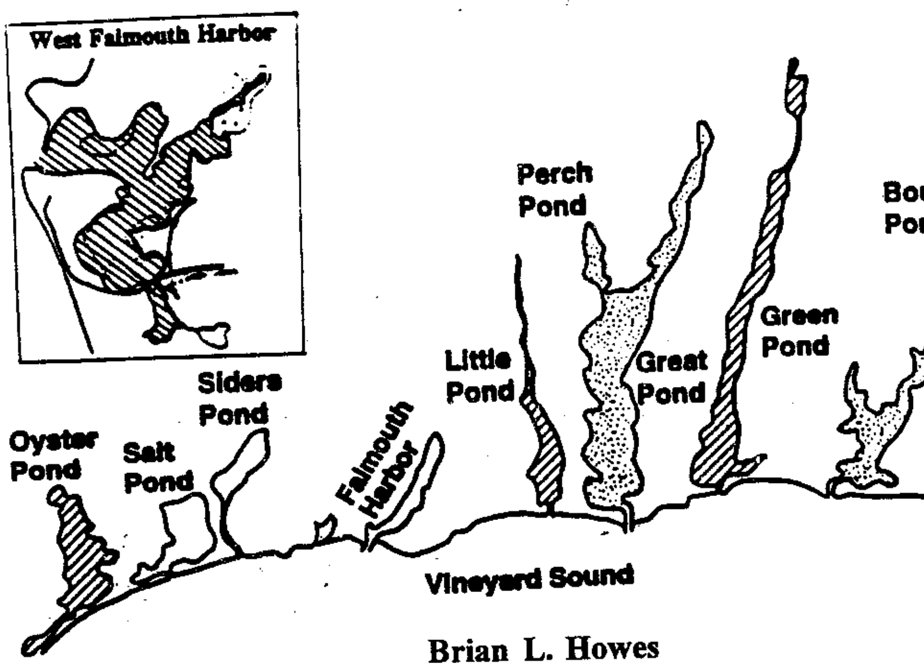
FALMOUTH POND WATCHERS

WATER QUALITY MONITORING OF FALMOUTH'S COASTAL PONDS: RESULTS FROM THE 1994 and 1995 SEASONS



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EXECUTIVE SUMMARY

PROBLEM: Steadily increasing nutrient inputs, resulting primarily from on-site septic systems, fertilizers and runoff associated with increased coastal development, poses a serious long-term threat to the health of our coastal environments. Our limited understanding of the natural processes controlling nutrient cycling and the impact of nutrient loading on coastal embayments, coupled with the variable success of nutrient remediation measures, has historically created serious obstacles for the development of intelligent management practices.

The degradation of coastal waters and watershed development are tied together through inputs of pollutants in runoff and groundwater flows, and to some extent through direct disturbance, i.e. boating, oil and chemical spills, and direct discharges. Excess nutrients, especially nitrogen, promote phytoplankton blooms and the growth of epiphytes on eelgrass and attached algae, often with adverse consequences. Where waters are made turbid by excessive plankton blooms, light penetration to benthic plants (like eelgrass) is reduced, thereby reducing their rate of photosynthesis and growth. Algal slime and other epiphytic growth on these plants may shade them further, so that they become stressed or die. Decaying phytoplankton and macro-organic matter build up on the bottom, increasing the oxygen demand upon bottom waters. At excessive levels of nitrogen inputs, bacterial decay processes combine with animal respiration and night-time plant respiration to draw down the dissolved oxygen supply, especially in the hot, still weather typical of July and August. Fish and shellfish kills and changes in overall benthic animal communities are a common result.

PROGRAM: To acquire baseline water quality data necessary for ecological management of Falmouth's coastal salt ponds and harbors, a citizen-based water quality monitoring project for Falmouth's was initiated in 1987 based on a collaborative effort between scientists, citizens and representatives of the Town of Falmouth. Monitoring of three original ponds, Oyster, Little and Green,

soon grew in 1990 to incorporate two additional ponds, Bournes and Great, also potentially subject to nutrient related water quality degradation. 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 Pond Watch Program continues to evolve its role as a monitoring program of the ecological health of Falmouth's coastal salt water ponds. Although Pond Watch still performs its central role of providing the environmental data relative to the Coastal Pond Overlay Bylaw (Nutrient Bylaw), it now performs a variety of other "services" relative to the Town's coastal management programs. First, the Pond Watch 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 Pond Watch program has become a repository for environmental information on the variety of Falmouth's coastal ponds. The data base currently incorporates both the core monitoring program and special project data on watershed nutrient loading and watershed delineations, circulation studies, wetland delineations, plants and animals etc. The stable consistent information center provides additional 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.

RESULTS: Through the current efforts of Falmouth's Citizen Volunteers, the Pond Watch Program has maintained its high level of success. In West Falmouth Harbor, we doubled the existing information on the system's health and began our trend analysis relative to the Wastewater Treatment Facility plume. The Pond Watch Program provided the first and clearest indication that the plume was discharging to the Harbor. In Green Pond the long-term trend of declining water quality appears is clear and the data is being used to begin planning and implementation of short and long-term water quality improvements. In Little Pond the Pond Watch Program assisted the Town in the design and permitting of the inlet redesign for improving the ecological health of the pond. The Pond Watch Program continues to monitor the remediation, providing a cost effective approach to meeting the permitting conditions of the project and gauging the level of success. Oyster Pond is also the focus for management. A synthesis of the management options for this pond is included in Appendix V, which

Oceanographic Methods" for the reprinting by the Oyster Pond Environmental Trust. Pond Watch data was central to the current plan for managing Oyster Pond. Continued monitoring is critical, since regulation of tidal flows to the Pond are linked to monitoring data. Ongoing evaluation of water quality conditions for Bournes and Great Ponds will continue to be important as the trends in their ecological health are not totally clear. In addition, the Pond Watch data on Green, Great and Bournes Ponds provide the only long-term context for evaluating the impacts of the Ashumet Valley Plume which is currently discharging to the coast focussing on the Green Pond.

It is clear that monitoring by Pond Watch continues to the active management of these coastal systems. However, the uses of the data now support: (1) Coastal Pond Overlay Bylaw, (2) ecological assessments for management and remediation, (3) remediation designs, (4) permitting, (5) post-implementation monitoring to meet regulatory requirements and to gauge efficiency of remediation, and (6) trend analysis for gauging entry of groundwater plumes from the Falmouth WWTP and Otis AFB. National recognition of the Falmouth Pond Watch 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, 1994 and 1995.

ECOLOGICAL STATUS:

Overall, taken as whole ecosystem units, the status of Green, Little, Great/Perch, Bournes, and Oyster Ponds is similar to that of previous samplings at almost all stations (Figure 1). This is expected since water quality tends to change slowly over time rather than in large rapid shifts. All of the five ponds on the southern shore 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. West Falmouth Harbor continues to exhibit the highest water quality and ecological health of the ponds being monitored. This high water quality is related in part to the Harbors much higher tidal exchange rate due to the 4 fold higher tide range in Buzzards Bay versus Vineyard Sound. The whole pond view is only part of the evaluation, since the ponds do not function as single units but rather as linked upper and lower pond components forming the whole. The most notable region-wide finding was that the positive effects of Hurricane Bob on the larger ponds had dissipated by the summer 1995.

The value of the monitoring data is that it is now beginning to detect these longer trends. From the 1994-95 data, conditions of some of the ponds, most notably Green Pond and West Falmouth Harbor, are clearly undergoing change. Green Pond shows a significant and continuing eutrophication, with the low water quality upper pond zone migrating toward the inlet. Lower Green Pond will receive an adjustment to the hydrodynamics as part of the new bridge construction. However, assessment of potential improvement awaits the completion of construction. In contrast, Green Pond is the recipient of nutrients from a groundwater plume originating from the now discontinued discharge from the Otis AFB sewage treatment facility. The role of this nutrient source in the eutrophication of Green Pond has yet to be quantified.

West Falmouth Harbor monitoring data has detected what appears to be the entry of the Falmouth WWTP plume. Although significant water quality declines have not been detected, it will take several years before the full plume discharge is felt.

Great and Bournes Ponds continue to have moderate to high water quality in their lower basins, however, their upper reaches are showing eutrophication. In addition, lower Great Pond is showing a trend to higher nutrient levels, although low oxygen conditions have yet to be detected. Flow between Great and Perch Ponds is becoming increasingly restricted with the effect that Perch Pond exhibits episodic freshening events and low water quality. The new inlet to Little Pond was completed in February 1995, but significant improvements in water quality were not obvious by that summers sampling. It is likely that it will require several years for the nutrient balance of the pond to adjust to a lower level as the sediments depurate and groundwater flow patterns become stabilized. Oyster Pond continues to freshen and show improving oxygen status in the inland basins. Oxygen persists at deeper depths than previously and the inland basins have oxygen throughout most of the summer. It is clear that with the freshening of the pond that vertical mixing is increasing. The restoration plan for Oyster Pond has been completed with the goal to return the pond to pre-mid 1980's conditions. After the salinity structure of the pond is restored, it will be possible to determine the new assimilative capacity of the pond for nutrients to determine if nutrient management is needed to achieve full restoration.

As the Pond Watch program continues the monitoring data will now be used to detect changes in West Falmouth Harbor and Green Pond as nutrient inputs increase, Little and Green Ponds to evaluate the inlet reconstruction and bridge alteration, Oyster Pond to determine the level of tidal restriction for salinity maintenance and evaluate the restoration project, and Great and Bournes Ponds to develop a management plans for these important embayments.

COASTAL SALT POND REPORT CARD

Pond	Ability To Make Bylaw Limit	Overall Water Quality	Status 1992	1993	1994	1995
Green Pond						
Upper	Fail	Poor	Same	Same	Same	Same
Lower	Fail	Moderate	Declining	Declining	Declining	Declining
Great Pond						
Upper	Fail	Poor	Same	Same	Same	Same
Lower	Fail	Good	Improving	Declining(?)	Declining	Declining
Bournes Pond						
Upper	Fail	Moderate-Poor		Same	Same	Declining Same
Lower	Fail	Moderate	Improving	Improving	Same	Same
West Falmouth Harbor						
Upper	Fail	Good	?	?	Declining(?)	Declining
Lower	Pass	Good	?	?	Same	Same
Little Pond						
Upper	Fail	Poor	Same	Same	Same	Same
Lower	Fail	Moderate-Poor		Same	Improving	Moderate-Same
Oyster Pond						
Shallow Basin	Fail	Poor	Improving	Improving	Same	Improving
Deep Basin	Fail	Poor	Same	Same	Same	Same

Figure 1.

PREFACE

The Falmouth Pond Watch Program was one of the first citizens monitoring programs of marine systems in the United States. Pond Watch presently monitors 6 coastal embayments in Falmouth, but is continually expanding its focus. Pond Watchers are involved citizens who are willing to give their time, energies and resources in order to protect and/or restore these sensitive coastal environments. The program strives to collect high quality data on nutrients, oxygen and biological parameters to support land-use planning and management to conserve these focal systems and to develop, implement and monitor innovative cost-effective restoration plans for degraded systems. To date, restoration plans have been developed for 3 and implemented for 2 of the 6 ponds.

National recognition of the Falmouth Pond Watch 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, 1994 and 1995. The greatest indication of the value of the program has been the use Pond Watch methodologies and program management structure by other coastal monitoring efforts arising in the region.

The Pond Watch Program began as a collaborative effort between Falmouth's Planning Office, WHOI Sea Grant and a group of dedicated (and trusting) citizens. The Program continues to be a unique partnership between resource managers, citizens and scientists. When the program began it was clear that long-term monitoring was needed to support management of Falmouth's changing embayments. When asked upon the initiation of monitoring, "How long will monitoring continue?", the response was "Until the water quality in the ponds stops changing." Unfortunately, with continuing development and now with the implementation of restoration plans, the ponds continue to change, but fortunately now there is a cadre of trained dedicated citizens who continue to track them. We are indebted all who have given of themselves to make this program work and to those who will steward these coastal systems for years to come.

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Woods Hole, MA

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INTRODUCTION

During recent decades, coastal communities like Falmouth have increasingly become aware of the declining water quality of their circulation restricted nearshore coastal salt ponds and harbors. Addressing these concerns through action, the Falmouth Pond Watchers have successfully provided the environmental data required both to determine the extent of potential degradation and to identify the causes. These data being fundamental to the development of effective land-use planning, conservation and remediation measures.

Pond Watch is a citizen-based volunteer monitoring effort, initiated in 1987, to assess the water quality conditions of Falmouth's circulation restricted coastal salt ponds. Initially monitoring three ponds (Little, Oyster and Green), the program expanded in 1990 to include two additional ponds (Bournes and Great), and again in 1992 to incorporate West Falmouth Harbor. (Figure 2). The fundamental purpose of the program is to provide a cost-effective approach to acquiring high quality water quality data for ecological management. Such quantitative environmental data, while crucial for successful management, is often out of the reach of most coastal communities. The project is jointly sponsored by the Town of Falmouth, scientists from the Woods Hole Oceanographic Institution, and Falmouth Associations Concerned with Estuaries and Saltponds (FACES) providing support for sampling equipment and analyses as well as publication support for dissemination of results. The success of the Pond Watchers program, however, is based on the dedication and enthusiasm of the citizen volunteers who donate their time, boats and energies to collect environmental data on these systems and on the unique partnership which has developed between the citizens, local government and scientists. Through this collaborative effort, information gained from the research can be swiftly and directly applied toward effective management decisions for these fragile coastal environments.

The goals of the study are broad: 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, and to involve local citizens directly in determining the present and future ecological health of their coastal ponds and harbors. An added benefit of this approach has been to community attention to the increasing human pressures on our fragile coastal resources. The information and an involved citizenry is particularly important relative to the Coastal Pond 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 N per liter for "Stabilization Areas," and 0.75 mg N per liter for "Intensive Water Activity Areas." Comprehensive data from the

Citizen's Monitoring Effort was designed to provide the nutrient information which is far too expensive to be provided wholly by already strained Town budget; to verify the validity of the stated threshold values; and to provide the Planning Board with supporting ecological information to interpret the Bylaw.

To increase the applicability of the monitoring data, other parallel scientific studies have been ongoing in concert with the overall monitoring program. One of these, was a more intensive study of one of the more nutrient overloaded ponds, Little Pond. The Little Pond "special study" was conducted to increase our understanding of the processes controlling inputs, losses and recycling of nutrients within these systems and to determine the role of natural versus anthropogenic (human) factors which structure the ponds ecology. The results provide information transferable to coastal ponds throughout the region. In addition, we have also been conducting research on Sesachacha Pond, Nantucket, to provide quantitative data on the before and after effects of remediation on a poorly flushed eutrophic coastal salt pond. Sesachacha Pond was historically opened one or two times per year to exchange with the sea, but was left "closed" for 10 years and only recently reopened annually. These in depth investigations have provided a base from which to interpret the monitoring data as well as contributing fundamental information on the ecological processes which ultimately determine water quality under a variety of nutrient and flushing characteristics. With each subsequent year of monitoring, the value of the data base has expanded tremendously. These long-term data sets enable the evaluation of trends in water quality conditions and provide the ability to separate short term, periodic events (such as periodic low oxygen events due to natural processes) from longer term trends in environmental health. With this data set, we are increasingly able not only to evaluate the health of Falmouth's coastal salt ponds, but also to confidently make predictions on the potential effectiveness of various remediation measures. Given the great expense and limited financial resources available for remediation of nutrient over-loaded embayments, a priori assessment of the potential efficacy of each management option is essential.

