# STUDIES OF FLUSHING IN ROUND COVE, ALLENS HARBOR, WYCHMERE HARBOR, AND SAQUATUCKET HARBOR, HARWICH, MASSACHUSETTS

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ASA Project # 92-81


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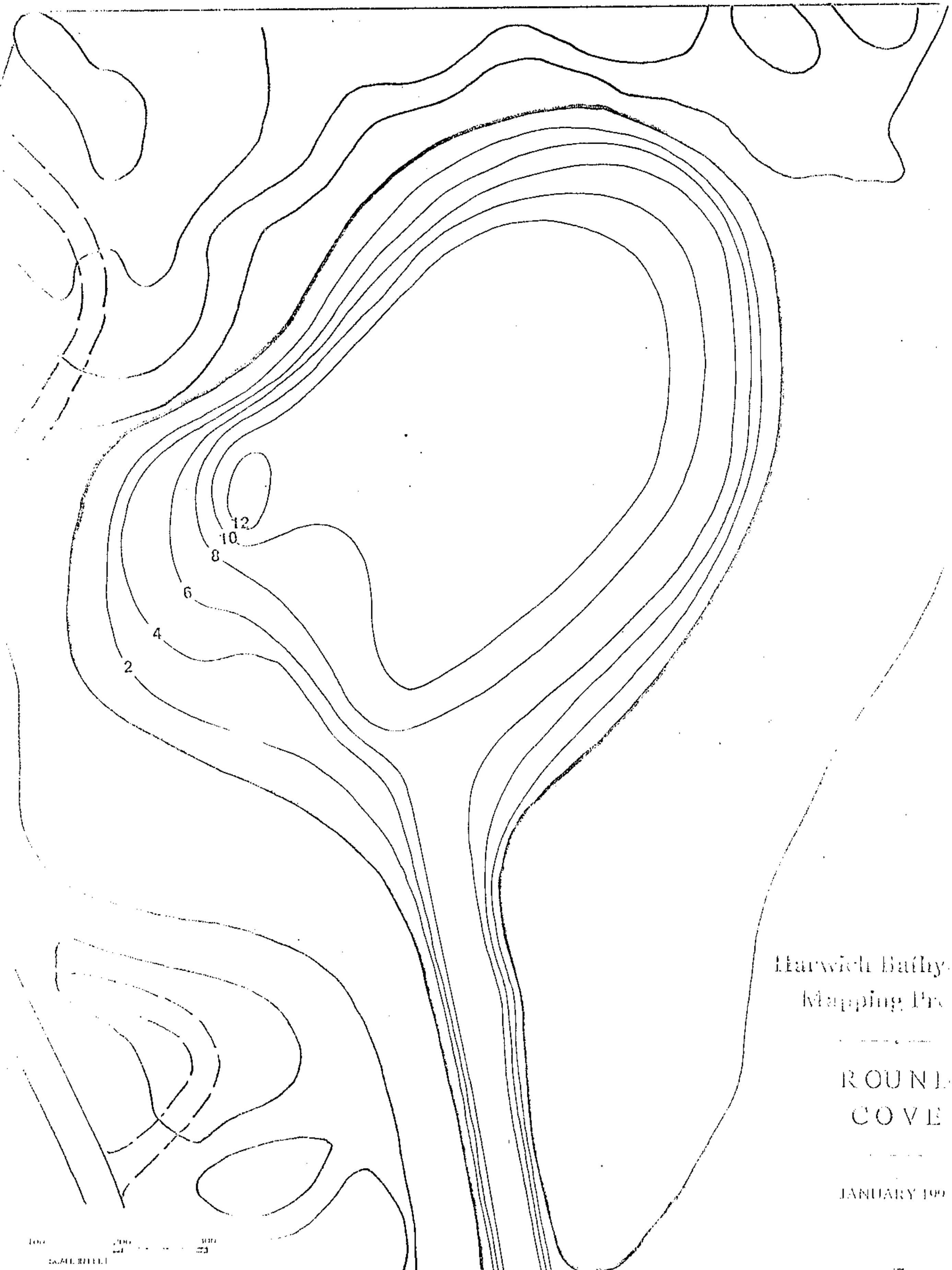


Map derived from U.S.G.S Quadrangle, Chatham, MA 1974
F M East's site observations.

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## EXECUTIVE SUMMARY


This report documents a study conducted in four coastal ponds located within the Town of Harwich MA. The ponds were Round Cove, located on Pleasant Bay in the Northeast corner of the town, and Allens, Wychmere and Saquatucket Harbors which are located on Nantucket Sound along the south coast of the town. The principal purpose of the study was to determine flushing rates and times for each pond. The approach was centered around dye releases in each of the ponds. Rhodamine WT, a red fluorescent dye, was released quickly over the surface of each pond across as much of its extent as possible. Measurements of dye concentrations were made at periodic intervals following the release, so that mean concentrations could be calculated as a function of time. The flushing rate estimates presented in this report are based principally on the calculation of the rate of decay of mean concentration. The estimates obtained for the ponds varied between 1.1-1.3 days for the south coast ponds to 2.4 days for Round Cove. Tidal prism flushing time estimates were consistent with the dye-based estimates, except in the case of Round Cove. The flushing of Round Cove was found to be significantly slower than a method based on tidal volume exchange would indicate. This behavior was attributed to the location of Round Cove near the head of Pleasant Bay. The relatively poor net transport characteristics of the area produce a much slower net movement of pollutants and make Round Cove relatively sensitive to pollutant loadings.

The range of tides expected during the study was near the mean for each area. It should be noted that the general timing of the study was not optimal in the sense that it was not performed during the summer season when weather conditions are relatively more quiescent. The present study was marred by the passage of a storm through the area. The surge accompanying the storm undoubtedly increased the rate at which the ponds were flushed. This is particularly true for Round Cove, where the barrier beach which normally separates the cove from Pleasant Bay was submerged.

The flushing time information have been used to construct a simple pollutant impacts model for each of the ponds in Section 5 of the report. Zero-dimensional models are presented for Round Cove, Wychmere Harbor, and Saquatucket Harbor. The behavior of the dye was found to be more complex in Allens Harbor. A one-dimensional box model is provided for pollutant impacts assessments in Allens Harbor.

# 1. INTRODUCTION

This report documents portions of a study of physical properties of four coastal ponds located within the Town of Harwich, MA. The study was funded by the Town of Harwich through its Planning Office. The study was performed to support planning and development activities for the areas around the ponds. The ponds included in this report were Round Cove, Saquatucket Harbor, Wychmere Harbor, and Allens Harbor (Figure 1.1). This report documents the methods and results of work by Applied Science Associates, of Narragansett, RI to define the flushing rates of the ponds. A separate document, submitted by Fugro-McClelland, Inc of Sandwich, MA documents other components of the study. The work by Fugro-McClelland included bathymetric measurements in the four coastal ponds listed above, and in three fresh water bodies: John Joseph Pond, West Reservoir, and Skinequit Pond.

The first coastal pond examined during this study, Round Pond is a small embayment located along the southwestern side of Pleasant Bay. As its name implies, the pond has a rounded shape and a surface area of 4.7 hectares. Round Pond is separated from Pleasant Bay by a thin barrier beach and connects to the bay through a narrow opening at its southern end. This opening is apparently maintained by tidal exchange, supplemented by occasional dredging. The mean tidal range for Pleasant Bay, including Round Cove is 1.0 m (NOS, 1991). Round Cove does not receive runoff from surface tributaries; freshwater inputs from the surrounding watershed are through subsurface inflows. Saquatucket Harbor is the easternmost of the three ponds studied which lies along the South coast of Cape Cod. Saquatucket Harbor has a surface area of 5.5 hectares. Two small tributary streams empty into the harbor at its north end. Saquatucket Harbor is connected to Nantucket Sound through a channel approximately 70 m wide and 300 m long. Wychmere Harbor empties into Nantucket Sound a few hundred meters to the west of the Saquatucket Harbor entrance. Wychmere Harbor is round in shape with a diameter of approximately 300 m and a surface area of 5.5 hectares. A breakwater extends 350 m offshore from the west edge of the Wychmere Harbor entrance to protect the Saquatucket and Wychmere Harbor entrances from prevailing westerly and southwesterly waves. Its entrance channel is approximately 200 m long and 30 m wide.

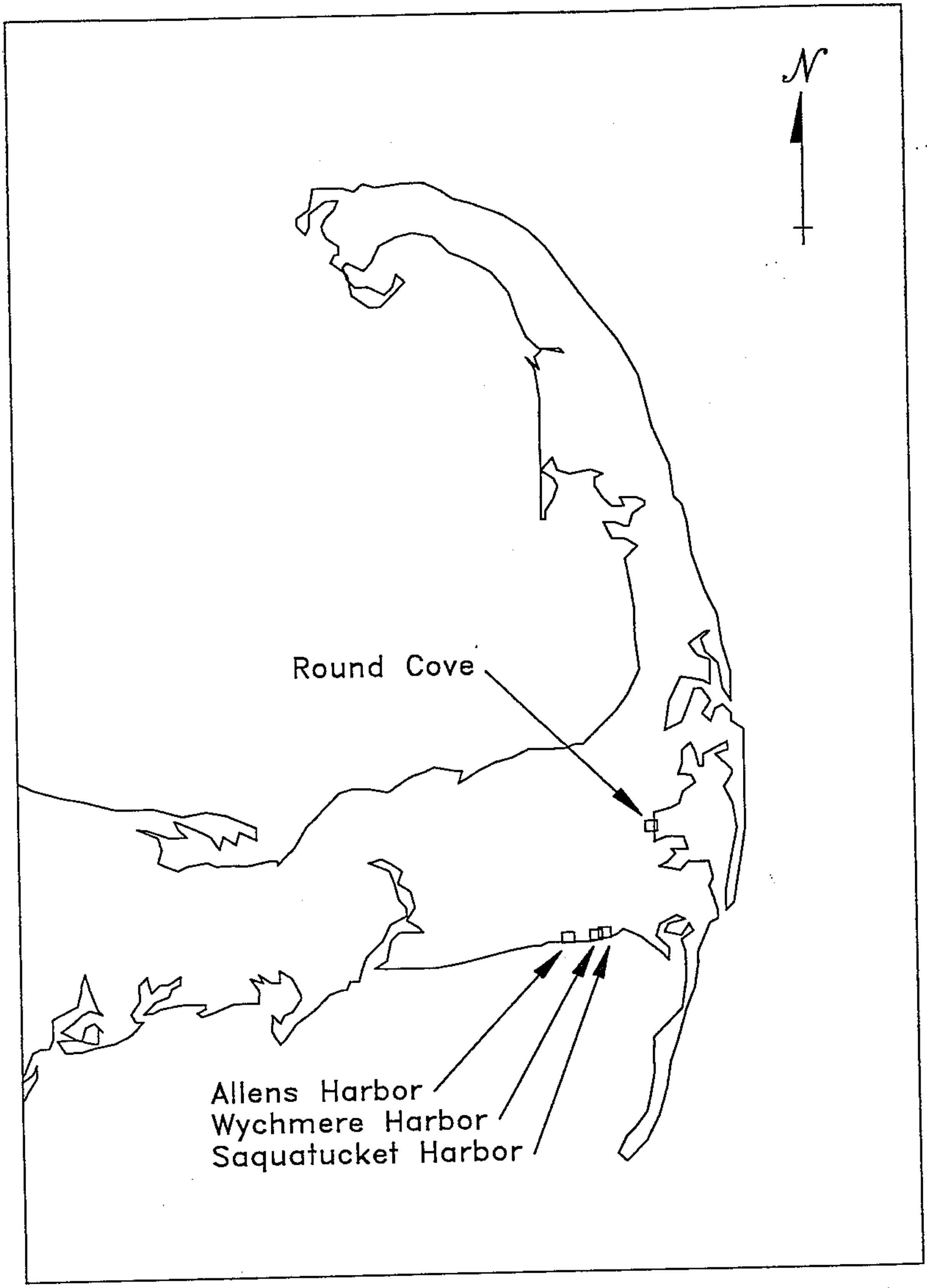


Figure 1.1 Location of Round Cove, Allens Harbor, Wychmere Harbor and Saquatucket Harbor on Cape Cod.

