FALMOUTH POND WATCHERS

INTERIM REPORT ON CITIZEN VOLUNTEER MONITORING OF WATER QUALITY IN FALMOUTH'S COASTAL PONDS

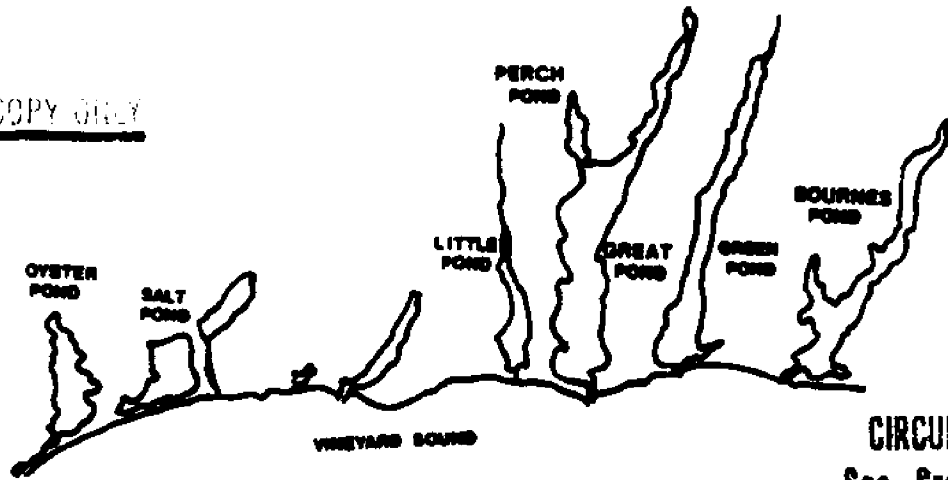

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

The 1990 field season of the Citizen's Monitoring Project for Falmouth's Coastal Ponds proved to be highly successful, due primarily to the enthusiasm and dedication of Falmouth's Volunteer "Pond Watchers". Through their continued efforts, we now have four years of data on three of Falmouth's ecologically fragile coastal salt ponds (Oyster, Little and Green Ponds). A major expansion of the volunteer effort coupled with a more focused temporal sampling scheme based upon the experience in these three ponds has enabled a major project expansion in 1990 to include two additional ponds (Bournes and Great) in the sampling program.

The goals of the project are:

1) to provide the Town of Falmouth with a data base of nutrient levels and nutrient related water quality of Falmouth's coastal ponds relative to the Coastal Overlay Bylaw;
2) to aid in evaluation of potential environmental management options for the ponds;
3) to provide a high quality independent evaluation of the impacts of both natural and man induced alterations (ex. changes to nutrient inputs or circulation) to the water quality of Falmouth's salt ponds; and
4) to foster a partnership between citizens, scientists and resource managers for maintaining the ecological health of these fragile coastal ecosystems.

It is becoming increasingly clear that, because of the large degree of environmental variability, the multi-year component of this effort is critical in providing accurate information on nutrient and oxygen conditions in these ponds for the development of long-term management strategies.

This report is an interim summary of ongoing work, updating the March, 1990 Final Report on Citizen Volunteer Monitoring of Water Quality in Falmouth's Coastal Ponds. It contains summary data from the project since its inception for comparison with the 1990 field season data; for specific comparisons, graphs and figures on data from previous year's samplings can be found in the 1990 Final Report. Since Bournes and Great Ponds have only one season's study, the results must be considered preliminary; additional data will be available after the 1991 field season.

It is clear from the data that portions of these five Falmouth coastal salt ponds are undergoing varying degrees of nutrient related stress. In 1990, major portions of all five ponds exhibited periodic water column stratification and periodic low oxygen and/or anoxia (hypoxia) events. The sensitivity of these systems to periodic hypoxia results from their estuarine circulation patterns and the high rates of oxygen consumption resulting from the large amount of nutrient stimulated organic matter production from phytoplankton and macrophytes. In all of the "finger" ponds (Green, Little, Bournes and Great Ponds), nutrient and oxygen conditions as well as water clarity showed a gradient of increasing quality moving from the headwaters toward Vineyard Sound. Nutrient and oxygen levels in the three salt ponds with multi-year data were not statistically different in 1990 from in previous years. However, it appears that nutrient levels may be increasing in some areas which will be clarified by the 1991 sampling. Oyster Pond, which had its inlet enlarged in 1990, did not appear to be significantly affected by this action by late summer. The lack of a change in pond nutrient or salinity levels is most likely due to the partial blockage of the inlet by sedimentation early in the season. The two "new" ponds, Bournes and Great Ponds, were very similar to Green Pond in both nutrient and oxygen levels, depth, stratification and water clarity. The nutrient levels in these ponds, with the possible exception of the stations directly adjacent Vineyard Sound, were in excess of 0.5 mg total nitrogen per liter.

The relative contribution of natural versus anthropogenic causes of this stress is being evaluated as a part of our efforts to provide information necessary for determining the potential success of a variety of remediative actions. The results from the Pond Watcher's efforts in concert with parallel scientific studies of these ponds now being conducted by WHOI-Sea Grant researchers are now beginning to provide the basis for designing data based management schemes not only for the Town of Falmouth, but for other coastal pond systems as well.

We are proud to convey that the Falmouth Citizen's Monitoring Project has been selected for inclusion in the 1991 Environmental Success Index of the Renew America Program, a "unique clearinghouse of information that will be made available to policymakers, citizens' groups, private and public organizations, the media and individuals interested in finding solutions to environmental problems...being part of the ESI means that this program will be promoted as a model for others." This effort has also been nominated for Renew America's National Environmental Achievement Award, an honor considering the relatively short history of this program.

INTRODUCTION

The Citizen Volunteer Monitoring Effort for Falmouth's Coastal Ponds (better known as the "Pond Watchers") is a partnership project between citizens, the Town of Falmouth and the Woods Hole Oceanographic Institution Sea Grant Program. The success of this project depends largely upon the efforts of a group of private citizens with wide ranging backgrounds and educational pursuits, all sharing a common interest in maintaining the health of their nearshore coastal waters. Concern over the potential deterioration of water quality in Falmouth's nearshore coastal salt ponds, the first indicators of nutrient pollution along the coast, has led this group of "activist volunteers" to, rather than complacently observe, put their concerns into action through active participation in identifying and monitoring the nutrient conditions in these systems (Figure 1). Through this scientific partnership, a great deal of data and information has been collected on Falmouth's coastal salt ponds. This project has completed four years of monitoring and we are now begining to be able to shift from characterization of existing conditions to assessing longer-term trends in the ecological health of these fragile coastal ecosystems.

The goals of the project are:

1) to provide the Town of Falmouth with a data base of nutrient levels and nutrient related water quality of Falmouth's coastal ponds relative to the Coastal Overlay Bylaw;
2) to aid in evaluation of potential environmental management options for the ponds;
3) to provide a high quality independent evaluation of the impacts of both natural and man induced alterations (ex. changes to nutrient inputs or circulation) to the water quality of Falmouth's salt ponds; and

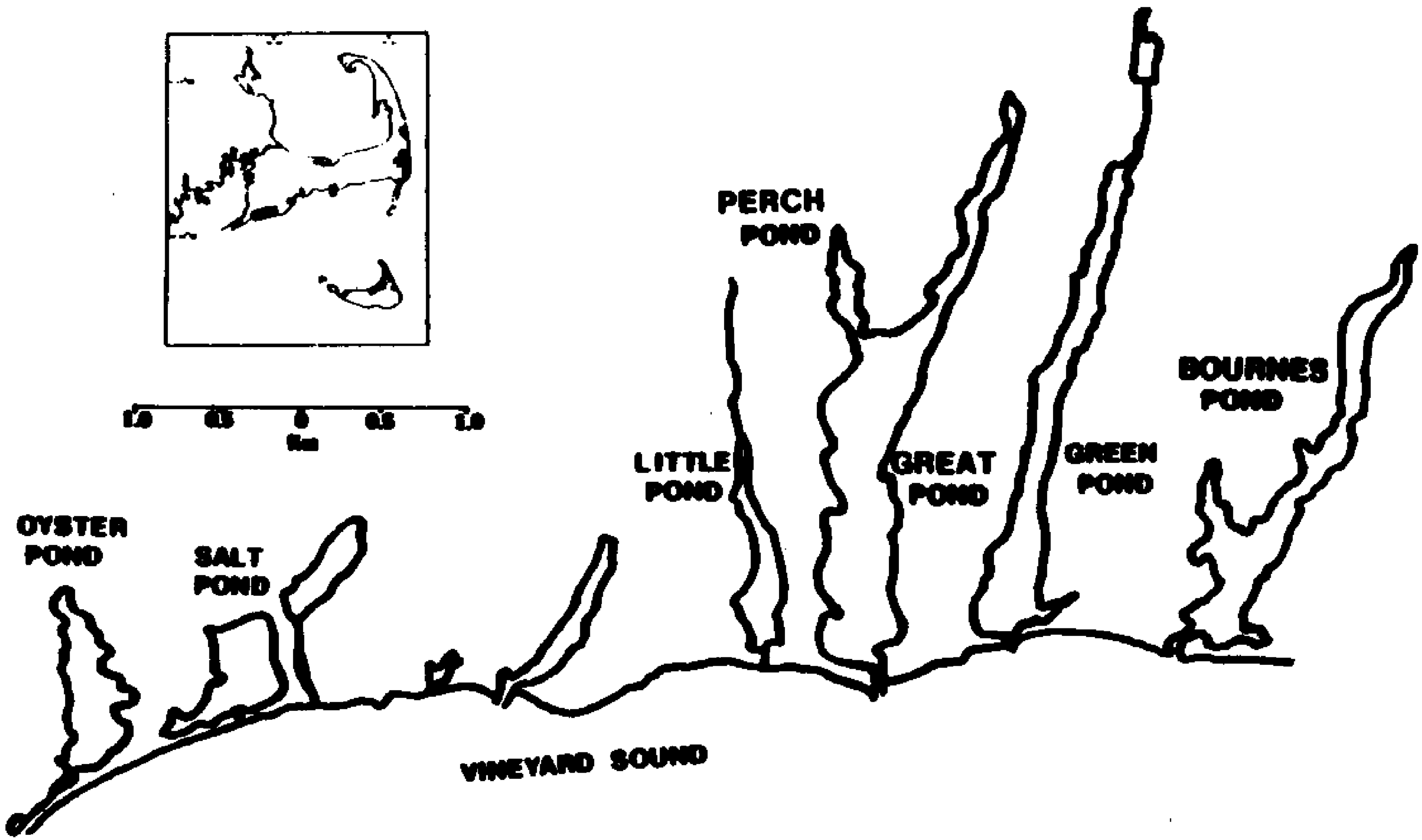


Figure 1. Relative locations of the coastal salt ponds in Falmouth, Massachusetts.

4) to foster a partnership between citizens, scientists and resource managers for maintaining the ecological health of these fragile coastal ecosystems.

Coastal salt ponds, because of their large shoreline area and generally restricted circulation and flushing properties, are usually the first indicators of nutrient pollution along the coast, especially for nutrients entering via groundwater such as nitrogen resulting from residential development with on-site septic disposal. These systems, by their nature, are highly productive, nutrient rich environments frequently providing suitable habitat for many species of commercially and recreationally valuable fish and shellfish. Although quite tolerant to high nutrient conditions, the delicate balance of these systems can be upset by excessive nutrient inputs resulting in the overfertilization (or "eutrophication") of these waters. Most all of Falmouth's coastal salt ponds presently show some signs of nutrient overenrichment. Portions of three in particular, Oyster, Little and Green Ponds indicate signs of advanced eutrophication, with periodic dense algal blooms, malodorous conditions and occasional fish kills from low oxygen conditions resulting from nutrient related oxygen depletion in bottom waters. Although it is often difficult to separate the results of natural processes from those induced by man, increased nutrient conditions resulting from excessive loading due to human activities will certainly result in declining water quality in these sensitive coastal ecosystems.

This program has been extremely successful on several fronts. First, it has provided a data base for the Town of Falmouth that can be used to evaluate its newly enacted Coastal Pond Nutrient Overlay Bylaw, a plan which identifies nutrient threshold limits for each independent ecosystem. Information generated by the citizen volunteers has shown that some of the ponds currently exceed these threshold values, a finding already being used in management decisions regarding these systems. Second, because of the large number of participants, the Pond Watchers can conduct simultaneous sampling at all sites under the same conditions of weather and tide, crucial to making site to site comparisons. Third, the Pond Watchers provide physical data and samples for the ongoing scientific studies of coastal nutrient cycling at WHOI, an effort which would not otherwise be possible under the constraints of funding and available manpower. Equally significant, the nearly unique (multiple pond and multi-year) information generated by the program would not be generated if "experts" (researchers, State or Federal agencies) were to conduct all of the work because of the expense. The joint effort between scientists and the community has kept costs low and created a conduit for immediate transfer of environmental information to an activist citizenry. The end result has been increased public awareness of the fragile nature of our coastal ecosystems not only among the Pond Watchers, but the local and regional community as well.

The role of the scientists in this study is to oversee the project in terms of sample collection and analysis, and to synthesize the data within the proper ecological context. The framework for this ecological context is based upon ongoing studies in Dr. Howes' laboratory which involve coastal nutrient cycling in systems ranging from larger more open coastal systems such as New Bedford and Nantucket Harbor to permanently ice covered stratified eutrophic marine lake systems in Antarctica. These associated projects are providing valuable information with which to better understand and interpret the results from the Citizen's Monitoring Project. One of the unexpected benefits of this program has been the cooperation and communication it has generated among research scientists, citizens and local government, demonstrating the wealth of untapped energy and dedication of private citizens to environmental conservation. In addition, the information from this effort is reaching beyond the immediate participants through presentations to community organizations, local and regional governments, as well as across the country through participation in national meetings on citizen's monitoring of the environment and scientific symposia.

For a coastal community, water quality has both direct and indirect economic benefits. The health of valuable natural resources such as recreational and commercial fish and shellfish species depends entirely on the environmental health of the ecosystem as a whole. Monitoring existing water quality in these systems as the pressure for development increases is crucial for their protection from serious damage resulting from man's activities. Differentiating between those alterations to water quality due to natural versus man-related sources is an important component to understanding alterations to any natural system. For many communities like Falmouth, tourism is an important economic resource. Poor water quality conditions seriously affect the desirability of a coastal area to the tourist industry as well as the value of real estate properties on or near these systems, and may subsequently impact an important economic resource for many of these towns. Not only does Falmouth benefit economically, but the natural resource itself is given some degree of protection by greater understanding of its importance to the community.

STATEMENT OF THE PROBLEM

Eutrophication is the natural response of coastal aquatic systems to excessive nutrient loading. Eutrophic conditions are caused by high nutrient inputs into coastal waters which severely impact the environmental health of coastal systems, in some instances resulting in water column anoxia, fish kills, and loss of valuable eelgrass and shellfish beds. Nitrogen is generally the nutrient limiting phytoplankton and algal productivity in marine systems, and increasing the availability of nitrogen will stimulate production of these microscopic plants in these systems, much like fertilizer additions to a garden. The subsequent deterioration of coastal waters therefore is not directly the result of nutrient loading, but rather a secondary effect of the resulting overproduction of phytoplankton and submerged aquatic plants. As these plants respire at night and ultimately die and decay, oxygen is consumed and may become severely depleted in the bottom sediments and water column. It is this oxygen depletion that is ultimately responsible for the detrimental effects of excessive nutrient loading in coastal ecosystems.