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. Data generated by the Pond Watchers has shown that nutrient conditions in some of the ponds already exceed these threshold levels specified by the Coastal Pond Overlay Bylaw (Nutrient Bylaw), an important discovery in for land-use planning and management of these systems. As well, the addition of West Falmouth Harbor to the suite of monitored 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 Falmouth Wastewater Treatment Facility and heading 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.

A major 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, critical to making 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 also allows rapid implementation of new approaches to monitoring and event based sampling. Pond Monitors allow for "rapid response" samplings when unusual conditions, such as fish kills, algal blooms or low oxygen events are observed. 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 Watch Program is its applicability to a wide variety of 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 and at low cost. The success of the program is reflected in its being adopted 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 Falmouth Pond Watch 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, 1994 and 1995.

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 beginning to be recognized and our limited understanding of their long-term consequences hinders protection of these systems. Of these activities, the most major concern revolves around the long-term impact of nutrient loading on the water quality of coastal salt ponds and harbors.

Although toxic contamination (eg. PCB's, pesticides, organic compounds, etc.) can present significant problems for these systems, their impacts tend to be localized. In contrast, nutrient overloading is wide spread and results in dramatic degradation or loss of coastal habitat. The increasing levels of nutrient inputs associated with changing land-use are the major threat to Falmouth's marine resources.

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. Coastal salt ponds, by their nature, are highly productive, nutrient rich environments frequently providing suitable habitat for many species of commercially and recreationally valuable fish and shellfish. However, these systems because of their large shoreline area and generally restricted circulation and flushing, are usually the first indicators of nutrient pollution along the coast, due to their lower rates of dilution and flushing.

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 levels 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. Higher frequencies and durations of low oxygen events result in the loss of stable plant and animal 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 not the rate of development but the distribution and total mass of nitrogen loading which determine the impact. 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, it appears that much of the "overload" stems from "new" sources related to human activities.

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 transform the nitrate to 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.

The number of 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 uptake and incorporation by phytoplankton in the watercolumn as the nitrogen is transported toward open coastal waters. This uptake and transformation is relatively rapid and significant inorganic concentrations are generally only observed in the very headwaters of the ponds. Measurements of benthic flux (Green, Little, Great and Bournes Ponds) 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 and is once again readily available to support algae production. The significance of this finding revolves around the fact that with each cycle 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 a one time input of nitrogen can impact the system many times until it is eventually lost to open coastal waters.

The deterioration of coastal waters therefore is due to nutrient enrichment generating an overproduction of phytoplankton and submerged aquatic plants resulting in low oxygen conditions. High nutrient levels are frequently associated with depletion of oxygen, potentially to the point of limiting or prohibiting survival of benthic infauna, shellfish and fish. 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.

SUMMARY OF PREVIOUS RESULTS: 1987 - 1993

The results of previous Falmouth Pond Watch samplings (1987-1993) have provided significant insights into the ecological health of Falmouth's coastal salt ponds. The extensive long-term data sets on most of these systems now enables us to evaluate future trends in nutrient related water quality, and 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 baseline data on the seasonal variability in nutrient and oxygen conditions in the ponds. The data has made it clear that nutrient and oxygen levels are the major determinants to the ecological health of the ponds. However, these parameters are highly variable both spatially and temporally, requiring multiple samplings and long-term data sets for accurate assessment of nutrient related ecological health of these coastal systems. Further study, emphasizing the importance of natural physical processes such as wind driven mixing and water temperature on the cycling and fate 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 the initial 3 years of sampling 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). This indicated that summer sampling gives a good average view of nutrient levels and is the critical period for ecosystem structuring 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. Also important, 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 year-round 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 (Nutrient 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 best 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 nutrient levels specified by the Coastal Overlay Bylaw 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 a costly underscaling of improvements.

Another 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 and its strong salinity stratification (1987-1993) virtually eliminates any wind driven mixing of oxygen into the deeper regions of the water column. In addition, light attenuation in the deeper depths minimizes production photosynthetically derived oxygen where decomposition processes are consuming oxygen. Although nutrient additions to Oyster Pond are likely impacting the system, the natural processes effecting the deep basin would occur regardless of additional nitrogen inputs. Therefore, by the standards of the Nutrient Bylaw (as well as most ecological standards) Oyster Pond 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.

Previous 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 the 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-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 surface waters 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 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 the five south shore ponds at both an upper and lower site within each pond. Fish species were collected using both "minnow" and larger commercial box traps at each station. Collections were in concert with the four summer watercolumn samplings to enable comparison of oxygen and nutrient conditions to species population and distribution data. 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 the species 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, and Great) 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.

Ongoing results from the program also indicate that the eutrophic nature of the ponds (and therefore high organic matter based turbidity) results in the limitation of light penetration through the watercolumn, even in the relatively shallow systems. By mid-summer, the watercolumns 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.

(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, fish kills 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, fish surveys, bird censuses, detailed salinity measurements, 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.

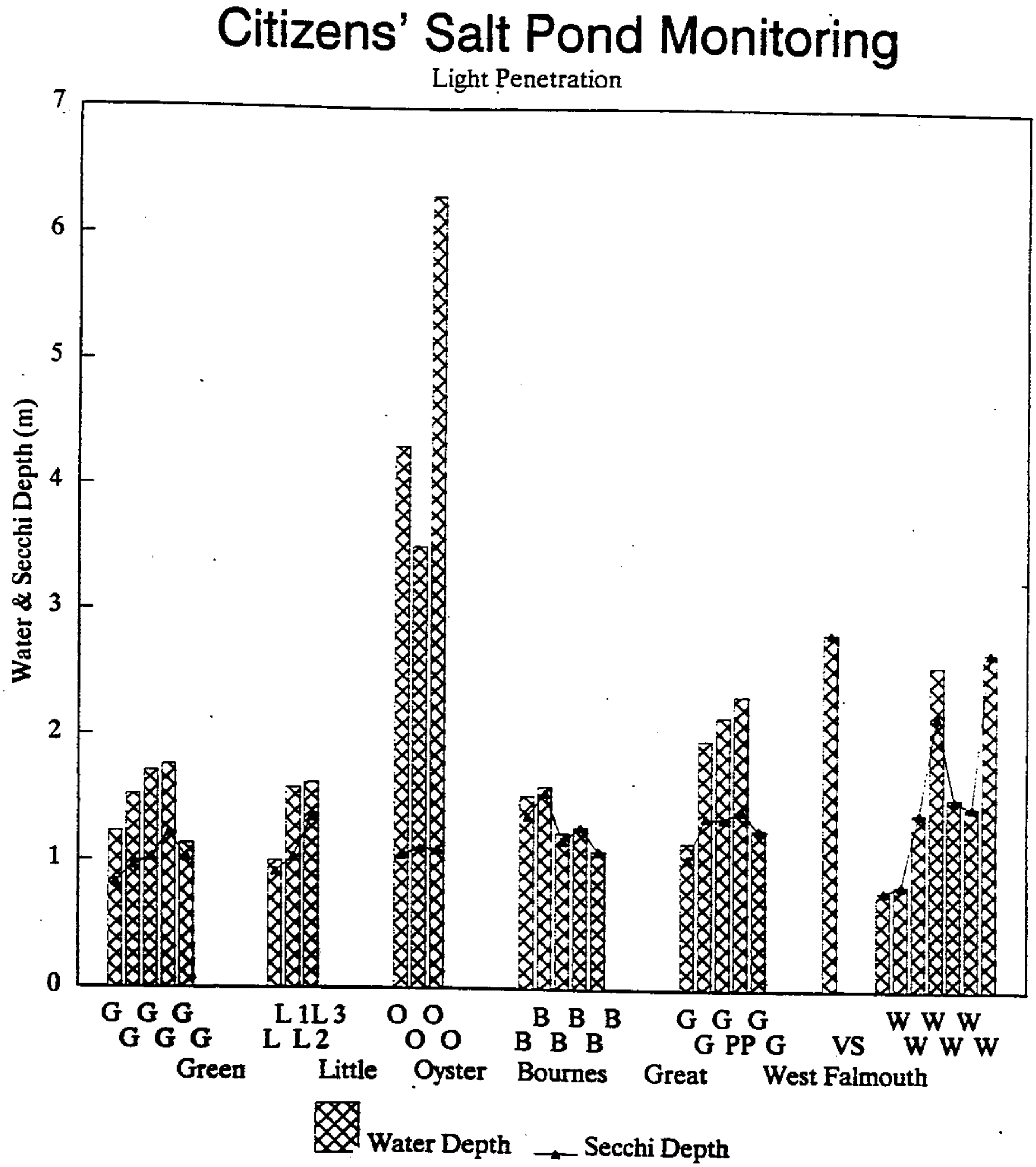
The Pond Watchers conducted 4 Special Projects in 1994 and 1995. Measurements of salinity (primarily in Oyster Pond, B. Livingstone, M. Zinn and S. Hart, see Appendix IV) and rainfall (B. Rogers) were monitored year-round in both years to provide needed data on the freshwater portion of the hydrologic balance of these systems and to determine seasonal cycles in these parameters. During the summer of 1994, B. Norris conducted high frequency oxygen monitoring of the Oyster Pond inner basin to observe potential variations in water column oxygen profiles prior to and during the summer months. This oxygen data was obtained specifically to examine potential salinity management of Oyster Pond as part of a restoration plan. During July and August 1995, a continuously recording oxygen sensor was placed in Little Pond to gauge the effects of the new inlet on bottom water oxygen levels. These Special Projects were conducted at the monitoring stations supplement the standard monitoring program and to address issues brought forward by Falmouth's resource managers.

RESULTS AND DISCUSSION

The past several years have seen a significant expansion in the focus of the Falmouth Citizens Salt Pond Monitoring Program. With more long-term data in hand, we began to place more emphasis upon management and remediation along with the continuing long-term mission of acquiring quantitative nutrient data relative to the Nutrient Bylaw and ecological health of all the salt ponds. We have continued this approach as the focus shifts away from merely documenting water quality trends towards application of the data for management and documentation of "water quality improvements" after implementation of restoration plans. With this in mind the analysis of the 1994-1995 results is divided into two parts: 1) a presentation of long-term trends and current ecological health of each of the embayments, and 2) progress on management and remediation plans for Little, Green and Oyster Ponds including the results of inlet modification in Little Pond.

Overall, taken as whole ecosystem units, the status of Green, Little, Great/Perch, Bournes, and Oyster Ponds is similar to that of previous samplings at almost all stations. This is expected since water quality tends to change slowly over time rather than in large rapid shifts. All of the five ponds on the southern shore 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. West Falmouth Harbor continues to exhibit the highest water quality and ecological health of the ponds being monitored. This high water quality is related in part to the Harbors much higher tidal exchange rate due to the 4 fold higher tide range in Buzzards Bay versus Vineyard Sound. The whole pond view is only part of the evaluation, since the ponds do not function as single units but rather as linked upper and lower pond components forming the whole.

The value of the monitoring data is that it is now beginning to detect these longer trends. From the 1994-95 data, conditions of some of the ponds, most notably Green Pond and West Falmouth Harbor, are clearly undergoing change. Green Pond shows a significant and continuing eutrophication, with the low water quality upper pond zone migrating toward the inlet. West Falmouth Harbor monitoring data has detected what appears to be the entry of the Falmouth WWTP plume. Although significant water quality declines have not been detected, it will take several years before the full plume discharge is felt. The most notable region-wide finding was that the positive effects of Hurricane Bob on the larger ponds had dissipated by the summer 1995.



B.L. Howes, WHOI Sea Grant
When Secchi Depth = Water Depth: the potential for macroalgal blooms exists.

Figure 3.

Ecological Health: Status

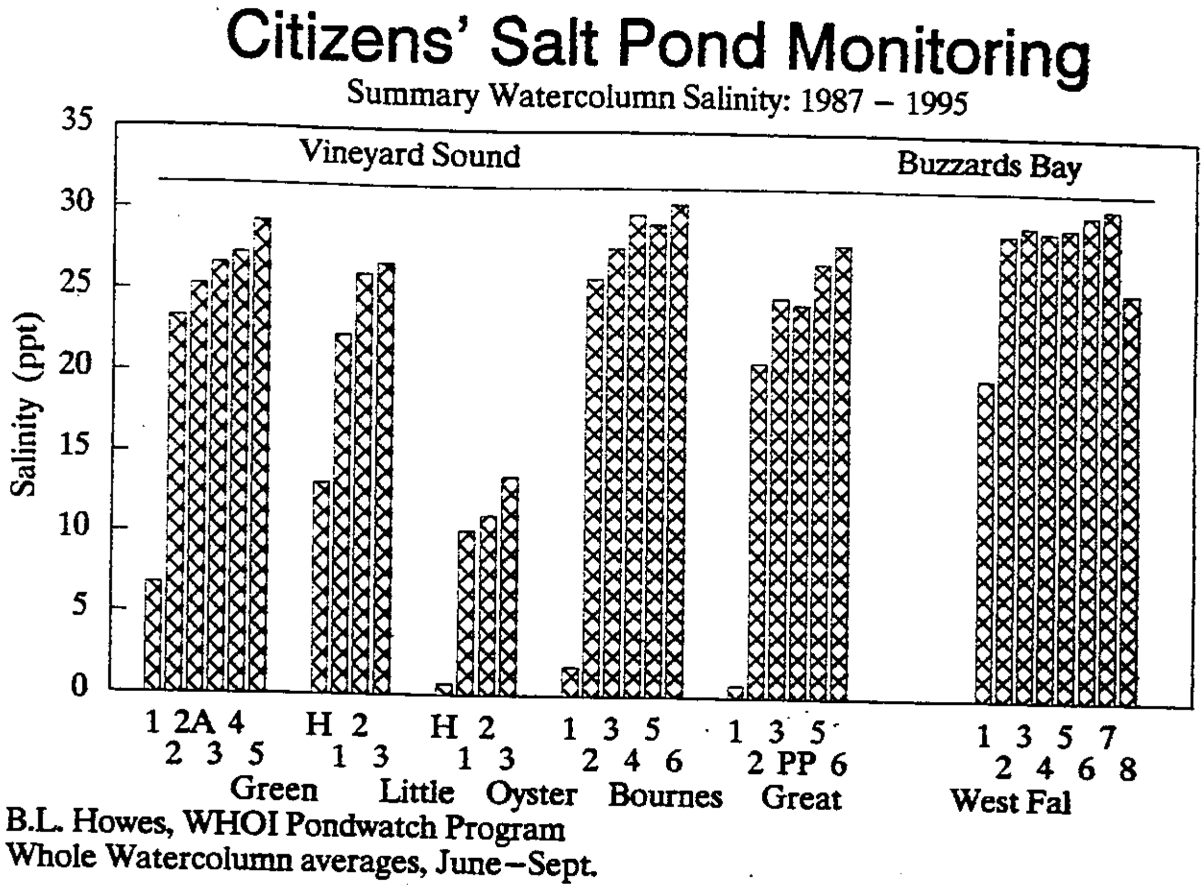
Approximately 2500 chemical assays (each in duplicate) and almost 1000 physical measurements were conducted throughout the six embayments (Figure 2) monitored by the Falmouth Pond Watchers in each year during 1994 and 1995. Consistent with previous years, variations in nitrogen or oxygen levels were often observed at individual sites between samplings. These variations stress the importance of multiple samplings in assessing nutrient related water quality in these dynamic coastal systems.

