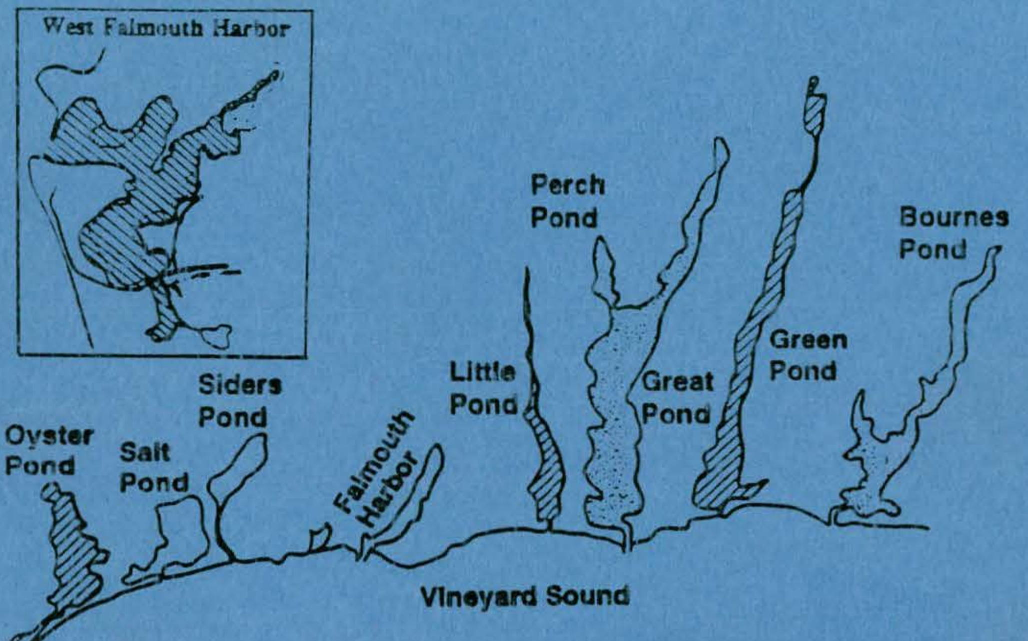
FALMOUTH POND WATCHERS

WATER QUALITY MONITORING OF FALMOUTH'S COASTAL PONDS RESULTS FROM THE 1993 SEASON



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June, 1994

This cooperative project is conducted with funding from the Town of Falmouth Planning Office and the Woods Hole Oceanographic Institution Sea Grant Program

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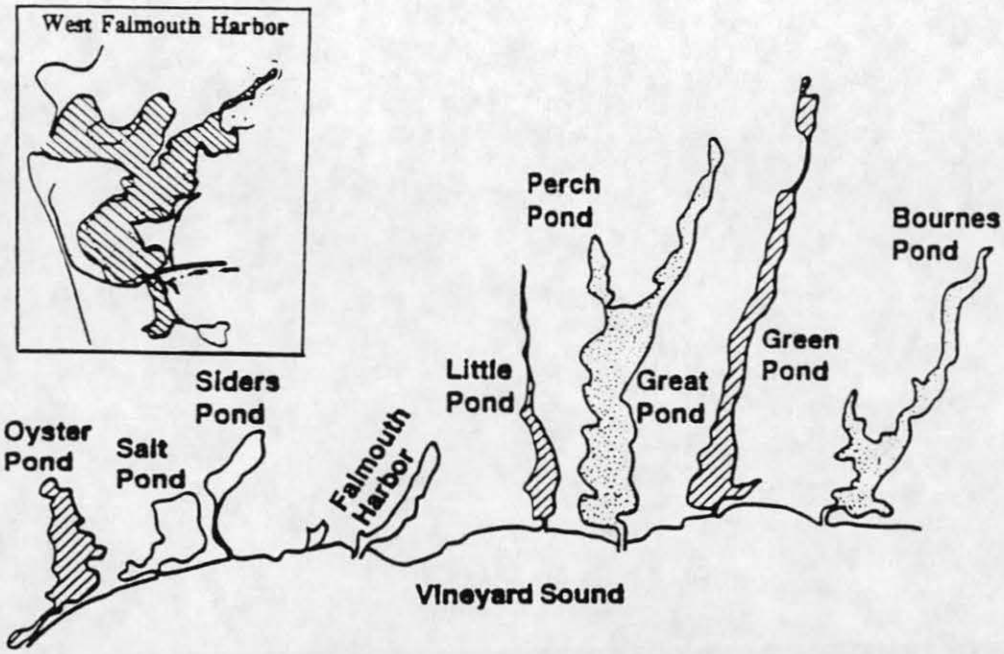

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EXECUTIVE SUMMARY

A citizen-based water quality monitoring project for Falmouth's coastal ponds was initiated in 1987 with the goal of acquiring baseline water quality data necessary for developing ecologically based management plans for Falmouth's coastal salt ponds and harbors. Starting with the three original ponds, Oyster, Little and Green, the project grew to incorporate two additional ponds, Bournes and Great, in 1990. Further expansion of the project included West Falmouth Harbor in 1992 to provide baseline data in anticipation of evaluating any potential impact from the nutrient plume generated by the Falmouth Wastewater Treatment Facility.

The Falmouth Pondwatch Program continues to evolve its role as a monitoring program of the ecological health of Falmouth's coastal salt water ponds. Although Pondwatch still performs its central role of providing the environmental data relative to the Nutrient Overlay Bylaw, it now performs a variety of other "services" relative to the Town's coastal management programs. First, the Pondwatch program provides additional senior personnel time as requested by various town boards to bring together ecological information relative to specific water quality issues. Second, as remediation plans for various systems are implemented the continued monitoring both satisfies demands by State regulatory agencies and provides quantitative information to the Town as to the efficacy of their measures. Third, the Pondwatch program has become a repository for environmental information on the variety of Falmouth's coastal ponds. The data base includes not only that collected by the core monitoring program but now includes watershed nutrient loading data and watershed delineations, circulation studies, wetland delineations, plant and animal productivities etc. The stable consistent information center provides direct benefits as remediation or management plans are designed and implemented or when environmental permits are required, since the data available reduces and may in some cases eliminate the need for costly new studies.

Through the efforts of Falmouth's Citizen Volunteers the Pondwatch Program has maintained a high level of success, with 1993 being no exception. The value of the information collected during the 1993 season varied depending upon the embayment in question. In West Falmouth Harbor, we doubled the existing information on the systems health and began our trend analysis relative to the

Wastewater Treatment Facility plume. In contrast, in Green Pond the long-term trend of declining water quality appears to now be clear and the data is being used to begin planning and implementation of short and long-term water quality improvements. While in Little Pond the Pondwatch Program assisted the Town in the design and permitting of the soon to be implemented inlet redesign (which will improve the ecological health of the pond) and also provides a cost effective approach to the future monitoring associated with the permitting of the project.

The results of the 1993 sampling indicated once again that, overall (with the exception of the majority of West Falmouth Harbor), all of the ponds continue to exhibit high nutrient levels and periodic bottom water oxygen depletion especially at the upper stations. Only slight variations were observed in the water quality conditions of Oyster, Little, Green, Great and Bournes Ponds from previous years, with a declining trend for Green Pond. The small improvements in lower Great and Bournes Ponds found in 1991-92 and ascribed to Hurricane Bob effects appeared to have diminished by the summer of 1993. All stations exceed the nutrient levels specified by the Nutrient Overlay Bylaw (except the small high intensity use area in lower Green Pond). Measurements in West Falmouth Harbor continue to indicate high levels of water quality, however the inner reaches of the harbor do exceed those levels specified by the Bylaw. Our "Coastal Salt Pond Report Card" (Figure 1) reviews the status of these systems. Although the condition of the ponds is as yet less than optimal, much is happening on the remediation front and we look forward to seeing some improvement in the coming years. Through the continued efforts of the Pond Watchers and the close collaboration with the Town we hope to identify this improvement through data collected by the program.

COASTAL SALT POND REPORT CARD

Pond	Ability* To Make Bylaw Limit	Overall Water Quality	Status 1992	1993
Green Pond				
Upper	Fail	Poor	Same	Same
Lower				
Intensive	Pass	Moderate	Declining (?)	Declining
High Quality	Fail	Moderate	Declining (?)	Declining
Great Pond				
Upper	Fail	Poor	Same	Same
Lower	Fail	Good	Improving	Declining (?)
Bournes Pond				
Upper	Fail	Moderate-Poor	Same	Same
Lower	Fail	Moderate	Improving	Improving
West Falmouth Harbor				
Upper	Fail	Good	?	?
Lower	Pass	Good	?	?
Little Pond				
Upper	Fail	Poor	Same	Same
Lower	Fail	Moderate-Poor	Same	Improving
Oyster Pond				
Shallow Basin	Fail	Poor	Improving	Improving
Deep Basin	Fail	Poor	Same	Same

* Based on long-term average

Figure 1.

INTRODUCTION

The Citizen Volunteer Monitoring Effort for Falmouth's Coastal Ponds (better known as the "Pond Watchers"), was initiated in 1987 in response to concern over the apparently deteriorating water quality of Falmouth's circulation restricted coastal salt ponds. Beginning with three ponds (Little, Oyster and Green), the program was expanded in 1990 to include two additional ponds (Bournes and Great), and again in 1992 incorporating West Falmouth Harbor (Figure 2). The fundamental purpose of the program is to provide much needed water quality data for the development of management plans established on the firm footing of quantitative, high quality environmental data. The project is jointly sponsored by the Town of Falmouth and the Woods Hole Oceanographic Institution Sea Grant Program, providing support for sampling equipment and analyses as well as avenues for direct application of results from the study. The backbone of the Pond Watchers program, however, is the effort and enthusiasm of the citizen volunteers who donate their time, boats and energies to collect environmental data on these systems. The quantitative measures obtained from the program are crucial for developing management plans, data which is often out of the reach of most coastal communities. The effectiveness of the program lies both in the enthusiasm and dedication of the Pond Watchers and the unique partnership which has developed between the citizens, local government and scientists whereby information gained from the research can be swiftly and directly applied toward effective management decisions for these fragile coastal environments.

The overall goals of the study are to provide the Town with information on current water quality conditions in the ponds, both to help plan watershed land use and to help guide potential remediation plans where possible. In addition, the project was designed to involve local citizens directly in determining the present and future ecological health of their coastal ponds and harbors, as well as to draw community attention to the increasing human pressures on our fragile coastal resources. The need for the information and an involved citizenry is particularly important relative to the Coastal Pond

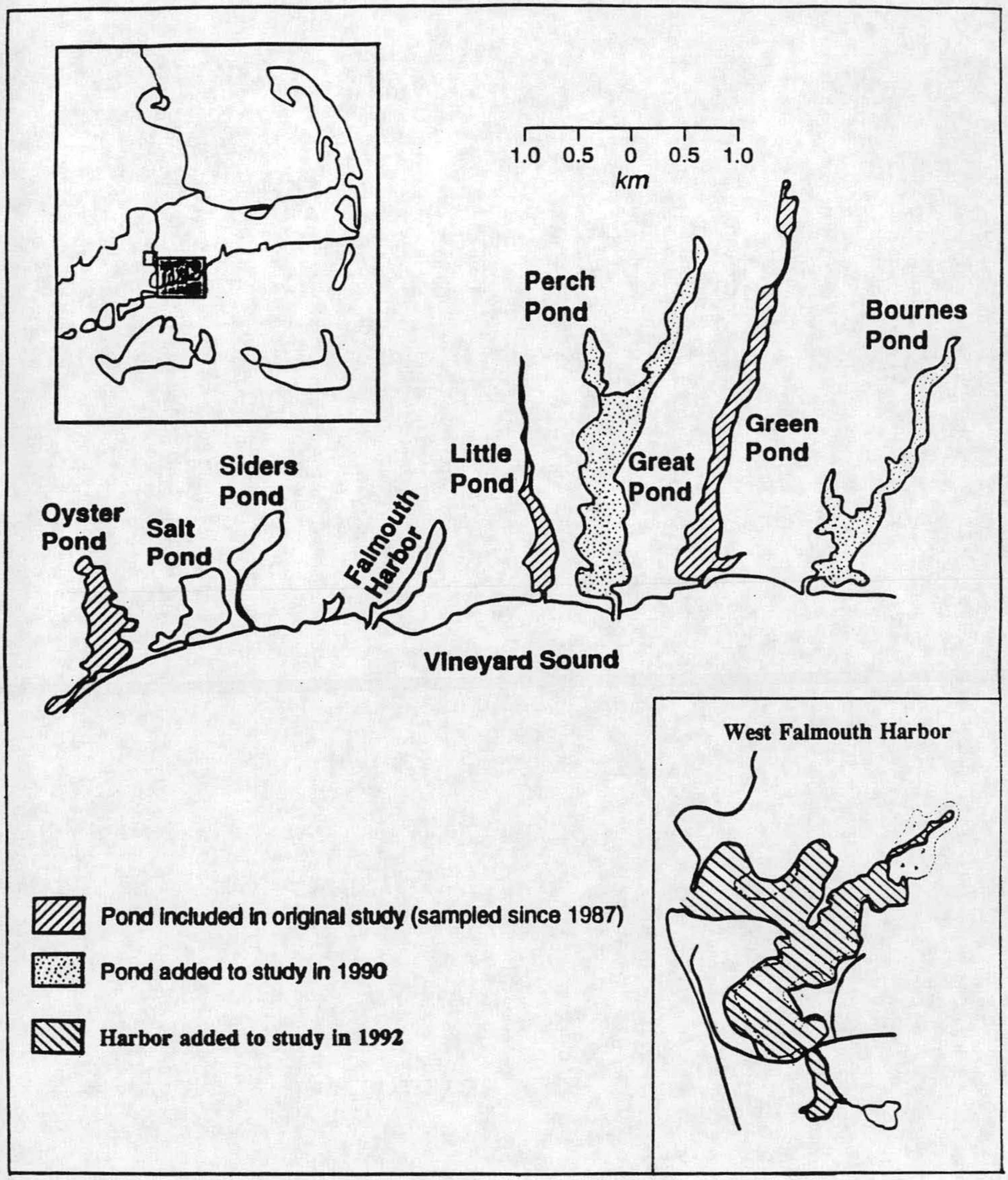


Figure 2. Relative locations of the study sites for the Falmouth Pond Watchers.

Overlay Bylaw, enacted by Falmouth in 1988 to guide land use decisions around the ponds by specifying annual mean threshold values for total nitrogen concentrations in Falmouth's pond waters. 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 was designed to provide the nutrient information far too expensive to be provided wholly by already strained Town budgets to verify the validity of these threshold values as well as provide the Planning Board with additional ecological information to interpret the Bylaw.

To magnify the applicability of the monitoring data as well as assist in its interpretation, a parallel detailed scientific investigation of one of the monitoring ponds, Little Pond, was undertaken 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. As the results from this parallel study are now available, we are able to apply the information from this detailed study to management objectives for all of Falmouth's ponds. 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.

The importance of long-term data sets in evaluating trends in coastal water quality cannot be understated. Without year to year comparisons of ecological conditions it is impossible to evaluate apparent changes in water quality relative to natural processes (such as storms or natural shoreline changes) or anthropogenic (development or remediation related) impacts. The consistent and high quality data provided by the Pond Watchers is now enabling evaluation of various potential management directions for each individual system relative to both cost and ecological effectiveness. As well, the addition of West Falmouth Harbor to the suite of monitoring ponds provides a unique opportunity to obtain crucial "before" data with which to evaluate any potential future impact of the nutrient plume originating from the new Falmouth Wastewater Treatment Facility currently on a predicted course toward the Harbor.

The primary objectives 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 develop and evaluate various 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;
4) to evaluate the effectiveness of implemented management programs aimed at protecting or improving nutrient related water quality,;
5) to provide baseline water quality data for evaluation of potential impacts to West Falmouth Harbor of the nutrient plume from the Falmouth Wastewater Treatment Facility;
6) to develop heightened public awareness of the cumulative impact of human activities on these ponds with the ultimate objective of fostering interactive partnerships between

citizens, scientists and resource managers for maintaining the ecological health of these fragile coastal ecosystems.

With each subsequent year of monitoring, the value of the data base expands tremendously. These long term data sets enable the evaluation of trends in water quality conditions and provide the ability to identify what represents a short term, periodic event (such as periodic low oxygen events due to natural processes) and what is part of longer term trends in environmental health. With this data set, we are more able to evaluate not only the health of Falmouth's coastal salt ponds but also to more confidently make predictions on the potential effectiveness of various remediation measures. The unique partnership approach to addressing ecological and economic consequences of coastal eutrophication (scientists-citizens-local government) has proven to be extremely valuable toward the rapid implementation of results from the study. The direct application of data to management through close communication with the Town is especially effective in providing a data base for the Town to evaluate and implement its Coastal Pond Nutrient Overlay Bylaw. The effectiveness of this land use management plan is important both locally and regionally as it is now under consideration for adoption by many coastal communities. Interestingly, data generated by the Pond Watchers has shown that nutrient conditions in some of the ponds already exceed these threshold levels, an important discovery in evaluating management decisions for these systems.

A valuable advantage of the Pond Watchers program over other types of monitoring programs revolves around sampling methodology. Because of the large number of citizen volunteers, simultaneous sampling is conducted at all 34 stations on each sampling date. This provides data collected under the same conditions of weather and tide which is critical to making any system to system or station to station comparisons. This approach, although vital to providing the tools with which to make educated and effective management decisions for these complex systems, is frequently lacking in monitoring programs primarily due to the extensive labor requirements and associated costs. The joint effort between scientists and the community has the additional advantage of rapid implementation of new approaches to the monitoring plan based on the data collected, for instance "rapid response" efforts to provide more detailed information should unusual conditions be identified such as fish kills, algal blooms or low oxygen events. This cooperation has also served to keep costs low and provide for immediate transfer of information not only to the citizen volunteers but local and regional governments and the community as a whole. Most of all, the partnership has served to increase interest and understanding of the fragile nature of these valuable coastal resources.

Another important aspect of the Falmouth Pond Watcher's program is its wide ranging applicability to other types of coastal systems. Techniques and methods used by the Pond Watchers have been specifically designed so that virtually any coastal community can undertake this type of effort efficiently but at low cost. The success of the program is reflected in its adoption as a model for the EPA Bays Program/Buzzards Bay Project Citizen's Monitoring Program for the embayments of Buzzards Bay, and the number of other communities which are currently exploring mechanisms to establish similar Pond Watcher programs for their own harbors and ponds. National recognition of the Pond Watcher program was gained in 1991 when the National Environmental Awards Council cited the program for a National Environmental Achievement Award; recognition was again given to the program by Renew America as an innovative model for grassroots environmental protection programs, with a citation in their Environmental Success Indexes for 1992, 1993 and 1994.

NITROGEN AND EUTROPHICATION OF THE PONDS

Over the past several centuries, Falmouth's coastal ponds and harbors have experienced major shifts in both marine and land based activities, many of which have affected the health of the adjacent coastal waters. Some activities, such as overfishing, were identified early on as potentially detrimental to some of these systems, but with sufficient time to implement management strategies. However, other impacting activities are only recently beginning to be recognized and our limited understanding of their long-term consequences hinders development of sound management policies to insure protection of the system. Of these activities, the most recent focus of concern is the long-term impact of nutrient loading on the water quality of nearshore coastal salt ponds and harbors.

Although toxic contamination (eg. PCB's, pesticides, organic compounds, etc.) can present significant problems for these systems, they tend to be localized, with the major threat to Falmouth's aquatic resources being primarily from increased nutrient inputs. In 1602 when Gosnold was sailing the waters of Cape Cod the nitrogen inputs to coastal waters, especially in the shallow marginal areas, was substantially lower than today. The growth in residential development and increased tourism is frequently identified as the cause for water quality declines, the long term implications of which are still unclear. Periodic eutrophication (or overproduction) events occur when increased nutrient inputs stimulate the overproduction of algae and phytoplankton which, with dark respiration activities and decomposition, can result in oxygen depletion in these water bodies. Coastal salt ponds, because of their large shoreline area and generally restricted circulation and flushing, are usually the first indicators of nutrient pollution along the coast, where lower rates of dilution and flushing are less effective in ameliorating the effects of additional inputs. In addition, stimulated growth of epiphytes on eelgrass as a result of increased nutrient loading can cause the decline of eelgrass beds, important in the production of bay scallops and other commercially valuable species. 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 over-fertilization of these waters. Most all of Falmouth's coastal salt ponds presently show some signs of nutrient over-enrichment. Portions of four in particular, Oyster, Little, Great 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.

Eutrophication is the natural response of coastal aquatic systems to excessive nutrient loading. At the highest levels of nutrient inputs into coastal waters the environmental health of coastal systems is severely impacted, in some instances resulting in water column anoxia, fish kills, and loss of valuable eelgrass and shellfish beds. Nitrogen is a natural and essential part of all ecosystems, aquatic and terrestrial. For the coastal ponds, as for most temperate coastal systems, nitrogen is limiting to phytoplankton, algal and rooted plant productivity and therefore secondary production, especially shellfish. It would, therefore, seem that increasing nitrogen inputs would be a benefit to the system, increasing fisheries harvests. Yet, there is much current discussion about the problems associated with nitrogen loading to coastal systems and there are multi-million to billion dollar projects to reduce nitrogen loading to the coastal zone. The apparent paradox stems from the fact that at low levels of nitrogen in coastal waters, increased loading does have a stimulatory effect upon secondary production (eg. fish and shellfish); at higher levels increased yields may still be achieved but changes in community structure begin to occur (eg. phytoplankton species, benthic animal species and impacts to eelgrass habitats). At higher loadings, however, the increased oxygen demand in the watercolumn and sediments from the increased plant production exceeds the rate of oxygen input from photosynthesis and by mixing from the atmosphere, and lowered oxygen concentrations can occur (hypoxia, anoxia). It is the stress associated with low oxygen concentrations which has the most deleterious effects upon plant and animal communities which at higher frequencies and durations of occurrence result in the loss of stable populations and their replacement with opportunistic species. This sequence of nitrogen inputs to low oxygen concentrations in aquatic systems is called eutrophication, and when the nitrogen inputs are the result of human activity (as opposed to natural processes) it is termed cultural eutrophication. Much of Oyster Pond, with its deep basins, is naturally eutrophic, however for all of Falmouth's coastal salt ponds and harbors, cultural eutrophication represents the greatest potential long-term threat to their ecological health.

Current nitrogen inputs to pond waters include natural inputs from undisturbed areas, microbial nitrogen fixation and exchanges with offshore waters, and inputs due to development: directly through precipitation and runoff and indirectly through groundwater transport from septic systems, lawn and agricultural fertilizers and animal farming. While the population of the watershed has been increasing steadily since colonial days, only recently have significant signs of incipient cultural eutrophication become apparent in the coastal ponds. One reason for this is that it is both the distribution and the total mass loading of nitrogen which determine the impact are related not to the rate of population increase but to the number of persons. Since there is no evidence that the "natural" sources of nitrogen have changed significantly over the past 350 years and since the assimilative capacity (the ability of the system to receive more nutrients without deleterious effects (has only recently been approached for most of the embayments, evaluation of "sources will focus the "new" sources related to human activities, i.e. the ones capable of being managed.

Sources of nutrient pollution into coastal waters are generally classified into two types: point sources, which tend to be discrete and easily quantifiable; and non-point sources, those which are more widespread, more difficult to measure and generally reach coastal waters through groundwater transport. Point sources have historically been regulated and quantified while non-point sources are a recent area of research and have a larger error associated with their estimates. The difficulty with managing nitrogen loading is its widespread distribution from a wide array of sources. 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. Regardless of the original form of the nitrogen, the form of almost all nitrogen in groundwater is nitrate. For example, while both organic and inorganic nitrogen enter septic systems, as a result of degradation and anaerobic conditions within tanks almost all of the nitrogen released is as ammonium. Even at the very high resulting concentrations, the ammonium is rapidly oxidized by bacteria (nitrification) to nitrate generally after a few meters of infiltration. Once the nitrate reaches the groundwater it is transported nearly conservatively (or unaltered) to 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 nitrogen compounds enter the water column of coastal water bodies, the extent of their impact is determined by the rate at which they are lost through tidal exchange or burial in the sediments. Readily available nitrogen (nitrate or ammonia) can be taken up by algae and phytoplankton. These plants may fall to the bottom upon dying, or may be eaten and "processed" digestively by zooplankton (microscopic animals), fish or shellfish. Subsequent microbial activity in the sediments can re-release the nitrogen bound in such decaying organic matter to the overlying water column, where it once again becomes available as a nutrient for plant growth. Thus the harbor sediments act as sort of a "storage battery", 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. Each cycle magnifies the impacts of a one-time input. Since sediments store large amounts of nitrogen, the extent of recycling determines how long nutrient-related problems persist after the original sources from groundwater or surface runoff from land are stopped. Evidence for this magnification of impact and the significance of biological transformations which occur in these systems, especially in the finger ponds, is represented from observed changes in the dominant form of nitrogen which occurs in different segments of the ponds. In the upper reaches of the finger ponds, readily available dissolved forms of nitrogen such as nitrate and ammonium dominate, however moving down the ponds toward Vineyard Sound the dominant nitrogen species shifts toward the particulate form, reflecting transformation and uptake by phytoplankton in the water column as the nitrogen is transported toward open coastal waters. Separate benthic flux measurements show that a portion of the nitrogen the particulate form which has fallen to the sediments does indeed become re-released as inorganic nitrogen from the sediments, providing once again a readily available source of nitrogen for plant production in the water column. The significance of this finding revolves around the fact that with each round of particulate-dissolved transformation which occurs in the sediments, oxygen is consumed. In addition, with each new bloom of phytoplankton, night-time respiration by these plants increases the demand for oxygen in the water column when light is not available for photosynthesis. It appears from the data that nitrogen is actively transformed and recycled within the ponds as it moves from headwaters until it is eventually flushed out of the pond and therefore the one time input of nitrogen can impact the system many times until it is eventually lost to open coastal waters.

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. 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. It is this oxygen depletion that is directly responsible for most of the detrimental effects of excessive nutrient loading in coastal ecosystems. 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.

MANAGEMENT

Maintaining high levels of water quality has both direct and indirect economic benefits for coastal communities. The health of natural resources such as recreationally and commercially valuable fish and shellfish species depends on the environmental health of coastal ecosystems. Similarly, poor water quality conditions seriously affect the desirability of a coastal area for the tourist industry and the value of real estate properties on or near these systems, thus potentially impacting important economic resources for many coastal cities and towns. The continuing partnership between citizens, managers, scientists and local government to monitor the health of Falmouth's salt ponds for the development, implementation, evaluation and maintenance of environmental management plans is our best and most cost-effective method for maximizing the ecological and economic benefits of these important coastal resources.

