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Lagoon Pond Study:
An Assessment of Environmental Issues
and
Observations on the Estuarine System

Final Report
WHOI Proposal 3599

Prepared for the Boards of Selectmen
Town of Oak Bluffs
Town of Tisbury
Martha's Vineyard, Massachusetts

by

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ABSTRACT

Issues and problems surrounding use of Lagoon Pond are identified, documented (where possible) and discussed. Principal concerns involve: public health; shellfishing; navigation and moorings; recreation; and environmental quality. Some of these can be addressed or resolved using existing government bodies or technologies. For example, public health concerns such as failing septic systems are the responsibility of State and local government bodies that set standards, approve designs, monitor water quality, enforce regulations and mitigate problems. For proposed navigational improvements, the needed technology is available and if the appropriate town decides that the public interest is served and costs are justified by benefits, realization of the project is a matter of logistics. Resolution of still other issues, such as arise from conflicting recreational uses of the Lagoon, revolves about the political process institutionalized in exiting government bodies and processes. However, some concerns relate to manifestations of complex ecological processes that are not sufficiently understood to confidently identify remedial steps. Issues surrounding shellfishing and environmental quality are examples. A further difficulty is that some of these issues are based on perceptions that are difficult to document or could not be supported by available data. In some of these cases improved record keeping may be needed.

Aspects of the Lagoon Pond estuarine system are characterized using existing information and limited new data. The significance of land use to estuarine water quality is identified as an important consideration requiring greater attention. Data on nutrient concentrations, salinity distribution, tidal exchange, freshwater input and other variables are presented, which begin to provide a basis to evaluate future changes in the Lagoon Pond system, to compare the Lagoon with other estuaries on the Cape and Islands, and to plan future studies. Results of this work have already been used to identify data gaps and help shape the currently ongoing "Clean Lakes Program" study of Lagoon Pond, the first such study in Massachusetts to address an estuarine body.

CONTENTS

FOREWARD

In 1604 Bartholomew Gosnold founded the first European colony in America on a small island in a coastal pond at Cuttyhunk. Although the colony was not to become a permanent one, over the years people have continued to be attracted to the shelter, resources and peaceful vistas of coastal ponds. As the remote Cape and Islands' fishing and farming villages of 17th, 18th and 19th centuries have given way to burgeoning towns of today, many of the uses of coastal ponds have become sources of conflict. Examples are the conflict between active and passive recreation, residential versus commercial development, recreational versus commercial fishing, and so forth. As the scale and density of human activity increases, new and more subtle kinds of problems have become evident. One example, central to this study, is the contamination of groundwater with sewage-derived nutrients and their impact where these materials discharge with the groundwater in streams, wetlands and estuaries.

The present study has roots that go back to discussions I had with a former director of the Martha's Vineyard Commission several years ago. He expressed concern with possible water quality degradation in Lagoon Pond, and our discussion reminded me of similar ones I had (and continue to have) with selectmen, shellfish wardens and interested individuals from around Cape Cod and the Islands: they are deeply concerned with environmental deterioration but have few economic or staff resources to respond, and little access to expert advice. At the Marine Assistance Service our difficulty in providing assistance stems from three constraints:

a) The perceived problem (e.g. overabundance of seaweeds or jellyfish or starfish, reduced abundance of fish or shellfish, etc.) is often likely to be only one manifestation of more profound ecological changes or interactions, which in themselves are not sufficiently well understood by scientists to permit effective management.

b) Commonly the perceived problem carries significant value judgment or aesthetic content. For example, concern for siltation often presumes boating should be encouraged; alarm over water discoloration may presume uses such as swimming should have priority over shellfishing. In many of these instances resolution of the issue calls for the political process, not scientific advice (although often scientific arguments are used to "support" concerns based in aesthetics).

c) The Marine Assistance Service itself has only modest staff and resources.

Nevertheless, by working with town and regional officials and concerned individuals we feel we can provide useful assistance in certain ways:

a) To characterize coastal ponds with regard to their physical, chemical, geological, and biological features using existing information and limited new data.

b) To help document, clarify, assess and rank concerns and problems of coastal ponds from a relatively objective viewpoint.

c) To recommend future courses of action, where appropriate.

To date, we have studied three coastal ponds on the Cape and Islands. Table 1 outlines some of the steps and information involved; Figure 1 gives the locations of these water bodies.

The study reported on here was jointly conducted by the Martha's Vineyard Commission (MVC) and WHOI Sea Grant. The Towns of Oak Bluffs and Tisbury each approved expenditures of $2,000 in support of the project, which funds went primarily toward water analyses. Mr. Douglas Ewing of MVC coordinated interactions with the Towns and with an ad hoc Lagoon Pond Study Committee which provided us with information and field assistance (Table 2). As I indicated to the Selectmen at the outset, "...this is a very small study, with modest resources and objectives and we cannot be expected to 'solve' the problems of Lagoon Pond. On the other hand, by bringing the issues into sharper definition it is possible that some of the 'problems' will be found not to exist at all, to be insignificant, or to be readily addressed. Others may be insoluble for practical purposes." One of the principal accomplishments of the Committee's work, in cooperation with Ms. Chris Duerring of the Division of Water Pollution Control, was to assist in designing the first Clean Lakes Program study of an estuary in Massachusetts, now ongoing in Lagoon Pond. We have spoken with the contractors for that study and they were given copies of all field data collected by our study prior to beginning their work.

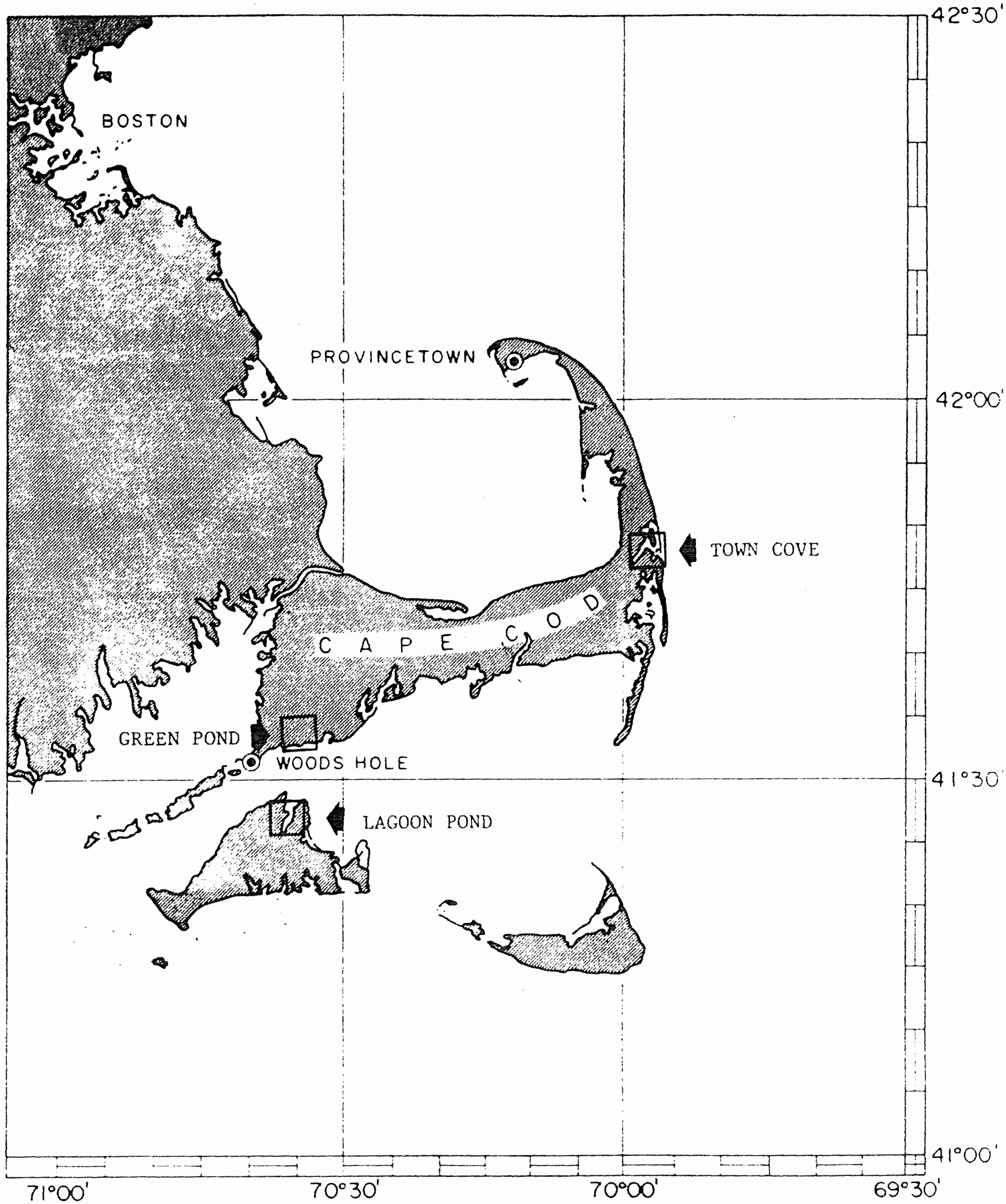


Figure 1. Location map for Lagoon Pond, Martha's Vineyard, Massachusetts, and other area coastal ponds included in this study.

Table 1. Study elements and their status for the Coastal Ponds Project for Cape Cod and the Islands. The three ponds presently involved are Lagoon Pond (Tisbury and Oak Bluffs), Green Pond (Falmouth) and Town Cove (Orleans). X= complete; P= partial.

	Lagoon Pond	Green Pond	Town Cove
Pre-Study Technical Consultation			
Technical Working Group	X	X	X
Definition of issues	X	X	X
Survey of Public Opinion	X	-	-
Definition of Assistance Capacity			
Existing Information	P	P	X
Technical Group Participation	X	X	X
Fieldwork	X	X	X
Definition of Landform			
Natural Features	X	P	X
Anthropogenic Modifications	X	X	X
Watershed	X	X	X
Recharge Area	X	X	X
Tidal Analysis	P	P	X
Freshwater Balance	P	P	X
Spatial Definition of Variables			
Axial Transects	P	P	P
Areal Surveys	P	P	P
Vertical Profiles	-	P	P
Primary Productivity	P	P	X
Nutrient Fluxes	P	P	X
Living Resource Inventory	-	-	-
Future Courses of Action	P	P	P

Table 2. Composition of the Lagoon Pond Study Committee.

Ms. Margeurite Bergstrom	Mr. Rick Karney
Mr. Ed Bugbee	Mr. Donald King
Mr. Donald Burt	Ms. Doris Low
Mr. Robert Culbert	Ms. Judy Miller
Ms. Susan Custer	Ms. Karen Ogden
Ms. Chris Duerring	Mr. Ned Rice
Ms. Edith Eber	Mr. Russ Smith
Mr. Douglas Ewing	Mr. Michael Syslo
Mr. David Franz	Ms. Ruth Todd
Dr. Arthur Gaines	Mr. Bill Wilcox
	Mr. Michael Zoll

ACKNOWLEDGEMENT

In the course of this work the Lagoon Pond Study Committee has been an effective and energetic source of information, concern and encouragement--hopefully they will not consider the appearence of this report the signal for the end of their labors. I suspect they won't. Special thanks go to Mr. Douglas Ewing who was the kingpin for this study, and Mr. Russ Smith, both of Martha's Vineyard Commission. Mr. Edwin Bugbee, in addition to his substantial work in many other areas, provided transportation and assistance in the field. Mr. Michael Syslo let us set up lab in the Lobster Hatchery; and Mr. David Franz provided use of his boat for our 30-hour time series in the Lagoon.

Chemical analyses were performed in the WHOI Analytical Facility by Dr. Zophia Mlodzinska. I was assisted in the field by Ms. Jenny Olson and Ms. Susan Cherkofsky. The study was supported by funds from the Town of Tisbury and the Town of Oak Bluffs, with salary support from Woods Hole Oceanographic Institution Sea Grant Program (Grant # NA83-AAD-00049 and NA84-AAD-00033) and from Martha's Vineyard Commission.

GEOLOGICAL AND HISTORICAL OVERVIEW OF LAGOON POND

Lagoon Pond lies in a landform that owes much of its present geometry to its glacial origin. The valley occupied by this estuary and by Vineyard Haven, including the deep basins of the Upper Lagoon and major contours now defining shoreline configuration (Figure 2) were formed roughly 10,000 years ago, when buried ice blocks melted during late glacial times. Hence the cliffs and steep slopes comprising much of the shoreline of the Lagoon were not formed by erosion, but instead by collapse of glacial sediment into a depression left by melted ice. The individual basins of Lagoon Pond indicate that more than one ice block was present.

Since a considerable amount of water was tied up as ice during the glacier, sea level was much lower than at present--approximately 300 feet according to our best information. Therefore, when the ice melted in the area of Martha's Vineyard (which was the first area of glacial retreat) Vineyard Sound was absent and the Vineyard was merely a low hill on the plain extending south from Cape Cod. Within a few thousand years, however, most of the North American ice cap had melted and the sea began to inundate the glacial landscape of southern New England. Included on that landscape were numerous hummocks and fresh ponds, and some water bodies we know as estuaries today were originally occupied by freshwater. One known example is the Narrow River in Rhode Island (Gaines, 1975) where cores of the sediments show a layer of recent estuarine mud underlain by freshwater mud. It is possible that the deep basins of Lagoon Pond are other examples of former fresh ponds, but definitive word must await a study of the sediments there.

As the sea came to bear upon the glacial landscape, areas exposed to waves and currents were eroded and modified, in some places producing cliffs (such as on the outer Cape and the south shore of Martha's Vineyard). Movement of sand produced barrier beaches and spits, such as at Cape Pogue. The barrier between Vineyard Haven and Lagoon Pond is at least partially a barrier beach, probably formed a few thousand years ago as sand from the exposed cliffs at East Chop was driven southward by waves along the shore.

The natural condition of what is now the causeway is depicted in historical maps and charts, such as those shown in Figure 3. The earliest chart shown here, made in 1860 (unfortunately, reproduction quality is poor) shows a barrier beach extending across the mouth of Lagoon Pond all the way to near what is now "five corners", where a natural inlet permitted exchange between the Pond and Vineyard Haven harbor (then known as Holmes Hole Harbor). A second inlet is shown near the site of the present inlet, along with a shoal near the location of the present launching ramp on the causeway. The origin of this shoal is most likely as a flood delta, produced when sand from outsde the Lagoon was transported through the inlet by tidal currents and deposited in the quiet water inside. The backshore of this barrier beach showed the cuspate form characteristic of many barrier beaches today, and fringing marshes occurred in the area now known as the West Arm. Because of the presence of the inlet at the western extreme of the barrier beach, the village of Holmes Hole (now Vineyard Haven) was restricted to the area north of what is now the ferry dock. These features are shown more or less unchanged on the 1877 map (Figure 3).