The data indicate that physical structure (i.e. shape and depth) of each of the embayments plays a major role in their susceptibility 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 and Perch Pond (and Salt Ponds) and West Falmouth Harbor's Oyster Pond from drowning of kettle holes. The "finger" ponds tend to be long, narrow and shallow with generally uniform depths 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). West Falmouth Harbor is the most complex of the 6 embayments having a "T" shape, with the large Snug Harbor salt marsh and an associated kettle salt pond, Oyster Pond, respectively, at each of its headwaters.

Pond 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, particularly in the headwaters, 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 and West Falmouth Harbor's Oyster Pond 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 in both depth and water clarity. The result is that throughout much of 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 (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. 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 at any location within an 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



Citizens' Salt Pond Monitoring
Summary Watercolumn Salinity: 1987 – 1995
Vineyard Sound
Buzzards Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
1 2A 4
2 3 5
Green
H 2
1 3
Little
H 2
1 3
Oyster
1 3 5
2 4 6
Bournes
1 3 5
2 PP 6
Great
1 3 5 7
2 4 6 8
West Fal
B.L. Howes, WHOI Pondwatch Program
Whole Watercolumn averages, June–Sept.

Figure 4.

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 and inlet restructuring with the replacement of the inlet culverts in February 1995 resulted in higher salinities as a result of the increased flushing. 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 their inlet configuration.

The potential for eutrophication is directly related to the concentration of dissolved nutrients entering the headwaters of these systems via groundwater flow (Figure 5), the volume of groundwater input and the potential for export of nutrients via exchange with Vineyard Sound. High concentrations of dissolved inorganic nitrogen (which is readily available for plant uptake and production) in freshwater inflows reflects high levels being discharged to groundwaters within the watershed. While there is more than a 4 fold range in observed concentrations, the levels at each site are relatively well constrained. This is consistent with a groundwater source of the fresh water. The absolute concentration coupled with the volume of groundwater flow is directly related to the overall input of DIN to the water body. For the finger ponds along the south facing coast (Green, Little, Bournes and Great), the relative concentrations of DIN entering the ponds through freshwater inflows are closely correlated to the relative overall water quality in their upper reaches.

One of the environmental factors contributing to variations in nutrients and oxygen levels is the frequency and magnitude of storms/rainfall (Figures 6, 7). 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. 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 as yet 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. 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 their organic matter levels (which are ultimately controlled by nutrient inputs). In addition, the importance of physical processes such as temperature effects on oxygen solubility (cooler waters able to contain more oxygen than the same water at a higher temperature) must also be taken into account. Because of their circulation restricted and shallow nature, all of the ponds maintain a higher water temperatures relative to Vineyard Sound and Buzzards Bay 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 and inlet restructuring with the replacement of the inlet culverts in February 1995 resulted in higher salinities as a result of the increased flushing. 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 their inlet configuration.

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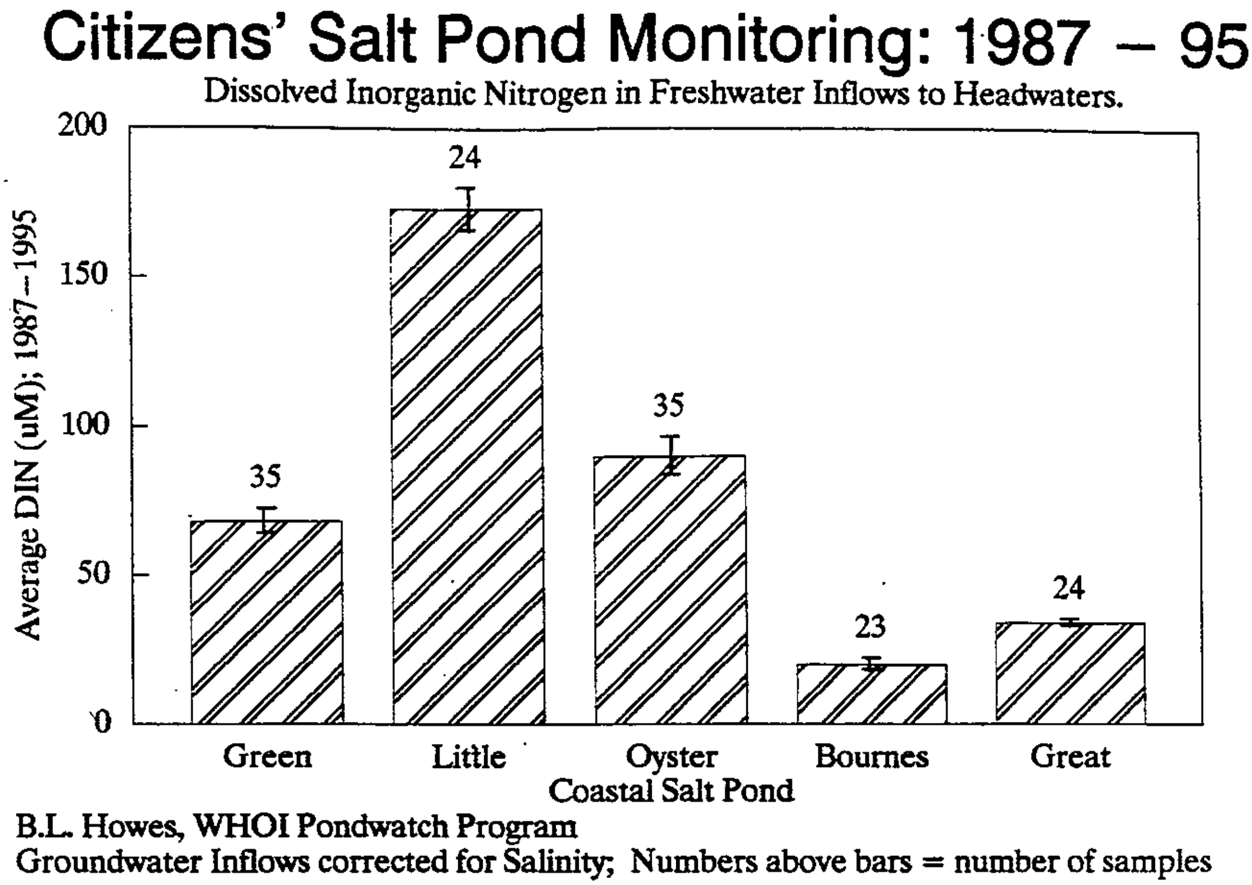
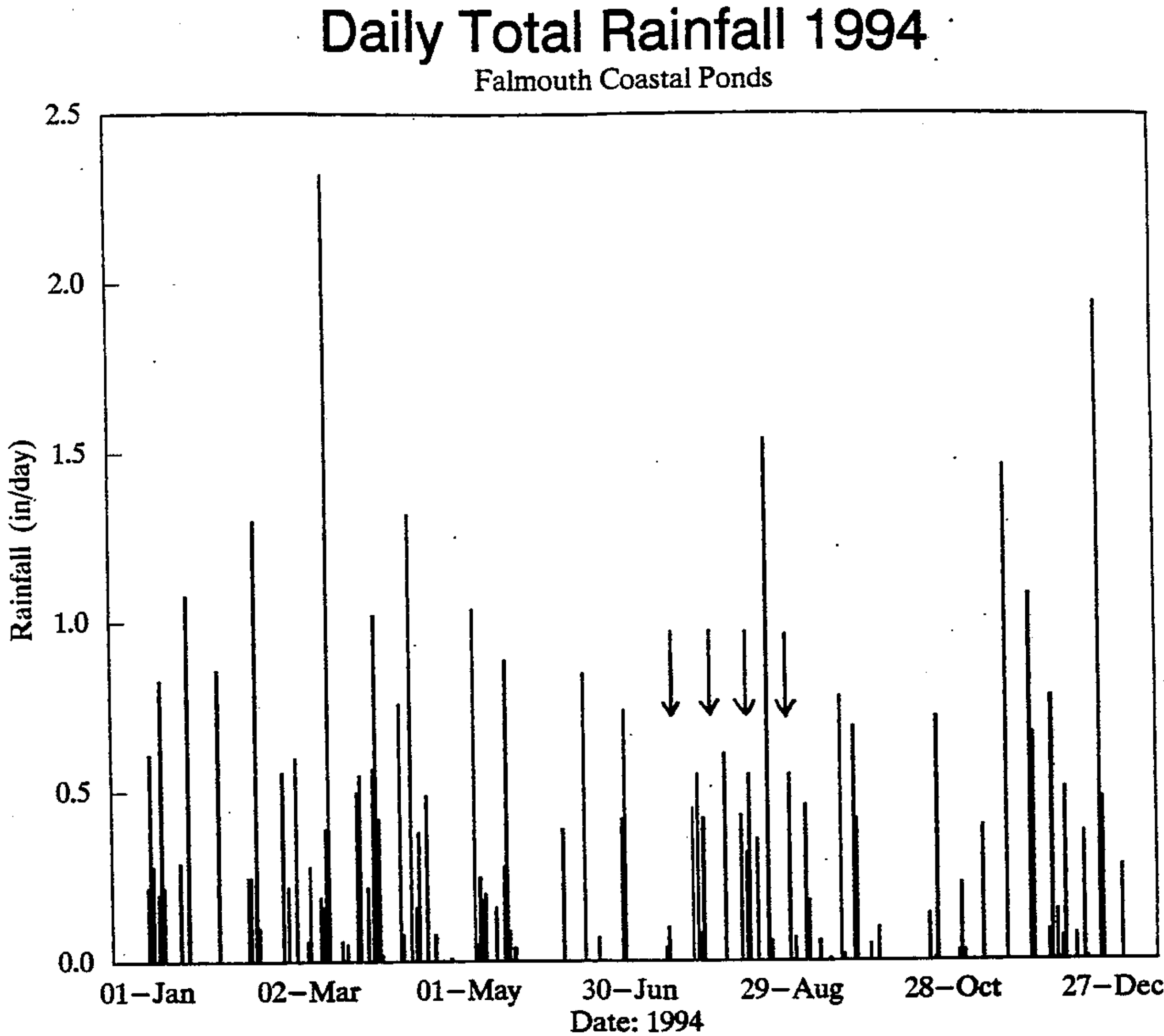
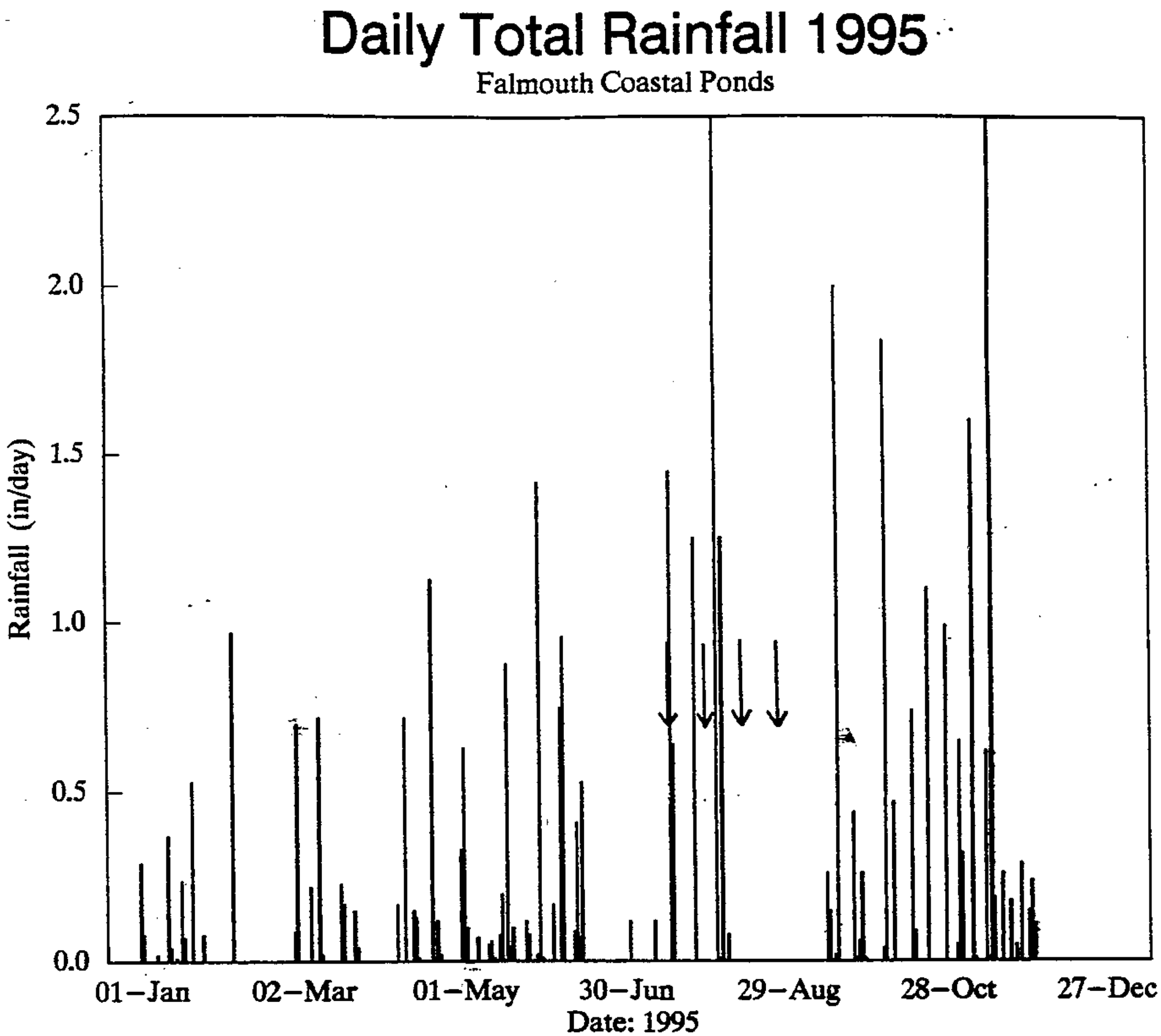

Citizens' Salt Pond Monitoring: 1987 – 95
Dissolved Inorganic Nitrogen in Freshwater Inflows to Headwaters.
200
150
100
50
0
Average DIN (uM); 1987 – 1995
24
35
35
23
24
Green
Little
Oyster
Bournes
Great
Coastal Salt Pond
B.L. Howes, WHOI Pondwatch Program
Groundwater Inflows corrected for Salinity; Numbers above bars = number of samples

Figure 5.



WHOI Sea Grant Pond Watchers
Arrows indicate 1994 pond samplings.

Figure 6.



WHOI Sea Grant Pond Watchers
Arrows indicate 1995 pond samplings.

