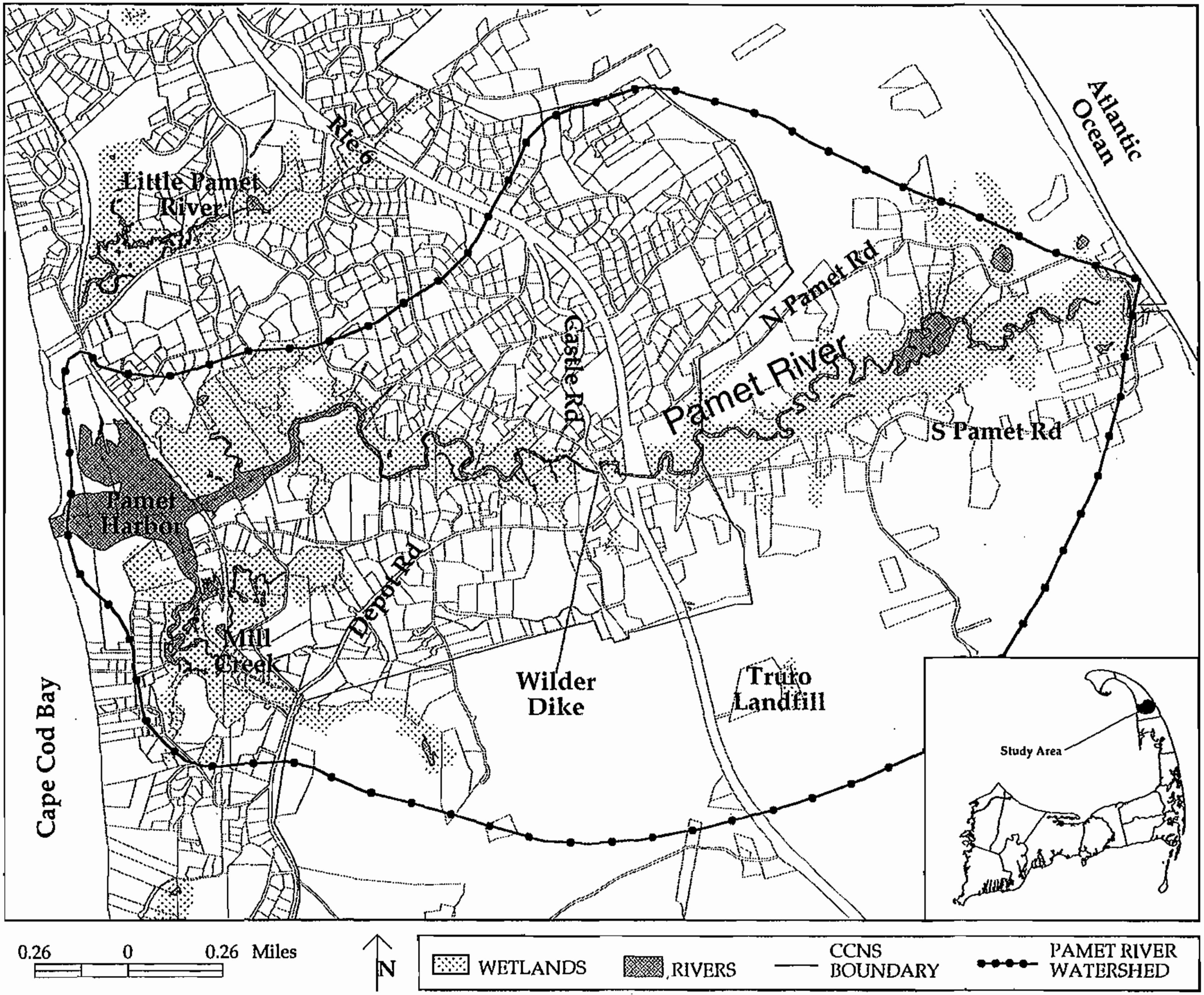
The Pamet River is an estuarine and freshwater river system located within the Town of Truro, MA and Cape Cod National Seashore (Figure 1). The Pamet River is divided into two hydrologically different sections by Wilder Dike and a tidal gate near Route 6. The tidal gate prevents the saltwater tides from reaching the upper Pamet River system. As a result of the tidal gate, the upper portion of the River has become a freshwater dominated ecosystem, while the lower portion is influenced by tides from Cape Cod Bay.

During significant storms in 1978, 1991, and 1992, Ballston Beach, which is located at the eastern edge or Atlantic Ocean side, of the Pamet River system was breached and overwashed. The storm in December 1992 resulted in the Upper Pamet River valley being flooded with four feet of saltwater from the Atlantic Ocean. The large inflow of saltwater was able to only slowly drain into the lower Pamet River because the tidal gate was closed during the hours around high tide. In addition, the size of the Route 6 culvert did not allow a significant volume of water to leave the upper system during low tide.

Discussions among town, county, state, and federal officials in the aftermath of the 1992 storm resulted in a significant number of questions regarding the future management of the Pamet River and how natural processes, such as the increasingly frequent overtopping of Ballston Beach, might impact management plans (Pamet River Workshop, March, 1993). As a result of these discussions, a consensus was achieved to assess the potential impacts of removing the tidal gate and allowing tidal actions within the upper Pamet River. Previous investigations of the potential restoration of tidal flows in other areas of the Lower Cape had suggested an aquifer thickness of 43 to 95 ft would prevent impacts on private wells (Fitterman and Dennehy, 1992) and impacts would be limited to changes in the plant community within the affected marsh (Roman, 1987; Roman, *et al.*, 1995). Concerns that have been raised about the removal of the Pamet River tidal gate have included degradation in drinking water quality in wells adjacent to or located in the Pamet River floodplain and flooding of existing septic systems due to an expected rise in groundwater levels throughout the Upper Pamet River valley.

In order to assess some of these questions, the Town of Truro and the National Park Service (NPS) requested the Army Corps of Engineers (ACOE) to conduct an investigation of the impact of removing the tide gate and dike structure located at Route 6 on the Pamet River. One portion of the study was designed to investigate the potential groundwater impacts. The following groundwater study was completed for $25,000, $6,000 of which was supplied by a grant to the Town from Cape Cod Commission Water Resource Office contract funds with the remaining balance supplied by the Town of Truro, the NPS, and the ACOE. The entire Pamet River Investigation study is being conducted by the ACOE under the Planning Assistance to States (PAS) Program. This report details the groundwater

Figure 1. Pamet River Watershed, Truro, MA.



study conducted by the Cape Cod Commission (CCC) under contract to the ACOE to assess the potential impacts of removing the tide gate on drinking water and groundwater levels in the upland area of the Upper Pamet River.

History and Current Conditions in the Pamet River

Glacial melting during the retreat of the last Pleistocene ice advance approximately 12,000 years ago formed the Pamet River valley (Koteff, *et al.*, 1967; Oldale, 1968). The word "pamet" is recognized by geologists as a channel in glacial deposits eroded by glacial meltwater (Strahler, 1966). The main channel of the Pamet River extends east from Cape Cod Bay across Truro and terminates approximately 150 feet west of Ballston Beach, which is on the Atlantic Ocean.

The river has been artificially separated into two sections, the Lower Pamet, an intertidal estuary, and the Upper Pamet, a freshwater river. The Lower Pamet marsh area, including the river, covers approximately 229 acres and the Upper Pamet marsh approximately 159 acres (Cape Cod Commission - GIS Dept.). Three side arms, the Little Pamet to the north, and Mill Creek and Bang's Creek to the south, flow into the Lower Pamet system.

The two sections were created by the installation of Wilder Dike and the tidal gate. Wilder Dike, which is located at Castle Road in Truro, was constructed in 1869 to replace a rotting railroad bridge across the mid-section of the Pamet River. The tidal gate at Wilder Dike and dike structures related to Route 6 were constructed in 1950s (Giese, *et. al.*, 1990).

The tidal gate utilizes a clapper valve to prevent saltwater and tidal influences from moving east of Castle Road. The clapper valve pivots based on fluctuations in freshwater and saltwater elevations (Figure 2). As currently configured, the clapper valve is forced closed by tidal saltwater approximately two (2) hours before high tide. The valve remains closed for four to six (4-6) hours. While the valve is closed, fresh surface water from the Upper Pamet fills the area to the east of the clapper valve, rising to ~ 0.75 ft above saltwater levels on the western side. Approximately three hours after high tide, the clapper valve gradually opens and freshwater drains from the Upper Pamet.

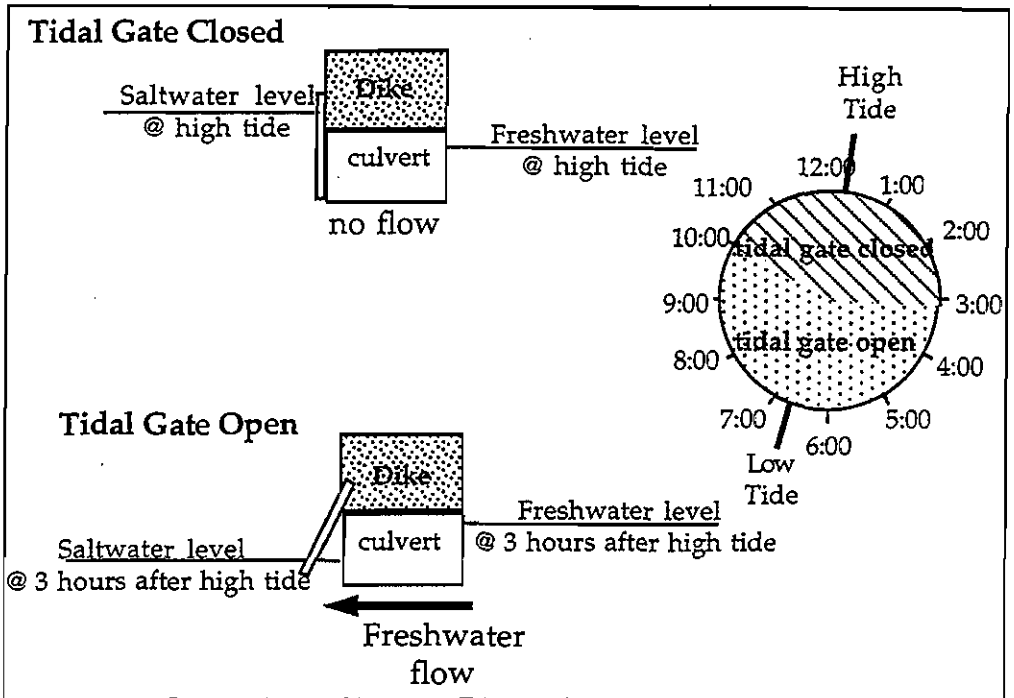


Figure 2. Operation of Pamet River clapper valve.

Water quality near the tidal gate is determined by the stage of the tide. With the tidal gate closed, the water just west of Castle Road is brackish (17 - 20 parts per thousand (ppt)) (Lewis, 1989). With the opening of the tidal gate, salinity concentrations decrease to near 1 ppt as freshwater flows through the tidal gate.

Since the mid-1970s various reports have evaluated the tidal conditions within the river and discussed the restoration of tidal flow to the entire Pamet River (see Appendix I (Annotated Bibliography) for a review of pertinent studies). Initial research by Giese and Westcott (1980) predicted the Pamet River estuary's size may be 16% less than pre-dike conditions. Subsequent development of a one-dimensional model by Giese and coworkers (1990) suggested that the removal of the clapper valve would result in minimal changes to the volume affected by the tides (*i.e.*, the tidal prism). This model averaged the velocity and tidal flow across the tidal channel and relied on assumptions about the tidal channel length (2.4 miles), width (15 ft), and depth (3 ft). The model predicted the current volume of the tidal prism (6.3×10^5 m^3 (mean tide)) would not be significantly altered if tidal influences are allowed east of Wilder Dike. The model predicts that tidal influence would extend across Route 6, but the current mean high tide at Castle Road would be lowered.

The re-introduction of tidal flow has been suggested as a means to increase the Pamet's tidal prism and reduce the rate of sand and mud buildup in the vicinity of

Pamet Harbor (Giese and Westcott, 1980; Horsley and Witten, Inc., 1994; Robinson, 1985b). It has also been suggested that the return of tidal flow throughout the Pamet River system may improve the water quality and shellfishing and finfishing opportunities within the river (Horsley and Witten, Inc., 1994). These benefits have been countered by concerns about the potential adverse effects on private wells, septic systems, and the freshwater biota in and around the Upper Pamet River.

Study focus

The Cape Cod Commission was selected by the Army Corps of Engineers (ACOE) to assess the potential groundwater impacts in the Upper Pamet River area that would be caused by the removal of the tide gate and dike structures on the Pamet River. The scope of services approved by the ACOE included: 1) review of existing hydrogeologic studies, 2) location of existing drinking water wells, 3) installation of shallow and deep groundwater wells, 4) collection of water levels and flow information, 5) development of groundwater model for the Upper Pamet, and 6) preparation and presentation of a final report. This report details each of these steps.

II. CONCEPTUAL HYDROGEOLOGY OF THE UPPER PAMET RIVER

The Pamet River is at the margin of two groundwater lenses, the Pamet lens to the north, and Chequesset lens to the south (Guswa and LeBlanc, 1981). Previous water table maps of the area (Cambareri, *et al.*, 1989a and 1989b; Cape Cod Commission, Wellfleet Harbor Mini-Bay Project) indicate that the Pamet River is a discharge area for both lenses. Based on these water tables, the watershed to the river is 2,694 acres, with 1,314 acres to the east of Route 6 (see Figure 1). Based on the Commission's Geographic Information System (GIS) information, the surface of the Upper Pamet River is 14.21 acres and the surrounding marsh is approximately 159 acres.

Initial hypotheses about the hydrogeology in the area have suggested that the surrounding groundwater lenses discharge through the sandy bottom of the Pamet River. Observations of the marsh ecosystem have indicated that freshwater vegetation overlay freshwater marsh peat, which in turn overlays approximately 3 ft of salt-marsh peat (John Portnoy, National Park Service, personal communication). In certain sections, the peat extends to a depth of 15 feet below the land surface. The salt-marsh peat is thought to be the result of more than 1,000 years of salt-marsh growth prior to the construction of the dike and tidal gate structures.

Peat layers conduct little groundwater movement through them, as compared to sand and gravel sediments (Freeze and Cherry, 1979). The thick deposits of marsh peat in the Upper Pamet River area, if continuous, would tend to isolate the river from the underlying aquifer (Figure 3).

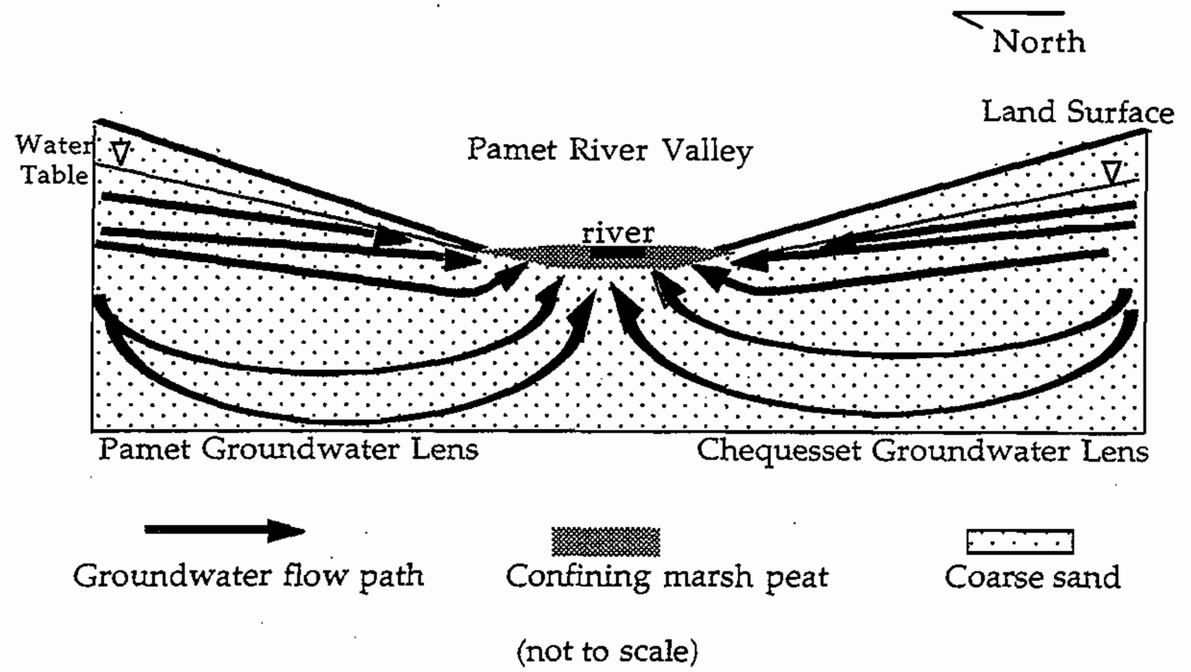


Figure 3. Conceptual Groundwater Flow within the Pamet River Valley.

III. HYDROGEOLOGIC ASSESSMENT AND DATA ACQUISITION METHODS

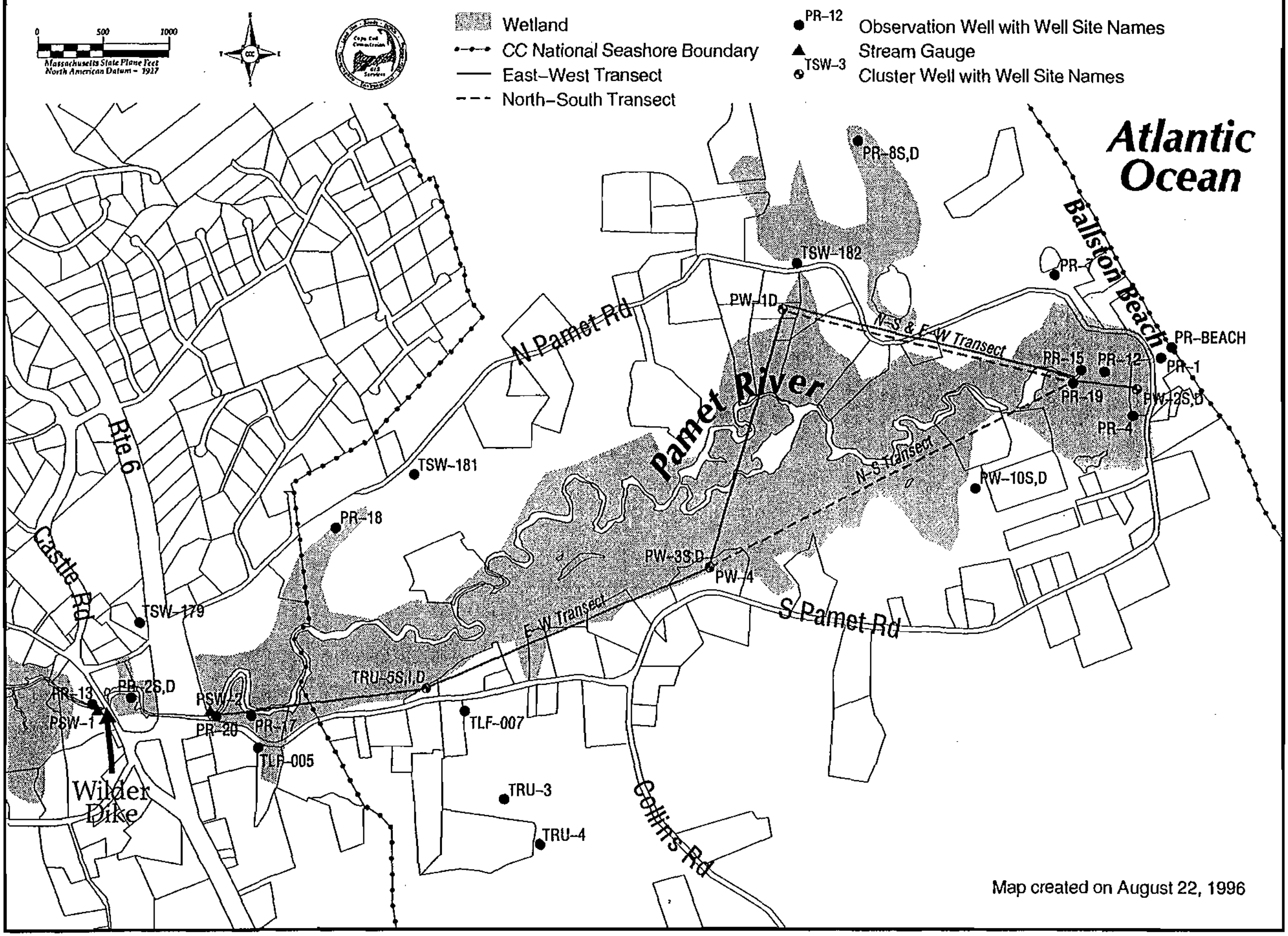
Commission staff reviewed existing studies of the Upper Pamet River area to identify previously installed monitoring wells (Cambareri, *et al.*, 1989a and 1989b; LeBlanc, *et al.*, 1986; Marc Adams, National Park Service, personal communication) and to identify potential locations for additional wells. Eleven pre-existing wells were identified for inclusion in the monitoring network for this study.