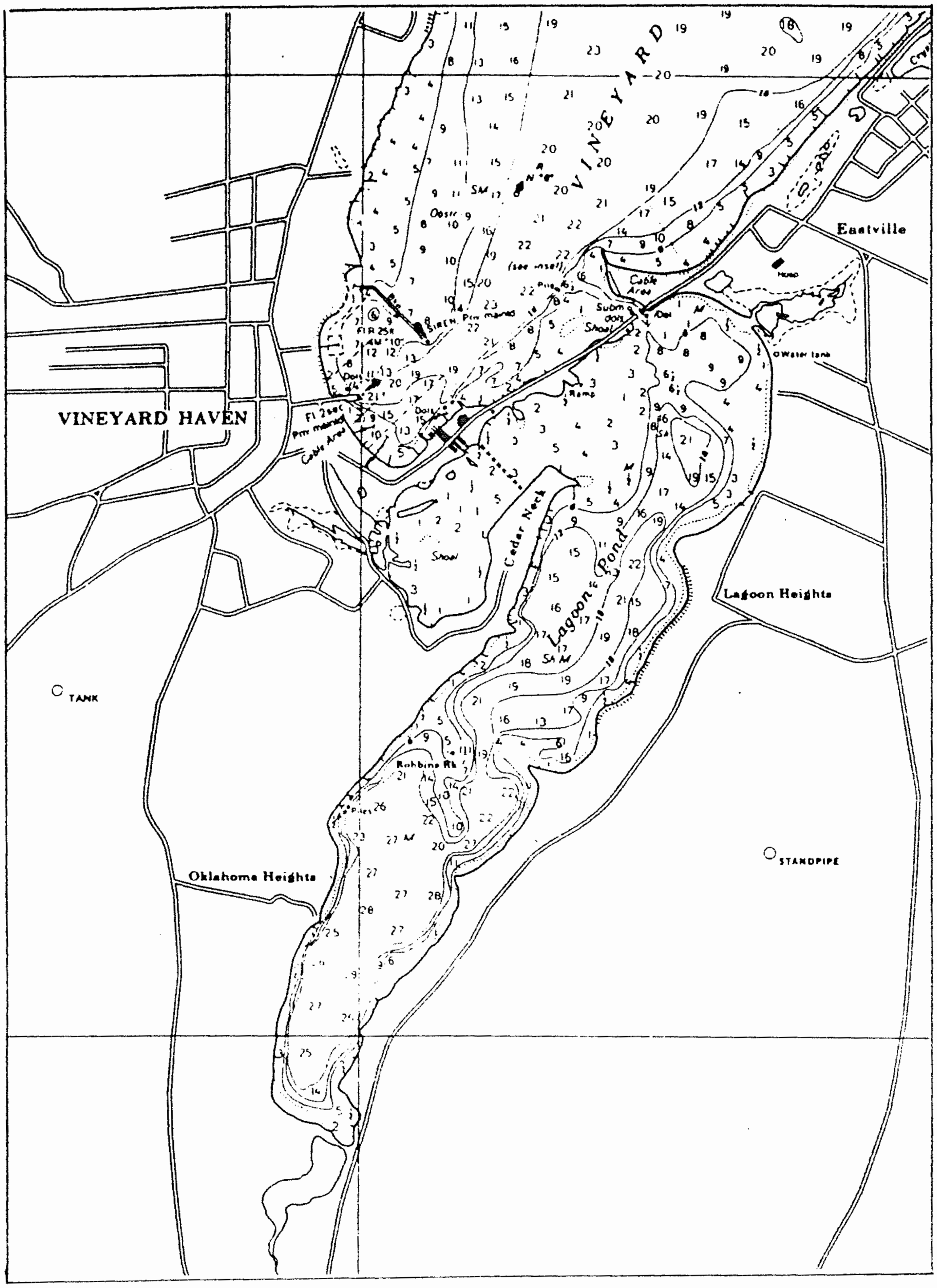
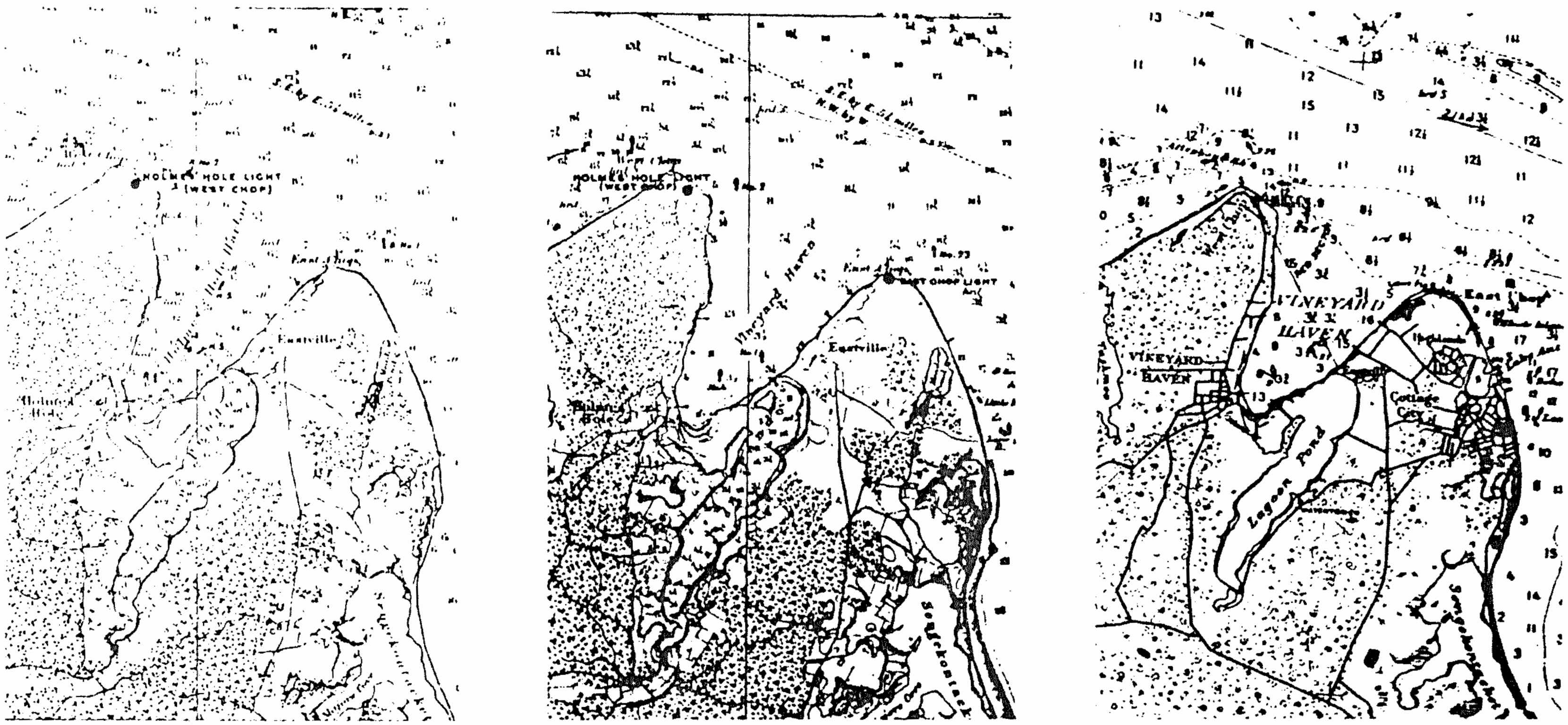


Figure 2. Bathymetry of Lagoon Pond and adjacent waters of Vineyard Haven Harbor, Martha's Vineyard, Massachusetts (from NOAA, 1984).



A B C

Figure 3. Portions of historical charts depicting Vineyard Haven and Lagoon Pond in A) 1860, B) 1877 and C) 1909 (U.S.G.S. 1860, 1877, 1909)

Subsequent maps document the filling of the inlet at Holmes Hole, construction of the road on the causeway, fortification of the barrier beach, stabilization and dredging of the present inlet, construction of the bridge, and filling and stabilization of the backshore of the barrier beach in the West Arm. A map published in 1909 (Figure 3) depicted two causeways across parts of the West Arm of the Lagoon, both now abandoned. This map and the others also show the small marsh islands in the western extreme which are still present.

One purpose of this short geological sketch is to point out that most features of Lagoon Pond are a result of things that happened long before man inhabited this area. As a scientist would expect, the depths reported for basins in Lagoon Pond on the 1877 map match closely what we find today. However, human activities have been responsible for stabilization of the barrier beach and landfilling near Vineyard Haven. It is likely that the stabilized inlet permits greater exchange between the Lagoon and adjacent waters than occurred under natural conditions, because the managed inlet is probably much greater in size than the natural ones were.

PROBLEMS AND ISSUES OF LAGOON POND

The first objective of the Lagoon Pond Study Committee was to identify principal issues and problems of Lagoon Pond. We used two approaches: first, members of the Lagoon Pond Study Committee, which includes shellfish constables, conservation commission members and other knowledgeable residents of Oak Bluffs and Tisbury, assembled a list of their own perceptions of the issues (Table 3). This was done at a public meeting of the Committee held at the Martha's Vineyard Commission. No effort has been made to screen this list, although similar issues have been grouped. The list is not meant to imply consensus on any particular issue on the part of members of the committee.

Our second approach involved a public opinion survey of Lagoon Pond issues and use priorities. The purpose of this was to involve a larger number of people in those aspects of our work involving significant value judgments. A questionnaire prepared by the Committee was published in the Vineyard Gazette and respondents were asked to mail the completed form to the Martha's Vineyard Commission. Identification of the respondent was optional (86% gave their names and addresses). This approach no doubt has certain inherent biases, but as long as this is kept in mind the results are of interest (Table 4). The relatively low number of respondents (76), considering the circulation of the Vineyard Gazette (about 13,000), suggests management and environmental issues surrounding Lagoon Pond are not a high priority among the general readership.

81% of respondents said Lagoon Pond has shown signs of decreasing environmental quality in the past five years, and 49% indicated it is now poor quality (8% believe it is still pristine). Evidence of declining quality cited was increased algae (22%) or seagrasses (15%), overabundance of jellyfish (14%) and human debris (11%). Of those who shellfish, 87% believe the stocks have decreased, particularly since 1977. These respondents most commonly associate the decrease with increasing seagrasses and muddiness of the bottom.

Table 3. Problems and issues of Lagoon Pond, as identified at a public meeting of the Lagoon Pond Study Committee.

Overabundance of:
- Starfish
- Seaweed (Codium and Gracilaria)
- Green seaweeds
- Drills
- Seagulls
- Ducks
- Jellyfish

Declining:
- Shellfish (especially bay scallops)
- Shellfish industry
- Flounder

Unpleasant Odors
Algal blooms
Nutrient enrichment from septic systems
Problems in the shellfish and lobster hatcheries
Fouling of bottom
Siltation of channels and surrounding Hines Point
Surface runoff at street culverts
Blooms of epiphytes
Pesticide use on adjacent lands
Possible coliform contamination
Groundwater contamination from housing development
Anoxic bottom water
General eutrophication of West Arm

Table 4. Characteristics of respondents to the Lagoon Pond Management Survey. Number of respondents = 76.

36% year-round residents
67% Massachusetts residents
- (other states: CA, CT, FL, IL, NJ, VT, PA, NH)

Year-round or summer residence on Island from 5 to 60 years
- 78% more than 13 years
- 50% more than 24 years
- 25% more than 35 years

Reason for Interest in Lagoon Pond
- 67% own land (of these, 75% own a house)
- 16% general concern for area
- 9% commercial shellfishing
- 8% recreational use of Pond

Principal uses of the Pond were identified as follows:
- swimming and aesthetics (about 75%)
- sailing (52%)
- recreational shellfishing (44%)
- recreational fishing; motorboating, canoeing, rowboating; mooring recreational boats (about 30%)
- water skiing (14%)
- mooring commercial boats (4%)

Other uses mentioned included: diving, baitfish collecting, and hobby specimen collecting.

The questionnaire asked respondents to identify existing and future threats to Lagoon Pond, as well as factors that did not constitute a threat in the foreseeable future, with the following results:

Existing Threats
- Septic systems (64%)
- Pollution (60%)
- Runoff (38%)
- Houses (32%)
- Commercial activities (28%)

Future Threats
- Commercial activities (45%)
- Houses (39%)
- Boats (31%)
- People (18%)

Not a Threat
- Land-use regulations (89%)
- Water-use regulations (88%)
- Overfishing (78%)
- Shoaling (74%)

Other possible threats to Lagoon Pond cited in this survey were: power boats; starfish; restraints on public access; wastes from the hospital treatment plant; runoff from a horse farm; destructive public access; and, boat moorings.

88% of respondents indicated no further commercial development should be allowed. Others indicated commercial aquaculture, a marina, boat rentals, shipyard development and dredging were desirable.

78% answering the questionnaire said the towns should not develop further public use of Lagoon Pond. Those with the other view suggested more town moorings; a town recreation area at the Girl Scout Camp; improvement of the launching ramp.

The questionnaire also asked respondents to rank various activities in Lagoon Pond from "desirable" to "unacceptable" with options to identify varying amounts of regulation for intermediate choices. The results (Table 5) indicate most people regard boating and sailing as desirable; and commercial moorings, housing development, public or private marinas and business uses of Lagoon Pond as "unacceptable". The survey results suggest recreational fishing and shellfishing are acceptable; but call for regulation or strict regulation of moorings, commercial shellfishing and fishing, public access, water skiing and house construction.

Table 5. Various activities ranked from "desirable" through "unacceptable" for Lagoon Pond by respondents to a questionnaire. Numbers indicate percent of respondents marking each response option (activities have been organized by decreasing acceptability).

Activity	Desirable	Acceptable	Regulation	Strict Regulation	Unacceptable
Boating	74	21	3	1	0
Sailing	67	29	3	1	0
Rec. fishing	30	44	17	7	3
Rec. shellfishing	24	40	20	14	1
Rec. moorings	18	21	28	24	10
Comm. shellfishing	19	15	18	41	7
Public access	19	9	20	26	27
Comm. fishing	8	15	18	34	25
Water skiing	7	15	22	26	30
Comm. moorings	0	11	6	30	53
Housing devel.	0	0	8	33	58
Public marina	4	4	4	11	77
Private marina	3	6	1	9	84
Businesses	0	0	3	6	92

Discussion

Many of the issues listed in Table 3 have been discussed for several years (e.g., Martha's Vineyard Commission, 1977; Marine Resources Management, Inc., 1980; see also annual reports of Towns of Tisbury and Oak Bluffs) and were identified earlier by Town Conservation Commissions (e.g., Renear, 1983, appendix 1), operators of hatcheries in the Pond (e.g., Hughes, 1981 see appendix 2; Karney, 1982 see appendix 3) and others, some of whom served on our Lagoon Pond Study Committee. For purposes of discussion, issues cited in Table 3 can be grouped into five categories: public health, shellfishing, navigation, recreation, and environmental quality.

-Public Health

For several years there has been concern over possible fecal contamination of Lagoon Pond, especially in the West Arm (MRM, 1980), and this is the sole public health concern in Lagoon Pond of which we are aware. According to MVC (1977, figure 20 page 138), all on-site septic systems along the northern shores of Lagoon Pond, comprising about half of the shoreline, were suspected of improper operation in 1977. Concern has also been expressed regarding possible malfunctioning of the Martha's Vineyard Hospital septic system.

There is no question this public health issue deserves major attention and, in fact, there is a very large government infrastructure devoted to public health concerns surrounding septic systems and fecal contamination. For this reason, for the purposes of this study, it is assumed that the agencies responsible for public health are devoting appropriate attention to this issue, in terms of field monitoring, regulation and mitigation.