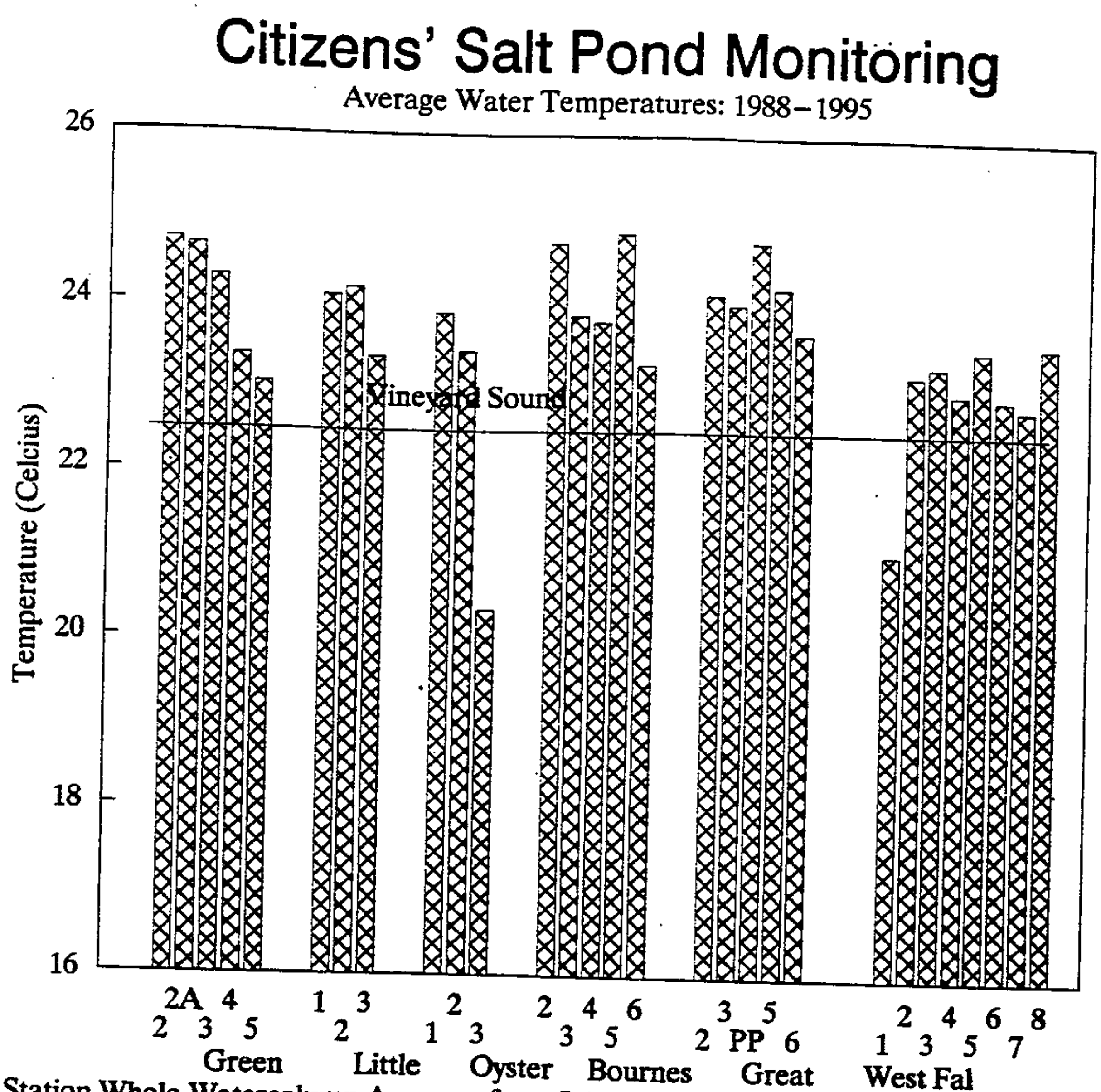
Figure 7.

waters (Figure 8). The only exception is the deep (>6m) basin of Oyster Pond which remains cold and unmixed throughout the summer.

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 was 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. Lower temperatures would have a significant effect upon oxygen uptake during the most critical period for pond oxygen depletion.

Given the variety of factors involved in controlling watercolumn oxygen levels and their shifting importance from year to year, it is likely that only through long term analysis will the issue be fully elucidated. It is clear, however, that the potential for water column stratification is closely linked to both the physical structure and flushing characteristics in concert with the overall nutrient load to the pond system (Figure 9). In general, water column stratification occurs more frequently in the more poorly flushed sections of each pond. These sites are generally the headwater regions which are typically the areas of highest nutrient and freshwater inputs, especially in the finger ponds. In contrast, Oyster Pond is more strongly influenced by the deep basin bathymetry and therefore is permanently stratified at the deepest part due to the physical limitations to mixing imposed by the basin depth.

Although similar in many respects, each pond maintains their own unique set of physical and biological characteristics that both determine the impact of human activities within the watershed and the effect of natural processes on pond water quality and ecological health. The complexity of these various interactions necessitates consideration of each system on a pond-by-pond basis in the development of management criteria. Through long-term data analysis, however, much can be gained in identifying seasonal and year to year variability within each pond, and similarities and differences between ponds under the same conditions of weather and tide, a primary objective of the sampling program.



Station Whole Watercolumn Averages from July and August Pondwatch Program, WHOI.

Figure 8.

Citizens' Salt Pond Monitoring: 1987 – 1995

Watercolumn Stratification: Surface vs Bottom

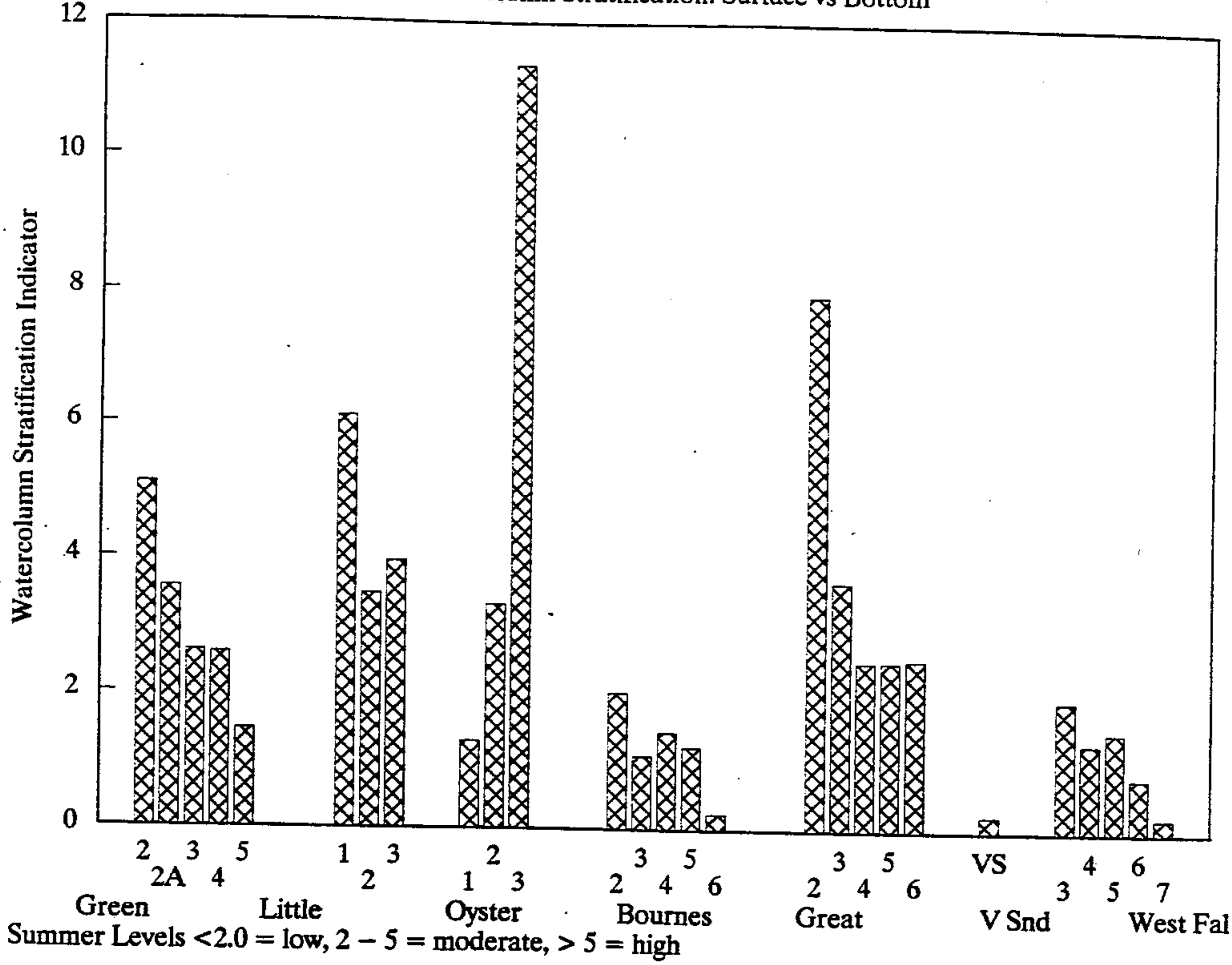


Figure 9.

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. The decline was correlated with 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. What was not known until recently is that the plume from the Otis AFB sewage treatment facility likely began discharging to the headwaters of Green Pond prior to 1995. At this time it is not known when this new source of nitrogen was added to the balance for Green Pond. However, part of the current Pond Watch Program for Green Pond is to ascertain the timing and load attributed to this plume and to attempt to determine its potential role in the continuing decline of this system.

The upper reaches of Green Pond have consistently 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 (Figure 10). We have been following a possible decline in oxygen minima and increasing nitrogen levels to gauge this effect (Figures 11, 12). The improved water quality associated with the large flush of Green Pond due to Hurricane Bob (and possibly some inlet scouring), appears to have been lost by 1994-95. While the oxygen depletions are not consistently as low as pre-Bob, the nitrogen levels at all stations have been higher than the 1987-90 mean in each of the past 3 years (Figure 12). It also appears that nitrogen levels may increase further based upon the temporal trajectory at some of the upper stations.

In contrast to the biogeochemical factors, what appeared to be a slow but steady decline in watercolumn transparency from 1988-1993 at the upper stations (with the exception of the "cleansing" effect of Hurricane Bob in 1991) was not supported by the 1994-95 Secchi data. While the transparency remains low, measurements have been relatively constant 1993-95 (Figure 13). Measurements of particulate organic carbon and secchi depth, however, do indicate that the turbidity observed in the pond is most likely due to algal production (Figure 14). The lower reaches of the Green Pond, closest to the inlet, had been maintaining moderately good water quality. The concern over potential declines in ecological health of Green Pond should not only focus on further declines in the uppermost (already degraded) regions but on the mid-region (Station 4) (Figure 15). It is the mid-region where the transition from low to high water quality occurs. It appears that increased nutrient loading which is seen in the continually rising nitrogen levels in the upper pond is now causing a migration down-pond of the low water quality region. Increasing nutrient loading is partially due to the long travel time for groundwater to discharge new nutrient sources to the pond waters, hence the effects may not yet be fully developed. Another factor in the growing eutrophication of Green Pond

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 appears that Green Pond Station 4 (above the bridge) has been transitioning from the water quality of the lower pond to that of the upper pond system.

Management: The past several years have been active ones concerning the management of Green Pond, most notable being the reconstruction of the Menauhant Bridge. After extensive consultations on design with the Town of Falmouth and local citizen's groups (most notably, Seacoast Shores Association), it was decided that the "new" bridge would basically conform to the original approachways and span. However, the hydrodynamics of Lower Green Pond were altered by the construction of the original Bridge in 1926, and we have documented the water quality declines within Green Pond (see above). The bridge reconstruction provided an opportunity to attempt a partial restoration of the transitional region of the pond (Station 4). Since the current bridge opening does not significantly restrict tidal exchanges with the upper pond, restoration could not be through enhancing flushing. Instead, an attempt was made to directly enhance particulate nutrient losses to the Sound by breaching the bridge causeways.

The approachways, as originally constructed consist of fill and are rip-rapped. They therefore act as barriers to the circulation of Pond waters. These "barriers," spanning more than two-thirds of the Pond's width, can affect Green Pond's ecological health in many ways: increasing the residence time of nutrients and biologically active particles within the Pond, altering velocity fields so as to increase organic deposition hence sediment oxygen demand, etc. The concept of nutrient remediation through "breaching" of the current approachways is based upon the need to return circulation (as opposed to volumetric exchange) to the conditions prior to the alteration of hydrodynamics associated with the original bridge construction in 1926.

As part of a parallel study, we investigated the effects of various hydrodynamic patterns relating to the Bridge's approachways and their ultimate impacts on nutrient retention and oxygen consumption. This portion of the effort required a detailed mapping of the patterns of sediment deposition adjacent to the causeway and determination of the impact of depositional patterns on rates of biogeochemical processes controlling water quality in these areas. In addition, since the long-term impact on water quality resulting from hydrodynamics associated with the Bridge approachways is directly coupled to the entry of "new" nitrogen to Green Pond from developed areas of the watershed, we evaluated present and future N loadings. Since the placement of causeway culverts could also result in changes in tidal range within the Pond, we determined the areal extent and plant species composition of each of the tidal wetlands within Green Pond in order to evaluate any changes in tidal range predicted from the hydrodynamic study. Using measurements by the Pond Watchers the potential relationship of the flow barrier established by the present approachway configuration and the oxygen demand of associated pond waters and sediments could be coupled with measured nutrient and oxygen levels in pond waters, animal diversity within the pond, and present and future nitrogen loading rates from the Green Pond watershed.

Nitrogen loading from the upland to Green Pond includes inputs from residential development (the primary source of nutrient loading to Green Pond), cranberry agriculture, a golf course and cemetery, undeveloped land and direct rain inputs. The Otis Plume has not been quantified at this time. We assessed the contribution of each of these sources from measurements of their area and measurements of nitrogen contributions from similar land uses within the region. Currently, residential development within the Green Pond watershed accounts for 78% of the total nitrogen loading to the Pond. Inputs from septic systems predominate with lawn fertilizers, impermeable surfaces and roads accounting for the remainder of the residential component. Inputs from cranberry agriculture and fertilization of the golf course and cemetery were less important, accounting for less than 18% of the total inputs, even though representing 28% of the watershed area. Direct rainfall and inputs from undeveloped land represent relatively small and unregulatable nitrogen sources. The effect of the surface biological filter is clear from the nearly 50 fold reduction in rainfall nitrogen when it falls upon nearly equal areas of naturally vegetated land before entering the Pond versus direct deposition on the Pond surface.

The results of the bridge studies indicated that the causeways did alter the circulation of the pond and did cause significant organic deposition on both the up and down pond sides. These deposits were highly organic and consisted of particles which would most likely have been flushed from the pond had "normal" circulation been in place. Oxygen uptake and inorganic nutrient regeneration from these deposits was found to be magnifying the impact of existing nutrient loads to the pond and facilitating eutrophication of pond waters. Hydrodynamic modelling (J. Ramsey, ACI) indicated that inserting culverts through either side of the causeway would result in tidal "jets", which would not increase the total volumetric exchange through the causeway, but would reduce the deposition in the present circulation "dead spots". These tidal "jets" were fashioned to provide flow velocities sufficient to maintain organic particles in suspension for export from Green Pond to the Sound. The goal is to slow or reverse of the decline in water quality of lower Green Pond. The remediation plan was backed by Rep. Cahir and Rep. Turkington and agreed to by the Massachusetts Highway Department. The remediation plan is being implemented and tidal "jets" will be placed in the causeway as part of the bridge costs (out of State funds). The culverts should be in place by the end of 1996, their impact will be monitored as part of the ongoing Pond Watch Program.

Great and Perch Ponds: The Great/Perch Pond system maintains nitrogen levels all above the levels specified in the Nutrient Bylaw (Figures 16, 17). 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. This system exhibited higher oxygen levels in 1992 apparently due to the cleansing effects of Hurricane Bob but by 1993 conditions were returning to those prior to the storm (Figure 18). By 1995 nutrient levels were at pre-Bob levels and periodic low oxygen events were again observed throughout the upper pond. The water quality of upper Great and Perch Pond in 1995 showed significant symptoms of eutrophication. The periodic low oxygen events, bottom water oxygen below 4 mg/l, are stressful to animal communities and lower the quality of the habitat.