Of the various forms of pollution that threaten coastal waters (nutrients, pathogens and toxics), nutrient inputs are the most insidious and difficult to control. This is especially true for nutrients originating from non-point sources, such as nitrogen transported in the groundwater from on-site septic treatment systems or lawn fertilizers. These introduce nitrogen to groundwater primarily as nitrate, which passes generally unaltered to the sediments underlying ponds and coastal waters. At the sediment/water interface at the bottom of a salt pond or harbor, the nitrate either passes up into the harbor (where it is available for plant uptake), or may be "detoxified" by a natural community of denitrifying bacteria which release the nitrogen as harmless nitrogen gas. How nitrate input is partitioned between these processes determines its effect on the biological activity and environmental health of a receiving water body. Once in the water column, the impact of a one-time input of nitrogen may be magnified many times over depending on how many times the nitrogen cycles between sediments and overlying waters column. The re-release of nitrogen after algáe and phytoplankton (whose growth has been stimulated by the initial availability of nitrogen) die and decompose results in the nitrogen once again becoming available for production. Accumulated both organic and inorganic nitrogen within pond sediments may act as a "storage battery" for nutrients, continuing to provide a source of nitrogen for biological production even though the original inputs may have diminished or ceased. How many times the nitrogen cycles between sediments and the water column before being flushed out to the ocean or buried permanently in the sediments is directly related to the potential for eutrophication. Eutrophication resulting from overproduction of organic matter due to excessive nutrient loading ultimately impacts oxygen conditions. High nutrient levels are frequently associated with depletion of oxygen, potentially to the point of limiting or prohibiting survival of benthic infauna, shellfish and fish in these waters. Through the efforts of the Pond Watchers we now have several years of data on these parameters, enabling comparison of nutrient and oxygen conditions between ponds on time scales relevant to potential changes in development related inputs.

By providing a sustained data base on nutrient conditions in Falmouth's coastal salt ponds, the Citizen's Monitoring Project is enabling consolidation of several parallel investigations on nutrient cycling and water quality in these ecosystems, permitting application of new results from each effort to the range of environments found in each of the monitoring ponds and in effect multiplying the value of each project. Because the Pondwatchers are currently monitoring a range of coastal pond systems encompassing a variety of nutrient loading conditions and flushing regimes, information gained from this effort can now be applied to a wide range of coastal pond ecosystems found in the region.

BRIEF HISTORY OF THE PROJECT

The Citizen's Monitoring Project was spawned from a cooperative effort begun in 1987 between the Town of Falmouth, The Woods Hole Oceanographic Institution (WHOI) Sea Grant Program and the research laboratory of Dr. Brian Howes in the Biology Department of WHOI. Concerned over the apparent continued degradation of water quality in its coastal salt ponds, the Town of Falmouth (through the Falmouth Planning Board) provided $5,000 as "seed money" toward initiating a water quality study of the ponds. These funds were then substantially augmented through the efforts of Dr. David Ross, coordinator of the Woods Hole Oceanographic Institution Sea Grant Program as well as a Town Meeting Member, with funding from the Sea Grant Program of NOAA, as well as with continued support from the Town.

The goals of the study were to provide the Town with information on current water quality conditions in the ponds, data critical to assessing and developing intelligent management actions to insure the protection of these fragile coastal ecosystems. In addition, the project was designed to involve local citizens directly in determining the present and future ecological health of these systems, as well as to draw community attention to the increasing human pressures on our fragile coastal resources. The value of this information became more important with the inception of a Coastal Pond Overlay Bylaw enacted by the Town in 1988, specifying annual mean threshold values for total nitrogen concentrations in Falmouth's coastal ponds. The Bylaw specified limitations of 0.32 mg total nitrogen per liter for "High Quality Areas," 0.50 mg per liter for "Stabilization Areas," and 0.75 mg per liter for "Intensive Water Activity Areas." Comprehensive data from the Citizen's Monitoring Effort would now provide crucial information far too expensive to be provided by limited Town budgets to verify the validity of these threshold values as well as provide the Planning Board with information to interpret this new Bylaw.

Preliminary surveys were conducted in 1987 by Dr. Howes, Dr. Alan White (then Marine Science Advisor for WHOI Sea Grant, currently with the National Marine Fisheries Service in Woods Hole) and Dale Goehringer, a Research Associate in the Biology Department of WHOI. This preliminary data base provided needed background information and paved the way for a comprehensive water quality monitoring study initiated in 1988 involving the participation of citizen volunteers. Identification of sampling stations and development of sampling protocols for the monitoring effort were an important part of the preliminary studies, extending the time base and gaining data for determination of appropriate sampling intervals and analyses. The Citizen's Monitoring Project then began in the late spring of

1988 by response to requests for volunteers through newspaper articles, radio and TV announcements. The response was beyond all expectations, with over 65 volunteers expressing a sincere interest in participating in the project. Volunteers came from all age ranges and backgrounds, all sharing a common interest in understanding and maintaining the health of their fragile coastal ecosystems. After an initial training session, (with refresher

courses each year for continuing and new volunteers), the study began and has now taken on an energy all its own, as well as a nickname, the volunteers now referred to as the "Falmouth Pond Watchers." In addition to collecting samples and physical measurements, the Pond Watchers serve as the "eyes, ears and noses" of the ponds, reporting unusual occurrences such as fish kills, algal mats, odors, etc.

Parallel with the inception of the Citizen's Monitoring Project was the initiation of a more detailed scientific investigation of one of the monitoring ponds, Little Pond, by Dr. Howes' laboratory to provide in depth understanding of the processes controlling nutrient cycling and the impact of additional nutrient inputs on salt pond ecosystems. In addition, the consequences of pond management are being investigated as related to Falmouth's salt ponds in a WHOI Coastal Research Center/Sea Grant study of Sesachacha Pond, Nantucket. Sesachacha Pond is a eutrophic coastal salt pond historically opened one or two times per year to exchange with the sea, but which was left unaltered for 10 years and only recently been reopened. This pond is providing supplemental information on the efficacy of circulation management on improving salt pond environmental conditions. It has been our contention that given the great expense and limited financial resources available for remediation made necessary by excessive nutrient loading that a priori assessment of the potential efficacy of each management option is essential.

SAMPLING LOGISTICS AND EQUIPMENT

Prior to the commencement of field sampling each year, the Pond Watchers are given a refresher course on sampling procedures and information on any additional solo projects such as the 1989 oyster growth experiment or rainfall monitoring. Pond Captains for each pond are then responsible for distribution of sampling equipment to each of the sampling teams for the season. The individual Pond Captains are:

Oyster Pond -	John Dowling
	Julie Rankin
Little Pond -	Jack Shohayda
Upper Green Pond -	Frank Souza
Lower Green Pond -	Edmund Wessling
	Armand Ortins
Upper Bournes Pond -	Jim Begley
	Steve Molyneaux
Lower Bournes Pond -	John Soderberg
Great Pond -	Dick Erdman

Sampling equipment consists of a sampling kit with: Secchi disk fastened on a fiberglass measuring tape; color wheel for phytoplankton identification; thermometer; filters, syringes, filter forceps and in-line filter holders for field processing of nutrient samples; oxygen kit, maps, data sheets, instruction sheets, waste reagent container, pens and pencils; and other miscellaneous items of need such as clippers for opening reagent pillows, etc. Coolers for transporting and storing samples are provided as well as instruments for collection of water samples; because of the presence of deep basins in Oyster Pond, Niskin bottles were used there, pole samplers with bottles attached at fixed depths were used for the four other shallower ponds. For specific measurements such as rainfall, electronic rain gauges were purchased and installed at the homes of Bob Livingston (Oyster Pond), Alan White (Siders Pond), Robert Roy (Little Pond) and Ed Wessling (Green Pond). Rainfall amounts have been recorded on a daily basis by these conscientious Pond Watchers since August 1988 and are compiled with records maintained at a permanent weather station located at nearby Long Pond. In addition, tide gauge and water column light transmission stations were established on Little Pond at the homes of Joe Johnson and Robert Roy. The additional effort of these individuals above and beyond the routine collection of samples and physical measurements has provided ancillary data tremendously useful in interpreting the results of the monitoring effort.

Within each pond, sampling stations were located on the basis of a preliminary water quality survey, attempting to represent major ecological and physical zones within each pond. Samples are collected from each station with depth profiles made at stations deeper than 0.5 meters. These depth profiles are critical in identifying potential stratification events as well as in generating an overall understanding of the individual ecosystems. The number of stations at each pond are as follows: Oyster Pond - four; Little Pond - four; Green Pond - six; Bournes Pond - six; and Great Pond - six with an additional reference station in Vineyard Sound. Specific sampling locations are shown in Appendix I. On a given sampling, 27 stations must be sampled nearly simultaneously.

The selection of pre-determined sampling dates is based upon the compilation of the previous data. The sampling dates focus on periods potentially sensitive to eutrophication events. The 1990 sampling dates were chosen to more closely identify nutrient conditions during summer months when warmer weather results in increased biological activity and increased probability of low oxygen events. The previous 16 samplings indicated that the annual variation in nutrient levels was within the range encountered during summer sampling alone. The result is that summer sampling should give a good average view of nutrient levels and an estimate of the occurrence of low oxygen events. This is important because even periodic brief low oxygen events can significantly alter benthic animal populations so that knowing the lowest level of oxygen rather than the annual average is what is needed for environmental evaluation.

Four Pond Watcher samplings were conducted in 1990: July 15, July 29, August 12 and September 9. Cooperative weather conditions enabled sampling on pre-scheduled dates with no postponements. After early morning consultation between project coordinators and Pond Captains, the Pond Captains released their individual teams previously equipped for sampling. All teams sampled their stations nearly simultaneously (± 2 hrs) to make sure samples were collected during the same conditions of weather and tide. Simultaneous sampling of all sites is crucial to enabling site to site and pond to pond comparisons and was made feasible only through the large volunteer effort of the Pond Watchers. After sampling, coolers containing samples and data sheets were turned in to the Pond Captains for transfer to the Woods Hole laboratories for subsequent chemical and data analyses.

The following measurements and assays were conducted on each sampling:

Physical Measurements:

- Total Depth
- Temperature
- Light Penetration (Secchi disk)
- Water Color
- Rainfall

Chemical Measurements:

- Nitrate + Nitrite
- Ammonium
- Dissolved Organic Nitrogen
- Particulate Organic Nitrogen
- Total Dissolved Nitrogen
- Phosphate
- Oxygen Content
- Salinity
- Chloride
- Periodic Sulfide and Chlorophyll

In addition, Pond Watchers record observations of pond state, weather and wind conditions, and any other pertinent information which may later prove useful to interpretation of the data such as algal blooms or unusual odors.

RESULTS AND DISCUSSION

The sampling program in 1990 went exceedingly well, especially given that nearly twice as many stations had to be sampled as in to previous years due to the addition of Bournes and Great Ponds. Approximately 2000 chemical assays (each in duplicate) and 1000 physical measurements were conducted in the monitoring effort in 1990 alone. In addition, individual rainfall records on Oyster, Little, and Green Ponds were conducted, along with tide recording on Little Pond. Smaller scale data collection with the assistance of Pond Watchers included CTD data from Oyster Pond and "rapid response sampling" to document an anoxic event on Green Pond.

It should be noted here that this is an "Interim Report" and that only limited information is available on Bournes and Great Ponds. The discussion will attempt to focus upon those areas for which we have the best data, but the interpretation will be subject to adjustment as we include the data from the 1991 field season. It is important to realize that while we have been living within the watersheds of Falmouth's coastal ponds for hundreds of years, very little quantitative information is available on their functioning and water quality. For example, in 1990, the first year that they were included, we more than doubled the existing data on Bournes and Great Ponds even though Bournes Pond has recently undergone extensive circulation management.

The fact is becoming increasingly clear that nutrient and oxygen levels within the ponds are highly variable both spatially and temporally. Our data from all five ponds indicate that a two-fold variation between samplings is not unusual. These results stress the importance of multiple samplings and longer-term data collection for assessing nutrient related water quality in these systems.

One of the environmental factors contributing to the observed variation in nutrients and oxygen levels is rainfall. Large rain events appear to be associated frequently with low oxygen events, and relatively unflushed ponds like Oyster Pond may exhibit salinity fluctuations related in part to annual rainfall. Rainfall in 1990 was only slightly below the 11 year average (Figure 2), however summer levels were almost 20% below normal. Pond sampling was by chance conducted both after periods of high and low rainfall (Figure 3). The very large rain event preceding the July 29th sampling resulted in a salinity stratification in areas of all of the ponds, resulting in turn in an anoxic event in Green Pond July 27th and low oxygen measurements in all five ponds on July 29th. The biological and physical conditions controlling the rapid changes in pond oxygen levels make it likely that the July 29th oxygen readings were not "worst case," but that the ponds were showing higher oxygen levels than the nights or days before. As more data accumulate, we are attempting to develop methods to predict the meteorological conditions which result in low oxygen events in the various salt pond areas.

The bathymetries of the five ponds are in keeping with their different modes of formation: Green, Little, Bournes and Great Ponds by groundwater sapping of glacial outwash versus Oyster Pond (and Salt Pond) from kettle holes. The "finger" ponds tend to be long, narrow and shallow with generally uniform depths of 1-2 m (Figure 4), while kettle ponds (freshwater ones as well) tend to be more circular and deeper (eg. Oyster Pond, 6 m).

An important consequence of the eutrophic state and water depth of the ponds is that light is generally attenuated before reaching the bottom where it could support benthic algae. It appears that light is generally attenuated within the water column (Figure 5) by the large biomass of phytoplankton within the ponds. We will be investigating this further since

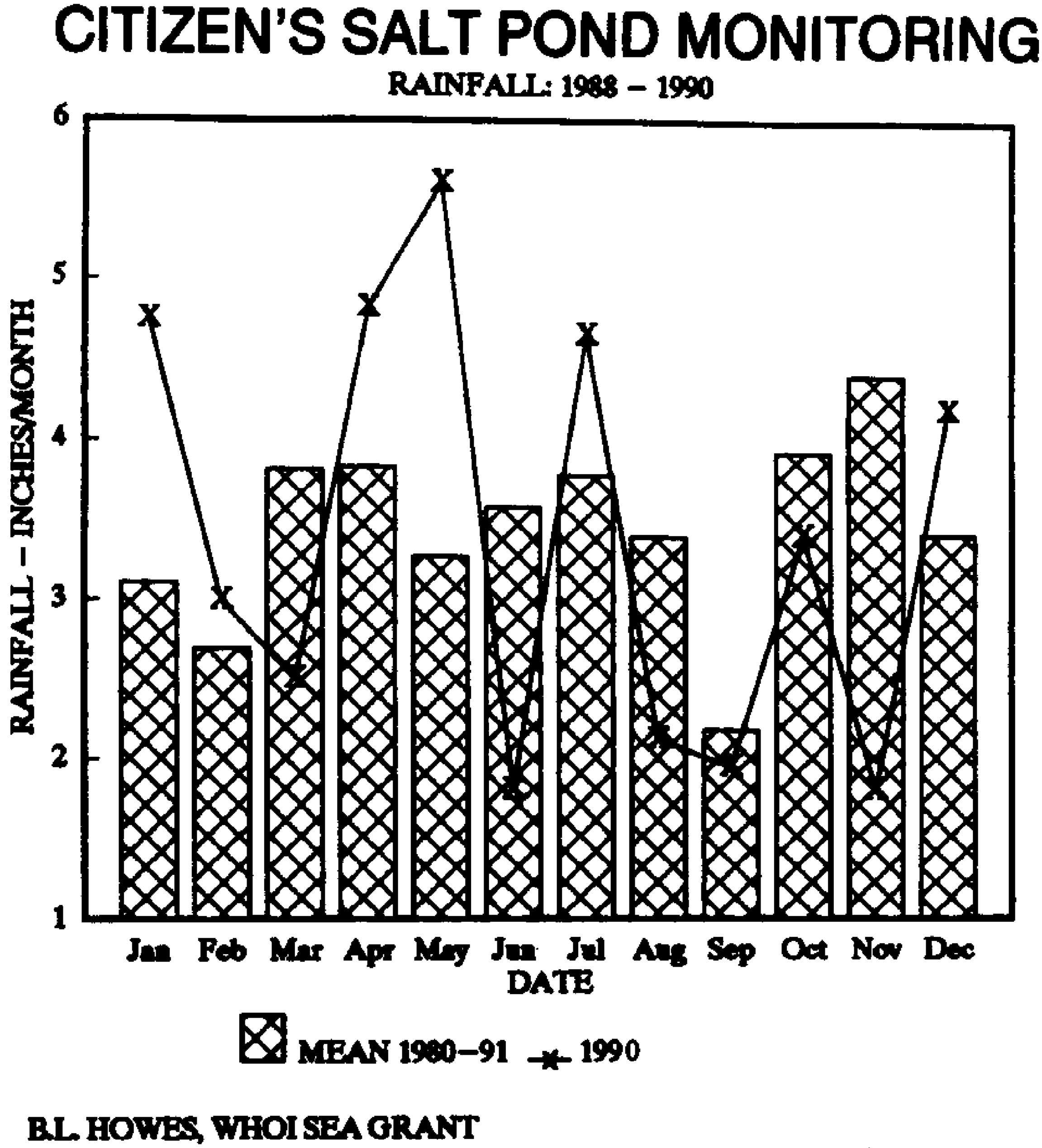


Figure 2. Monthly rainfall for 1990 compared to the 11 year average. Total rainfall in 1990 was only slightly below average. However, during summer rainfall was almost 20% below normal.