The entrance to Allens Harbor is located approximately 2 km to the west of Wychmere Harbor. Allens Harbor has a narrow entrance, about 30 m wide and 200 m long. A long narrow channel 10-20 m wide and 400 m long extends to the west from the center of the pond.

The National Ocean Survey (NOS, 1985) reports a mean tide range of 1.1 m for Wychmere Harbor. This range is representative for Saquatucket and Allens Harbors because of their proximity, similar size and geometry.

## 2. STUDY GOALS AND APPROACH

The principal objective of this study was to obtain information which could be used to calculate flushing times for each of the ponds. The information collected by the study would also be implemented into a simple modeling framework for use in estimating the water quality impacts associated with current and future land use and development. Secondary objectives of the study were to obtain information on tidal and other properties of the ponds which would be helpful in understanding the mixing and transport properties of the areas.

The determination of flushing time for each pond was based on dye release and measurement studies. A fluorescent dye was sprayed as evenly and completely over the surface of each pond as was possible using a sprayer. Measurement of dye concentration were made at multiple depths at five stations in each pond and at one station outside each pond on subsequent ebb tides, shortly after the time of high tide. A limited set of salinity and temperature measurements were also conducted in and outside each pond to provide some information on the vertical distribution of salinity. The measurements were made principally to determine whether a significant 2-layered estuarine circulation was present in each pond.

The rate of change in mean dye concentration obtained from the dye measurements was used for the flushing time determination in each pond. The results of this analysis are presented in Section 4 below. The dye decay, salinity, and tide data were then combined with the bathymetric and geometry information obtained by Fugro-McClelland to develop a simple flushing model which may be used for the analysis of impacts. A description of the model system and its application to the Harwich coastal ponds is presented in Section 5.

## 3. METHODS

The study began with the deployment of an Endeco Model 1029 tide gauge in Saquatucket Harbor on November 6, 1992. The Model 1029 consists of a surface unit which contains most of its processing circuitry which is connected by a 50 foot long sensor cable to a submerged transducer. The transducer contains a differential pressure cell which is exposed to atmospheric pressure through a small air vent line contained in the sensor cable. The differential pressure sensed by the cell is recorded at periodic intervals (10 minutes) and stored in magnetic form inside the surface unit. The first tide gauge was placed adjacent to the concrete wall at the Municipal Marina. The gauge's sensor was placed 8.5 ft below the top of the wall, and the surface unit was placed inside the compressor building for the marina bubbler system. An attempt was made to deploy a second gauge in Round Cove or in Pleasant Bay, however the absence of suitable sites in that area forced a delay in the installation of the gauge until November 18. The second gauge was deployed along the north shore of Round Cove on the afternoon of November 18.

A dye study was conducted to determine the flushing rate in each pond. Dye measurements were made *in situ* with a Turner Model 10 fluorometer. Prior to the study, the fluorometer was calibrated using a sample of the dye used for the study. A set of 12 standard dilutions were prepared, covering the range between 0.048 - 48 ppb. The instrument response was measured on each of the eight sensitivity ranges for each standard. A linear regression was established for each sensitivity range so that fluorometer readings in the field could later be converted to dye concentrations.

The fluorometer was configured so that water could be pumped through the instrument in the field. Water samples were pumped from depth by a 12 volt submersible pump at a rate of approximately 30 gpm through a 3/4" hose into and through the instrument. The temperature of the water was sensed by a digital thermometer located on the discharge line so that a temperature correction to fluorescence could later be determined.

Table 3.1 Dye release timetable.

| Location | Time (EST) | Amt Released (lb) |
|---|---|---|
| November 18: | | |
| Round Cove | 0550-0630 | 21 |
| November 19: | | |
| Allens | 1640-1700 | 28.5 |
| Wychmere | 1740-1750 | 23 |
| Saquatucket | 1810-1825 | 24.3 |

The dye releases were carried out in each of the four ponds during November 18-19, 1992. Rhodamine WT dye in 20% solution form was released using a pressurized 2 gallon garden sprayer. The dye was sprayed from a moving boat along several transects across the surface of each pond. Each release was carried out during the middle portion of the flood tide, approximately 2-3 hours before high tide. A summary of the timing of each release as well as the amount released in each pond is presented in Table 3.1. A background fluorescence survey was carried out in each pond shortly before each release. The purpose of the survey was to resolve the fluorescence levels due to naturally occurring sources. Measurements were made at 1-2 stations and two depths in each cove. In all cases, the ambient fluorescence levels were found to be negligibly small, corresponding to an equivalent Rhodamine concentration of approximately 0.03-0.04 ppb. The background data were stored and later subtracted from the post-release fluorometer observations.

### 3.1 Round Cove

A summary of predicted tides and heights of the tide in Pleasant bay during the period of the study is presented in Table 3.2. The predictions are based on tidal differences for Boston and are based on measurements made before the 1987 breach of the Nauset barrier beach.

Table 3.2: Tide table for Pleasant Bay and Round Cove during the period of the study based on NOS data.

| Date | Low Tide Time | Ht (ft) | High Tide Time | Ht (ft) | Low Tide Time | Ht (ft) | High Tide Time | Ht (ft) |
|---|---|---|---|---|---|---|---|---|
| 1992/11/18 | 0212 | 0.0 | 0741 | 3.3 | 1441 | 0.2 | 2003 | 3.4 |
| 1992/11/19 | 0310 | 0.0 | 0840 | 3.4 | 1544 | 0.1 | 2105 | 3.3 |
| 1992/11/20 | 0407 | -0.0 | 0937 | 3.5 | 1643 | -0.1 | 2206 | 3.3 |
| 1992/11/21 | 0503 | -0.1 | 1033 | 3.6 | 1740 | -0.3 | 2305 | 3.3 |
| 1992/11/22 | 0556 | -0.1 | 1126 | 3.7 | 1834 | -0.4 | | |
| 1992/11/23 | 0000 | 3.3 | 0647 | -0.1 | 1217 | 3.8 | 1925 | -0.5 |
| 1992/11/24 | 0052 | 3.3 | 0736 | -0.0 | 1305 | 3.8 | 2014 | -0.5 |
| 1992/11/25 | 0140 | 3.2 | 0824 | 0.0 | 1351 | 3.8 | 2102 | -0.4 |
| 1992/11/26 | 0226 | 3.2 | 0912 | 0.1 | 1437 | 3.7 | 2150 | -0.3 |

A total of 21 lb. of dye were released into Round Cove between 0550 and 0620 on the morning of November 18. Winds were light from the northeast during the 18$^{th}$. Following the start of the ebb tide shortly before 0800, a portion of the dye cloud exited Round Cove and moved into the southwestern corner of Pleasant Bay. The surveys were conducted at five stations inside the cove and one station outside the cove (Figure 3.1). A survey was conducted during the first low tide on the afternoon of November 18 to ensure that adequate data would be obtained if the dye were to decline too rapidly. The dye appeared to remain in Round cove and the adjacent area of Pleasant Bay through the fifth survey on November 21. Dye concentrations

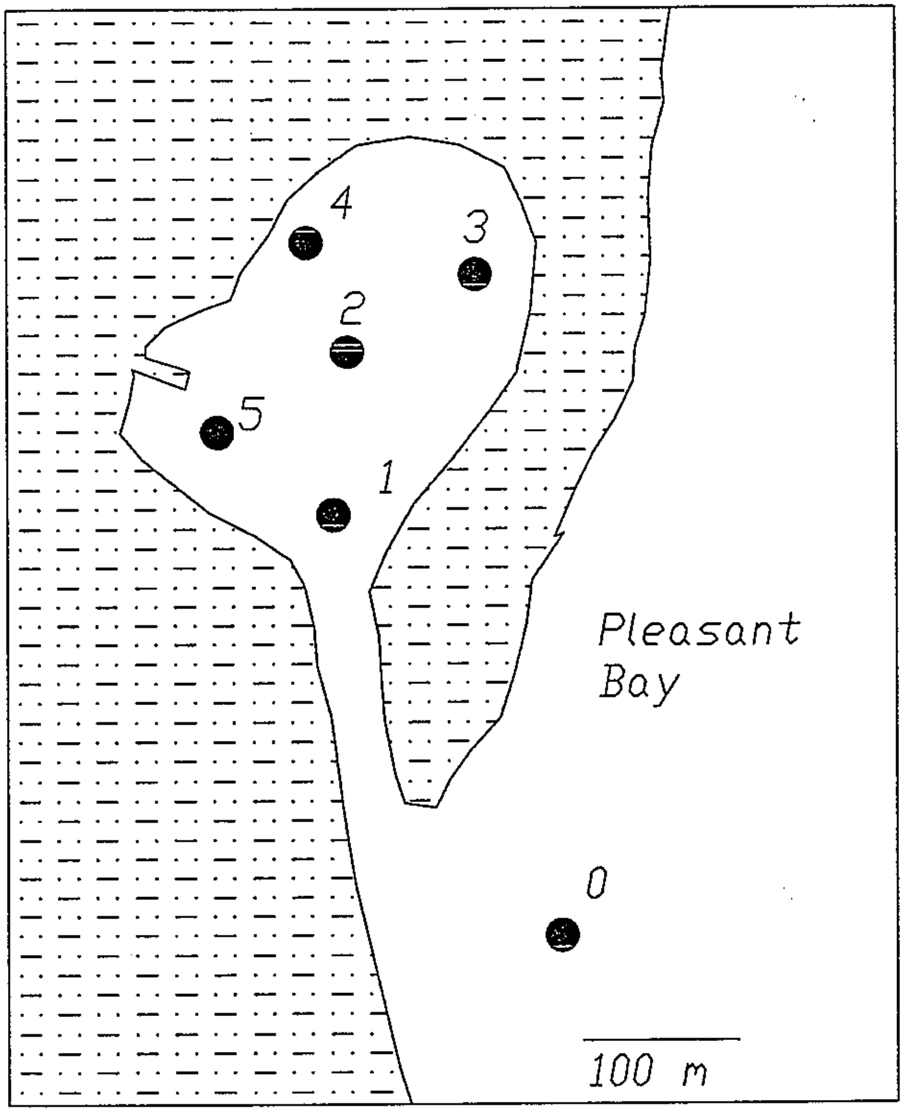


Figure 3.1 Schematic of Round Cove showing station locations.

Table 3.3 Timing of Surveys in Round Cove.

| Survey # | Date/Time |
|---|---|
| Background | 0540-0550,11/18/92 |
| 1st High | 0856-0921,11/18/92 |
| 1st Low | 1431-1448,11/18/92 |
| 2nd High | 2031-2052,11/18/92 |
| 3rd High | 0853-0924,11/19/92 |
| 4th High | 2155-2221,11/19/92 |

in Pleasant Bay outside the mouth of Round Cove were typically as high as concentrations inside the cove. This observation indicates that the net circulation in Pleasant Bay was not transporting dye away from the mouth of the cove. As a result, water leaving Round Cove during each ebb tide would remain in the vicinity of the entrance and would then be able to reenter the Cove during the following flood tide. A summary of the surveys made in Round Cove is shown in Table 3.3. Wind and weather conditions were relatively mild during November 18-21, with winds calm or light from the North or Northeast. Dye concentrations were still relatively high by the time of the fifth survey on November 21. A sixth survey was therefore conducted on November 24. The November 24 survey was preceded by a rapidly moving storm which brought winds and rain to the Cape during the 23$^{rd}$. The storm was also accompanied by high tides late on the 23$^{rd}$ and the morning of the 24$^{th}$.