Unlike the upper pond which has returned to the eutrophic levels of pre-Hurricane Bob, it is clear that the main basin of the lower pond (stations 5 & 6) is showing lower water quality from 1993-95 than 1990-92. Nitrogen levels are consistently higher throughout the lower basin over the past 3 years, although absolute concentrations remain significantly lower than those of the upper pond and Perch Pond. This nutrient increase has yet impacted oxygen concentrations (Figure 18) nor water column transparency (Figure 19) in the lower pond. It is likely that the higher exchange rates with Vineyard Sound and greater mixing in the main basin are helping to maintain the oxygen status of this part of the system. However due to the multiple factors influencing these parameters continued focus is warranted.

Perch Pond nitrogen concentrations, are too variable to suggest a trend. Oxygen and transparency values, however, have returned to pre-Hurricane Bob levels and are indicative of a stressed ecological system. The stress appears to be related to the high nutrient levels and salinity stratification of this kettle salt pond. Salinity levels were highly variable in both 1994 and 1995 with ranges of 10 ppt (Figure 20). The salinity regime reflects a restriction of exchange with Great Pond which allows the pond to freshen significantly after major rain events. The freshwater input also stratifies the pond with resulting impacts on bottom water oxygen levels (Figure 18). The interannual differences observed within the Great Pond system demonstrate the significant variability even in this large embayment and the importance of long-term monitoring for water quality assessment.

Management: Monitoring of the Great and Perch Pond system began in 1990. Overall, the Great Pond system is showing poor water quality (low D.O.) in the upper reaches and in Perch Pond and a trend

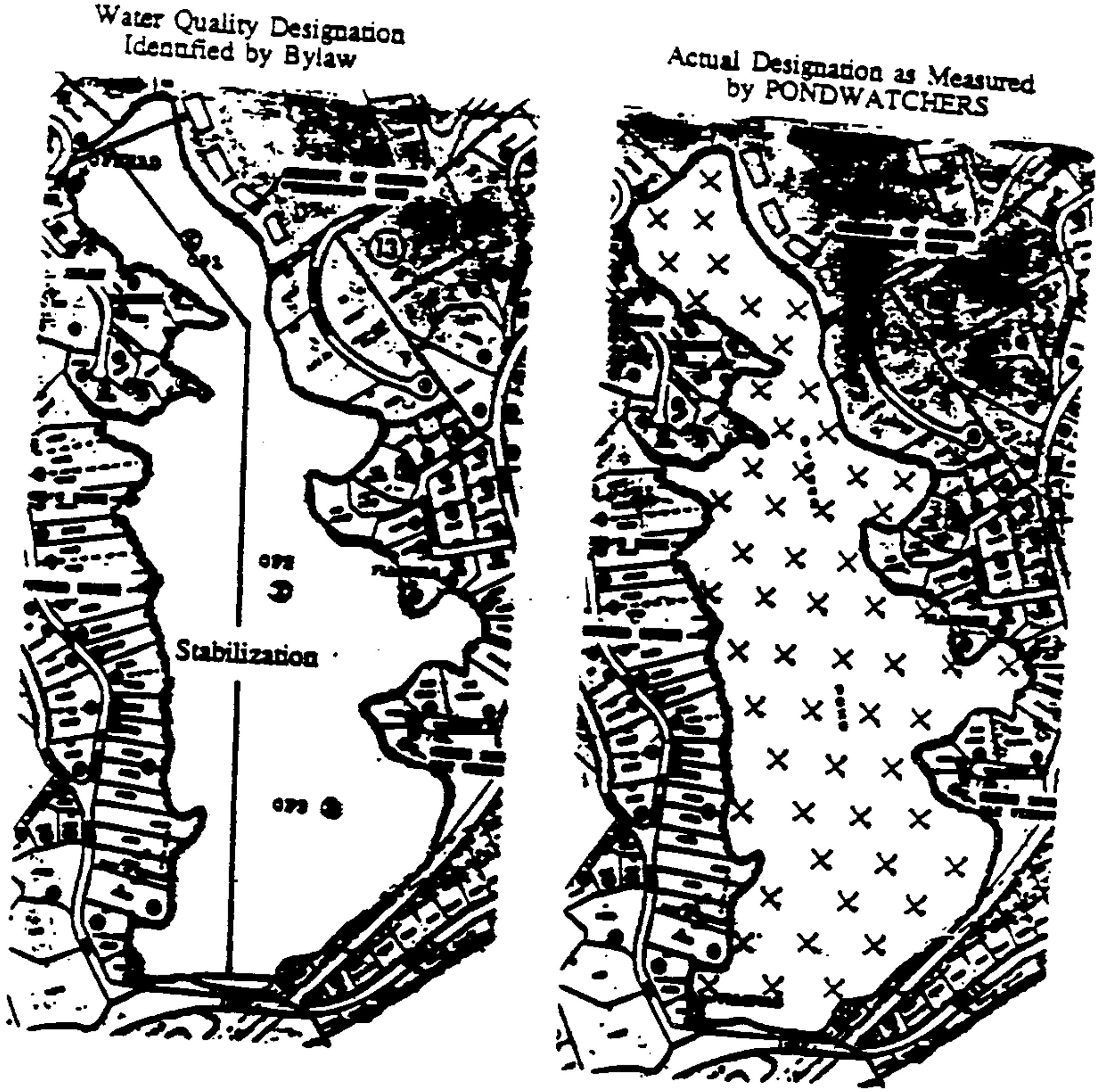
[redacted]

no indication that West Falmouth Harbor experiences periodic low oxygen events and the high water clarity allows sufficient penetration of light to support abundant eelgrass beds and a variety of animal communities. Although the plume from the Falmouth Wastewater Treatment Facility appears to be discharging to the Harbor system, it is likely that potential impacts may not be observed for another few years as the plume discharge becomes fully developed. Long-term monitoring of the system is important, considering the plume has the potential to effectively double the current nutrient load. West Falmouth Harbor's high nutrient assimilative capacity is likely to balance the additional nutrients entering the system. However, it is possible that localized impact may occur (particularly to the Snug Harbor region). Given the difficulty in quantifying and delineating the current extent of the plume we can project only from the existing data base. The Pond Watch Program will continue its focus on this system to provide vital "before and after" data as the plume continues to discharge and will focus on separating natural variation from nutrient related impacts. Additional study of the Snug Harbor marsh area by Pond Watch is likely.

Oyster Pond: What follows is an overview of the current ecological health and management plan for Oyster Pond. A more complete review is presented in Appendix IV.

Somewhat unique in our suite of monitoring ponds due to its physical structure, Oyster Pond represents a highly eutrophic system with significantly restricted tidal exchange and substantially lower salinity waters than all of the other systems. All stations in Oyster Pond have mean watercolumn nutrient concentrations above 1 mg/l, well above the bylaw limits (Figure 28). As the most eutrophic of the ponds, Oyster Pond maintains the highest nitrogen levels and lowest oxygen concentrations, especially in its deep basins (Figures 29, 30, 31; note different vertical scales in Figure 29 for perspective). The impact of these high nutrient levels are also reflected in the low watercolumn transparency (Figure 32) and high turbidity (Figure 33; resulting primarily from algal production) within the pond. In the initial years of study the 2 shallower 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 these 4 m and 3.25 m deep basins in summer. The deeper the basin the longer the period of anoxia during summer (Figure 34 & 39, B. Norris Special Project), This relationship is critical for interpreting the potential for restoring oxygenated bottom waters to generated increased habitat in some of the shallower basins. The main basin (Station 3) has had continuously anoxic bottom waters at least for several decades.

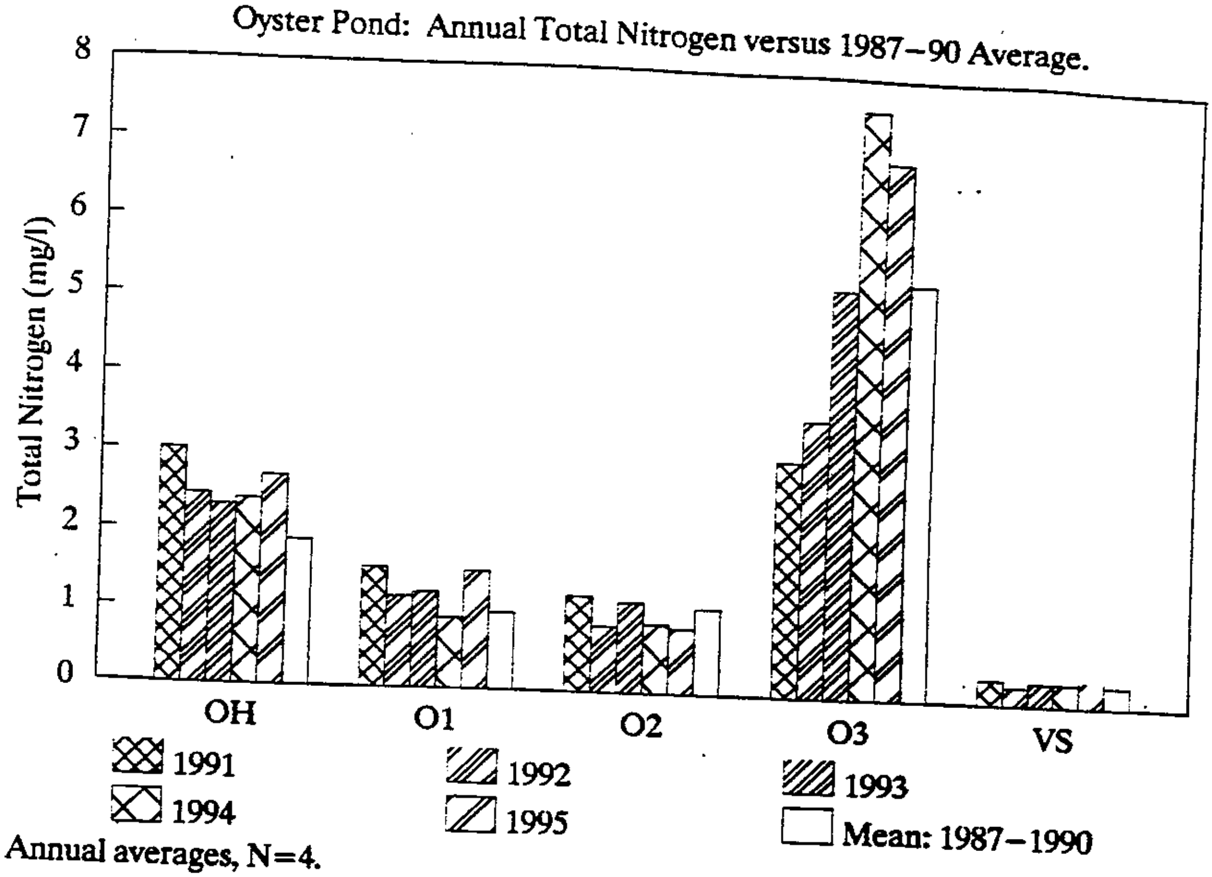
Oyster Pond station locations and Water Quality Designation as identified by Coastal Pond Overlay Bylaw (adopted by Falmouth Town Meeting, April. 1988) and actual designations according to the Bylaw as measured by Falmouth Pondwatchers.



"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	
< 0.32 mg/l	= High Quality Area	○

Figure 28.


Oyster Pond: Annual Total Nitrogen versus 1987–90 Average.
Total Nitrogen (mg/l)
8
7
6
5
4
3
2
1
0
OH
O1
O2
O3
VS
1991
1992
1993
1994
1995
Mean: 1987–1990
Annual averages, N=4.

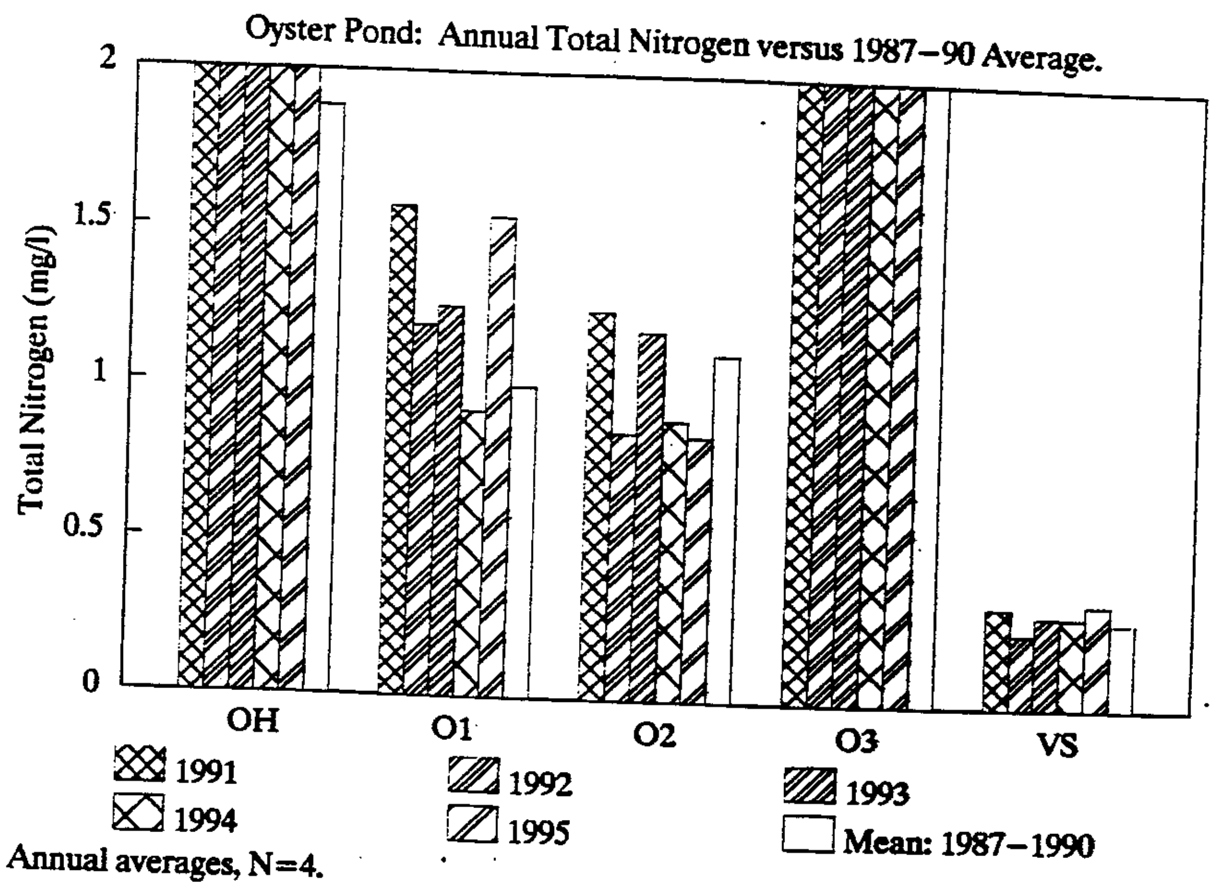
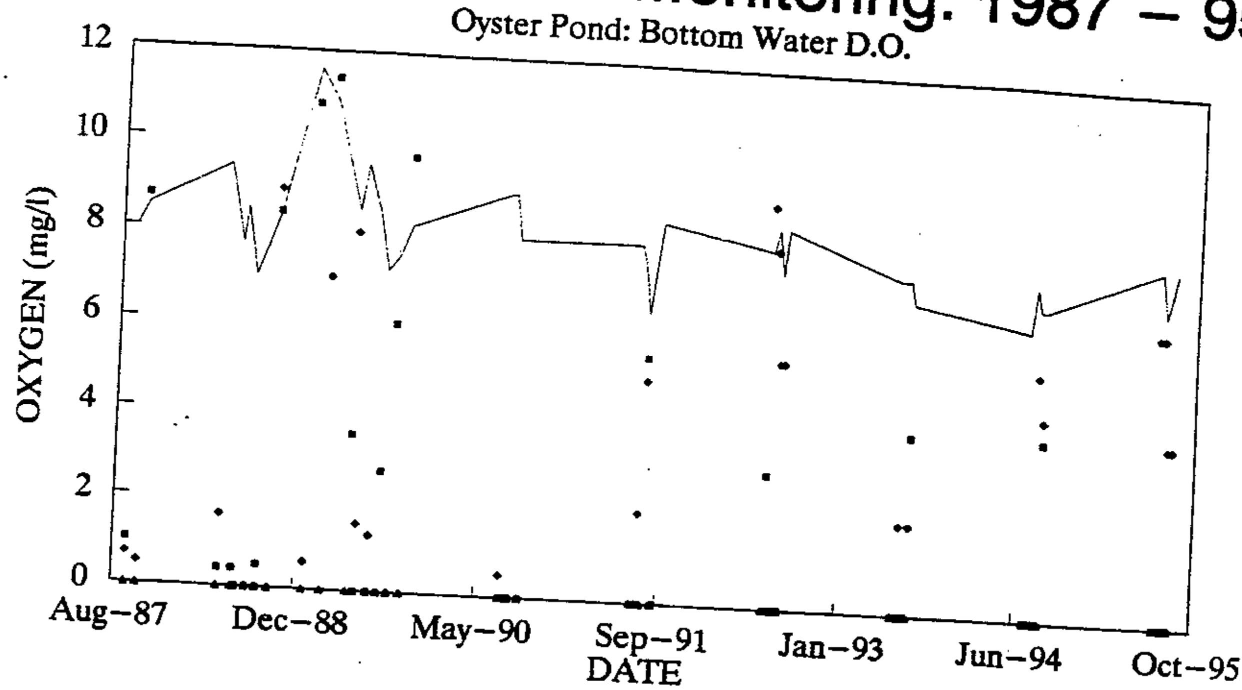