Increasing our understanding of these coastal salt ponds, as well as the relative success or failure of remediative measures to improve their water quality, allows us to better predict the potential impacts which may result from alteration of one or more of the dominant processes which structure them such as nutrient inputs or losses. This project provides the quantitative information for the development of site-specific management plans crucial to protecting the economic, aesthetic and recreational value of Falmouth's embayments and coastal salt ponds. Maintaining healthy ecological systems goes well beyond the economic benefits of harvest and recreation. The cost of remedial projects, such as those undertaken for Bournes Pond, New Bedford Harbor and Boston Harbor can be extremely expensive, ranging from multi-million to even billion dollar efforts. In addition, many of the coastal ponds are linked hydrologically, with potential hydrologic alteration of one causing secondary effects in watershed-pond nutrient delivery rates to adjacent systems. Even more direct secondary impacts are created when nutrient removal by sewering a watershed is performed, nutrients removed from one watershed usually being merely transferred to a different embayment after treatment. By better understanding these ecosystems and their linkages as well as the impact of human activities on their environmental health, we may help to avert the need for expensive remediation measures before they become necessary, and if necessary we will be able to recommend appropriate cost effective remediation options.

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. In addition, 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.

SUMMARY OF PREVIOUS RESULTS: 1987 - 1992

The results of previous samplings (1987-1992) have provided significant insights into the ecological health of Falmouth's coastal salt ponds, and we are now in a position: a) to evaluate potential future trends in water quality conditions for some of these systems, b) to develop and implement remediative management options for the more heavily impacted areas.

In the initial stages of this study, measurements were conducted over annual cycles, providing information on the seasonal variability in nutrient and oxygen conditions in the ponds. It has become clear that both of these major determinants to ecological health are highly variable both spatially and temporally, emphasizing the importance of multiple samplings and long-term data sets for assessing nutrient related water quality in these systems. Further study, with additional emphasis on the importance of natural physical processes such as wind driven mixing and water temperature on the fate and transformations of nutrients and oxygen, resulted in the focussing of field sampling effort to summer months when the systems are most biologically active and sensitive to nutrient inputs. Results from previous samplings indicated that the annual variation in nutrient levels was within the range encountered during summer sampling alone and that for the 15 stations where two annual cycles were measured, the average summer total nitrogen values were the same as those in winter (with the exception of the stream samples). The result is that summer sampling gives a good average view of nutrient levels and is the critical period for low oxygen events. In addition, the ability to concentrate samplings during the more biologically active summer months without impacting the data yield permitted more efficient use of volunteers and resources and allowed more frequent samplings during the period when conditions of low water quality become most apparent. In addition, it is during the summer period when nutrient related water quality structures the benthic animal and plant communities for the remainder of the year. However, without the initial annual sampling program, it would not be possible to rely on the more focused effort and be confident that the important ecological questions are actually being addressed.

The most significant finding from previous work was that almost every region of every pond exhibits total nitrogen concentrations above the allowable levels as specified by the Falmouth Coastal Pond Overlay Bylaw, and that the levels were fairly stable from year to year. In fact, many of the areas exceed the highest level of 0.75 mg/l specified for intensive use areas; some designated as "high quality" or "stabilization" areas would need reductions of more than 50% to reach the currently specified levels according to the Bylaw. In addition, the results show that the high nitrogen areas are indeed associated with low water quality as defined by low dissolved oxygen levels (especially in bottom waters), and frequently macroalgal blooms as well. This is most well demonstrated by the longer data sets on Little, Green and Oyster Ponds, all nutrient rich and eutrophic systems. Bournes and Great Ponds also exhibit periodic low oxygen conditions (less than 4 mg/l, generally considered to be stressful to benthic and bottom dwelling organisms) at most stations. It is not possible at present to assess the duration and extent of low oxygen conditions over the entire summer for these latter two systems without a more intensive sampling regime such as has been conducted in Little Pond. What is clear from the study to date is that the higher nutrient levels in the Bylaw do reflect poor water quality and all areas with total nitrogen levels below 0.32 mg/l are indicative of healthy, productive systems, eg. Vineyard Sound and Buzzards Bay. It appears that, if anything, the specified nutrient levels are a little too low to achieve stated ecological standards. In other words, low oxygen conditions and impoverished animal communities are found at lower nitrogen levels than anticipated.

The importance of long-term data in these systems was underscored by the advent of Hurricane Bob (Aug. 1991) which appeared briefly to increase the nutrient flushing from the ponds. For the remainder of 1991 and partially for 1992, water quality was "improved" at many pond sites and particularly for lower Great and Bournes Ponds. However, the 2 post hurricane years now reveal that the improvement was short-lived with almost all sites returning to pre-hurricane levels (or worse). Management based upon the anomalous short-term improvement would have allowed for a higher assimilative capacity of the pond systems or costly underscaleing of improvements.

An additional major finding of the study reflects the importance of differentiating natural processes from anthropogenic impacts in evaluating those factors responsible for water quality conditions in these systems. For instance, the physical structure of Oyster Pond with its deep anaerobic basin is a good example of a naturally eutrophic system. The very structure of this pond, with its deep basin, virtually eliminates any wind driven mixing of oxygen into the deeper regions of the water column. In addition, light attenuation in the deeper depths of the water column minimizes photosynthetically derived oxygen at the same time decomposition processes consume oxygen. Although nutrient additions to Oyster Pond are impacting the system, the natural processes effecting the deep basin would occur regardless of additional nitrogen inputs and therefore by the standards of the Bylaw (as well as most ecological standards) would be considered to have eutrophic, oxygen depleted bottom waters regardless of human activities around the pond. Nevertheless, additional nutrient loading to this system without parallel increases in nutrient loss (i.e. via flushing) has the potential to seriously impact the ecological health of the shallow areas once the assimilative capacity for new nutrients has been exceeded. However, it is also clear that managing the health of Oyster Pond must include not just nutrient but also salinity management since our work has revealed that most of the ecological changes in this pond result from its shift in 1987-88 from a fresh/brackish water (surface water=2ppt) to a saline (surface water=15ppt) pond.

Project results also indicate that rainfall plays an important role in contributing to observed variations in nutrients and oxygen. Significant rain events appear to be frequently associated with low oxygen events, and ponds with very limited flushing such as Oyster Pond may reflect changes in salinity related partially to annual rainfall. Not all rain events lead to low oxygen in the ponds, however, and we are focusing on developing methods to predict the meteorological conditions which result in low oxygen events in the various salt pond areas. So far we have observed multi-year changes due to Hurricane Bob and moderate changes due to interannual rainfall variations as well as short-term effects of individual rain events. These results, again, underscore the need for long-term monitoring of these dynamic coastal systems.

Since our concern with high nutrient levels and low oxygen conditions is primarily due to its severe negative impacts on animals and plants living in the ponds, special projects were undertaken by the Pond Watchers focusing on evaluating the comparative health and growth of animal species living in the different ponds. These projects involved oyster growth experiments, and fish and invertebrate surveys. Oysters were found to grow best with very low mortality at sites in Little Pond (LP3) and Green Pond (GP4, GP2); oysters located in Oyster Pond, however, exhibited poor growth and about 15 percent mortality. The low success in Oyster Pond may be potentially due to the reduced salinity of the pond, or the unpalatability of the specific phytoplankton species present as food since there were high levels of particulate organic nitrogen suggesting plentiful organic matter in the water column. The data suggests that shellfish can survive in all of the ponds, however it is important to note that oysters in these experiments were suspended in nets above the bottom and therefore do not reflect survivorship of infaunal animals.

Fish and invertebrate censuses were conducted in each of five ponds (prior to the inclusion of West Falmouth Harbor) with both an upper and lower site within each pond. Fish species were collected using both "minnow" and larger commercial box traps at each stations, with collections in concert with the four watercolumn samplings to enable comparison of oxygen and nutrient conditions to species population and distribution. Although traps do not provide perfect quantitative results since some species may avoid entering traps, the results of the census were consistent between all sites: areas with low bottom water oxygen had a lower number of species present than higher oxygen areas. This result is independent of which species were found and whether one considers fish or invertebrates. This finding is supported by basic ecological theory where high stress habitats generally have a lower species diversity. The lowest diversity was generally found in Oyster, Little and Upper Green Ponds, and in the less eutrophic ponds (Bournes, Great and Lower Green) there was a tendency for a lower diversity in the upper versus lower sites. These results support the contention that low oxygen and high nutrient areas are of low ecological health.

Previous results from the program also indicate that the eutrophic nature of the ponds is resulting in the limitation of light penetration through the water column, even in the relatively shallow systems. By mid-summer, the water columns of most of the stations are supporting large phytoplankton populations consistent with the high measured concentrations of particulate organic carbon and nitrogen. This increased production resulting from the nutrient rich nature of the waters is most likely the cause of the decrease in light penetration and is the likely proximate cause of the decline in eelgrass beds in some areas. We are currently investigating in more detail the relationship between light penetration, eelgrass and macroalgal growth as eelgrass provides very valuable habitat, and overproduction of phytoplankton or some macroalgal species can have deleterious ecological consequences to coastal pond systems.

SAMPLING LOGISTICS AND EQUIPMENT

Prior to the commencement of field sampling each year, the Pond Watchers take part in a refresher course on sampling procedures and receive information on any "Special Projects" to be undertaken that year. 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 for 1993 were:

Oyster Pond -	John Dowling
	Julie Rankin
Little Pond -	Bobby Rogers
Upper Green Pond -	Matt Adamczyk
Lower Green Pond -	Matt Adamczyk
	Armand Ortins
Upper Bournes Pond -	Steve Molyneaux
Lower Bournes Pond -	John Soderberg
Great Pond -	Charles Haley
West Falmouth Harbor -	Rhett Lamb

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 other shallower systems. For specific measurements such as rainfall, electronic rain gauges were purchased and installed at the homes of Bob Livingstone (Oyster 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, and attempt 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; Great Pond - six; and West Falmouth Harbor - seven with an additional reference station in Vineyard Sound. On a given sampling, all of these 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. 1993 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. As stated earlier, results from previous samplings indicated that the annual variation in nutrient levels was within the range encountered during summer sampling alone and that for the 15 stations where two annual cycles were measured, the average summer total nitrogen values were the same as those in winter (with the exception of stream samples). 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.

The four Pond Watcher samplings were conducted as scheduled. 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 ($\pm$ 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 (O = On Site; L = Lab):

Physical Measurements:

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

Chemical Measurements:

(L) Nitrate + Nitrite
(L) Ammonium
(L) Dissolved Organic Nitrogen
(L) Particulate Organic Nitrogen
(L) Total Dissolved Nitrogen
(L) Phosphate
(O) Oxygen Content
(L) Salinity
(L) Chloride
(O/L) 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.

SPECIAL PROJECTS

"Special Projects" are conducted each year to gather information of a non-routine monitoring nature but which are useful either to interpret monitoring data, or directly assess habitat quality for animals and plants within the ponds. The linkage of nutrient based studies with direct habitat assessments provides a powerful tool for refining the critical nutrient levels required for maintaining the plant and animal resources. In previous years, the Pond Watchers have conducted oyster growth experiments, a fish survey, detailed watercolumn profiling of Oyster Pond, and continue to operate in a "rapid response" mode when fish kills or other low oxygen events trigger non-routine water sampling.

Several of the Pond Watchers have been participating in a bird census initiated in 1992. The goal of this ongoing survey is to get an accurate assessment of the number of waterfowl occupying Falmouth's coastal ponds throughout the year; the data will then be coupled with nutrient and coliform data. With this information, we will then be able to assess the importance of waterfowl to both nutrient and coliform loading to the ponds.

RESULTS AND DISCUSSION

The past year, 1993, has seen a significant expansion in the focus of the Falmouth Citizens Salt Pond Monitoring Program. In 1992 we began to place more emphasis upon management and remediation in addition to the continuing long-term mission of acquiring quantitative nutrient data relative to the Nutrient Bylaw and providing current water quality status of the salt ponds. We have continued this shift through 1993 as the focus shifts away from merely documenting water quality trends towards application of the data for management and then documenting "water quality improvements". With this in mind the analysis of the results is divided into two parts: 1) a presentation of long-term trends and current ecological health of each of the embayments with additional focus on West Falmouth Harbor (since the system is still new to the program) and 2) progress on management and remediation plans for Little, Green and Oyster Ponds including the results of a pre-inlet redesign experiment in Little Pond.

Overall, taken as whole ecosystem units, the status of Green, Little, Great/Perch, Bournes, and Oyster Ponds remains as in previous samplings at almost all stations. These five ponds continue to exhibit high nutrient levels and periodic oxygen depletion in their upper reaches and all exceed nutrient levels specified by the Nutrient Overlay Bylaw. However, the ponds do not function as single units but rather as linked upper and lower pond components forming the whole. Assessing individual stations within each pond gives a different view with the declining trend in water quality in Green Pond now apparently confirmed and the small improvements in lower Great and Bournes ponds observed post-Hurricane Bob (possibly due to increased circulation) no longer detectable. However, the greatest potential change (first seen in 1992) involves improving conditions in Oyster Pond and may suggest a partial remedy for that system.

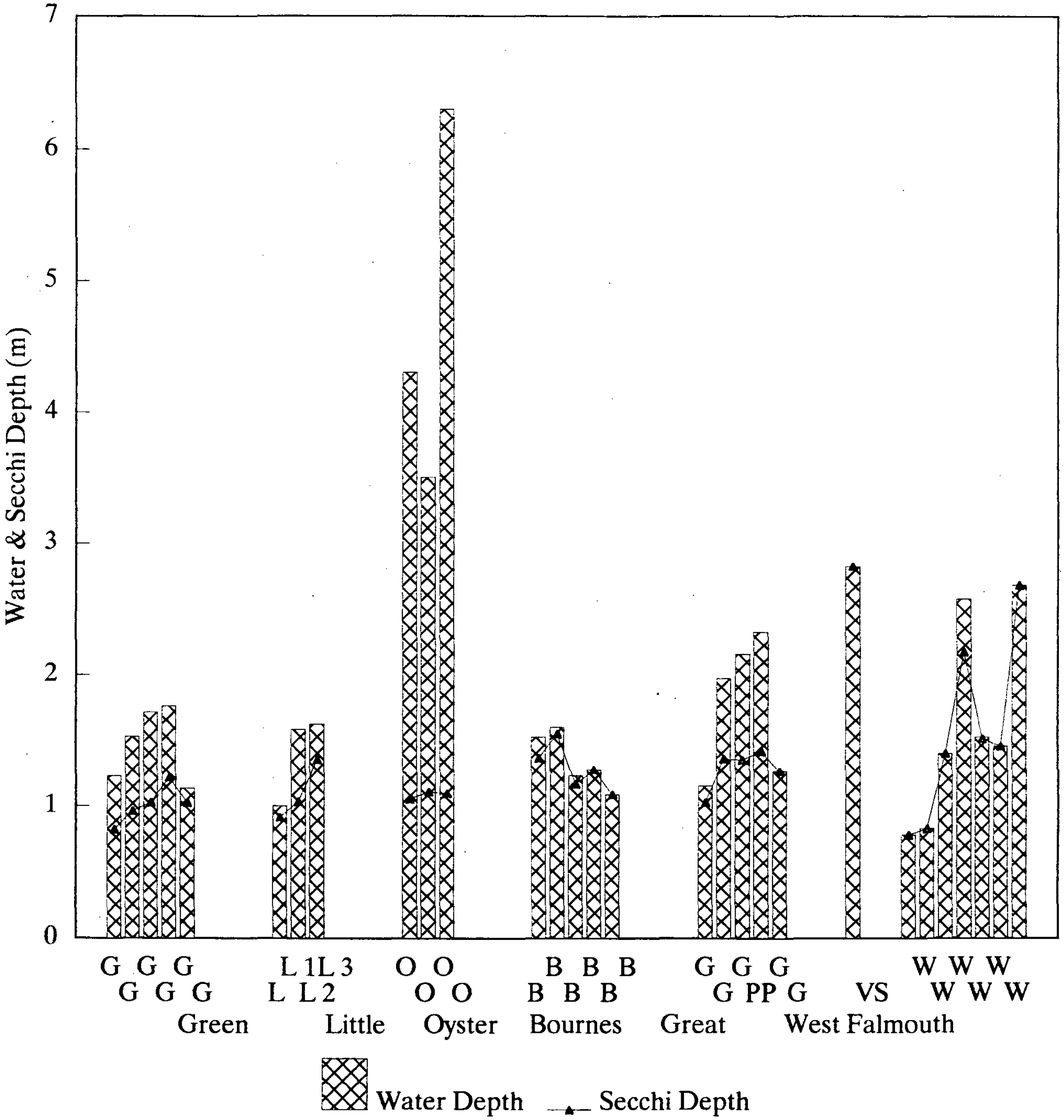
Ecological Health: Status

Approximately 2500 chemical assays (each in duplicate) and almost 1000 physical measurements were conducted throughout the six embayments (Figure 2) monitored by the Falmouth Pond Watchers in 1993. Consistent with previous years, variations of almost two fold in nitrogen or oxygen levels were frequently observed at individual sites between samplings. However, at four of the twenty seven stations monitored in 1993, significant changes in either oxygen or nitrogen were found from previous years. These changes stress the importance of multiple samplings and longer-term data collection for assessing nutrient related water quality in these dynamic coastal systems.

The physical structure, shape and depth, of each of the embayments appears to play a major role in their susceptibliy to ecological impacts from nutrient loading. The bathymetries of each of the five salt ponds are in keeping with their modes of formation: Green, Little, Bournes and Great Ponds by groundwater sapping of glacial outwash versus Oyster Pond (and Perch and Salt Ponds) from drowning of kettle holes. The "finger" ponds tend to be long, narrow and shallow with generally uniform depths

Citizens' Salt Pond Monitoring

Light Penetration: 1993



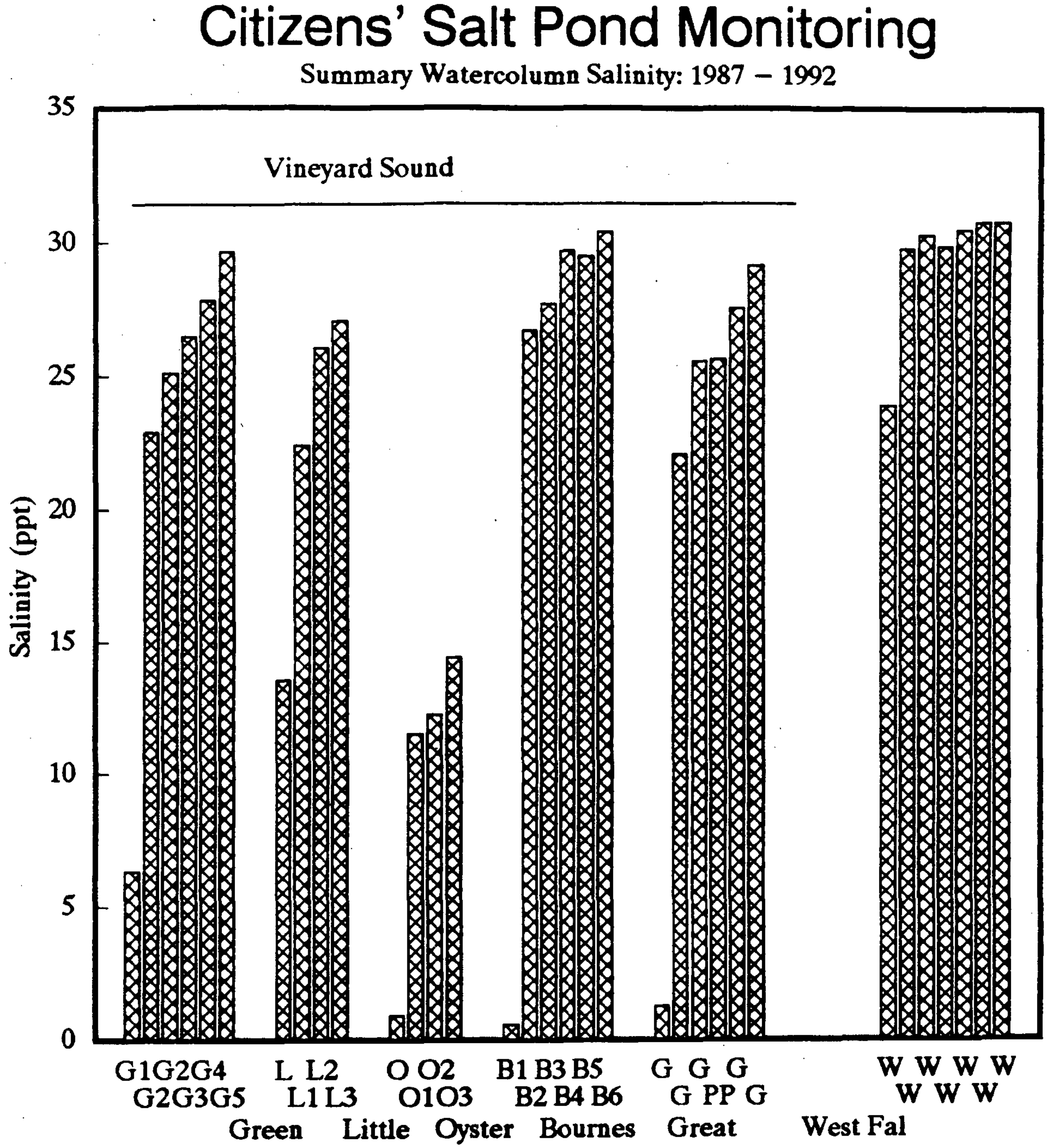
B.L. Howes, WHOI Sea Grant

When Secchi Depth = Water Depth: the potential for macroalgal blooms exists.

Figure 3.

of 1-2 m, while kettle ponds (freshwater ones as well) tend to be more circular and deeper (eg. Oyster Pond, 6m). West Falmouth Harbor is intermediate in these respects functioning much like the main basins of Great and Bournes Ponds but without the long narrow upper portions (Figures 2 & 3). Shape and depth effect water quality as a function of the decreasing exchange with lower nutrient offshore waters as distance from the inlet increases, hence the more elongated portions tend to be more susceptible to nutrient related impacts. The role of water depth is linked more to oxygen status than nutrient levels in that the deeper the water, the less likely that the watercolumn will be uniformly mixed from top to bottom. Since the ponds frequently require oxygen inputs from the atmosphere to surface waters and subsequent physical mixing to bring oxygenated waters to depth to maintain oxygen balance, deeper waters are more likely to experience periodic oxygen depletions when vertical mixing doesn't reach the bottom (stratification). Oyster and Perch (because of its isolated basin) Ponds are the most susceptible to negative impacts due to basin depth.

In addition to its relation to potential stratification, basin depth coupled with the particle concentration in the pond waters (primarily plankton and macroalgae) determines the potential for light to reach the bottom sediments. An important consequence of the eutrophic state and water depth of the ponds is that light is generally attenuated in summer before reaching the bottom where it could support benthic algae (Figure 3). The importance of water clarity is indicated by comparing pond stations with Vineyard Sound which had light reaching the bottom at over 3 meters depth. In contrast, most of even the relatively shallow Green, Great and Little Ponds and the deep basins (4 & 6m) of Oyster Pond had limited light penetration. While this may reduce the susceptibility to benthic blooms, the low water clarity is due to the already eutrophic conditions. It appears that the watercolumns at most of the stations by mid-summer are supporting large phytoplankton populations consistent with the measured high particulate organic nitrogen and carbon concentrations. West Falmouth Harbor, at all stations, was similar to the lower, more well flushed regions of Green, Great and Bournes Ponds and Vineyard Sound



B.L. Howes, WHOI Sea Grant
Watercolumn averages, all data.

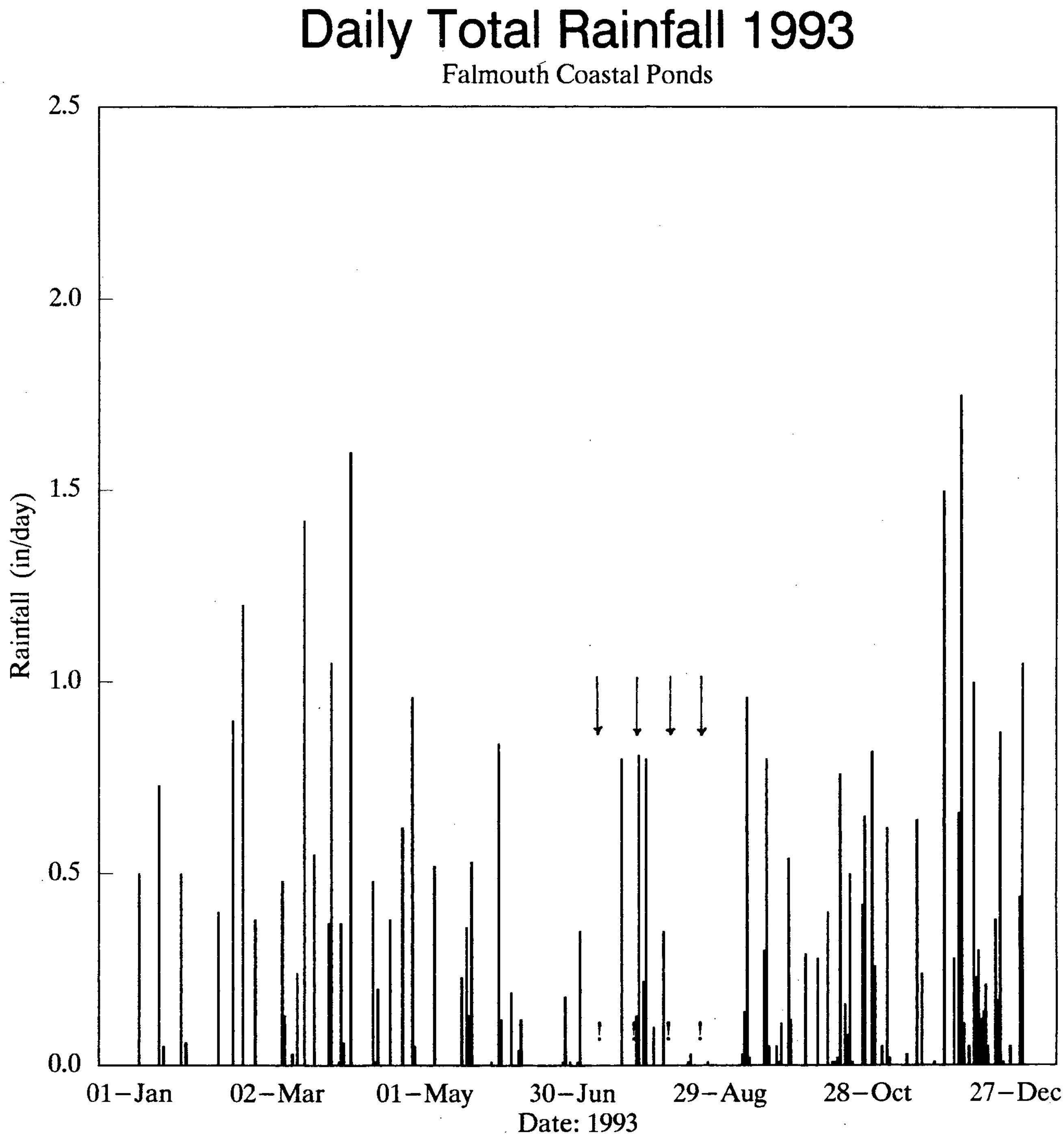
Figure 4.

in both depth and water clarity. The result is that throughout the Harbor, bottom sediments can support benthic algae and rooted plants eg. eelgrass.