A tide gauge was deployed along the North shore of Round Cove on the afternoon of November 18. The sensor was attached to a metal fence post which then driven into the bottom approximately 10 m offshore at low tide. The position of the gauge was not referenced to a local benchmark. The gauge remained deployed until November 24.

Salinity profiles were obtained in Round Cove and off the entrance in Pleasant Bay during the first low tide and third high tide survey.

## 3.2 Allens, Wychmere, and Saquatucket Harbors

The dye studies were carried out simultaneously in the three South coast harbors. A summary of times of high and low water during this period are shown in Table 3.4. The locations of the dye measurement stations are shown in Allens, Wychmere and Saquatucket Harbors in Figures 3.2-3.4 respectively. The first release was made in Allens Harbor, following

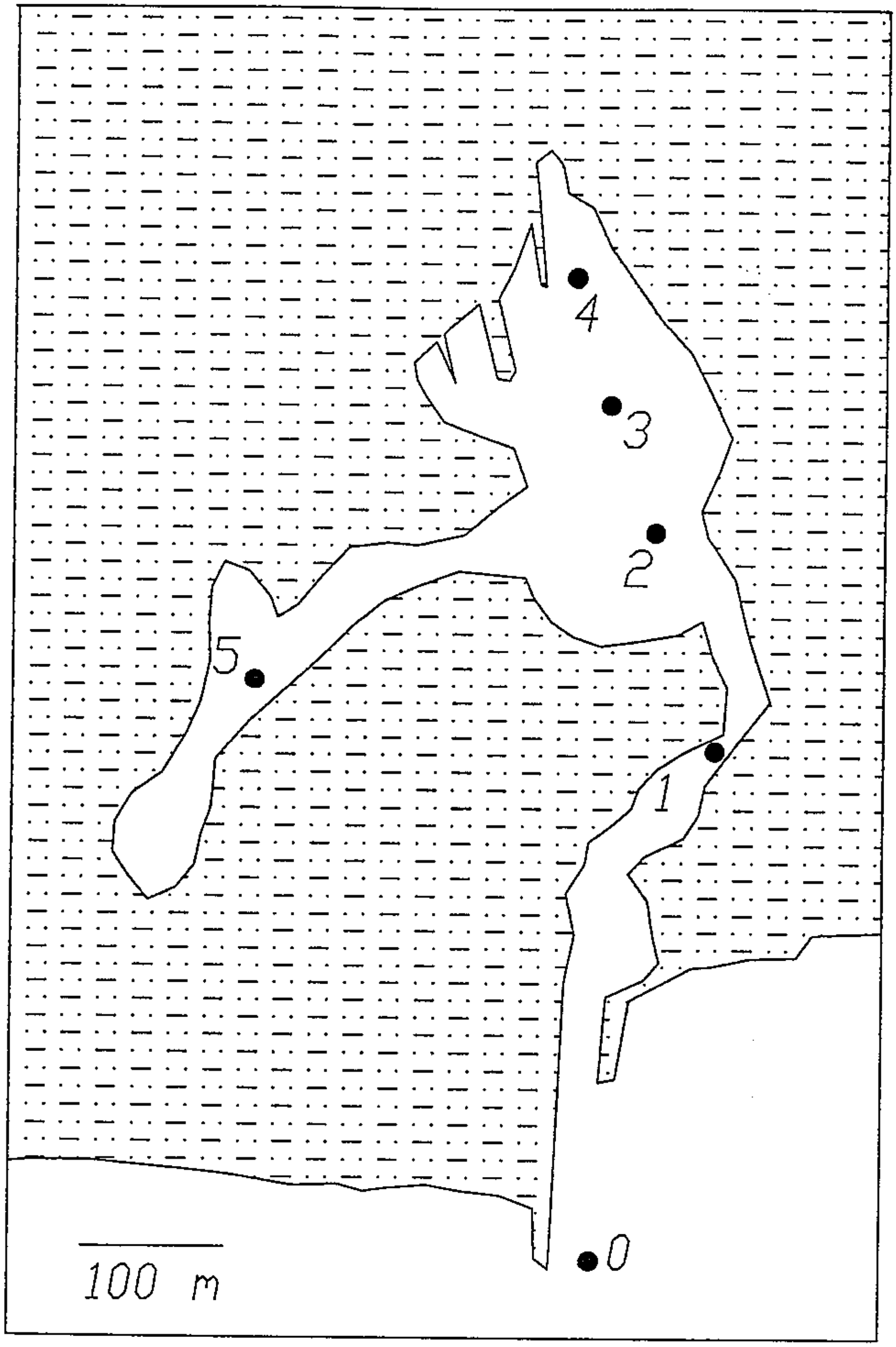


Figure 3.2 Schematic of Allens Harbor showing station locations.

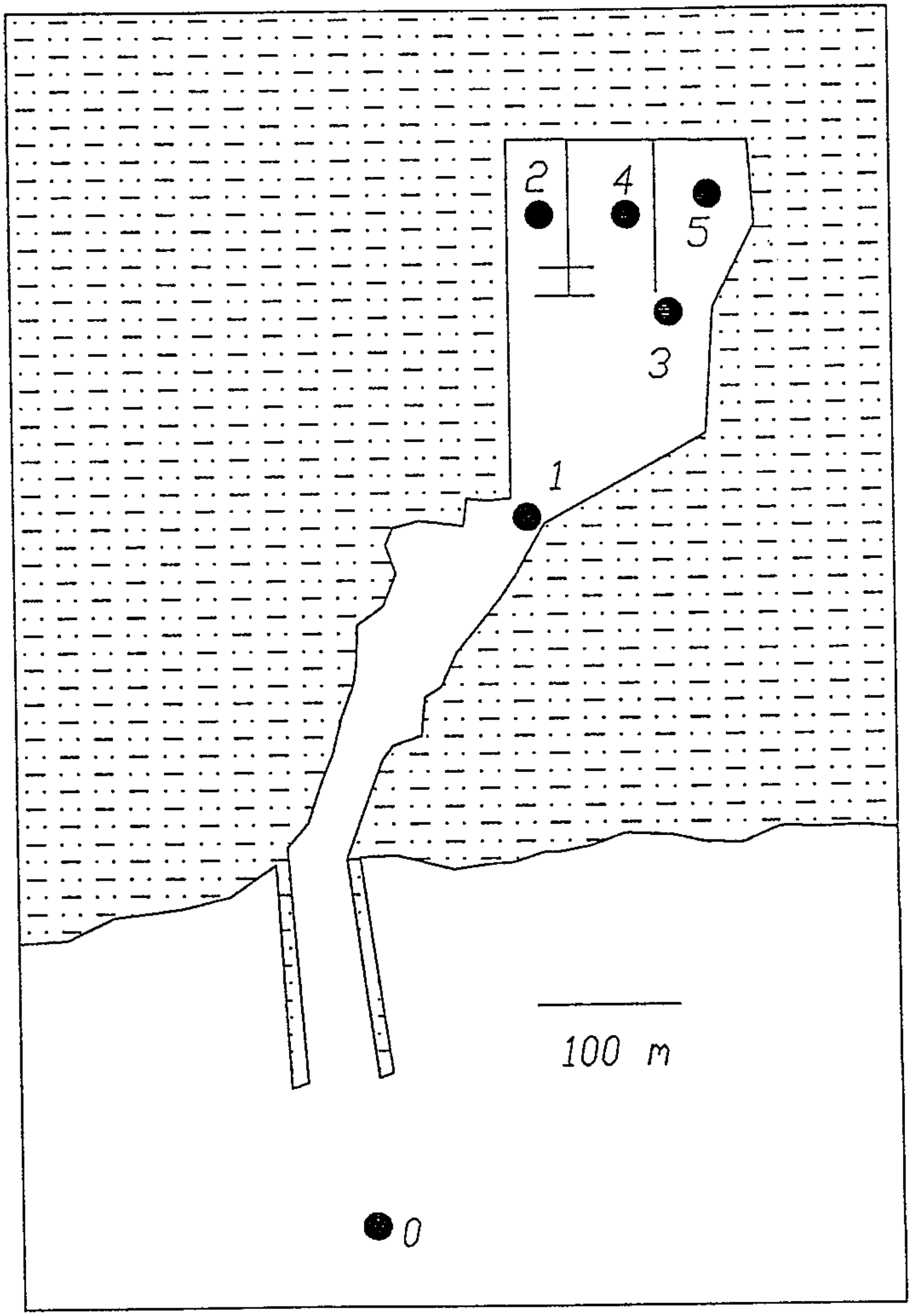


Figure 3.4 Schematic of Saquatucket Harbor showing station locations.

the background survey. A total of 28.5 lb of Rhodamine were applied to the harbor. The application included the area in the narrow channel which extends to the West from the center of the harbor. The Wychmere and Saquatucket Harbor releases were started at 1740 and 1810, respectively. The first high tide survey began in Allens Harbor at 2015 (Table 3.5); in each case approximately three hours were allowed for mixing of the dye in the water column. Subsequent surveys were performed 12, 24, 48, and 108 hours after the first high tide. As discussed in Section 3.1, the final survey was conducted following a period of wind, rain and tidal surge. Salinity profiles were obtained in the three harbors during the November 20 morning high tide survey.

Table 3.4. Tide table for the South shore pond during the period of the study.

| Date | Low tide Time | Low tide Ht(ft) | High tide Time | High tide Ht(ft) | Low Tide Time | Low Tide Ht(ft) | High tide Time | High tide Ht(ft) |
|---|---|---|---|---|---|---|---|---|
| 1992/11/19 | 0016 | -0.1 | 0659 | 3.9 | 1249 | 0.0 | 1925 | 3.8 |
| 1992/11/20 | 0114 | -0.1 | 0756 | 4.1 | 1351 | -0.1 | 2026 | 3.8 |
| 1992/11/21 | 0211 | -0.1 | 0851 | 4.2 | 1450 | -0.3 | 2124 | 3.9 |
| 1992/11/22 | 0305 | -0.1 | 0943 | 4.4 | 1545 | -0.4 | 2218 | 3.9 |
| 1992/11/23 | 0356 | -0.1 | 1033 | 4.4 | 1637 | -0.5 | 2309 | 3.9 |
| 1992/11/24 | 0446 | -0.1 | 1120 | 4.4 | 1726 | -0.5 | 2358 | 3.8 |
| 1992/11/25 | 0533 | -0.0 | 1207 | 4.4 | 1813 | -0.4 | | |
| 1992/11/26 | 0045 | 3.8 | 0620 | 0.1 | 1252 | 4.3 | 1858 | -0.3 |

Table 3.5 Schedule of surveys in Allens, Wychmere and Saquatucket Harbors.

| **Survey #** | **Date** | **Survey Time** | | |
|---|---|---|---|---|
| | | **Allens Harbor** | **Wychmere Harbor** | **Saquatucket Harbor** |
| Background | 11/19/92 | 1628-1631 | 1738 | 1802 |
| 1st High | 11/19/92 | 2015-2030 | 2043-2056 | 2106-2120 |
| 2nd High | 11/20/92 | 0901-0934 | 0941-1001 | 1010-1032 |
| 3rd High | 11/20/92 | 2022-2045 | 2041-2115 | 2122-2142 |
| 4th High | 11/21/92 | 2256-2320 | 2200-2233 | 2054-2122 |
| 5th High | 11/24/92 | 1105-1120 | 1133-1158 | 1204-1221 |

## 4. STUDY RESULTS

In this section, the data collected during the November field effort will be analyzed to produce estimates of flushing rates for each of the coastal ponds studied. The flushing rate parameter, R, is defined as the rate at which the volume of the estuary is replaced through exchange with adjacent water bodies. The flushing rate may alternately be defined as flushing time, $T_f$ through the relationship :

$$T_f = \frac{V}{R}, \tag{1}$$

where V is the volume of the water body. The flushing time may then be seen to be the time required for the complete replacement of the volume of the water body.