Oyster Pond: Annual Total Nitrogen versus 1987–90 Average.
Total Nitrogen (mg/l)
2
1.5
1
0.5
0
OH
O1
O2
O3
VS
1991
1992
1993
1994
1995
Mean: 1987–1990
Annual averages, N=4.

Figure 29.

Citizens' Salt Pond Monitoring: 1987 – 95



Pond has been losing salinity over the past 4 years.
Hurricane Bob: August 1991; Major Storms in August 1992.

Figure 30.

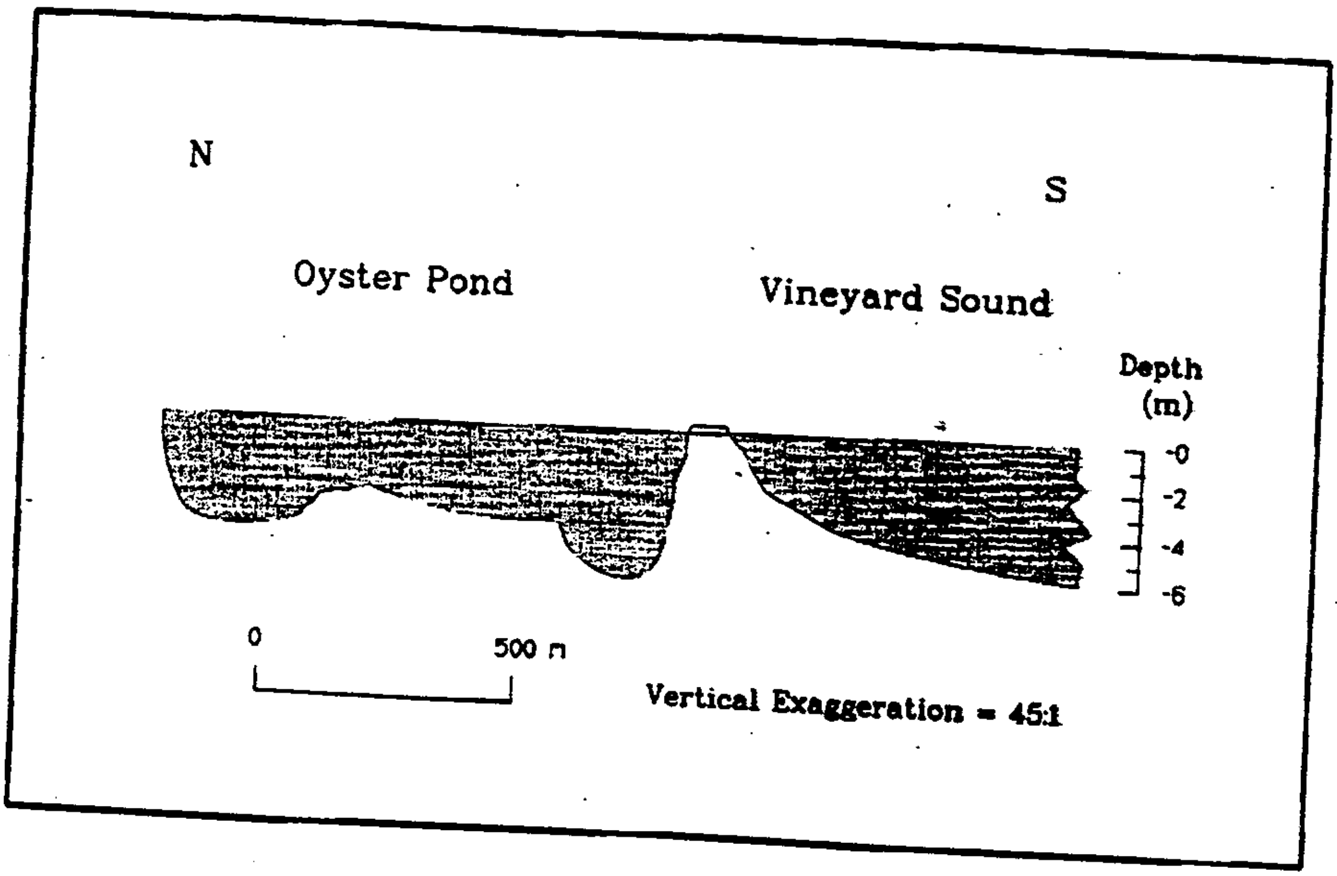
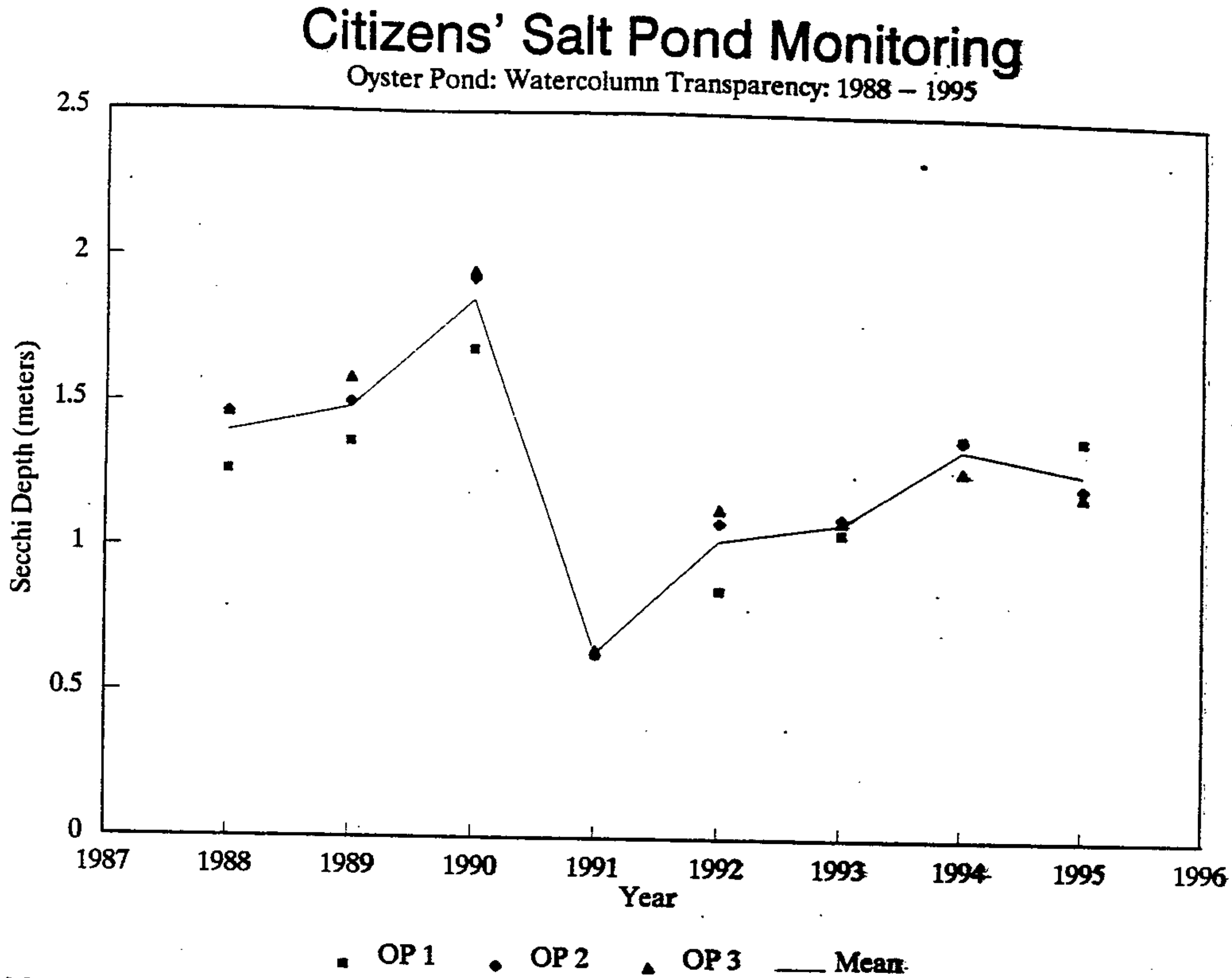
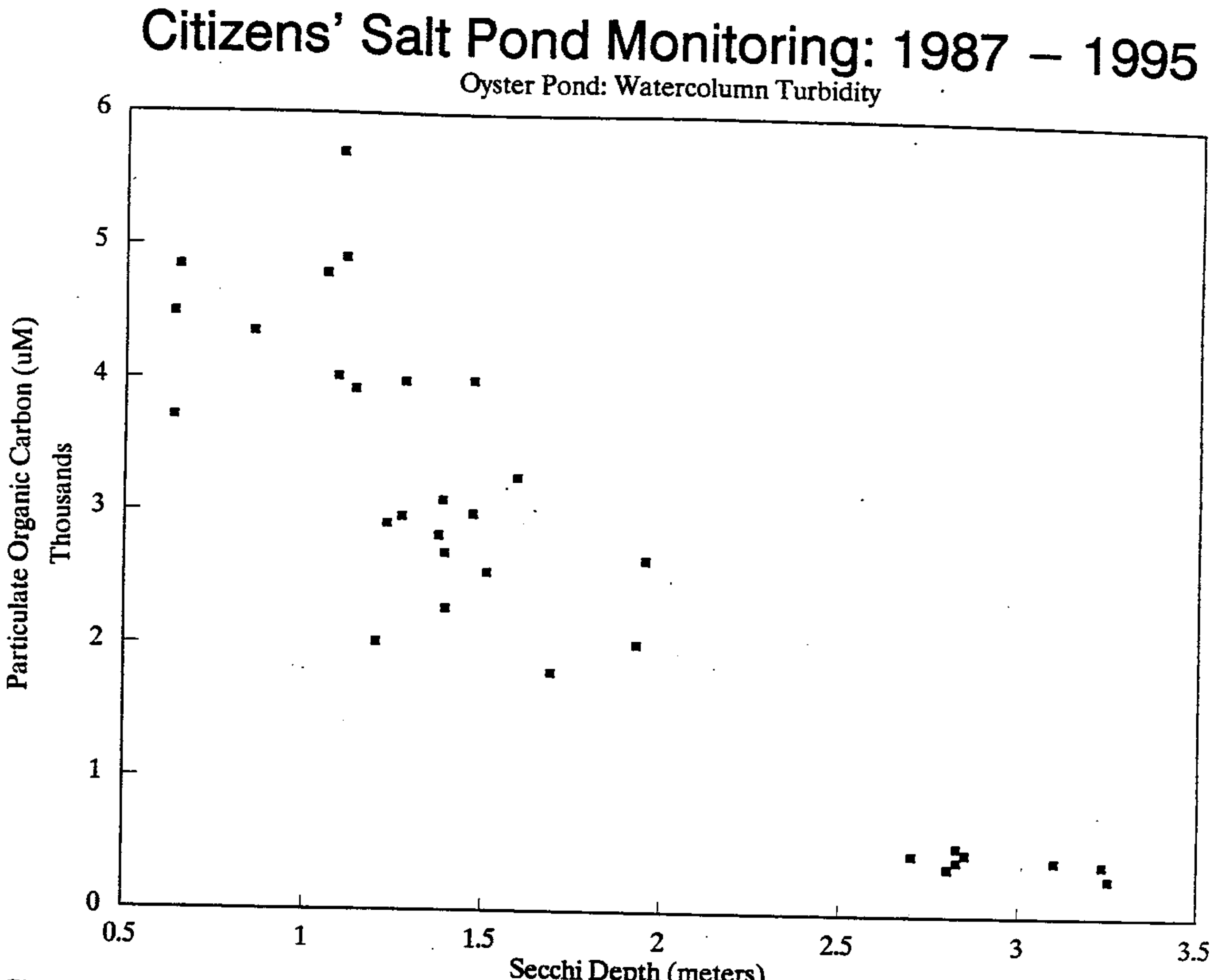

N
S
Oyster Pond
Vineyard Sound
Depth
(m)
-0
-2
-4
-6
0
500 m
Vertical Exaggeration = 45:1

Figure 31.