Twenty-four additional monitoring wells and 2 stream gauges were installed for this investigation (Figure 4). The wells installed are: fourteen (14) hand augered one-inch PVC wells at depths between 7 ft and 12 ft below land surface; six (6) three-quarter inch steel drive point wells at depths between 15 ft to 25 ft below land surface; three (3) drilled wells at a depth of 50 ft, and one (1) drilled well at a depth of 150 ft below land surface. Elevations of all wells were determined relative to the National Geodectic Vertical Datum (NGVD), which is likely within 0.5 ft of mean sea level in this location. See Table 1 for characteristics of monitoring wells and stream gauges.

The drilled wells (PW-1, PW-2d, and PW-3d) were installed using a lead screened auger by Desmond Well Drilling, Inc. on May 20 and 21, 1996 (see Appendix II for well logs). Water samples were taken approximately every 5 ft as the auger was advanced. Salinity (%), specific conductivity (µmhos/cm), and temperature (°C) measurements were collected at each sampling point after three well volumes had been pumped from the well.

Study Area and Data Point Map–Upper Pamet River

Figure 4



Map created on August 22, 1996

Table 1. Physical characteristics of monitoring wells.

Site Name	Depth (ft)	Well Type	Elevation of Well (ft)	Approximate elevation of top of screen (ft)	Approximate elevation of bottom of screen (ft)
PR-1	20	3/4" DP	10.325	-7.675	-9.675
PR-2d	25	3/4" DP	4.545	-18.455	-20.455
PR-2s	7	1" PVC	4.625	-0.375	-2.375
PR-4	7	1" PVC	7.555	2.555	0.555
PR-7	7	1" PVC	7.560	2.560	0.560
PR-8d	25	1" PVC	7.785	-15.215	-17.215
PR-8s	7	1" PVC	7.100	2.100	0.100
PR-10d	20	3/4" DP	10.320	-7.680	-9.680
PR-10s	7	1" PVC	9.120	4.120	2.120
PR-12	7	1" PVC	5.570	0.570	-1.430
PR-13	12	1" PVC	8.620	-1.380	-3.380
PR-15	7	1" PVC	3.780	-1.220	-3.220
PR-17	7	1" PVC	3.895	-1.105	-3.105
PR-18	12	1" PVC	8.860	-1.140	-3.140
PR-19	30	3/4" DP	3.450	-24.550	-26.550
PR-20	20	3/4" DP	6.060	-11.940	-13.940
PR-Beach	12	1" PVC	10.495	0.495	-1.505
PW-1	50	2" PVC	6.900	-38.100	-43.100
PW-2d	50	2" PVC	5.810	-39.190	-44.190
PW-2s	7	1" PVC	5.275	0.275	-1.725
PW-3s	7	1" PVC	6.130	1.130	-0.870
PW-3d	150	2" PVC	7.265	-137.735	-142.735
PW-4	50	2" PVC	6.945	-38.055	-43.055
TLF-005	N/A	2" PVC	N/A	N/A	N/A
TRU-3	65	2" PVC	7	-48	-58
TRU-4	85	2" PVC	15	-60	-70
TRU-5s	20	2" PVC	7.03	-7.97	-12.97
TRU-5i	47	2" PVC	7.03	-34.97	-39.97
TRU-5d	60	2" PVC	6.95	-48.05	-53.05
TSW-179	N/A	microwell	9.97	N/A	N/A
TSW-181	N/A	microwell	9.02	N/A	N/A
TSW-182	N/A	microwell	7.02	N/A	N/A
TSW-184	N/A	microwell	19.83	N/A	N/A
TSW-185	N/A	microwell	15.71	N/A	N/A
PSW-1	stream gauge		-1		
PSW-2	stream gauge		0		

Drive point wells were installed using a 60 pound slide hammer with 5 ft sections of steel pipe. Holes of 3/64 inch diameter were drilled in the bottom 1 to 2 ft of the first pipe section to serve as an effective well screen. The wells were developed by slug tests to ensure hydraulic connection to the underlying aquifer. Drive point well locations PR-19 and PR-20 are of particular note because these wells were driven through the bottom of the river. Water level measurements were taken after the installation of every 5 ft section of pipe at these two wells sites.

Water table measurements were taken from measuring points on July 15, July 25, August 2, and August 6. Water levels were obtained in the wells using a Slope Indicator electric tape (Model# 51453). Water levels at the two stream gauges (PSW-1 and PSW-2) were read from previously installed gauges. On July 15, water level measurements were collected from 5 locations near Route 6 and Wilder Gate and at 4 locations near Ballston Beach over a 12 hour tidal cycle in half-hour increments. These readings were taken during a new moon tide, which had a high tide elevation of 9.4 ft NGVD at the Cape Cod Bay side of the Pamet River (personal communication, Pamet Harbor Yacht Club).

Stream flow measurements were taken August 1 and 6 using a Rickly Hydrological Co. pygmy meter. Flow measurements were taken at two locations: 1) the culvert opening just east of Route 6 and 2) a transect just west of Route 6, perpendicular to wells PR-2s and 2d. Flow measurements were taken at the first site in 1 ft increments across the front of the culvert opening. A cross-sectional area of the culvert was calculated to assess the volume of freshwater leaving the Upper Pamet during the low tide period when the clapper valve is open. At the second location flow measurements were taken in 2 ft increments across the river.

Parcel information and building locations were used to assess the location of private wells. Parcel information is based on Town of Truro 1993 assessor's information, which was previously digitized by the Cape Cod Commission GIS Dept. Building locations within parcels are based on US Geological Survey topographic maps and a review of 1993 aerial photographs of the area. The parcel and building location information was combined through the use of the CCC GIS.

IV. ASSESSMENT FINDINGS AND DISCUSSION

Identification of Existing Residential Homes and Private Wells

There are approximately thirty (30) residential homes bordering the Upper Pamet River. The majority (26) of these private homes are located above the 10 ft elevation contour. The minimum distance between residential homes and the river channel is approximately 500 ft.

A survey of private well water quality for the Lower Cape was completed previously by the Lower Cape Water Management Task Force (LCWMTF) (Sobczak and

Cambareri, 1995). The LCWMTF database includes nitrate, sodium, specific conductance, and iron levels for private wells. Between 1987 and 1994, approximately 783 private wells were sampled within the Town of Truro. Seventy-seven private wells are identified as being located within the Pamet River watershed. The wells have been classified based on location within one of the four geographic quadrants within the Pamet River watershed, with Route 6 and the river serving as dividing lines. Table 2 presents the statistical averages of four geographic quadrants of the Pamet River watershed.

Table 2. Average Drinking Water Quality in Private Wells in the Pamet River Watershed.

LOCATION	NUMBER OF SAMPLES	NITRATE LEVEL (ppm)	SPECIFIC CONDUCTANCE (µmhos/cm)	SODIUM (ppm)	IRON (ppm)
North Lower Pamet River Quadrant	24	1.34	187	26	0.47
South Lower Pamet River Quadrant	21	1.64	168	20	0.31
North Upper Pamet River Quadrant	12	0.65	137	16	0.54
South Upper Pamet River Quadrant	20	0.66	143	19	0.40
Truro (Whole Town)	783	1.10	146	19.86	0.41
Drinking Water Standards		10*		20**	0.3***

*MA Drinking Water Standard (*i.e.*, maximum contaminant limit)

** *MA Drinking Water Guideline (i.e., standard promulgated by USEPA but not yet effective)*

*** MA Secondary Maximum Contaminant Level (*i.e.*, aesthetic standards, not health based)

Within the Lower Pamet quadrants, where tidal influences currently occur, sodium and specific conductance levels within private wells are higher than in the Upper Pamet quadrants (see Table 2). Existing sodium and specific conductance characteristics of the Upper Pamet quadrant wells are somewhat lower than Truro as a whole. Nitrate-nitrogen concentrations in the Lower Pamet quadrants are more than double those in the Upper Pamet quadrants, but this would be expected due to the relative lack of development in the surrounding National Seashore in the Upper Pamet watershed. There also appears to be a difference between the water quality at the margin of the two different lenses; iron concentrations are higher in the northern quadrants (the Pamet Lens) than in the southern quadrants (the Chequesset Lens).

Screened Auger Groundwater Quality
Figure 5 presents the specific conductance readings recorded at PW-1, PW-2, and PW-3 as the screened auger was advanced. Specific conductance is a measure of the concentration of dissolved substances, or ions, in a sample of groundwater. Higher concentrations in freshwater are usually indicative of contamination. Frimpter and Gay (1979) found a median specific conductance of 123 µmhos/cm in 202 samples throughout Cape Cod. The highest concentration found in Truro landfill monitoring has been 2,150 µmhos/cm (Cambareri, *et al.*, 1989a). Saltwater from the Atlantic Ocean would have a concentration of approximately 50,000 µmhos/cm.

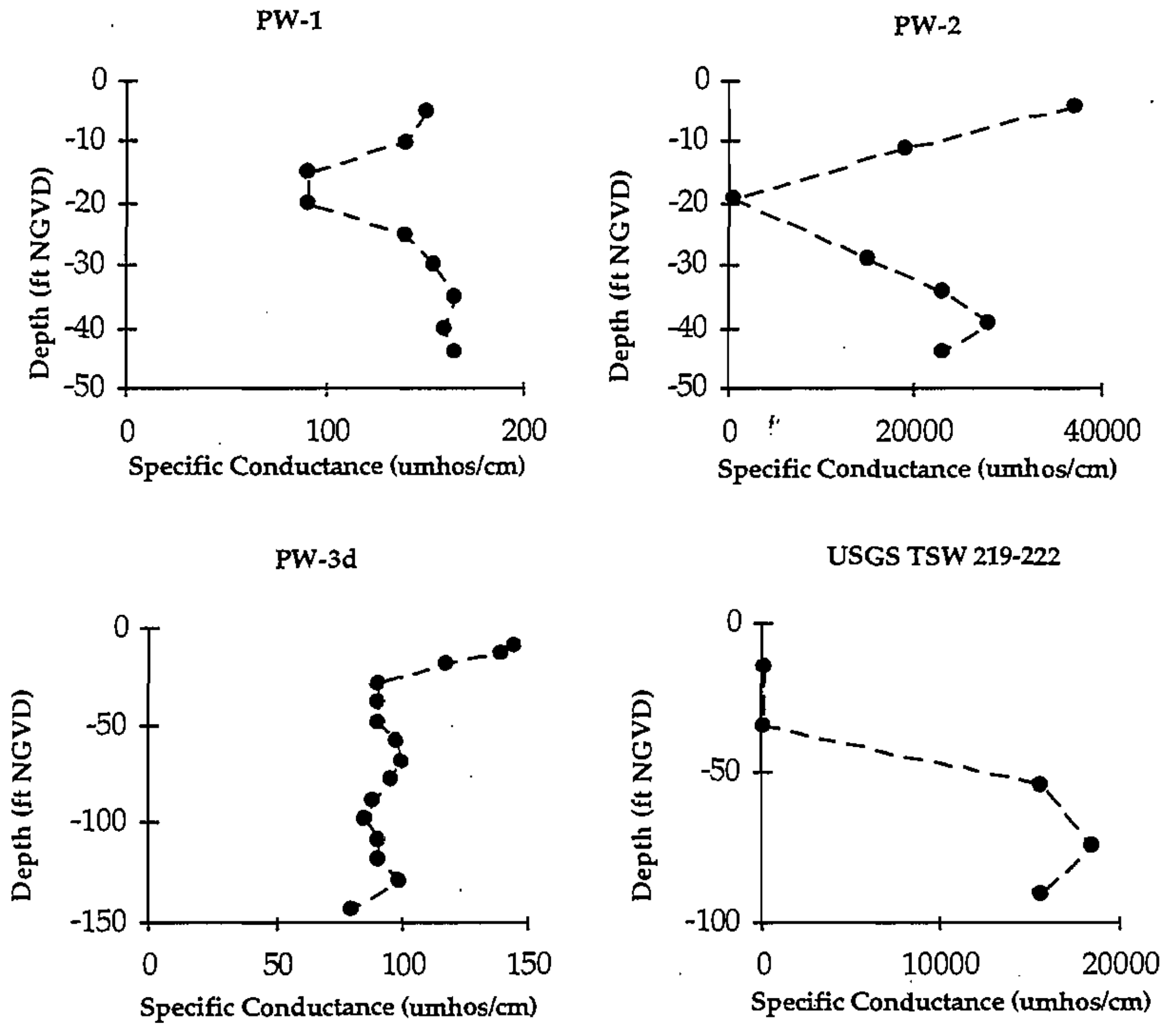


Figure 5. Specific Conductance Readings for Drilled Wells.

At PW-2 (Ballston Beach parking lot), no freshwater was encountered. Groundwater encountered throughout the 50 ft depth of the well was generally between 13.5 and 23.5% salinity, with specific conductance readings of between 600 and 37,000 µmhos/cm. A U.S. Geological Survey zone of transition well (TSW 219-222) that was installed near this location in 1975 found a chloride concentration of approximately 100 ppm at - 10 ft NGVD and nearly 12,000 ppm at - 60, - 75, and - 90 ft NGVD. The higher specific conductance in PW-2 compared to the earlier USGS well seems to indicate an increase in salt groundwater at the eastern end of the Pamet. This increase may be the result of the Atlantic Ocean overwash events. Lewis (1989) had previously documented that surface water salinity concentrations in the first 100 feet of the Pamet River were 20 ppt, but this level quickly decreases to 0 ppt 100 feet from the head of the river.

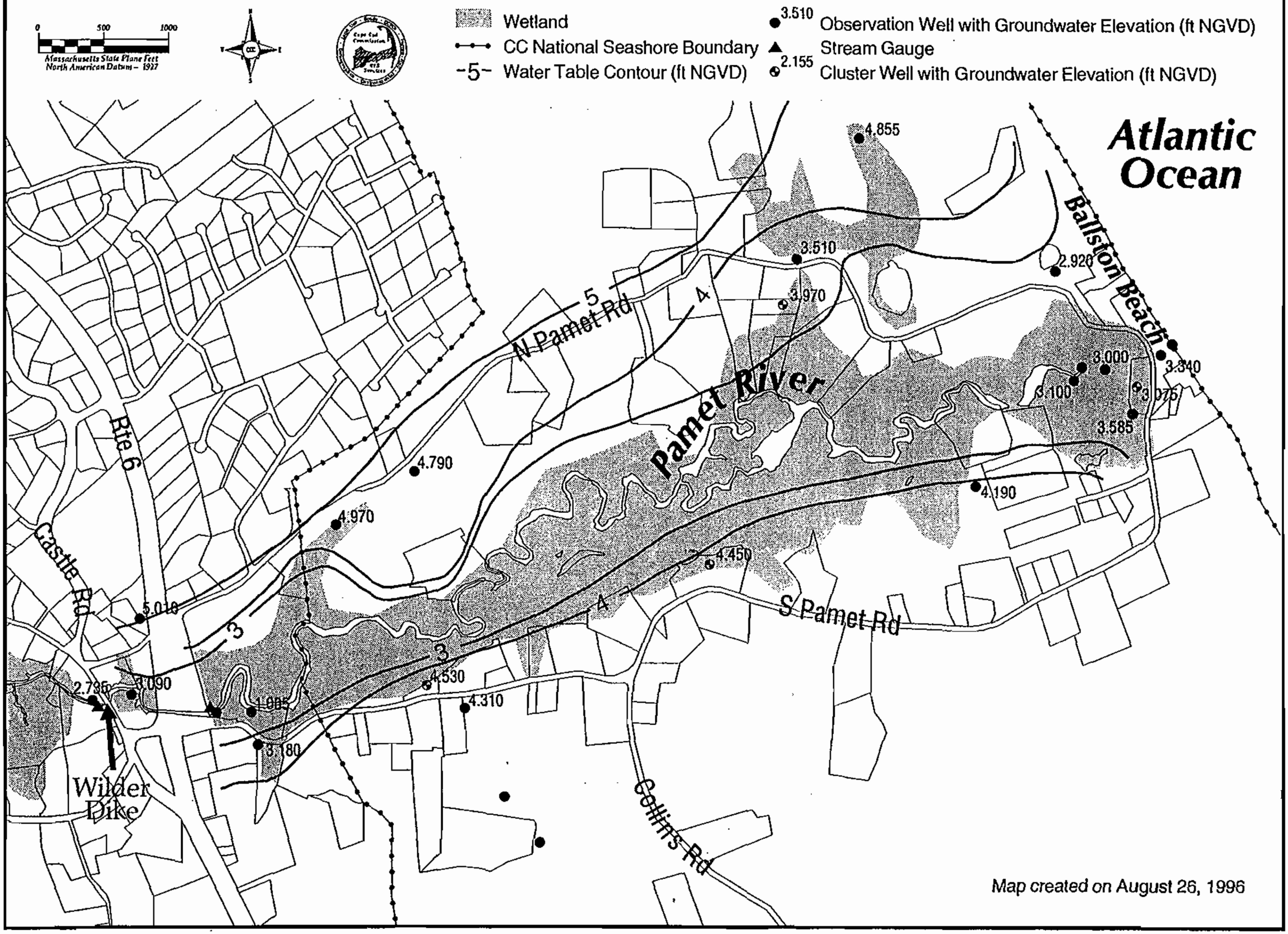
In contrast, saltwater was not encountered at PW-3 and specific conductivity readings suggest good quality water. PW-3 was drilled to 150 ft and water table elevation at this site is between 3 and 5 ft NGVD. Based on the Ghyben-Herzberg approximation (Freeze and Cherry, 1979), the saltwater interface should be located between 120 and 200 ft below the water table. Water pumped from the bottom of the borehole had no salinity and low specific conductivity (80 µmhos/cm). Thus, the saltwater interface is deeper than 150 ft at this location. The significant thickness of the groundwater lens in this area suggests that typical private wells, which penetrate 20 to 30 ft into the aquifer, are well separated from the saltwater interface.

Regional Water Levels

Groundwater levels collected from the top of the Pamet and Chequesset aquifers (*i.e.* the water table) generally show a decrease in elevation as one moves from either the north or south toward the Pamet River (Figure 6). These decreases in elevation indicate that groundwater in the northern and southern portions of the study area is flowing toward the Pamet River. Comparison of water levels collected during this study with historical water levels at TSW-179 indicate August 1996 water levels were slightly above average. The water level at TSW-179 has averaged 4.48 ft NGVD with a range of between 5.46 and 3.6 ft NGVD based on 12 years of monthly measurements (Figure 7). The July 1996 water level in this well was 4.84 NGVD.

Water Table Contours Map–Upper Pamet River

Figure 6



Map created on August 26, 1996

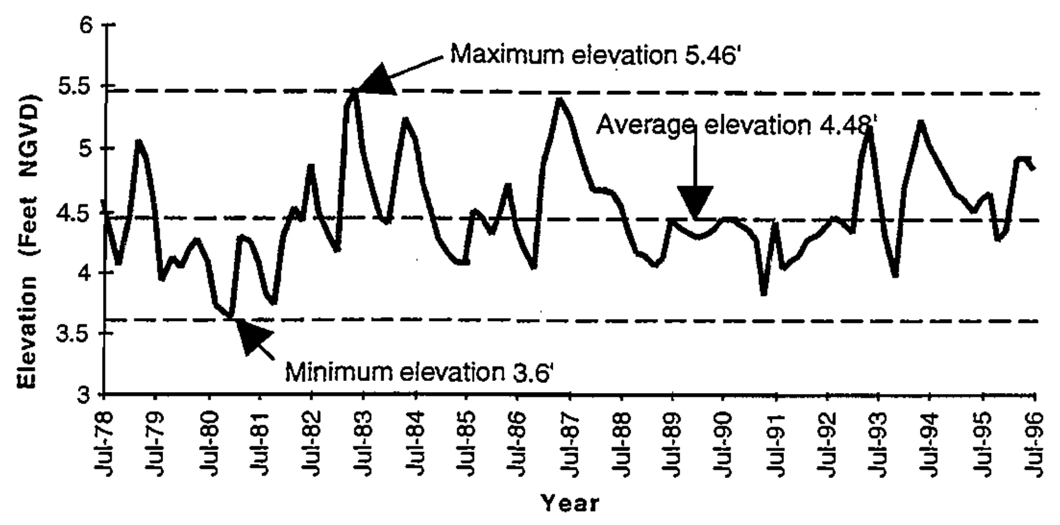


Figure 7. Hydrograph for USGS Monitoring Well TSW-179.