Estimates of flushing rate and time will be derived by two approaches in this report. The first method, called the tidal prism method, is based on the relationship between the tidal prism volume, the volume of water which enters and leaves during a characteristic tidal cycle, and the low tide volume of the pond. Flushing time may be expressed as:

$$T_f = \frac{VT}{P}, \tag{2}$$

where V is the mean volume of the pond, P is the tidal prism volume and T is the tidal period (12.4 hours). The second estimate of flushing will be based on the rate of decay of dye following its release into the pond. The change in mean dye concentration, C, following the release may be expressed as a function of dye loss rate through the expression:

$$\frac{dC}{dt} = -kC \tag{3}$$

The solution to this expression is:

$$C(t) = C_0 \exp(-kt),$$

which states that the concentration of dye or any pollutant which is released to the pond decays exponentially with time. The rate of decay is dependent on the parameter k, which is equal to the inverse of the flushing time. Hence:

$$k=\frac{1}{T_f}=\frac{R}{V} \qquad (5)$$

where $T_f$, R and V are as previously defined. The decay of mean dye parameter k may be shown to be the slope of the log of C(t) versus time.

## 4.1 Round Cove Flushing Calculations

The bathymetric survey of Round Cove by Fugro-McClelland produced the following information:

Surface area: $4.7 \times 10^4$ $m^2$

Average depth: 2.16 m

Mean Volume: $1.02 \times 10^5$ $m^3$

The tide record obtained in Round Cove during the period of the study is shown in Figure 4.1. A summary of the tide observations which references the tide data to the Fugro-McClelland bathymetric data is shown in Figure 4.2. The record was ended on November 23, when the initial surge produced by the storm caused the sensor to flood. The record retrieved from the gauge covered a period of five days, or nine complete tidal cycles. The mean range from the record was 1.2 m. The salinity obtained during the November 18 and 19 surveys are shown in Figure 4.3. The profiles show the water column to be relatively well-mixed vertically in Round Cove and Pleasant Bay. This observation indicates that the water column in Round Cove may be represented by one vertical layer.

The tidal prism flushing time for Round Cove may be calculated from the information above gives an estimate of 0.9 days.

The mean dye concentration as a function of time in Round Cove is shown in semi-log form in Figure 4.4. The linear regression on the dye time history is shown as the dotted line in the figure. The regression excludes the first high tide survey data point. This point was excluded because it did not appear that the dye had adequately mixed in the cove by the time

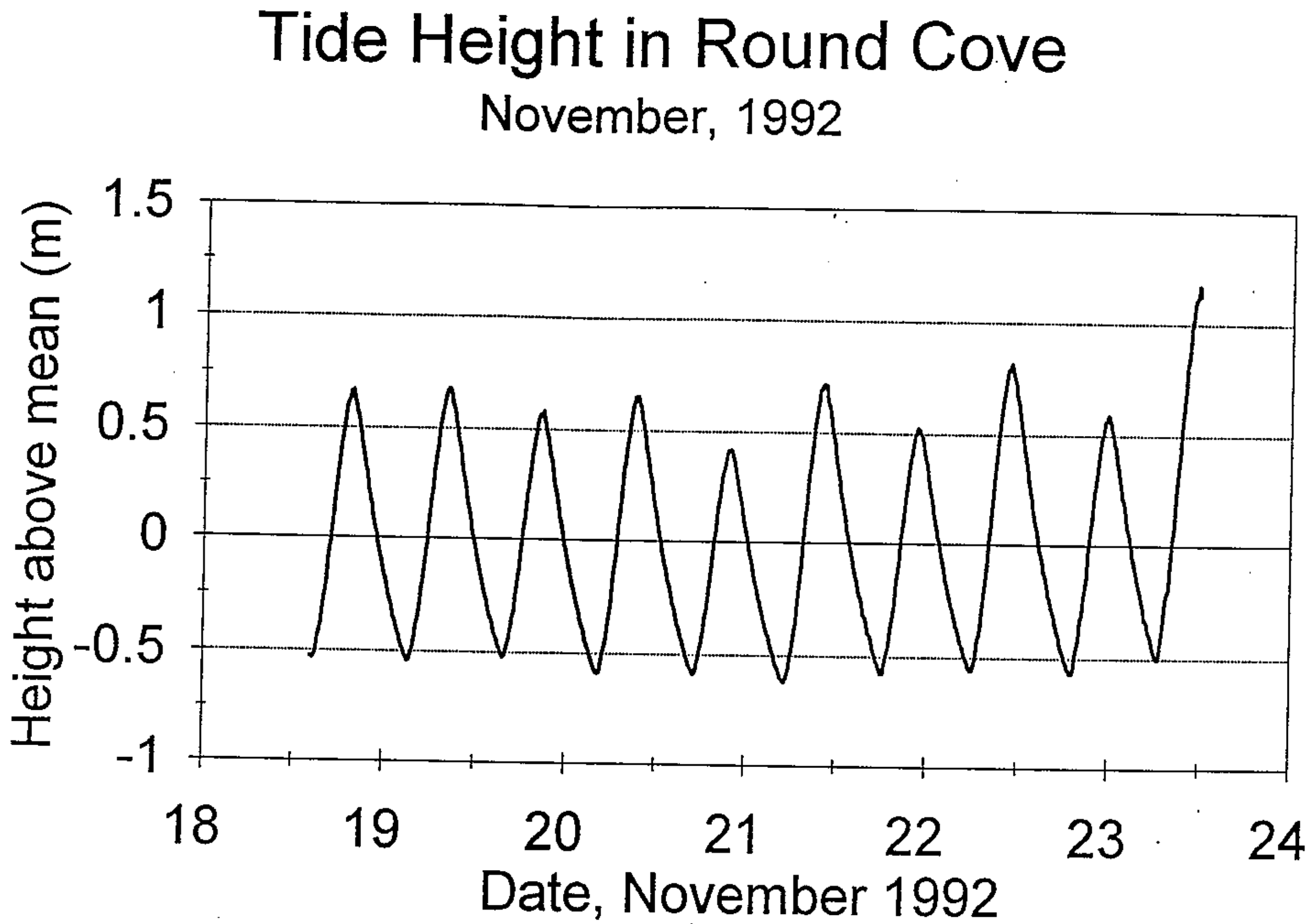


Figure 4.1 Tide height in Round Cove between November 18-23, 1992.

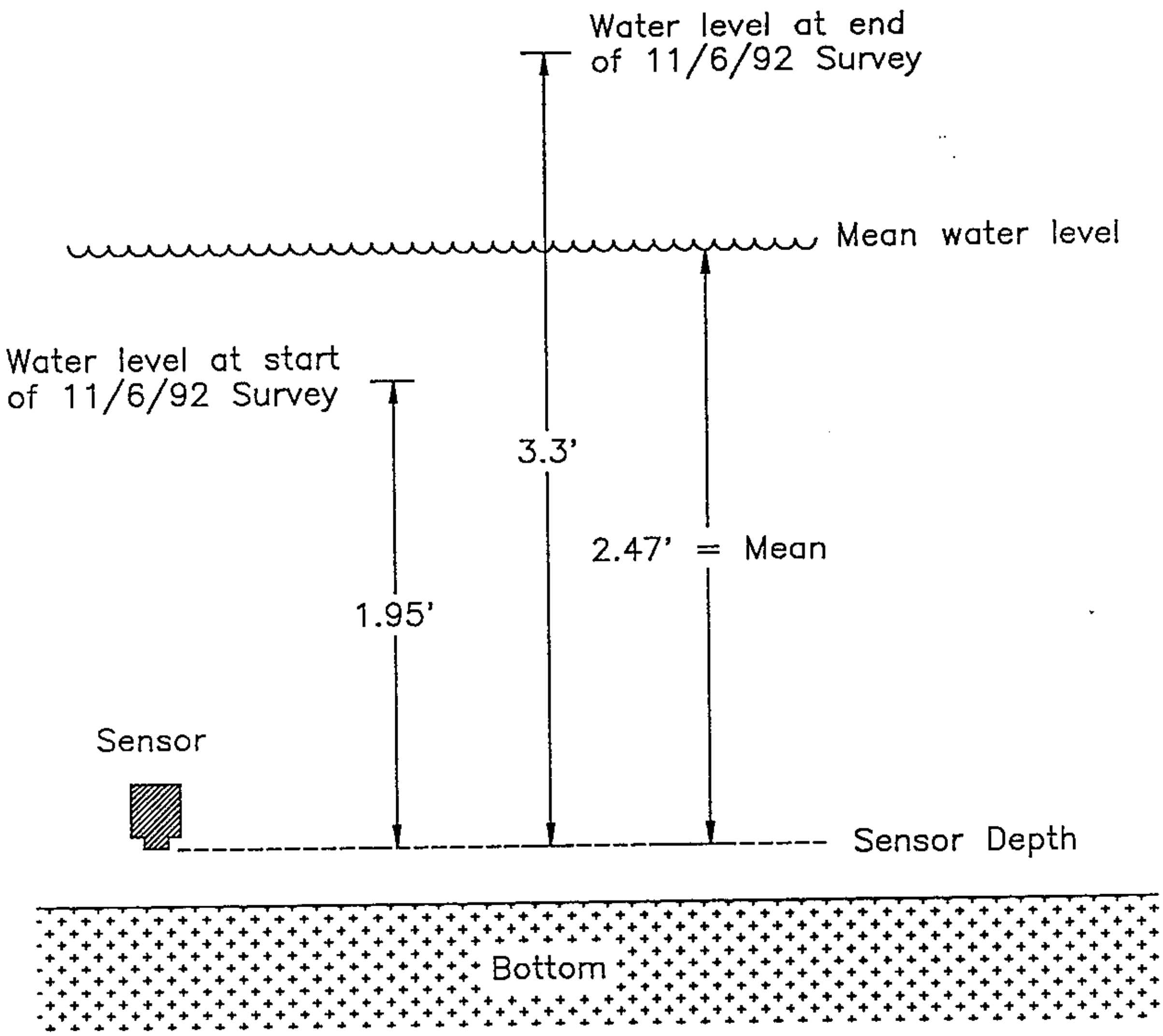


Figure 4.2 Schematic showing mean water level and height of tide in Round Cove Harbor during the Fugro-McClelland survey to vertical datums.