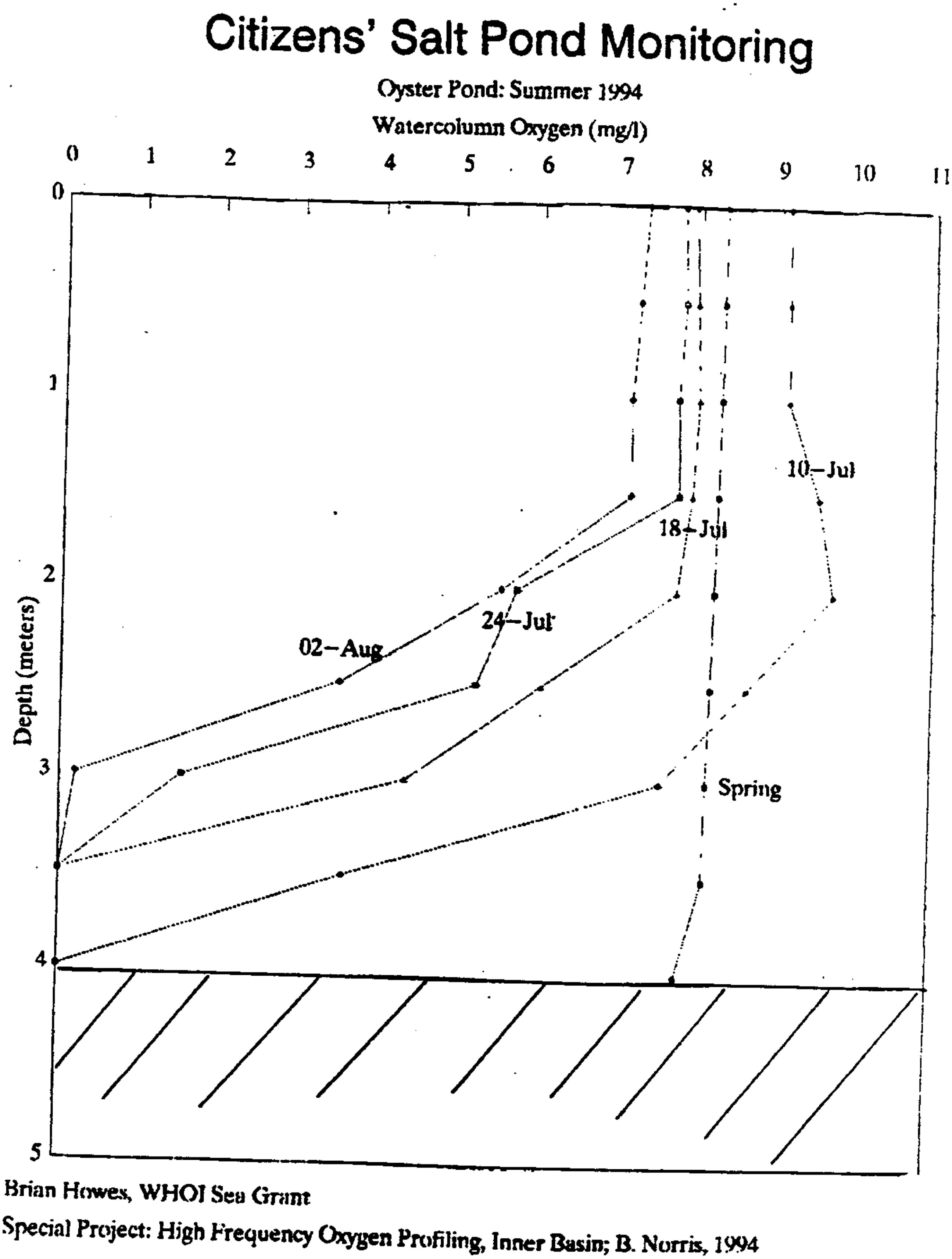
Means depths: June – August.
Hurricane Bob: August 1991

Figure 32.



Cluster of Higher Secchi Depths from Vineyard Sound.
Secchi Depth logarithmicly related to POC suggesting algal growth controlling turbidity.

Figure 33.



Citizens' Salt Pond Monitoring
Oyster Pond: Summer 1994
Watercolumn Oxygen (mg/l)
0
1
2
3
4
5
6
7
8
9
10
11
Depth (meters)
0
1
2
3
4
5
10–Jul
18–Jul
24–Jul
02–Aug
Spring
Brian Howes, WHOI Sea Grant
Special Project: High Frequency Oxygen Profiling, Inner Basin; B. Norris, 1994

Figure 34.

The anoxia and/or the frequency and duration of low oxygen conditions was shown to significantly increase with depth in the water column, with nearly 70% of measurements conducted between July and August 1994 showing less than 0.4 mg/l in the main basin (Figure 35). In addition to low oxygen conditions, limitations to light penetration and high sulfide concentrations in the deep basin waters result in over half of Oyster Pond unsuitable for establishment of animal and plant communities. At present over 40% of the benthic habitat in Oyster Pond is devoid of animal communities for much of the year although the frequency of summer oxygen in the inner basins is increasing.

Unlike the other ponds where nutrient levels declined after Hurricane Bob, Oyster Pond showed higher levels in the inner 2 basins. Mass balance indicates that the mixing associated with Bob, injected some of the high nutrient water from the deep basin into the surface waters. The result was to enhance the surface waters of the pond, but lower the nitrogen levels in the basin of OP3 (Figure 29). This is clearly seen in the large decrease in nitrogen levels in 1991 compared to the previous years. The up-mixing of the nutrient rich water resulted in a major phytoplankton bloom in the pond and a significant reduction in water clarity (Figure 32). Over the intervening years, it appears that nitrogen deposition and regeneration in the basin at OP3 is recharging the deep water.

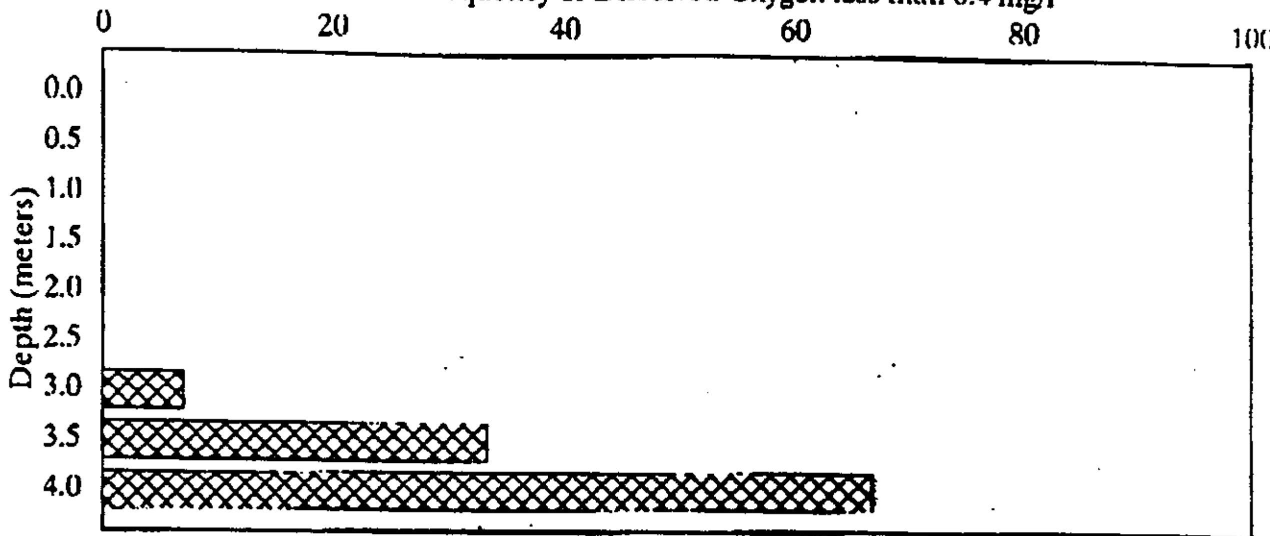
Management: Oyster Pond has been a major focus for the Pond Watch Program in recent years. The pond (with Little Pond) has been slated for restoration of water quality. Unlike Little Pond the cause of the eutrophic conditions in Oyster Pond is mediated by natural physical factors. The poor water quality conditions found in Oyster Pond result from its current nutrient loading, its restricted inlet, and its deep basins. The physical nature of this pond is a major factor as its depth and salinity stratification limits mixing of the water column from top to bottom. This stratification allows for the depletion of oxygen in the pond's bottomwaters. The salinity stratification is a direct result of the basins collecting the occasional pulses of salt water into the pond and the continual input of freshwater to the pond surface helping to maintain a greater than 5 ppt gradient from surface to bottom. This factor represents a natural process and would exist regardless of the level of nutrient loading to the system. In contrast, the amount of nitrogen loading to the shallower areas of the pond (<3m) may significantly influence their habitat quality for colonization by animal and plant communities.

Contributions of nitrogen from the Oyster Pond watershed (Figure 36) are limited primarily to on-site septic disposal of human wastes (63%), fertilizers and other residential inputs (20%) and rainfall and natural areas (17%). Although the watershed has seen a rapid population increase over the last 20 years, population density remains very low in relation to some of the other south facing ponds being

Citizens' Monitoring Program

Oyster Pond, Station 1: July–August 1994

Percent Frequency of Dissolved Oxygen less than 0.4 mg/l



Measurements by Barry Norris, 1994

Frequency based upon 57 measurements, 0700–0900hrs; Bottom= 4.0 meters.

Figure 35.

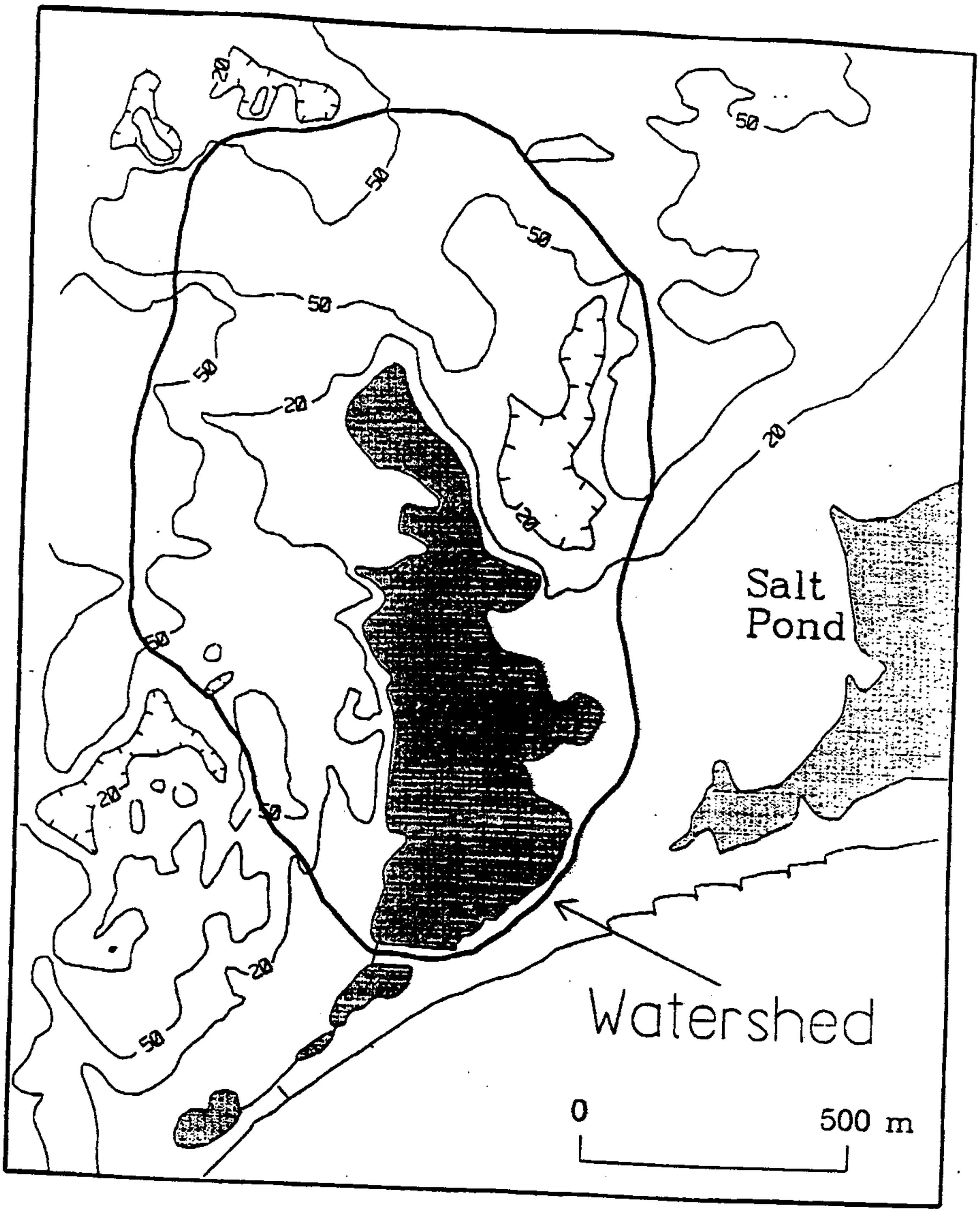

20
50
50
50
50
50
20
20
20
Salt
Pond
50
20
20
20
50
Watershed
0
500 m

Figure 36.

monitored. The level of nitrogen input to the pond is being magnified by the ponds configuration and salinity structure maintaining it in a eutrophic state.

Given the roles of pond hydrography and salinity on Oyster Ponds overall ecological health, these parameters were central to the restoration and management plan. Historic salinity records indicate that occasional massive salinity intrusions like Hurricane Bob and during the 1938 hurricane function to maintain salinity stratification (top less salty-lighter, bottom more salty- heavier) when coupled with the limited exchange of salt water and surface input of freshwater (Figures 37, 38, 39, 40). Because of the unique nature of the Oyster Pond system, any potential remediation measures to resolve the pond's low bottom water oxygen conditions would require significant effort to minimize or eliminate the system structuring nature of the salinity-based stratification. In addition, the salinity history (Figure 38) clearly indicates that for the first 40 years of the 50 year record that Oyster Pond had very low salinities (2-4 ppt) and was essentially a brackish coastal pond. During this interval even the deepest basin was observed to become oxygenated by complete pond mixing during winter. Alteration of the inlet during the late 1980's allowed a large entry of tidal water from Vineyard Sound which increased the pond surface water salinity more than 4 fold. It was this rapid salinity shift which is responsible for the ecological shifts observed by local residents. These included changes in marginal plant communities to more salt tolerant species and the decline of brackish water fish species (including herring).

At present the restoration and management plan for Oyster Pond is aimed at returning the Pond to pre-1985 conditions (see Appendix IV for details of alternative plans). The goal is to restore the salinity structure of the pond to brackish levels via a tidal restriction at the ponds current outlet under Shore Drive. The restriction will be configured to allow free passage of fish but only enough salt water inflow to keep the pond in the 2-4 ppt range. The tidal restriction will be adjusted based upon monitoring data collected by Pond Watchers for salinity maintenance and ecological recovery. Measurements in 1994 indicate that as the pond has naturally freshened that vertical mixing in the inner basins has also increased. The result has been that these shallower basins are oxygenated through all or most of the summer. With further freshening, a significant increase in the pond bottom will be oxygenated year-round providing a major increase in habitat and enhancing the ecological health of Oyster Pond. This restoration program has proceeded through the engineer stage (J. Ramsey, ACI) and is in the construction phase. It should be noted that the tidal restriction plan was the least costly of the alternative plans. It is likely that more than 5 years will be required after salinity stabilization to realize the full impact of the restoration project.