We will note, however, that the adequacy of using coliform bacteria as an indicator of human fecal contamination is a topic that has been debated for many years. The interpretation of coliform data is not straightforward and there are numerous other bacteria that can test "positive" for coliforms. The State agencies are well aware of these facts and take them into account in their use of coliform data; but amateurs can often be led astray in interpreting coliform counts. A second point worth mentioning is that fecal contamination of Vineyard Haven Harbor may be more severe than in Lagoon Pond (MRM, 1980). Thus it is possible that water outside the Pond could represent a potential source of contamination.

-Shellfishing

Lagoon Pond contains appreciable stocks of clams (Mya arenaria), quahogs (Mercenaria mercenaria), and scallops (Argopectin irradians). 44% of respondents to our questionnaire indicated they are recreational shellfishermen; and the Pond has for many years supported a significant fraction of the towns' commercial shellfishing industry. The value of shellfishing to Martha's Vineyard goes well beyond the dollar value attached to landings, or even to economic multipliers; shellfishing is linked to the aura of this island and it is ineffably related to the reason people want to live here, to own summer homes here and to visit.

The foremost concern regarding shellfishing in Lagoon Pond is that stocks have declined. 87% of respondents to our questionnaire believe this is true, and both town shellfish constables agree with this view. Surprisingly, even such a widely held belief is not substantiated by available data. Data for recreational shellfishing in Lagoon Pond for Oak Bluffs (not available for Tisbury) from 1967 through 1983 suggest clam and quahog harvests have been constant or increased slightly, with an exceptionally good year in 1979, after which harvests returned to "normal" (Figure 4). The recreational scallop harvest was also very strong in 1979 and appears to have declined to more characteristic levels more recently. The sharp variability in scallop landing from year to year, typical throughout southern New England makes it difficult to assign trends to the data, even in a 15 year record (see Capuzzo, 1984).

The commercial scallop harvest for Lagoon Pond also does not strongly suggest a trend, based on 15 years of available records (through 1983 for both towns; Figure 5). The strongest feature of these data is the ice kill of 1977 (Bugbee, 1977), following which almost no scallops were taken from the Pond for a year. However the commercial harvest for the succeeding three years was excellent. The overall commercial scallop harvest from waters of both towns, despite variability, perhaps suggests a slight increasing trend over the time interval from 1967 (Figure 6).

The disparity between the widespread perception of decreasing shellfish catches and the available data is troubling. Possible explanations are:

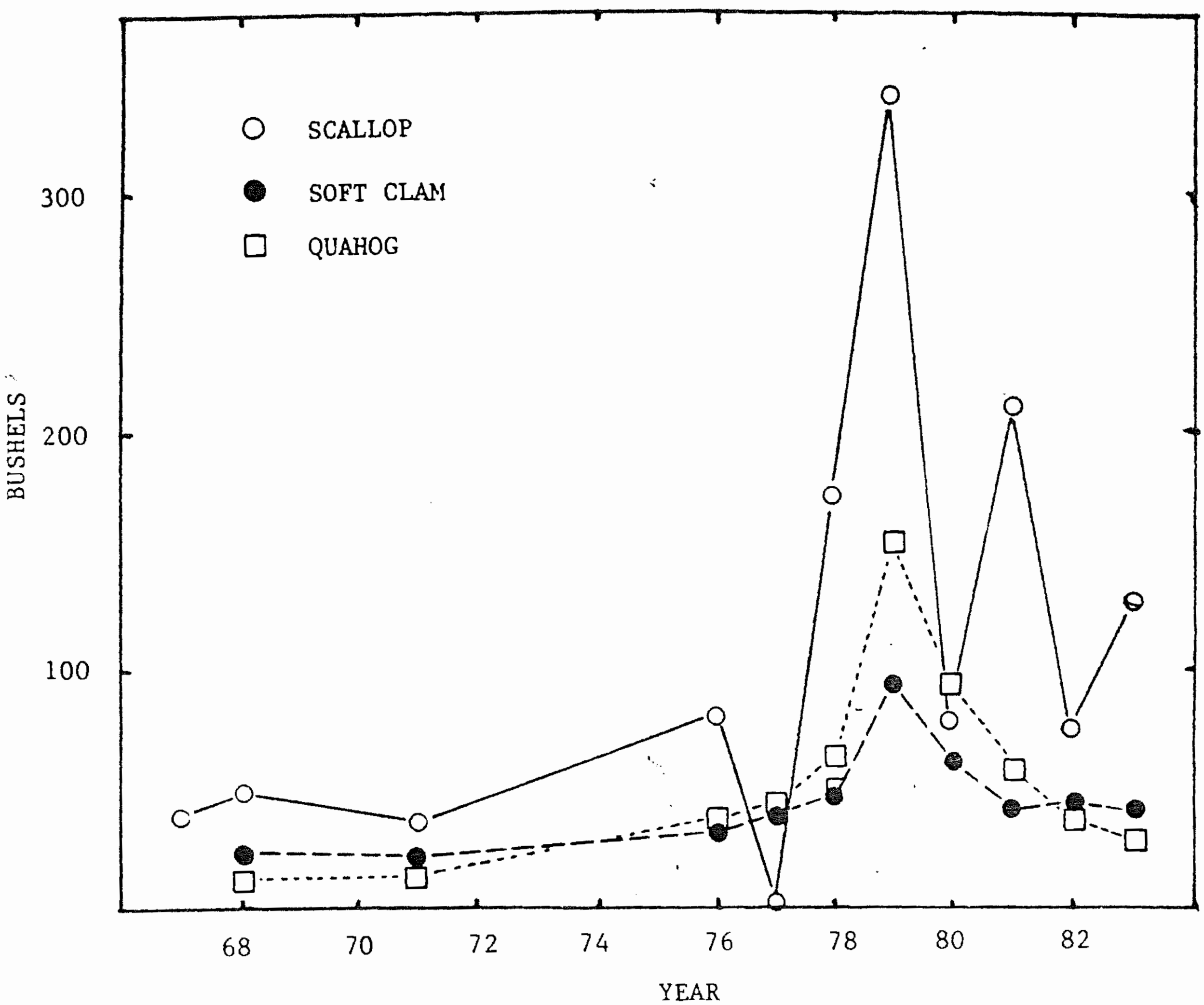


Figure 4. Recreational shellfish harvests from Oak Bluffs waters of Lagoon Pond, 1967-1983 (source: Shellfish Constables Report, Oak Bluffs Annual Reports [as available] 1967-1983).

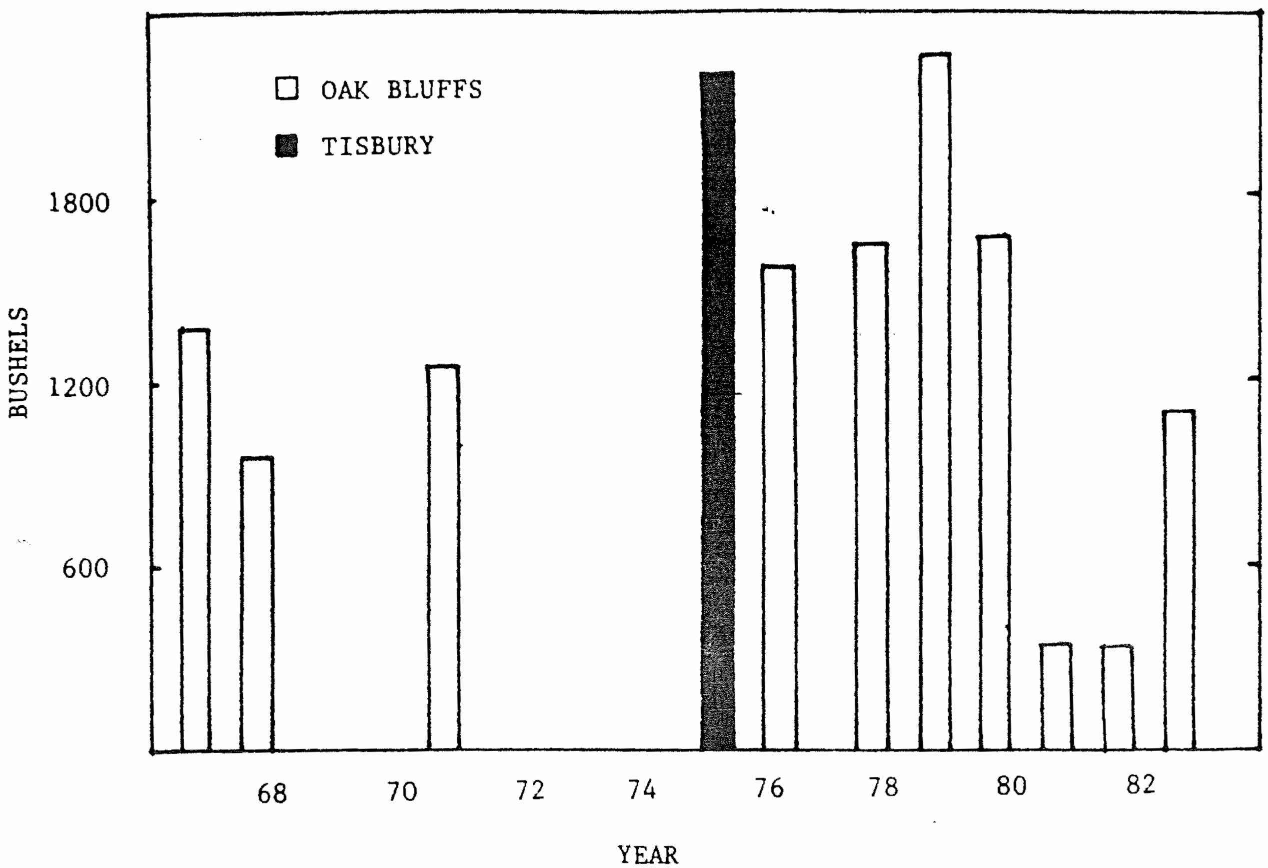


Figure 5. Commercial harvest of bay scallops from Oak Bluffs and from Tisbury waters of Lagoon Pond, 1967-1983 (source: Shellfish Constable Reports, Towns of Tisbury and Oak Bluffs, Annual Reports [as available] 1967-1983).

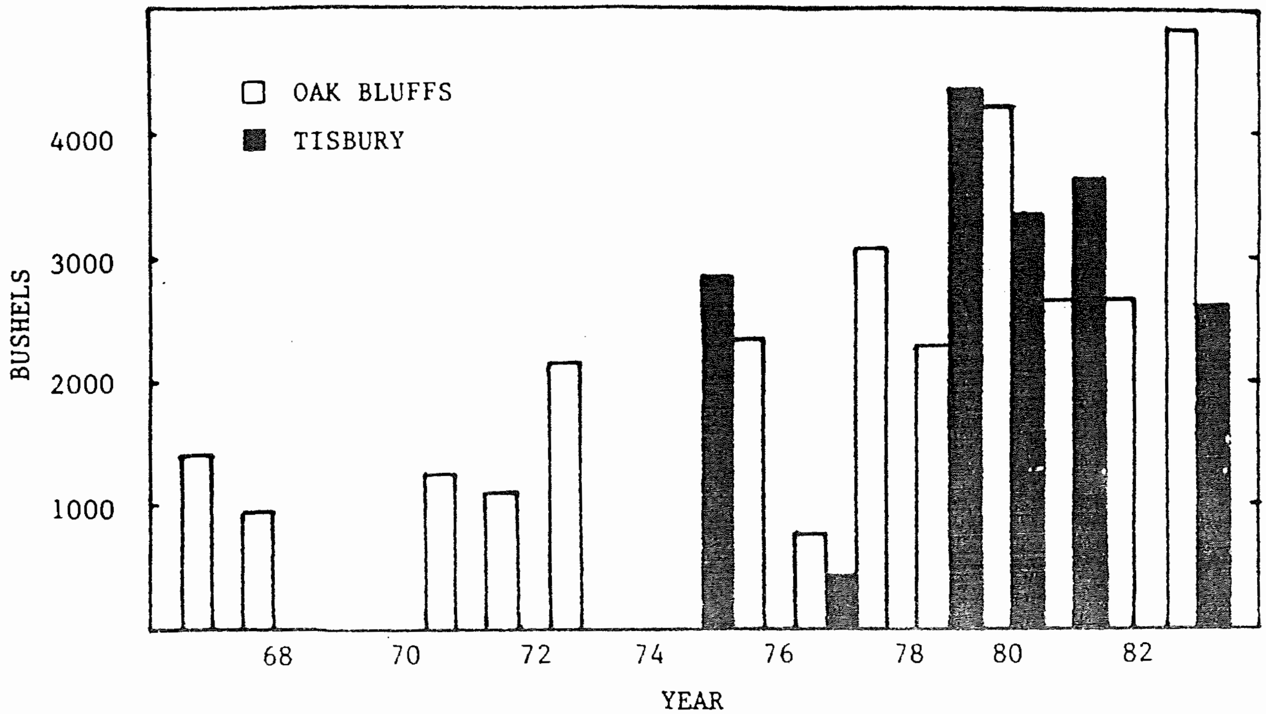


Figure 6. Townwide commercial harvest of bay scallops in the Towns of Tisbury and Oak Bluffs, 1967-1983 (source: Shellfish Constable Reports, Towns of Tisbury and Oak Bluffs [as available] 1967-1983).

-the widespread perceptions are incorrect
-the data are incorrect (or incomplete)
-greater numbers of shellfishermen are sharing the harvest with the result that each one gets less

Other issues surrounding shellfishing focus primarily on predators or on factors associated with diminished quality of shellfish habitat. Both of these issues are a major concern wherever shellfisheries exist, and a large literature exists on the topic. Unfortunately, to date no simple answers have been identified to resolve these concerns.

The principal predator mentioned is the starfish, and both towns have had starfish control programs for several years (see town annual reports). Despite these ongoing predator control programs involving collection and destruction of starfish (in some years the harvest of starfish, in bushels, exceeded the recreational harvest of scallops), Bugbee (1981) reported "more starfish were removed than ever before...."

Other known shellfish predators are also present in Lagoon Pond, including drills, seagulls and ducks, and each of these species was identified as "overabundant". The population size of ducks and seagulls is probably associated with factors larger than the Lagoon itself; it is possible control measures for these species could incur adverse public response and in some cases may be illegal.

Factors attributed with decreasing the shellfish habitat quality are overabundance of certain seaweeds and increased organic siltation, which are believed to foul the shellfish or smother them. It is known that Codium ("dead man's fingers") is an introduced species of green seaweed unknown to New England before the mid-1950s. This seaweed has spread rapidly since its accidental introduction and in southern New England washes up in places on the beach to form thick deposits; it is believed to have an adverse impact on certain shellfish, such as scallops (Kelly and Kirby, undated; see Appendix 4). Codium accumulation was specifically mentioned as a problem on beaches in Vineyard Haven Harbor (MRM, 1980) producing odors and unsightly deposits. Factors responsible for the spread and proliferation of Codium are not known, and it has not been demonstrated that nutrient enrichment of coastal waters is a contributing factor. Anecdotal reports indicate areas of Buzzards Bay once heavily infested with Codium have in recent years been relatively free of the alga. Various methods have been tried for its removal, such as harvesting and application of lye at low tide, but no easy remedy is known, and secondary effects of chemical treatments are not clear.

Another alga identified as a nuisance and destructive to shellfish habitat is Gracilaria, a red seaweed that forms loose clumps on the bottom in still waters. This plant is believed by some to smother shellfish or hamper harvesting, but it is not clear whether the alga causes the problem or is only the symptom of a larger one.