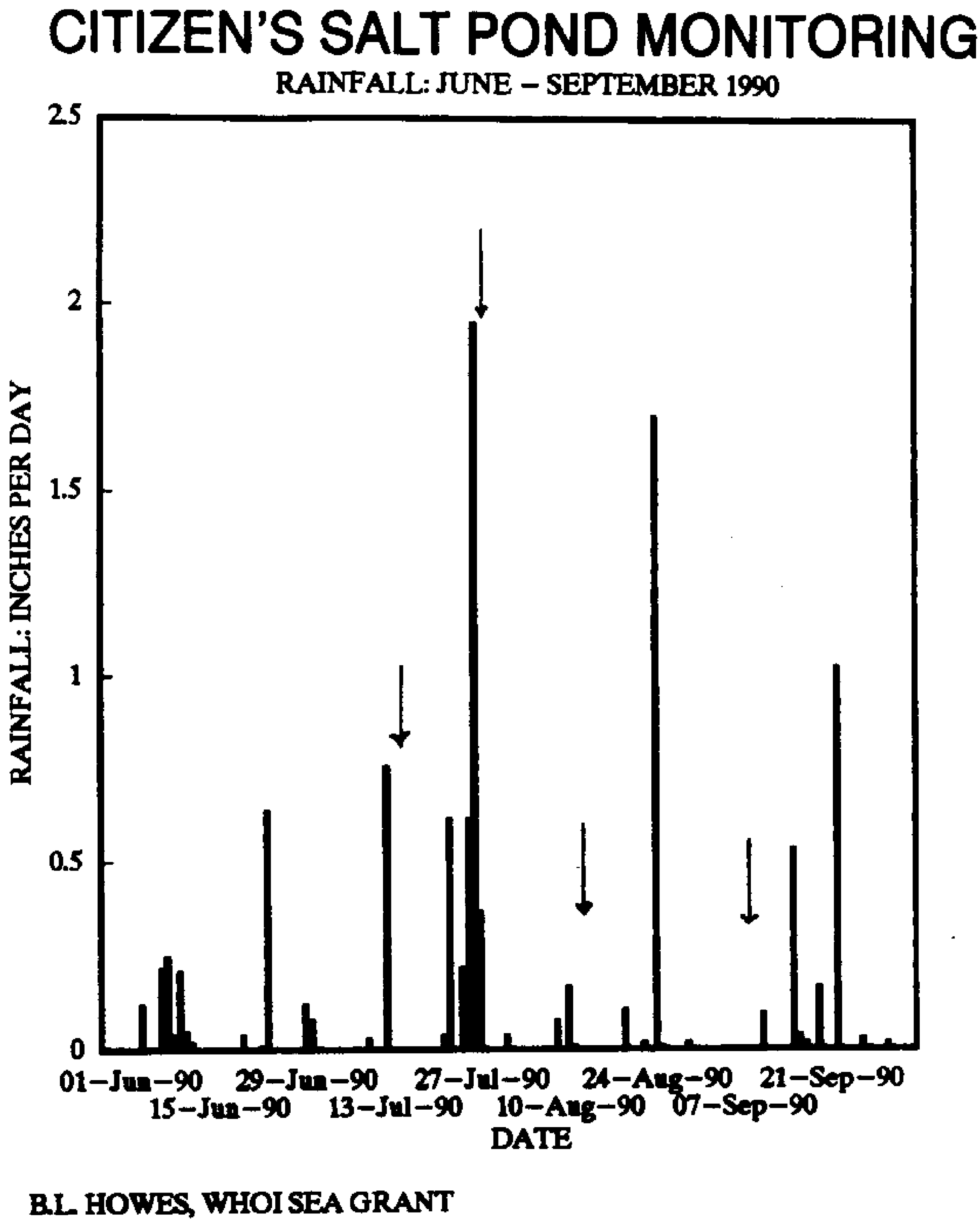


Figure 3. Rainfall during 1990 sampling period. Arrows represent sampling dates. Note large rain just prior to July 29 sampling which found low oxygen conditions at various locations in all of the ponds.

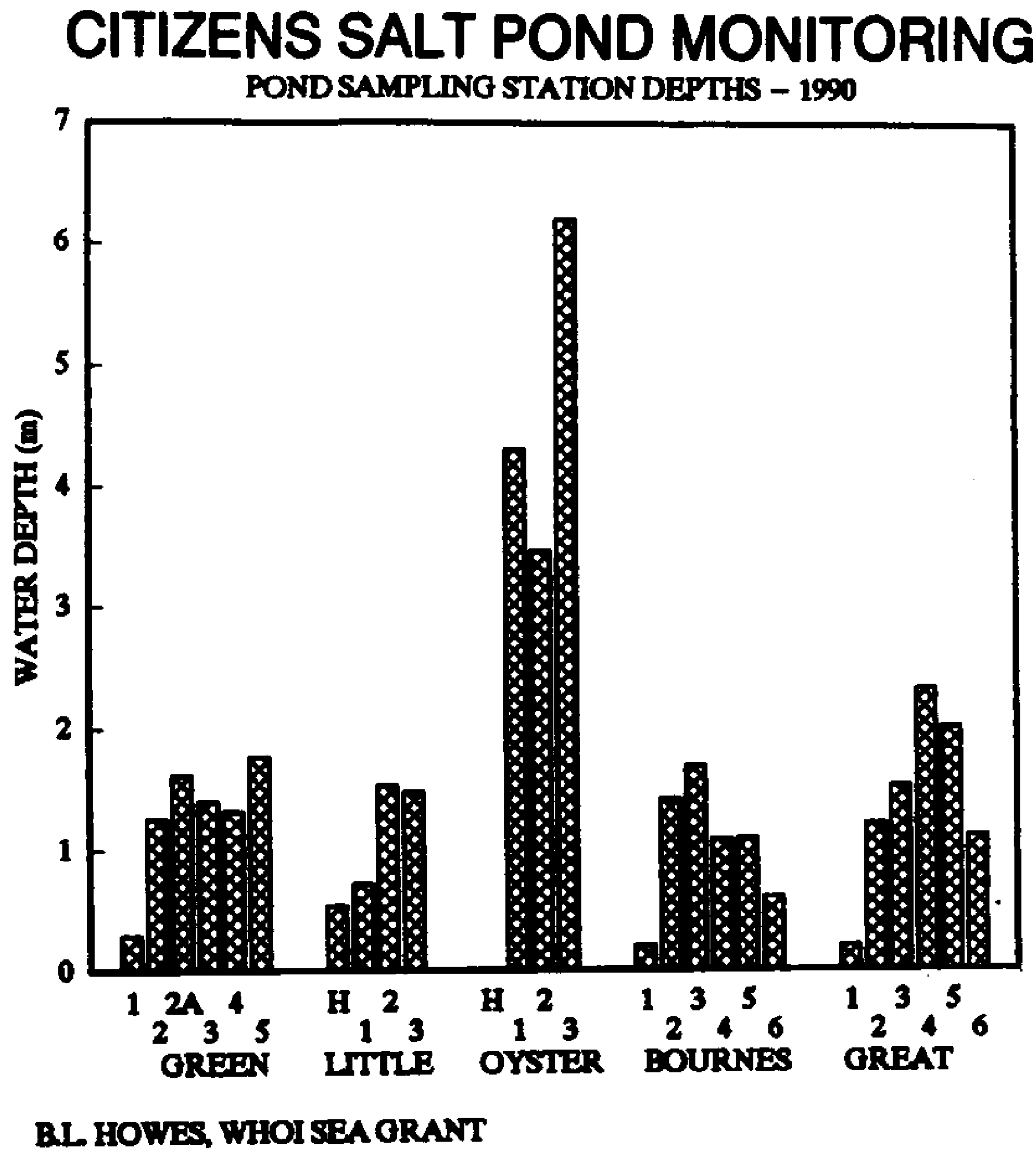


Figure 4. Average station depths for 1990. Locations are shown on maps in Appendix I, but depths reflect mid channel values.

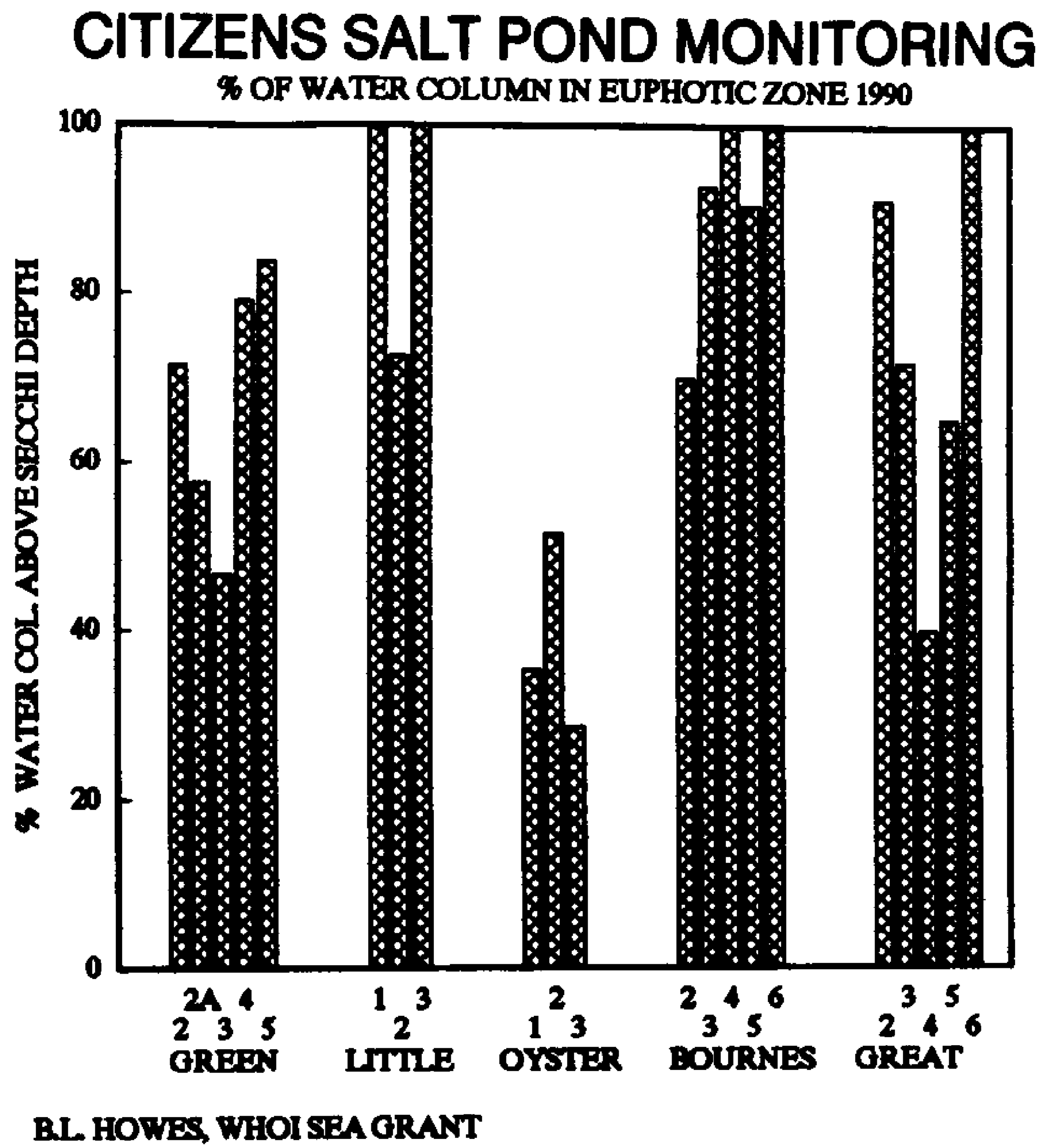


Figure 5. Average % of the water column having light penetration to support plant production. Low light penetration or low % above Secchi depth is generally due to low water clarity.

macroalgal production can have deleterious ecological consequences to coastal salt pond systems.

One consistent feature of all of the ponds is the increasing salinity moving from the inland headwaters toward Vineyard Sound (Figure 6). Green, Little, Bournes and Great Pond are for the most part saline ponds with average salinities above 25 ppt. Oyster Pond, because of its very restricted tidal exchange, is much fresher than the other four ponds. The depth averaged salt concentration lessens the difference, but when we divide the water column into the "mixed layer" (0-2 m) versus the residual salt water in the bottom of the deep (Figure 4) stratified basin (3.25-6 m), the surface water shows a range of between 7 and 15 ppt (Figure 7).

This salinity stratification is responsible for the absence of oxygen from the main basin (OP3 - 6m) and the summertime anoxia from the shallower 3.25 (OP2) and 4 m (OP1) basins (Figure 4). All of the other ponds are shallower and have greater tidal velocities and therefore do not exhibit this degree of stratification and are subject "only" to occasional brief periods of hypoxia. The physical structure (eg. bathymetry, flushing, salinity) is as important a consideration in evaluating nutrient related water quality problems as the level of nutrient loading.

Prior to the 1990 field season, the Town of Falmouth (Department of Public Works) enlarged the opening for tidal exchange between Oyster Pond and Vineyard Sound (through the Trunk River). As part of the 1990 monitoring, we wanted to gauge the impact of this management practice on Oyster Pond. Since Oyster Pond contains fairly fresh water compared to Vineyard Sound, our method of evaluating the planned increase in tidal exchange is to measure the increase in pond salinity levels. Given that the 1990 measurements revealed only a small increase in salinity levels, it is not possible at present to quantify accurately the increase in the volume of tidal exchange. The problem is that the

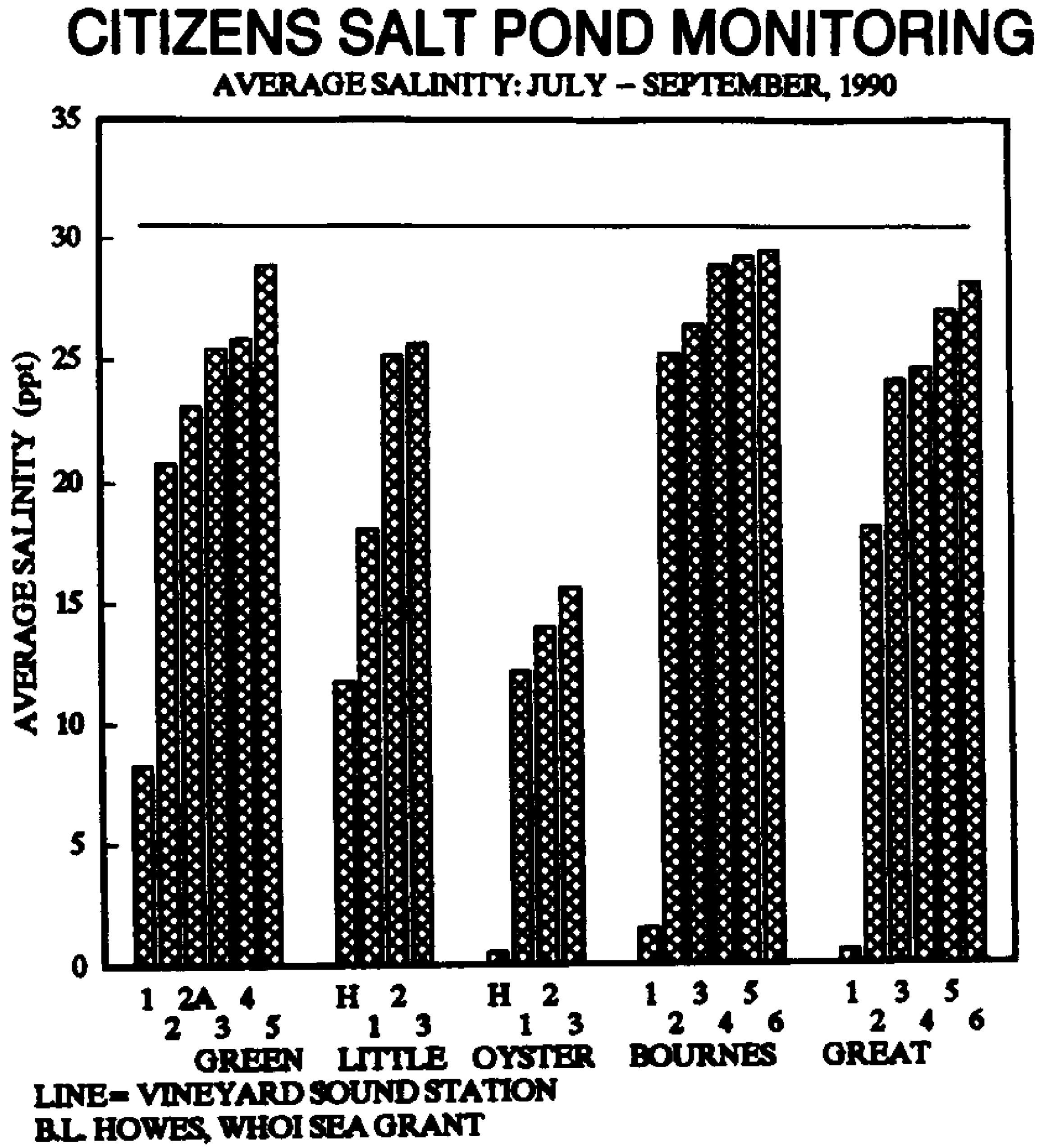


Figure 6. Average water column salinity of the five salt ponds in 1990. The first station (either H or 1) is from the inland headwaters which in Oyster, Bournes and Great Ponds are collected directly from freshwater streams. In Green and Little Ponds, headwater stations are tidal and therefore contain some salt water signal.