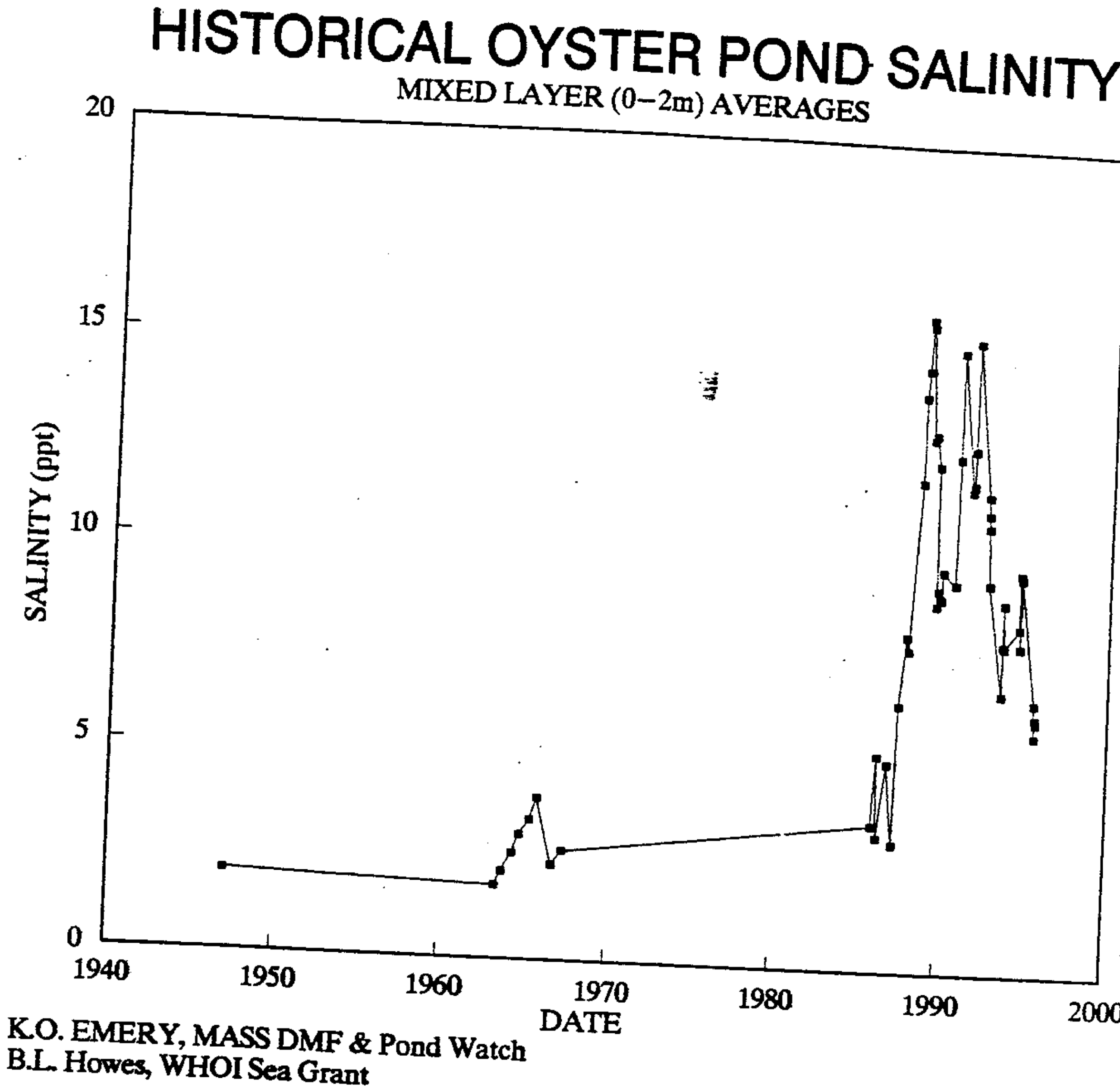

HISTORICAL OYSTER POND SALINITY
MIXED LAYER (0–2m) AVERAGES
SALINITY (ppt)
20
15
10
5
0
1940
1950
1960
1970
1980
1990
2000
DATE
K.O. EMERY, MASS DMF & Pond Watch
B.L. Howes, WHOI Sea Grant

Figure 37.

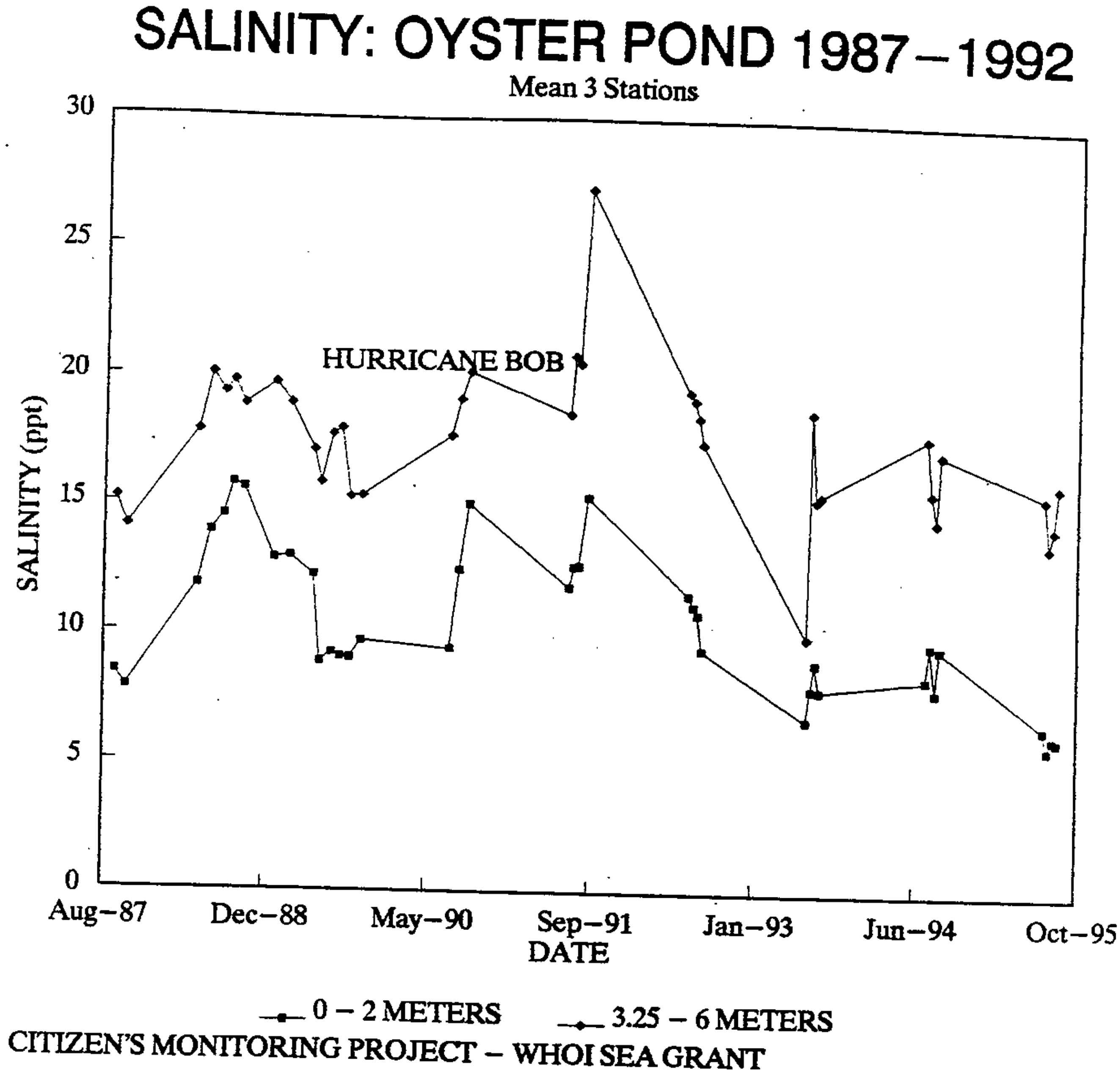

SALINITY: OYSTER POND 1987–1992
Mean 3 Stations
SALINITY (ppt)
30
25
20
15
10
5
0
HURRICANE BOB
Aug–87
Dec–88
May–90
Sep–91
Jan–93
Jun–94
Oct–95
DATE
0 – 2 METERS
3.25 – 6 METERS
CITIZEN'S MONITORING PROJECT – WHOI SEA GRANT

Figure 38.

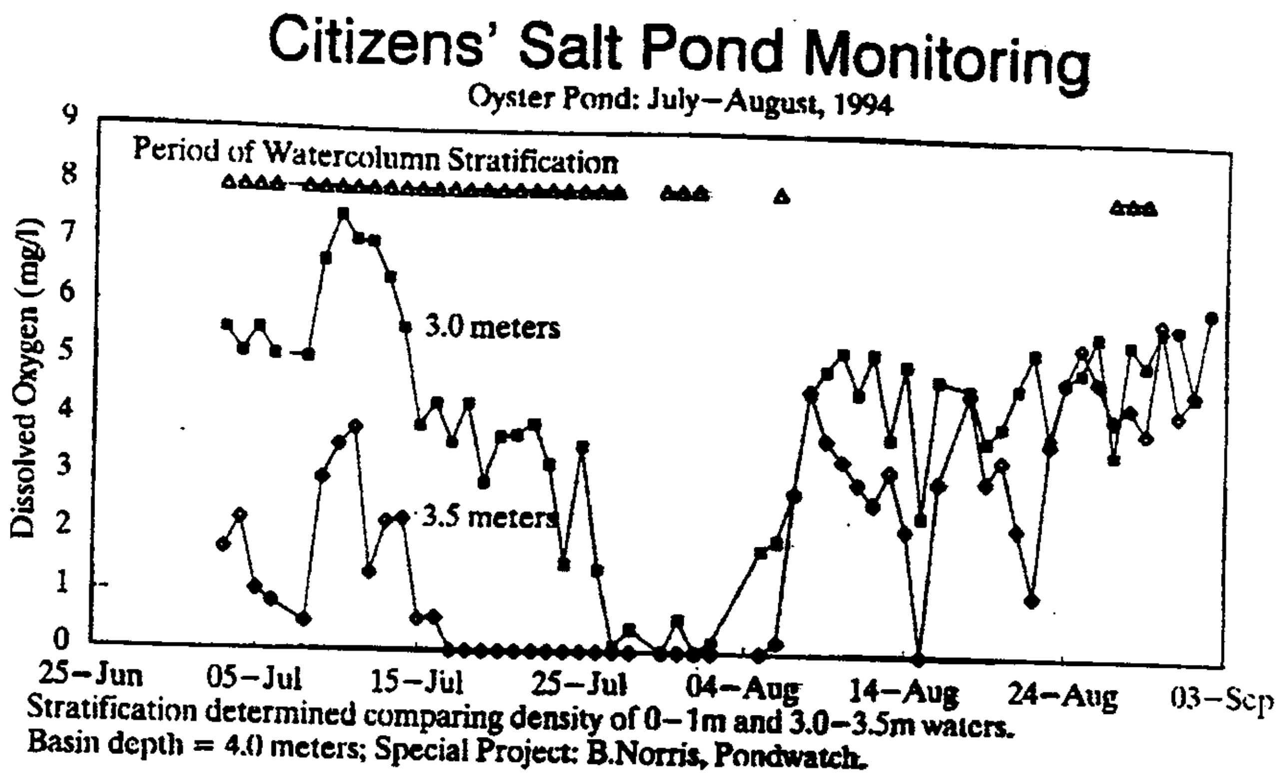
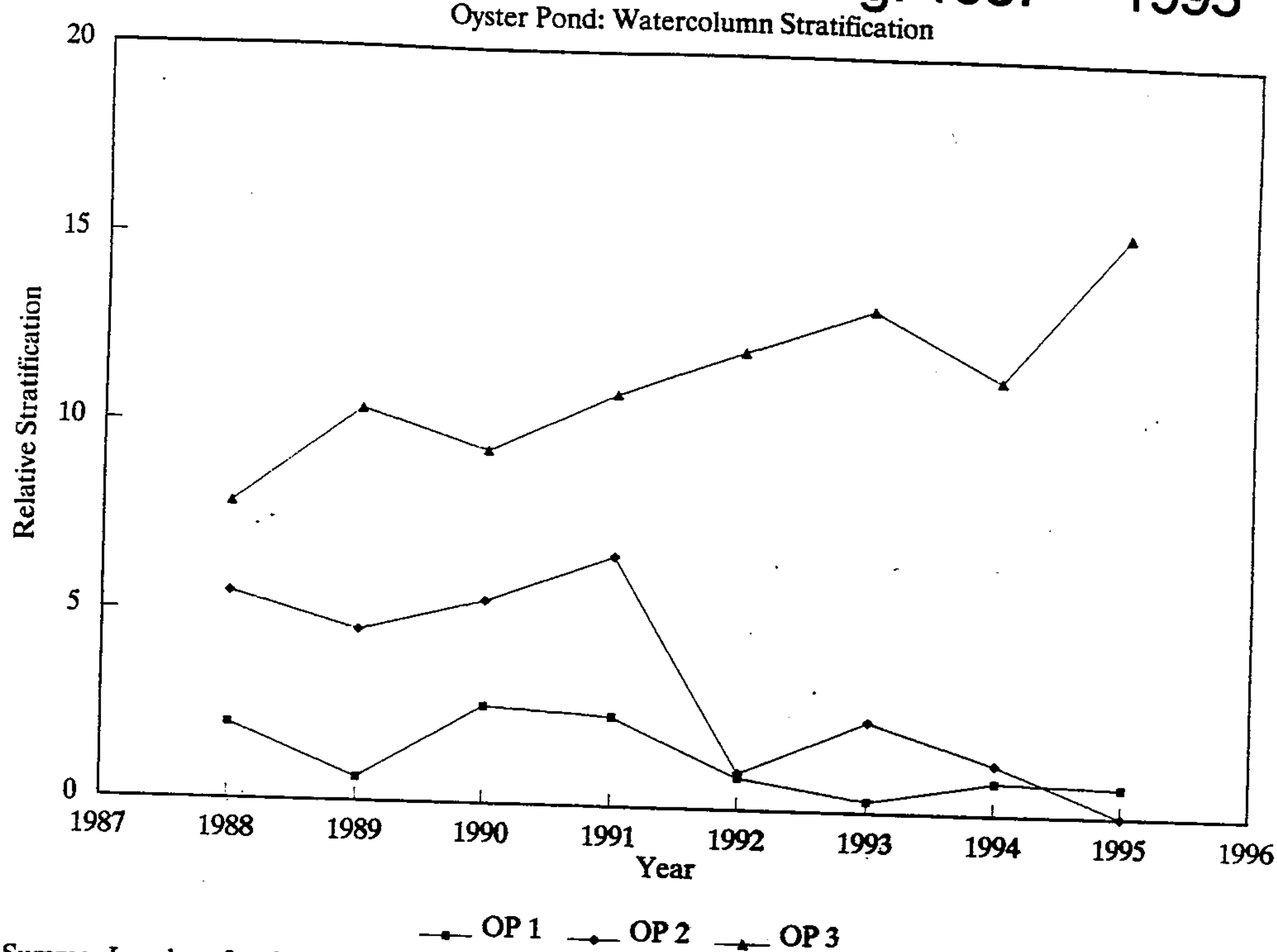

Citizens' Salt Pond Monitoring
Oyster Pond: July–August, 1994
Period of Watercolumn Stratification
3.0 meters
3.5 meters
Dissolved Oxygen (mg/l)
0
1
2
3
4
5
6
7
8
9
25–Jun
05–Jul
15–Jul
25–Jul
04–Aug
14–Aug
24–Aug
03–Sep
Stratification determined comparing density of 0–1m and 3.0–3.5m waters.
Basin depth = 4.0 meters; Special Project: B.Norris, Pondwatch.

Figure 39.

Citizens' Salt Pond Monitoring: 1987 – 1995



Summer Levels: <2 = low, 2 – 5 = moderate, >5 = high
Determined by comparing sigma t of Surface and Bottom water.

Figure 40.

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 New Culvert Need to Maintain Inlet Sediments
Oyster Pond	Deep Basin (naturally Eutrophic) Too Little Flushing	Increase Flushing (Salt Water Solution) Limit/Cease Flushing (Fresh Water Solution)

Appendix IV. Oyster Pond - Three Decades of Change (Addendum to the reprinting of K.O. Emory's Book "A Coastal Salt Pond Studied by Oceanographic Methods")