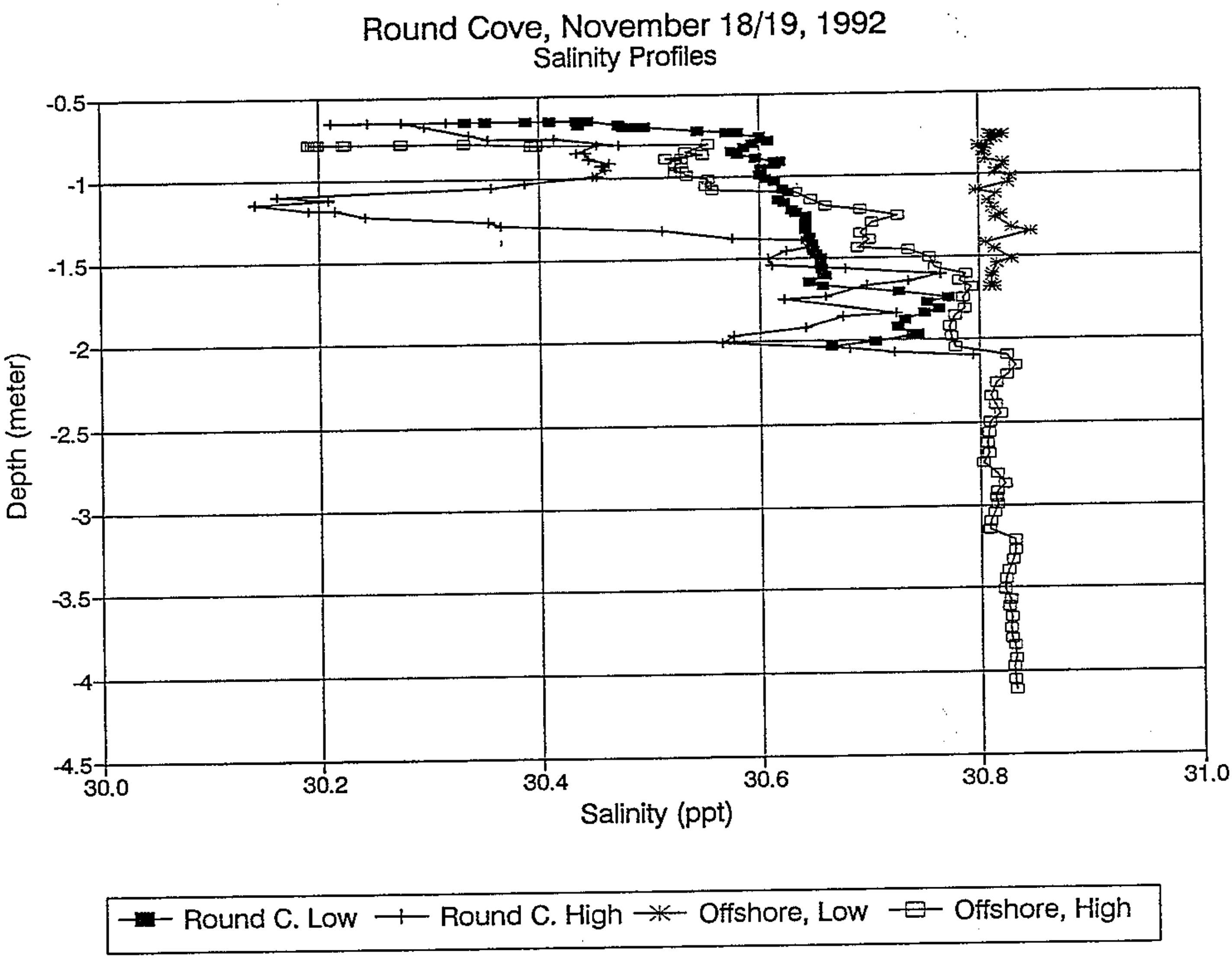


Figure 4.3 Salinity profiles obtained in Round Cove and Pleasant Bay during the study.

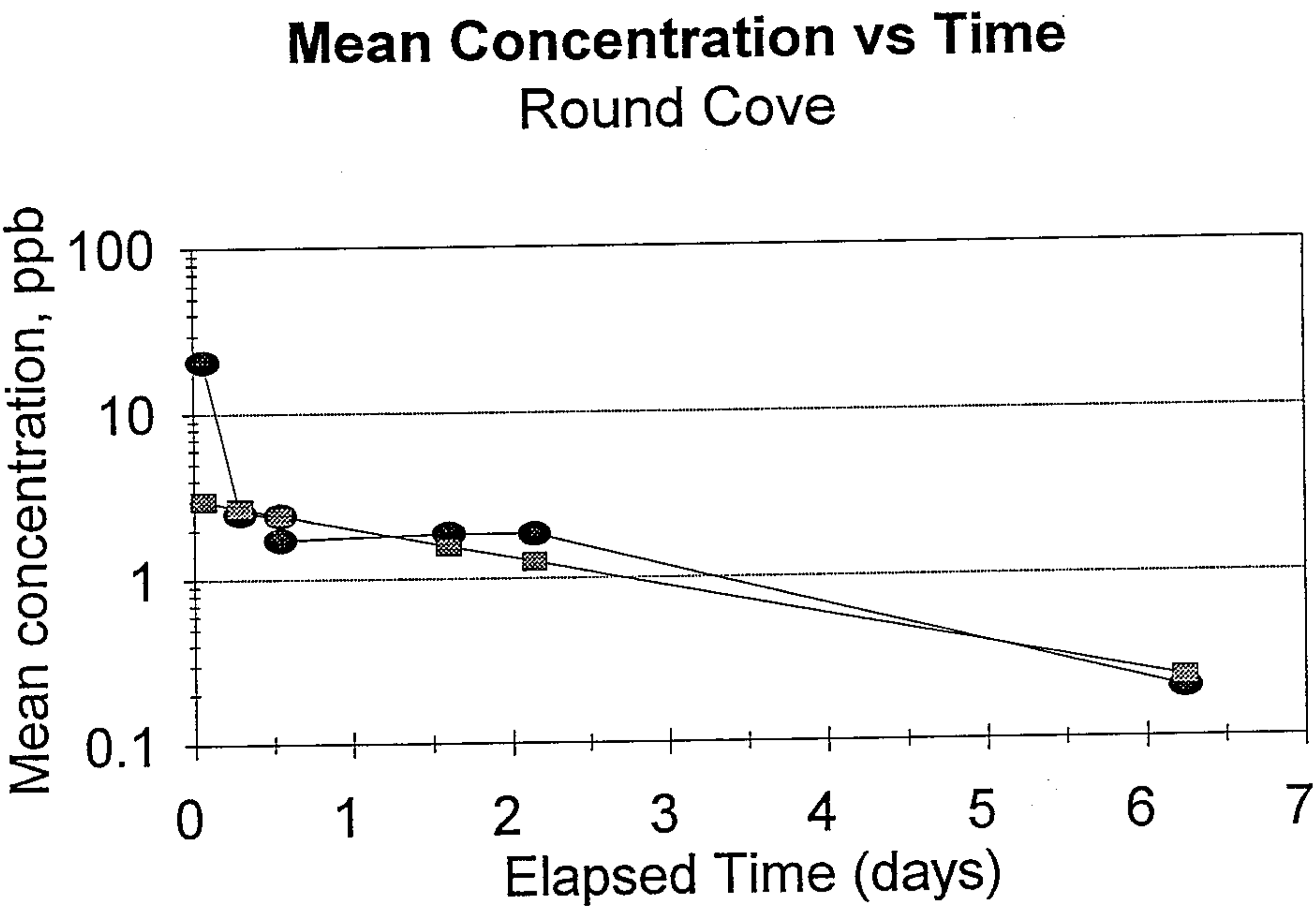


Figure 4.4 Time history of dye decay in Round Cove (square symbols) and regression on the decay series (round symbols).

the survey was made. This point may be demonstrated by examining the vertical profiles of dye concentration at station 2 in the center of the pond (Figure 4.5). The profiles show that the dye was significantly higher at the 0.5 m depth during the first survey. During subsequent surveys, the dye appeared to be relatively evenly spread through the water column. The first survey was considered as not representative and excluded from the analysis.

The regression line slope in Figure 4.4 is 0.43 day$^{-1}$. The corresponding flushing time based on the dye decay measurements is 2.4 days. This estimate is significantly higher than the 1.1 days calculated by the tidal prism method. The difference between the two numbers is attributable to the poor net circulation in Pleasant Bay in the vicinity of Round Cove.

## 4.2 Allens Harbor Flushing Calculations

The Fugro-McClelland bathymetric survey produced the following information for Allens Harbor:

Surface area: $6.54 \times 10^4$ m$^2$

Average depth: 1.86 m

Mean Volume: $1.21 \times 10^5$ m$^3$

The tide record obtained in Saquatucket Harbor during the period of November 6 - December 11 is shown in Figure 4.6. The schematic referencing the tidal measurement and mean sea level to the Fugro-McClelland data is shown in Figure 4.7. The tide gauge record was retrieved without incident, covering period of 35 days, or 69 tidal cycles. The mean range from the record was 1.1 m. A summary of the salinity data obtained in the south coast harbors and outside in Nantucket Sound is shown in Figure 4.8. The profiles shown that the three ponds are relatively well-mixed vertically. The data do not show the presence of a relatively fresh surface lens on the surface of Saquatucket Harbor, which was visually observed during the study.

The tidal prism flushing time for Allens Harbor is 0.9 days, calculated in the manner discussed for Round Cove. The dye decay time history for Allens Harbor is shown in Figure 4.9. The slope of the regression line is -0.95 day$^{-1}$. The corresponding flushing time for the entire harbor is 1.06 days, which is relatively close to the tidal prism estimate.

The dye study revealed that the channel extending to the west from the main area of the harbor was flushed at a significantly slower rate than the rest of the harbor. The flushing time calculated from the station 5 data was 1.64 days, while the flushing time for stations 1-4 was

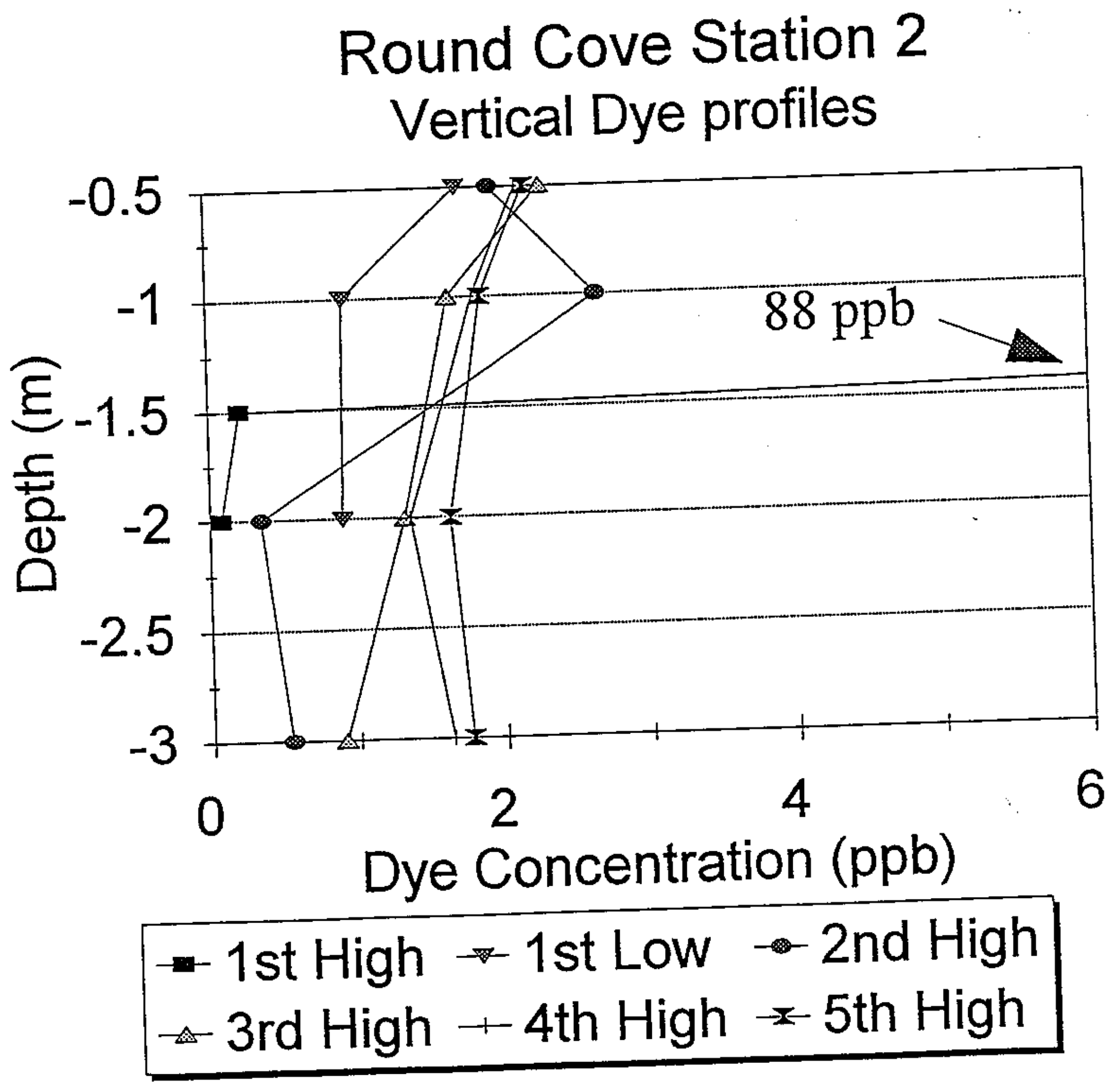


Figure 4.5 Vertical profiles of dye concentration at Station 2 during the study.