Vertical Groundwater Gradients
Water levels in wells below the water table can indicate the direction of flow at depth. Water levels along a longitudinal cross-section (Figure 8) and perpendicular cross-section (Figure 9) indicate regional horizontal and local vertical flow toward the Pamet River.

In Figure 9, the well cluster at PW-3, which is located approximately 500 feet from the river, indicates lower groundwater elevations closer to the surface than at depth. These levels indicate that there is a upward component of groundwater flow toward the river. A similar pattern was observed at PR-19, near the culvert to Route 6.

A layer of peat was encountered at the locations of wells driven through the river bottom (PR-19 and PR-20). The presence of peat was determined by the relative ease of driving the wells. The peat extends approximately 18 feet below the land surface at the Ballston Beach location (PR-19) and approximately 16 feet below the land surface at Route 6 (PR-20). These thicker layers of peat may be indicative of a thicker layer throughout the river bottom. Hydraulic heads directly below the peat are above the land surface (*i.e.*, artesian flow conditions) in both PR-19 (Table 3) and PR-20 (Table 4). The artesian conditions indicate that the peat layer acts as a confining layer, which restricts groundwater flow into the river. During the installation of PW-3, a fibrous peat and clay layer was also encountered approximately 1 ft below the land surface and it is approximately 3 ft thick. Hand augered wells installed in close vicinity to the riverbed also encountered a clay/peat layer at a depth of 1 ft below land surface. The existence of a relatively thick layer of peat (3 to 5 ft) was also

Figure 8. East-West Transverse Cross-Section of the Upper Pamet River, Truro, MA.

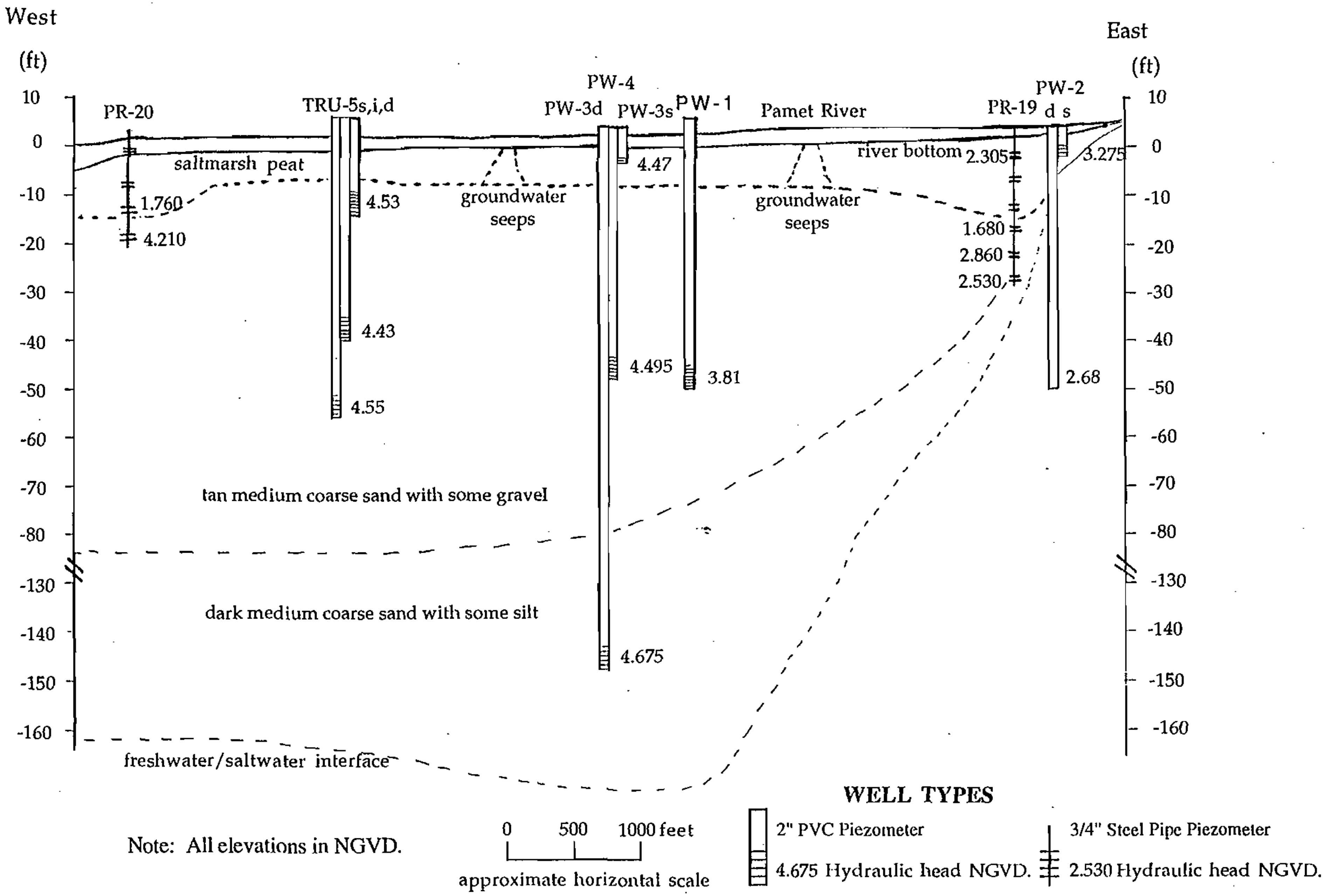
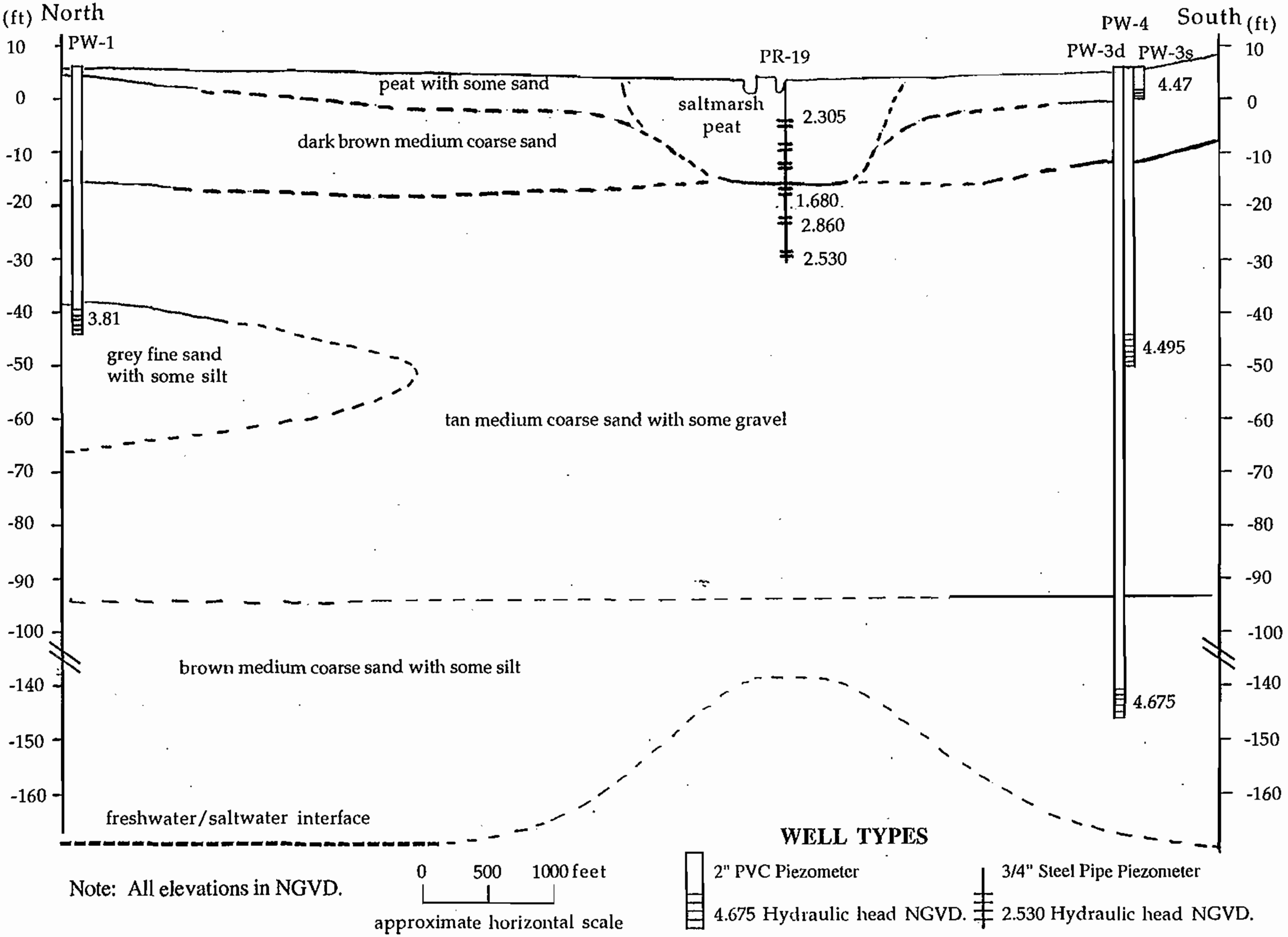


Figure 9. North/South Transverse Cross-Section of the Upper Pamet River, Truro, MA.



Note: All elevations in NGVD.

established at numerous sites surrounding the river when a 4 ft steel probe could be easily and completely inserted.

Table 3. Water Levels at PR-19 (1,000 ft west of Ballston Beach) (8/7/96).

Well Length (ft)	Elevation (ft)	Elevation of Bottom Of Well (ft)	Depth to Water (ft)	Water Elevation in well (ft)
Surface water	--	--	--	2.5
5	2.855	-2.145	0.55	2.305
10	2.610	-7.39	5.67	-3.060*
15	2.740	-12.26	9.57	-0.830*
20	2.780	-17.22	1.10	1.680
26.5	4.420	-22.08	1.56	2.860
30	3.450	-26.55	0.92	2.530

All Elevations relative to NGVD
* Water level in peat; did not allow to equilibrate.

Table 4. Water Levels at PR-20 (Route 6 culvert) (8/7/96).

Well Length (ft)	Elevation (ft)	Elevation of Bottom of Well (ft)	Depth to Water (ft)	Water elevation in Well (ft)
Surface water	--	--	--	1.75
5	3.250	-1.75	1.49	1.760
10	1.910	-8.09	4.85	-2.940*
15	1.780	-13.22	9.36	-7.580*
24	6.060	-17.94	1.85	4.210

All Elevations relative to NGVD
* Water level in peat; did not allow to equilibrate.

Stream Flow Measurements

During this study, stream flow measurements were taken August 2 at the culvert opening east of Route 6 (PSW-2) and August 6 in the river adjacent to PR-2s and 2d. Preliminary stream flow measurements on August 2 were taken at two times: 1) approximately two hours before the clapper valve closed and 2) approximately five minutes before the clapper valve closed. Stream flows at PSW-2 were calculated to be 9.63 and 6.39 cubic feet per second (cfs), respectively (Table 5). The readings on August 2 may have been confounded by 1.25 inches of rain in the study area during the prior two days (Jenny Woods, National Park Service, personal communication).

Table 5. Stream Flow Measurements.

Location	Date	Time	Total Flow (cfs)
At Route 6 culvert (PSW-2)	8/2/96*	9:00	9.63
	"	9:10	9.40
	"	9:20	8.99
	"	11:03	6.39
Near PR-2	8/6/96#	9:50	10.87
	"	9:55	10.49
	"	10:30	9.46
	"	11:00	8.36
	"	11:30	7.66
	"	12:00	5.89
	"	12:30	5.65

* High tide at 2:19 p.m. # High tide at 5:57 p.m.

On August 6, stream flow readings were taken over a 2.5 hour period after the clapper valve opened. These readings were taken to establish base flow within the river. Base flow is the sustained rate of groundwater discharge in a stream after the accounting of transient precipitation events, stream bank storage, and tidal effects. The August 6 readings show a gradual decline in stream flow from 10.87 cfs to 5.65 cfs (see Table 5). Since surface water elevations and the stream flow during the period of the last two reading showed little change, the 5.65 cfs reading at 12:30 p.m. can be considered to be baseflow discharge (Figure 10).

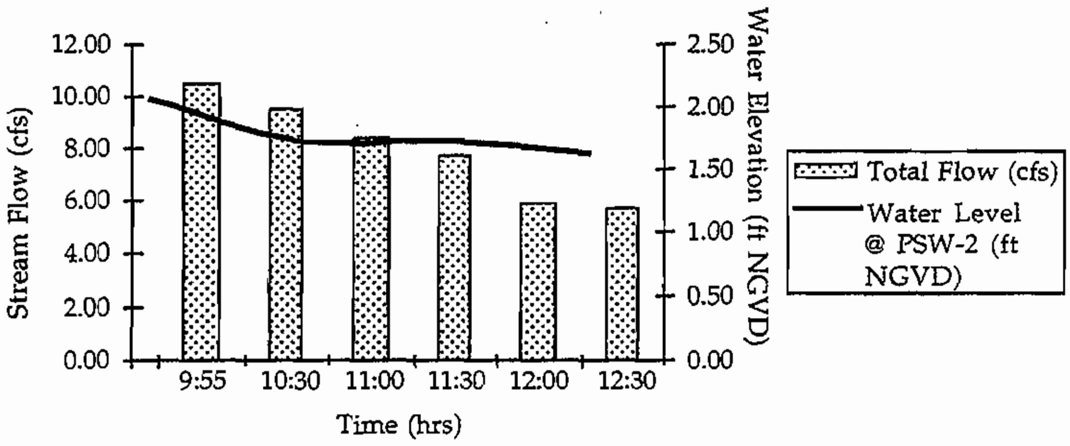


Figure 10. Stream Flow and Surface Water Levels at Route 6 Culvert.

The baseflow measurement in the Pamet River system will always be a direct reflection of the elevation of the water table in the study area. August 1996 base flow measurement is higher than most of the readings collected by Lewis (1989) at the Route 6 culvert (3.6 to 5.2 cfs using dye and 6.5 cfs using a meter). Lewis' readings were collected in the summer of 1988 when water levels in the study area were approximately a foot below the August 1996 levels (see Figure 7). These lower water levels would tend to decrease the discharge into the river from the surrounding lenses leading to a lower base flow.

A previous assessment of streamflow in the Waquoit Bay watershed (Cambareri, *et al.*, 1993) found that annual average recharge within a river watershed agrees with measured water flow within the river. If the average Cape Cod annual recharge rate (18 in/yr) is applied across the previously delineated 1,469 acre watershed of the Upper Pamet River, the resulting base flow would be 3 cfs. This flow is ~ 0.6 cfs lower than the lowest streamflow estimates calculated by Lewis (1989) and ~ 2.6 cfs lower than the 5.65 cfs measured in this study. These disagreements between data sets suggest that additional readings are warranted. The groundwater model developed for this study was used to evaluate these readings (see Groundwater Model section).

Influence of Tides on Water Levels

During the July 15 tidal monitoring round, high tide occurred at 12:09 p.m. at Pamet Harbor. Wilder Dike (PSW-1) experienced a peak level of 5.05 ft NGVD between 12:10 p.m. and 12:37 p.m (Figure 11). These observations indicate an approximate 10 minute lag in the high tide at Cape Cod Bay and at Wilder Dike. These readings also indicate that the clapper valve is closed for approximately 5 hours per tidal cycle and the valve opens approximately 3 hours after peak tidal levels are experienced at Wilder Dike. The tidal range at Wilder Dike was observed to be 4.2 ft, with a low of 0.85 ft NGVD and a high of 5.05 ft NGVD. At monitoring well PR-13, which is 5 ft from the channel bank, the range of groundwater fluctuations was 0.87 ft (see Figure 11). At monitoring wells east of Wilder Dike and west of Route 6 (PR-2s and 2d), the range of groundwater fluctuations were observed to be 0.46 ft in the shallow well and 0.09 ft in the deep well.

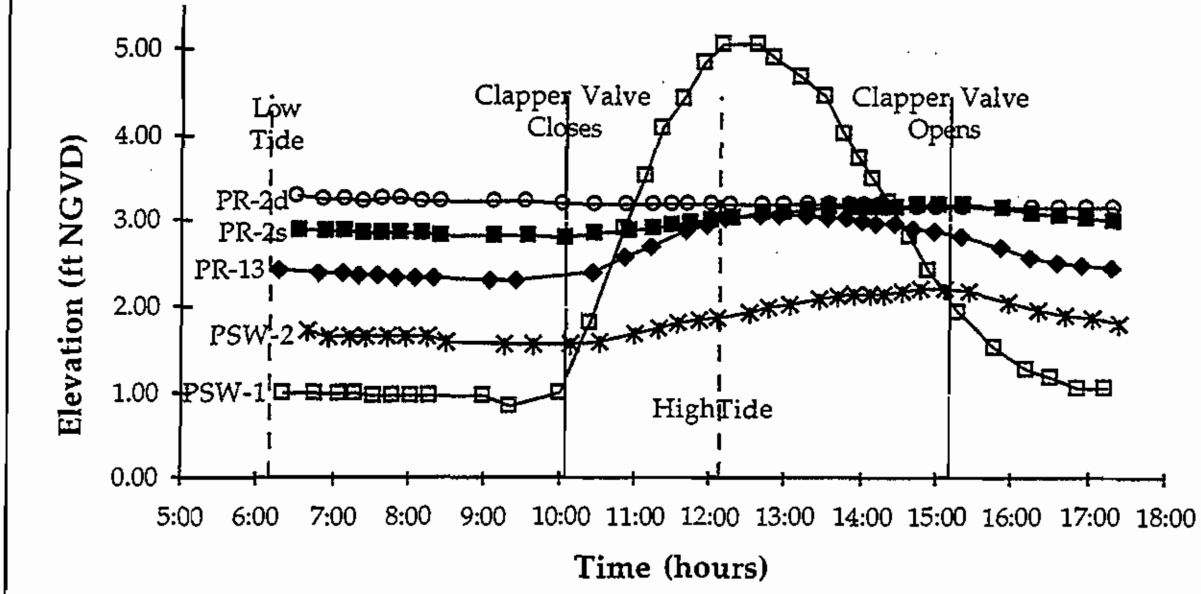


Figure 11. Tidal Influences in Groundwater and Surface-Water in the Vicinity of the Tidal Gate/Wilder Dike (7/15/96).

At the Route 6 culvert (PSW-2), water levels were lowest (1.55 ft NGVD) just before the clapper valve closed (between 9:39 a.m. and 10:09 a.m.); approximately 3 hours after low tide. The highest water levels at PSW-2 were at 3:06 p.m. (2.21 ft NGVD), approximately 3 hours after high tide and just before the clapper valve opened. The range of fluctuations in the river stage was 0.66 ft.

The water level and tidal information near Wilder Dike and Route 6 indicate that groundwater levels on both sides of the Dike are affected by the closing of the clapper valve. The rise in groundwater levels due to the tidal rise (0.87 at PR-13) and ponding of river water (0.46 ft at PR-2s) are notably less than the fluctuations observed in the river (4.2 ft and 0.66 ft, respectively). The groundwater impacts also appear to be most markedly expressed at the water table and are dampened at depth (0.09 ft fluctuation at PR-2d). It is also notable that tidal levels in the river exceed groundwater levels for approximately 3 hours during a complete tidal cycle (see Figure 11).

Tidal fluctuations at Ballston Beach were monitored through the installation of a 1 inch PVC well (PR-Beach) at the upper reach of the high tide mark. During high tide, this well was in 2 inches of water and at low tide, ocean water was approximately 25 ft from the well. The tidal range at this well was 5.43 ft, with a low of -1.05 NGVD and high of 4.38 NGVD (Figure 12). At PR-1, which is approximately 100 ft west of the beach monitoring well, the tidal range was less than 0.01 ft. At monitoring wells southwest of PR-1, tidal fluctuations were 0.5 ft in PW-2d and 0.1 ft at PR-4, a well 400 ft south of PW-2d and 400 ft west of the Atlantic Ocean. PR-12, 247 ft to the west of PR-1, had a tidal range of 0.08 ft. At PR-15, 526 ft to the west of PR-1, tidal fluctuations were negligible (less than 0.01 ft). At PR-7, adjacent to a kettle pond 50 ft north of North Pamet Road, water levels fluctuated 0.12 ft.