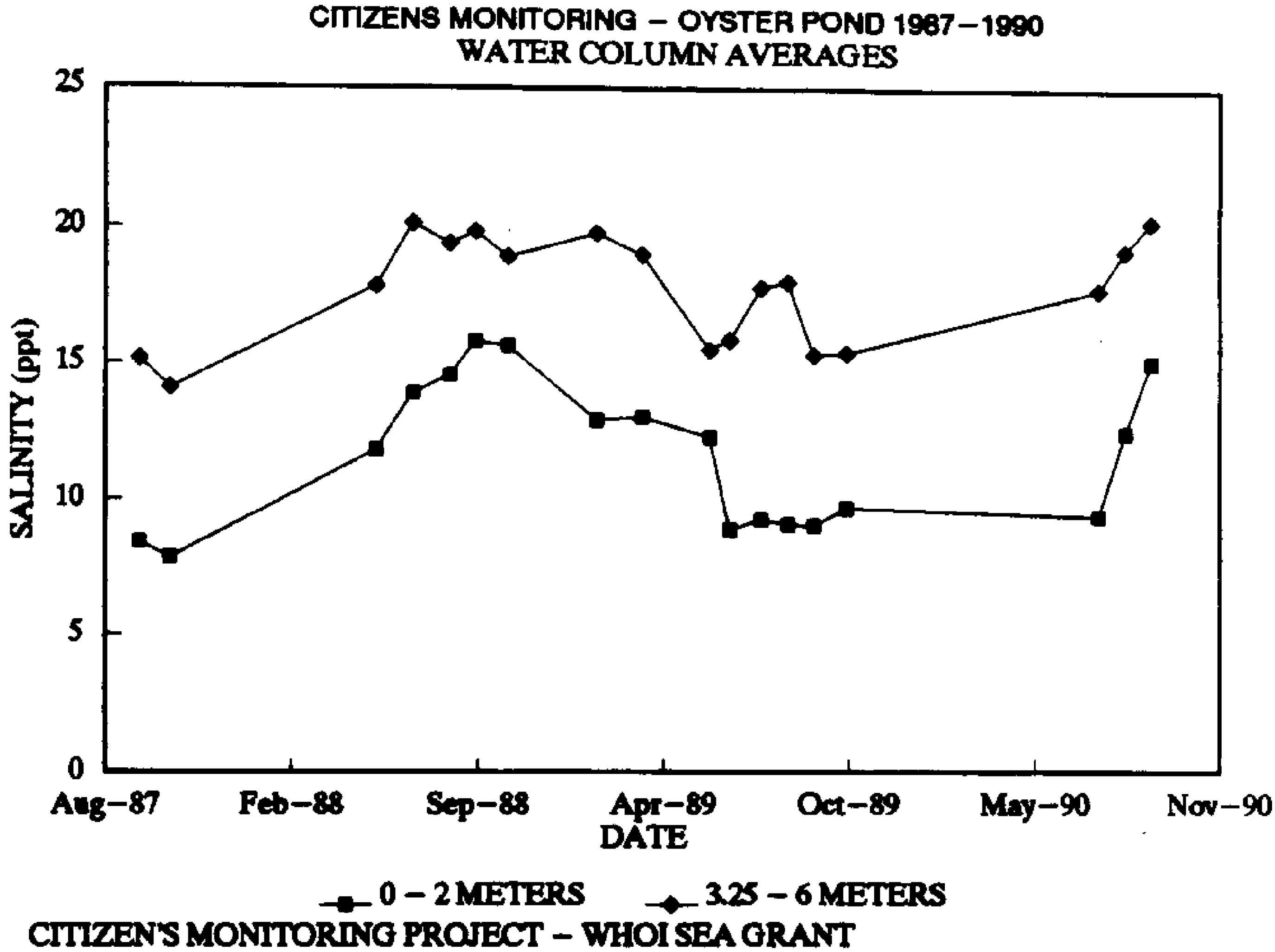


Figure 7. Pond wide average of the well mixed surface layer of Oyxter Pond (0-2 m) and the deep stratified layer (3.25-6 m) from 1987-1990. Note the constant occurrence of "lighter" low salt water on the surface versus the "heavier" higher salinity water on the bottom causing a strong salinity stratification of the pond. Enlargement of the tidal opening was conducted before the 1990 field season.

measured rise in salinity is the same as measured in years previous to the improved opening and, since rain input was lower than average (Figure 2), at least some of the increase in salt concentration could be due to a decrease in freshwater input as opposed to increase in salt water input. This effect has been documented previously by K.O. Emery.

However, whatever fraction of the salinity increase may be due to the improved opening, the effect appears to have been small. Of the potential causes, one likely reason is the rapid sedimentation of the larger pond opening due to the small tidal prism. This results in the blocking of the channel and a rapid return to pre-opening conditions. This scenario is supported by the comparison of nutrient measurements in Oyster Pond in 1990 versus the mean summer values from 1987-1989. Overall, mean 1990 levels of total nitrogen were equivalent to previous years (Figure 8a, Table 1). However, the initial measurements at Stations BP1 and OP2 appeared to be lower followed by a continuous rise through the later samplings. Whether this is a result of altered circulation or not will be confirmed by the 1991 data as these types of changes generally require years to establish the new conditions. Nutrient levels remain high generally as a result of the deep basin. It is significant that in 1990 as in previous years the bottom waters from all three stations were anaerobic (no oxygen) for the entire sampling period. These anoxic conditions in Oyster Pond prohibit colonization by benthic animals or fish in waters or sediments below about three meters. This represents about half of the bottom.

In contrast, all of the finger ponds exhibit lower nitrogen levels and better oxygen conditions, but the headwaters flowing into all five ponds were high in total nitrogen ranging from a low at Great Pond (GTP1) of about 0.7 mg N/l to a high in Little Pond of over 2 mg N/l. Little Pond, much like in previous years, remains the most eutrophic of the "finger" ponds (Figure 8b). However, this is deceptive as nitrogen and oxygen concentrations in the upper reaches of Green (Figure 8c), Bournes (Figure 9a) and Great (Figure 9b) Ponds are all

CITIZENS SALT POND MONITORING

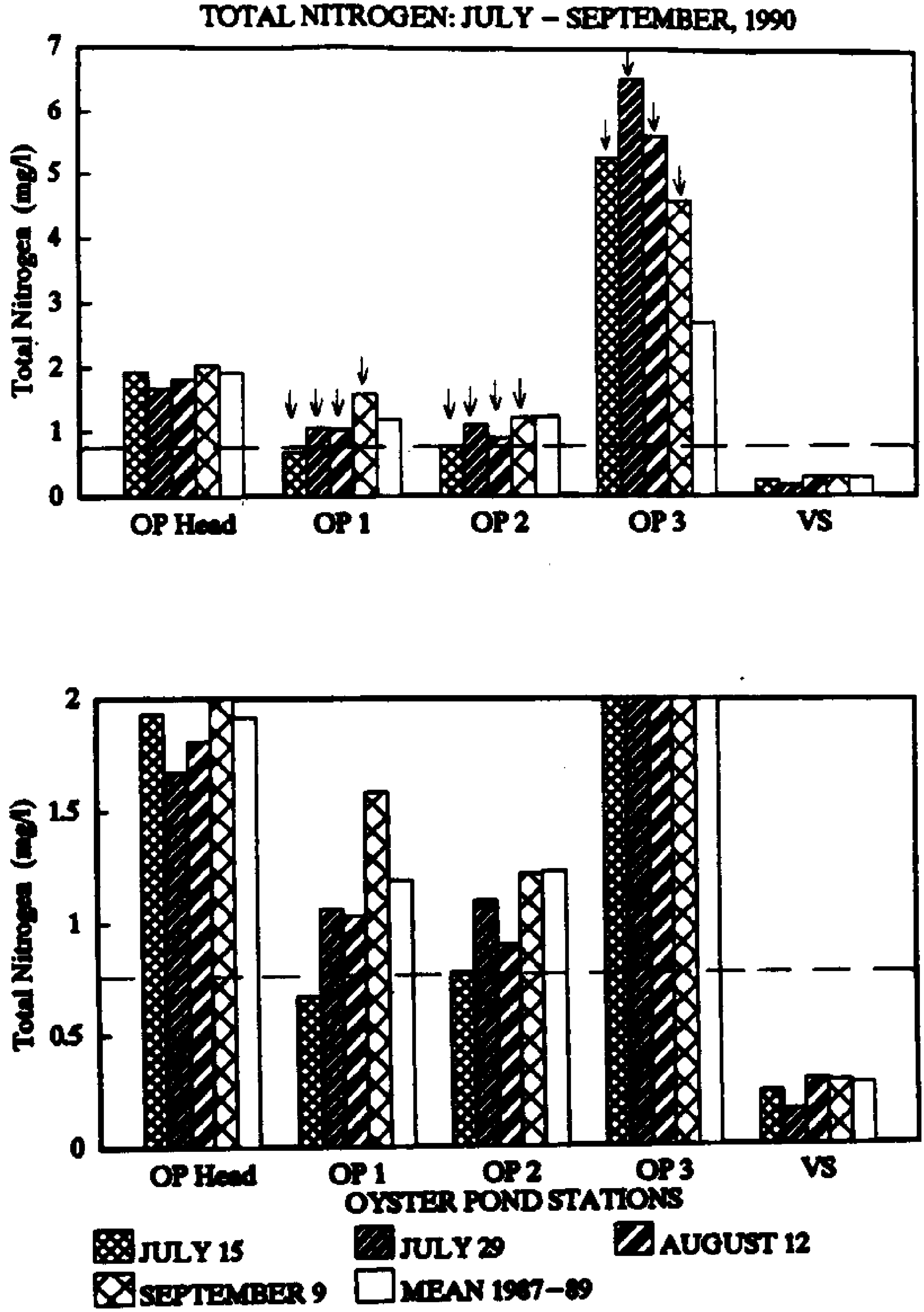
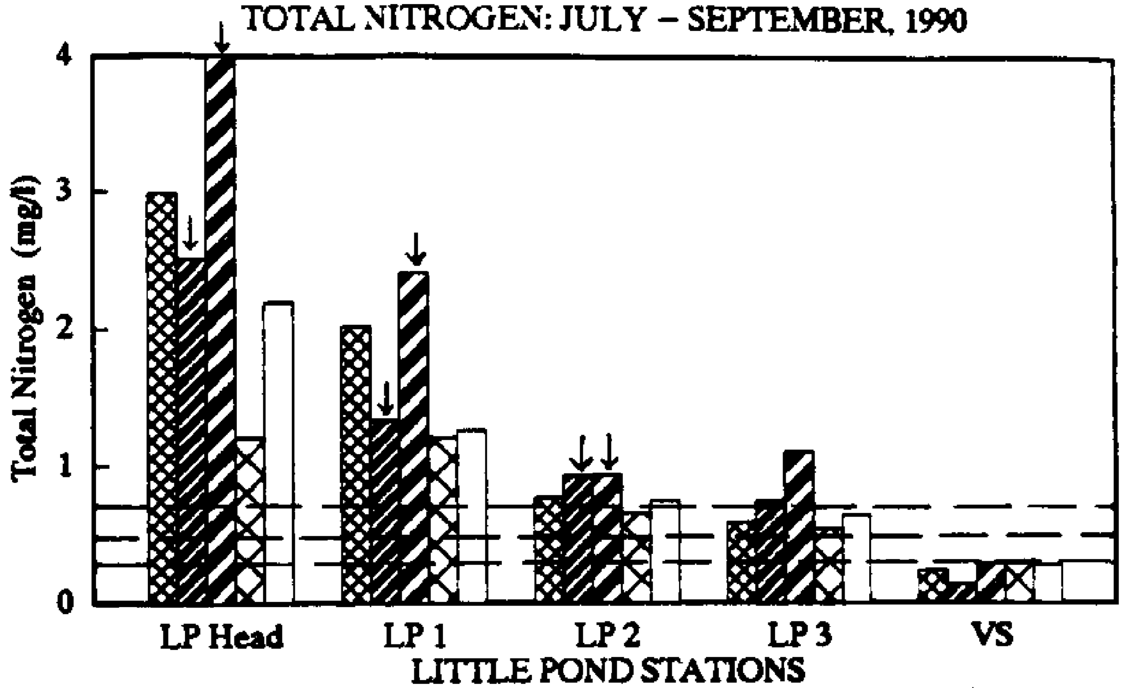


Figure 8a, b & c. Water column weighted averages of total nitrogen in each of the four samplings in 1990 versus the average of summer samplings from 1987-1989. Note the initially low values on July 15 with increasing levels in later samples. Arrows represent periods when low levels of dissolved oxygen (less than 5 mg/l, generally less than 3) were measured. VS represents Vineyard Sound levels; dashed line represents Nutrient Overlay Bylaw threshold limits of 0.32 mg/l ("High Quality Areas"), 0.50 mg/l ("Stabilization Areas") and 0.75 mg/l ("Intensive Water Activity Areas").

CITIZENS SALT POND MONITORING

TOTAL NITROGEN: JULY – SEPTEMBER, 1990



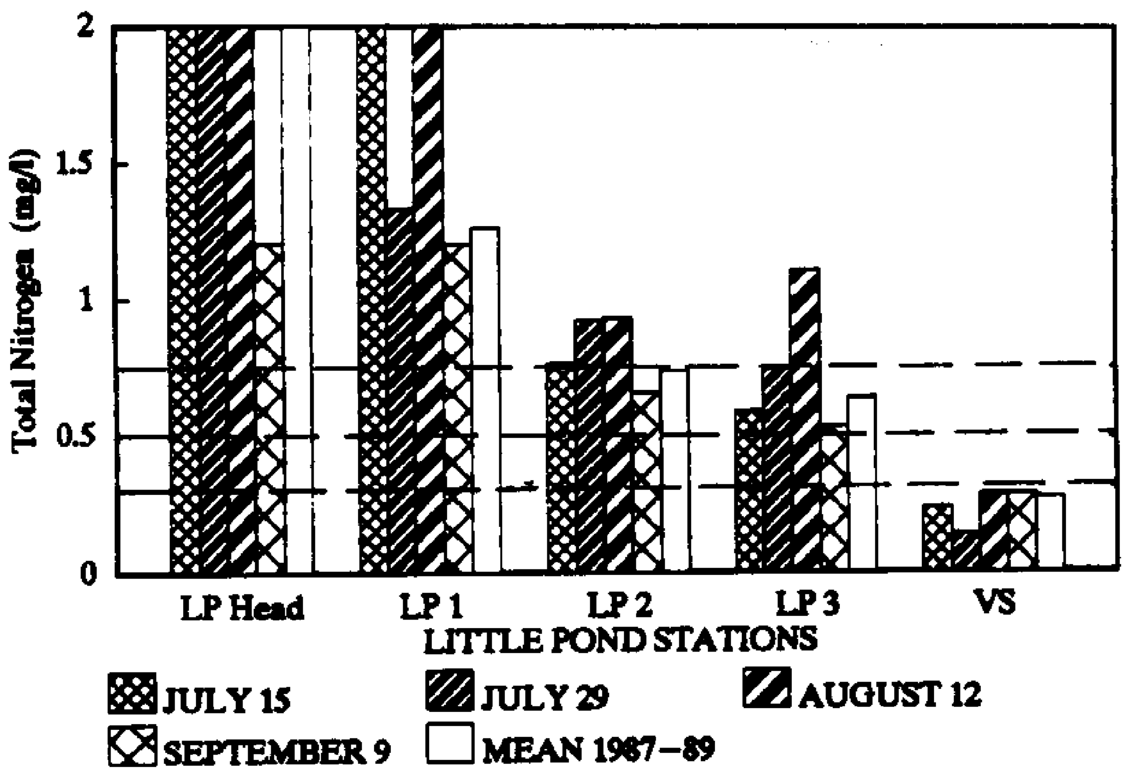


Figure 8b.