It is useful to compare the secchi depths from those areas of each pond where the light does not reach the sediments but is attenuated within the watercolumn. From this analysis it is clear that regardless of the pond the most eutrophic areas have secchi depths of about 1 meter or less (Little, Green Oyster Ponds) compared to greater than 1 meter for the moderately healthy sites (Bournes and Great Ponds) and almost 2 meters for the most healthy sites (Vineyard Sound and West Falmouth Harbor). The reason is that the secchi depth appears to be most closely related to the phytoplankton biomass within the watercolumn of these systems which is related to the productivity and the balance between nutrient input and export through flushing. It is notable that only West Falmouth Harbor has secchi depths approaching the waters of Vineyard Sound. The present high water quality in West Falmouth Harbor versus the other coastal ponds is significantly related to the greater tidal prism generated by the much greater tide range in Buzzards Bay versus Vineyard Sound.

A major ecosystem structuring parameter in these circulation restricted coastal embayments is salinity (Figure 4). The animal and plant communities within any embayment are able to tolerate a moderate range of salinities but not the full spectrum from fresh to seawater. The result is that major changes in salinity can result in the replacement of whole communities independent of water quality issues. At present all of the six systems contain salt water, and except for Oyster Pond, almost all stations were above 25ppt with fresher headwaters where groundwater and streamflows are greatest and highest salinities near the seawater source at the inlet. These high salinities will support most estuarine species including most shellfish. A relative indicator of the efficiency of tidal exchange in each of the six systems can be derived from the magnitude of the salinity gradient from the inlet inland. Oyster Pond's fresher water is directly the result of its restricted inlet which limits tidal inflow. As might be expected from morphology and water clarity (Figures 2 & 3) the lower portions of Green, Great, Bournes Ponds and most of West Falmouth Harbor all had salinities approaching the source waters consistent with their good tidal exchange. Little Pond, due to the restriction of its inlet by sedimentation over the 1987-1992 period, was experiencing a gradual freshening of its waters due to its diminishing tidal flux. However, intensive inlet maintenance in 1992-93 resulted slightly higher salinities in the 1993 field season more similar to 1987 (Data not shown). The upper regions of Green, Great and Bournes Ponds are most similar to Little Pond except that the diminished flushing of their waters (relative to the lower regions) is due to their distance from the inlet more than changing inlet structure.

One of the environmental factors contributing to the observed variation in nutrients and oxygen levels is the frequency and magnitude of storms/rainfall. Rain events appear to be frequently associated with low oxygen events; relatively unflushed ponds like Oyster Pond may exhibit salinity fluctuations related in part to annual rainfall. Pond sampling each year is generally conducted relative to high and low rainfall periods as was true for 1993 (Figure 5). At present, the relative importance of rainfall versus the extent of low light conditions and low wind speeds (low vertical mixing) which co-occur with rain events in triggering low oxygen events is unclear. However, in 1990 and 1991 in all five salt ponds the major low oxygen events appeared to be associated with these conditions. Not all such weather patterns had associated low oxygen events and the magnitude of the rainfall may play a role as suggested from the 1992 data. In 1993, there once again was again indication of a relation between rainfall and low oxygen conditions, although there was limited opportunity for comparison. It appears that the relation between storm events and low oxygen is "real" but is controlled by the overall susceptibility of the ponds themselves to hypoxia as determined by organic matter levels (which are ultimately controlled by nutrient inputs). The lack of storm related hypoxia 1992 seems to have been partially related to temporary local improvements in general nutrient related water quality residual from Hurricane Bob. By 1993 the return of the systems to pre-Bob status appears to once again signal their susceptibility to periodic storm related stratification triggering low oxygen conditions.

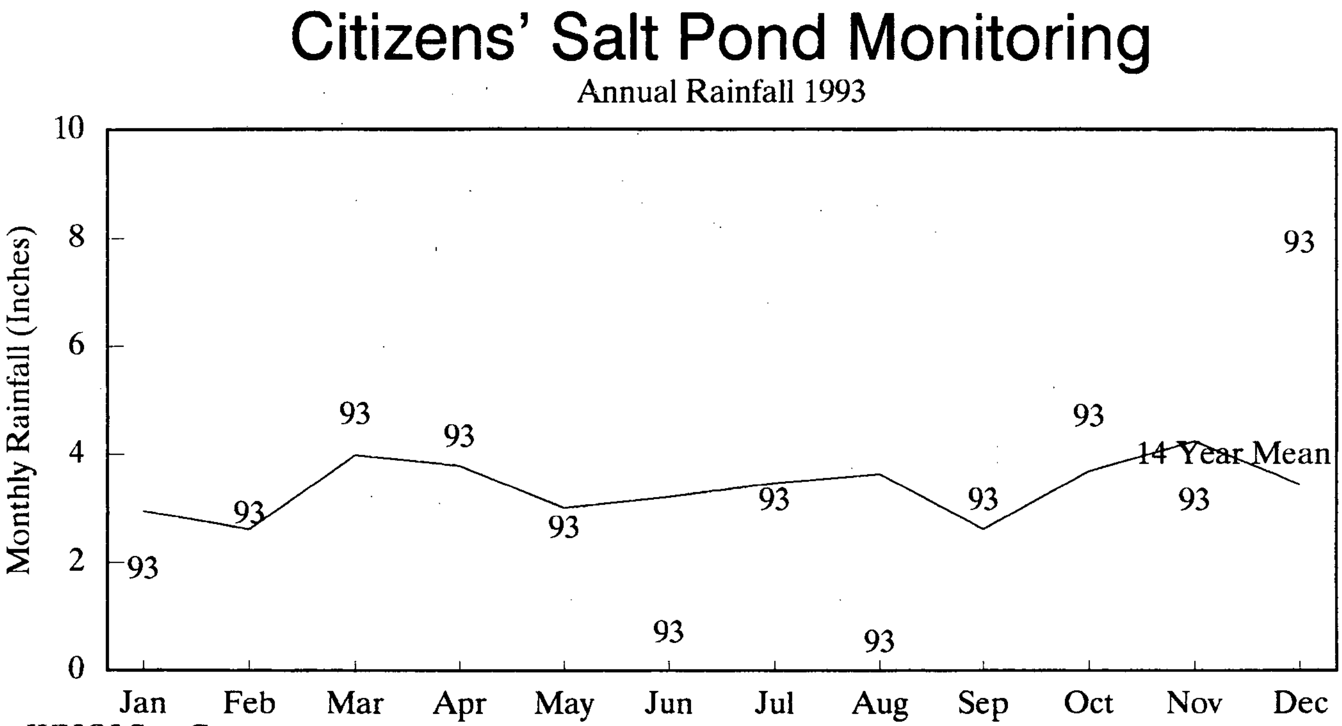


WHOI Sea Grant Pond Watchers
Arrows indicate 1993 pond samplings.

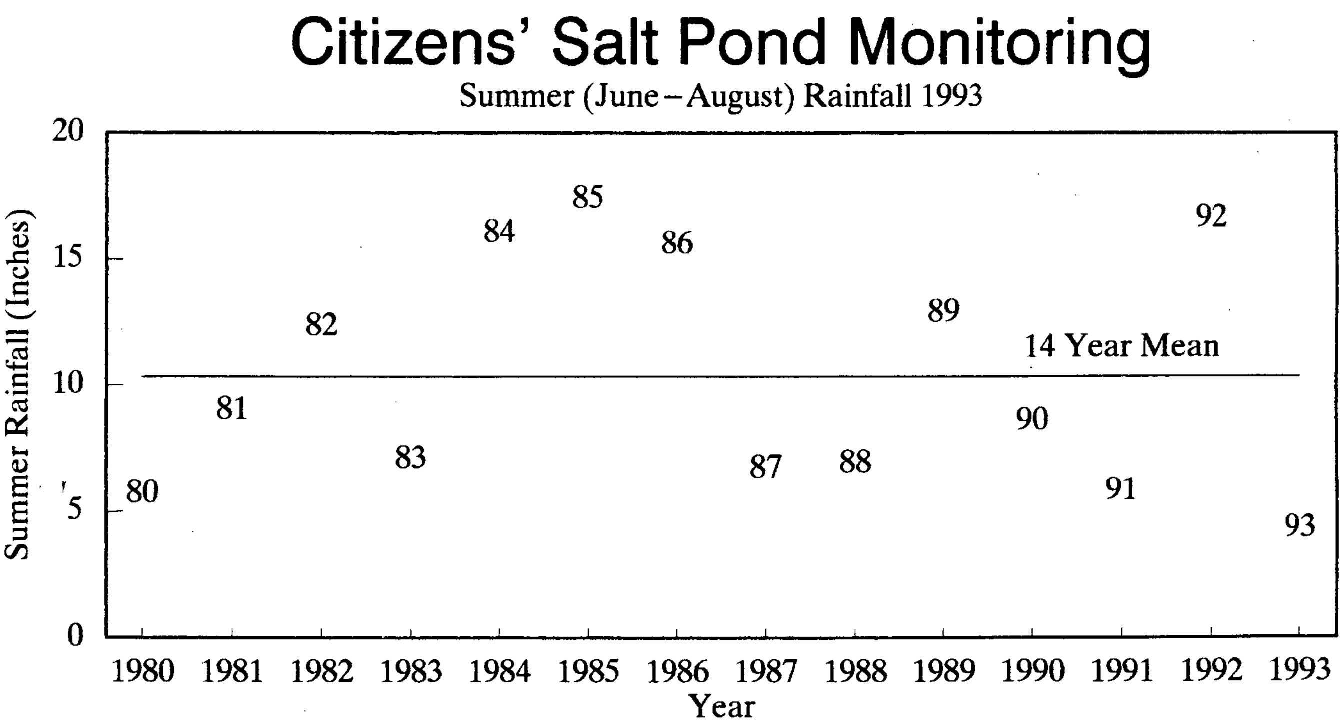
Figure 5.

Summer rainfall in 1993 was exceptionally low, following on the exceptionally high inputs in 1992. In fact the total rainfall for the summer season (June-August) was the lowest of the past 14 years (Figure 6), with both June and August yielding virtually no precipitation. The variable effects of storms on oxygen conditions may be related to the magnitude of the event with: 1) moderate storm/rainfall events serving to briefly reduce photosynthesis (oxygen production) and stratify the pond (via freshwater inflow) causing bottom water oxygen depletions; and 2) high and prolonged storm and rain activity improving oxygen balance by increased flushing of ponds due to massive freshwater inflows coupled with lower water temperatures from the decreased insolation causing a reduction in the rate of oxygen uptake. Support for the effect of moderate storm effects and low oxygen conditions has been found in previous years. Partial support for the latter mechanism is seen in 1992 where the water temperatures were unusually cool, significantly lower than the long-term average throughout August 1992, presumably due to the lower insolation during this period. This lower temperature would have a significant effect upon oxygen uptake during the most critical period for pond oxygen depletion. We will continue our investigation of the relationships between meteorological events and pond water quality to better understand both the frequency of low oxygen events and to facilitate water quality evaluations in light of short-term effects of stochastic events. Given the variety of factors involved in controlling watercolumn oxygen levels and they shifting importance from year to year, it is likely that only through long term analysis will the issue be fully elucidated.

Green Pond: Green Pond was one of the initial three ponds selected for study in 1987 due to concerns that its water quality was declining from increasing nutrient loading to its watershed, the increased loading being the result of expansion of the developed land area and use of on-site septic disposal of wastewater within the pond's zone of contribution. We have been following a possible decline in oxygen minima and increasing nitrogen levels to gage this effect. The upper reaches of Green Pond



WHOI Sea Grant
Total annual rainfall about 14 yr average (1980–93).



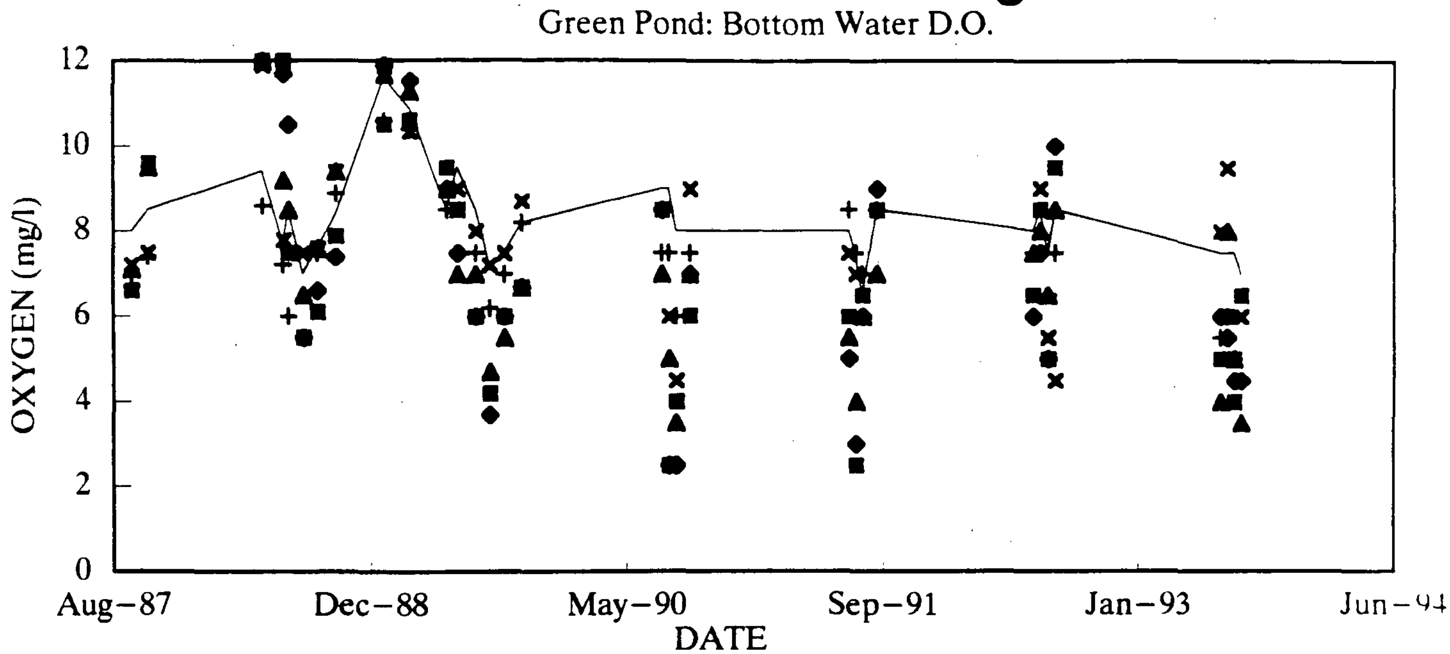
WHOI Sea Grant
Total annual rainfall about 14 yr average.

Figure 6.

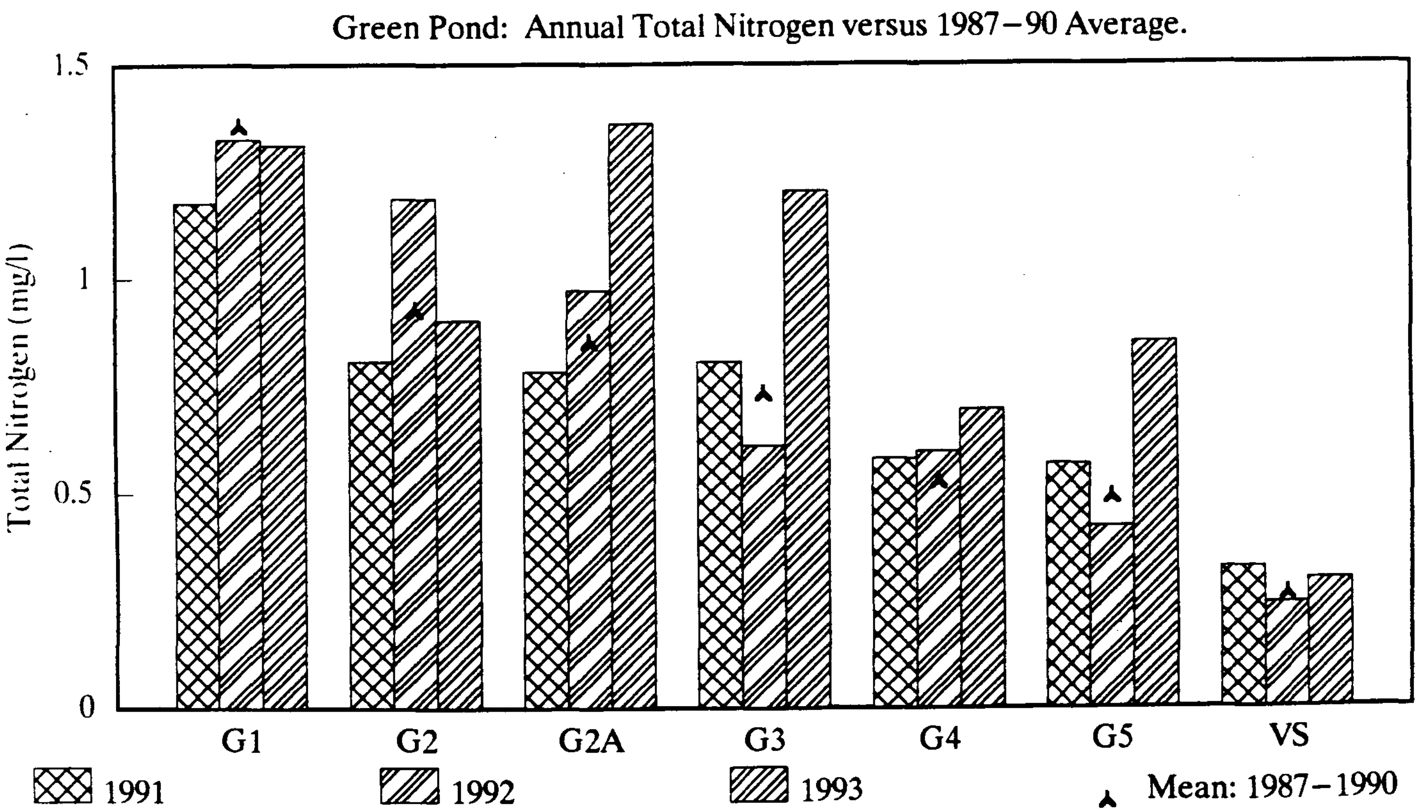
have exhibited high nitrogen levels, exceeding 0.75 mg/l and low oxygen events, less than 4 mg/l for several years, similar to the upper portions of most of the ponds. In contrast, the lower reaches of the Green Pond, closest to the inlet, had been maintaining moderately good water quality (Figure 7). The concern over potential declines in ecological health of Green Pond have not focussed on further declines in the uppermost (already degraded) regions but on the mid-region (Station 4). It is the mid-region where the transition from low to high water quality occurs. Increased nutrient loading causes the low water quality region to expand with the effect that the zone of high impact appears to move down the pond. Since the level of nutrient loading has been increasing, partially due to the long travel time for groundwater to discharge new nutrient sources to the pond waters, the effects may not yet be fully developed. Another factor is the possible sedimentation of the inlet which, to the extent that tidal exchange has become increasingly restricted (yet undocumented), would cause increases in pond nitrogen levels. For the past few years it appeared that Green Pond Station 4 (above the bridge) was transiting from the water quality of the lower pond to be more like the upper pond system. The difference now appears to be "real" with this area of the pond experiencing low oxygen events and an upshifting of mean nitrogen levels from the 0.32-0.5 mg/l designation to the 0.5-0.75 mg/l level (Figure 8). The after effects of Hurricane Bob in late 1991 and the lower temperatures in 1992 may be responsible for the cessation of the decline observed in 1992 but by 1993 conditions were following the longer term trend established at the start of the study (Figure 7). It now appears that conditions have worsened within Green Pond and that the area of low water quality is expanding down the axis of the pond.

Management: We have not yet completed the nutrient balance and circulation studies for Green Pond required for completion of a pond management plan. We have, however, documented the eutrophic nature of the system from our survey of fish and epibenthic invertebrates in 1991 and in 1993 with measured rates of phytoplankton production in the ponds upper and lower regions and a study of

Citizens' Salt Pond Monitoring: 1987 - 93



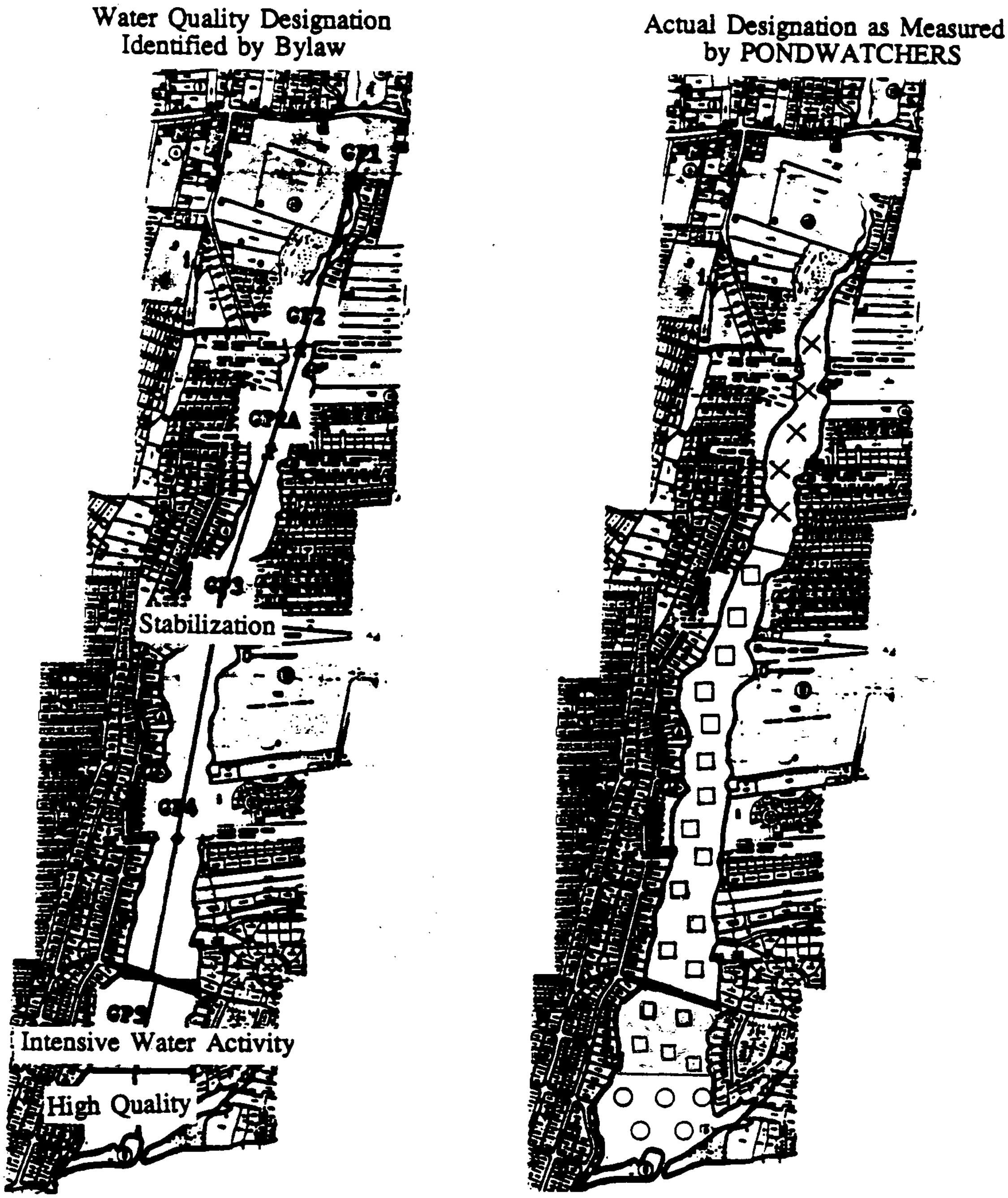
B.L. Howes, WHOI Sea Grant
Major Storms in August 1992.



Annual averages, N=4.

Figure 7.

Green Pond station locations and Water Quality Designation as identified by Coastal Pond Overlay Bylaw (adopted by Falmouth Town Meeting, April 1988) and actual designations according to the Bylaw as measured by Falmouth Pondwatchers.



"Critical Eutrophic Levels" as designated by Coastal Pond Overlay Bylaw
(Total Nitrogen as Average Over Year)

> 0.75 mg/l	= Above Highest "Critical Eutrophic Levels"	×
0.5 - 0.75 mg/l	= Intensive Water Activity Area	□
0.32 - 0.5 mg/l	= Stabilization Area	○
< 0.32 mg/l	= High Quality Area	

Figure 8.