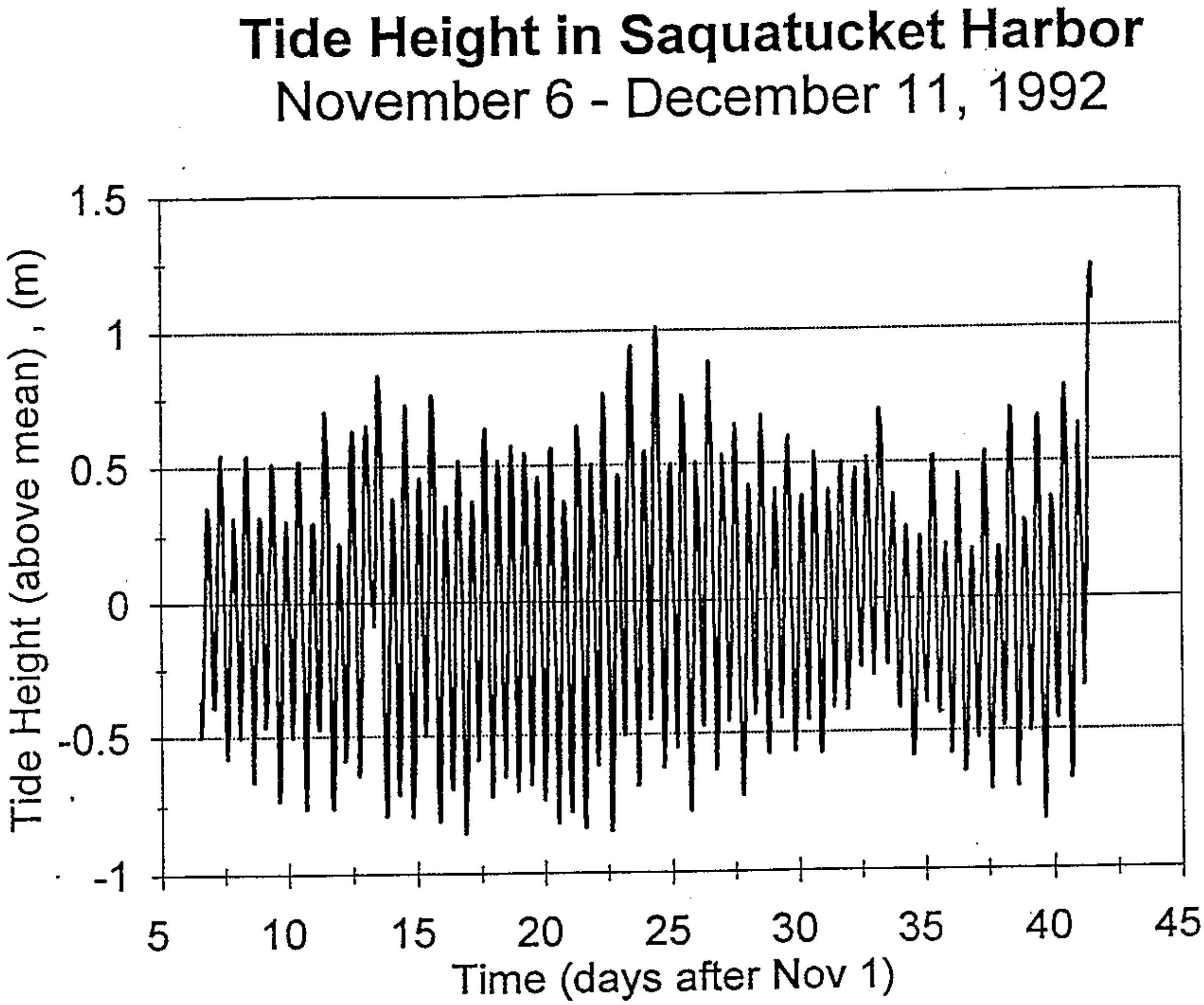


Figure 4.6 Tide height in Saquatucket Harbor between November 5 - December 11, 1992.

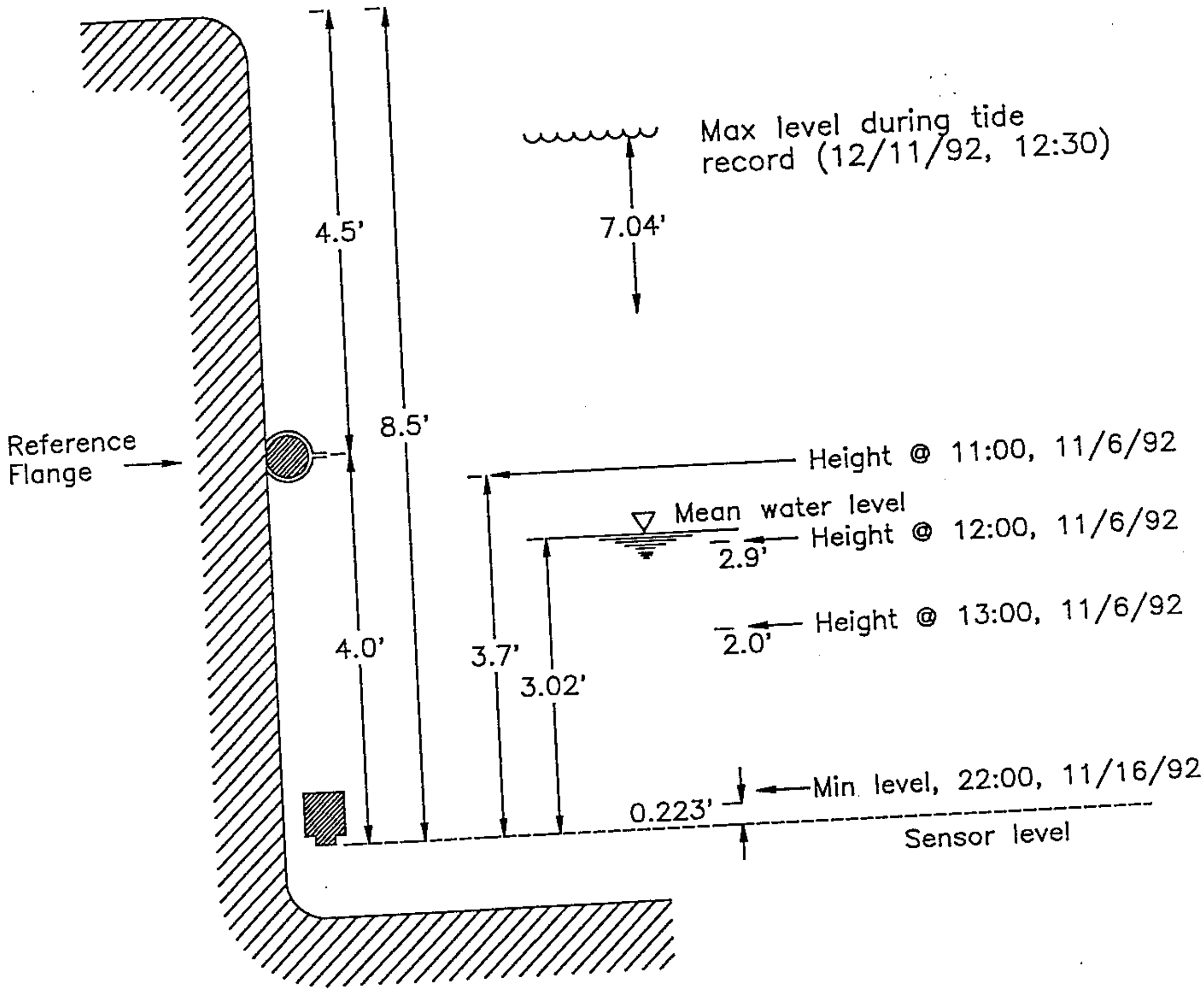


Figure 4.7 Schematic showing mean water level and height of tide in Saquatucket Harbor during the Fugro-McClelland survey to vertical datums.

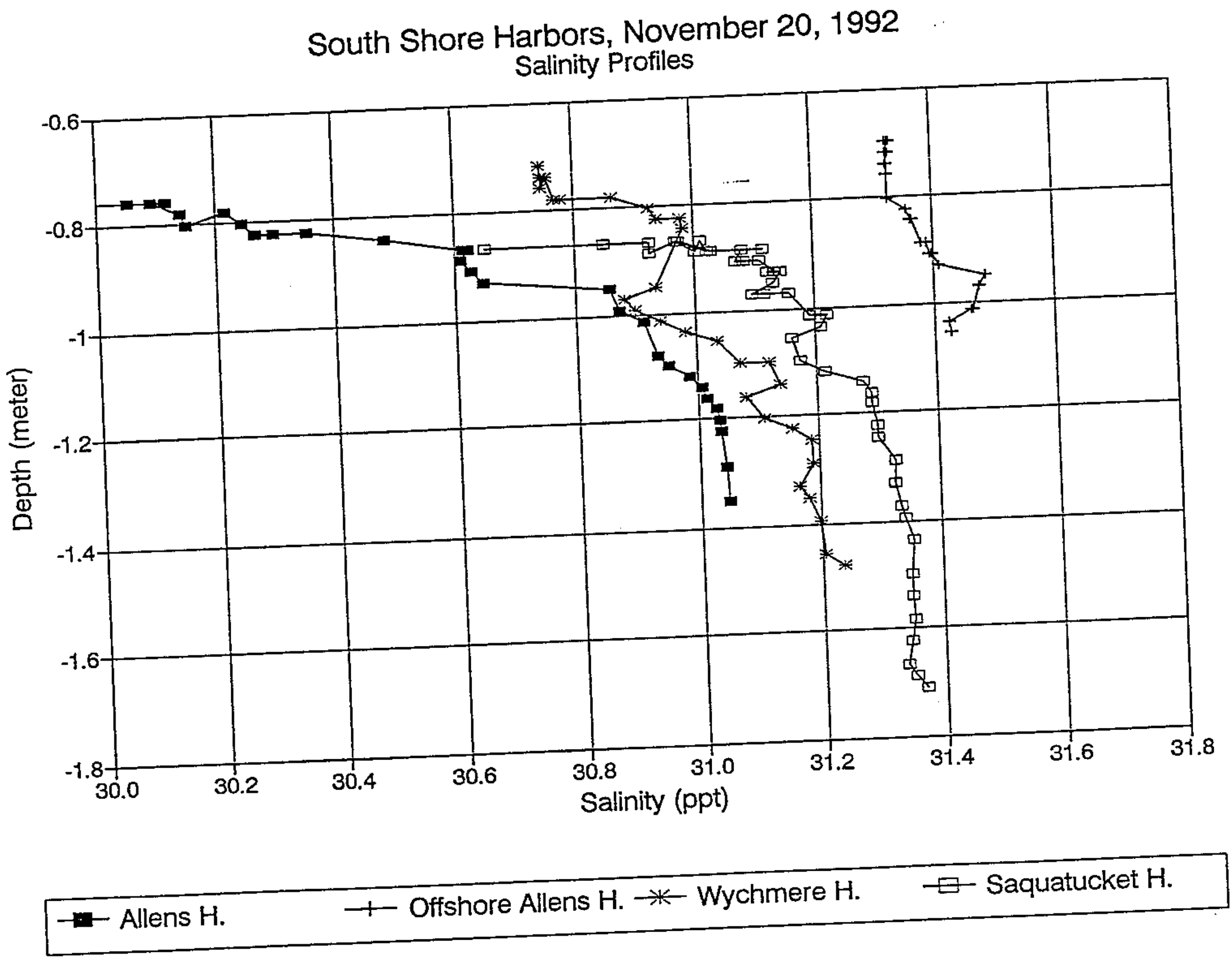


Figure 4.8 Salinity profiles obtained in South Shore ponds and Nantucket Sound during the study.