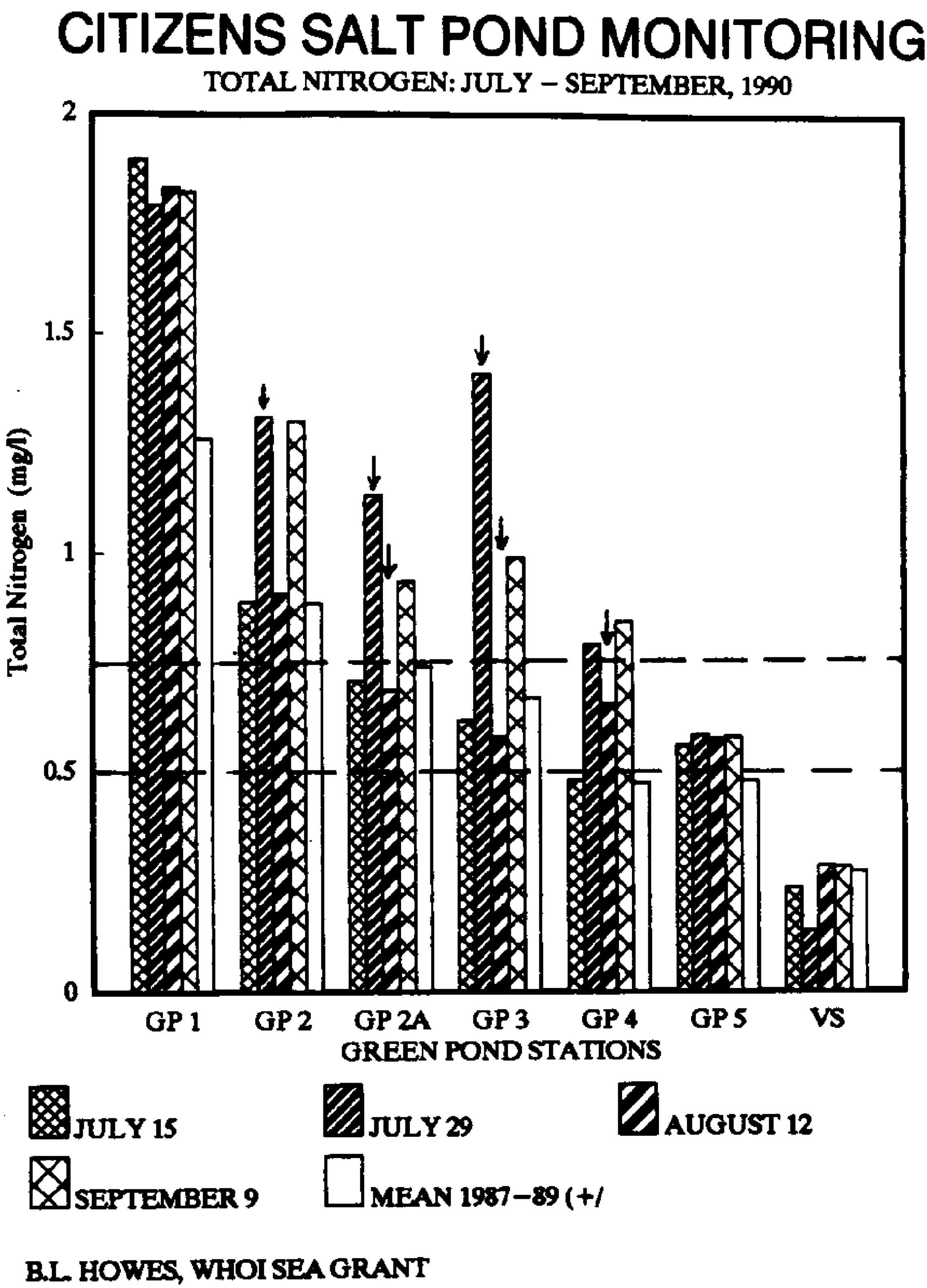

CITIZENS SALT POND MONITORING
TOTAL NITROGEN: JULY – SEPTEMBER, 1990
Total Nitrogen (mg/l)
2
1.5
1
0.5
0
GP 1
GP 2
GP 2A
GP 3
GP 4
GP 5
VS
GREEN POND STATIONS
JULY 15
JULY 29
AUGUST 12
SEPTEMBER 9
MEAN 1987–89 (+/
B.L. HOWES, WHOI SEA GRANT

Figure 8c.

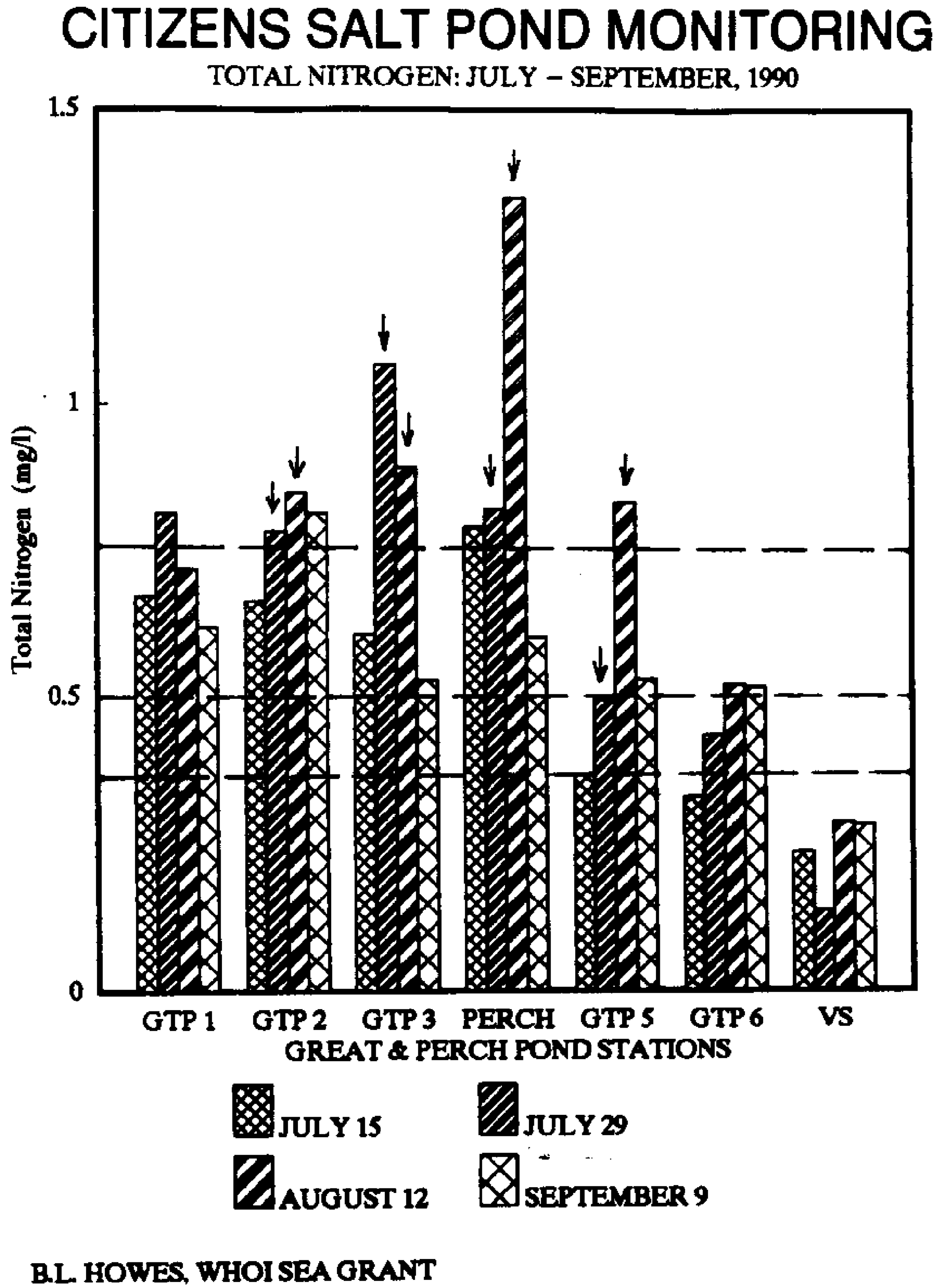


Figure 9 a & b. Total nitrogen values from 1990. Arrows represent periods of low oxygen concentration. Horizontal lines represent Falmouth Bylaw levels of 0.32, 0.5 and 0.75 mg N/l. VS represents the pristine waters of Vineyard Sound.

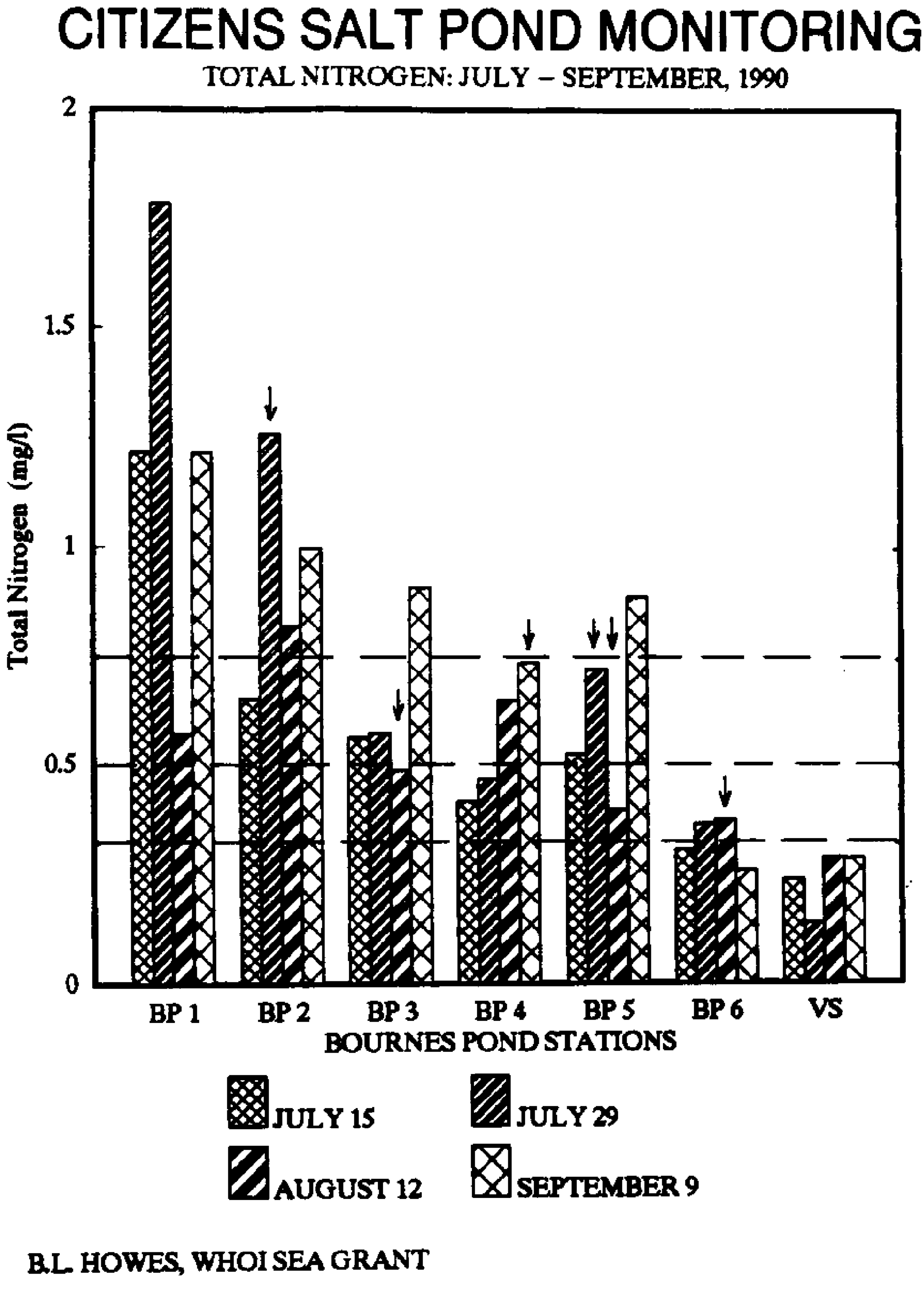

CITIZENS SALT POND MONITORING
TOTAL NITROGEN: JULY – SEPTEMBER, 1990
Total Nitrogen (mg/l)
2
1.5
1
0.5
0
BP 1
BP 2
BP 3
BP 4
BP 5
BP 6
VS
BOURNES POND STATIONS
JULY 15
JULY 29
AUGUST 12
SEPTEMBER 9
B.L. HOWES, WHOI SEA GRANT

Figure 9b.

TABLE I.

SUMMARY DATA: CITIZENS SALT POND MONITORING STUDY, 1987 - 1990
SEA GRANT PROGRAM-WOODS HOLE OCEANOGRAPHIC INSTITUTION AND TOWN OF FALMOUTH
Dr B.L. HOWES, D.D. GOEHRINGER & Dr. A.W. WHITE