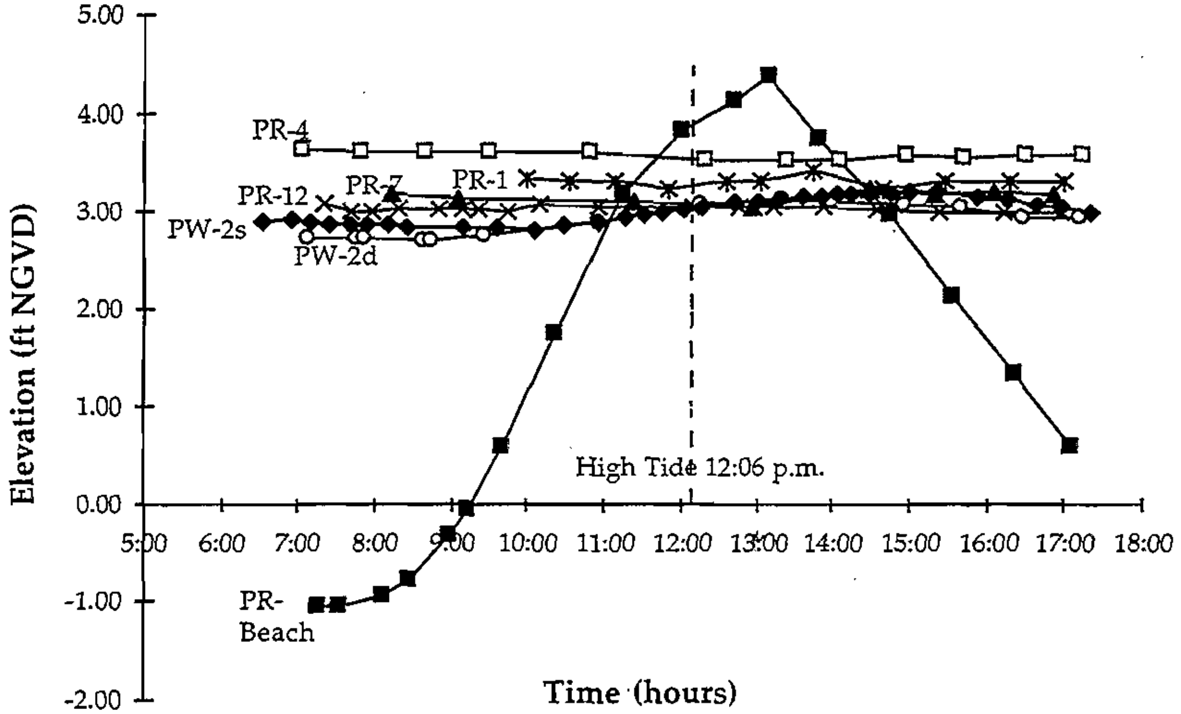


Figure 12. Tidal Influences in groundwater Levels in the Vicinity of Ballston Beach (7/15/96).

These readings indicate that tidal influences on the groundwater levels in the Ballston Beach area are negligible; most of the wells within 500 feet of the ocean had fluctuations of approximately 0.1 ft, which is less than 2% of the range in the ocean (see Figure 12). Of note among the readings is the higher fluctuation (0.5 ft) observed at PW-2d. This well is screened between - 45 and - 50 ft NGVD in an area of highly conductive substrates (see Appendix II). These more permeable materials may allow better transmission of the pressure gradient created by the high tide than the overlying materials. It is also notable that water collected at this depth was green, also possibly indicating a highly permeable connection to the ocean. Ocean tidal levels exceeded water levels in the Ballston Beach area for approximately 2.5 hours (see Figure 12).

On July 15, groundwater levels were also collected at the PW-3 well cluster for 2 hours after high tide in order to assess if tidally induced groundwater fluctuations would be observed in an interior portion of the Upper Pamet study area. No fluctuations were observed in any of the wells in this cluster.

A simplified hydraulic cross-section of the Pamet River was prepared to summarize the observed fluctuations in surface water levels collected during this study (Figure 13). The figure shows the relatively constant water level (~ 3 ft NGVD) at the western side of Ballston Beach (PW-2), the ~ 1 ft range of water levels at Route 6 (PSW-2), the ~ 6 ft tidal range at the Atlantic Ocean (PR-Beach) and the ~ 4 ft tidal range at Wilder Dike (PSW-1). The cross-section shows the relatively constant water level at PW-2 maintaining a gradient of surface water flow at high and low water levels toward Route 6 and the clapper valve. High tides at Ballston Beach exceed the PW-2 water level by approximately 2 ft or a third of the tidal range, while high tide at the Wilder Dike exceeds the PSW-2 high water level by approximately 3 ft or 75% of the tidal range. The difference in the percentage of the tidal range also helps to explain why groundwater levels near Wilder Dike and Route 6 fluctuate much more than those near Ballston Beach (*i.e.*, a greater proportion of the tidal range is above the high groundwater levels causing a more sustained gradient towards the inland portion of the Upper Pamet River). During storm surge conditions at Ballston Beach, the increase in the higher portion of the tidal range likely increases flow from the ocean to the river in this area.

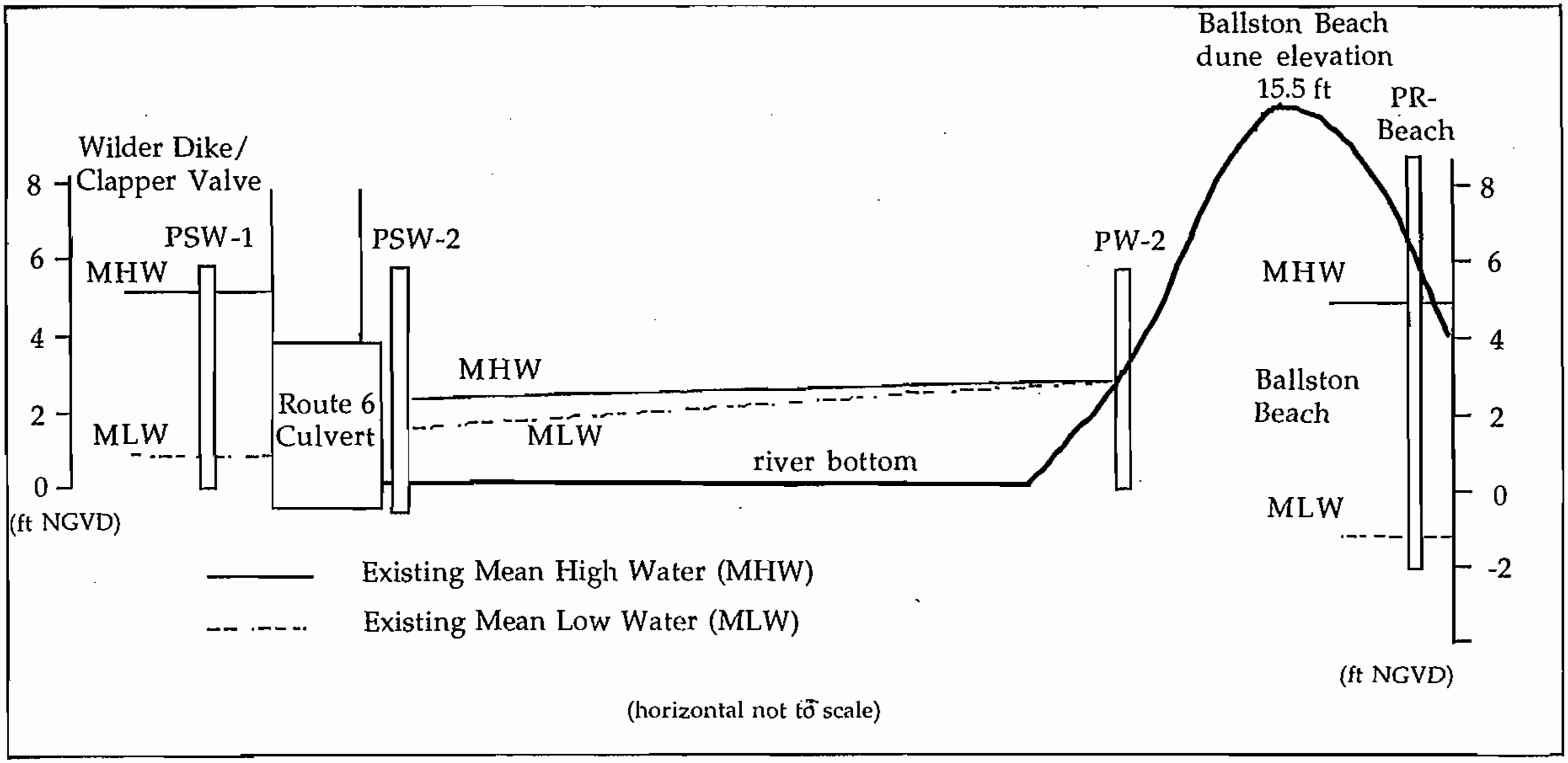


Figure 13. Simplified Hydraulic Cross-Section of the Upper Pamet River

Groundwater Model
The Cape Cod Commission subcontracted the Lower Cape Water Management Task Force to prepare a groundwater flow model for the interlens discharge area of the Pamet River. The objective of the modeling effort was to assist in characterizing the system and to use the model to explore hypotheses about its functions. In addition, development of the model can assist in determining where collection of additional information would be desirable for a more refined characterization. This reconnaissance level model is not intended, nor can it be used, for evaluation of various tidal/clapper valve scenarios. Additional data collection and model enhancements would be necessary to evaluate tidal scenarios.

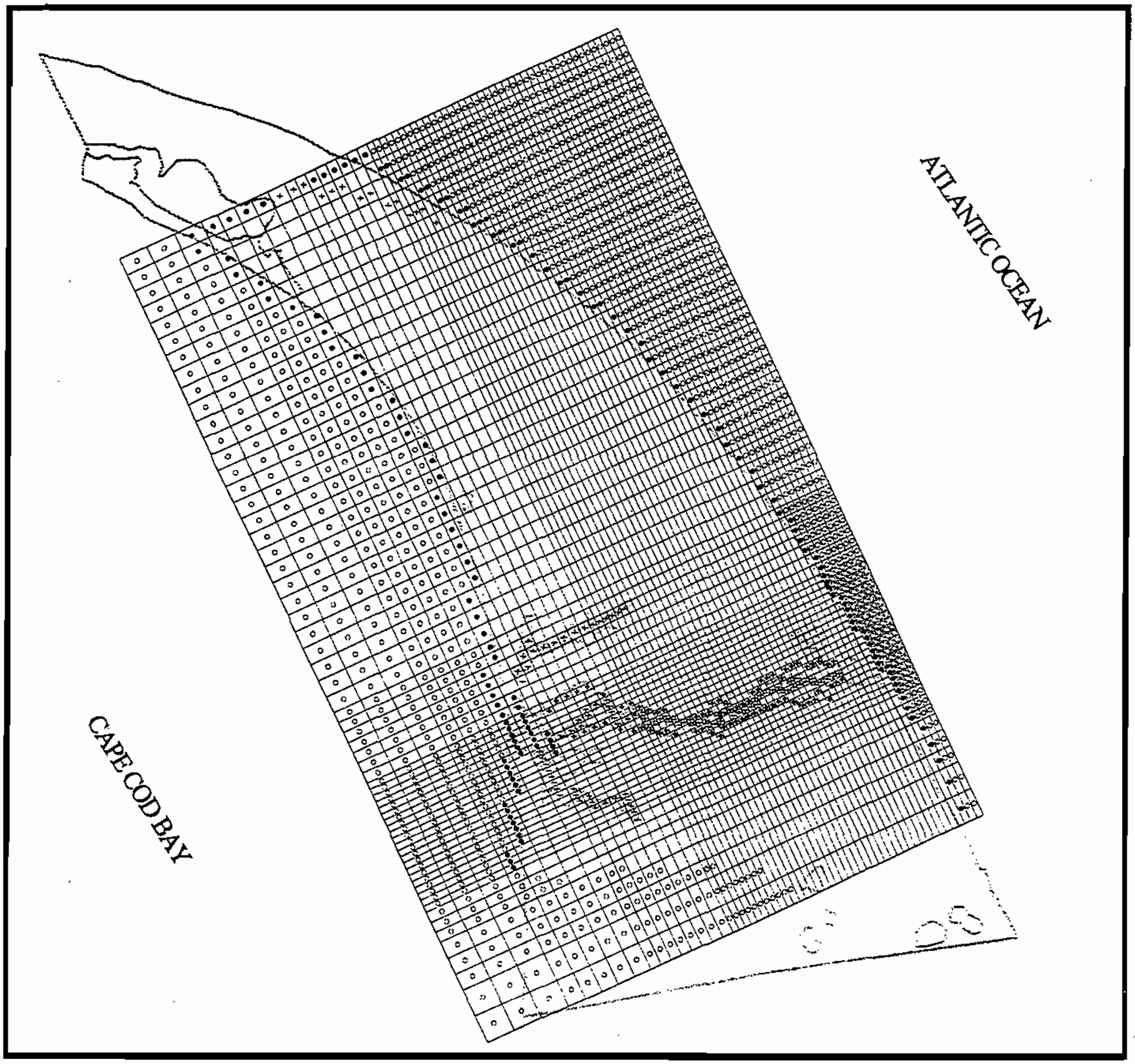
The model for the Pamet River stream-aquifer system extends from Great Pond in Truro to Pilgrim Lake in Truro and is bounded by Cape Cod Bay and the Atlantic Ocean. The lateral extent of the model was chosen to: 1) include the entire watershed of the Pamet River, 2) incorporate current pumping stresses in the Pamet Lens, and 3) be useful for future modeling work on the Pamet Lens.

Model Structure
The model consists of 7 vertical layers. The six lower layers generally use elevations and hydraulic parameters developed by the US Geological Survey (USGS) for their regional models of the Pamet and Chequesset Lenses (Guswa and LeBlanc, 1985; Masterson and Barlow, 1994). Modeling information developed by the National Park Service was also considered (Martin, 1993). An additional layer was added to the top of the model to accommodate comparison between simulated and observed vertical gradients beneath the Pamet River.

The 16.5 mi^2 modeled area is subdivided into a grid of rectangular cells arranged in 64 rows and 57 columns (Figure 14). Cell dimensions range from a minimum of 300 by 300 ft to a maximum of 1,250 by 1,250 ft. Grid spacing is smallest near the Pamet River so that the detailed field data collected in this area can be utilized in the calibration of the model and so groundwater interactions in this area can be accurately simulated.

Hydraulic Parameters
Hydraulic conductivity is a parameter that describes the ability of a material to allow water to flow through it. Hydraulic conductivity is expressed in units of length/time (ft/day in the model) and higher values are assigned to sands and gravel and lower values to clays and peat (Freeze and Cherry, 1979). Hydraulic conductivity in the vertical direction is represented in groundwater models by a derivative of hydraulic conductivity called vertical conductance (units of ft^{-1}), which describes the hydraulic conductivity between layers of the model.

Hydraulic conductivities and vertical conductances for the upland portions of the model primarily correspond to values determined in previous investigations by



EXPLANATION

- ○ inactive area of model
- ● areas of coastal discharge and constant groundwater level
- + areas of vertical stream seepage underneath streambed
- ✚ areas of horizontal seepage along the perimeter of the marsh

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Figure 14

Grid Area for Groundwater Flow Model

Guswa and LeBlanc (1985) and Masterson and Barlow (1994). In general, horizontal conductivities in the model range from 350 ft/day for coarse sand to 50 ft/day in areas of fine sand and ratios of vertical to horizontal hydraulic conductivity range from 1:3 for medium sand and gravel to 1:30 for fine sand (Masterson and Barlow, 1994). Horizontal hydraulic conductivities and vertical conductance generally decrease with depth in the model. Marsh sediments were assigned a hydraulic conductivity of 0.5 ft/day to represent the generally low conductivity of clay and peat sediments (Freeze and Cherry, 1979).

Existing Pumping

Groundwater is pumped at the Paul Daley, Knowles Crossing, and North Truro Air Force Base (NTAFB) municipal wells in the northern portion of the Pamet Lens. Pumping rates of 0.6 million gallons per day (Mgal/day) for the Paul Daley well and 0.1 Mgal/day for the NTAFB well were simulated in the fourth layer from the top of the model. A 0.1 Mgal/day pumping rate from Knowles Crossing was simulated in layer 3. Return flow between Route 6 and Route 6A accounts for 16% of the total amount of pumped water. The remaining 84% is transported outside the modeled area to provide drinking water to Provincetown and North Truro. No provision was made in the model to account for the pumping of private wells because on-site septic systems are assumed to return an equivalent volume of water to the same parcel.

Boundary Conditions

In order to run a groundwater model, conditions along the periphery of the modeled area need to be selected. These parameters are called boundary conditions. Poorly chosen boundary conditions can result in the selection of inaccurate aquifer parameters during the calibration of the model and faulty simulation results. The boundary conditions discussed below were chosen to represent average annual conditions within the flow system.

The bottom boundary of the model is defined by the interface between freshwater and saltwater saturated sediments. The depth to the interface was estimated using the Ghyben-Herzberg relationship that each foot of groundwater above mean sea level corresponds to an equivalent 40 feet of groundwater below mean sea level. Flow across the interface is assumed to be insignificant and is modeled as a no-flow boundary.

The southern boundary of the modeled area approximates the top of the groundwater divide on the Chequesset Lens. Groundwater to the north of this divide is assumed to flow toward the Pamet River and groundwater to the south is assumed to flow toward Herring River system in Wellfleet. This is called a no-flow boundary because groundwater never flows across the divide. In the natural system, however, the location of the divide may shift in response to seasonal changes in recharge to the water table.

The model boundaries on the east and west are the Atlantic Ocean and Cape Cod Bay, respectively. Groundwater discharge is assumed to occur along the edge of coastline in the model. Because these coastal discharge areas exhibit only minimal changes in groundwater levels, the cells in the model representing these areas are assigned constant groundwater levels. The assigned water levels have been converted to equivalent freshwater levels because the discharging groundwater is overlain by saltwater. Pilgrim Lake defines the northern boundary of the model and is also modeled as an area of constant water level.

The inland area of the upper surface of the model is bounded by the water table and areas of stream discharge. The modeled area annually receives about forty inches of precipitation, approximately half of which is assumed to reach the water table. The low hydraulic conductivity of marsh sediments, high rates of evapotranspiration from marsh vegetation, and high potential for surface water runoff diminish recharge in marsh areas.

Stream drainage of groundwater within the modeled area occurs at Pamet River, Mill Pond, Little Pamet River, and Salt Meadow. The volume of discharge to these streams depends on the hydraulic gradient between the streams and surrounding aquifer, hydraulic properties of the surrounding sediments, and the elevation and geometry of the stream channel. The hydraulic conductance of streambed sediments is a parameter in the model which represents a wide assortment of stream-aquifer characteristics. Streambed conductance is calculated for each cell containing a reach of stream by the relationship $C = KLW/T$ where K is the hydraulic conductivity of streambed sediments (ft/day), W is the width of the stream channel (ft), L is the length of river in the cell (ft) and T is the thickness of the streambed sediments (ft). The altitude of the streambed of the Pamet River east of Route 6 was assigned a uniform value of 0.2 ft NGVD based on survey information collected by the ACOE. The hydraulic conductivity of streambed sediments were assumed to equal that of the surrounding marsh sediments.

Model Calibration

Calibration is a process in which model parameters are adjusted within reasonable ranges until the simulated results of the model match actual observations made in the field. The study area model was calibrated to water levels taken at 27 observation wells, streamflow in the Pamet River at Route 6, and vertical gradients below the streambed measured near Route 6 and Ballston Beach (see Figures 9 and 10). Because the modeled area combines information from two previous models of the Pamet and Chequesset Lenses and new information collected near the Pamet River, statistical comparisons of simulated and observed water levels were conducted separately for the Pamet Lens, Chequesset Lens, and Pamet River areas of the model (see Appendix III for modeling documentation).