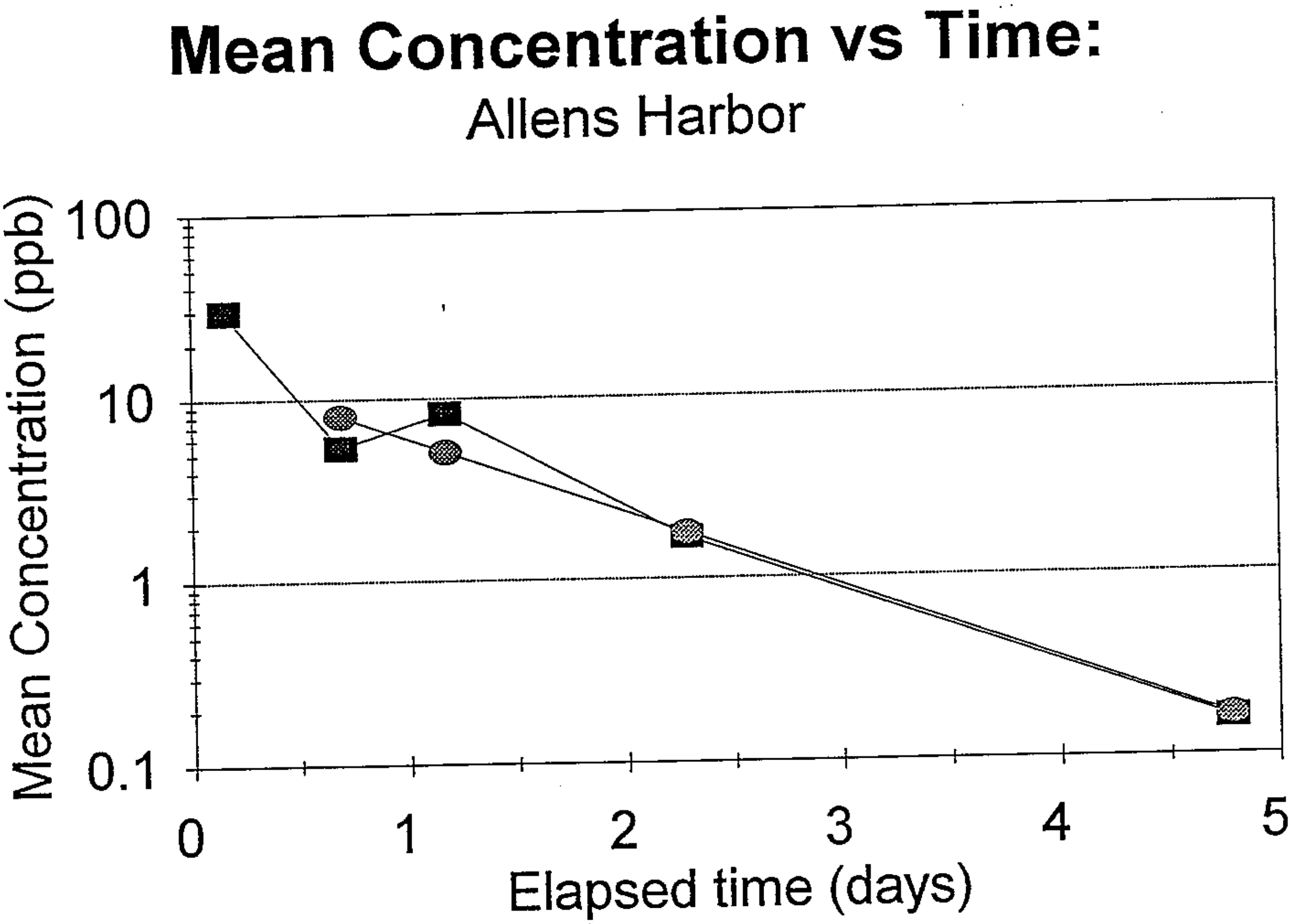


Figure 4.9 Time history of dye decay in Allens Harbor (square symbols) and regression on the decay series (round symbols).

only 0.9 days. Figure 4.10 illustrates the difference in flushing rate as evidenced in the different rates of decay of dye in the two areas during the experiment. It was concluded that a two element model would be appropriate for Allens Harbor.

### 4.3 Wychmere Harbor Flushing Calculations

The Fugro-McClelland bathymetric survey produced the following information for Wychmere Harbor:

Surface area: $5.0 \times 10^4\ m^2$

Average depth: 2.53 m

Mean Volume: $1.26 \times 10^5\ m^3$

Following the method above, the tidal prism flushing time for Wychmere Harbor is 1.2 days. The dye decay time history for Wychmere Harbor is shown in Figure 4.11. The slope of the regression line is -0.746 $day^{-1}$ corresponding to a flushing time of 1.34 days, which again is relatively close to the tidal prism estimate.

### 4.4 Saquatucket Harbor Flushing Calculations

The Fugro-McClelland bathymetric survey produced the following information for Saquatucket Harbor:

Surface area: $5.52 \times 10^4\ m^2$

Average depth: 2.74 m

Mean Volume: $1.51 \times 10^5\ m^3$

Following the method above, the tidal prism flushing time for Saquatucket Harbor is 1.3 days. The dye decay time history for Saquatucket Harbor is shown in Figure 4.12. The slope of the regression line is -0.79 $day^{-1}$ corresponding to a flushing time of 1.27 days, which is almost identical to the tidal prism estimate.

## 5. A MODEL OF POLLUTANT IMPACTS

The dye study and the other measurements in the four ponds suggest that a relatively simple approach may be taken in simulating the response of the ponds to loadings of pollutants which are conservative (do not decay) in nature. A zero-dimensional model is presented below for three ponds: Round Cove, Wychmere Harbor, and Saquatucket Harbor, whose behavior was

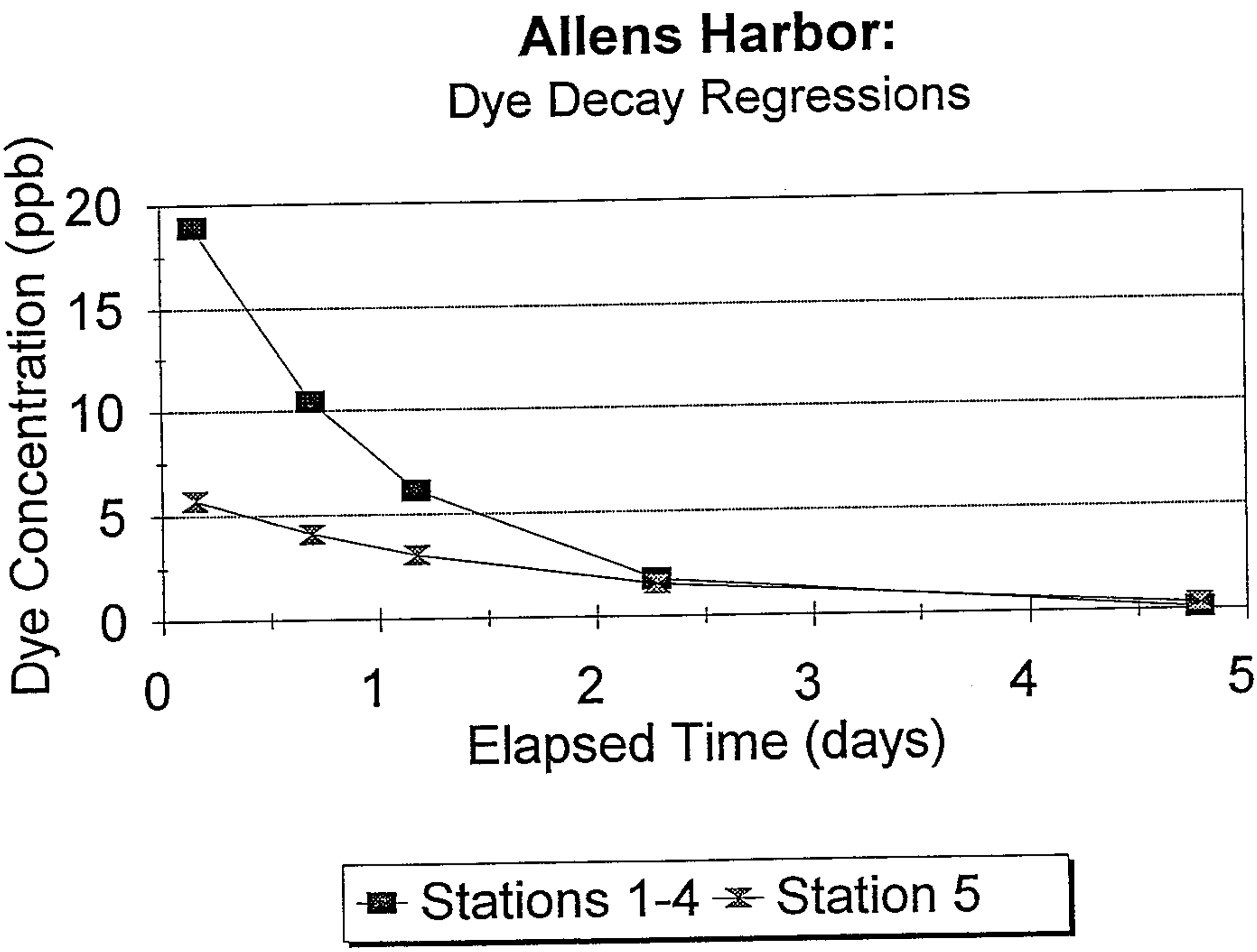


Figure 4.10 Comparison between decays rates at Station 5 and the main area of Allens Harbor (stations 1-4).