TOTAL NITROGEN (milligrams per liter) --- WATERCOLUMN WEIGHTED AVERAGE

Station	1987		1988						1989								1990				1987 - 1990 TOTAL N	
	16-Sep	19-Oct	27-May	06-Jul	17-Jul	14-Aug	11-Sep	16-Oct	19-Jan	10-Mar	21-May	11-Jun	16-Jul	13-Aug	10-Sep	15-Oct	15-Jul	29-Jul	12-Aug	09-Sep	MEAN	S.E.
GREEN POND																						
GP 1	0.847	1.180	1.250	1.507	0.952	1.637	1.656	0.791	1.658	0.593	0.984	1.459	1.113	1.146	1.000	0.841	1.980	1.812	1.037	1.819	1.299	0.089
GP 2	0.954	0.664	1.200	0.644	0.818	1.586	0.837	0.693	1.133	0.430	0.906	0.795	0.804	0.774	0.659	0.733	0.892	1.331	0.913	1.299	0.907	0.061
GP 2A			1.719	0.509	0.546	0.968	0.773	0.498	1.056	0.316	0.839	1.014	0.734	0.763	0.611	0.588	0.711	1.152	0.691	0.933	0.801	0.069
GP 3	0.421	0.786	0.931	0.480	0.451	1.703	0.596	0.824	0.598	0.295	0.614	0.974	0.373	0.525	0.500	0.513	0.618	1.429	0.584	0.909	0.710	0.077
GP 4	0.429	0.395	0.660	0.500	0.431	0.412	0.465	0.389	0.209	0.226	0.550	0.678	0.336	0.550	0.459	0.331	0.404	0.812	0.662	0.843	0.495	0.036
GP 5	0.379	0.436	0.364	0.355	0.312	0.557	0.435	0.283	0.283	0.217	0.428	0.377	0.761	0.511	0.632	0.702	0.566	0.606	0.582	0.579	0.468	0.033
LITTLE POND																						
LP Head	3.729	1.154	2.399	2.162	2.351	2.167	0.761	1.047	0.412	1.222	2.651	0.995	1.939	2.976	2.593	1.381	3.363	2.524	4.515	1.205	2.077	0.233
LP 1	0.703	0.847	0.935	1.157	0.910	2.135	0.708	0.991	0.541	0.917	1.758	0.902	1.300	2.244	1.231	1.391	2.212	1.354	2.056	1.280	1.279	0.116
LP 2	0.650	0.670	0.648	0.618	0.753	1.108	0.614	0.452	0.700	0.923	1.224	0.864	0.519	0.680	0.831	0.594	0.765	0.942	0.936	0.651	0.757	0.042
LP 3	0.506	0.808	0.578	0.498	0.580	1.139	0.751	0.609	0.609	0.805	0.678	0.817	0.430	0.376	0.642	1.529	0.589	0.765	1.112	0.531	0.718	0.060
OYSTER POND																						
OP Head					2.038	1.644	1.759	1.026	0.972	1.242	0.931	2.053	1.872	2.122	1.922	1.564	1.932	1.673	1.811	2.025	1.662	0.088
OP 1	0.692	0.617	1.014	1.149	1.303	1.464	2.029	1.079	1.233	1.150	0.966	1.932	0.709	0.691	0.723	1.142	0.668	1.060	1.033	1.581	1.112	0.087
OP 2	0.697	0.746	1.119	1.447	1.510	2.061	1.732	1.185	1.214	1.138	1.142	1.074	0.997	0.733	0.794	1.030	0.777	1.098	0.896	1.215	1.126	0.076
OP 3	5.559	7.602	2.378	1.693	1.427	2.101	1.908	2.920	3.706	3.503	2.476	2.034	3.286	2.523	2.981	1.741	5.289	6.535	5.631	4.618	3.536	0.303
VINEYARD SOUND																						
VS		0.282	0.299	0.239	0.277	0.251	0.341	0.262	0.246	0.341	0.265	0.299	0.240	0.232	0.296	0.135	0.239	0.158	0.291	0.282	0.262	0.011
BOURNES POND																						
BP 1																	1.220	1.802	0.576	2.774	1.593	0.404
BP 2																	0.652	1.278	0.823	0.995	0.937	0.116
BP 3																	0.563	0.590	0.491	0.903	0.637	0.079
BP 4																	0.417	0.486	0.649	0.727	0.570	0.062
BP 5																	0.523	0.737	0.398	0.882	0.635	0.094
BP 6																	0.308	0.383	0.376	0.255	0.331	0.026
GREAT POND																						
GTP 1																	0.675	0.835	0.724	0.617	0.713	0.040
GTP 2																	0.667	0.805	0.853	0.813	0.784	0.035
GTP 3																	0.609	1.088	0.897	0.526	0.780	0.112
GTP 4																	0.791	0.842	1.355	0.600	0.897	0.140
GTP 5																	0.369	0.517	0.836	0.529	0.563	0.085
GTP 6																	0.333	0.455	0.525	0.514	0.457	0.038

We have recalculated Oyster Pond total nitrogen data to better reflect the true water column weighted average, a consequence of this more accurate representation is that impact of the large nitrogen pool at the bottom of the anaerobic basin at Oyster Pond Station 3 is diminished. Headwaters and OP 1 and 2 stations are relatively unchainged under these revised calculations. This recalculation provides a better indicator of total water column concentration than the straight average, the method generally used.

This recalculation only affects Figures 10b, 10c, 10d (revised versions appended to this report) and Table I in the March 1990 Final Report on Citizen Volunteer Monitoring of Water Quality in Falmouth's Coastal Ponds. None of the conclusions in the 1990 report are affected by this change. This recalculation is done to facilitate use of the data in nitrogen mass balance equations and represents a permanent shift in the way we will present data in the future.

similar and in some cases have lower water quality than stations in Little Pond. The relatively restricted opening of Little Pond to Vineyard Sound serves to give Little Pond circulation and conditions like equal areas of the upper reaches of the other three ponds. In essence, since Little Pond has a relatively small surface area relative to the other ponds, it really has no greater area of low water quality than is found in each of the other three finger ponds.

Green Pond exhibited nutrient and oxygen levels on the order of previous years (1987-1989). However, there appears to be a possibility that nutrient levels are showing a gradual increase in Green Pond. The 1991 samples are essential to confirm the existence of this trend. However, a multi-year time lag between increasing nutrient loading to a watershed and impacts on receiving pond waters is well known, and if nutrient levels are increasing in Green Pond, this is a likely contributing cause.

As expected from their watershed nutrient loadings and physical structures, Bournes and Great Ponds showed similar nutrient and oxygen patterns to Green Pond. Nitrogen levels were high, generally over 0.5 mg/l and frequently over 0.75 mg/l, with oxygen depletions commensurate with the high nutrient levels.

Perch Pond (GTP4), a sub-basin of Great Pond, is a small deep basin with a shallow sill to Great Pond. It is highly eutrophic with average total nitrogen levels over 0.75 mg/l and large accumulations of organic matter on the bottom. However, oxygen conditions though very poor were not exceptionally so and certainly not on the order of Oyster Pond. The rest of Great Pond was similar to Green and Bournes Pond with a continuous increase in water clarity and water quality approaching Vineyard Sound.

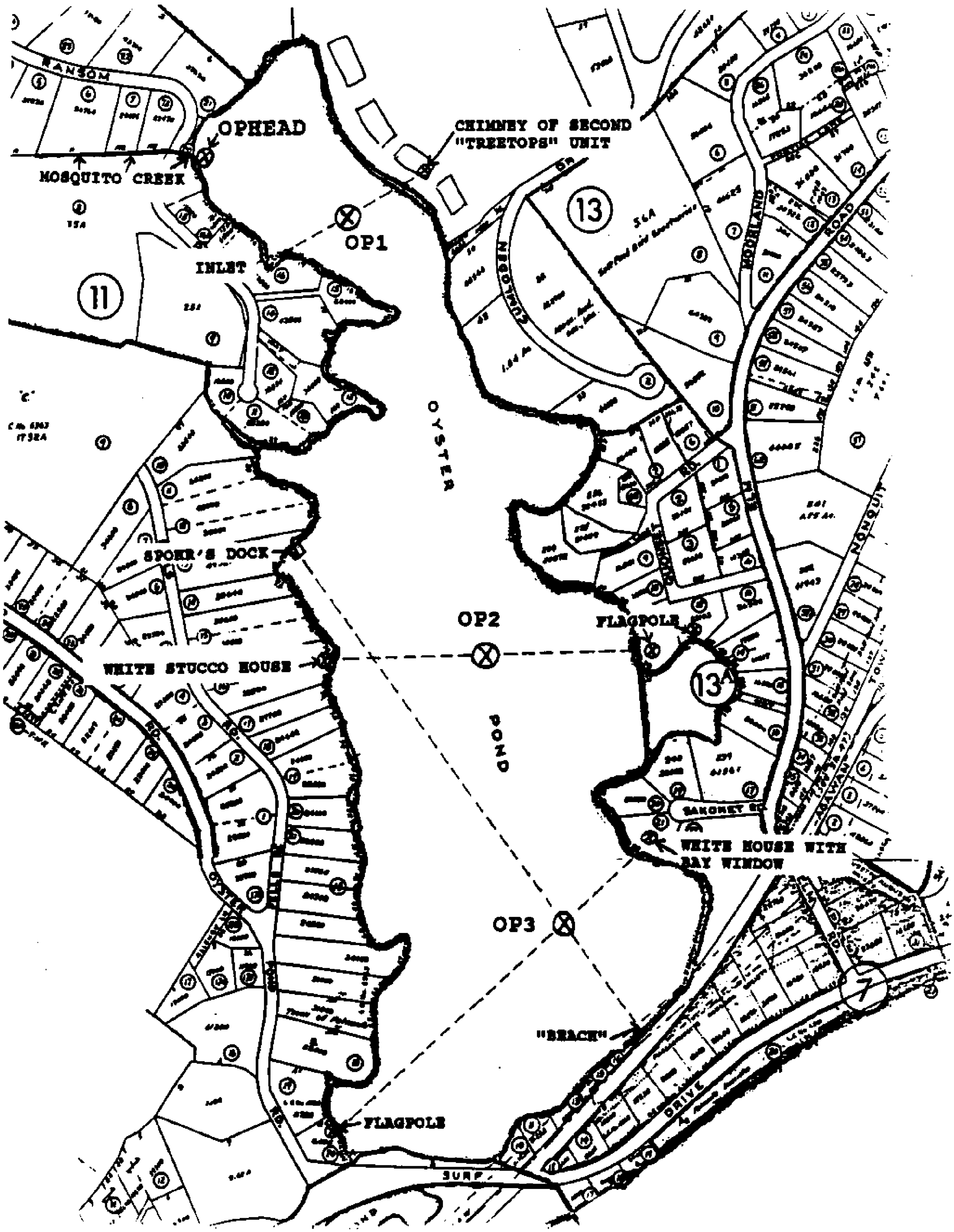
Bournes Pond, the recipient of extensive circulation alteration in the mid 1980's, had marginally better water quality than Green and Great Ponds. However, the upper reaches as in the other ponds have high nutrient levels and experience periodic low oxygen conditions. Unfortunately, it is not possible to gauge the level of "improvement" caused by remediation.

Although this is a progress report and will be amended as new data is added, several features are clear. First, portions of all five coastal ponds exhibit elevated nutrient levels, exceeding Falmouth Bylaw limits, and are exhibiting periodic low oxygen and diminished water quality. Second, water quality within the ponds is an admixture of nutrient loading, natural estuarine circulation and natural physical variables (eg. temperature, salinity, stratification, depth). Third, initial improvement in Oyster Pond water quality from recent alterations were at most small and possibly non-existent due to diminished flushing as a result of sedimentation of the tidal channel. Fourth, Green Pond may be experiencing increasing nutrient levels, confirmation of which will require the 1991 data. This emphasizes the importance of this type of monitoring in that long-term trends can be detected in their early stages, giving time for early management actions. Fifth, management of pond water quality must be conducted on not just a pond-by-pond basis but by subsections of each pond (eg. upper versus lower regions).

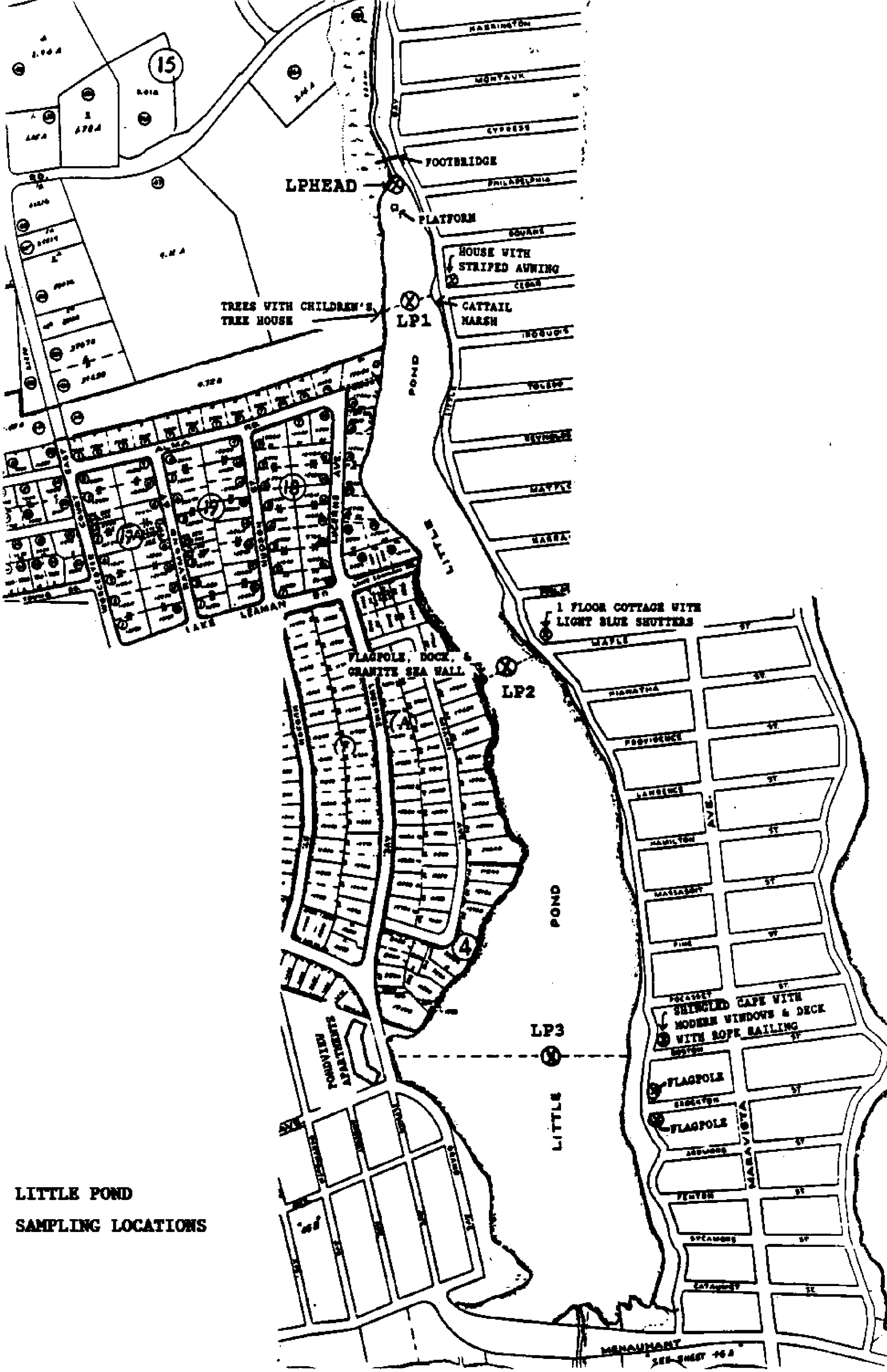
This study is dedicated to all of those who give of themselves to protect these fragile ecosystems called Salt Ponds, and in the process gain understanding to the benefit of all.

APPENDIX I.