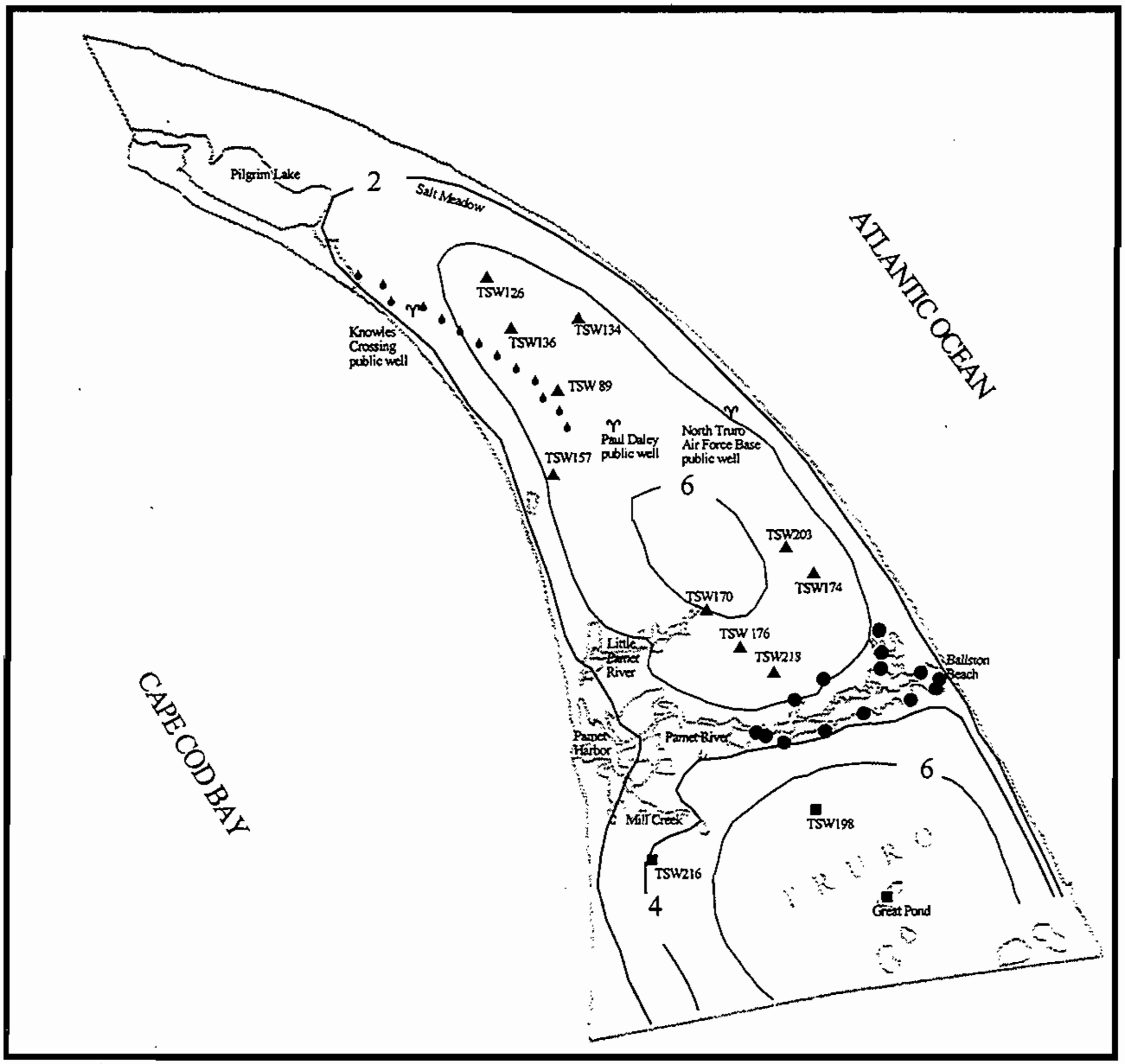
The model was calibrated by adjusting various parameters and boundary conditions. It was initially assumed that groundwater discharge occurred primarily as vertical seepage through the bottom of streambed sediments underlying the Pamet River. However, this conceptual design of the model consistently underestimated streamflow by more than half of observed and historical (Lewis, 1989) values. Review of aerial photographs and visual observation of surface flows entering the river though mosquito ditches and other surface drains suggested that these may be important contributors to the observed streamflows in the river. A random measurement of one seepage ditch on South Pamet Road found flows ranging between 0 and 0.6 cfs.

Based on these observations, a horizontal seepage component along the entire perimeter of the marsh was added to the model at 2.5 ft NGVD. The groundwater which drains off the aquifer as a result of this seepage component was assumed to directly discharge into the river. The ratio of seepage conductance along the marsh perimeter to seepage conductance beneath the river was assumed to be 60:1 to reflect the higher hydraulic conductivity of sandy sediments at the perimeter of the marsh.

Other efforts to calibrate the model to more closely match observed streamflow included increasing the initial estimates of recharge in non-marsh areas of the model from 20 in/yr to 23 in/yr and increasing initial estimates of recharge in marsh areas of the model from 0 in/yr to 8 in/yr. Hydraulic conductivity of the uppermost layer was uniformly increased by thirty percent (30%) and vertical conductances of the lower six layers in the southern portion of the model were reduced by an order of magnitude to more closely match observed water levels. A map of the resulting simulated water table is shown in Figure 15.

There is generally close agreement between observed and calculated water levels, streamflow at Route 6, and vertical gradients below the streambed. The mean error between the absolute value of observed water levels minus simulated water levels in observation wells located in the Pamet and Chequesset Lenses is 0.4 ft, which corresponds to between 5 and 9% of the maximum and minimum water levels in these portions of the modeled area, respectively. The mean error of the observed water levels minus simulated water levels in observation wells located near the Pamet River is 0.6 ft, which corresponds to between 12 and 22% of water levels in this portion of the modeled area. The higher mean error in the Pamet River area is likely due to observed water levels in the area being approximately 0.5 ft above the average annual conditions the model was developed to represent (see Figure 7).

Field measured streamflow at Route 6 range from 4 to 6 cfs in this and previous investigations. The model simulates an annual average streamflow of 3.7 cfs at Route 6 and an annual average streamflow of 5.8 cfs for the entire Pamet River. As discussed above (Stream Flow Measurements section), corresponding estimated streamflows based on 1.5 ft of annual recharge on the Upper Pamet River and whole



EXPLANATION

— model simulated water table

● observation well near Pamet River

▲ observation well in Pamet Lens

■ observation well in Chequesset Lens

ϒ existing public supply wells

• areas of return flow

Figure 15

Simulated Water Table Map

N

⇧

half miles

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Pamet River watersheds are 3.0 and 6.3 cfs, respectively. The modeled and recharge method streamflow estimates show good agreement, but they are between 8 and 50% less than the streamflow measurements at Route 6 collected for this study. These differences were examined during the sensitivity analysis of the model.

A water budget of the model was developed to account for the various water flows with the modeled area (Table 6). This analysis in the upper Pamet River also showed that approximately eighty-five percent (85% or 3.1 cfs) of total flow in this portion of the model originates as seepage along the perimeter of the marsh and fifteen percent (15%) originates as vertical seepage through the bottom of the main channel. This difference accentuates the importance of the surface drains along the margins of the marsh to the observed flow within the river.

Table 6. Simulated Water Budget.

Water Budget Item	freshwater flow (cfs)	percentage (%) of total model discharge
MODEL INFLOW		
recharge	26.6	99.4
wastewater return flow	0.2	0.6
MODEL OUTFLOW		
COASTAL DISCHARGE:	18.8	70.1
Pamet Harbor	1.4	5.1
Ballston Beach	0.6	2.1
all other coastal areas	16.8	62.9
STREAM DISCHARGE:	6.8	25.1
Upper Pamet River	3.7	13.8
Lower Pamet River	2.1	7.7
Mill Pond creek	0.4	1.6
Little Pamet	0.4	1.6
Salt Meadow	0.2	0.6
PUBLIC WELLS	1.2	4.6
MODEL ERROR	0.0	-0.1

Sensitivity Analysis

Following calibration of the model, a sensitivity analysis was completed to determine which model parameters and boundary conditions exhibit the greatest control on the response of simulated water levels, streamflow, and vertical gradients below the streambed. This analysis was done because model parameters (such as hydraulic conductivity, vertical conductance, and streambed conductance) and boundary conditions (such as recharge and depth to the saltwater interface) are best estimates of the actual parameters and conditions, but they are still estimates. This type of analysis can also be used as a guide for prioritizing future data collection to improve characterization of the system. Parameters and boundary conditions were uniformly adjusted across the range of values reported below in Table 7 and the model was run a number of times to measure its sensitivity to these adjustments.

Table 7. Parameter Ranges and Boundary Conditions Adjusted in the Sensitivity Analysis of the Groundwater Model.

MODEL PARAMETER	CALIBRATED VALUE	SENSITIVITY RANGE
hydraulic conductivity of wetland	0.5 ft/day	0.005 to 50
vertical conductance of wetland	0.008/day	0.001 to 1
elevation of perimeter of marsh seepage	2.5 ft	0.5 to 4.5
hydraulic conductivity of seepage along marsh perimeter	50 ft/day	0.5 to 500
hydraulic conductivity of layer 1	variable	multiplied by 0.001 to 100
vertical conductance between layers 1 and 2	variable	multiplied by 0.001 to 100
recharge in non-marsh areas	23 in/yr	12 to 35
recharge in marsh areas	8 in/yr	0 to 23
hydraulic conductivity of layer 7	variable	multiplied by 0.01 to 100
vertical conductance between layers 6 and 7	variable	multiplied by 0.01 to 100
depth to saltwater interface	40:1 ratio	30:1 to 50:1

Simulated water levels are most sensitive to removal of horizontal seepage along the perimeter of the marsh. When removed, simulated streamflow at Route 6 decreases to 1.1 cfs. Stream flow increases to 3.5 cfs in this same configuration when areas modeled as marsh are replaced with areas with hydraulic parameters representative of coarse sand. However, this adjustment is contrary to field observations of low permeable sediments throughout the marsh areas and at depth beneath the river.

Water levels in all areas of the model and streamflow are also sensitive to the vertical conductance between layers 1 and 2 in non-marsh areas, recharge to non-marsh areas, the depth of the saltwater interface, and the altitude that seepage occurs along the perimeter of the marsh. Simulated streamflow in the Pamet River increased by 59% (to 5.88 cfs) when recharge was increased by 50% (to 34.5 inches/yr) and increased by 51% (to 5.59 cfs) when the vertical conductance between layers 1 and 2 was reduced by three orders of magnitude. Since groundwater seeps in the river bottom were observed and estimated as approximately 10% of the river bottom, a model configuration assigning 10% of the layer 1 cells a higher streambed conductance was also evaluated. This configuration had negligible effect on the resulting stream flows in the calibrated simulation.

Streamflow increased by 22% (to 4.51 cfs) when the depth of the saltwater interface was reduced by 25% (from 40 ft to 30 ft for every foot of groundwater above NGVD). Streamflow increased 23% (to 4.55 cfs) when the altitude of seepage along the perimeter of the marsh was lowered 2 feet (from 2.5 to 0.5 ft NGVD). The reduction in the depth to the saltwater interface is contrary to the observations at PW-3 and other wells in the Pamet Lens. It should be noted that adjustments in the above parameters to increase stream flow decreased the accuracy of the calibrated simulation considerably by over-predicting the water levels throughout the watershed (*i.e.*, the differences between observed and modeled water levels increased).

Simulated vertical gradients beneath the Pamet River are most sensitive to the altitude that seepage occurs along the perimeter of the marsh, the hydraulic conductivity of the marsh, and the vertical conductance between the marsh sediments and layer 2. All aspects of the model were relatively insensitive to the adjustment of hydraulic properties at depth.

Data Collection Recommendations based on Groundwater Modeling

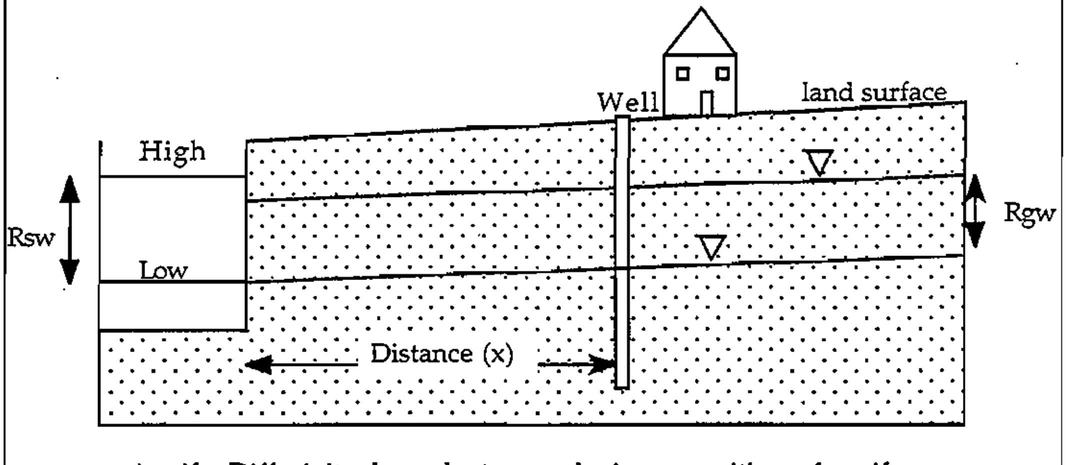
Since the model predicted flows in the Pamet River lower than observed flows, further characterization of the various aspects of the Pamet River system is warranted to improve the precision of the model. Characterization of freshwater flow to the Pamet River can be improved by measuring the freshwater flow contribution from mosquito ditches and other surface tributaries, the altitude of the tributaries and the thickness of the underlying marsh sediments (if any), and measuring streamflow at several stations along the entire length of the river. Measurement of streamflow along the length would help in characterizing the groundwater interactions along different portions of the river. Further characterization of freshwater discharge from the Pamet River and other streams in the modeled area can also be improved with more precise estimates of the amount and seasonal variability of precipitation and recharge and the depth and thickness of the interface between freshwater and saltwater saturated sediments.

Analytical Tidal Rise Model

In a previous study of the Sagamore Marsh, the USGS assessed the potential impact on groundwater levels resulting from an increase in tidal flow (Walter, *et al.*, 1995). The USGS utilized an analytical model developed by Ferris (1963) to complete this assessment. The analytical model uses the following equation and a known range of surface water levels to predict a range of groundwater levels at a specified distance from a tidal channel:

$$\log \frac{Rgw}{Rsw} = -0.77x\sqrt{\frac{1}{\alpha t}}$$

Rgw is the range (ft) of groundwater levels in an observation well, *Rsw* is the range (ft) of surface water levels in the channel or tidal body, *x* is the distance (ft) of the groundwater observation well from the tidal channel; *t* is the period (days) of the tidal cycle; and α is the aquifer diffusivity (ft^2/day). Diffusivity is defined as the transmissivity (T) divided by the storage coefficient (S). The storage coefficient is defined as the volume of water that flows from a volume of an aquifer due to a change in water levels (Freeze and Cherry, 1979). Transmissivity is defined as the hydraulic conductivity times the thickness of the aquifer. Figure 16 presents a schematic representation of the variables involved with the analytical model.



Aquifer Diffusivity dependent on geologic composition of aquifer

Figure 16. Schematic Explanation of Analytical Tide Rise Model.

To calculate the diffusivity of the Upper Pamet marsh, staff utilized the groundwater and tidal fluctuations measured at monitoring well PR-2s (R*gw* = 0.4 ft) and stream gauge PSW-2 (R*sw* = 0.65 ft), respectively. PR-2s is approximately 5 ft from the tidal channel and the tidal period is 0.51 days. A diffusivity of 654 ft^2/day is calculated using these input parameters in the analytical model. Walter and his coauthors (1996) determined diffusivities of 170 and 380 ft^2/day at two sites in the Sagamore Marsh.

The ACOE has utilized UNET, a one-dimensional, finite-difference model, to conduct a preliminary assessment of the expected tidal ranges within the Pamet River. The ACOE modeled the potential rise in water elevations at Wilder Dike, the east side of Route 6, and at Ballston Beach under existing conditions, with the removal of the tidal gate, and with the tidal gate removed and an open channel through Wilder Dike and Route 6 (Table 8). The model predicts a 0.9 ft increase in the river level at Ballston Beach and a 2.4 ft increase at the Route 6 culvert with the removal of the tidal gate and an opening of a channel under Wilder Dike and Route 6. At Wilder Dike, the mean high water mark is predicted to decrease by 0.4 ft under the same conditions (see Table 8).

Table 8. Predicted Changes in Stage Elevations within the Upper Pamet River.

CONDITION	WATER ELEVATION (FT)			
	PAMET HARBOR	WILDER DIKE	EAST OF ROUTE 6	PAMET RIVER AT BALLSTON BEACH
Existing	5.3	5.2	2.2	3.0
Tidal gate removed	5.3	5.2	2.7	3.2
Tidal gate removed and an open channel through Wilder Dike and route 6	5.3	4.8	4.6	3.9

Note: Elevations are at mean high water mark NGVD.

Using the calculated diffusivity of 654 ft^2/day, the two increases (0.9 and 2.4 ft) in the range of river water elevations, and the calculated diffusivity of 654 ft^2/day, the analytical model was used to determine the predicted rise in water levels at various distances from the river channel (Figure 17). These results show that at a distance of 46 ft from the river channel at Ballston Beach and 56 ft from the river channel at Route 6, the range of groundwater fluctuations would be 0.01 ft. Thus, the expected rise in river water elevations should have a decreasing impact on groundwater fluctuations as one moves away from the river and as one travels towards the east along the Pamet River. In addition, since the minimum difference between a house and the river channel is 500 ft, the maximum predicted tidal range (2.4 ft) should have no measurable impact at this distance. This attenuation of the tidal range is due to the low permeability peat layer within the marsh, which acts as a buffer to the tidal fluctuations occurring in the river.

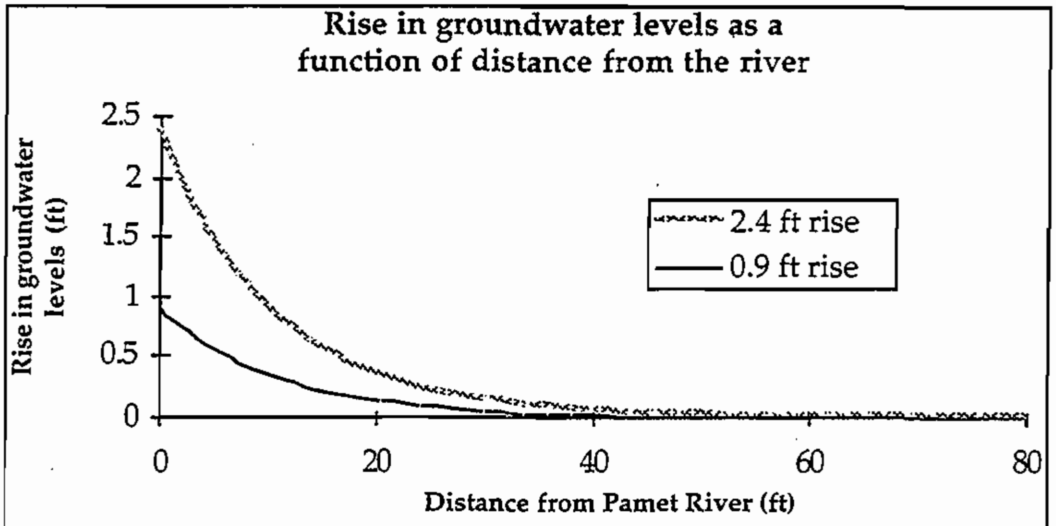


Figure 17. Predicted Rise in Groundwater Levels in Pamet Marsh

The results of the analytical model are dependent on the selection of an appropriate diffusivity of the marsh sediments. Within the Sagamore Marsh study area, diffusivity values ranged from a 275 ft^2/day average for marsh sediments to 2.25 x 10^5 ft^2/day for sand and silt sediments (Walter, *et al.*, 1996). An increase in the diffusivity value corresponds to an increase in the hydraulic conductivity of the sediments. Thus as diffusivity increases, the difference between the tidal fluctuations and the tidal-induced groundwater fluctuations approaches zero.