Several respondents to our survey indicated they thought increased seagrasses on the bottom of Lagoon Pond contributed to loss of shellfish. The most common seagrass in this area is eelgrass (Zostera), although it is not certain these respondents were referring to this plant (some may have interpreted "seagrass" to include seaweeds). A study currently underway by Mr.

Joseph Costa of the Boston University Marine Program in Woods Hole is quantifying the distribution of eelgrass from historical and current aerial photographs for the Buzzards Bay and Vineyard Sound area. In the near future a rigorous assessment of trends in the distribution of this plant in Lagoon Pond should be available.

Eelgrass is very sensitive to water clarity and its distribution in other areas (such as Chesapeake Bay) has been shown to be increasingly restricted to shallow waters if water turbidity increases. Since the general sense of opinion on Lagoon Pond is toward increasing eutrophication (algal blooms, etc.) and diminished water clarity, it is surprising that eelgrass should be expanding its distribution here. A second paradox, however, is that eelgrass has generally been associated with good scallop habitat in other estuaries, and is considered ideal or essential for attachment of early life stages of the scallop. To the extent that eelgrass contributes to stagnation of the near bottom zone or serves as a trap for organic silt, it may be deleterious for the adult, but areas of siltation are generally not favorable for this grass either. In any case it should be clear that the relationship between eelgrass and scallops is by no means straightforward, and control measures for eelgrass as a scallop management strategy are by no means appropriate at this time.

-Navigation and Moorings

Concern over impaired navigation in Lagoon Pond was expressed by relatively few respondents to our questionnaire, but is a major concern of the Tisbury Shellfish Constable (King, personal communication) and of marina operators bordering on the West Arm of the Lagoon. Water depth over most of the East Arm of the Lagoon exceeds 12 feet and in places is deeper than Vineyard Haven Harbor and access to the Upper Lagoon appears to pose no problem (Figure 2). Reference has been made to impaired navigation at the inlet near the causeway. This site is characterized by active flood and ebb deltas, and active sand transport and channel migration and filling would be expected there. The inlet has been stabilized and dredged periodically to keep it open and will undoubtedly require continued maintenance to retain desired water depth in the years to come.

Within the Pond itself, we are not aware of any records to document sedimentation. The concern over recent shoaling in the East Arm is perplexing from the scientific viewpoint because charts of the area have depicted the West Arm as very shallow for several years (Figures 7a and 7b) and currents there do not appear strong enough to resuspend or transpoort sediments. If filling results from organic material produced in the Lagoon, this source would not seem adequate to cause rapid filling (in this area organic sediments normally accumulate at less than one inch per year (see Teal, 1983; Gaines, 1975). The process of beach overwash, typical of unstructured barrier beaches, which can be an important source of lagoonal sedimentation, has been inactive for many years at Lagoon Pond since artificial stabilization of the causeway and construction of a seawall.

It is possible that a channel in the West Arm was formed by tidal erosion at an earlier time when an inlet existed closer to the Vineyard Haven end of the causeway. After stabilization of the inlet at its present location, the relict channel in the West Arm would be subject to infilling by collapse of its walls. Perhaps it is also possible (although we have no record of

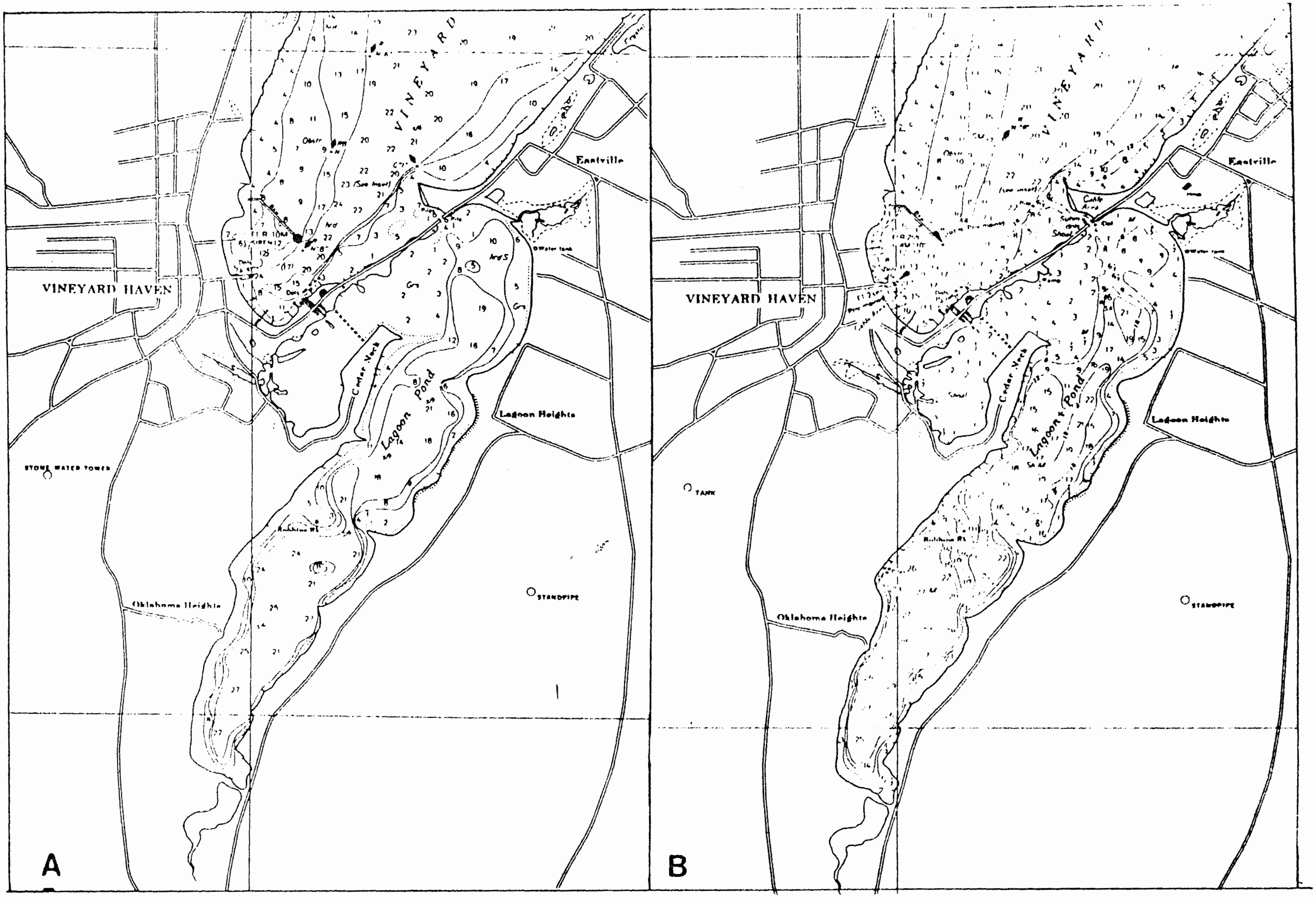


Figure 7. NOAA charts of Lagoon Pond and adjacent waters for A) 1963 and B) 1984 (NOAA, 1963, 1984).

this) that a channel was dredged into the West Arm many years ago when these activities were not closely regulated, and the reported shoaling represents localized infilling of that channel.

In any case, if the Town of Tisbury desires to have a navigational channel in the West Arm of Lagoon Pond it would seem to be a comparatively minor engineering task to dredge one (although dredge disposal can be a frustrating problem) and in view of the low current energy there the project would probably be long lasting. Whether or not the channel was formerly deeper seems beside the point in this issue. However, proposed secondary benefits of dredging should be viewed with caution, because they are most certainly not easily predicted.

A third area identified as shoaling in recent years is the area off Hines Point on Cedar Neck. This is also perplexing from a scientific point of view because circulation here is most likely wind driven and not likely to generate currents sufficient to transport beach sand. It is possible storm waves could drive beach sediments to the end of the Point, but it is difficult to see how localized accretion there could interfere with navigation in the deep natural channel to the west (Figure 7b). Furthermore, this area has long been depicted as shallow on navigational charts and presumably active deposition would have produced a subaerial feature by now. It is not clear what end would be served by attempts to manage this area.

Approximately 107 private moorings were sited in Lagoon Pond in 1984 (Bugbee, personal communication; Figure 8). Use of the pond for moorings was evidently a more heated issue in the mid-1970s when Oak Bluffs passed a bylaw preventing individuals from renting private moorings (Bugbee, personal communication). Thus, there were 82 fewer moorings in Oak Bluffs waters of the Lagoon in 1984 than in 1974 (data from Bugbee, personal communication). As indicated earlier, more than 80% of respondents to our questionnaire indicated commercial moorings were unacceptable in Lagoon Pond or should be strictly regulated.

-Recreation

Active and passive recreation (aesthetics) were the major uses of Lagoon Pond according to the results of our questionnaire. In a sense, this category of issues subsumes all other categories since it involves not only perceptions of environmental quality but of all uses of the environment.

One of the most widespread complaints about Lagoon Pond has to do with the presence of stinging jellyfish that interfere with all activities involving human contact with the water (75% of respondents to our survey indicated they swim in the Lagoon). While doing fieldwork in the East Arm of Lagoon Pond on July 30, 1984, we had difficulty collecting a bucket of surface water free of jellyfish. However, there are no data we are aware of providing a basis to determine if they are changing in abundance over the years. According to King (personal communication) jellyfish had been abundant elsewhere in town waters many years ago. Anecdotal reports in the summer of 1985 indicated that jellyfish were much less abundant than previously.

Although 30% of respondents to our survey indicated they water ski, 78% felt this activity should be regulated. 30% identified water skiing as unacceptable in Lagoon Pond. As recreational use of the pond increases, it is

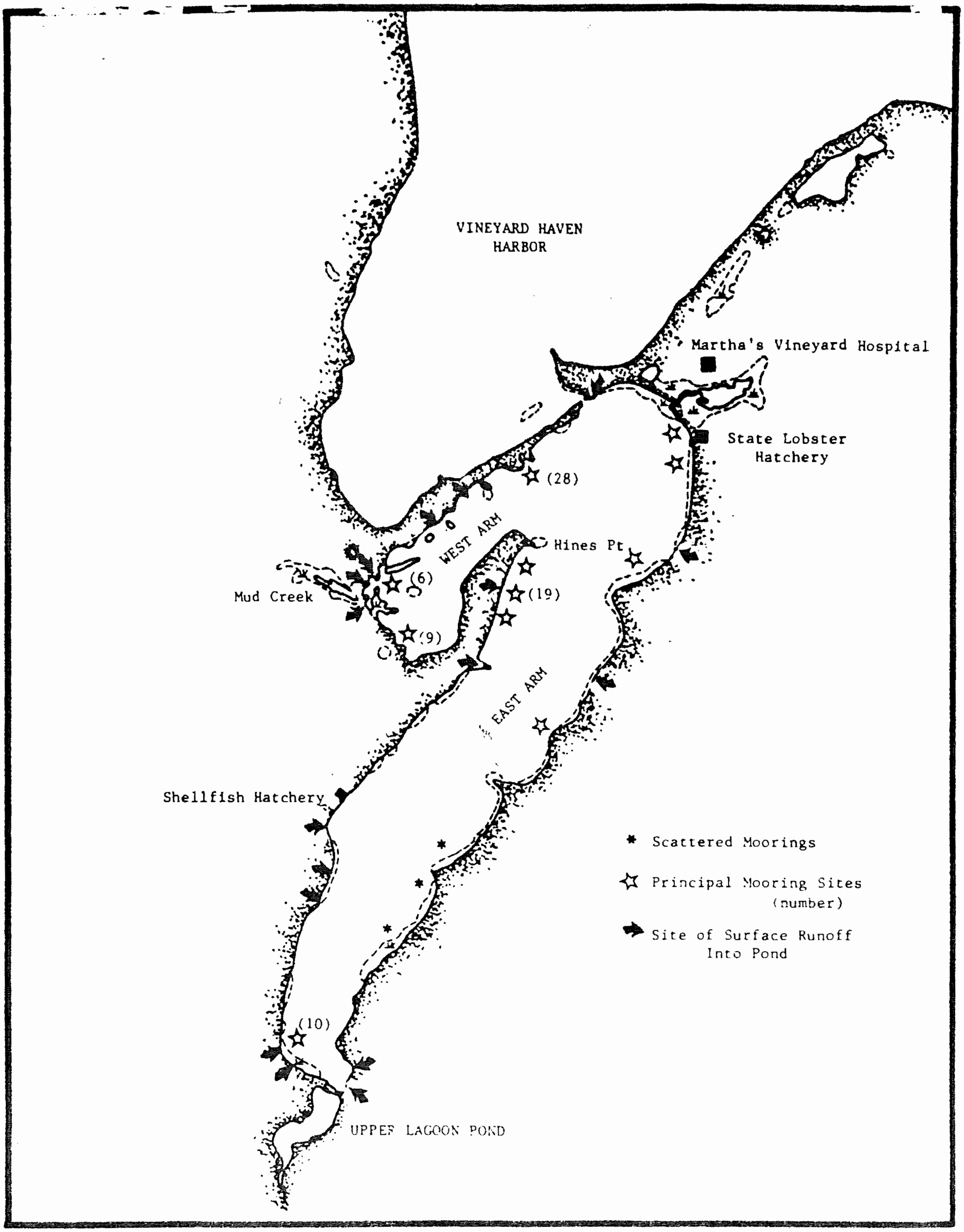


Figure 8. The distribution of moorings in Lagoon Pond and sites of surface runoff into the Pond (Bugbee, personal communication).

inevitable that active forms of recreation, such as this one, will incur increasing conflict.

-Environmental Quality

Blooms of algae are another concern in Lagoon Pond. These should be divided into blooms associated with nutrient enrichment and those independent of it. Examples of the latter, as far as we know, are the occurrence of "red tide", the causative agent for paralytic shellfish poisoning in southern New England,and the proliferation of certain seaweeds such as Codium, mentioned before. Both of these organisms are believed to be introduced species, and their occurrence has not so far been linked to pollution or nutrient enrichment of coastal waters.

Algal blooms in other cases are believed to be caused by nutrient enrichment. The occurrence of thick algal mats containing the green seaweed Enteromorpha, filamentous green algae and other organisms, in the Lagoon is believed to result from this cause. According to Bugbee (personal communication; see Appendix 5) many residents complained about the odor of algal accumulations on the beaches in Lagoon Pond during the summer of 1984 and that swimming or walking near the shore was impossible. According to Bugbee, masses of the green seaweed Enteromorpha were attached to eelgrass, to a water depth of about 5 feet, along much of the shore from the bridge at the inlet southward along the Oak Bluffs shore. Areas particularly affected were near the Lobster Hatchery, and from the inlet to beyond the boat ramp on the Tisbury side. Complaints associated with this algal accumulation persisted throughout the month of August.

During our fieldwork on July 30-31, 1984 we also observed thick floating algal masses over several hundred yards in the vicinity of the Lobster Hatchery, extending about 100 feet offshore. Operation of an outboard motor in these masses was not possible. Similar accumulations of floating algae, some anchored to eelgrass, were observed in Green Pond, Falmouth, on July 10, 1984. We counted 40 floating algal masses, from about 1 to 10 square feet in area, along a 500 yard transect along the axis. These masses also contained a conspicuous number of tunicates. To keep perspective on this issue, I have also observed masses of floating algae, though smaller in extent, in a lagoon on Pasque Island (Elizabeth Islands) which is virtually uninhabited by people. The extent to which the algal condition has worsened in Lagoon Pond over the years is not quantitatively documented.