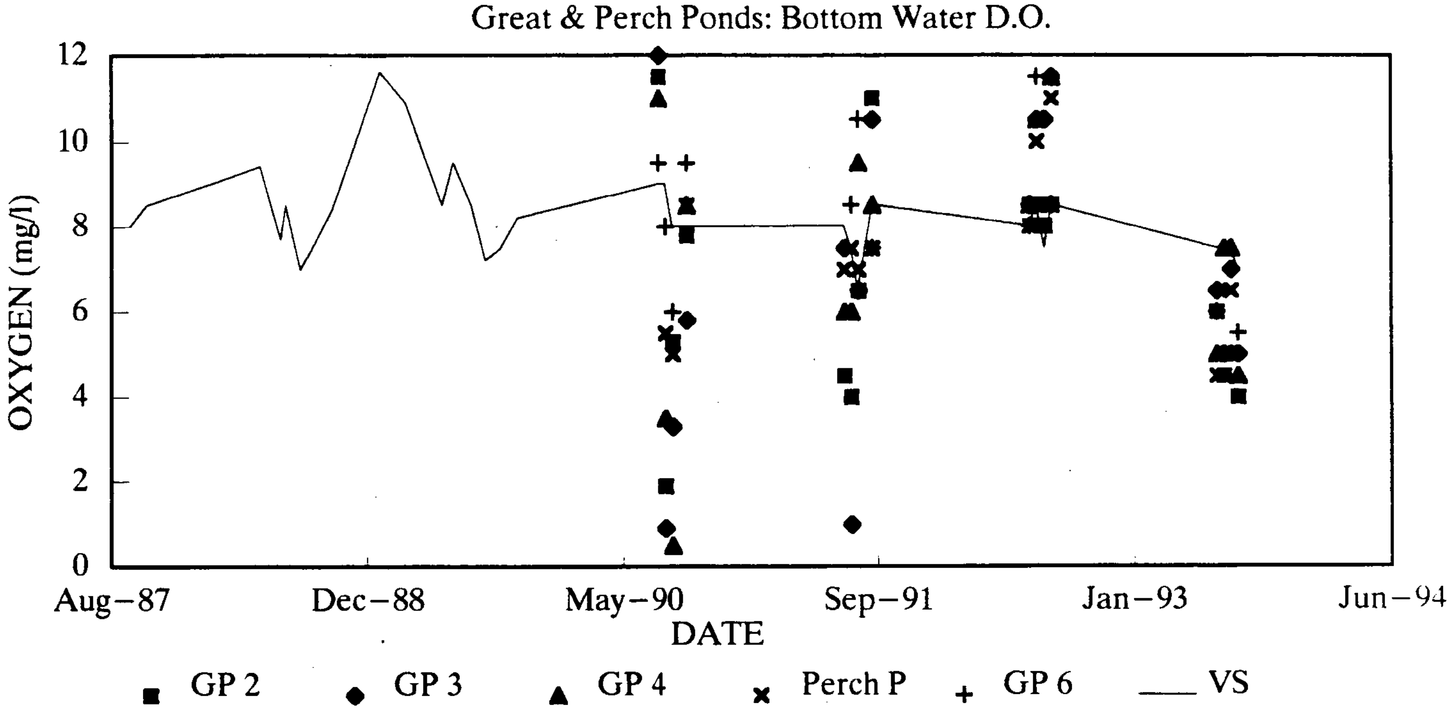
watercolumn and sediment oxygen consumption rates during the summer. The productivity studies revealed exceedingly high rates of phytoplankton production consistent with the high rates of measured water column oxygen uptake by respiration in the dark and the frequent low oxygen events. The animal survey indicated very limited populations in the upper reaches also consistent with the periodic low oxygen events. In contrast, the sediment studies revealed a somewhat surprising result. The lower reaches had many times the oxygen consumption rate of the upper reaches. In examining this further it was ascertained that, in general, the plankton production in the upper reaches of all of the elongated or "finger" ponds was being deposited to the sediments of the lower reaches of the ponds or was being exported out to Vineyard Sound through the inlets. The extent of the partitioning of this deposition versus export ultimately controlling the sediment oxygen demand and effecting the watercolumn oxygen status. The bridge across the lower portion of Green Pond appears to be affecting this partitioning. The existing bridge prevents the free flow of water within the lower pond (between stations 4 and 5) because it only allows water to flow under the center section, the approaches being impermeable (for bridge location see map Figure 8). It appears that increased organic matter settling is occurring in the up and down pond diminished circulation regions associated with these approaches and that these regions have the highest oxygen demand of the pond's sediments. It is these oxygen demand "hot spots" which are likely contributing to some of the water quality declines of the lower pond. While the ultimate solution to Green Pond's water quality requires either a decrease in the nutrient loading from the watershed or an increase in the rate of export of nutrients through the inlet (most likely both), a partial improvement may be affected through improved circulation in the lower pond. As part of our work in 1994 we will be investigating the extent to which creating small flows through breaches in the bridge approaches will help to maintain the organic matter in suspension that is currently being deposited and facilitate its export to Vineyard Sound (which has a exceedingly high capacity to assimilate these nutrients). Since the bridge is soon to be replaced and the approaches refurbished potential breaches of the approaches if they will enhance the pond's water quality are a practical reality. In addition, if this water quality improvement task is added to the bridge work it will be performed at nominal cost and should not affect the construction schedule. The Pondwatch Program has been working with various town departments, the state agencies and Reps. Turkington and Cahir on this project. It should be stressed that this will not solve Green Pond's water quality problems but if it appears that it will return the circulation to a less impacted form and enhance nutrient export, it may be an important component of future efforts.

Great and Perch Ponds: The Great/Perch Pond system, like Green Pond, exhibited much higher oxygen levels in 1992 but by 1993 conditions were similar to 1991 (although not as bad as 1990). Also like Green Pond, the mid-region of Great Pond (Station 3) showed a parallel single season change in lowered nitrogen levels (Figure 9). The effect of this single year improvement is likely to be small. Its cause is not completely accounted for but increased flushing of the pond due to the high freshwater discharge in 1992 and reports of inlet scouring resulting from Hurricane Bob (1991) are a likely partial factors. Great and Perch Ponds exhibited only moderate water quality in 1993. These interannual differences indicate the potential for erroneous conclusions about the state of a Pond from a single season study.

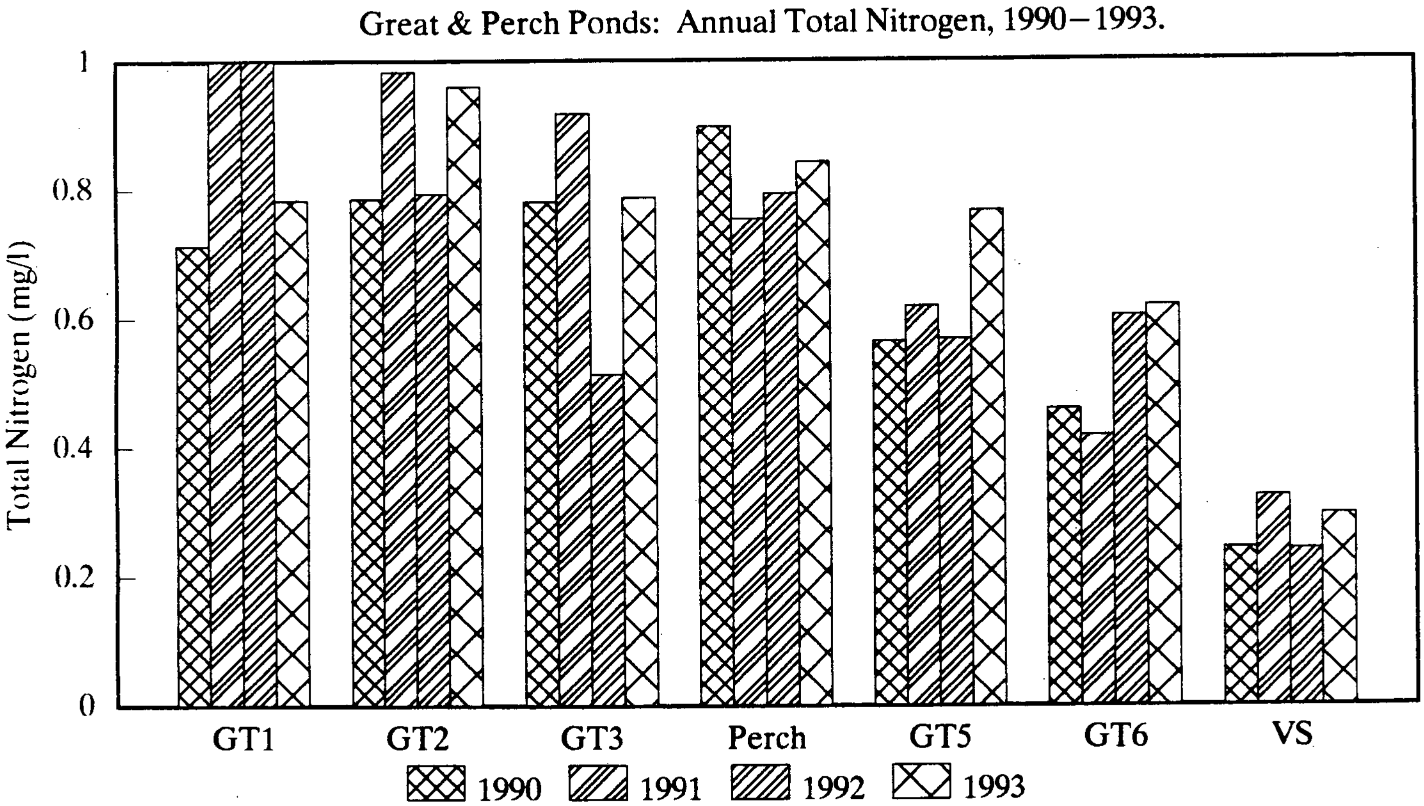
The 1992 nitrogen levels of the Great/Perch Pond system are all above the levels specified in the Nutrient Bylaw (Figure 10). As in Green Pond the upper reaches had total nitrogen levels in excess of 0.75 mg/l and almost 2/3 of the pond area was above 0.5 mg/l (Figure 11).

Management: We only began study of the Great and Perch Pond system in 1990. While the system has moderate water quality overall, the upper regions were exhibiting the negative impacts of eutrophication in 1990. The high degree of environmental variability over the past 4 years has limited our development of management options, although we continue to gather information toward that goal.

Citizens' Salt Pond Monitoring: 1987 – 93



B.L. Howes, WHOI Sea Grant
Hurricane Bob: August 1991



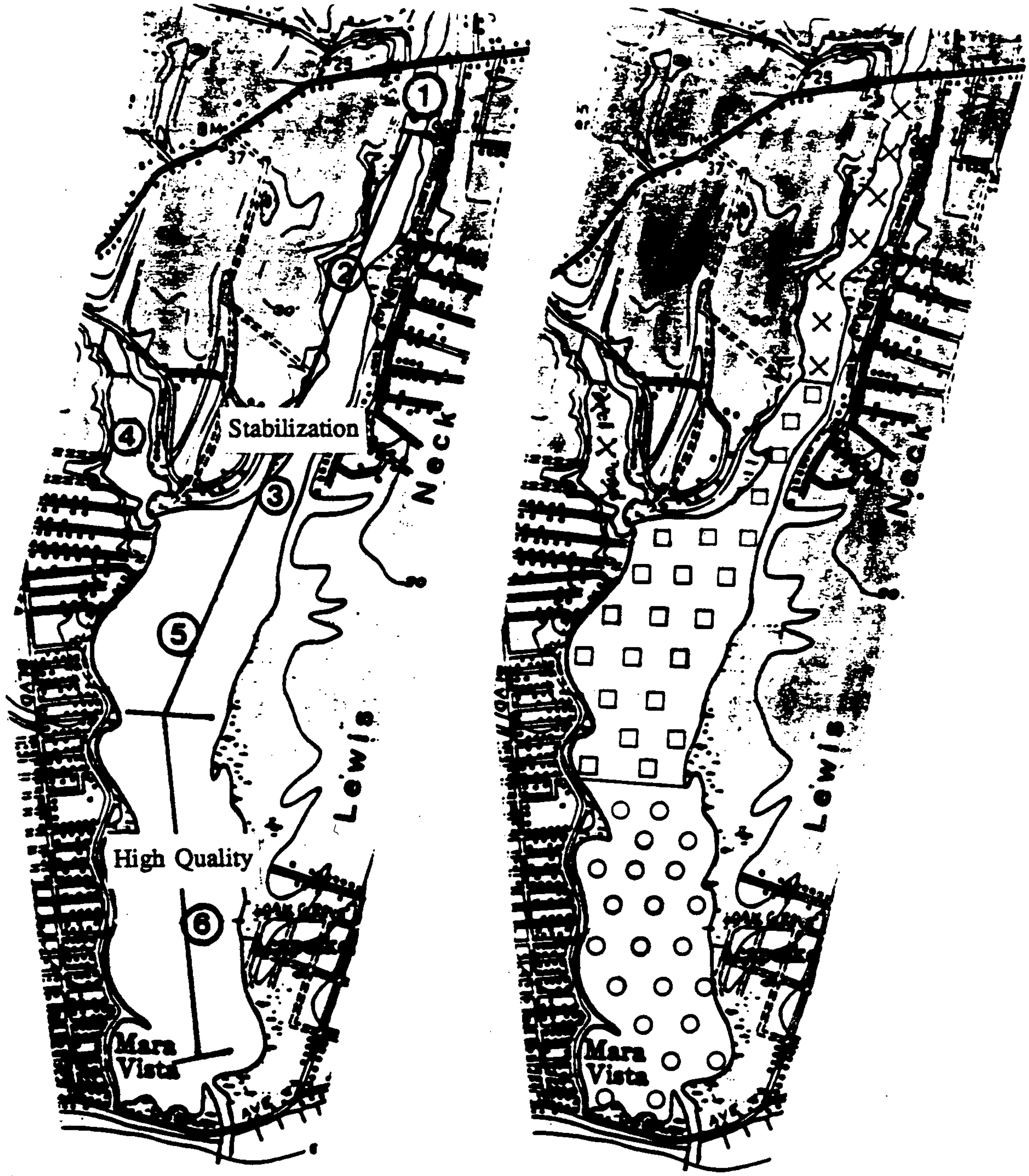
Annual averages, N=4.

Figure 9.

Great Pond station locations and Water Quality Designation as identified by Coastal Pond Overlay Bylaw (adopted by Falmouth Town Meeting, April 1988) and actual designations according to the Bylaw as measured by Falmouth Pondwatchers.

Water Quality Designation Identified by Bylaw

Actual Designation as Measured by PONDWATCHERS



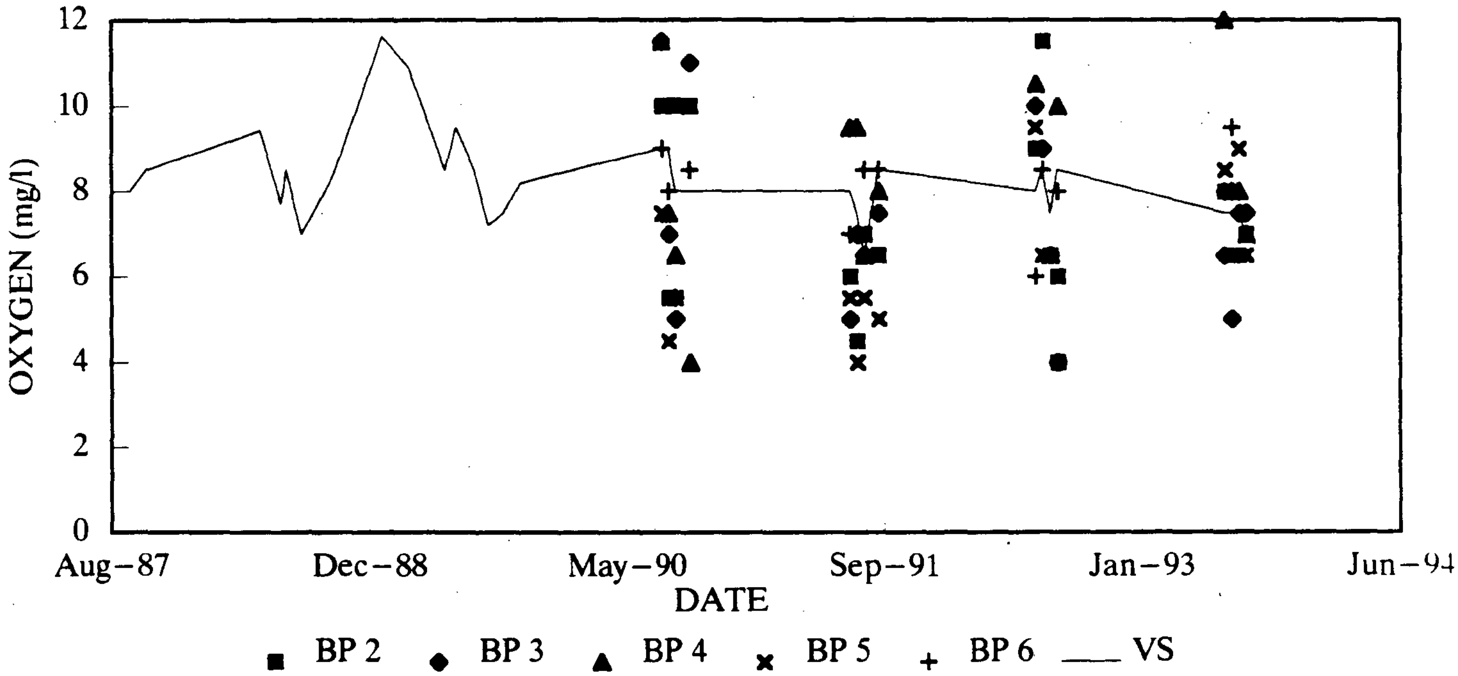
"Critical Eutrophic Levels" as designated by Coastal Pond Overlay Bylaw (Total Nitrogen as Average Over Year)

> 0.75 mg/l	= Above Highest "Critical Eutrophic Levels"	×
0.5 - 0.75 mg/l	= Intensive Water Activity Area	□
0.32 - 0.5 mg/l	= Stabilization Area	○
< 0.32 mg/l	= High Quality Area	

Figure 10.

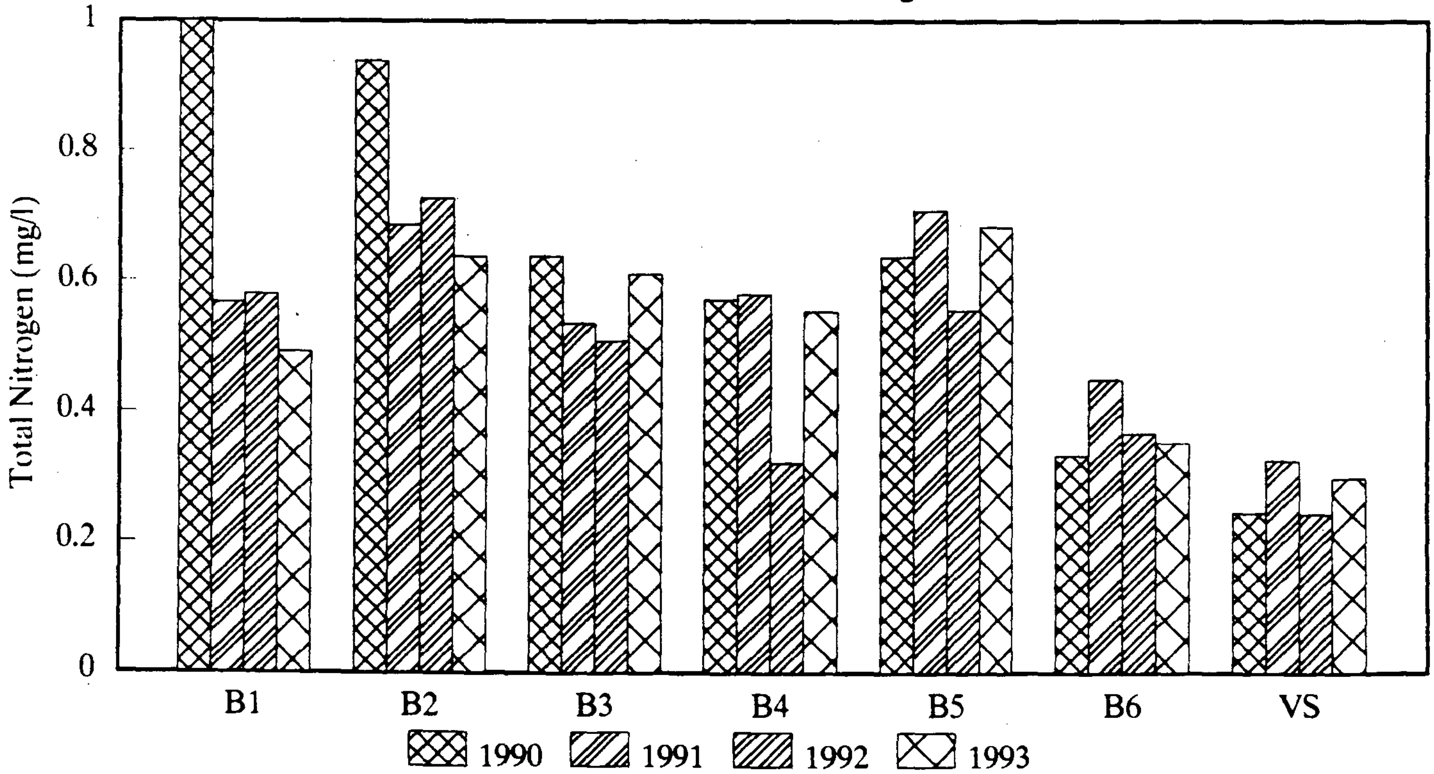
Citizens' Salt Pond Monitoring: 1987 – 93

Bournes Pond: Bottom Water D.O.



B.L. Howes, WHOI Sea Grant
Major Storms in August 1992.

Bournes Pond: Annual Total Nitrogen, 1990–1993.



Annual averages. N=4.

Figure 11.

However, for the Ponds on Falmouth's southern shore Great Pond remains one of the healthier systems overall.

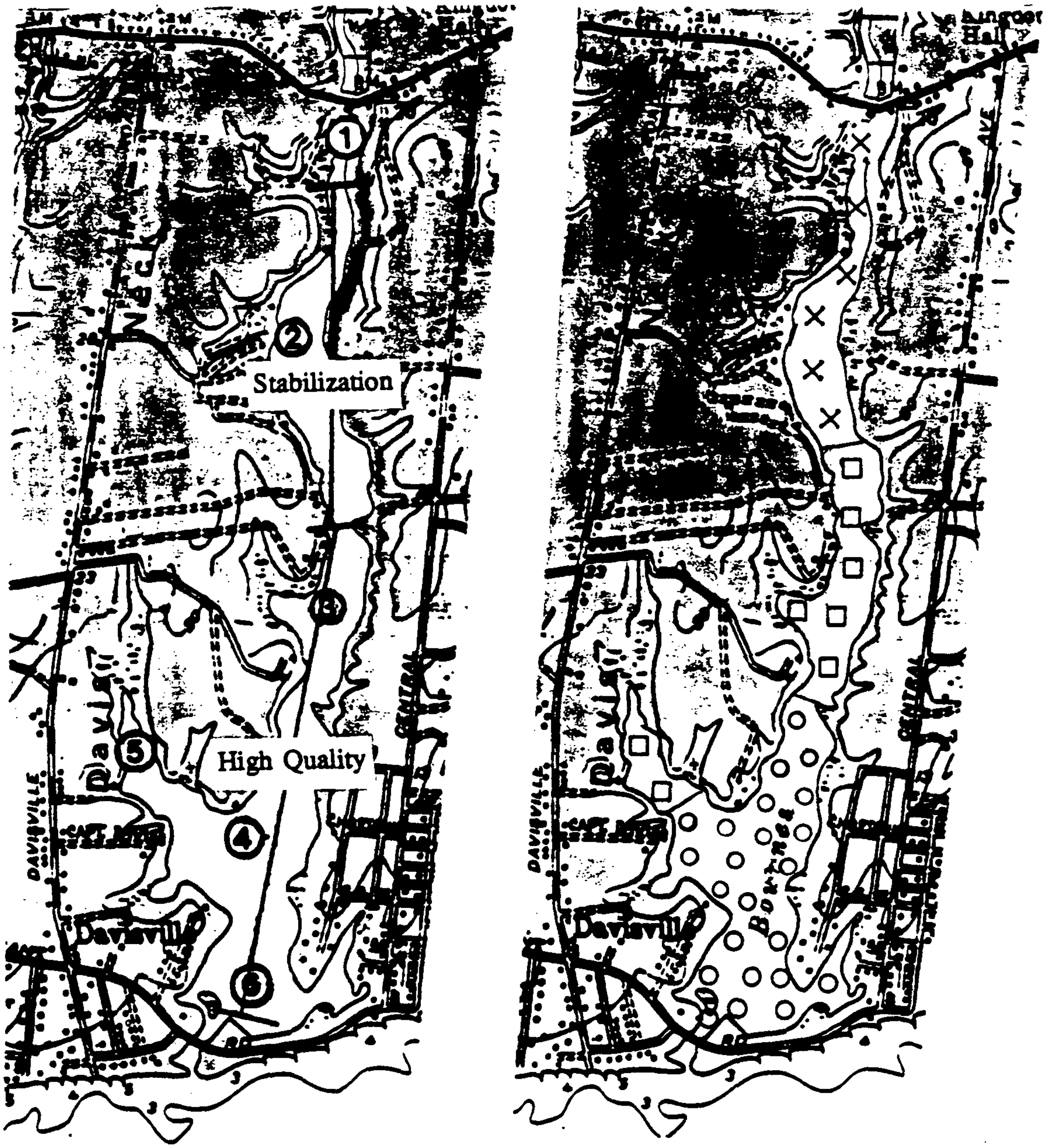
Bournes Pond: Bournes Pond is physically very similar to Great Pond and showed trends almost identical to Great Pond both in 1992 and earlier years. As in Great Pond, the mid-pond stations exhibited lower total nitrogen levels in 1991-92 but have returned to earlier levels in 1993 (Figure 11). Oxygen levels are also returning to earlier conditions. However, unlike the Great/Perch Pond system, Bournes Pond's low oxygen events rarely reach 4 mg/l yielding the best habitat conditions of the southern shore's ponds. Similar to all of the elongate ponds the lowest oxygen levels are consistently found in the upper reaches. It appears that the upper reaches of Bournes, Great and Green Ponds function as similar systems, all experience high nutrient levels and low oxygen events (in some years); the key factor determining the extent of low water quality appears to be related to the distance from a main water body. For Green Pond the main high quality water source is Vineyard Sound, while for the upper reaches of Great and Bournes Ponds it appears to be the main pond basin. The increased distance is related to the ability of water exchange in the upper reaches to transport the nutrient load to open waters. Nutrient loading remains the ultimate source of water quality problems with circulation determining the magnitude of the impact.