The calculated diffusivity for the Upper Pamet Marsh was determined to be 654 ft^2/day. Using this diffusivity value and either of the predicted surface water rises (0.9 ft at Ballston Beach and 2.4 ft at Route 6), less than 0.01 ft of groundwater rise is predicted at a distance of 500 ft from the river at either location. If a diffusivity for sand (2.25 x 10^5 ft^2/day) is used, the predicted groundwater rises at a 500 ft distance increase to 0.07 ft and 0.18 ft, respectively (Figure 18). With the higher diffusivity value and the higher surface water, at a distance of 1,000 ft, the rise in groundwater levels is predicted to be 0.01 ft. Thus, even with a much better hydraulic connection between the river and the surrounding materials, the predicted fluctuations in water levels are less than the historic fluctuations (~ 1.8 ft) in groundwater levels in the area (see TSW discussion). Figure 18 presents the predicted impact on groundwater levels at a distance of 500 feet from the river channel with various diffusivity values.

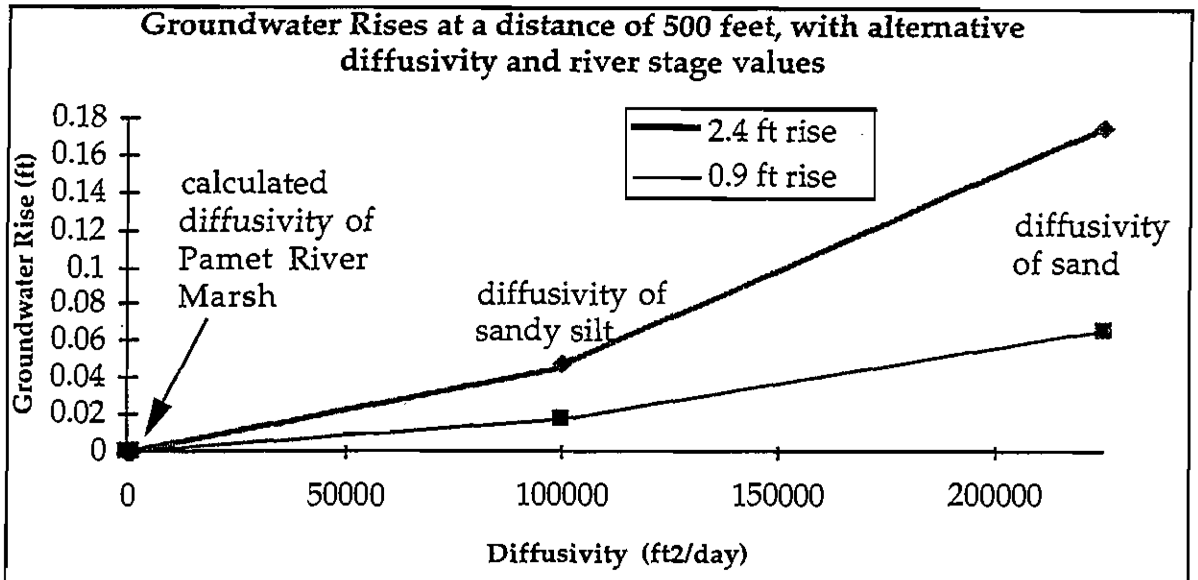


Figure 18. Sensitivity Analysis for Analytical Groundwater Rise Model

V. CONCLUSIONS

Water level measurements in the Pamet River valley indicate that the Pamet River is a discharge area for the Pamet and Chequesset groundwater lenses. Significant upward gradients toward the river have been observed at both local and regional scales. Groundwater modeling based on the collected hydrogeologic information suggest that the marsh surrounding the Pamet River serves to isolate the river from all but limited direct contact with the aquifer underlying the marsh. Modeling results indicate that 85% of the river discharge comes from surface water drains (*i.e.*, mosquito ditches) of the surrounding aquifer that flow across the top of the marsh and discharge into the river. Field observations combined with modeling results suggest that the remaining 15% of the river flow comes from direct groundwater discharge through highly conductive portions of the river bottom.

Analysis of water levels in the river suggest that relatively constant groundwater levels (~ 3 ft NGVD) are maintained at the eastern end of the Pamet River with fluctuations of ~ 1 ft at the Route 6 culvert. The nearly constant water levels near Ballston Beach cause the river to flow toward Route 6 during both high water and low water conditions near Wilder Dike. Tidal modeling of possible water level fluctuations within the river by the ACOE suggest that if the clapper valve at Wilder Dike and flow restrictions under the Route 6 culvert are removed, water levels near Ballston Beach will increase by 0.9 ft, while water levels near Route 6 will increase 2.4 ft.

This study used these modeling results to evaluate the impact of removing the clapper valve on groundwater levels. The analytical model used to evaluate the impact predicted minimal impacts (< 0.01 ft) on the range of groundwater fluctuations at the nearest (~ 500 ft from the river) wells and septic systems. The model suggests that water levels at wells and septic systems greater than 500 ft from the river will experience even less change in groundwater fluctuations.

These results indicate that the limited flow characteristics of the peat in the marsh system surrounding the Upper Pamet River cause tidal ranges within the river to have minimal effect on groundwater levels in the Upper Pamet River valley. In addition, the significant thickness of the aquifer system (greater than 150 ft in the middle portion of the Upper Pamet River valley) and upward groundwater gradients suggest that salt water flow from the river into the surrounding groundwater lenses will be prevented.

VI. RECOMMENDATIONS

Although this report has determined that there will be insignificant impacts on groundwater levels surrounding the Pamet River from increased tidal activity in the Upper Pamet, additional data collection and analyses are necessary to better understand how groundwater flows into the river, to quantify the magnitude of the river/aquifer system interactions with the underlying saltwater interface, and to determine how improvement in tidal interaction in the Upper Pamet might affect draining of salt water from the system during the next overwash of Ballston Beach. The following recommendations address these concerns:

1) Establishment of a long term stream flow monitoring program with a measuring point at Wilder Dike and various points within the river. This data will help to establish the variability of river flows and groundwater discharge along the river.
2) Incorporation of the above recommended data into the groundwater model and introduction of variable density capability into the model to simulate the potential movement of the saltwater interface.
3) Coordination of an iterative design analysis process between the groundwater model and a surface water model, which includes tidal influences, to better understand the impacts of surface water flows on groundwater levels and vice-a-versa.
4) Establishment of an overwash response plan to facilitate the removal of saltwater following the overwash of Ballston Beach. Prior to the establishment of a long term management plan for the Upper Pamet River, a plan should be established to hasten the draining of overwashed saltwater from the Upper Pamet.

REFERENCES

Cambareri, T.C., E. M. Eichner, and C. A. Griffeth. 1993. Hydrogeologic Evaluation for the Waquoit Bay Land Ecosystem Research Project. Characterization of the Watershed and Submarine Groundwater Discharge. Cape Cod Commission, Barnstable, MA.

Cambareri, T.C., G. Belfit, and D.S. Janik. 1989a. Hydrogeologic Assessment of the Truro Landfill, Truro, Massachusetts. Cape Cod Planning and Economic Development Commission, Barnstable, MA.

Cambareri, T.C., G. Belfit, D.S. Janik, P. Irvin, B. Campbell, and D. McCaffery. 1989b. Truro/Provincetown Aquifer Assessment and Groundwater Protection Plan. Cape Cod Planning and Economic Development Commission, Barnstable, MA.

Fitterman, D.V. and K.F. Dennehy. 1992. Verification of Geophysically Determined Depths to Saltwater Near the Herring River (Cape Cod National Seashore), Wellfleet, Massachusetts. Boston: National Park Service. Technical Report NPS/NAROSS/NRTR-92/05.

Ferris, J.G. 1963. Cyclic water-level fluctuations as a basis for determining aquifer transmissivity: in Methods of determining permeability, transmissibility, and drawdown. Bentall, Ray ed. U.S. Geologic Survey Water Supply Paper 1536-I, pp. 305-318.

Freeze, R.A. and J.A. Cherry. 1979. *Groundwater*. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Frimpter, M.H. and F.B. Gay. 1979. Chemical Quality of Ground Water on Cape Cod. Water-Resources Investigations 79-65. United States Geological Survey, Washington, DC.

Giese, G.S., C.T. Friedrichs, D.G. Aubrey, and R.G. Lewis, II. 1990. Application and Assessment of a Shallow-Water Tide Model to Pamet River, Truro, MA. Report submitted to the Truro Conservation Trust.

Giese, G.S., and C.T. Westcott. 1980. Pamet Inlet: A study of shoaling and erosion problems with recommendations for management. Provincetown: Provincetown Center for Costal Studies. No. 80-2.

Guswa, J. and D. LeBlanc. 1981. Digital Models of Ground-Water Flow in the Cape Cod Aquifer System. US Geological Survey Water Resources Investigation - Open-File Report 80-67. US Geological Survey, Marlborough, MA.

Guswa, J.H., and D.R. LeBlanc. 1985. Digital Models of Groundwater Flow in the Cape Cod Aquifer System, MA, US Geological Survey Water Supply Paper 2209. US Geological Survey, Marlborough, MA.

Horsley & Witten, Inc. 1994. Final Report: Pamet Harbor management plan. Barnstable, MA.

Koteff, C., R.N. Oldale, and J.H. Hartshorn. 1967. Geologic Map of the North Truro Quadrangle, Barnstable County, Massachusetts. Geologic Quadrangle Maps of the United States. U.S. Geologic Survey, Washington, DC.

LeBlanc, D.R., J.H. Guswa, M.H. Frimpter, and C.J. Londquist. 1986. Ground-Water Resources of Cape Cod, Massachusetts. Hydrogeologic Investigations Atlas. US

Geological Survey, Marlborough, MA.

Lewis II, R.G. 1989. A presentation of data collected during the summer of 1988 concerning tidal characteristics and pollution in the Pamet River Basin. Parsons Laboratory, MIT, Cambridge, MA.

Martin, L. 1993. Investigation of Effects of Ground Water Withdrawals from the Pamet and Chequesset Aquifers, Cape Cod National Seashore. Technical Report NPS/NRWRD/NRTR-93/14. National Park Service, Water Resources Division, Fort Collins, CO.

Masterson, J.P. and P.M. Barlow. 1994. Effects of Simulated Ground-Water Pumping and Recharge on Ground-Water Flow in Cape Cod, Martha's Vineyard, and Nantucket Island Basins, Massachusetts. US Geological Survey Open-File Report 94-316. US Geological Survey, Marlborough, MA.

Oldale, R. 1968. Geologic Map of the Wellfleet Quadrangle, Barnstable County, Massachusetts. Geologic Quadrangle Maps of the United States. U.S. Geologic Survey, Washington, DC.

Pamet River Workshop. 1993. Discussion for long term management. Paper read at Pamet River Workshop, March 18, at Truro, MA.

Provincetown Center for Coastal Studies. 1979. Summary Report of a Study of Pamet Inlet. Provincetown: July.

Robinson, Mark H. 1985a. Fiscal impacts of seasonal versus year-round residences in Truro, MA. Truro. Truro Conservation Trust, Truro, MA.

Robinson, Mark H. 1985b. Opening Pamet: Possible changes due to reintroduction of tidal flow to Pamet River system. Truro Conservation Trust, Truro, MA.

Roman, C.T. 1987. An valuation of alternatives for estuarine restoration management: the Herring River ecosystem (Cape Cod National Seashore). Center for Costal Studies - Rutgers University, New Brunswick, NJ.

Roman, C.T., R.W. Garvine, and J.W. Portnoy. 1995. Hydrologic modeling as a predictive basis for ecological restoration of salt marshes. *Environmental Management*. 19(4): 559-566.

Sobczak, B. and T. Cambareri. 1995. Interim Report. Lower Cape Water Management Task Force. Cape Cod Commission, Barnstable, MA.

Strahler, A.N. 1966. *A Geologist's View of Cape Cod*. The Natural History Press, Garden City, NY.

Truro Conservation Commission. 1993. The Pamet River: What is its future?

Walter, D.A., J.P. Masterson, and P.M. Barlow. 1996. Hydrogeology and Analysis of Ground-Water-Flow System, Sagamore Marsh Area, Southeastern Massachusetts. US Geological Survey Water Resources Investigations Report 96-4200. US Geological Survey, Marlborough, MA.

Appendix I: Annotated Bibliography

Annotated Bibliography of Studies of the Pamet River and associated areas

Cambareri, T.C., G. Belfit, and D.S. Janik. 1989. Hydrogeologic Assessment of the Truro Landfill, Truro, Massachusetts. Cape Cod Planning and Economic Development Commission, Barnstable, MA.

Detailed water-table maps for the Pamet and Chequesset Lenses were completed. The study identified potential municipal supply well sites within the lenses. Additional aspects of the study address zones of contribution for existing municipal supply wells and nitrogen loading analysis for existing wells.

Fitterman, David V., and Kevin F. Dennehy. 1992. Verification of Geophysically Determined Depths to Saltwater Near the Herring River (Cape Cod National Seashore), Wellfleet, Massachusetts. Boston: National Park Service. Technical Report NPS/NAROSS/NRTR-92/05. July.

Identified possible impacts on domestic water wells caused by adjustments to the tidal control structure on the Herring River in Wellfleet, MA. Electromagnetic measurements, water conductivity data, and inductions logs were utilized to predict the location of the saltwater-freshwater interface, which was found approximately 13 to 29 meters below the water table. Adjusting the tidal flow into the upper portions of the Herring River is predicted to have negligible impacts on domestic wells. An increase in tidal flow within the Herring River will cause only a minor rise (~ 0.5 m) in saltwater levels.

Giese, G.S., and C.T. Westcott. 1980. Pamet River: A study of shoaling erosion problems with recommendations for management. Provincetown: Provincetown Center for Costal Studies. No. 80-2.

Report on historical changes within Pamet Harbor. Predicts a 20% increase in the tidal prism with the removal of dike structures in the Lower Pamet. Within the Upper Pamet River, the tidal range was predicted to be 2 feet. Report recommends a management program to increase the navigability of the Harbor and to protect and further develop the barrier beach on the northern edge of the Pamet inlet.

Giese, G.S., C.T. Friedrichs, D.G. Aubrey, and R.G. Lewis, II. 1990. Application and assessment of a shallow-water tide model to Pamet River, Truro, MA.: Woods Hole Oceanographic Institute.

Finite-difference numeric models were used to predict the change in tidal prism after the removal of tidal structures at Wilder's Dike on the Pamet River. Less than a five percent (5%) increase the tidal prism was predicted. Because only the removal of one dike structure was considered, further studies are recommended to predict the impacts of complete removal of all dike structures within the system.

Horsley & Witten. 1994. Final Report: Pamet Harbor management plan. Barnstable: June.

Plan to restore the usefulness of Pamet Harbor as a navigational channel for recreational boats and small commercial fishing boats. The Plan recommends dredging the Harbor to enhance navigation, water quality, and beach replenishment,

while at the same time protecting the natural resources of the harbor.

Lewis II, Richard G. 1989. A presentation of data collected during the summer of 1988 concerning tidal characteristics and pollution in the Pamet River Basin. Cambridge: Parsons Laboratory MIT. February.
Data collected on the Pamet River's hydrology is the first phase of a three year project. Salinity, tidal flow and tidal elevation were taken during the summer of 1989. Data used by Giese *et. al.* (1993) for numeric tidal modeling of the Pamet.

Masterson, John P., and Paul M. Barlow. 1994. Effects of simulated ground-water pumping and recharge on ground-water flow in Cape Cod, Martha's Vineyard, and Nantucket Island Basins, Massachusetts. : U.S. Geological Survey Open-File Report 94-316. U.S. Geological Survey, Marlborough, MA.
The report reviews the regional hydrology, geology, and research work within the Cape Cod Basin. Historic, current, and projected water demand issues are discussed. MODFLOW based models are used to simulate the effects of groundwater pumping on water table elevations, pond elevations, and the saltwater/freshwater interface. The models, which include models of the Chequesset and Pamet lenses, can be customized by users to address specific pumping conditions.

McDonald, M.G., and A.W. Harbaugh. 1988. A modular three-dimensional finite-difference ground-water-flow model. U.S. Geological Survey Techniques of Water Resources Investigations book 6 (Chap. A1): 586.
Outlines the development and operation of MODFLOW, a three-dimensional, finite-difference, single-fluid flow model. MODFLOW is capable of simulating changes in groundwater level and flow under transient and steady state conditions.

Pamet River Workshop. 1993. Discussion for long term management. Proceedings from the Pamet River Workshop, March 18, at Cape Cod National Seashore, Marconi Station Headquarters.
Conference coordinated to address issues related to overwash of Ballston Beach during the winter of 1991. Various scientists and town officials discuss potential impacts and recommended efforts to cope with future overwashes. Conference attendees suggest a detailed hydrogeologic study of the area is necessary to predict possible impacts of overwashes and any mitigative measures that might be taken to reduce flooding to the River system.

Provincetown Center for Coastal Studies. 1979. Summary Report of a Study of Pamet Inlet. Provincetown: July.
A summary of the historical changes that have occurred within the Pamet River system. The study identifies human induced changes to the tidal flow patterns and land formations to the Lower Pamet, specifically the harbor area. Study recommends dredging of the Inner Harbor be undertaken to reduce shoaling. Dredged material should be used to "rebuild" the barrier beach and jetty on the northern side of the Pamet Inlet.

Robinson, Mark H. 1985. Opening Pamet: Possible changes due to reintroduction of tidal flow to Pamet River system.: February.
Discussion paper identifying the range of possible alternatives and consequences that must be addressed when considering the removal of the dike structure and tidal controls on the Pamet River. The paper highlights the need to include National Park Service support for any possible mitigative measures. Possible opponents to the dike removal are proposed to be landowners abutting the river and local officials and taxpayers if changes require an extensive outlay of local money.

Roman, C.T. 1987. A valuation of alternatives for estuarine restoration management: the Herring River ecosystem (Cape Cod National Seashore). New Brunswick, NJ: Center for Costal Studies- Rutgers. October.
Ecological and hydrological report on the Herring River System in Wellfleet, MA. Various research techniques were utilized to assess the current ecological conditions within the saltwater, brackish, and freshwater sections of the Herring River. Hydrological assessments were conducted on salinity levels, tidal flow, and the historical, current, and alternative tidal prisms.

Roman, C.T., R.W. Garvine, and J.W. Portnoy. 1995. Hydrologic modeling as a predictive basis for ecological restoration of salt marshes. *Environmental Management*. 19 (4): 559-566.
Research was conducted on the Herring River, Wellfleet, MA to determine the horizontal and vertical extent of tidal intrusion to a previously diked section of the river. Ecological assessments of the tidal and freshwater section of the river were undertaken to identify differences among vegetation and microinvertebrate populations. An one-dimensional model is presented to simulate the impacts of alternative tidal inflows on flood-prone areas and physical structures.

Truro Conservation Commission. 1993. The Pamet River: What is its future? Truro: February.
A discussion of the consequences related to the overwash at Ballston Beach during a December 1992 storm. The Conservation Commission presents a series of options available to cope with possible future overwashes. The 1992 storm flooded the Upper Pamet River with four feet of saltwater. The clapper valve was not equipped to drain this amount of water, causing extensive week-long floods in the area. The reports suggests more research is needed to identify all possible scenarios, including no future action impacts.

Walter, Donald A., John P. Masterson, and Paul M. Barlow. 1996. Hydrogeology and Analysis of Ground-Water-Flow System, Sagamore Marsh Area, Southeastern Massachusetts. US Geological Survey Water-Resources Investigations Report 96-4200. U.S. Geological Survey, Marlborough, MA.
Report predicting impact to a municipal drinking water supply well from potential increase and restoration of tidal flow within the Sagamore Marsh, Bourne, MA. Tidal flow to the marsh has been artificially restricted to a small culvert from the Cape Cod Canal. A numerical model was used to predict the contributing area to the supply well and the well will not be impacted by an increase in tidal flow to the marsh.