Location of Sampling Stations for
Oyster, Little, Green, Great and Bournes Pond

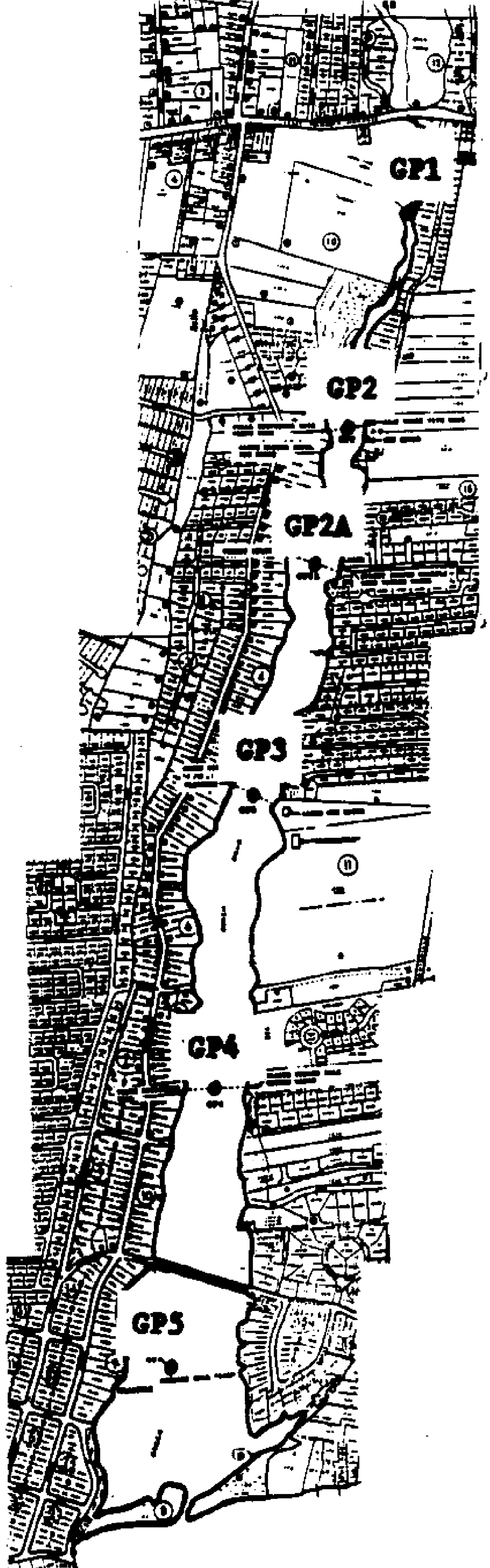


OYSTER POND SAMPLING LOCATIONS

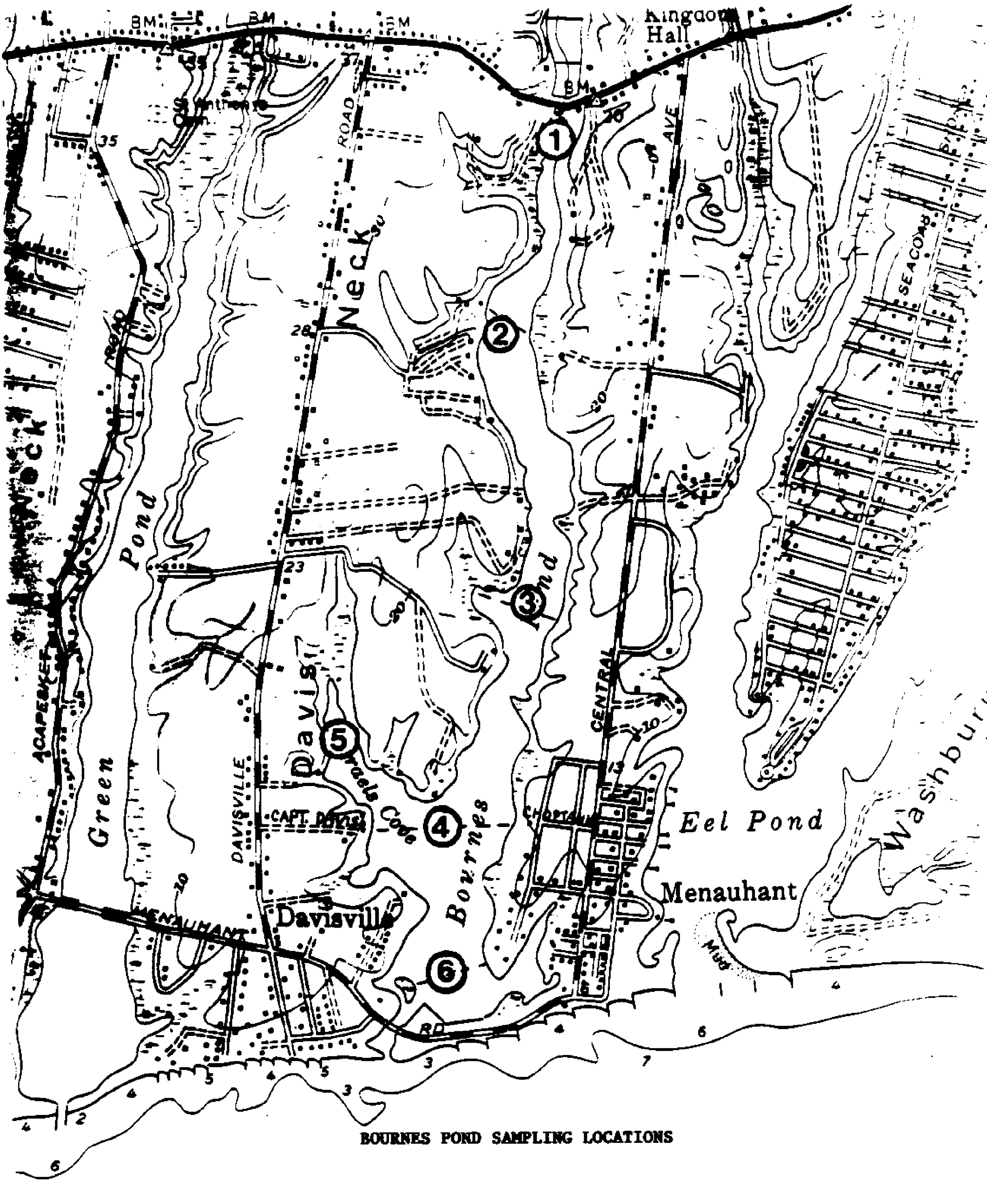


LITTLE POND

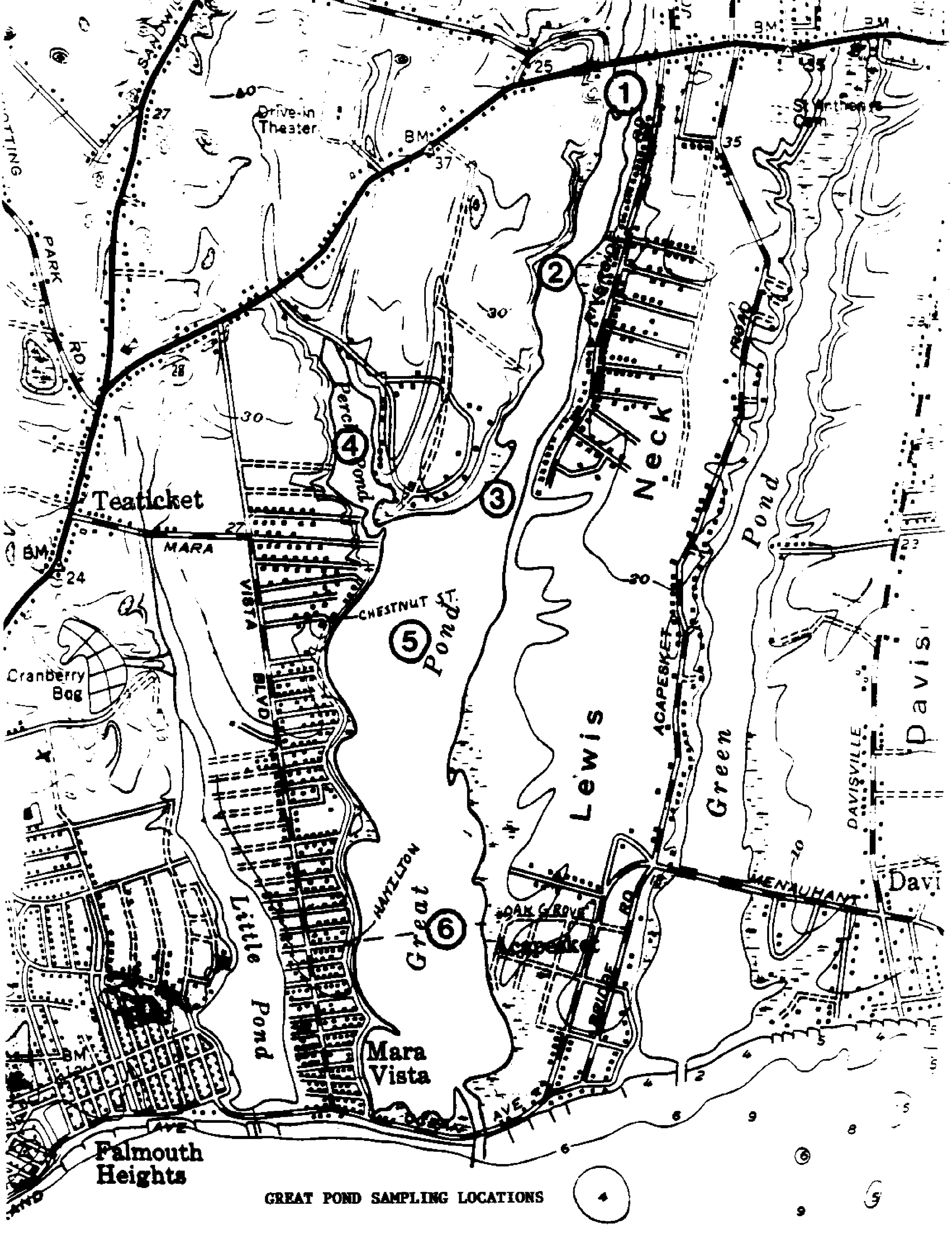
SAMPLING LOCATIONS



GREEN POND SAMPLING LOCATIONS



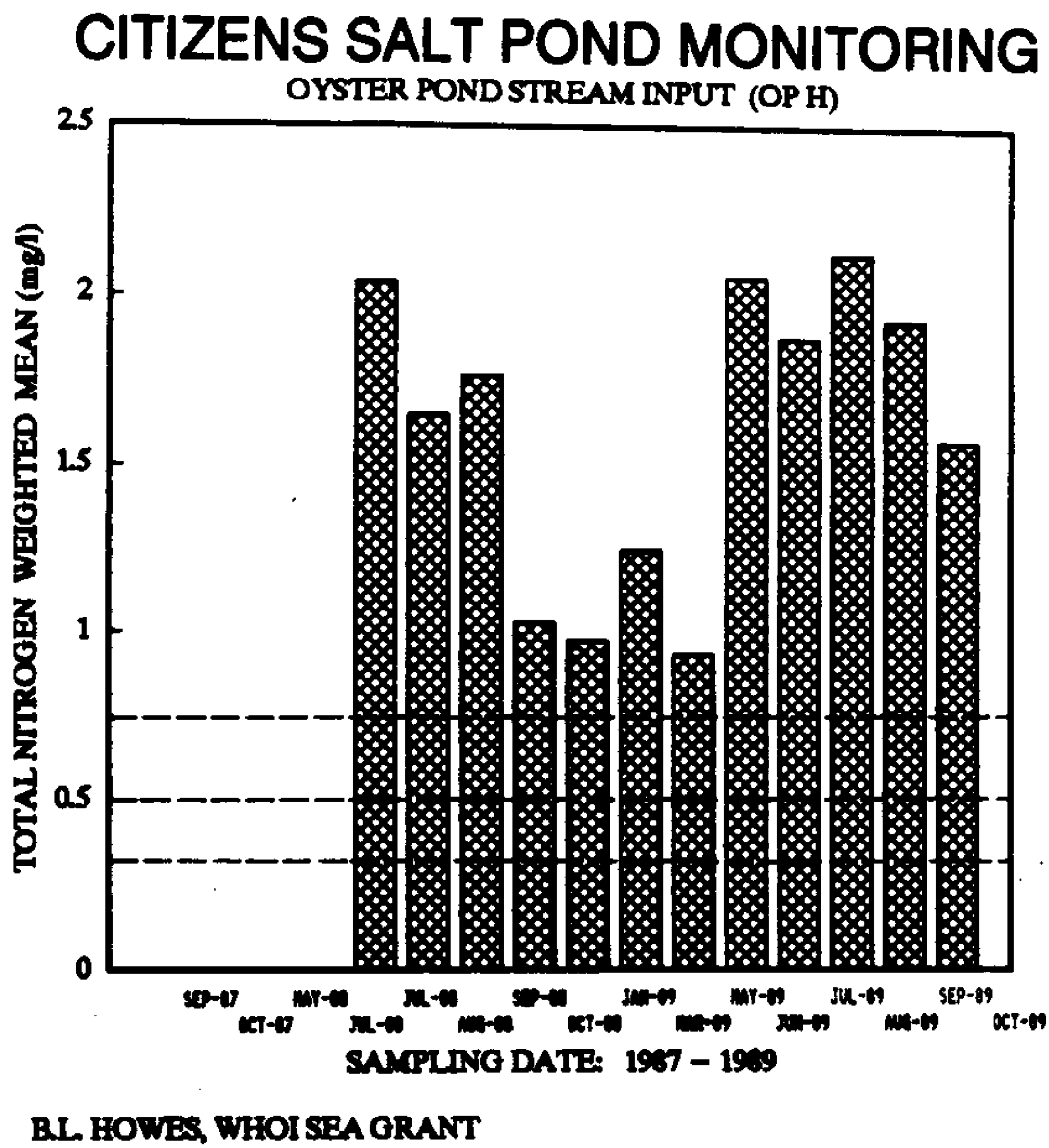
BOURNES POND SAMPLING LOCATIONS



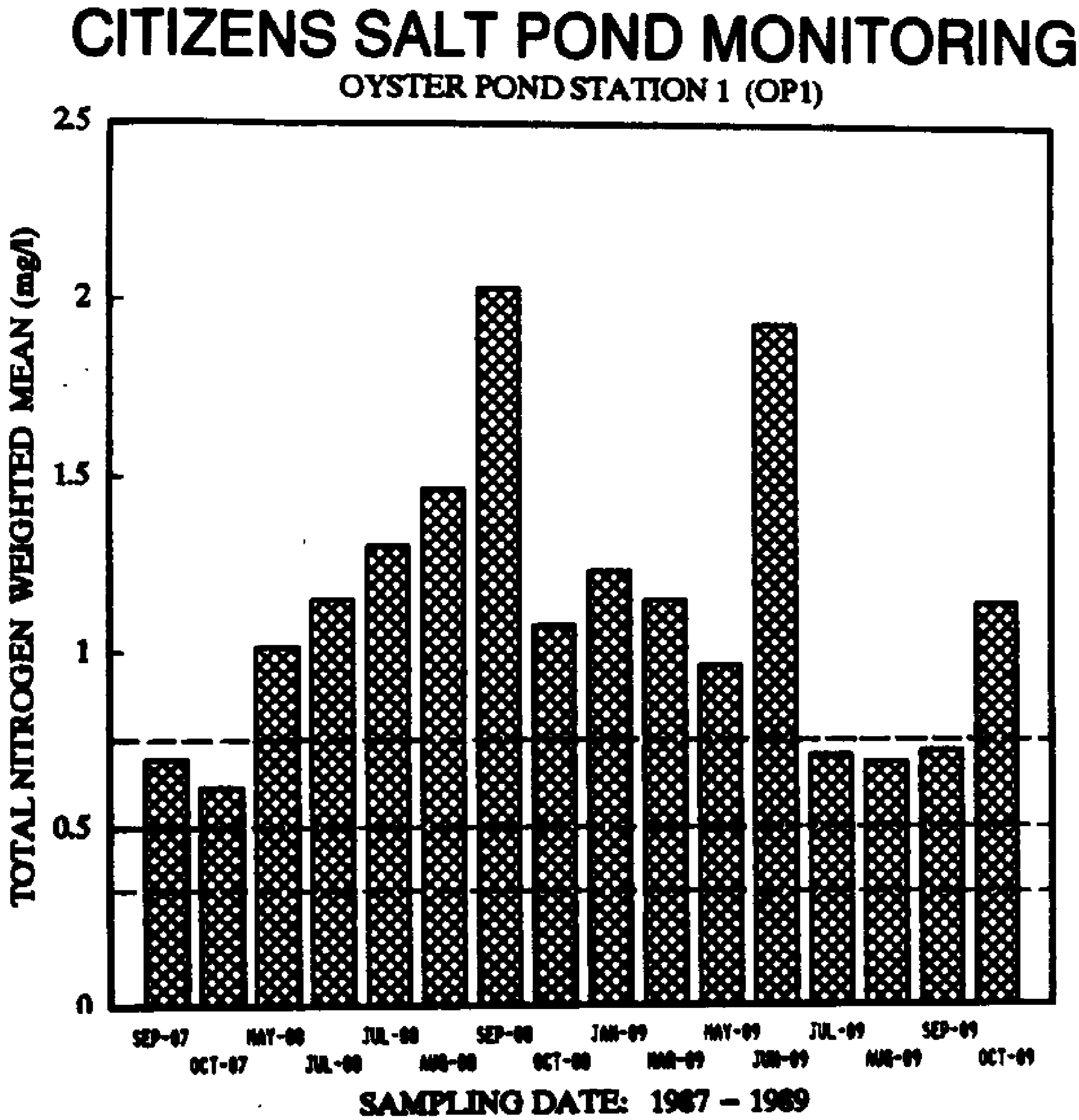
GREAT POND SAMPLING LOCATIONS

APPENDIX II.

Revised versions of Figures 10a, 10b, 10c, and 10d from the March 1990 Final Report on Citizen Volunteer Monitoring of Water Quality in Falmouth's Coastal Ponds to reflect true water column weighted average calculations as referred to in Table I. This recalculation provides a better indicator of total water column concentration than the straight average generally used, and facilitates use of the data in nitrogen mass balance equations. This reflects a permanent change in the way we will present data in the future.