It is generally accepted among marine biologists that blooms of seaweeds and other algae can be caused by nutrient enrichment of estuarine waters. The exact relationship between nutrient dose and algal response, however, is not known, and neither is the species of algae that will predominate under given enrichment conditions. Work on these questions is currently underway at several institutions, both in the field and in laboratory mesocosms.

Unpleasant odors was also identified as an occasional problem in the Lagoon. It is difficult to comment on this issue as value judgments become very important in defining "unpleasant". Certain substances, such as sulfides associated with degradation of organic matter, are normally present in the estuarine environment, and they characteristically have an odor many people find unpleasant in high concentration. Those who have walked in the intertidal zone or on a salt marsh are familiar with the smell of hydrogen sulfide, common to those sites, which also has an odor often considered unpleasant.

A related concern is anoxia (or oxygen depletion) in the deep waters of Lagoon Pond. In anoxic aqueous environments hydrogen sulfide can accumulate to very high levels and during periodic ventilation events the sulfide reaches the surface and can be smelled over a great distance. Although oxygen depletion and anoxia are conditions brought on by large organic inputs or extreme eutrophic conditions associated with pollution, they also occur naturally in deep estuarine basins and sediment pore waters. Southern New England estuaries with basins exceeding about 15 feet are subject to natural oxygen depletion in bottom waters. In the Narrow River (Pettaquamscutt River), R.I., which has two basins 60 feet and 45 feet deep, respectively, bottom waters have been anoxic for nearly two thousand years since sea water first inundated this landform (Gaines, 1975; Orr and Gaines, 1973). Similar anoxic estuaries occur in Falmouth, MA (Siders Pond) and Fishers Island, NY (Ocean Pond). In Town Cove, Orleans, we measured depressed oxygen levels in the 12 foot basin there, with periodic anoxic events. It is suspected, although data are not available to substantiate this, that the 27 foot basin forming the southern end of Lagoon Pond (Figure 7) is another naturally anoxic environment, and it can be expected that sulfide odors would be detectable during episodic ventilation, or flushing, of the deep water here. Under conditions of complete ice cover, such as occurred in Lagoon Pond in 1977, it is possible even the upper water column may become anoxic. Possibly the "ice kill" of scallops reported by Bugbee (1977) was a result of oxygen depletion.

Anoxia of surface waters under natural conditions is not common, and is often associated with pollution and extreme eutrophic conditions. In Green Pond (Falmouth, MA) a shallow estuary, an anoxic event occurred in 1984 that left hundreds of fish dead along the shores and presumably killed benthic organisms over a wide area of bottom. The exact cause of this event is not certain, although over-enrichment of the estuary by nutrients from houses along the shore is suspected. Another possibility is that the initial fish kill resulted from herbicide application to upstream cranberry bogs (Souza, personal communication) leading to anoxia as a secondary event.

One point of these comments is to indicate that anoxia is not a condition that estuarine plants and animals never experience naturally. It may be desired to take management steps to prevent anoxia (which is sometimes done in freshwater lakes by pumping bottom water onto the ice surface throughout the winter); however, estuarine systems have evolved over geologic time with the existence of this condition.

Although soils surrounding the Lagoon are highly permeable ("Carver Series"), surface runoff in places enters the estuary (Figure 8) and was identified as a source of concern. At most of these sites road drainage is conveyed to the shore in a pipe. Stormwater runoff is known to be a possible source of several pollutants, such as domestic animal excreta, hydrocarbons and their derivatives, organic materials and nutrient substances, although to date none of these substances has been measured in runoff entering the Lagoon to our knowledge.

The last issue to be discussed here, is one of the most far reaching and all inclusive--general eutrophication. Along with two related concerns, groundwater contamination by domestic septic systems and nutrient enrichment from septic systems, this probably represents the greatest threat to water quality in the Lagoon as well as to the many uses that are directly impacted by diminished water quality. This issue is particularly important because it was largely overlooked by the 1977 208 Water Quality Plan for Martha's Vineyard (MVC, 1977). It should be stated at the outset that groundwater contamination by septic systems does not presently constitute a public health threat to most of the Island population, which is served by municipal water systems.

In the course of normal operation, the typical on-site domestic septic system captures and kills all coliform and pathogenic bacteria and viruses, as well as all of certain nutrient materials such as phosphorus compounds. However, other nutrients, especially the nitrogen-containing ones, are highly soluble and leach out of these systems along with water and eventually reach the underlying groundwater, which slowly makes its way to discharge zones in streams, wetlands, estuaries and elsewhere along the coast. At these discharge sites, the nitrogen compounds can serve as nutrients to stimulate plant growth and, depending upon the ecosystem involved and the rate of nitrogen loading, the environmental response can vary from imperceptible to very strong. This important process, by which nutrients from septic systems can cause eutrophication of lakes, streams and estuaries, is emphasized here because it has been overlooked by the principal water quality planning program for Martha's Vineyard (MVC, 1977). In fairness, that study was based on conventional wisdom of its time; however, the need is now urgent to incorporate more recent information into the framework established by that study. Further discussion of nutrient loading via groundwater discharge continues in the next section.

THE LAGOON POND ESTUARINE SYSTEM

The most generally accepted definition of an estuary is: a semi-enclosed portion of the coast with a free connection to the sea in which sea water is measurably diluted with fresh water. Because many of the small brackish water bodies of the Cape and Islands, a) have restricted connections or inlets (some of which are open only part of the year), or, b) are open to larger embayments, estuaries or sounds, rather than directly to the sea, we refer to them as coastal ponds. Since they are brackish and usually tidal, these water bodies are in many ways like small estuaries.

As a result of land development and increasing human population on Cape Cod and the Islands in recent years, there is mounting concern regarding associated adverse impacts on inshore waters and especially coastal ponds. In most cases we find that the information needed to predict impacts of development on coastal water bodies is not available, and decisions to permit development are almost always made on an incomplete basis. Furthermore, after development of coastal land the needed follow-up studies to assess resulting impacts are seldom if ever done and, as a result, little or no progress has been made over the years in accruing case history experience on the relationship between land use and estuarine water quality. Therefore, as development pressure increases we have not improved in our ability to address the environmental aspects.

In part the problem lies with the complexity of estuaries. It is probably accurate to say that at our present scientific level of understanding we do not have a predictive understanding of even the best studied estuary. In most cases, however, we don't even have sufficient information against which to judge future changes, so there is no way of recognizing the accuracy of a prediction or the legitimacy of publicly perceived changes in our coastal ponds--such as many of those discussed above for Lagoon Pond. A second problem is the expense of conducting estuarine and coastal research. Nevertheless, the entire annual expenditure of the Woods Hole Oceanographic Institution on coastal research is less than the cost of a single housing development or some recent condominium projects on Cape Cod.

For the past three years we have been collecting baseline data in three coastal ponds on Cape Cod and the Islands (Figure 1) in cooperation with town planners, ad hoc environmental concern committees and, in the present case, a regional planning commission. The purpose of this modest activity in these ponds has been:

a) to provide a basis for assessment of long term changes in water quality and aquatic productivity;
b) to help characterize the relationship between land use and ecosystem properties in these estuaries;
c) to characterize basic features of these coastal ponds to support management decisions and allow comparisons among them.

All of the coastal ponds under study are landforms and watercourses of glacial origin that were flooded by the sea many centuries ago. All of them are separated from the adjacent sound or sea by barrier beaches, through which tidal exchange occurs via natural or stabilized inlets. All of the coastal ponds have been modified both by natural and human processes. Examples of the latter are dredging, causeway construction, diversion of groundwater through municipal well and water distribution systems, shoreside filling, etc. Finally, all of the coastal ponds we are studying are about the same size and have approximately the same climate and rainfall and are exposed to the same array of flora and fauna, which inhabit them or not according to complex, and largely unknown ecological factors, processes and interactions.

The coastal ponds we are studying also are different from each other in many ways. They have different geometry and tidal forcing (tidal height and form), receive different amounts of freshwater input and have differing amounts and distribution of housing development, agricultural land, and other land uses within their groundwater recharge areas, as well as numerous other known and unknown differences.

Nutrient Sources in Lagoon Pond

The importance of nutrients to plant growth, from algae to agricultural plants and forests, is well known. In estuaries it is widely accepted that nitrogen compounds are especially important and can be responsible for excessive plant growth, leading to algal blooms, discolored water, odors and, in the extreme, anoxia of surface waters and disruption of typical estuarine food chains with loss of certain desirable species such as fish and shellfish. Therefore, human activities that add nitrogen compounds to estuaries are regarded as potential sources of undesirable impact.

The pathway of nitrogen compounds in an estuary is known to be quite complex. For example, nitrogen is rapidly cycled between plants and animals in the normal course of herbivory, and can be stored in sediments or in living organisms as particulate material, exported (or imported) with the tides, transformed from one form to another by bacteria (including to nitrogen gas which can be lost to the atmosphere), etc. (Figure 9). In constructing a nitrogen budget the objective is to assign values to each input, loss or transformation, to assess the relative importance of each part of the budget. The complexity of the budget means in part that one process can change in rate to accommodate changes in another. This ability to adjust is known as assimilative capacity and represents a system's ability to adjust to new sources of nutrients or other modifications of the system without showing dramatic changes overall. The ability of natural systems to accommodate changes can leave us with the false impression that no change or impact has occurred, and when assimilative capacity is exhausted a sudden and dramatic impact may become evident.

One objective of our study is to assemble information on the response of coastal ponds to nitrogen loading from human activities. A fundamental consideration in this analysis is to define the area of adjacent land upon which human activities affect a given water body. For nutrients and other materials entering with runoff or groundwater discharge, this area is the groundwater recharge area--the land area for which all precipitation entering the ground eventually discharges into the estuary. Recharge area can be estimated by assuming it equals the drainage area (the area within which all surface water flows to the estuary), by assuming it is the area defined by a line equidistant from neighboring discharge areas, or by contouring the water table (from measurements in numerous wells) and assuming the flow is downgradient toward the estuary. In practice a combination of these methods is often used.

Table 6 gives recharge areas and other data for the coastal ponds under study, arrived at by different methods. For Lagoon Pond this area is estimated between 13.5 to 19.7 square Km (Figure 10), the smaller area corresponding more closely to the interpretation of Kaye (see Figure a3 in MVC, 1977), the greater area more closely to Delaney (18.1 square Km; see Smith, 1984; Appendix 6, this report). Land use within this area can ultimately impact Lagoon Pond. Because of the slow movement of groundwater (as little as a foot per day) materials added 400 feet away from the shore could take a year to reach it; sources a mile away could require 14 years to impact the coast. It should be noted that landfills for both towns (and the Oak Bluffs septage disposal area) are located partly or entirely in this area, as are the Regional High School, the Martha's Vineyard Hospital, two campgrounds and other institutional buildings. Agricultural land uses within the recharge area estimated by Wilcox (personal communication) include:

grapes	38 acres
fruit	8
hay	26
vegetables	63
cattle grazing	20

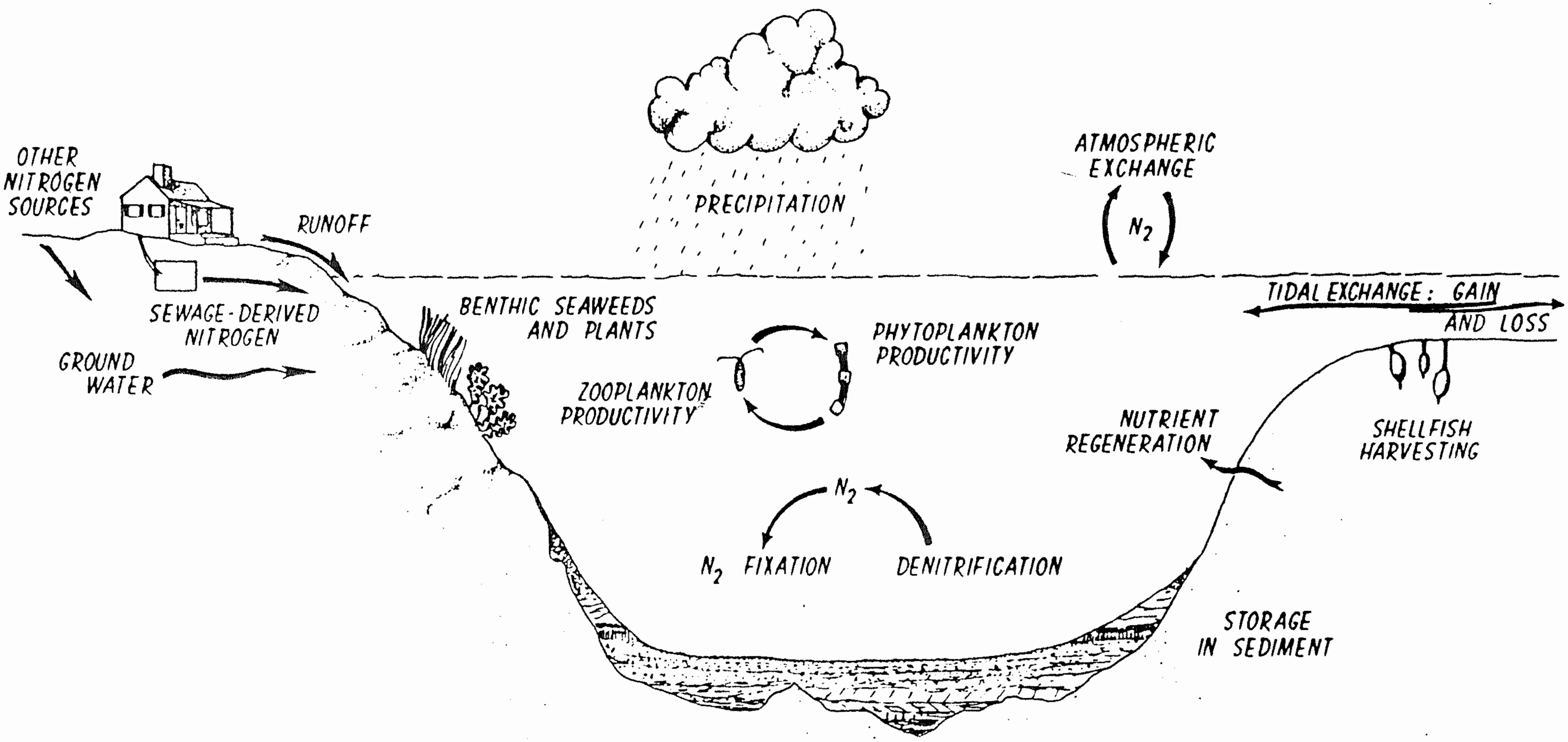


Figure 9. Elements of a nitrogen budget for a New England estuary.