As in Great Pond, all of Bournes Pond is above the nitrogen levels specified by the Nutrient Bylaw (Figure 12). Similarly, the mid-pond station showed a net reduction in nitrogen levels, changing the designation from 0.5-0.75 mg/l to 0.32-0.5 mg/l. The duration and causes of this improvement are probably the same as stated above for Great Pond.

Management: Bournes Pond is, at present, unique among the ponds in that it has already undergone major modification to improve its health. The remediation, which predates the Pondwatch Program, is a major focus of study since the effectiveness of the inlet redesign has not been ascertained. While

Bournes Pond station locations and Water Quality Designation as identified by Coastal Pond Overlay Bylaw (adopted by Falmouth Town Meeting, April 1988) and actual designations according to the Bylaw as measured by Falmouth Pondwatchers.

Water Quality Designation Identified by Bylaw — Actual Designation as Measured by PONDWATCHERS



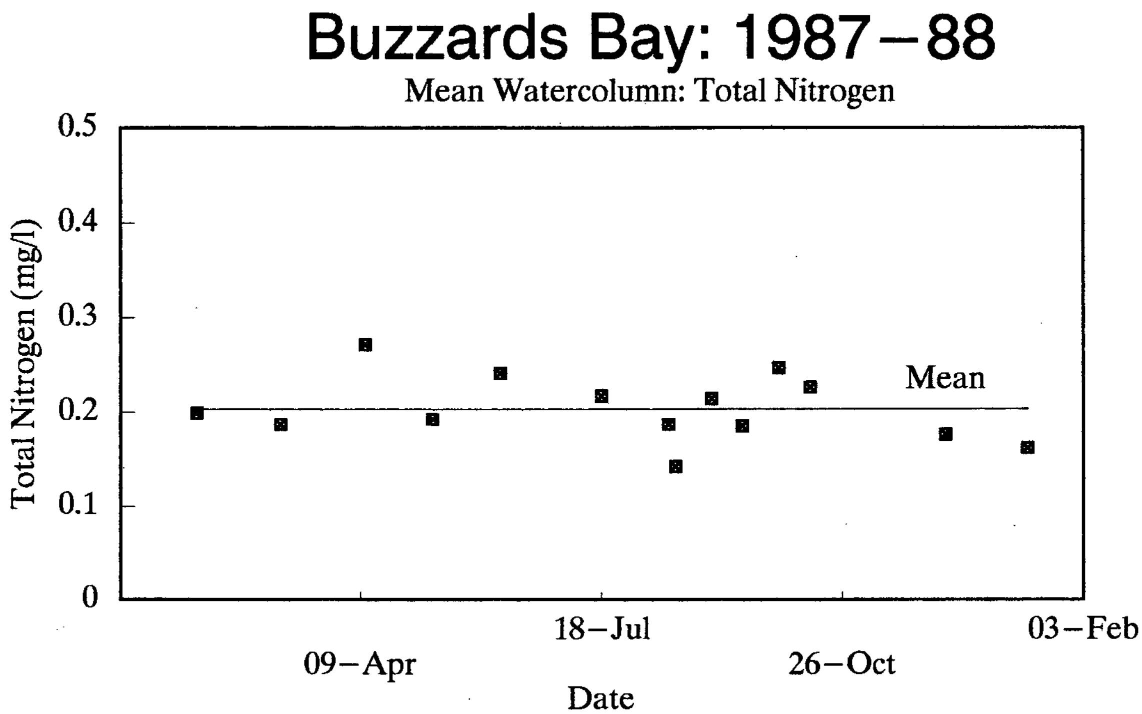
"Critical Eutrophic Levels" as designated by Coastal Pond Overlay Bylaw
(Total Nitrogen as Average Over Year)

> 0.75 mg/l	= Above Highest "Critical Eutrophic Levels"	X
0.5 - 0.75 mg/l	= Intensive Water Activity Area	□
0.32 - 0.5 mg/l	= Stabilization Area	O
< 0.32 mg/l	= High Quality Area	

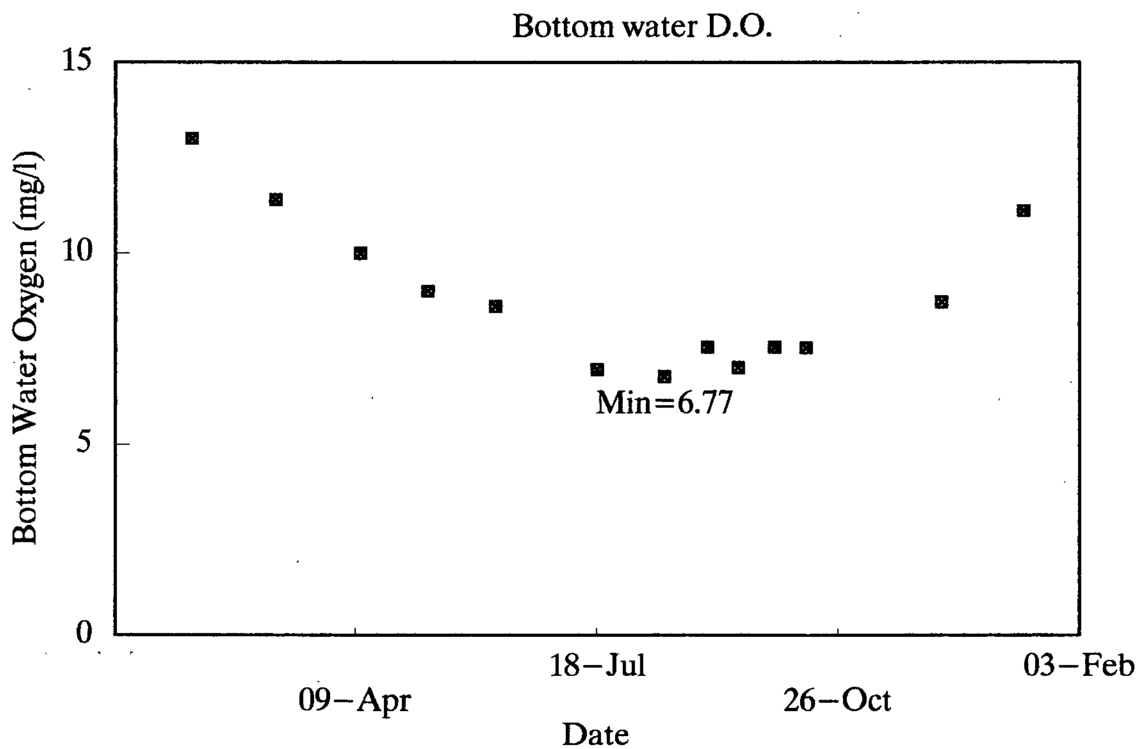
Figure 12.

it appears that conditions within Bournes Pond have improved due directly to the remediation efforts, the quantitative improvement remains largely anecdotal. The value of the Bournes Pond data is more to determine the relative health of the system with its measured nutrient load and tidal exchange. It is likely that if future remediation of the pond is desired that the focus will be limited to reducing inputs. Like the Great/Perch Pond system we are only beginning to develop management options relating to Bournes Pond.

West Falmouth Harbor: West Falmouth Harbor was included in the Citizens' Monitoring Program for the first time in 1992. The harbor is an embayment of Buzzards Bay (See map in Appendix I). Buzzards Bay has a high level of water quality similar to Vineyard Sound with low total nitrogen and high oxygen levels found in previous studies (Figure 13). Buzzards Bay also has a much greater tide range than Vineyard Sound which increases the potential water exchanges with its embayments enhancing their water quality. The high salinities found throughout West Falmouth Harbor are partially due to this high rate of water exchange with Buzzards Bay waters (Figure 4). West Falmouth Harbor currently exhibits high quality waters and a healthy ecosystem. The low nutrient levels (Figure 14) and low level of eutrophication allow light penetration to the bottom allowing eelgrass beds to persist (Figure 3). At present there is no indication of periodic low oxygen in the harbor (Figure 14). Unlike the other five embayments in our study, most of West Falmouth Harbor meets the levels specified by the Nutrient Bylaw and the areas which exceed the limits are still in the 0.32-05. mg/l range (Figure 15). We caution that this is a limited data set from 2 years in which the other systems were showing short-term change. We will continue to monitor this system as it is the likely recipient of the nutrient plume from the Falmouth Wastewater Treatment Facility. This plume, if it discharges to the harbor, will effectively double the current nutrient loading to the system with a yet to be determined level of



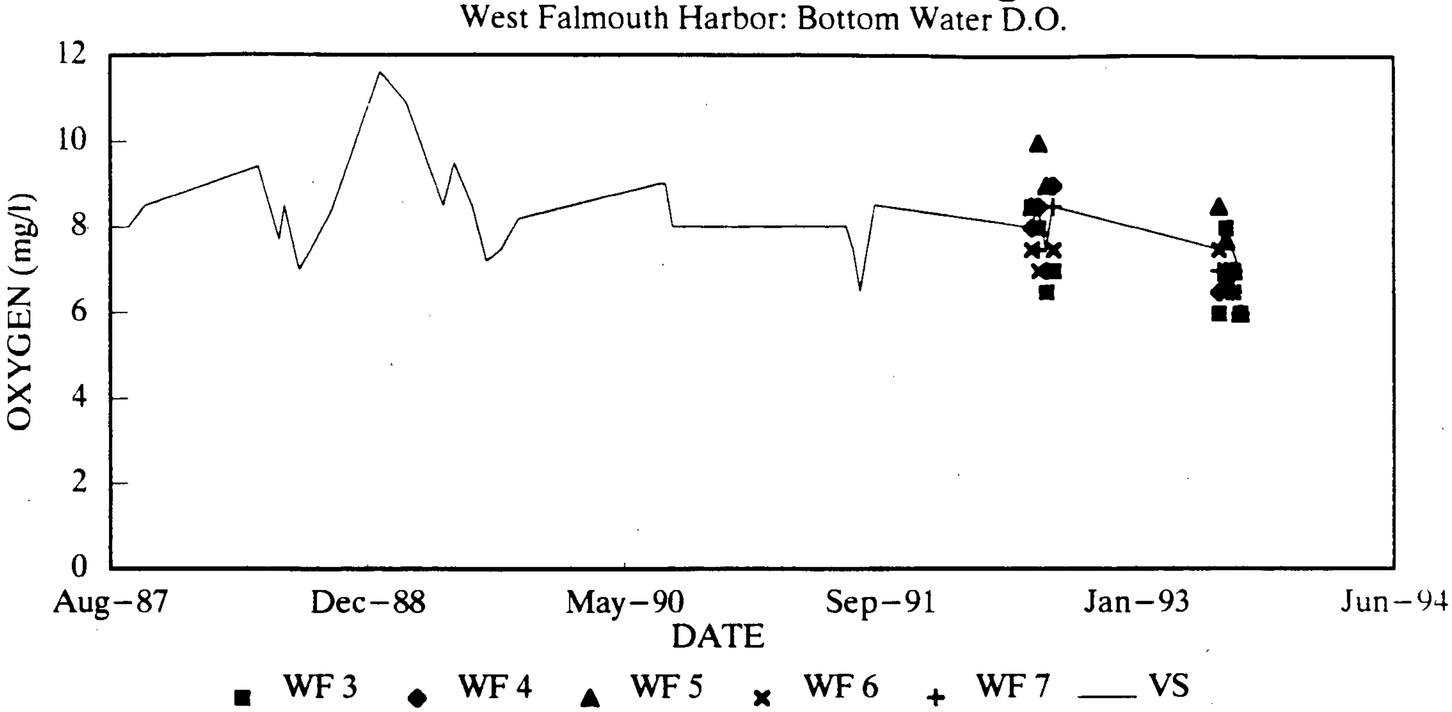
B.L. Howes, WHOI Sea Grant
Source water for West Falmouth Harbor.



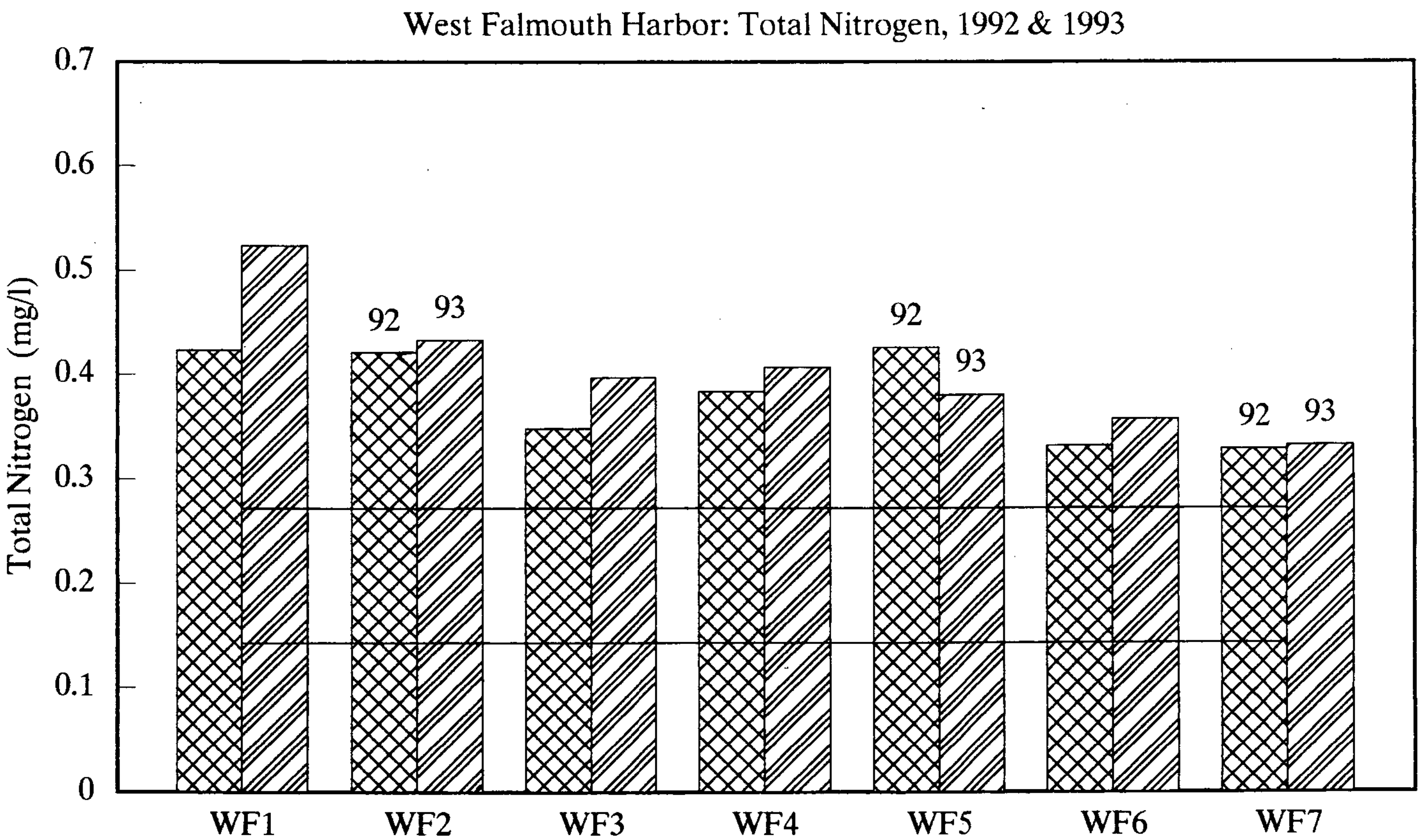
B.L. Howes, WHOI Sea Grant

Figure 13.

Citizens' Salt Pond Monitoring: 1987 - 93



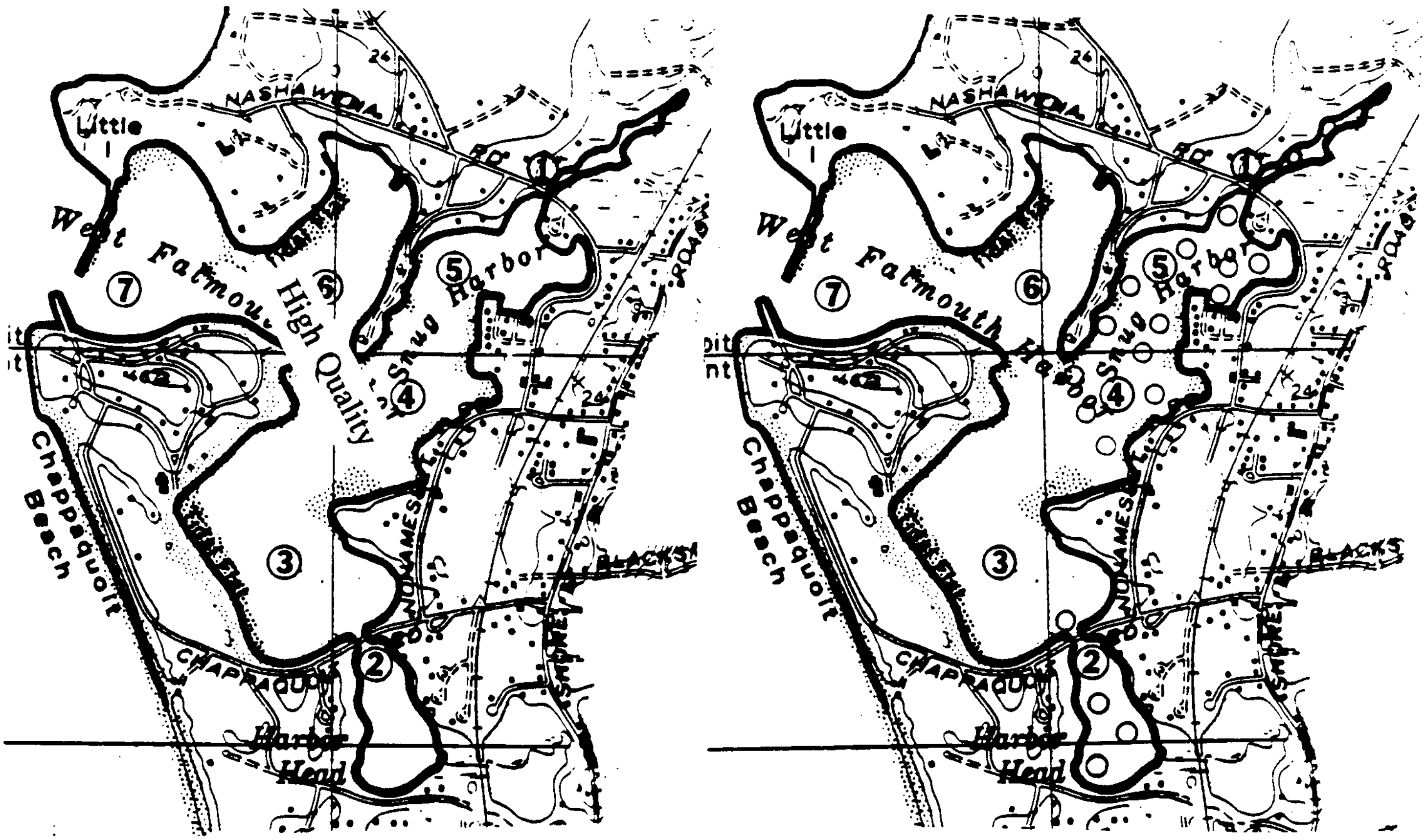
B.L. Howes, WHOI Sea Grant
Major Storms in August 1992.



—— Lines represent Maximum and Minimum Buzzards Bay Values.
Means of Both Pondwatcher and Buzzards Bay Monitoring Data.

Figure 14.

West Falmouth Harbor station locations and Water Quality Designation as identified by Coastal Pond Overlay Bylaw (adopted by Falmouth Town Meeting, April 1988) and actual designations according to the Bylaw as measured by Falmouth Pondwatchers.



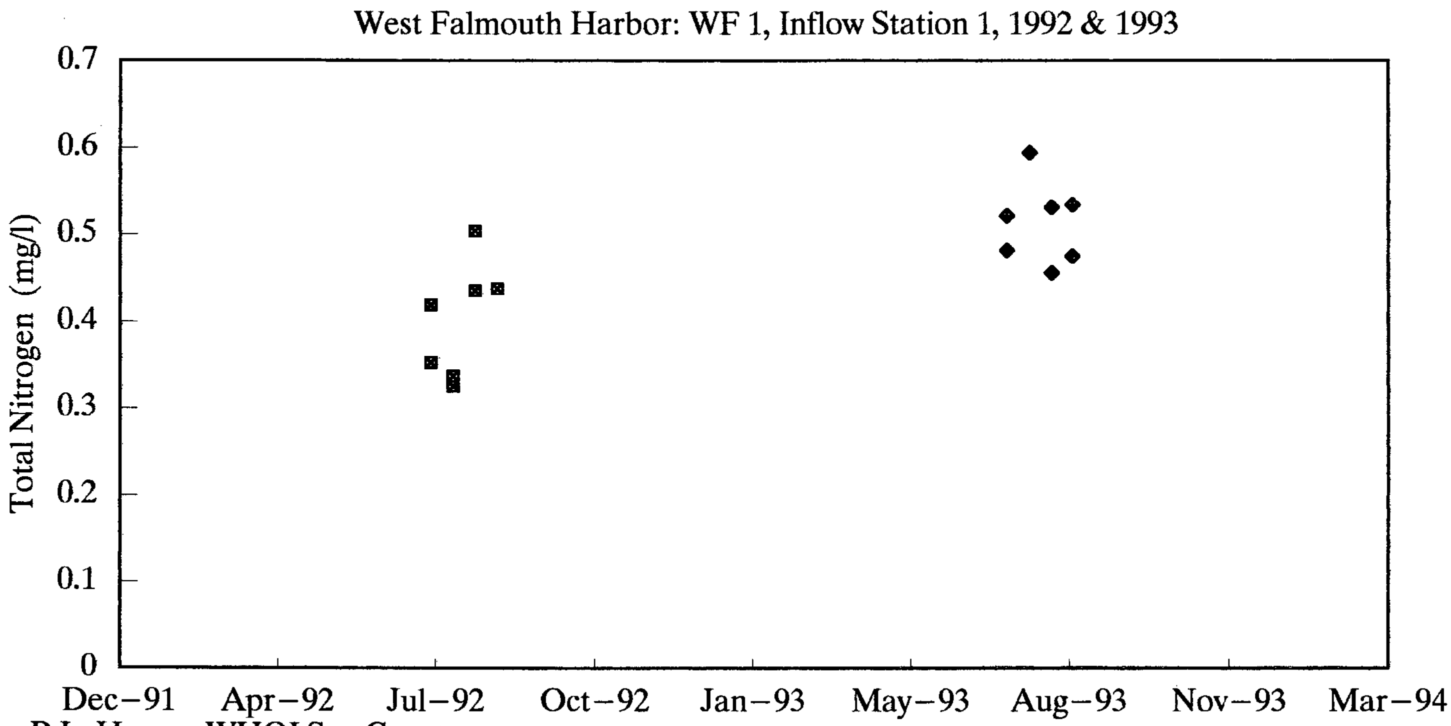
"Critical Eutrophic Levels" as designated by Coastal Pond Overlay Bylaw
(Total Nitrogen as Average Over Year)

> 0.75 mg/l	= Above Highest "Critical Eutrophic Levels"	×
0.5 - 0.75 mg/l	= Intensive Water Activity Area	□
0.32 - 0.5 mg/l	= Stabilization Area	○
< 0.32 mg/l	= High Quality Area	

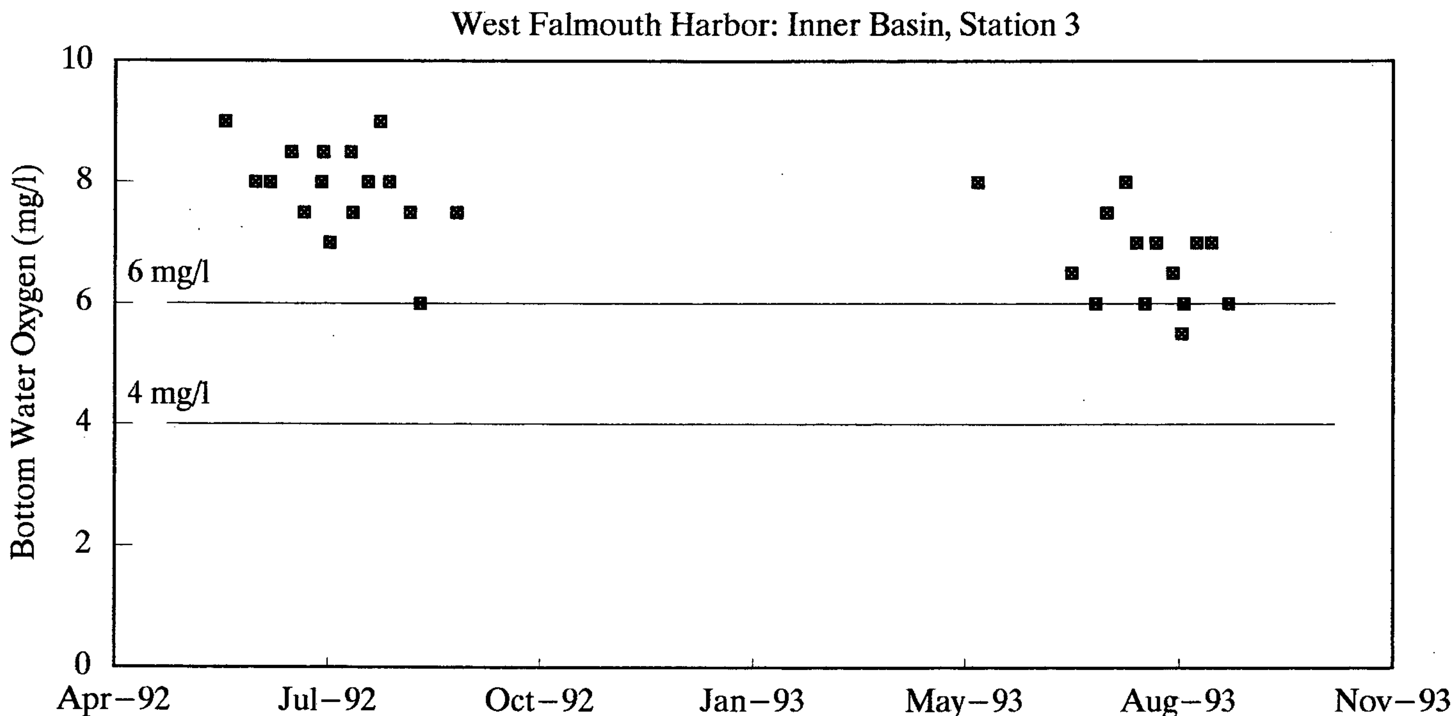
Figure 15.

impact. The detailed circulation study presently being contracted by the Town (to be performed in July 1994) should help us to better predict the level of nutrient related stress expected from the interception of this plume. As part of the Pondwatch Program we have assessed the current and future nutrient loading to West Falmouth Harbor. As part of a special project in 1994 we will be determining the susceptibility of the Harbor waters to undergo stratification, an essential part of determining the assimilative capacity of a system. In addition, we continue to monitor the arrival of the nutrient plume. Our station (#1) is placed (Figure 15) at the outlet from the likely plume catchment area for the Harbor proper. Analysis of this site in the 2 years of study is interesting but requires more data before assessments as to plume arrival can be made. Similarly, analysis of all of the bottom water oxygen data collected by Pondwatch and by the Buzzards Bay Monitoring program at the central inner harbor station (#3) will provide a sensitive indicator of potential nutrient loading effects (Figure 16). It is not possible to draw conclusions as to trends from 2 years of data, however, at present West Falmouth Harbor remains a healthy coastal embayment. The Pondwatch Program will continue to intensify its investigations of the West Falmouth Harbor system relative to the approaching nutrient plume while attempting to refine its estimates of the nutrient assimilative capacity of the Harbor which it began in 1991 (for the Town and Falmouth EDIC). As specified by the Falmouth Planning Office the goal is to predict the potential effects before they become acute and to have management options in hand as they become required.