Appendix II. Drilled Well Logs

Boring No. PW-1

BORING LOG

Sheet 1 of 1

PROJECT PAMET RIVER PROJECT- CCC/ACOE

LOCATION Aiken Property

ELEVATION AND DATUM

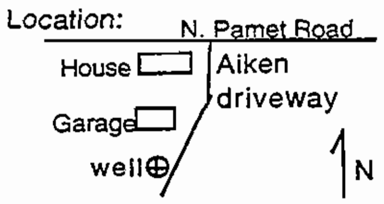
BORING CONTRACTOR T. E. Desmond

DATE 5/20/96

COMPLETION DEPTH 50ft

BORING EQUIPMENT Hollow Stem Screened Auger

OBSERVED WATER LEVEL DATA ~ 3.5 ft

ELEV.	DESCRIPTION	DEPTH SCALE (ft)	WELL DETAILS	SAMPLE NO.	REMARKS
	dark brown coarse/ medium sand	0		Bentonite Seal	~6 in. above ground, 2". PVC Sch. 40 with flush threaded joints, 5ft section of 10 slot screen, blue locking cover grouted in place with concrete, key # 3476
	tan coarse/medium sand, some gray	5			
	brown coarse/medium sand	10			
					150 umhos/cm,~10 gpm
		15			
					140 umhos/cm,~10 gpm
	tan coarse/medium sand, some gravel	20			
					90 umhos/cm,~10 gpm
		25			
					90 umhos/cm,~10 gpm
		30			
					140 umhos/cm,~10 gpm
		35			
					155 umhos/cm,~10 gpm
		40			
					165 umhos/cm,~10 gpm, orange water
	some gray mottling then back to tan	45			
					160 umhos/cm,~8 gpm,
	gray fine sand/silt	50			165 umhos/cm, ~2 gpm, tan cloudy water
			BOH		

INSPECTOR: Eichner/ Livingston

Boring No. PW-2

BORING LOG

Sheet 1 of 1

PROJECT PAMET RIVER PROJECT- CCC/ACOE

LOCATION Ballston Beach Parking Lot

ELEVATION AND DATUM

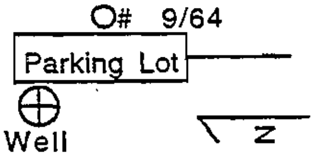
BORING CONTRACTOR T. E. Desmond

DATE 5/20/96

COMPLETION DEPTH 50ft

BORING EQUIPMENT Hollow Stem Screened Auger

OBSERVED WATER LEVEL DATA ~ 2 ft

ELEV.	DESCRIPTION	DEPTH SCALE (ft)	WELL DETAILS	SAMPLE NO.	REMARKS
	dark brown medium/ coarse sand	0		Bentonite Seal	~1 ft. above ground, 2" PVC Sch. 40, with flush threaded joints, 5 ft section of 10 slot screen, blue locking cover grouted into place with concrete, key # 3476
		5		no pump	
		10			37,000 umhos/cm, 25% salinity 19 degree C
	dark brown silt/fine sand, H2S smell	15			
					19,000 umho/cms, 13.5% salinity
		20			no pump
	LOCATION: Telephone Pole  	25			600 umhos/cm, 1% salinity
		30			no pump
	dark brown fine/medium sand, gray fine sand in water	35			15,000 umhos/cm, 15% salinity ~15 gpm (good pump)
		40			23,000 umhos/cm, 19% salinity ~15 gpm (good pump)
	green water, brown fine sand gray fine sand in water	45			28,000 umhos/cm, 23.5% salinity ~15 gpm (good pump)
	brown medium/coarse sand some clay /small gravel	50	BOH		23,000 umhos/cm, 18% salinity (ok pump)

INSPECTOR:

Eichner/ Livingston

Boring No. PW-3 s and d

BORING LOG

Sheet 1 of 3

PROJECT PAMET RIVER PROJECT- CCC/ACOE

LOCATION Mooney Farm

ELEVATION AND DATUM

BORING CONTRACTOR T. E. Desmond

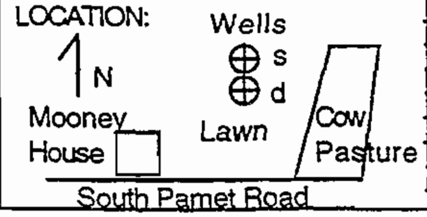
DATE 5/20-5/21

COMPLETION DEPTH PW-3d 150ft, PW-3s 50 ft

BORING EQUIPMENT Hollow Stem Auger (3s) Hollow Stem Screened Auger (3d)

OBSERVED WATER LEVEL DATA ~ 4 ft

ELEV.	DESCRIPTION	DEPTH SCALE	WELL DETAILS	SAMPLE NO.	REMARKS
	dark brown peat	0			PW-3s and d: 2" PVC Sch. 40, with flush threaded joints, ~1' above grade, two 5' well screens, 10 slot, green locking covers grouted into place with concrete, key #3476, screened auger used only on 3d drilling
	interbedded peat and sand			Bentonite Seal	
		5			
	dark brown fine/medium sand	10			
	dark brown medium sand	15			
					145 umhos/cm, 0% salinity, milky brown water
	brown coarse/medium sand with some gravel	20			140 umhos/cm, 0% salinity, milky orange/brown water, good pump
	tan coarse/medium sand with some gravel	25			118 umhos/cm, 0% salinity, milky orange/brown water, good pump
		30			
		35			90 umhos/cm, 0% salinity good pump, water color same
		40			
		45			90 umhos/cm, 0% salinity good pump, water color same, cleared a bit
		50		BOH	
					INSPECTOR: Eichner/ Livingston



Boring No. PW-3s and d

BORING LOG

Sheet 2 of 3

PROJECT PAMET RIVER PROJECT- CCC/ACOE

LOCATION Mooney Farm

ELEVATION AND DATUM

BORING CONTRACTOR T. E. Desmond

DATE 5/20-5/21

COMPLETION DEPTH PW-3d 150ft, PW-3s 50 ft

BORING EQUIPMENT Hollow Stem Screened Auger (3d)

OBSERVED WATER LEVEL DATA ~ 4 ft

ELEV.	DESCRIPTION	DEPTH SCALE	WELL DETAILS	SAMPLE NO.	REMARKS
		55			90 umhos/cm, 0% salinity good pump, same water color
	tan coarse sand, some gravel	60			
		65			98 umhos/cm, 0% salinity poor pump, same water color
		70			
		75			100 umhos/cm, 0% salinity, poor pump
		80			
		85			95 umhos/cm, 0% salinity ~10 gpm, good pump
		90			
	tan, coarse sand with some gravel	95			88 umhos/cm, 0% salinity ~10 gpm, good pump
		100			
	brown medium/coarse sand, some silt				INSPECTOR: Eichner/ Livingston

Boring No. PW-3s and d

BORING LOG

Sheet 3 of 3

PROJECT PAMET RIVER PROJECT- CCC/ACOE

LOCATION Mooney Farm

ELEVATION AND DATUM

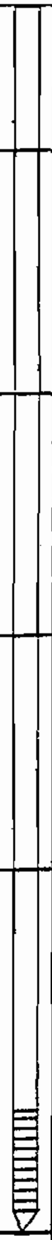
BORING CONTRACTOR T. E. Desmond

DATE 5/20-5/21

COMPLETION DEPTH PW-3d 150ft, PW-3s 50 ft

BORING EQUIPMENT Hollow Stem Screened Auger (3d)

OBSERVED WATER LEVEL DATA ~ 4 ft

ELEV.	DESCRIPTION	DEPTH SCALE	WELL DETAILS	SAMPLE NO.	REMARKS
	brown medium/coarse sand with some silt				
		105			85 umhos/cm, 0% salinity ~10 gpm, good pump
	tan coarse/medium sand with some gravel	110			
		115			90 umhos/cm, 0% salinity, ~10 gpm, good pump
		120			
		125			90 umhos/cm, 0% salinity, ~10 gpm, good pump
		130			
		135			99 umhos/cm, 0% salinity, ~10 gpm, good pump
		140			
		145			
		150		BOH	80 umhos/cm, 0% salinity, ~10 gpm, good pump
					INSPECTOR: Eichner/ Livingston

BORING NO. TRU-3

BORING LOG

SHEET 1 OF 1

PROJECT: TRURO LANDFILL

PROJECT:

LOCATION: Fauk Driveway South off S. Pamet

ELEVATION AND DATUM:

BORING CONTRACTOR: T. E. DESMOND

DATE: 4/13/94

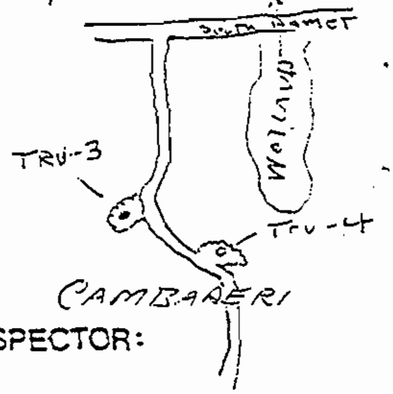
COMPLETION DEPTH:

BORING EQUIPMENT: Screened Auger w/ Hollow Stem Auger

OBSERVED WATER LEVEL DATA:

ELEV.	DESCRIPTION	DEPTH SCALE	WELL DETAILS	SAMPLE NO.	REMARKS
	DARK HUMIC V. COARSE BRN SAND				
	COARSE LHT BRN SAND	10		≈ 80 umho	10gpm
	COARSE-MED BRN SAND	20		≈ 78 umho	10gpm
				≈ 92 umho	Slow
		30		≈ 85, 82 umho	10gpm
				≈ 80 umho	5 gpm
		40		≈ 115 umho	3-2 gpm
				≈ 100 umho	5 gpm
	VERY COARSE AND COARSE MED SAND	50		≈ 110 umho	10gpm
		60		≈ 150 umho	10gpm
	DARK BRN VC-C SAND some granuals			≈ 158 umho	3 gpm
	VC-C-M SAND	70		≈ 125 umho	3 gpm
	BOH	80		≈ 130, 115	3 gpm

One well 2" PVC w/ 10' screen, 10 slot



INSPECTOR: CAMBAAERI

BORING NO. TRU-4

BORING LOG

SHEET 1 OF 1

PROJECT TRURO Landfill

PROJECT

LOCATION Fauk Driveway South of S. Pamet Rd

ELEVATION AND DATUM

BORING CONTRACTOR T. E. Desmond

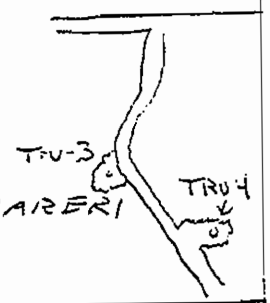
DATE 4/13/94

COMPLETION DEPTH

BORING EQUIPMENT Hollow Stem Auger

OBSERVED WATER LEVEL DATA

ELEV.	DESCRIPTION	DEPTH SCALE	WELL DETAILS	SAMPLE NO.	REMARKS
	DARK HUMIC SOIL				
	COARSE BRN SAND	10			
	M-C BRN SAND ∇		∇		
		20			
		30			
		40			
	C BRN SAND				
		50			
		60			
		70			
		80			
	BOH				
		90			One 2" PVC threaded joint pipe w/ 10' 10 slot Screen



CAMBARERI
INSPECTOR:

BORING NO. TRU-5

BORING LOG

SHEET 1 OF 1

PROJECT: Truro Landfill

PROJECT

LOCATION: John Kelley (South Pamet Rd)

ELEVATION AND DATUM

BORING CONTRACTOR: T. E. Desmond

DATE: 5/13/94

COMPLETION DEPTH

BORING EQUIPMENT: Screened Auger / Hollow Stem Auger

OBSERVED WATER LEVEL DATA: ~2 ft

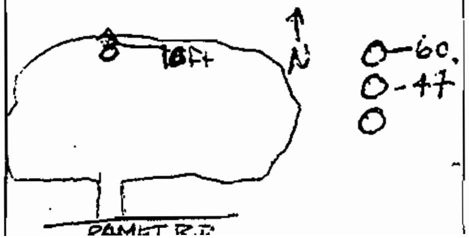
ELEV.	DESCRIPTION	DEPTH SCALE	WELL DETAILS	SAMPLE NO.	REMARKS
	DARK HUMIC SOIL		BENTON.		
	DARK BRN SAND M				
	BRN M SAND SOME FINES	10		≈ 60 μmhos	
	GRAY M-F SAND			≈ 60 μmhos	
	BRN M AND F SAND SOME C	20			
				≈ 122 μmhos	
		30		≈ 122 μmhos	
	BRN M-C SAND TRACE VC, F				

Screened Auger / Hollow Stem Auger

~2 ft

ELEV.	DESCRIPTION	DEPTH SCALE	WELL DETAILS	SAMPLE NO.	REMARKS
	DARK HUMIC SOIL		BENTON.		
	DARK BRN SAND M				
	BRN M SAND SOME FINES	10		≈ 60 μmhos	
		40		≈ Singl developed 15gpm 1-5ft drawdown 122 μmhos	
				155 μmhos ≈ 15gpm	
		50			
				140 μmhos ≈ 15 gpm	
		60			
		70		139 μmhos ≈ 10 gpm	
				106 μmhos	
		80	EOH		

3 wells w/ 5ft screens
set @ 60, 47, & 20 Feet
2inch SCH-40 PVC



Appendix III. Groundwater Model Documentation

Table A-1. Comparison of observed and simulated measurements for calibrated model

name of monitoring well	model		average measured water levels, in feet above sea level	Aug-96 measured water levels, in feet above sea level	model simulated water levels, in feet above sea level	residual of observed minus simulated, in feet
	row	col				
Pamet River Observation Wells						
TSW126	56	16	4.2	NA	4.5	-0.3
TSW136	53	16	4.3	NA	5.0	-0.7
TSW134	52	25	4.9	NA	4.6	0.3
TSW89	49	18	4.4	NA	5.1	-0.7
TSW157	45	14	4.4	NA	4.6	-0.2
TSW203	36	38	5.7	NA	5.5	0.2
TSW170	34	24	5.9	NA	6.1	-0.2
TSW174	33	40	5.6	NA	5.1	0.5
TSW176	30	26	5.6	NA	5.7	-0.1
TSW218	25	29	5.2	NA	5.1	0.1
standard error is -0.1 ft, absolute error is 0.3 ft, standard deviation is 0.4 ft						
Chequesset Lens Observation Wells						
TSW216	7	9	4.1	NA	4.9	-0.8
TSW198	6	26	7.6	NA	7.0	0.6
Great Pond	1	31	8.0	NA	8.0	0.0
standard error is -0.1 ft, absolute error is 0.5 ft, standard deviation is 0.6 ft						
Pamet River Observation Wells						
PR13	18	23	NA	2.7	2.0	0.7
PR2S	16	24	NA	3.1	2.6	0.5
PR17	15	26	NA	3.2	2.6	0.6
PR18	20	30	NA	5.0	4.1	0.9
TLF007	14	32	NA	4.3	3.9	0.4
TSW181	21	35	NA	4.8	4.3	0.5
PW3S	14	38	NA	4.5	3.5	1.0
PW1D	19	43	NA	4.0	3.2	0.8
TSW182	24	45	NA	4.9	3.9	1.0
PR8S	13	45	NA	4.2	3.4	0.8
PR10S	16	48	NA	3.1	3.0	0.1
PR4	13	49	NA	3.6	3.4	0.2
PR13	14	50	NA	3.3	3.0	0.3
standard error is 0.6 ft, absolute error is 0.6 ft, standard deviation is 0.3 ft						
Entire Set of Observation Wells						
standard error is 0.3 ft, absolute error is 0.5 ft, standard deviation is 0.5 ft						

NA - not available

Figure A-1. Graphical comparison of observed and measured groundwater levels

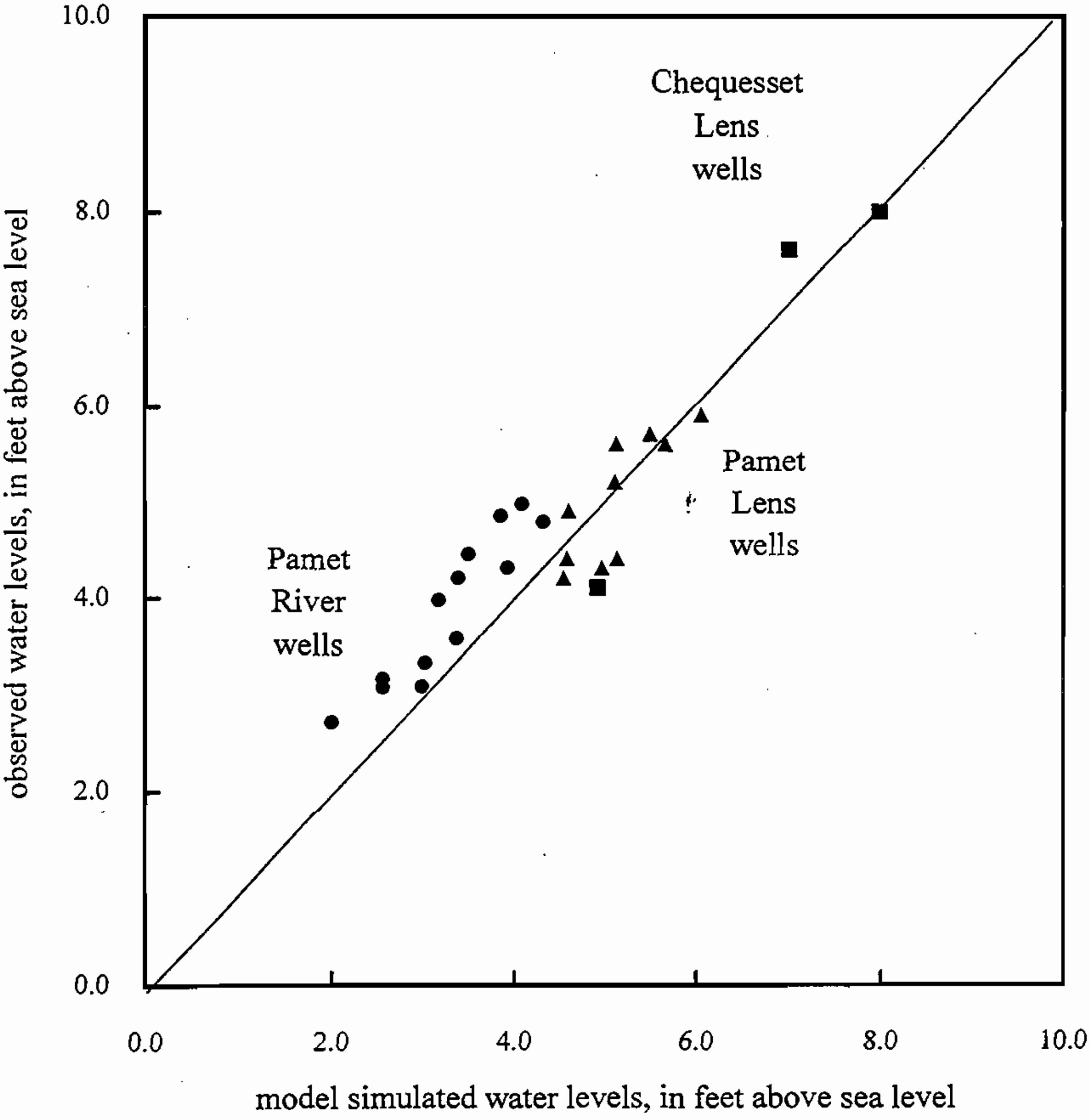


Table A-2. Sensitivity analysis of calibrated model

brief descriptions	statistical comparison of observed and simulated heads (observed - simulated)												flow	vertical
of how model	Pamet Lens			Chequesset Lens			Pamet River			All			at Rt 6	gradient
was adjusted	SE	AE	SD	SE	AE	SD	SE	AE	SD	SE	AE	SD	(cfs)	(ft/25 ft)
calibrated model														
	-0.11	0.32	0.37	-0.07	0.47	0.57	0.60	0.60	0.28	0.25	0.48	0.50	3.68	1.49
hydraulic conductivity of wetland is fluctuated, calibrated value is .5 ft/d														
.005 ft/d	-0.24	0.37	0.36	-0.37	0.59	0.68	0.31	0.60	0.68	0.02	0.51	0.64	3.73	-0.34
.05 ft/d	-0.21	0.36	0.36	-0.31	0.57	0.66	0.37	0.57	0.56	0.06	0.49	0.59	3.72	0.03
.5 ft/d	0.00	0.35	0.40	0.19	0.45	0.48	0.81	0.81	0.43	0.43	0.59	0.58	3.58	2.49
50 ft/d	0.05	0.38	0.42	0.28	0.44	0.46	0.87	0.87	0.47	0.49	0.63	0.59	3.54	2.62
vertical conductance of wetland is fluctuated, calibrated value is .008 /d														
.001/d	-0.18	0.34	0.36	-0.23	0.53	0.63	0.63	0.63	0.42	0.22	0.51	0.59	3.70	2.70
.01/d	-0.10	0.32	0.37	-0.05	0.47	0.57	0.60	0.60	0.28	0.26	0.48	0.50	3.68	1.32
.1/d	-0.05	0.32	0.39	0.06	0.48	0.54	0.57	0.62	0.38	0.27	0.49	0.50	3.69	0.22
1/d	-0.04	0.33	0.40	0.08	0.48	0.54	0.56	0.63	0.41	0.27	0.50	0.51	3.69	0.02
elevation of overland seepage is fluctuated, calibrated value is 2.5 ft above sea level														
.5 ft	0.30	0.64	0.65	0.78	0.89	0.74	1.87	1.87	0.55	1.14	1.28	0.96	4.55	0.66
1.5 ft	0.10	0.46	0.49	0.36	0.68	0.66	1.25	1.25	0.38	0.70	0.88	0.72	4.12	1.07
3.5 ft	-0.32	0.41	0.34	-0.50	0.53	0.48	-0.06	0.27	0.31	-0.21	0.35	0.38	3.22	1.92
4.5 ft	-0.52	0.57	0.42	-0.94	0.94	0.38	-0.73	0.77	0.46	-0.68	0.71	0.46	2.73	2.34
hydraulic conductivity of overland seepage is fluctuated, calibrated value is 50 ft/d														
.5 ft/d	-0.57	0.63	0.47	-1.09	1.09	0.33	-0.94	0.95	0.69	-0.82	0.84	0.61	2.62	2.47
5 ft/d	-0.18	0.34	0.35	-0.23	0.48	0.54	0.37	0.37	0.28	0.09	0.37	0.45	3.54	1.64
250 ft/d	-0.10	0.32	0.38	-0.05	0.48	0.58	0.62	0.62	0.28	0.27	0.49	0.51	3.70	1.48
500 ft/d	-0.10	0.32	0.38	-0.05	0.48	0.58	0.63	0.63	0.28	0.27	0.49	0.51	3.70	1.48