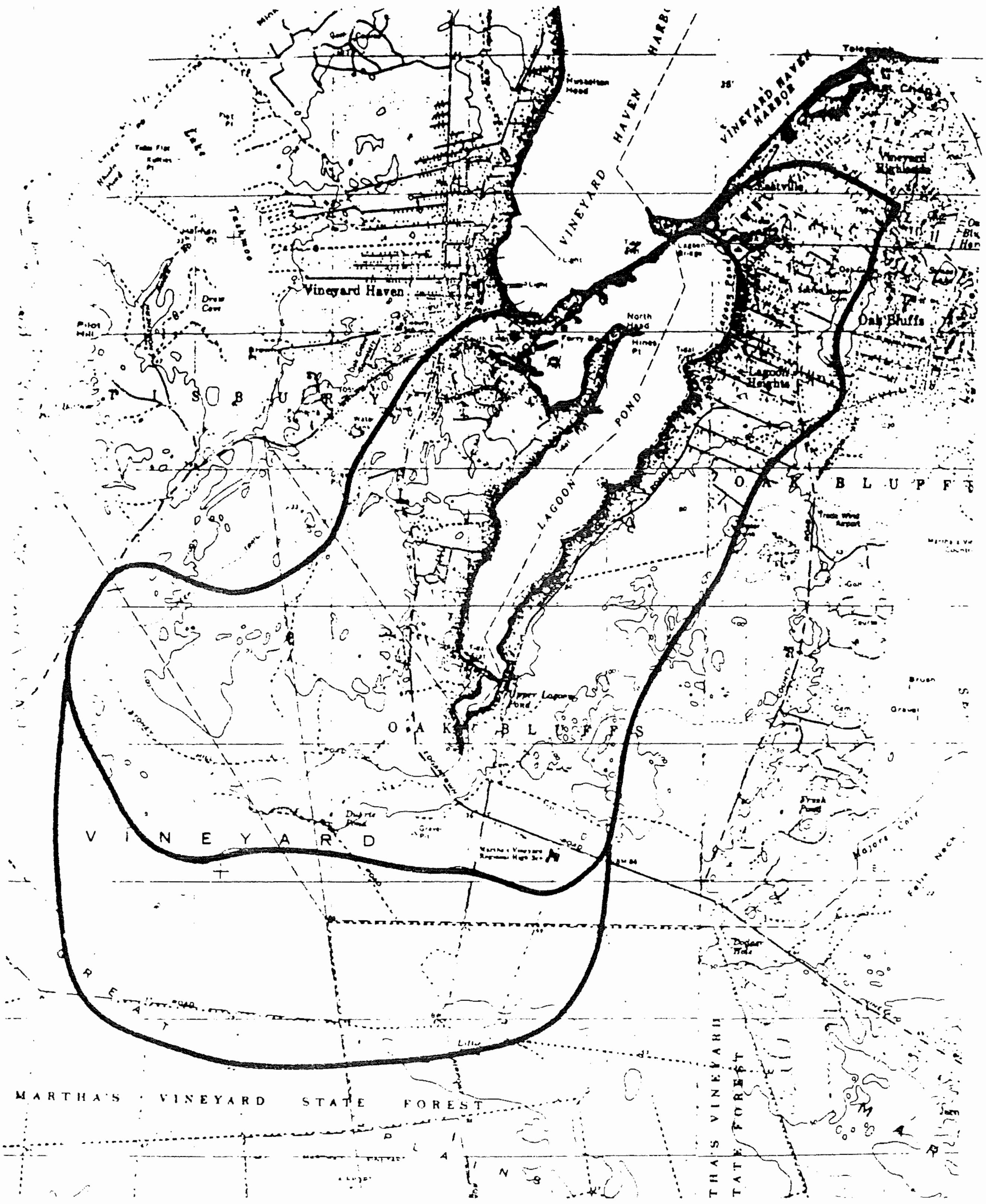


Figure 10. Approximate demarkation of the groundwater recharge area for Lagoon Pond. The smaller area corresponds more closely with the analysis of Kaye (in MVC, 1977) while the larger area more nearly follows Delaney (see Smith, Appendix 6 to this report). Dis charge calculations for Lagoon Pond suggest the larger area may be more appropriate.

Table 6. Data and calculations for groundwater recharge, anthropogenic nitrogen loading, and other characteristics of Lagoon Pond (Martha's Vineyard), Green Pond (Falmouth) and Town Cove (Orleans).

	Lagoon Pond	Green Pond	Town Cove	
Shoreline Length (Km)	11.6	9.3	11.5	
Tidal range →				
Coastal Pond Area (square Km)	2.18	0.63	1.63	
mean depth →				
Groundwater Recharge Area (Square Km)	13.5- 19.7	4.3- 7.6	4.6	
Flushing time				
Pond Area/Recharge Area	6.2- 9.0	6.7- 12.1	2.8-	
Number of houses	732 732	837 984	659	
Nitrogen Loading (Kg N/day)				
residential use (15 lbs/house/yr.*)	13.6	15.6- 18.3	12.3	
lawn fertilizer (9 lbs/house/yr*)	8.2	9.4- 11.0	7.4	
total	21.8 5.68 x10^5 = 261 mmol	24.9- 29.3 7.07 x10^5 1121	19.7 5.14x10^5 315	moles N m moles/m²/yr
Groundwater Recharge (cubic M/day)				
@ 16.1 in./yr (=0.41m/yr.)	15,000 22,000	4,800 8,500	5,100	
@ 22 in/yr. (=0.55m/yr)	20,700 29,700	6,500 11,600	7,100	
Average N Concentration				
mg/l (=ppm)	0.7-1.5	2.1-6.1	2.8-3.9	
uM/L	50-107	150-435	200-280	

* EPA estimates

Practices surrounding application of fertilizers and other chemicals could ultimately be of significance to Lagoon Pond. Although agriculture is generally regarded as a safe land-use practice even within watersheds of municipal drinking water systems, some of the highest nitrogen levels for groundwater are associated with intensive agriculture in the U.S. midwest. Farming has been identified as a major source of nutrients to the Chesapeake Bay.

As mentioned above, domestic septic systems are a source of nitrogen to groundwater. The greatest present density of houses and residential land-use practices in the Lagoon Pond recharge area surrounds the northern end of the Pond (Figure 11). However, the sparsely populated southern portion of the recharge area is where future development will ultimately determine overall nitrogen loading of the estuary.

Based on some simple calculations it is possible to begin to define the elements of a nitrogen budget for Lagoon Pond. Table 6 contains estimates of the number of houses contributing nitrogen to the Lagoon and to other coastal ponds and, based upon EPA estimates of nitrogen release by typical residences, one can arrive at values for the resulting nitrogen loading. The number of houses was estimated from USGS topographic maps and aerial photographs and are probably within 10-15% (probably low) of the correct value. Also, the number of houses involved depends upon how the recharge area was defined (for Lagoon Pond this was not important because the southern area is not significantly populated). It should be noted that a large fraction of domestic nitrogen release is associated with use of lawn fertilizer (Table 6) and local gardening practices can have a significant effect. The resulting estimates indicate nitrogen loading from domestic sources is quite similar for the three ponds: about 20 to 30 Kg N/day. Estimates for Town Cove based upon measured groundwater nitrogen concentrations and discharge rates were 19-35 Kg/day versus 19 Kg/day estimated as described above in Table 6. Despite their similarity in nitrogen loading, the future implications are very different for these ponds, since of the three only Lagoon Pond has a comparatively large undeveloped remaining portion of its recharge area.

Observations on the nutrient content, salinity and exchange processes of Lagoon Pond.

In order to provide basic information on the Lagoon ecosystem and to compare it with other small estuaries on the Cape and Islands, we made several field measurements and observations during July, 1984. A principal approach was collection of data hourly or half-hourly intervals over a 30-hour time period at station 3 in the inlet to the Lagoon (Figure 12), where the changing tides alternately deliver water from the Lagoon and from Vineyard Haven Harbor, the source of seawater to this estuary. The importance of these data (Table 7) will undoubtedly increase over time. Although a full technical assessment will not be given here, these data allow us to characterize some important aspects of the nutrient and water balance, including their short term variability (which many studies fail to characterize) and provide a benchmark for future studies.

The tidal measurements indicate Lagoon Pond has a strong M-4 tidal constituent, which gives it a distinctly double high tide feature (Figure 13a). The pattern of salinity variation associated with tidal flow reversals is characterized by distinct plateaus in salinity (Figure 13b). This suggests

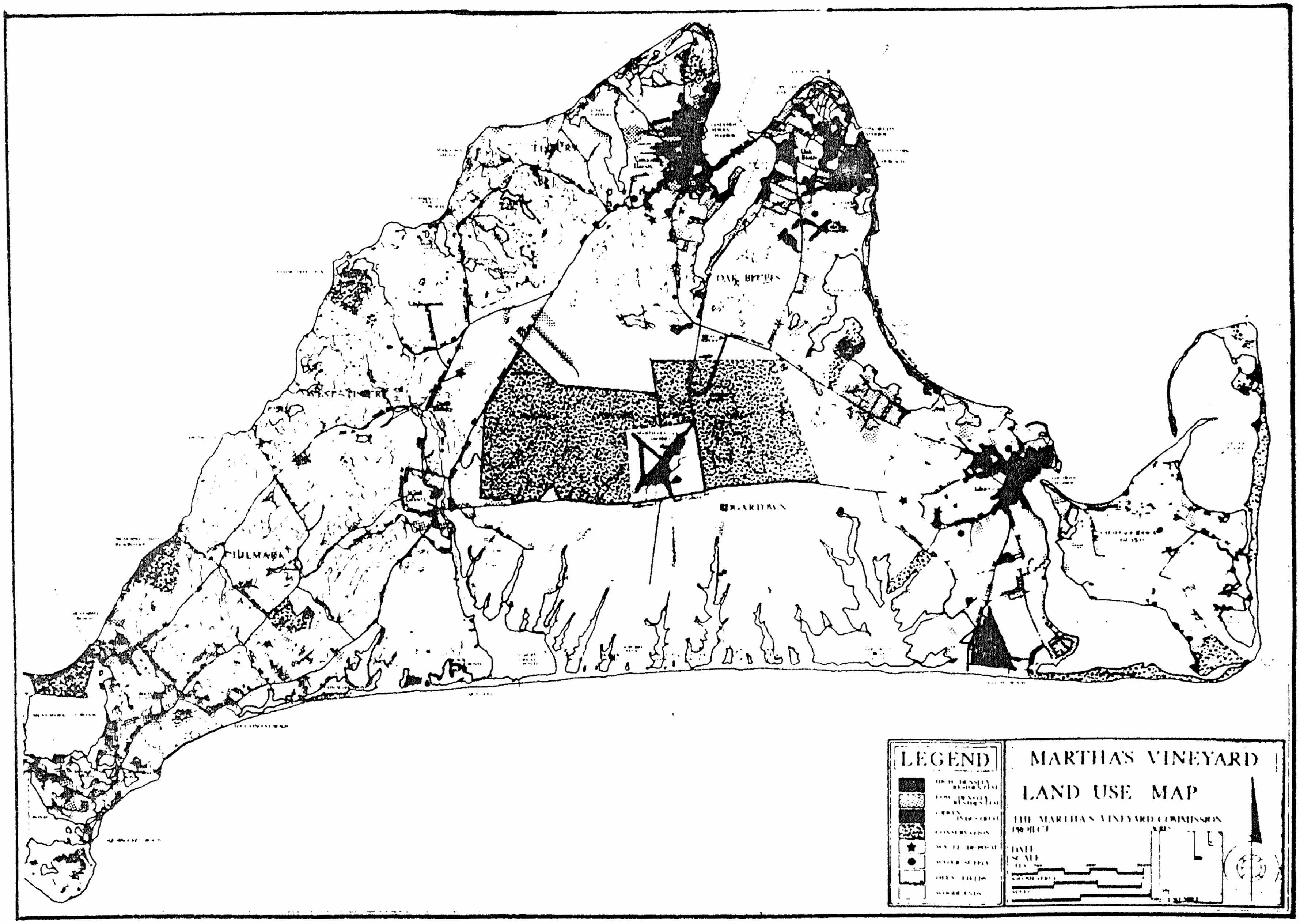


Figure 11. Land use distribution for the area of Martha's Vineyard surround ing Lagoon Pond. Black indicates high density residential development (modified from MVC, 1977, figure 7).

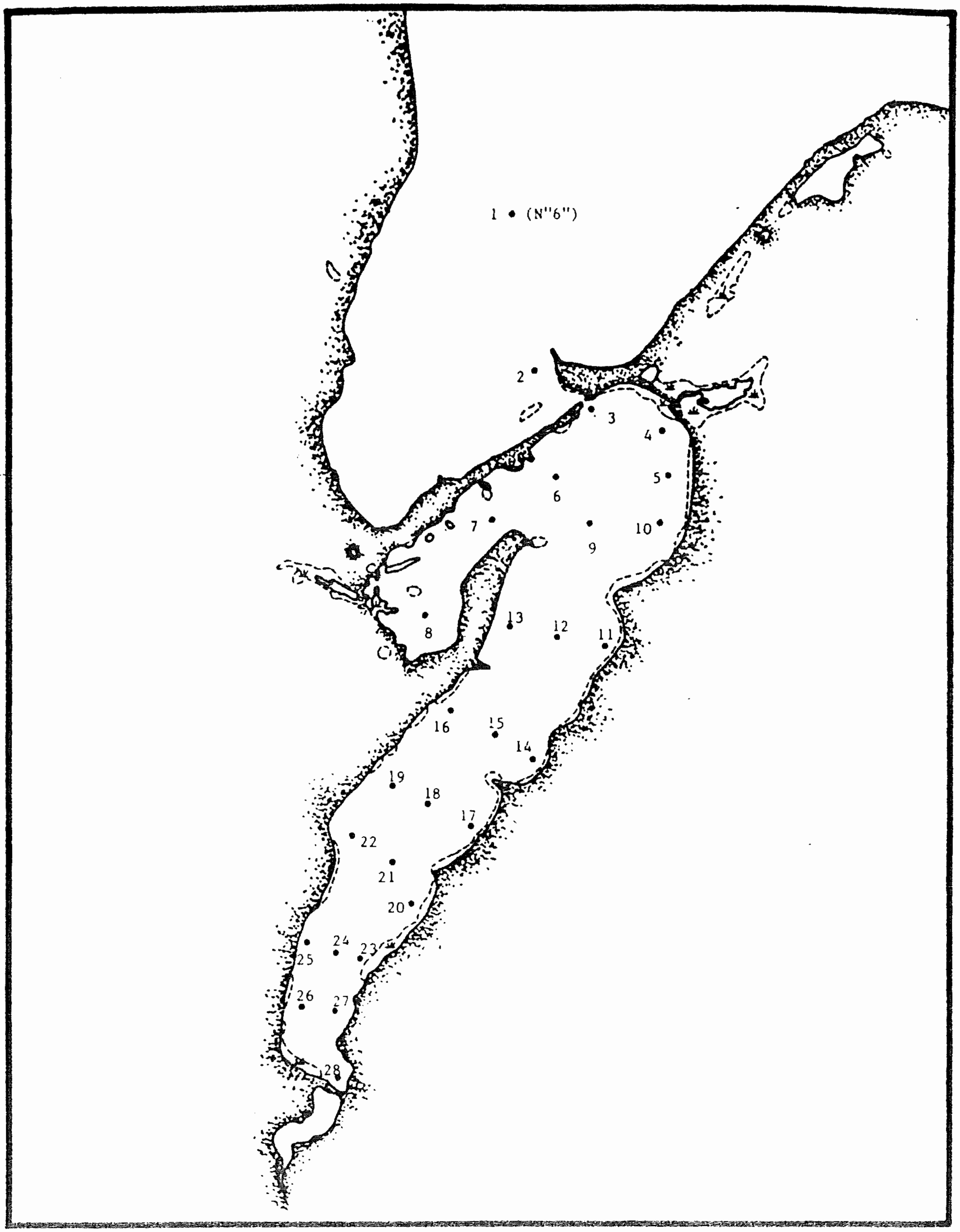


Figure 12. Water sampling stations in Lagoon Pond (Martha's Vineyard, MA).