Oyster Pond: Little and Oyster Ponds are extremely eutrophic and have relatively poor water quality throughout. Both ponds have restricted tidal exchange with resulting fresher waters than the other four embayments (Figure 4). These ponds were selected for the initial study due their obvious water quality problems. Oyster Pond is the most eutrophic of the six embayments (Figure 2), has the highest nitrogen and lowest oxygen levels (Figure 17). The pond has the most restricted inlet which has resulted in its



B.L. Howes, WHOI Sea Grant.
Falmouth Pondwatcher Data Only.

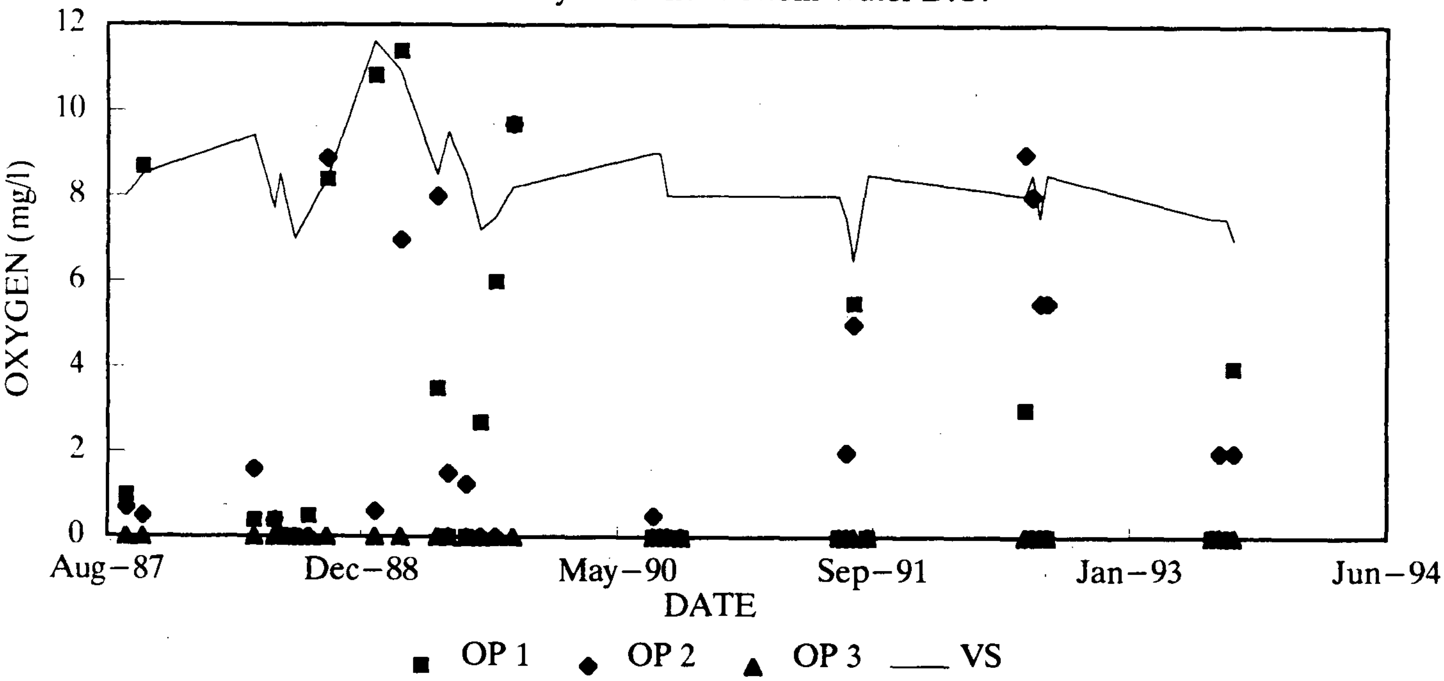


B.L. Howes, WHOI Sea Grant, 1992 & 1993.
Data from both Pondwatch and Buzzards Bay Monitoring Programs.

Figure 16.

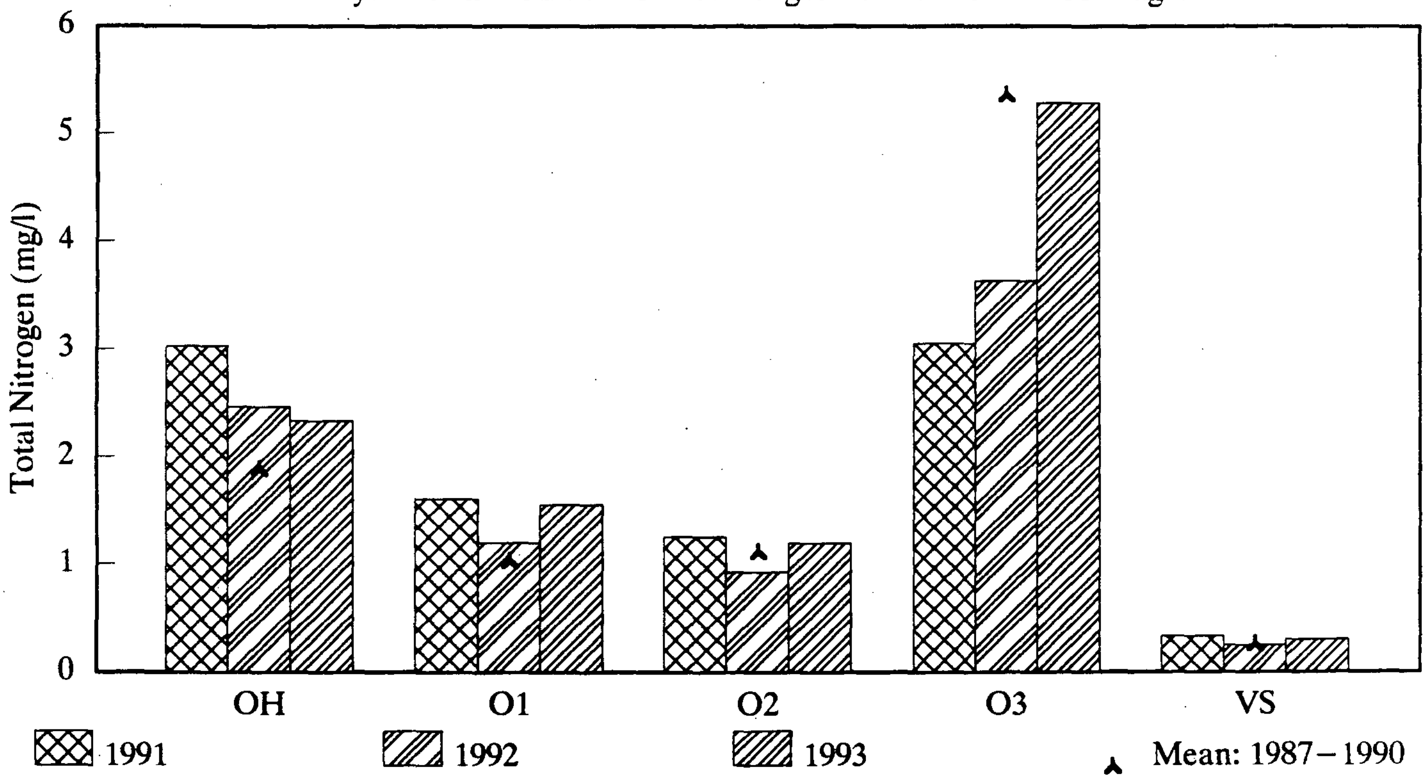
Citizens' Salt Pond Monitoring: 1987 – 93

Oyster Pond: Bottom Water D.O.



B.L. Howes, WHOI Sea Grant
Major Storms in August 1992.

Oyster Pond: Annual Total Nitrogen versus 1987–90 Average.



Annual averages, N=4.

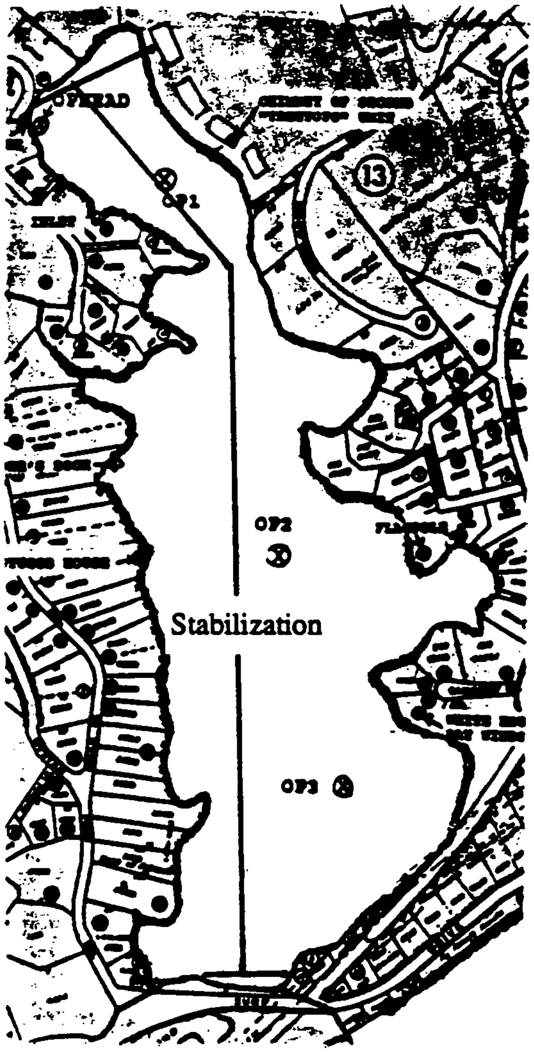
Figure 17.

relatively fresh surface waters (<10 ppt) and retention of plant nutrients. As a result of its inlet, for the past century Oyster Pond has been functioning more like a salt lake than a tidal embayment. All stations in Oyster Pond have mean watercolumn nutrient concentrations above 1 mg/l (Figure 17), well above the bylaw limits (Figure 18). In the initial years of study each of the 3 basins of Oyster Pond were oxic in winter but would become anoxic (zero oxygen) throughout the summer months. In recent years there has been a trend toward periodic oxygen appearance in the 4 meter and 3.25 more inland basins in summer. The main basin (Station 3) has had continuously anoxic bottom waters at least for several decades. The factors underlying the periodic anoxia are related to basin geometry discussed below. The effect of current water quality conditions in Oyster Pond is that almost 60% of the bottom is typically devoid of animal communities.

Management: As stated above, Oyster Pond has summertime oxygen depletions throughout much of its bottom preventing the establishment and growth of animal communities. The effect is that more than half of the pond area is unsuitable for animal and plant habitat. Oyster Pond's current water quality stems from its current nutrient loading, its restricted inlet, and its deep basins. However, most of Oyster Pond's present ecological "problems" result from "natural" processes with nutrient loading being a lesser factor. Simply stated, it is the inability to vertically mix the watercolumn that is the proximate cause of the low oxygen conditions. Oyster Pond has the deepest basins of all of the coastal systems studied (Figure 3). The configuration of these basins make vertical mixing to the bottom difficult. The salinity record of the pond indicates that occasional massive salinity intrusions like Hurricane Bob and during the 1938 hurricane occur. These periodic events and the small daily salt inputs through the inlet coupled with the freshwater inflows have maintained salinity stratification (top less salty-lighter, bottom more salty- heavier) throughout our study. The potential solution to Oyster Pond's oxygen problem must include a mechanism to breakdown the summer salinity-based stratification.

Oyster Pond station locations and Water Quality Designation as identified by Coastal Pond Overlay Bylaw (adopted by Falmouth Town Meeting, April 1988) and actual designations according to the Bylaw as measured by Falmouth Pondwatchers.

Water Quality Designation
Identified by Bylaw



Actual Designation as Measured
by PONDWATCHERS

"Critical Eutrophic Levels" as designated by Coastal Pond Overlay Bylaw
(Total Nitrogen as Average Over Year)

> 0.75 mg/l	= Above Highest "Critical Eutrophic Levels"	X
0.5 - 0.75 mg/l	= Intensive Water Activity Area	□
0.32 - 0.5 mg/l	= Stabilization Area	O
< 0.32 mg/l	= High Quality Area	

Figure 18.

While there is some debate over when the tidal exchange between Oyster Pond and Vineyard Sound first became restricted, it is clear that with the construction of the railroad embankment in 1872 that the current era began. Oyster Pond receives its daily exchange with the Sound via a culvert to the Trunk River. This corridor was altered in the mid 1980's and the culvert replaced with a larger unit prior to the summer of 1990. The current convoluted path forms a natural sediment trap which continually becomes restricted even with continual maintainence. The possibility to open a new entrance to Oyster Pond to increase tidal mixing and potentially make the water column uniformly saline (breaking down salinity stratification) has been proposed. However, in addition to being very costly its success is uncertain given the deep basins, the freshwater flows to the inner regions of the pond and the difficulty in maintaining what would be a relatively long channel between the pond and Vineyard Sound. A more cautious approach with much lower costs and one which could be easily altered would be to build a herring run into Oyster Pond and allow the Trunk River/culvert path to revert to the mid-1980 configuration. The effect would be to create a further freshening of the pond waters which our monitoring data suggests should reduce the oxygen problems throughout most of the pond.

Our conclusion that much of the oxygen problem for Oyster Pond would be removed stems from a re-analysis of our oxygen and salinity data for Station 2 from 1987-1993. It appears that there is a near perfect relationship between the salinity difference from top to bottom of the water column (bottom>top) and the presence or absence of oxygen in the bottom waters. When the salinity difference is small or absent bottom water oxygen levels are generally high, but when the difference is large (>2ppt) bottom waters are anoxic. It is our prediction that with further freshening the surface 3.5 to 4 meters may reach 2-4 ppt within a few years, greatly reducing the stratification potential and encouraging a predominantly oxygenated system. The dramatic difference in utilizable bottom area if this occurs can be gaged by comparing the 1987-1991 summertime anoxic area to that in 1992 (Figure 19). If this can be maintained the available benthic habitat should about double over previous years.

In our study of Oyster Pond it has become clear that much of the concern that the system was changing and traditional fish populations were disappearing was confirmed. Indeed the pond has changed in recent years, the reason however does not appear to be nutrient loading and too little flushing but too much flushing. Prior to alterations to the tidal pathway in the mid-1980's, Oyster Pond was fairly fresh with surface salinities of 2-4 ppt (Figure 20). With the increase in tidal exchange the salinity rose rapidly. It is most likely the salinity change which is responsible for the changing fish and plant populations, as most species living at 2 ppt cannot survive or spawn at 15 to 16 ppt. It was also the enhancement of the salt stratification which most likely resulted in the probable expansion of the summertime anoxic area. The main basin has been anoxic throughout the record most likely due to occasional massive salt intrusions (overwash).

Since most of the citizens abutting Oyster Pond cite the conditions prior to 1980 as a goal for remediation, it seems that the return to the pre-inlet manipulation (1987-88) configuration should accommodate this desire as well. Opening the inlet further would not. The inlet is now naturally reverting, but a herring run should be constructed to maintain low flows and to allow utilization of this traditional natural resource. Monitoring of the pondwaters by the Pondwatch Program (with special efforts by the Oyster Pond members) indicates that a reversion of pond salinities to pre-1987 levels will be rapid once the tidal exchanges cease. In less than 2 years of restriction (since the additional inlet redesign) the salinity has declined to half way between the maximum and pre-alteration levels.

To determine the potential efficacy and time required for a potential salinity based management plan for Oyster Pond, two Pondwatch special projects are planned for the 1994 season. The first is to determine the current volumetric exchange of tidal waters through the existing inlet and continuous recording of pond surface elevation with a stage recorder. The goal is to construct a salinity balance

OYSTER POND, FALMOUTH

Summer Oxygen Distribution

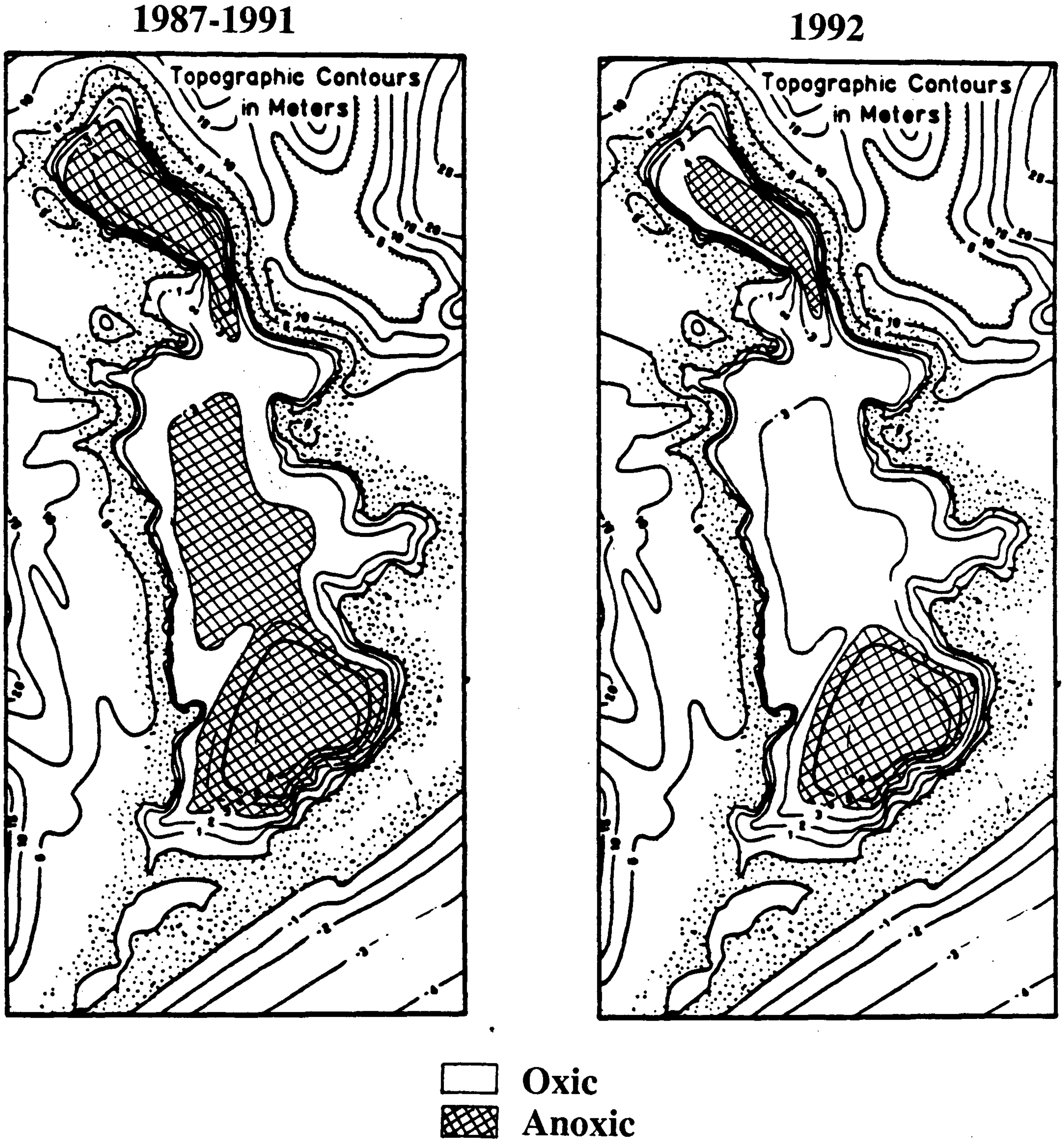


Figure 19.

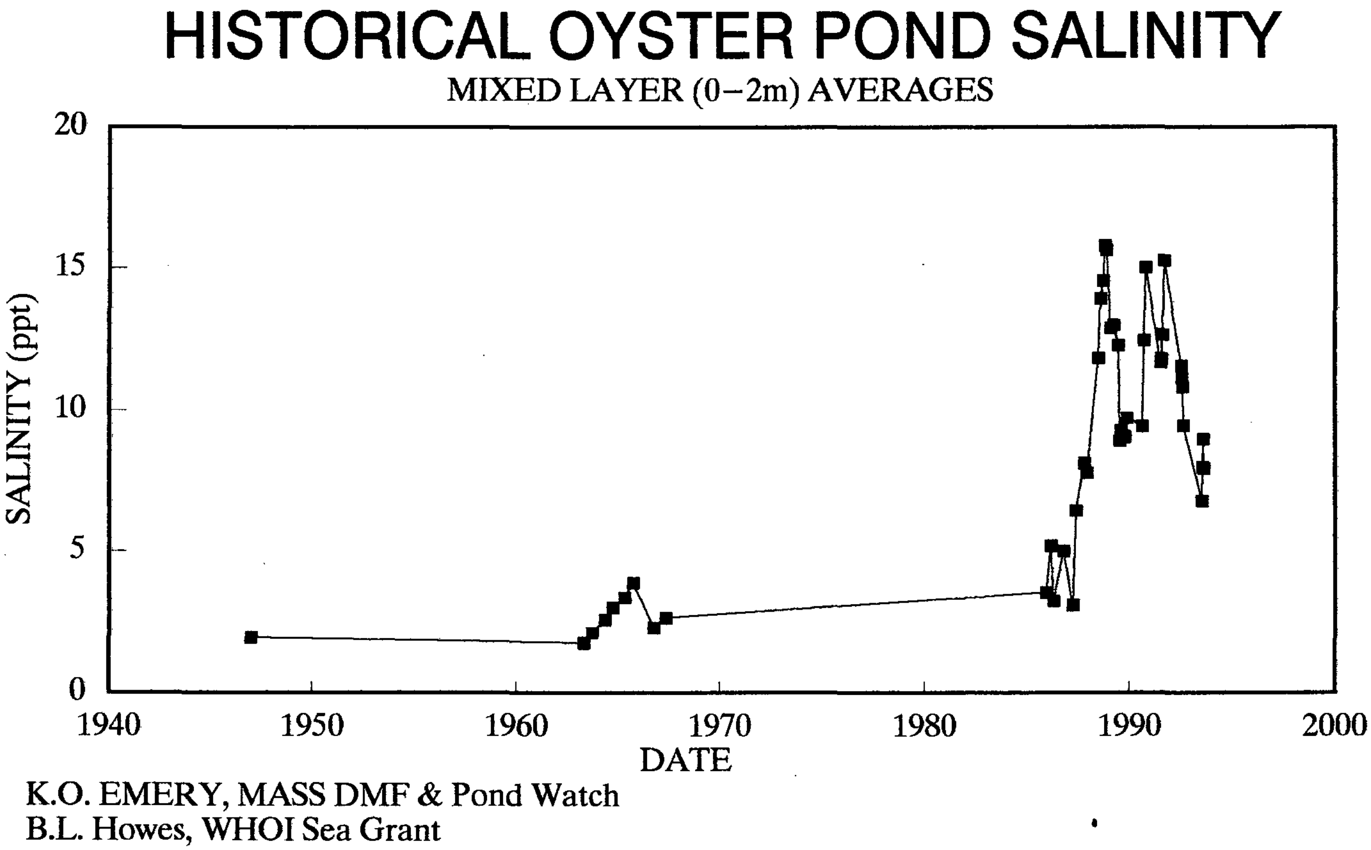

HISTORICAL OYSTER POND SALINITY
MIXED LAYER (0–2m) AVERAGES
SALINITY (ppt)
0
5
10
15
20
1940
1950
1960
1970
1980
1990
2000
DATE
K.O. EMERY, MASS DMF & Pond Watch
B.L. Howes, WHOI Sea Grant

Figure 20.

for the pond and based upon the existing records determine the time required to lower the pond salinity to a long-term level of 2 ppt through freshwater inflows (freshwater inflow estimates will be a refinement of the approach used previously by K.O. Emery). Second, a detailed study of the profile of oxygen in the watercolumn particularly near the sediment surface will be conducted in the innermost 4 meter deep basin. Changes in oxygen levels will be related to watercolumn salinity structure and wind speed and direction. The attempt will be to determine the potential for increased efficiency of wind driven mixing under lower salinity conditions.