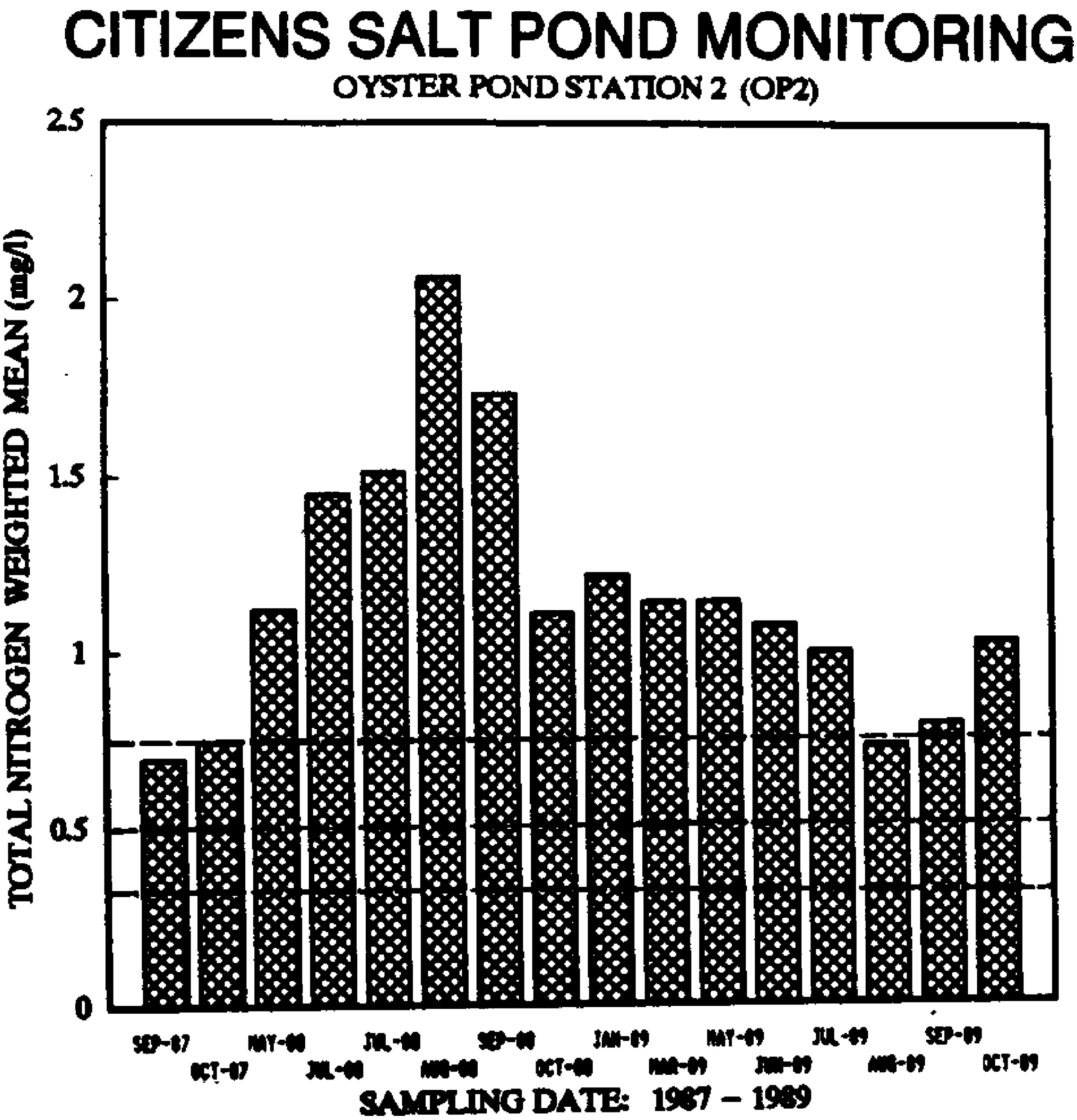


Revised Figure 10a. Summary of water column total nitrogen from Oyster Pond Headwaters, 1987-1989. Values are weighted water column averages.



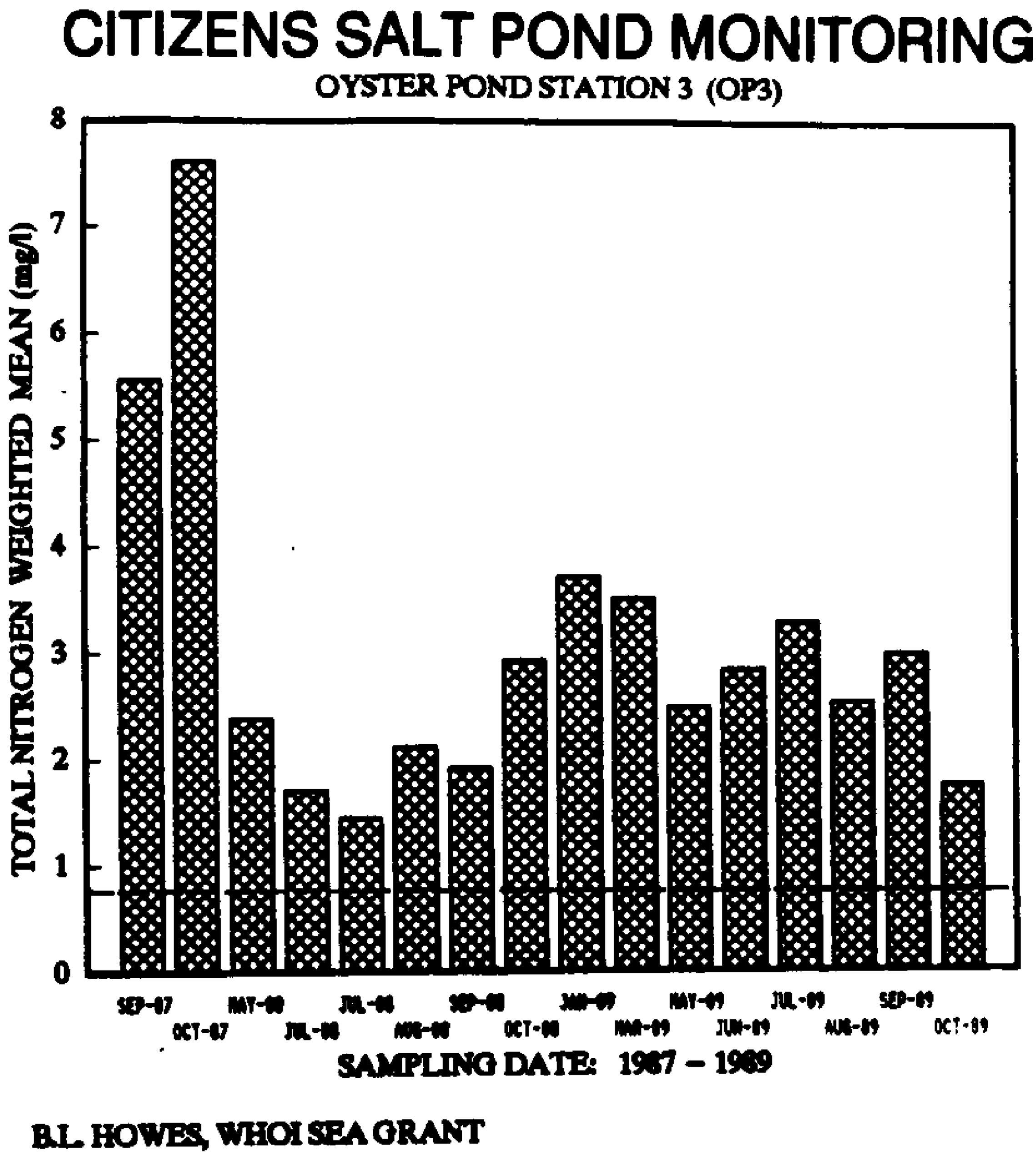
B.L. HOWES, WHOI SEA GRANT

Revised Figure 10b. Summary of water column total nitrogen from Oyster Pond Station 1, 1987-1989. Values are weighted water column averages.



B.L. HOWES, WHOI SEA GRANT

Revised Figure 10c. Summary of water column total nitrogen from Oyster Pond Station 2, 1987-1989. Values are weighted water column averages.



Revised Figure 10d. Summary of water column total nitrogen from Oyster Pond Station 3, 1987-1989. Values are weighted water column averages. This station is in the deep basin (6m) of the pond which exhibits steep chemical gradients in the lower 3m of the water column. the higher values in 1987 may represent the collection of deeper samples rather than a long-term change within the basin.

Appendix III.

Alphabetical Listing of the Falmouth Pond Watchers

Pond Watchers 1991

Matthew and Beth Adamczyk
10 Sharon Ann Lane
East Falmouth MA 02536
PHONE: 540-7334
POND: Green (Pond Captain)

Andrea Arenowski
Biology Department
WHOI
Woods Hole MA 02543
PHONE: ext. 2737
POND: General

Duncan Aspinwall
408 Elm Road
Falmouth MA 02540
PHONE: 540-3816
POND: Oyster

Eleanor Baldic
Mariners Lane
Falmouth MA 02540
PHONE: 548-2681
POND: Green

Edward L. Beattie
96 Shoreland Path
East Falmouth MA 02536
PHONE: 548-6216
POND: Green

Jim Begley
42 Elizabeth Jean Drive
East Falmouth MA 02536
PHONE: 540-6210
POND: Bournes (Upper)

Charles Blumsack
59 Partridge Lane
East Falmouth MA 02536
PHONE: 540-0247
POND: Green

Frank Britto
355 Davisville Road
East Falmouth MA 02536
PHONE: 540-0316
POND: Green

John Callahan
2 Ardmore Street
East Falmouth MA 02536
PHONE: 540-3165
POND: Little

Lee Anne Campbell
WHOI Sea Grant Program
WHOI
Woods Hole MA 02543
PHONE: Sea Grant Communicator
POND: General, CCEERC

Jane and Richard Carter
P.O. Box 22
North Falmouth MA 02556
PHONE: 563-5383
POND: Little

Jim Churchill
495 Blacksmith Shop Road
East Falmouth MA 02536
PHONE: 540-0526
POND: Green

Tracey Crago
WHOI Sea Grant Program
WHOI
Woods Hole MA 02543
PHONE: Sea Grant Staff Assistant
POND: General

Katherine Crew
P.O. Box 397
Falmouth MA 02540
PHONE: 548-8186
POND: General

Paul Crocker
37 Fells Road
Falmouth MA 02540
PHONE: 548-2106
POND: Oyster

Brian Currie
Town Planner
59 Town Hall Square
Falmouth MA 02540
PHONE: Town Planner
POND: Pond Watchers

Jonathan Cutone
Seacoast Shores
295 Edgewater Drive East
East Falmouth MA 02536
PHONE: 548-8178
POND: Green

Ellen DeOrsay
3318 Antilles Drive
Galveston TX 77551
PHONE:
POND: General

John Dowling
106 Ransom Road
Falmouth MA 02540
PHONE: 548-2926
POND: Oyster (Pond Captain)

Bill Elder
41 Millfield Street
Woods Hole MA 02543
PHONE:
POND: General

Dick Erdman
8 Providence Street
East Falmouth MA 02536
PHONE: 548-8868
POND: Great

Pond Watchers 1991

Angela Frater
2403 W. Hickory Lane
Mequon WI 53092
PHONE: 548-9513
POND: General

Dale Goehringer
Biology Department
WHOI
Woods Hole MA 02543
PHONE: ext. 2744
POND: General

Stan Hart
53 Quonset
Falmouth MA 02540
PHONE: 548-9005
POND: Oyster

Forbes Howard
65 Renee Lane
East Falmouth MA 02536
PHONE: 540-8228
POND: Green

Brian Howes
Biology Department
WHOI
Woods Hole MA 02543
PHONE: ext. 2319
POND: General

John Hulsey
Falmouth Town Hall
59 Town Hall Square
Falmouth MA 02540
PHONE: Assistant Town Plan
POND: General

Fran Jenney
53 School Street
Falmouth MA 02540
PHONE: 540-5026
POND: General

Joe Johnson
65 Miami Avenue
Falmouth MA 02540
PHONE: 548-0592
POND: Little

Perry Johnson
25 King Street
Falmouth MA 02540
PHONE:
POND: General

Clayton Jones
PO Box 181
North Falmouth MA 02556
PHONE: 540-5112
POND: Bournes (Lower)

John and Vera Justason
29 Miami Avenue
Falmouth MA 02540
PHONE: 548-2459
POND: Little

Mike Kinney
459 Davisville Road
East Falmouth MA 02536
PHONE: 548-2028
POND: Green

Robert & Marie Leavens
1 Iroquois Road
East Falmouth MA 02536
PHONE: 548-1473
POND: Little

Dick Lewis
Green Pond Fish N' Gear
366 Menauhant Road
East Falmouth MA 02536
PHONE: 548-2573
POND: Green

Donald & Helen Light
53 Quonset Road
Falmouth MA 02540
PHONE: 548-0277
POND: Oyster

Henry Little
Box 101
Buzzards Bay Estates
West Falmouth MA 02574
PHONE: 548-8537
POND: General

Bob Livingstone
1 Fells Road
Falmouth MA 02540
PHONE: 540-8065
POND: Oyster (Rain Gauge)

Werner&Birgit Loewenstein
102 Ransom Road
Falmouth MA 02540
PHONE:
POND: Oyster

Fred Martin
P.O. Box 1054
West Falmouth MA 02574
PHONE: 548-3362
POND: General

Les Martin
PO Box 855
East Falmouth MA 02536
PHONE: 548-3362
POND: Bournes (Lower)

Carol McKenzie
420 Shorewood Drive
East Falmouth MA 02536
PHONE: 548-4447
POND: Green

Pond Watchers 1991

Arthur (Rocky) Miller
175 Lakeview Avenue
Falmouth MA 02540
PHONE:
POND: General

Barbara & Barry Norris
52 Landfall Road
Falmouth MA 02540
PHONE: 540-7345
POND: Oyster

Armand & Mary Ortins
40 Bridge Street
East Falmouth MA 02536
PHONE: 548-1670
POND: Green (Pond Captain)

Julie Rankin

PO Box 97
Ashford CT 06278
PHONE: 563-3463
POND: Oyster (Pond Captain)

Gretchen Rittershaus
P.O. Box 69
East Falmouth MA 02536
PHONE: 548-0509
POND: Green

David Ross
WHOI Sea Grant Program
Woods Hole Oceanographic Institution
Woods Hole MA 02543
PHONE: 548-0476
POND: Green

David Schlezinger
Biology Department
WHOI
Woods Hole MA 02543
PHONE: ext. 2737
POND: General

Tony Millham
Biology Department
WHOI
Woods Hole MA 02543
PHONE: ext. 2319
POND: General

Fred O'Connor
168 Teaticket Highway
East Falmouth MA 02536
PHONE:
POND: Pond Watchers

Barbara Peri
2 Tortoise Lane
Falmouth MA 02540
PHONE: 548-2769
POND: Oyster

Richard Rebello
60 Lucerne Avenue
East Falmouth MA 02536
PHONE: 548-3650
POND: Little

Bobby Rogers
8 Iroquois Street
East Falmouth MA 02536
PHONE: 540-9372
POND: Little

Robert Roy
2 Massasoit Street
East Falmouth MA 02536
PHONE: 548-5139
POND: Little (rain gauge)

Jack Shohayda
36 Miami Avenue
Falmouth MA 02540
PHONE: 548-0472
POND: Little (Pond Captain)

Steve Molyneaux
P.O. Box 595
Woods Hole MA 02543
PHONE: 540-2484
POND: Bournes

Frances O'Donnell
49 Vineyard Street
East Falmouth MA 02536
PHONE: 548-6033
POND: Green

John Quinn
51 Weatherglass Lane
East Falmouth MA 02536
PHONE:
POND: General

Terry Riehl
111 Portside Circle
East Falmouth MA 02536
PHONE: 548-5186
POND: Green

Scott Rosewell
209 Fresh Pond Road
East Falmouth MA 02536
PHONE: 563-2058
POND: General

Adele Rustino
35 Willard Street
Cambridge MA 02138
PHONE:
POND: General

Jon & Nancy Soderberg
and Daughter
PO Box 823
East Falmouth MA 02536
PHONE: 540-0186
POND: Bournes (Lower)

Pond Watchers 1991

Frank and Diane Souza
55 Sharon Ann Lane
East Falmouth MA 02536
PHONE: 540-3246
POND: Green

Charles A. Swain
Town of Falmouth Planning Board
173 Main Street
Falmouth MA 02540
PHONE: Chairman
POND: Barn. County

Raymond Tavares
Falmouth Planning Board
59 Town Hall Square
Falmouth MA 02540
PHONE: Chairman, Planning
POND: Pondwatcher

Ted Tavares
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