Table 7. Time series for nutrients and other variables in Lagoon Pond (Martha's Vineyard), July 30-31, 1984 collected at the causeway bridge (Sta 3). Air temperature 18-25° C., calm. Nutrient concentrations in uM/L. Tidal height relative to arbitrary datum.

Time	Temp °C	Sal. (o/oo)	PO_4	NO_3	NO_2	NH_3	Total N	Tide	Ht. (cm)
0900	21	30.629	–	–	–	–	–	F	
0930	21	30.664	–	–	–	–	–	F	51
1000	21	30.608	–	–	–	–	–	F	57
1030	21	30.701	–	–	–	–	–	F	63
1100	21	30.614	0.38	0.02	0.01	0.24	28.4	HS	69
1130	22	29.531	–	–	–	–	–	E	69
1200	22	29.678	0.64	0.10	0.02	0.18	29.4	E	63
1230	22	29.824	–	–	–	–	–	E	61
1300	23	29.487	0.51	0.09	0.01	0.24	22.9	E	60
1330	22	29.965	–	–	–	–	–	ES	69
1400	21	30.581	0.48	0.04	0.02	1.02	18.0	F	
1430	23	30.088	–	–	–	–	–	E	66
1500	23	29.809	0.42	0.01	0.02	0.22	22.6	E	61
1530	23	29.932	–	–	–	–	–	E	56
1600	23	29.871	0.44	0.00	0.01	0.31	21.1	E	48
1630	23	29.813	–	–	–	–	–	E	43
1700	23	29.784	0.42	0.00	0.00	0.21	18.5	E	38
1730	23	29.834	–	–	–	–	–	E	34
1800	23	29.717	0.55	0.15	0.02	0.80	28.4	E	30
1830	23	29.682	–	–	–	–	–	E	26
1900	23	29.667	0.53	0.05	0.01	0.18	23.1	LS	25
1930	23	29.844	–	–	–	–	–	F	28
2000	21	30.542	0.44	0.04	0.02	0.22	20.2	F	30
2030	21	30.676	–	–	–	–	–	F	37
2100	20	30.706	0.36	0.02	0.01	0.15	16.5	F	46
2130	21	30.703	–	–	–	–	–	F	56
2200	22	30.650	0.43	0.03	0.01	0.20	25.4	F	66
2230	21	30.623	–	–	–	–	–	F	76
2300	21	30.662	0.34	0.04	0.00	0.18	23.7	F	79
2330	21	30.639	–	–	–	–	–	F	84
0000	21	29.627	0.40	0.04	0.01	0.46	33.9	F	71
0030	22	29.540	–	–		–	–	HS	86
0100	22	29.554	0.43	0.02	0.01	0.61	28.0	E	84
0130	21	29.311	–	–	–	–	–	F	84
0200	21	29.552	0.50	0.26	0.05	0.62	21.6	F	89
0230	21	30.512	–	–	–	–	–	HS	90
0300	22	29.949	0.42	0.03	0.02	0.42	20.2	E	85
0330	22	29.767	–	–	–	–	–	E	76
0400	22	29.890	0.51	0.07	0.02	0.77	19.7	E	66
0430	22	29.776	–	–	–	–	–	E	57
0500	22	29.767	0.48	0.05	0.02	0.65	21.6	E	51
0530	22	29.717	–	–	–	–	–	E	41
0600	22	29.765	0.41	0.00	0.01	0.36	18.7	E	33

Table 7 (Cont.) Time series for nutrients and other variables in Lagoon Pond (Martha's Vineyard), July 30-31, 1984 collected at the causeway bridge (Sta 3). Air temperature 18-25° C., calm. Nutrient concentrations in uM/L. Tidal height relative to arbitrary datum.

Time	Temp °C	Sal. (o/oo)	PO_4	NO_3	NO_2	NH_3	Total N	Tide	Ht. (cm)	
0630	22	29.790	-	-	-	-	-	E	25	
0700	22	29.753	0.65	0.07	0.07	1.38	21.9	E	20	
0730	22	29.789	-	-	-	-	-	E	15	
0800	22	29.746	0.40	0.00	0.01	0.19	20.2	F	16	
0830	22	30.548	-	-	-	-	-	F	20	
0900	22	30.600	0.47	0.07	0.02	0.32	19.6	F	28	
0930	21	30.691	-	-	-	-	-	F	35	
1000	21	30.708	0.35	0.00	0.01	0.21	20.3	F	46	
1030	21	30.687	-	-	-	-	-	F	55	
1100	21	30.687	0.33	0.02	0.00	0.22	18.8	F	63	
1130	22	30.697	-	-	-	-	-	F	66	
1200	22	30.693	0.36	0.01	0.00	0.27	20.7	F	67	
1230	23	29.944	-	-	-	-	-	E	68	1222 was HS
1300	23	29.028	0.99*	0.30	0.12	4.35	19.8	E	67	
1330	24	29.992	-	-	-	-	-	E	67	
1400	23	29.055	0.51	0.12	0.02	0.37	19.4	E	63	

* sample bottle broken

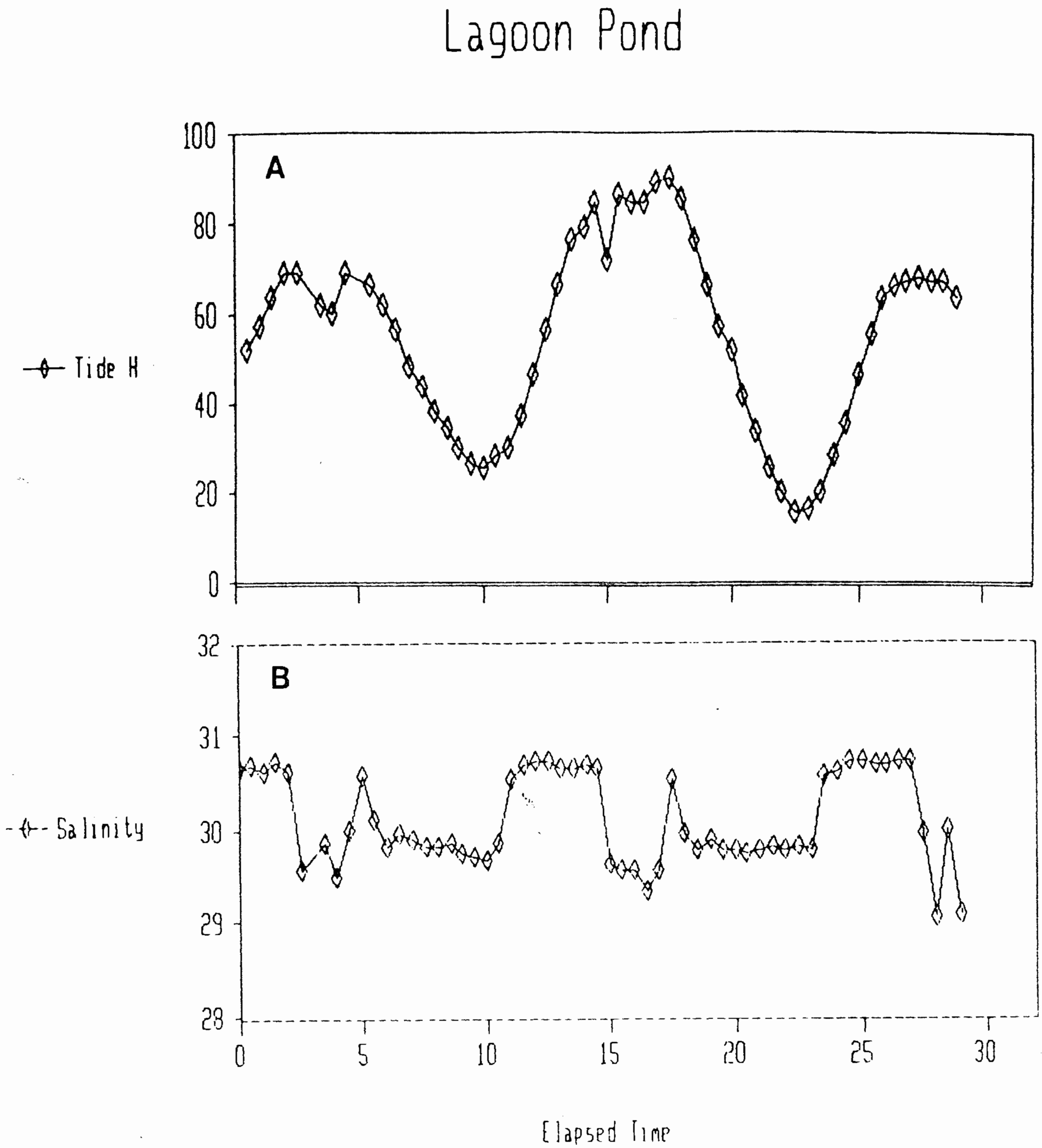


Figure 13. Data for the July 30-31, 1984 time series (half hourly measurements) at station 3 in Lagoon Pond. A) Tidal height (cm) relative to an arbitrary datum. B) Surface water salinity (accuracy is better than 0.01 ppt).

that Vineyard Haven Harbor water entering Lagoon Pond is effectively removed from the vicinity of the inlet, and ebbing water has a distinctly estuarine characteristic; similarly, ebb water is effectively lost to Vineyard Haven Harbor. One circulation pattern that could account for this, also observed in basins of the Narrow River (R.I.) and Town Cove, involves subsidence of entering water into the deeper basins with subsequent ebb of surface water (Figure 14). Presumably ebb water is effectively advected away by currents outside the estuary. In both of the other ponds we are studying, salinity changes accompanying tidal reversals usually were more gradual, suggesting advection back and forth of the same water past our sampling station.

The salinity and tidal data also give us one basis for estimating freshwater influx into these estuaries. Based upon the observation that flood waters have a higher salinity than ebb waters, it is possible to calculate how much freshwater is needed to cause the observed dilution. These calculations give the following results for dates on which we have samples:

Lagoon Pond	62,000 cubic meters/day
Green Pond	7,900 to 11,600
Town Cove	2,000 to 100,000

The discharge value for Lagoon Pond, determined in this way, is about twice the highest average estimate determined earlier (see Table 6); additional data will be needed to determine if a genuine contradiction exists (as discussed later, most of the discrepancy can be accounted for by a net loss of stored freshwater in the Lagoon). The values for Green Pond are much closer in this regard.

Our limited data suggest the total nitrogen content (dissolved and in fine particles) of surface water in the Lagoon was similar to values for Town Cove, but only about half of summertime levels for Green Pond, and concentrations of nitrate, nitrite and ammonia were lower here than for the other estuaries (Table 8). Dissolved phosphate was also lower for Lagoon Pond than for the other estuaries during summer observations. From differences in flood and ebb samples, we can in some cases surmise net transport into or out of the estuary. For example, data from Town Cove show some fairly clear relationships between direction of tidal flow and concentrations of nutrients (e.g., nitrate and phosphate) in winter, indicating offshore sources of these substances (Figure 15). The summertime observations at Town Cove suggest a more complex relationship.

During the course of our observations in Lagoon Pond (based on data in Table 9) an estimated 44.8 Kg N/day was imported into the estuary. As in the case of Town Cove (Teal, 1983), this could represent a very large term in the nitrogen budget: for Lagoon Pond it is nearly twice the anthropogenic input from residences (Table 6). Obviously, additional data would be required to confirm this as a year-round generalization.

1.17×10^6 Moles
$= 536$ mM
m^2/yr

Despite the implications of nutrient supply to the functioning of estuarine ecosystems, the photosynthetic and respiratory response by plants and other autotrophs to this supply is of even more direct significance. These metabolic activities determine the rate of production of organic matter that fuels the ecosystem and they play a major role in the oxygen balance. Where possible, we made replicate measurements of primary productivity, using

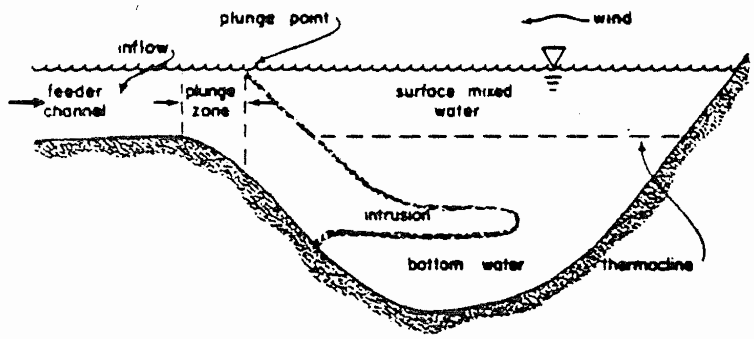


Figure 14. Tidal advection over a sill into an estuarine basin, where in flowing water is denser than surface estuarine water. Outflow under these conditions involves only the estuarine surface water (Modified from Aubrey, 1983 in Teal, 1983).

Table 8. Averages of nutrient concentrations and other variables in coastal ponds on Cape Cod and the Islands (Massachusetts; see Figure 1). Data from 24-30 hour time series at stations near the estuary mouth. x= average value; sd=one standard deviation unit; n= number of data points averaged.