Table A-2. Sensitivity analysis of calibrated model

brief descriptions of how model was adjusted	statistical comparison of observed and simulated heads (observed - simulated)												flow at Rt 6 (cfs)	vertical gradient (ft/25 ft)
	Pamet Lens			Chequesset Lens			Pamet River			All				
	SE	AE	SD	SE	AE	SD	SE	AE	SD	SE	AE	SD		
hydraulic conductivity of layer 1 (not including wetland areas) is multiplied by:														
0.001	-0.40	0.44	0.39	-0.42	0.55	0.51	0.43	0.43	0.28	0.01	0.45	0.55	3.67	1.56
0.01	-0.40	0.44	0.39	-0.42	0.55	0.51	0.43	0.44	0.28	0.01	0.45	0.55	3.67	1.56
0.1	-0.37	0.42	0.39	-0.38	0.54	0.51	0.45	0.45	0.28	0.04	0.45	0.54	3.67	1.55
1	1.17	1.17	0.33	1.45	1.45	0.87	1.15	1.15	0.40	1.19	1.19	0.47	3.50	1.28
10	2.96	2.96	0.35	3.67	3.67	1.28	1.76	1.76	0.64	2.44	2.44	0.98	1.66	1.01
100	4.10	4.10	0.49	5.31	5.31	1.57	2.84	2.84	0.72	3.61	3.61	1.17	0.20	0.36
vertical conductance between layers 1 and 2 (not including wetland areas) is multiplied by:														
0.001	-17.41	17.41	2.70	-17.29	17.29	1.82	-4.75	4.92	3.21	-11.06	11.15	6.94	5.59	5.33
0.01	-9.07	9.07	1.04	-7.90	7.90	0.71	-3.36	3.54	2.39	-6.08	6.17	3.30	4.93	4.83
0.1	-1.93	1.93	0.31	-1.77	1.77	0.44	-0.61	0.81	0.74	-1.25	1.35	0.87	3.99	2.35
1	0.13	0.35	0.39	0.18	0.57	0.59	0.78	0.78	0.29	0.46	0.59	0.49	3.64	1.38
10	0.15	0.36	0.40	0.21	0.58	0.59	0.79	0.79	0.29	0.48	0.60	0.49	3.63	1.36
100	0.16	0.36	0.40	0.21	0.59	0.59	0.80	0.80	0.29	0.48	0.61	0.49	3.63	1.36
upland recharge is fluctuated, calibrated values are 23.2 ft/yr and 22.7 ft/yr for the Chequesset and Pamet Lenses, respectively														
-50%	2.05	2.05	0.33	2.44	2.44	1.05	1.28	1.28	0.45	1.71	1.71	0.68	1.47	1.20
-25%	0.96	0.96	0.33	1.18	1.18	0.80	0.94	0.94	0.33	0.97	0.97	0.42	2.58	1.35
25%	-1.15	1.15	0.44	-1.29	1.29	0.44	0.27	0.37	0.33	-0.46	0.78	0.82	4.79	1.64
50%	-2.18	2.18	0.52	-2.50	2.50	0.47	-0.07	0.42	0.45	-1.16	1.34	1.20	5.89	1.78
wetland recharge is fluctuated, calibrated value is 13.1 ft/yr														
0 ft/yr	-0.05	0.31	0.38	0.02	0.46	0.54	0.64	0.64	0.29	0.30	0.49	0.50	3.46	1.62
23.2 ft/yr	-0.15	0.33	0.37	-0.14	0.49	0.60	0.57	0.57	0.27	0.21	0.47	0.51	3.85	1.40

Table A-2. Sensitivity analysis of calibrated model

brief descriptions of how model was adjusted	statistical comparison of observed and simulated heads (observed - simulated)												flow at Rt 6 (cfs)	vertical gradient (ft/25 ft)
	Pamet Lens			Chequesset Lens			Pamet River			All				
	SE	AE	SD	SE	AE	SD	SE	AE	SD	SE	AE	SD		
hydraulic conductivity of layer 7 is multiplied by:														
0.01	-0.11	0.32	0.37	-0.13	0.49	0.56	0.60	0.60	0.28	0.24	0.48	0.50	3.69	1.49
100	-0.11	0.32	0.37	0.08	0.60	0.62	0.60	0.60	0.28	0.27	0.49	0.50	3.67	1.49
vertical conductance between layers 6 and 7 is multiplied by:														
0.01	-0.11	0.32	0.37	-0.07	0.47	0.57	0.60	0.60	0.28	0.25	0.48	0.50	3.68	1.49
100	-0.11	0.32	0.37	-0.07	0.47	0.57	0.60	0.60	0.28	0.25	0.48	0.50	3.68	1.49
Perimeter seeps is removed and marsh sediments is modeled as sand/gravel sediments	0.69	0.91	0.86	1.83	1.83	0.48	1.36	1.36	0.40	1.15	1.24	0.74	3.46	0.12
Depth of interface is reduced by twenty-five percent (25%)	-2.06	2.06	0.78	-1.44	1.44	0.63	0.28	0.37	0.34	-0.82	1.14	1.26	4.50	1.60

SE - standard error, AE - absolute error, SD - standard deviation

Table A-3. Calibration adjustments made to model without seepage along the perimeter of the marsh

brief descriptions of how model was adjusted	statistical comparison of simulated vs observed water levels												stream flow at Rt 6 (cfs)	gradient below stream (ft)
	Pamet Lens			Chequesset Lens			Pamet River			All				
	SE (ft)	AE (ft)	SD (ft)	SE (ft)	AE (ft)	SD (ft)	SE (ft)	AE (ft)	SD (ft)	SE (ft)	AE (ft)	SD (ft)		
vertical conductance between wetland and underlying model layer is adjusted (1/day) to:														
0.001	-1.17	1.26	1.27	-1.46	1.46	0.42	-2.45	2.55	2.10	-1.85	1.93	1.77	0.23	6.91
0.005	-0.77	0.87	0.91	-0.85	0.85	0.46	-1.68	1.88	1.75	-1.23	1.37	1.42	0.81	4.85
0.01	-0.54	0.64	0.70	-0.49	0.49	0.51	-1.21	1.52	1.55	-0.87	1.06	1.22	1.19	3.56
0.05	-0.13	0.36	0.40	0.13	0.55	0.65	-0.35	1.03	1.21	-0.21	0.72	0.90	1.90	1.14
0.1	-0.04	0.31	0.37	0.26	0.62	0.69	-0.18	0.95	1.14	-0.08	0.66	0.85	2.06	0.62
0.5	0.03	0.28	0.35	0.38	0.68	0.73	-0.01	0.90	1.08	0.05	0.63	0.81	2.21	0.13
horizontal hydraulic conductivity of wetland is adjusted (ft/day) to:														
0.001	-0.13	0.36	0.40	0.13	0.55	0.65	-0.35	1.03	1.21	-0.21	0.72	0.91	1.90	1.14
0.01	-0.13	0.36	0.40	0.13	0.55	0.65	-0.35	1.03	1.21	-0.21	0.72	0.91	1.90	1.14
0.1	-0.13	0.36	0.40	0.13	0.55	0.65	-0.35	1.03	1.21	-0.21	0.72	0.91	1.90	1.14
1	-0.13	0.36	0.40	0.13	0.55	0.65	-0.35	1.03	1.21	-0.21	0.72	0.90	1.90	1.14
10	-0.13	0.36	0.40	0.13	0.55	0.65	-0.35	1.03	1.21	-0.21	0.72	0.90	1.91	1.13
100	-0.11	0.35	0.40	0.16	0.57	0.67	-0.32	1.02	1.20	-0.19	0.71	0.90	1.94	1.05
streambed conductance is adjusted (sq ft/day) to:														
0.001	-1.35	1.43	1.43	-1.74	1.74	0.42	-2.78	2.84	2.25	-2.11	2.17	1.92	0.01	0.00
0.01	-1.32	1.40	1.41	-1.69	1.69	0.42	-2.72	2.78	2.22	-2.06	2.12	1.89	0.05	0.03
0.1	-1.06	1.15	1.17	-1.30	1.30	0.44	-2.21	2.33	2.00	-1.66	1.76	1.66	0.44	0.26
1	-0.13	0.36	0.40	0.13	0.55	0.65	-0.35	1.03	1.21	-0.21	0.72	0.90	1.90	1.14
10	0.47	0.60	0.51	1.09	1.09	0.82	0.83	0.93	0.79	0.72	0.82	0.70	2.87	1.72
100	0.57	0.69	0.58	1.25	1.25	0.85	1.02	1.02	0.74	0.87	0.92	0.71	3.02	1.81

Table A-3. Calibration adjustments made to model without seepage along the perimeter of the marsh

brief descriptions of how model was adjusted	statistical comparison of simulated vs observed water levels												stream flow at Rt 6	gradient below stream
	Pamet Lens			Chequesset Lens			Pamet River			All				
	SE (ft)	AE (ft)	SD (ft)	SE (ft)	AE (ft)	SD (ft)	SE (ft)	AE (ft)	SD (ft)	SE (ft)	AE (ft)	SD (ft)	(cfs)	(ft)
stream bottom elevation for the Pamet River is adjusted as follows:														
subtract 0.5 ft	-0.08	0.33	0.38	0.20	0.59	0.69	-0.23	0.99	1.18	-0.13	0.69	0.88	2.05	1.23
add 0.5 ft	-0.17	0.39	0.43	0.07	0.50	0.62	-0.48	1.08	1.24	-0.30	0.74	0.93	1.76	1.05
wetland is shrunk to include only stream cells, hydraulic conductivity of the rest of layer 1 is multiplied:														
by 1	-0.12	0.36	0.40	0.14	0.55	0.66	-0.35	1.03	1.20	-0.21	0.71	0.90	1.90	1.14
by 10	-0.12	0.36	0.40	0.14	0.55	0.66	-0.35	1.03	1.20	-0.21	0.71	0.90	1.91	1.12
by 100	-0.10	0.34	0.39	0.17	0.57	0.67	-0.30	1.01	1.19	-0.17	0.70	0.89	1.96	1.01
wetland properties of layer 1 are replaced with layer 2 properties, streambed conductance is multiplied:														
by 0.01	-1.29	1.38	1.38	-1.65	1.65	0.42	-2.69	2.75	2.18	-2.03	2.09	1.87	0.05	0.01
by 1	0.02	0.28	0.35	0.36	0.67	0.72	-0.05	0.91	1.09	0.02	0.63	0.82	2.18	0.28
by 100	0.92	1.02	0.89	1.81	1.81	1.01	1.82	1.82	0.59	1.47	1.51	0.86	3.79	0.55

SE - standard error, AE - absolute error, SD - standard deviation

APPENDIX D

COST SHARING AGREEMENT
& SCOPE OF STUDIES

THE PAMET RIVER STUDY
COST SHARING LETTER AGREEMENT
BY AND BETWEEN
THE DEPARTMENT OF THE ARMY, CORPS OF ENGINEERS
AND
THE TOWN OF TRURO, MASSACHUSETTS,

THIS AGREEMENT, entered into this 20th day, of April, 1995, by and between the United States of America (hereinafter called the "Government"), represented by the Contracting Officer executing this Agreement, and the Town of Truro, Massachusetts, acting by and through the Town Administrator (hereinafter called the "Sponsor").

WITNESSETH, that

WHEREAS, Section 22 of the Water Resources Development Act of 1974 (Public Law 93-251), as amended, authorizes the Secretary of the Army, acting through the Chief of Engineers, to assist the states in the preparation of comprehensive plans for the development, utilization and conservation of water and related land resources; and

WHEREAS, Section 319 of the Water Resources Act of 1990 (Public Law 101-640) authorizes the Secretary of the Army to collect from non-Federal entities fees for the purpose of recovering fifty percent of the cost of the program established by Section 22; and WHEREAS, the Sponsor has reviewed the state's comprehensive water plans and identified the need for the planning assistance as described in the Scope of Studies incorporated into this agreement; and

WHEREAS, the Sponsor, has the authority and capability to furnish the services hereinafter set forth and is willing to participate in study cost-sharing and financing in accordance with the terms of this Agreement.

NOW THEREFORE, the parties agree as follows:

1. The Government, using funds contributed by the Sponsor and appropriated by the Congress, shall expeditiously prosecute and complete the Study, currently estimated to be completed in twelve months from the date of this Agreement (the Study Period), substantially in compliance with a scope of work to be developed by the Government and the Sponsor, and in conformity with applicable Federal laws and regulations and mutually acceptable standards of engineering practice.

2. The Government shall contribute in cash 50 percent of the total study cost for the Federal fiscal year 1995 and the Sponsor shall contribute in cash, fifty (50) percent of all study costs for this same fiscal year, the total cost of which is currently

estimated to be $90,000; provided that the Government shall not obligate any cash contributed by the Sponsor toward Study costs until such cash contribution has been made available to it by the Sponsor. The Sponsor's share of the study cost shall in no event exceed $45,000 without prior written approval of the Sponsor. Within 60 days of the execution of this Agreement, the Sponsor agrees to provide a cashier or certified check in the amount of $45,000 which shall be made payable to "FAO, U.S. Army Engineer Division, New England".

3. No Federal funds may be used to meet the Sponsor share of study costs under this Agreement unless the expenditure of such funds is expressly authorized by statute as verified by the granting agency.

4. Before any Party to this Agreement may bring suit in any court concerning any issues relating to this Agreement, such Party must first seek in good faith to resolve the issue through negotiation or other form of nonbinding alternate dispute resolution mutually acceptable to the Parties.

5. This Agreement shall terminate at the completion of the Study Period; provided, that prior to such time and upon thirty days written notice, either party may terminate or suspend this Agreement without penalty.

6. Within ninety days upon termination of this Agreement, the Study Management Team shall prepare a final accounting of the Study Costs, which shall display disbursements by the Government of Federal funds and cash contributions by the Government of Federal funds and cash contributions by the Sponsor. Subject to the availability of funds, within thirty days after the final accounting, the Government shall reimburse the Sponsor for excess non-Federal cash contributions that exceed the Sponsor's required share of the total study costs.

7. In the event that any one or more of the provisions of this Agreement is found to be invalid, illegal, or unenforceable, by a court of competent jurisdiction, the validity of the remaining provisions shall not in any way be effected or impaired and shall continue in effect until the Agreement is completed.

8. This Agreement shall become effective upon the signature of both Parties.

THE UNITED STATES OF AMERICA

Earle C Richardson (SEAL) 20 April 1995 (DATE)

Earle C. Richardson
Colonel, Corps of Engineers
Commanding

THE TOWN OF TRURO, MASSACHUSETTS

Paul J Guida 4/6/95 (DATE)

Mr. Paul J. Guida
Town Administrator

Pamet River Investigation
Section 22 Planning - Assistance To States Program

Scope of Studies

I. Introduction:

a. Authority

The Corps of Engineers was requested by the Town of Truro, Massachusetts to conduct an investigation into the impacts of removing the tide gate and dike structure located at Route 6 on the Pamet River. This study will be conducted under the authority contained in the Section 22, Planning Assistance to States Program. The Town of Truro is the cost sharing partner for this investigation. However, a portion of the Town of Truro's funds is being provided by the National Park Service.

b. Study Purpose and Scope

The purpose of this study is to:

1. Identify and investigate the advantages and disadvantages of reintroducing daily tidal flows to the present freshwater portion of the Pamet. Impacts which need to be identified and assessed include environmental and physical impacts.

2. Investigate flooding impacts associated with the existing railroad dikes on the bay side of the Pamet River, and identify a course of action for the town of Truro with respect to removing or repairing the dikes.

3. Evaluate the existing culvert/tide gate configuration at Route 6/6A in relation to its ability to adequately drain the Pamet River during overtopping events at Ballston Beach. Identify and evaluate alternative culvert/tide gate configurations to provide both the adequate drainage of the Pamet River and a new hydrologic regiime to establish a saltmarsh environment. Preliminary cost estimates of alternative configurations will also be developed. Complete a coastal analysis to determine the frequency and volume of

overtopping at Ballston Beach.

The study will be coordinated with all appropriate Federal, State, Municipal and other interested parties. Areas of additional study will also be identified, if necessary.

II. Project Tasks

a. Mathematical Model of Pamet River System

1. Develop a mathematical model to simulate tidal flow in the Pamet River system. This includes the Little Pamet River and the Mill Pond, Eagles Neck Creek area. The model will include the entire main stem of the Pamet River (from the inlet east to Ballston Beach) to determine the extent of tidal inundation in the freshwater portion of the Pamet River and the effects of the existing railroad dike. The model will be run for both existing conditions and for future configurations of culverts and tide gates including the effects of anticipated dredging of the harbor.

2. If suitable topographic mapping is not available, topographic surveying will be accomplished.

b. Determination of Advantages/Disadvantages of Saltwater Reintroduction

A qualitative assessment of the advantages and disadvantages of the impacts related to the reintroduction of tidal flow will be accomplished. This will include impacts of the reintroduction of tidal flow beyond Wilder's Dike (tide gate). This will include:

1. Environmental Impacts:

- document the existing freshwater marsh hydrology, vegetation, and functions;
- define a new hydrologic regime which will establish the saltmarsh surface area;
- document qualitative changes in or loss of the freshwater wetlands environment, including types of vegetation and wildlife which will be displaced or destroyed;
- qualitatively identify advantages of establishing a saltwater environment.

2. Groundwater Impacts:

- a review of existing data and a qualitative assessment of existing groundwater conditions and potential impacts will be accomplished.

c. Evaluate Railroad Dikes

The model developed in part "a." above will be used to identify flooding impacts at certain locations due to either dike removal or breaching. This will simulate the degradation of the railroad dike and its effects on flooding of adjacent areas. A course of action will be identified in regards to the removal or repair of failed portions of the railroad dike.

d. Evaluate Adequacy of Existing Culvert/Tide Gate Configuration

The adequacy of the existing culverts to drain flood water from overtopping of Ballston Beach will be evaluated. Existing culverts are located under Route 6 and Wilder's Dike. These existing culverts will also be evaluated for their potential to allow a sufficient volume of saltwater to reintroduce a saltmarsh environment in the existing freshwater environment. Various culvert configurations (size and number) will also be investigated and preliminary cost estimates developed. Mathematical models to determine river flows, water surface elevations, and overtopping volumes will be utilized.

The frequency and volume of overtopping at Ballston Beach will be determined, including an investigation of wave heights and water levels associated with overtopping. The frequency of overtopping events will be established and sea level rise will also be accounted for. Historical overtopping events and their impacts will also be reviewed.

e. Coordination. Project Management & Report Preparation

The results of this analysis will be coordinated with appropriate Federal, State, and local agencies to obtain their views. The results of the study will be summarized in a report and additional studies will also be identified, if necessary.

III. Report Documentation

A report will be submitted to the Town of Truro in draft form for comment and review. Upon resolution of provided comments, the New England Division will prepare and issue a final report.

IV. Project Coordination

This study will be conducted by the New England Division of the Corps of Engineers. The New England Division will coordinate with the Town of Truro on all issues concerning the study which deviate from the original Scope of Studies. The New England Division will maintain coordination with all appropriate Federal, State, and local agencies throughout the study.

V. Project Cost and Completion Schedule

It has been determined that the Pamet River study will cost $90,000 and will be completed within 12 months.