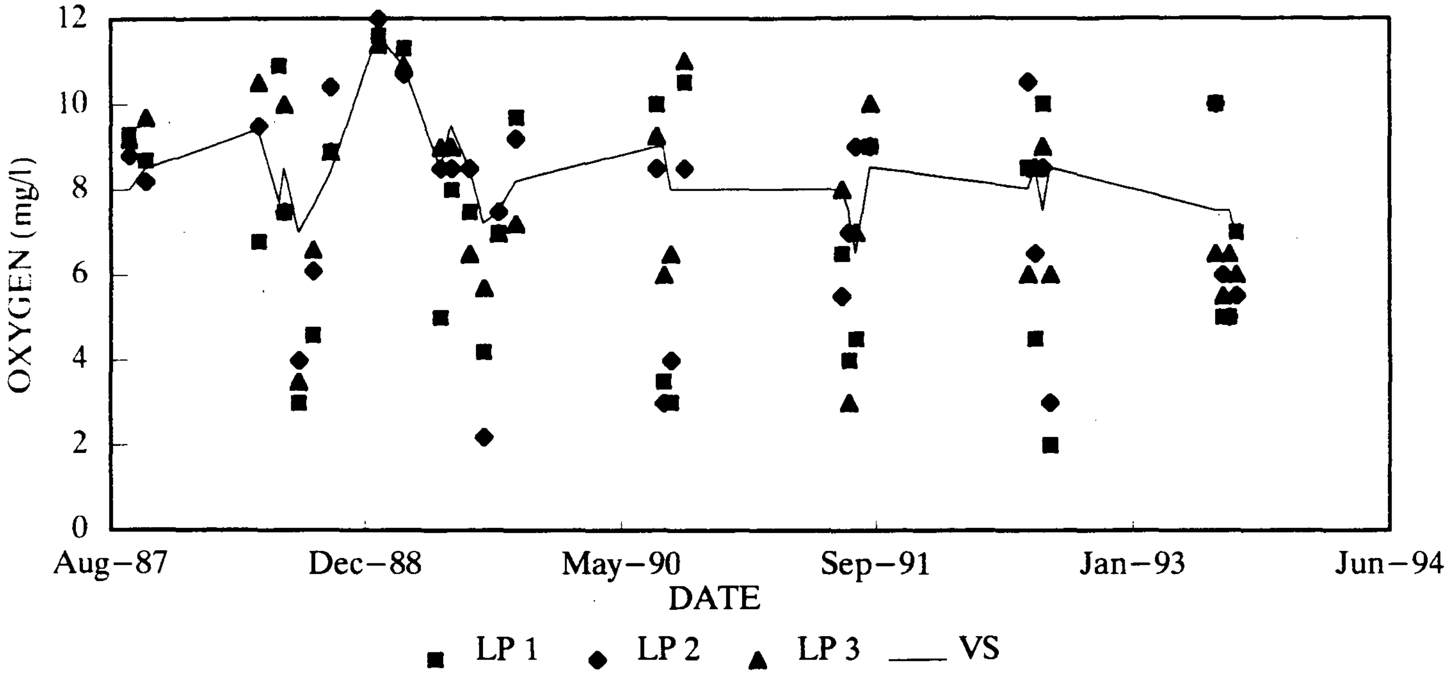
It is important to note that this is a summary, not the entire data base relating to the management of Oyster Pond, some additional information may be found in the 1992 report but a synthesis of all available information (including the results of the special projects) and management options will be produced after the upcoming 1994 field season.

Little Pond: Little Pond has typically had high nitrogen levels and periodic very low oxygen events (Figure 21). The effect is that benthic animal communities within the pond are impoverished or non-existent by the end of each summer season. In addition to the loss of animal communities, eelgrass beds have all but disappeared and macroalgal blooms cause floating mats, resulting in further declines in oxygen conditions. The ultimate cause of this poor water quality is the high nutrient loading due to development in the Little Pond watershed. The proximate cause is the recent (since 1989) high rate of sedimentation at the inlet causing very reduced flows and even a freshening of pond waters. Although in 1993 nitrogen levels remain above the limits of the Nutrient Bylaw throughout the pond with levels exceeding 1 mg/l in the upper reaches and 0.5-0.75 mg/l in the main basin (Figure 22), oxygen levels appeared improved.

The cause of the improvement in oxygen is most likely the result of intensive inlet maintainence in the 8 months prior to June 1993. The maintainence was designed to increase the flushing which has

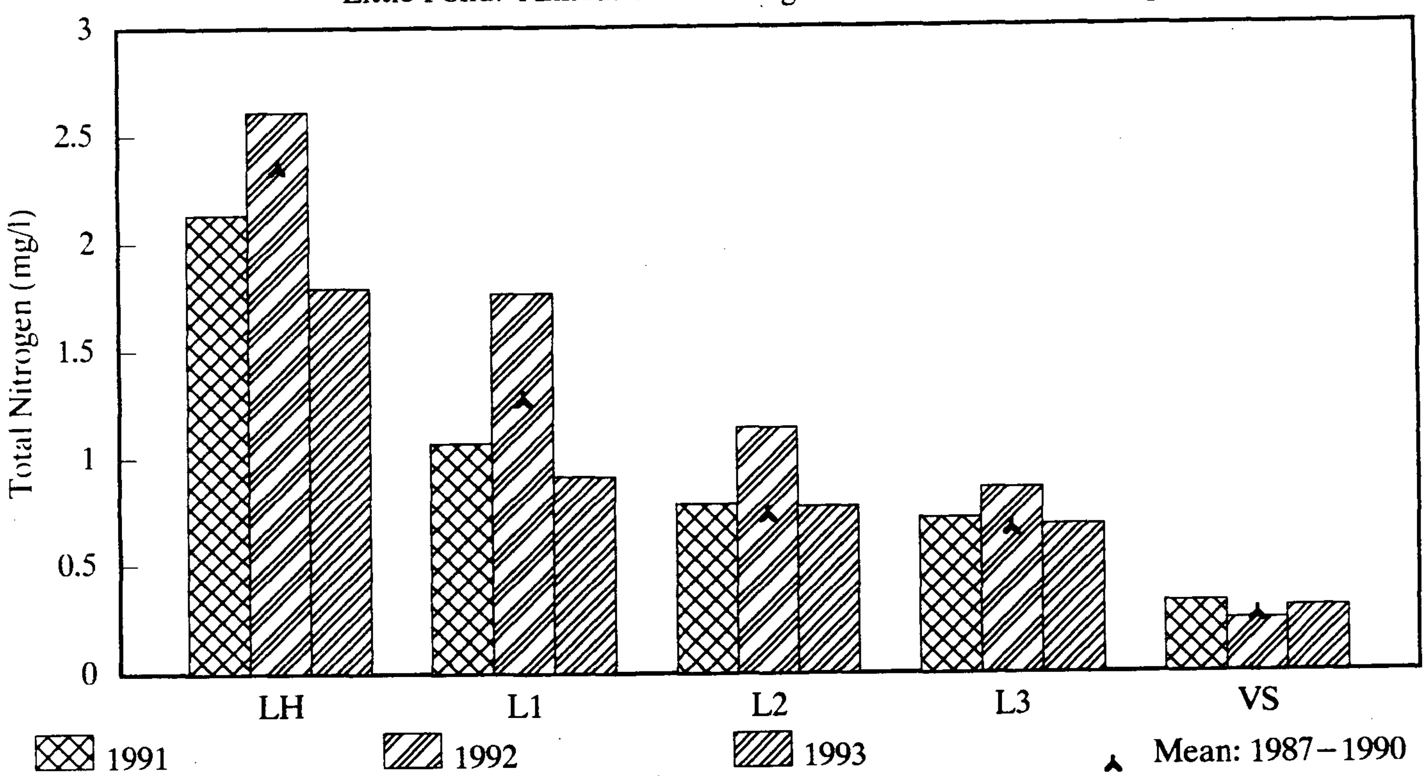
Citizens' Salt Pond Monitoring: 1987 - 92

Little Pond: Bottom Water D.O.



B.L. Howes, WHOI Sea Grant
Intense Town maintainence of Inlet throughout 1993.

Little Pond: Annual Total Nitrogen versus 1987-90 Average.



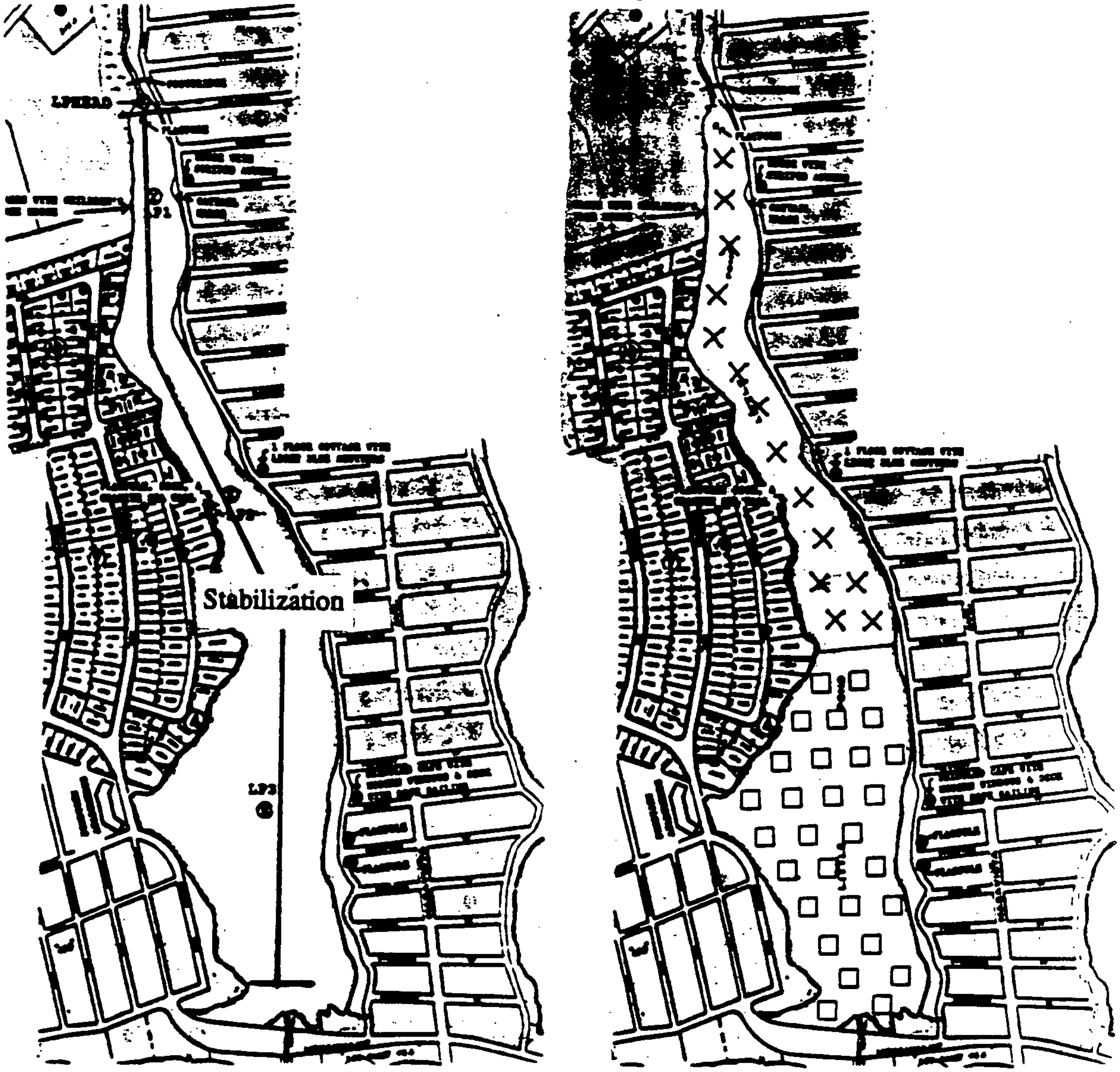
Annual averages, N=4.

Figure 21.

Little Pond station locations and Water Quality Designation as identified by Coastal Pond Overlay Bylaw (adopted by Falmouth Town Meeting, April 1988) and actual designations according to the Bylaw as measured by Falmouth Pondwatchers.

Water Quality Designation Identified by Bylaw

Actual Designation as Measured by PONDWATCHERS



"Critical Eutrophic Levels" as designated by Coastal Pond Overlay Bylaw
(Total Nitrogen as Average Over Year)

> 0.75 mg/l	= Above Highest "Critical Eutrophic Levels"	×
0.5 - 0.75 mg/l	= Intensive Water Activity Area	□
0.32 - 0.5 mg/l	= Stabilization Area	○
< 0.32 mg/l	= High Quality Area	

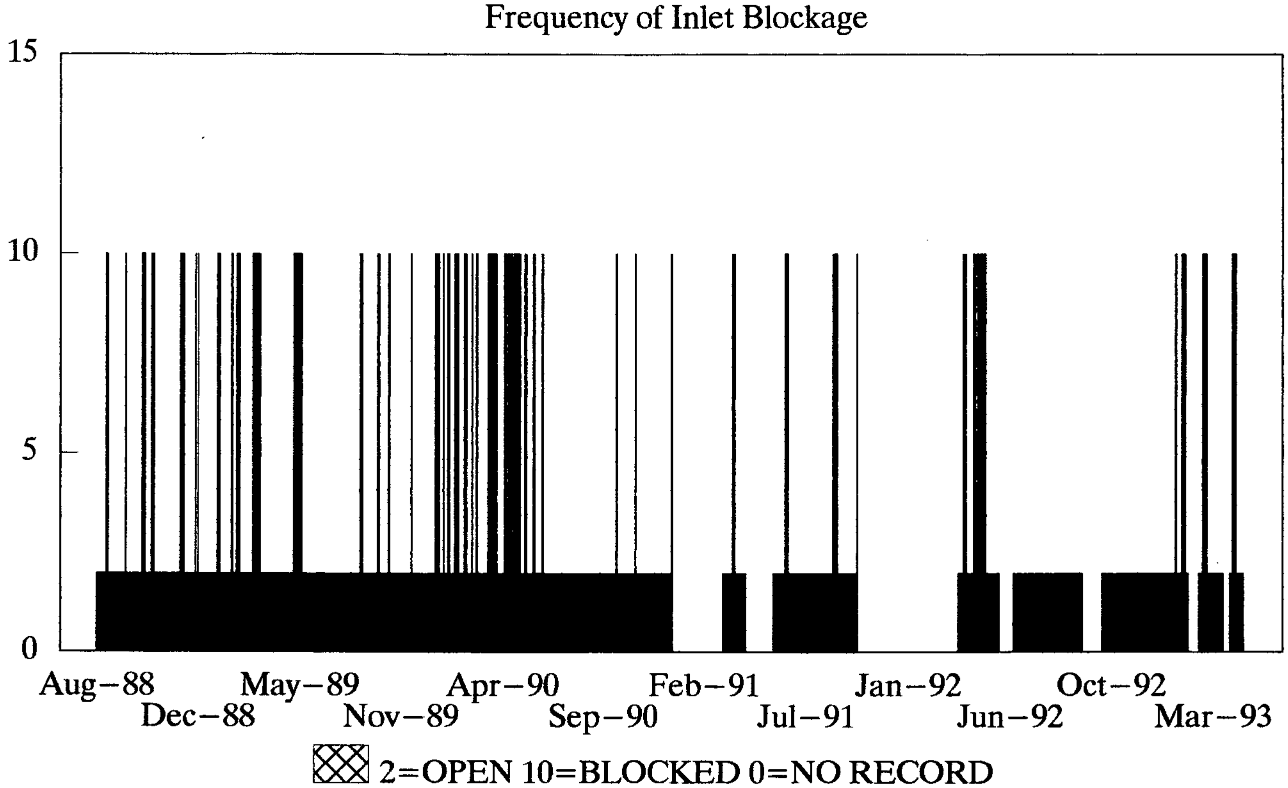
Figure 22.

been reduced in recent years due to movement of sand into the inlet channel both as part of littoral drift and during storms. The 1992-1993 experiment by the Town DPW and the Pondwatch program was initiated to test estimates of the flushing rates required to significantly improve water quality conditions within Little Pond. The study was a "proof of concept" to allow fine tuning of the soon to be initiated inlet reconstruction. The intensive digging out of the inlet was able to significantly decrease the periods of complete blockage (Figure 23), although tidal exchange was still impeded. However, conditions in Little Pond in 1993 were improved (although still highly eutrophic) over previous years. In addition, the finding of improved oxygen levels in Little Pond in the 1993 season following the inlet maintainence was used to support the scaling of the new inlet (Figure 21).

Management: While Little Pond and Oyster Pond show similar types of ecological stress the causes and solutions are very different. This underscores the problems with managing these systems which appear to have site specific problems and solutions.

Little Pond has the lowest water quality of the shallow embayments studied. Summertime low oxygen events are frequent and severe with the effect that benthic animal populations are almost completely absent by September each year even though there is a large and diverse set of young animals each Spring. Little Pond's ecological problems stem from too high nutrient inputs almost entirely from development and restricted exchange with Vineyard Sound. Phase II of Falmouth's WWTP plan is to sewer the Maravista peninsula reducing nutrient flow to Little Pond. However, a more certain and less costly approach involves improving the circulation of Little Pond. In the late 1800's Little Pond had a natural inlet to Vineyard Sound permitting free tidal exchange. With the construction of Menauhant Road the inlet was channelized and entry to the pond restricted. The man-made inlet has been altered many times and the pond was even fresh water for a brief period. The current problem is not that the present inlet is too small but that it has become frequently blocked with sand starting in late 1988 to present. The effect of the blocking in 1989-1990 was to decrease exchange over 30% which had the

LITTLE POND: Aug 1988 – May 93



B.L. Howes, WHOI Sea Grant
Recorder Off: 22 Oct 1991 – 18 Mar 1992

Figure 23.

effect of increasing nutrient loading by over 30%. Attempts to dig out the inlet in 1992 were not sufficient to improve the pond and low water quality persisted. Inlet reconfigurations are generally expensive and not advised. However, in our detailed study of Little Pond hydrology (available under separate cover) it appears that the current inlet and jetties are sufficient to improve Little Pond's ecological health if kept open. The jetties need only to be made sand tight and a box culvert should replace the existing double pipe as part of the already slated repairs to the jetties and culvert due to Hurricane Bob damage. As a result the costs are minimal.

Since the real problem is not the inlet structure but the sedimentation of the inlet this problem needs to be addressed or no improvement will be seen. When the current jetty and groin system was built on the barrier to Little Pond, the beach was much narrower than at present. In fact, the groin was constructed to build a beach and it has operated well as such. But now the sand has filled both the area behind the western jetty and the eastern groin with the effect that storms drive sand into the Little Pond inlet blocking its flow. One solution is to extend the jetties, but this also reduces the water flow into Little Pond and while the inlet may be kept open the level of ecological improvement could potentially be reduced. Another plan would be to simply dig back the beach a small amount. This would prevent the sedimentation of the inlet without effecting the inlet structures. While it is true that sand removal would have to be performed every 3-5 years it is also true that the sand is a resource with value for the nourishment of other Town beaches and protection of coastal structures. Sand nourishment is commonly a component of the Town's expenditures. Of course the initial clean out would also require removal of the extensive sand bar now inside the inlet in Little Pond, however this would also be required if the jetties were extended.

In 1993-94 the Town of Falmouth decided to adopt a combination of the above options and to extend only the eastern jetty, to remove sand and regrade the beach on the western side of the inlet, to conduct a "one time" dredging of the accumulated sand in the channel and of the flood tidal delta forming within the pond, and to expand the culvert based upon quantitatively predicted ecological improvements for Little Pond. As of this writing the project is in the final stages of permitting and was strongly facilitated through the state permitting process by the Pondwatch Program. The use of the data collected by Falmouth's citizen volunteers was used by town offices (led by engineering) to address all ecological issues raised in the process. The result was no additional environmental studies and no additional costs to the project. In addition, the requirement that the Town monitor Little Pond after the inlet is reconfigured was also met by the existence of Pondwatch, again due to the direct efforts of citizens. The overall result was a facilitation of the process and most likely a significant savings to the Town. This first pond remediation associated with the Falmouth Pondwatch Program stands as proof of the value of citizens monitoring and the co-operation between private citizens, a variety of Town Departments and scientists of WHOI Sea Grant. The experience of the Little Pond remediation should facilitate future management plans for Falmouth's coastal salt ponds.

Pondwatch will continue to monitor Little Pond to determine the accuracy of our predictions and to determine the effectiveness of the remediation and the level of ecological improvement, in order to refine future efforts. In addition, we will continue to assess the effects of the new inlet on returning the groundwater flow system surrounding Little Pond to a more coastal structure. With the last 2 reconfigurations of the inlet the mean level of the pond (the pond was even freshwater at one point, pre-1964) was raised. The new inlet should result in a lowering over present conditions. The effect on the groundwater system should be to intensify the focussing of discharge into Little Pond rather than the recent diversions to adjacent Great and Perch Ponds which have occurred due to the inlet blocking (Figure 24). Even without a lowering of the inlet base elevation increased groundwater focussing should occur since when the pond blocks the water level rises rapidly and significantly, altering the hydraulic gradients controlling groundwater flows and tending to divert flow. If as planned the new inlet is sufficient to improve Little Pond's water quality support groundwater discharge to Little rather

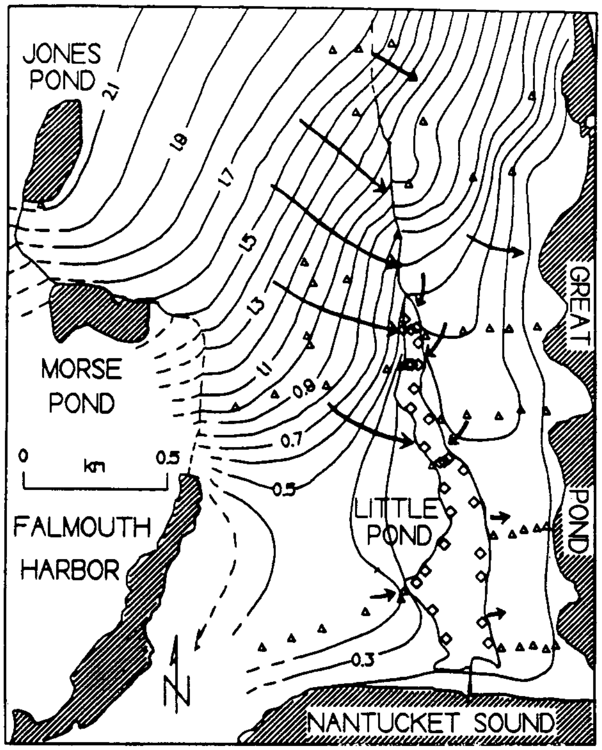


Figure 24. Water table elevations in the vicinity of Little Pond; arrows indicate direction of groundwater flow. Water table well network denoted by triangles, with sub-tidal and shoreline piezometers shown as diamonds. Water table and flow during periods when inlet is open (left panel) and closed (right panel). Water table within the peninsula between Little Pond and Great Pond is relatively flat creating the potential for infiltration from Little Pond into the aquifer. Right panel shows water table map at maximum embayment levels (0.68) during inlet blockage; flow from the pond (arrows along east and southwest shore) is based upon hydraulic gradients created to the east of Little Pond by the elevated embayment levels.

than Great Pond, there is an additional potential cost savings to the Town generated by the Pondwatch Program relating to the sewering of Maravista. If Little Pond can maintain even a moderate ecological health (a large improvement over existing conditions) then the need to sewer Maravista based upon ecological considerations becomes reduced. Of course addition refinements to our groundwater model of the peninsula to determine the extent of discharge to Great Pond will be needed but given the high cost of sewers and the additional demand on Falmouth's wastewater treatment facility emphasizes the benefits to the Town of allowing Little Pond to discharge the nutrients from Maravista to Vineyard Sound. This approach is especially important considering that most nutrients sent to the wastewater treatment facility eventually will be discharged (after transport through groundwater) to West Falmouth Harbor.

The Falmouth Pondwatch Program has successfully evolved from monitoring to providing the town with assistance in the protection and restoration of its coastal salt ponds. The enthusiasm of the volunteers is only increased by the application of "their" data to real environmental problems. Although the problems and solutions facing each of Falmouth's ponds differ (Figure 25), the high level of performance of trained citizens gives the Town the resources to develop individually tailored management plans for each system.