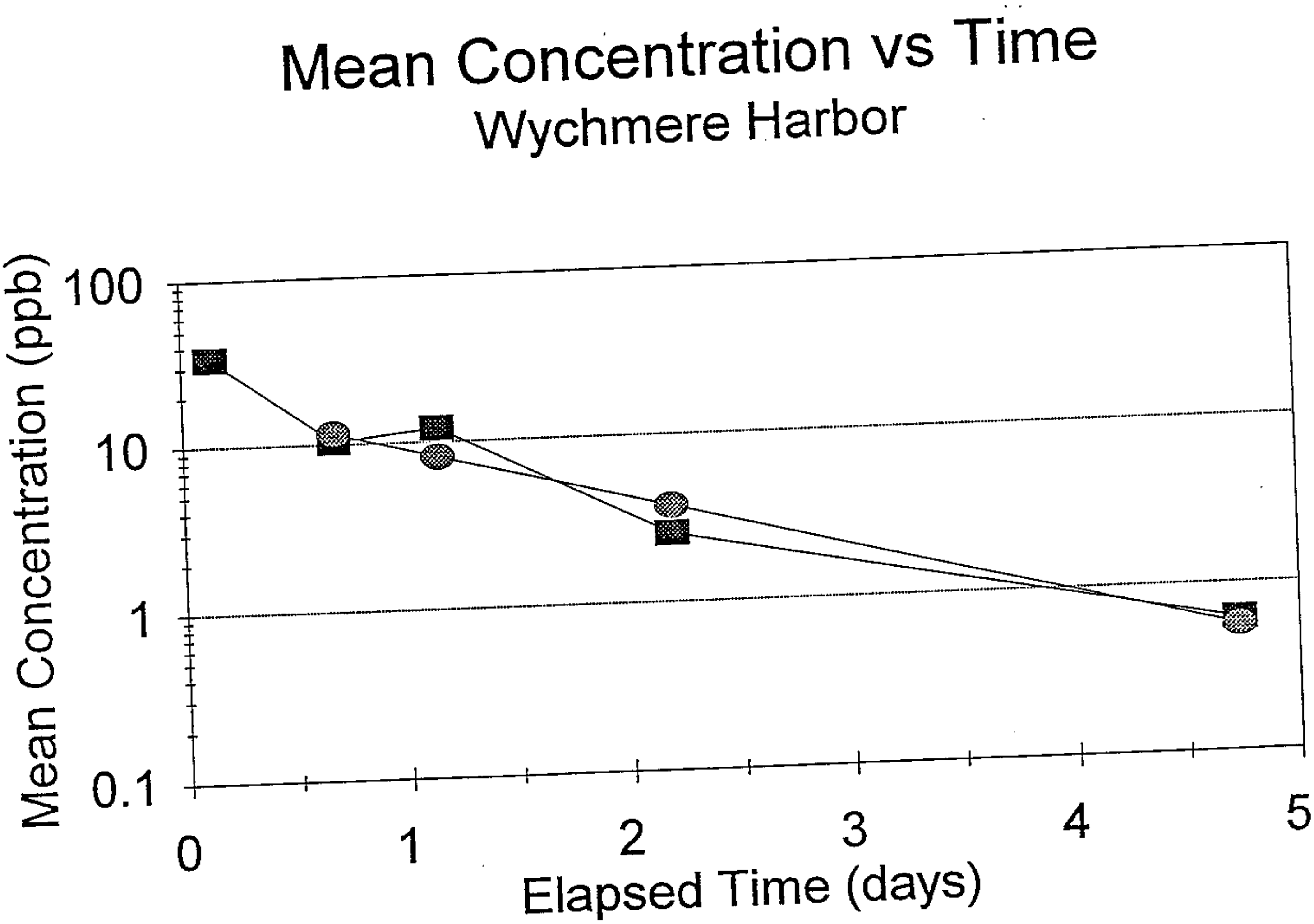


Figure 4.11 Time history of dye decay in Wychmere Harbor (square symbols) and regression on the decay series (round symbols).

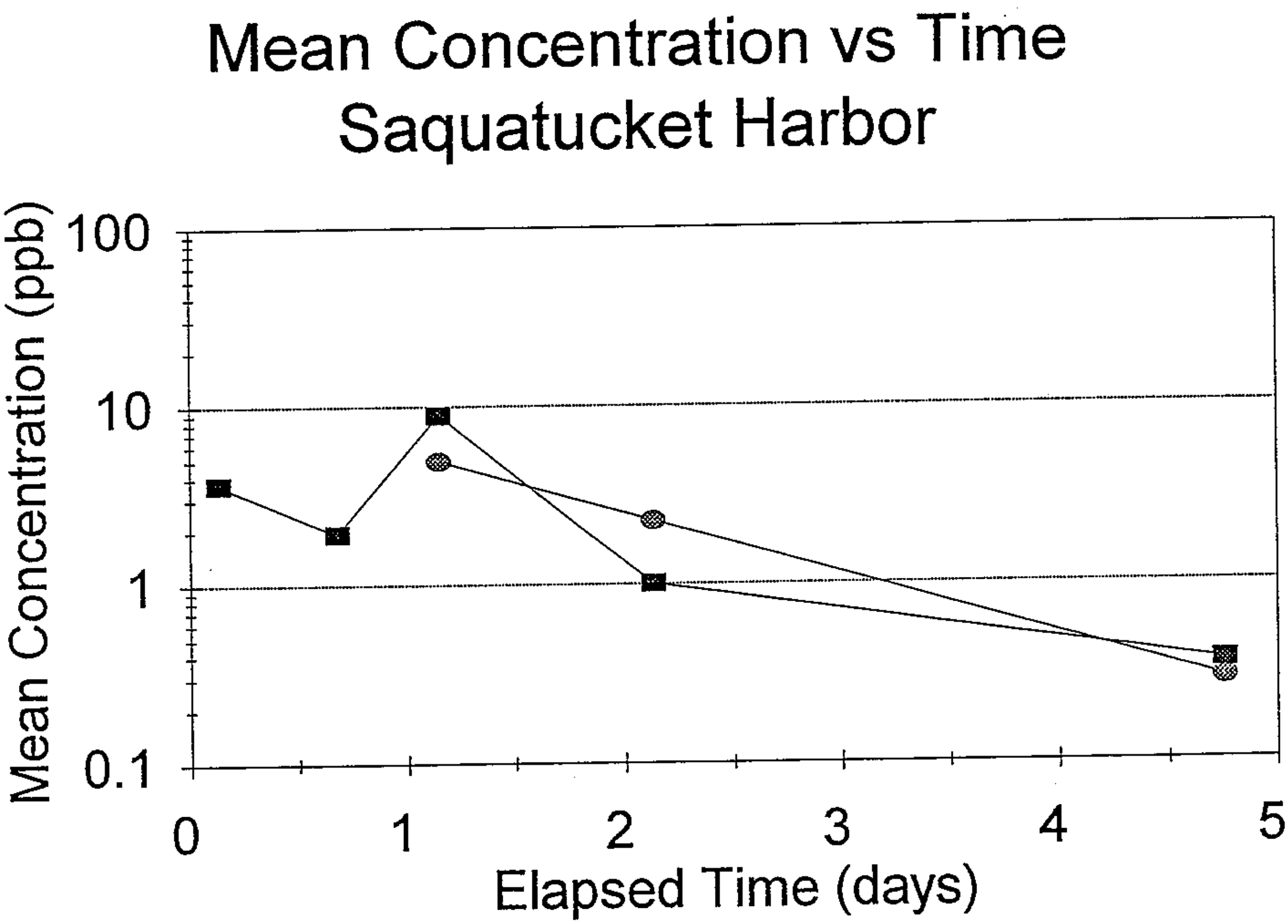


Figure 4.12 Time history of dye decay in Saquatucket Harbor (square symbols) and regression on the decay series (round symbols).

relatively homogeneous during the study. A one-dimensional model is proposed for Allens Harbor whose narrow western channel was found to flush at a relatively slower rate than the rest of the harbor.

## 5.1 Round Cove, Wychmere Harbor, and Saquatucket Harbor

The model for pollutant impacts in the three homogeneous harbors is as follows (Officer, 1976):

$$dC = \frac{T_f dL}{V} \tag{8}$$

where dC is the change in pollutant concentration (kg/m3)

$T_f$ is the flushing time of the water body (days)

dL is the pollutant loading or change in pollutant loading (kg/day)

V is the volume of the water body ($m^3$)

The applicable parameter values for each pond are given in Table 5.1.

Table 5.1 Model parameter values for Round Cove, Wychmere Harbor and Saquatucket Harbor.

| **Name** | **Flushing $T_f$ (days)** | **Volume V ($m^3$)** |
|---|---|---|
| Round Cove | 2.42 | $1.02 \times 10^5$ |
| Wychmere Harbor | 1.34 | $1.26 \times 10^5$ |
| Saquatucket Harbor | 1.27 | $1.15 \times 10^5$ |

### 5.2 Allens Harbor

A one-dimensional, two-box box model was used to approximate the steady-state concentrations of nitrogen in the large and small ponds. Figure 5.1 shows the location of the variables in the two boxes. Surface tributaries and the ocean were assumed to be negligible pollutant sources. The west channel is represented by box 1, the main harbor by box 2, and the ocean by box 3.

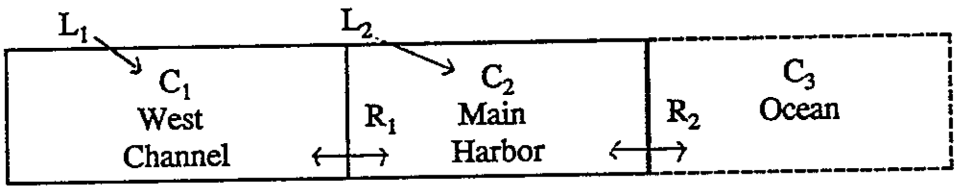


Figure 5.1 Schematic of the Allens Harbor box model.

The conservation of pollutant mass equation is represented by:

Box 1: $R_1C_2 + L_1 = R_1C_1$
Box 2: $R_1C_1 + L_2 + R_2C_3 = R_1C_2 + R_2C_2$

where:

$R_n$ = mean exchange rate of the down-estuary edge of box n in $m^3$/day, $V_n/{}^{T}f_n = R_n$

$C_n$ = time-averaged concentration of nitrogen in box n in units/$m^3$

$L_n$ = the nitrogen load on box n in units/day

The solution of these simultaneous equations is:

$$C_1 = L_1\left[\frac{1}{R_1} + \frac{1}{R_2}\right] + L_2\left[\frac{1}{R_2}\right]$$

$$C_2 = L_1\left[\frac{1}{R_2}\right] + L_2\left[\frac{1}{R_2}\right]$$

The derivatives of the solutions tell of the effect of changes in loading on the steady state concentrations. Given a constant load on the small pond ($L_1$), a change in the large pond's load ($L_2$) affects the concentrations in both the ponds equally:

$$\frac{dC_1}{Dl_2} = \frac{dC_2}{d\,L_2} = \frac{1}{R_2}$$

However, for a given load on the large pond, a change in the load on the small pond affects the two ponds differently:

$$\frac{dC_1}{dL_1} = \frac{1}{R_1} + \frac{1}{R_2} \quad , \quad \frac{dC_1}{dL_2} = \frac{1}{R_2}$$

## 6. CONCLUSIONS

This study produced flushing estimates which should be representative for the four ponds during average conditions. The range of tides expected during the study was near the mean for each area. It should be noted that the general timing of the study was not optimal in the sense that it was not performed during the summer season when weather conditions are relatively more quiescent. The present study was marred by the passage of a storm through the area. The surge accompanying the storm undoubtedly increased the rate at which the ponds were flushed. This is particularly true for Round Cove, where the barrier beach which normally separates the cove from Pleasant Bay was submerged.

A summary of the flushing time estimates for the ponds is presented in Table 6.1. The tidal prism flushing times were found to be roughly equivalent to the dye-based estimates in the south coast ponds where the pond geometry is simple. The flushing of Round Cove was found to be significantly slower than a method based on tidal volume exchange would indicate. This behavior was attributed to the location of Round Cove near the head of Pleasant Bay. The relatively poor net transport characteristics of the area produce a much slower net movement of pollutants and make Round Cove relatively sensitive to pollutant loadings.

Table 6.1 Summary of Flushing time and dye decay.

| **Location** | **Tidal Prism Flushing Time (days)** | **Dye Decay Flushing Time (days)** |
|---|---|---|
| Round Cove | 0.9 | 2.4 |
| Allens Harbor | 0.9 | 1.1 |
| Wychmere Harbor | 1.2 | 1.3 |
| Saquatucket Harbor | 1.3 | 1.3 |

## 7. REFERENCES


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