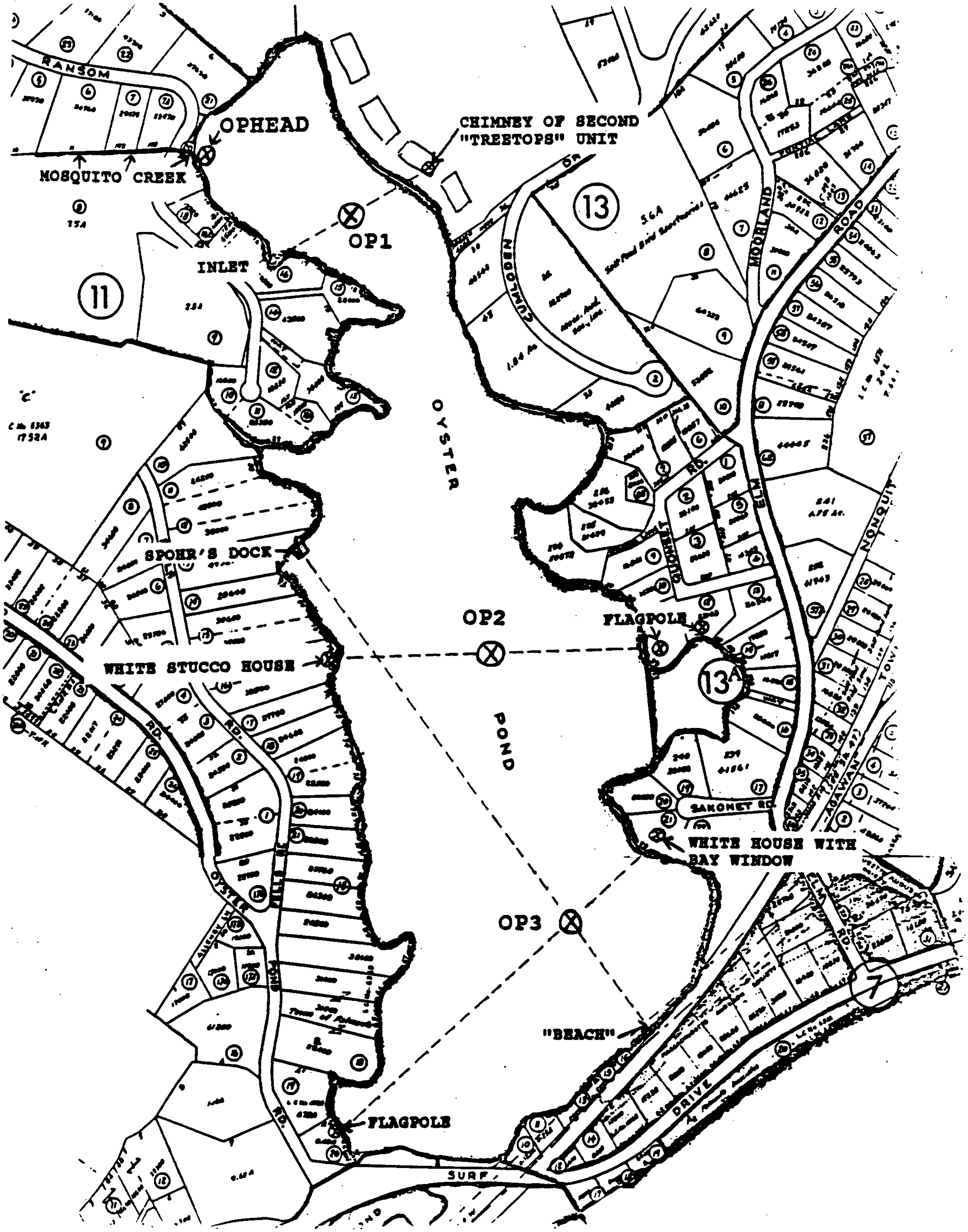
FALMOUTH COASTAL SALT PONDS

PROGRESS AND PROBLEMS

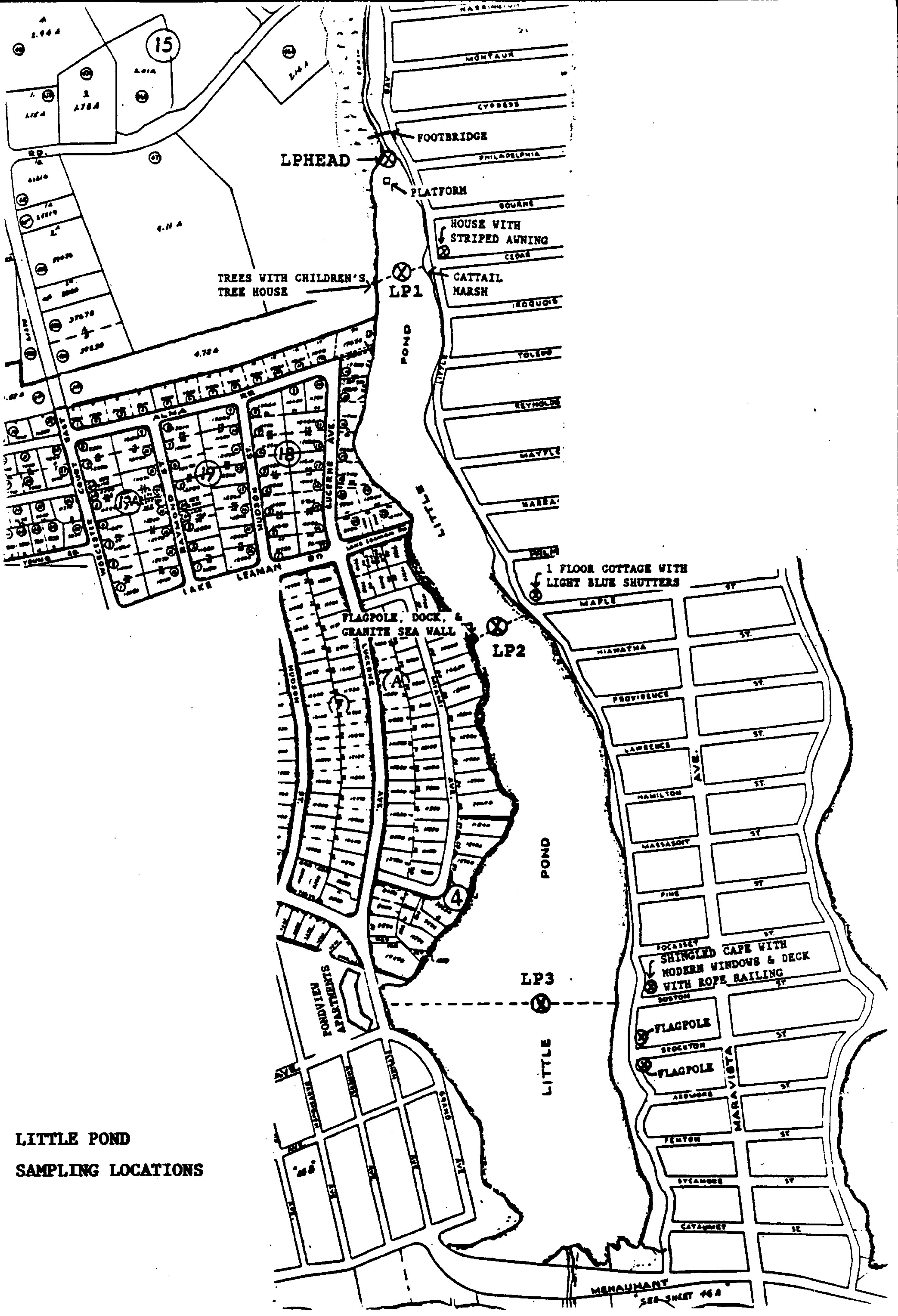
	Problem	Solution
Green Pond	Too Much Nitrogen Too Little Flushing	Increase Flushing via Improvements to Bridge
Great Pond	Too Much Nitrogen (Upper) Too Little Flushing (Upper)	?
Perch Pond	Too Much Nitrogen Too Little Flushing	Increase Flushing + Vertical Mixing via Dredging Berm
Bournes Pond	Too Much Nitrogen (Upper) Too Little Flushing (Upper)	-- --
West Falmouth Harbor	High Water Quality Overall	Minimize New Inputs
Little Pond	Too Much Nitrogen Too Little Flushing	Increase Flushing
Oyster Pond	Deep Basin (naturally Eutrophic) Too Little Flushing	Increase Flushing (Salt Water Solution) Limit/Cease Flushing (Fresh Water Solution)

Figure 25.

Appendix I. Location of Sampling Stations for Oyster, Little, Green, Great, and Bournes Ponds and West Falmouth Harbor.

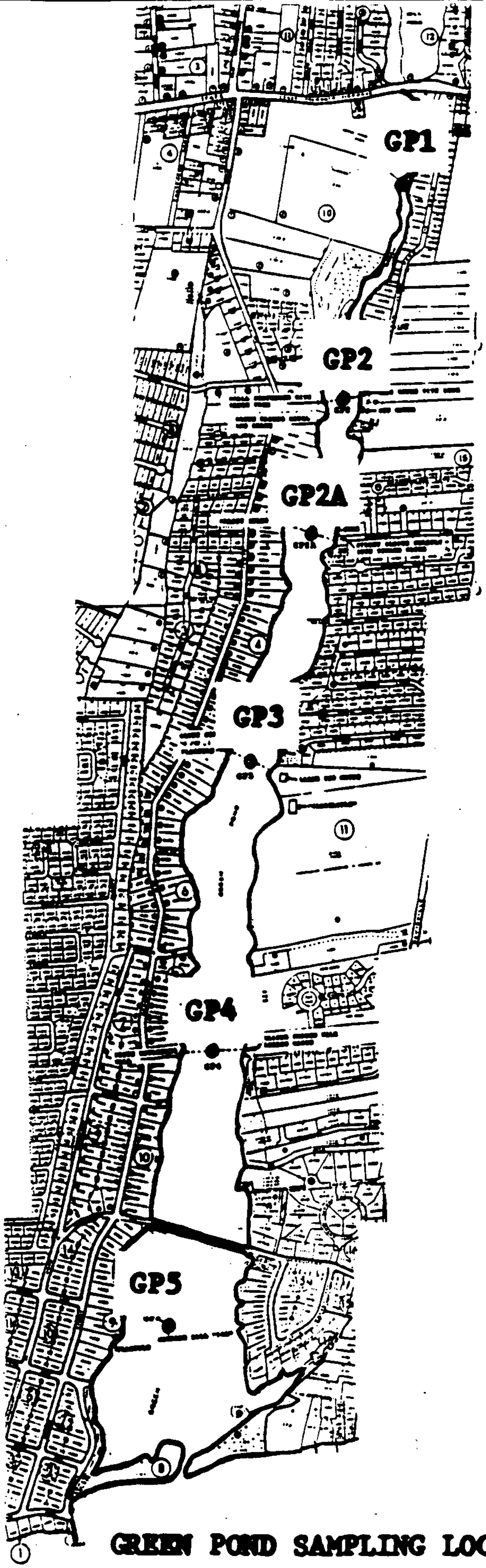


OYSTER POND SAMPLING LOCATIONS

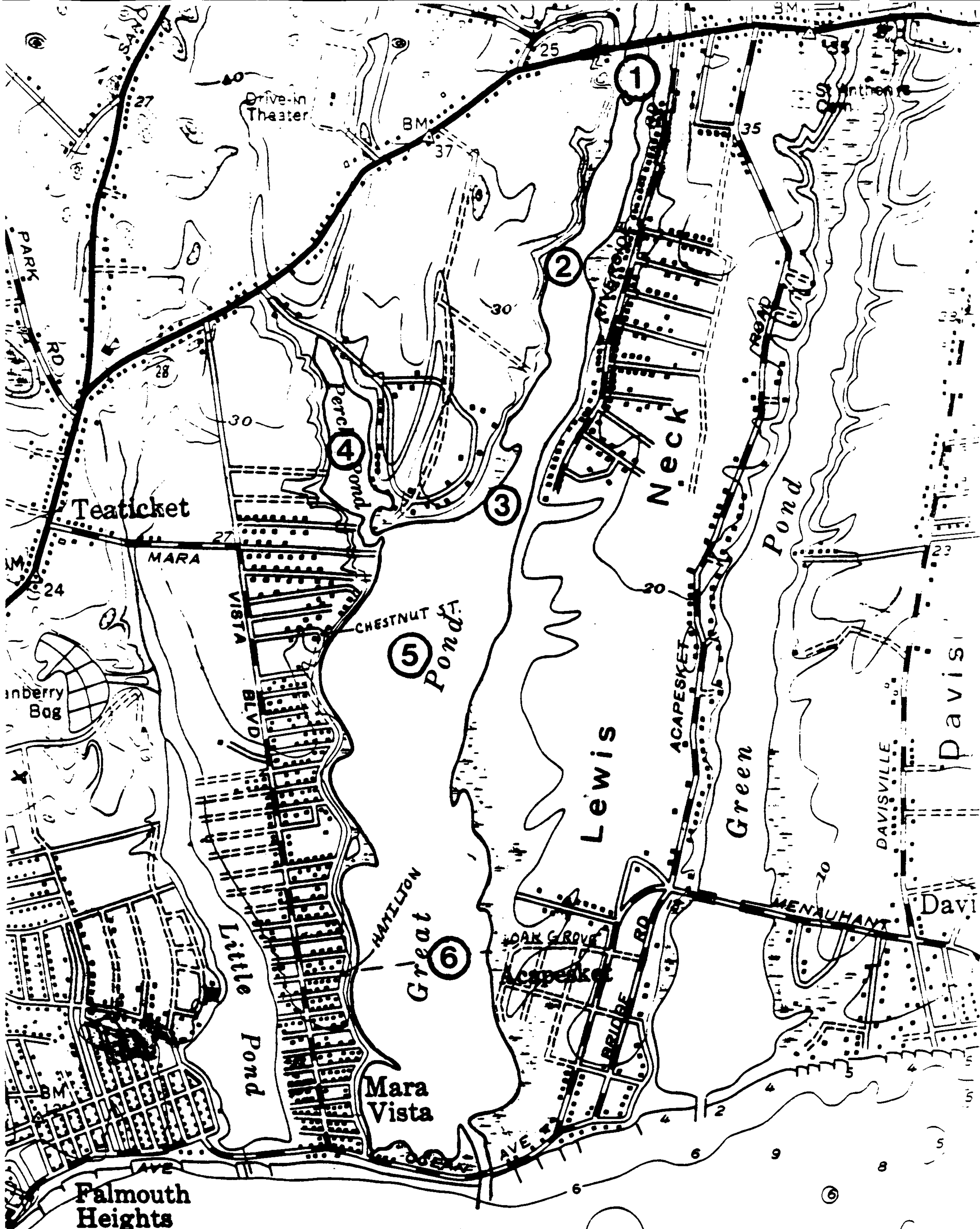


LITTLE POND

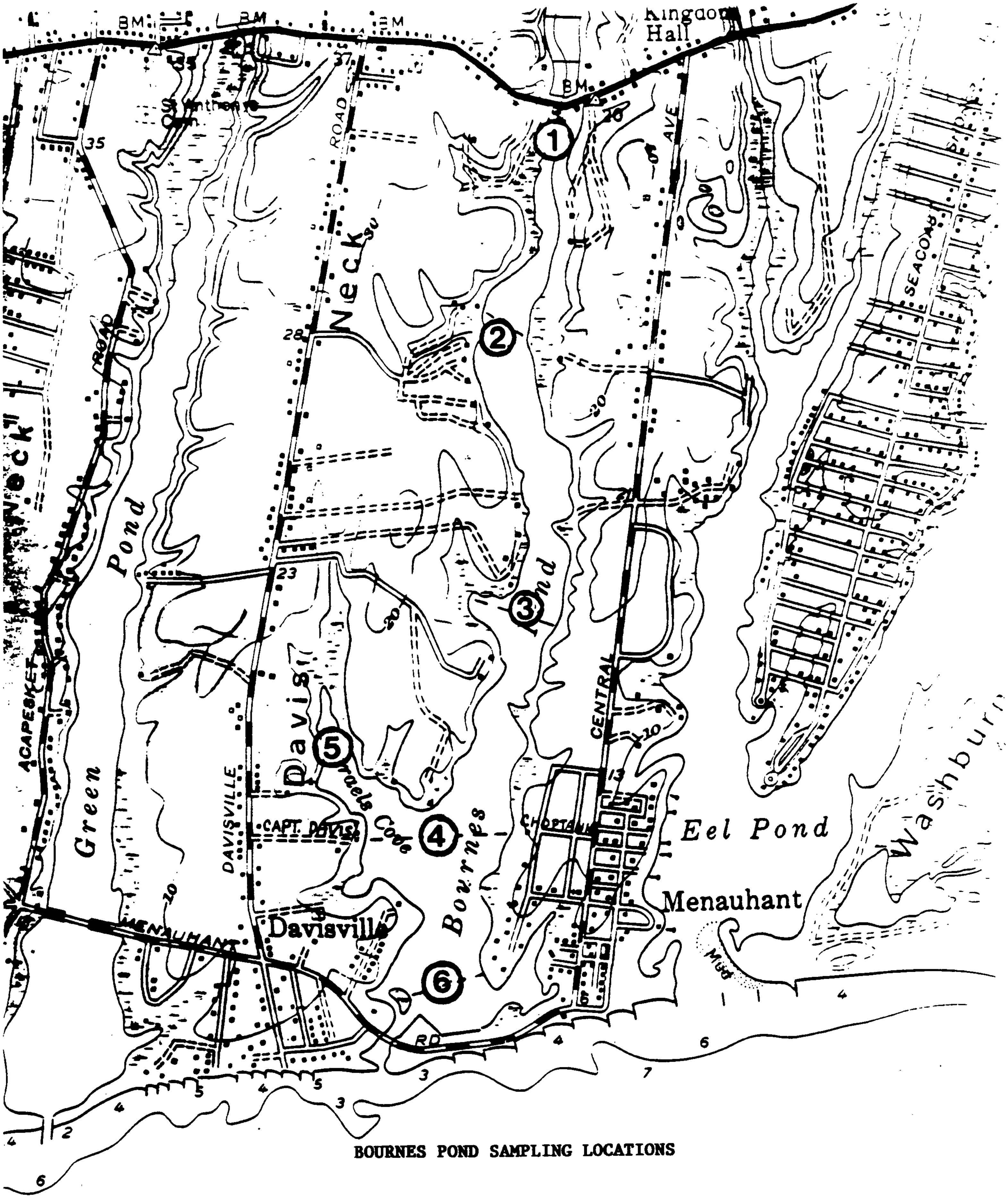
SAMPLING LOCATIONS



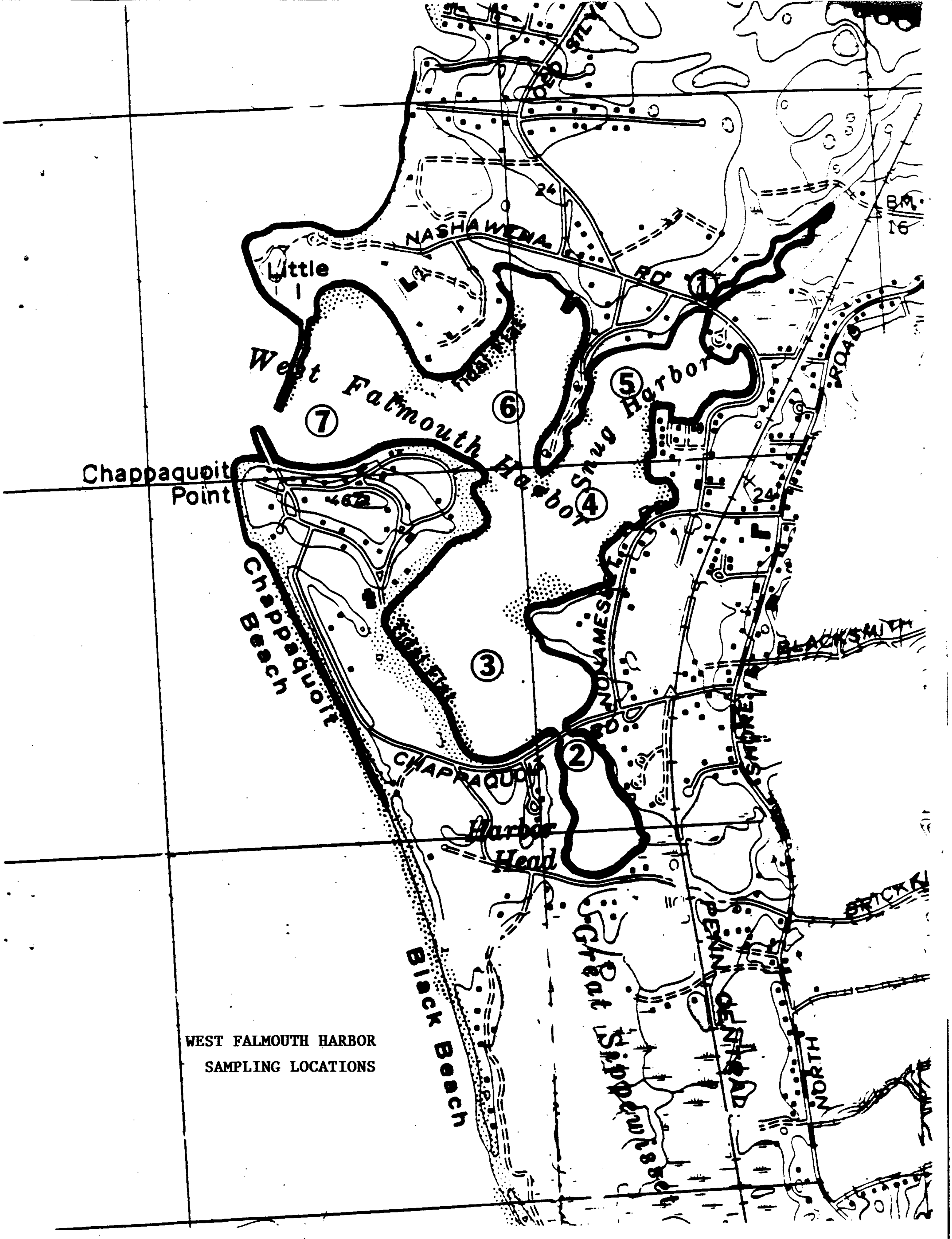
GREEN POND SAMPLING LOCATIONS



GREAT POND SAMPLING LOCATIONS



BOURNES POND SAMPLING LOCATIONS



WEST FALMOUTH HARBOR
SAMPLING LOCATIONS

Appendix II. Alphabetical Listing of the 1993 Falmouth Pond Watchers

Pond Watchers 1993

Matthew and Beth Adamczyk
185 Davisville Road
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PHONE: 540-7334 or 540-0961
POND: Green (Pond Captain)

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

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

Paul Bansbach
171 Bay Branch
E. Falmouth MA 02536
PHONE: 548-5868
POND: Green Pond

Deborah Barry
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East Falmouth MA 02536
PHONE: 540-4150
POND: Little Pond

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

Jim Begley
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PHONE: 540-6210
POND: Bournes (Upper)

Eugene Black
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East Falmouth MA 02536
PHONE: Great Pond
POND: 548-8716

Charles Blumsack
59 Partridge Lane
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POND: Green

Richard W. Bowman
8 Jamie Lane
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PHONE: 540-2675
POND:

Frank Britto
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POND: Green

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Pond Watchers 1993

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POND:

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Pond Watchers 1993

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J.F. Zietlow, Jr.
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Appendix III. Sampling Protocol for the Falmouth Pond Watchers

SAMPLING PROTOCOL

General:

The goals of the sampling program are to:

1) collect water column samples <u>without</u> disturbing the bottom sediments (this is <u>very</u> important, especially if you are standing nearby in the water);

2) process oxygen samples as quickly as possible and with the minimum chance of introducing atmospheric oxygen into the sample before the reagents are added.

The order of sampling is:

1) Collect Surface Samples
   - a) process for oxygen
   - b) temperature
   - c) salinity
   - d) nutrients

2) Collect Deeper Samples
   - a) oxygen
   - b) temperature
   - c) nutrients

3) Physical Measurements
   - a) Secchi depth
   - b) total depth

You will need sampling kit (with data sheets and protocol), and sampling pole (provided). You will need to bring an oxygen waste container; a one quart wide mouth juice container should last all season.

<u>Procedures:</u>

Note: For simplicity we use the sampling pole for both surface and deep water collection. If you like, you can fill the surface 1 liter nutrient bottle by hand; try not to suck in water directly from the surface.

1) Put stopper in pre-labelled (with date, pond, station & depth) 1 liter nutrient/salinity bottle and in the 0.5 liter oxygen bottle. Make sure the side tube on the 0.5 liter bottle is placed upwards.

2) Lower the bottle to the appropriate depth: 0.1 meter, 1 meter, 1.5 meter, etc. depending on your station.

REPEAT FOR EACH DEPTH SAMPLE

3) a) Pull oxygen bottle stopper (0.5 liter).
   b) then pull nutrient bottle stopper (1 liter).

4) Keeping the pole vertical, bring the samples on deck. Remember to support the bottles as they will be heavier out of water.
   - a) Remove nutrient (1 liter) bottle, put in thermometer, record temperature, cap and set aside.
   - b) **OXYGEN:** lower tube from oxygen bottle on pole to the bottom of the glass bottle (with glass stopper) from the blue oxygen kit. Drain about 3/4 of the 0.5 liter bottle (bottle with hose) through the glass bottle, overflowing the glass bottle. Tap glass bottle if bubbles stick to sides.
   - c) As volume reaches 3/4 of the 0.5 liter bottle, slowly remove the side tubing from the glass bottle and carefully insert the glass stopper (drop) so as not to trap any bubbles. IF THERE ARE BUBBLES SAMPLE MUST BE RETAKEN. **DO NOT SHAKE WATER OFF TOP OF BOTTLE.**

d) 1. Using the clippers in the blue oxygen kit open Reagent pillow 1;
2. remove glass stopper from glass oxygen bottle;
3. pour Reagent 1 into bottle;
4. open Reagent pillow 2 and add to bottle.
5. Replace glass stopper, <u>CAREFUL NOT TO TRAP BUBBLES.</u>
6. Shake bottle vigorously holding bottle and stopper (some reagent may stick to bottom of bottle...this is O.K.). Shake for 45 seconds turning bottle upside-down and rightside-up several times.
7. Let stand 2 minutes, shake again.
8. <u>When floc settles and the top 1/4 to 1/2 of bottle is clear</u>, open Reagent pillow 3, remove glass stopper, add powder to bottle, replace stopper, shake vigorously until water in bottle becomes clear (no particles but may be color). A dark yellow color indicates high oxygen.
9. Remove glass stopper and, rinse first with sample and fill small plastic tube to top TWICE (two volumes) pouring each time into the square glass bottle in the kit.
10. You are now ready to determine the oxygen content.
Take the eyedropper and fill with solution in the brown plastic bottle in kit (do not get on hands). Now the tricky part: HOLDING THE DROPPER VERTICALLY, add 1 drop to the square bottle and swirl. Continue to add drop by drop (about 10 seconds between drops) and swirl; continue to add drop by drop and swirl until the yellow color goes away. **DO NOT ADD DROPS TOO FAST.** At the point you think color is gone, add one more drop to check; often the eye is fooled by the color. Record the number of drops to turn clear; don't count the extra drop added as a check (1 drop = 0.5 mg O_2/liter). Surface samples usually takes 14-15 drops to turn clear.
11. Collect and save oxygen waste in juice container or the like; we will collect these at end of season for disposal.
12. Rinse glass bottles, plastic tube and dropper with distilled or tap water and let dry.

5) **Nutrients:** (Make sure all bottles are pre-labelled with station I.D., date & depth)
a) Remove bottle from pole.
b) Place filter in clear plastic filter holder; align steps in top and bottom of holder and screw on clamp to hold together.
c) Shake 1 liter bottle, and rinse and fill 60cc syringe with water from bottle by removing plunger and pouring in (cover hole on end so water doesn't get lost while you're pouring in), replace plunger.
d) Attach filter to syringe and discard first approx. 15-30 cc of water.
e) Push next 20-30 cc of water into the small sample bottle provided, replace cap, shake and discard water.
f) Now refill syringe and collect all water in the now rinsed bottle until bottle is full to shoulder, cap and put on ice.
g) Cap 1 liter bottle, check label and put on ice.

6) **Physical measurements:** - Light, color & depth:
1. Lower Secchi disk into water slowly from shady side of boat until it just disappears from view. Record depth of dissapearance as 1st Secchi depth from where tape meets water. Lower below view, raise until comes into view and record second secchi depth (these numbers should be very close).
2. Bring up to half of the disappearance depth and compare color of disk to color wheel, if available, and record.
3. Lower disk slowly until it touches bottom, record depth.

Note: Sometimes the disk will hit the bottom before it disappears --- record as bottom and the depth from the tape.

After sampling, hose down sampling poles, Secchi disk and clippers to minimize rusting.
Note any unique or unusual characteristics of station -- presence of algae, smell or anything that may appear unique.
When finished, keep samples cold and in the dark (on ice or in refrigerator, NOT freezer).