		Temp °C	Sal. (o/oo)	PO_4	NO_3	NO_2	NH_3	Total N	mg m^{-3}
Lagoon Pond 7/30-31/84	x	21.9	29.7	0.47	0.06	0.02	0.55	22.2	310
	sd	0.9	2.6	0.13	0.07	0.02	0.80	4.1	
	n	59	62	28	28	28	28	28	
Green Pond 8/13-14/84	x	24.2	28.3	0.71	0.32	0.03	0.85	40.4	566
	sd	0.8	2.8	0.08	0.39	0.01	0.58	9.3	
	n	52	52	25	26	26	25	26	
10/25-26/84	x	14.8	30.2	0.51	0.50	0.01	0.62	23.0	322
	sd	0.3	0.5	0.08	0.3	0.02	0.37	2.7	
	n	52	51	26	26	26	26	26	
Town Cove 3/14-15/83	x	4.3	30.3	0.05	1.73	0.08	0.71	15.2	213
	sd	1.6	0.9	0.06	1.34	0.05	0.40	2.9	
	n	48	55	28	28	28	28	28	
8/18-19/83	x	18.5	30.4	0.87	0.09	0.03	1.60	15.4	216
	sd	0.9	0.4	1.04	0.08	0.02	0.88	3.8	
	n	27	27	27	27	27	27	27	
8/28-29/84	x	20.1	30.7	0.86	0.17	0.04	0.72	20.9	317
	sd	1.2	1.5	0.30	0.11	0.01	0.40	6.0	
	n	62	62	30	30	30	30	31	

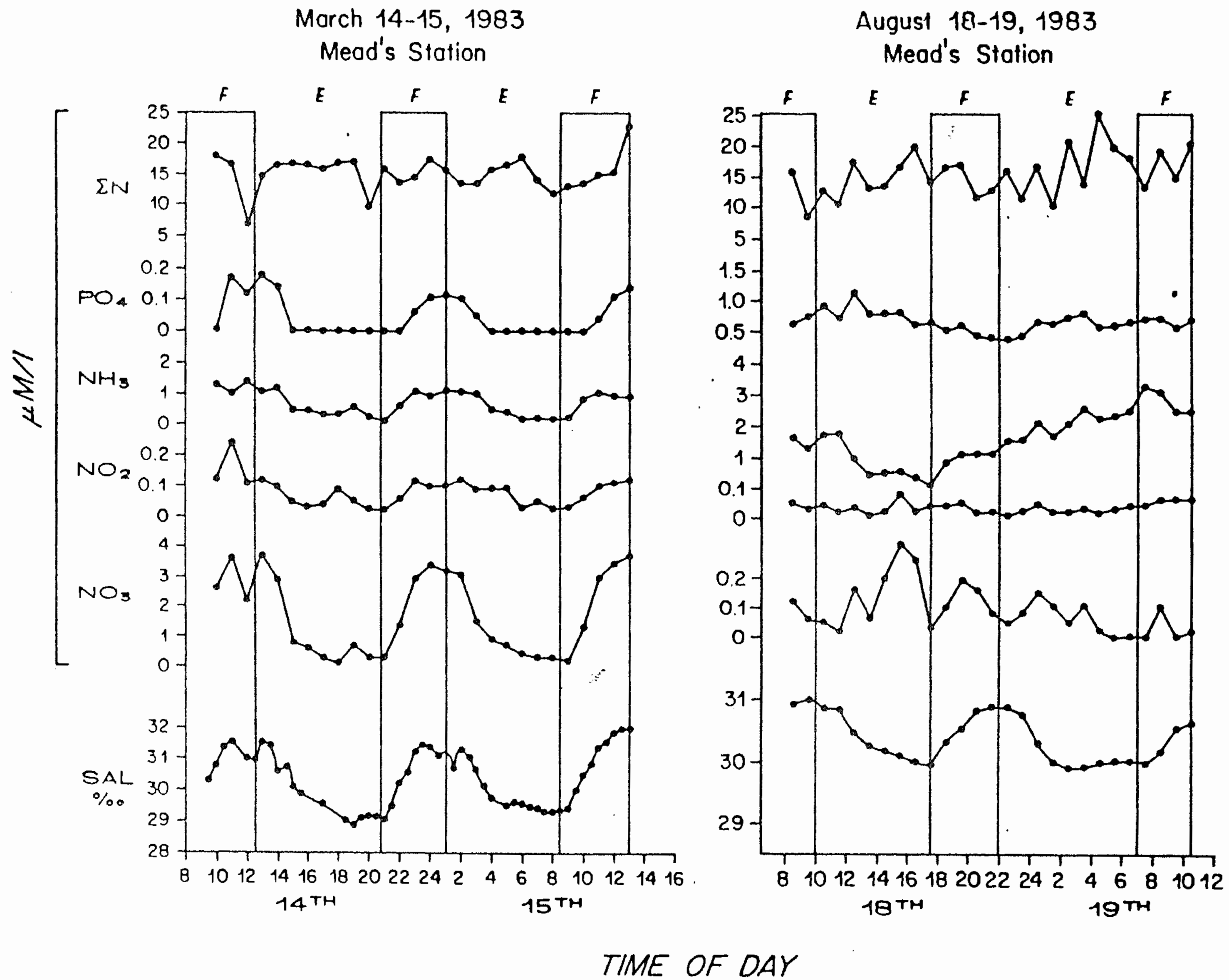


Figure 15. Time series of salinity, and surface water concentrations of nitrate, nitrite, ammonia, total nitrogen and phosphate in Town Cove, Orleans, for March and August, 1983.

Table 9. Averages of nutrient concentration (hourly samples), salinity and temperature (half-hourly samples) for flood and ebb flow in coastal ponds of Cape Cod and the Islands (Massachusetts). Data from 24-30 hour time series at stations near the estuary mouth. Number in () is one standard deviation unit.

	Tide	Temp °C	Sal. (o/oo)	PO_4 (um/l)	NH_3 (um/l)	Total N (um/l)
Lagoon Pond	E	22.7	29.8 (0.20)	0.50 (0.08)	0.40 (0.33)	23.0 (4.1)
7/30-31/84	F	21.3	30.2 (0.60)	0.41 (0.05)	0.35 (0.21)	25.6 (4.6)
	E	22.0	29.7 (0.07)	0.49 (0.10)	0.72 (0.41)	20.4 (1.3)
	F	21.5	30.5 (0.30)	0.38 (0.06)	0.24 (0.05)	19.9 (0.6)
Green Pond	F	25.0	28.6 (0.85)	0.72 (0.07)	0.43 (0.06)	41.6 (11.7)
8/13-14/84	E	25.0	28.5 (0.60)	0.74 (0.07)	0.53 (0.09)	43.4 (6.0)
	F	24.0	29.6 (0.70)	0.68 (0.08)	1.10 (0.70)	31.7 (4.6)
	E	23.4	28.4 (1.30)	0.70 (0.10)	0.92 (0.49)	44.9 (10.8)
	F	24.0	29.2 (1.34)	0.72 (0.06)	0.94 (0.12)	32.6 (4.3)
	E	15.0	29.8 (0.55)	0.50 (0.09)	0.59 (0.41)	23.3 (3.4)
10/25-26/84	F	15.0	30.3 (0.47)	0.55 (0.07)	0.75 (0.53)	22.9 (2.8)
	E	14.3	30.2 (0.25)	0.46 (0.09)	0.48 (0.12)	24.4 (1.7)
	F	14.5	30.7 (0.18)	0.52 (0.04)	0.62 (0.18)	21.8 (2.0)
Town Cove	F	3.3	31.0 (0.5)	0.10 (0.20)	1.2 (0.2)	13.7 (6.3)
3/14-15/83	E	4.6	29.8 (0.8)	0.04 (0.07)	0.6 (0.4)	15.4 (2.4)
	F	3.9	30.6 (0.9)	0.06 (0.06)	0.8 (0.4)	15.4 (1.5)
	E	4.1	29.9 (0.7)	0.02 (0.04)	0.5 (0.4)	14.7 (2.0)
	F	4.7	31.0 (0.9)	0.06 (0.06)	0.8 (0.4)	16.0 (4.0)
	F	17.5	30.9 (0.04)	0.68 (0.11)	1.5 (0.2)	12.3 (5.3)
8/18-19/83	E	19.4	30.8 (0.35)	0.82 (0.15)	0.9 (0.6)	14.8 (3.3)
	F	18.9	30.4 (0.38)	0.55 (0.09)	0.8 (0.5)	14.8 (2.5)
	E	18.1	30.3 (0.41)	0.60 (0.14)	2.0 (0.5)	16.3 (4.6)
	F	17.9	30.3 (0.32)	0.68 (0.05)	2.9 (0.4)	16.6 (3.4)
	E	20.9	30.7 (0.1)	1.00 (0.20)	0.60 (0.26)	20.8 (4.3)
8/28-29/84	F	19.2	30.8 (0.2)	0.74 (0.36)	0.41 (0.18)	17.9 (5.1)
	E	19.8	30.7 (0.2)	0.93 (0.30)	0.91 (0.51)	24.6 (7.8)
	F	19.7	30.8 (0.2)	0.78 (0.34)	1.00 (0.44)	18.5 (6.5)

the standard light/dark bottle, oxygen change method. Surface waters sampled for these measurements were collected both from the estuary as well as from the adjacent sound or sea in order to determine the relative productivity of the estuary and the water body supplying seawater. In this way, the effect of varying light and other factors was eliminated, since all samples were incubated under identical conditions, and a direct comparison of productivity was possible. The results show that net productivity for Green Pond was about 10 times greater than for the adjacent waters of Nantucket Sound; for gross productivity the ratio was from 3 to 10 (Table 10). These results are intuitively reasonable, since we anticipate estuaries will be more productive than the adjacent offshore waters. Surprisingly, in the case of Lagoon Pond we found both net and gross productivity were less than for Vineyard Haven Harbor (ratios of 0.6 to 0.9; Table 10). The potential significance of this is that the Harbor is more heavily loaded by nutrients than Lagoon Pond, which upon reflection seems entirely possible.

In addition to the above measurements, we attempted to characterize the spatial distribution of certain water properties within these coastal ponds. For Lagoon Pond we determined salinity for a 28-point grid encompassing the entire estuary, and repeated the survey 18 hours later (Figures 16 and 17). The tide level for the second survey was 0.46 m (=18 inches) lower than for the first. Since there were no precipitation or unusual meteorological events, differences from one survey to the other reflect only ordinary tidal discharge and summertime mixing and freshwater input over a time scale of about 18 hours. The salient difference in these salinity distributions is in the southern end of the Lagoon, where surface salinity dropped by about 2 parts per thousand. If this represents fresher water draining off the surface during the ebb process, the loss of freshwater amounts to about 30,600 cubic meters. This net loss from the estuary brings our two calculated freshwater discharge estimates into approximate accordance (i.e., 21,000 vs. 29,000 cubic meters per day) if the high range of estimates in Table 6 is closest to correct.

Another interesting feature of the salinity distribution on July 31 (Figure 17) is that within the Lagoon the highest salinities are in the southern end, with the highest salinity at station 28, in near proximity to Herring Creek, the only stream entering the Lagoon. To a lesser extent, this condition is reflected in the distribution of July 30, where station 28 also has the highest salinity, locally. This suggests some kind of upwelling process is active to displace the fresher water and bring more saline water to the surface at the head of the Lagoon.

The relative uniformity in the distribution of salinity in both surveys suggests freshwater input is relatively uniform around the margins of the East Arm. The comparative strong depression of salinity at station 8 in the West Arm suggests significant sources of discharge in that area--presumably from Mud Creek.

In order to characterize the gradient of water properties within Lagoon Pond, we measured certain nutrients as well as water transparency (using a secchi disk), along the axis of the East Arm of the Lagoon. Water transparency is a semi-quantitative measure of the amount of suspended particles in the water, as well as of discoloration. The results (Table 11) indicate uniformly increasing water transparency from the head of Lagoon Pond to

Table 10. Comparative primary productivity for surface water samples from Lagoon Pond (Martha's Vineyard) and Green Pond (Falmouth) as well as of surface samples from the adjacent body of waterad. Expressed as hourly change in dissolved oxygen (ml oxygen/liter/hour).

	Net			Gross			Resp
Lagoon Pond							
July 30, 1984	a/	b/	c/	a/	b/	c/	
Pond Sta 18	0.061 (0.046)	0.059	0.070	0.082	0.080	0.090	-0.020
July 31, 1984							
Pond Sta 18	0.039	-	0.057	0.069	-	0.087	-0.029
Harbor Sta 1	0.063	-	0.073	0.085	-	0.094	-0.022
ratio	0.6		0.8	0.8		0.9	1.3
Green Pond							
August 13, 1984							
Pond Sta 14	0.796	-	0.771	0.817	-	0.792	-0.020
Sound Sta 28	0.082	-	0.078	0.296	-	0.082	-0.204
ratio	9.7		9.9	2.8		9.7	0.1
August 14, 1984							
Pond Sta 14	0.957	-	0.971	1.100	-	1.120	-0.145
Sound Sta 28	0.082	-	0.089	0.198	-	0.204	-0.116
ratio	11.7		10.91	5.6		5.49	1.25

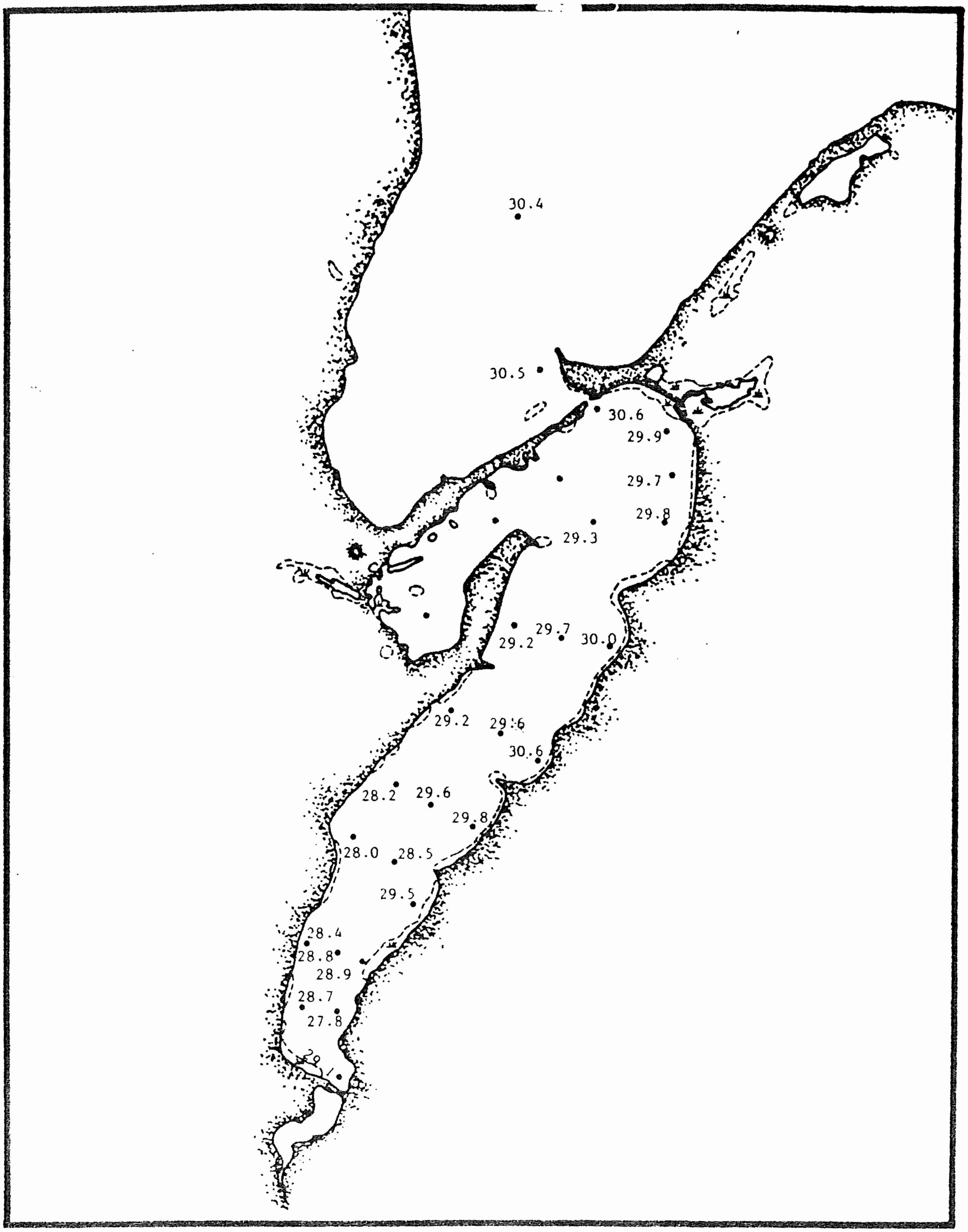


Figure 16. The quasi-synoptic distribution of salinity (ppt) in surface waters of Lagoon Pond, July 30, 1984, 14:30 EDT, tidal stage 66 cm.

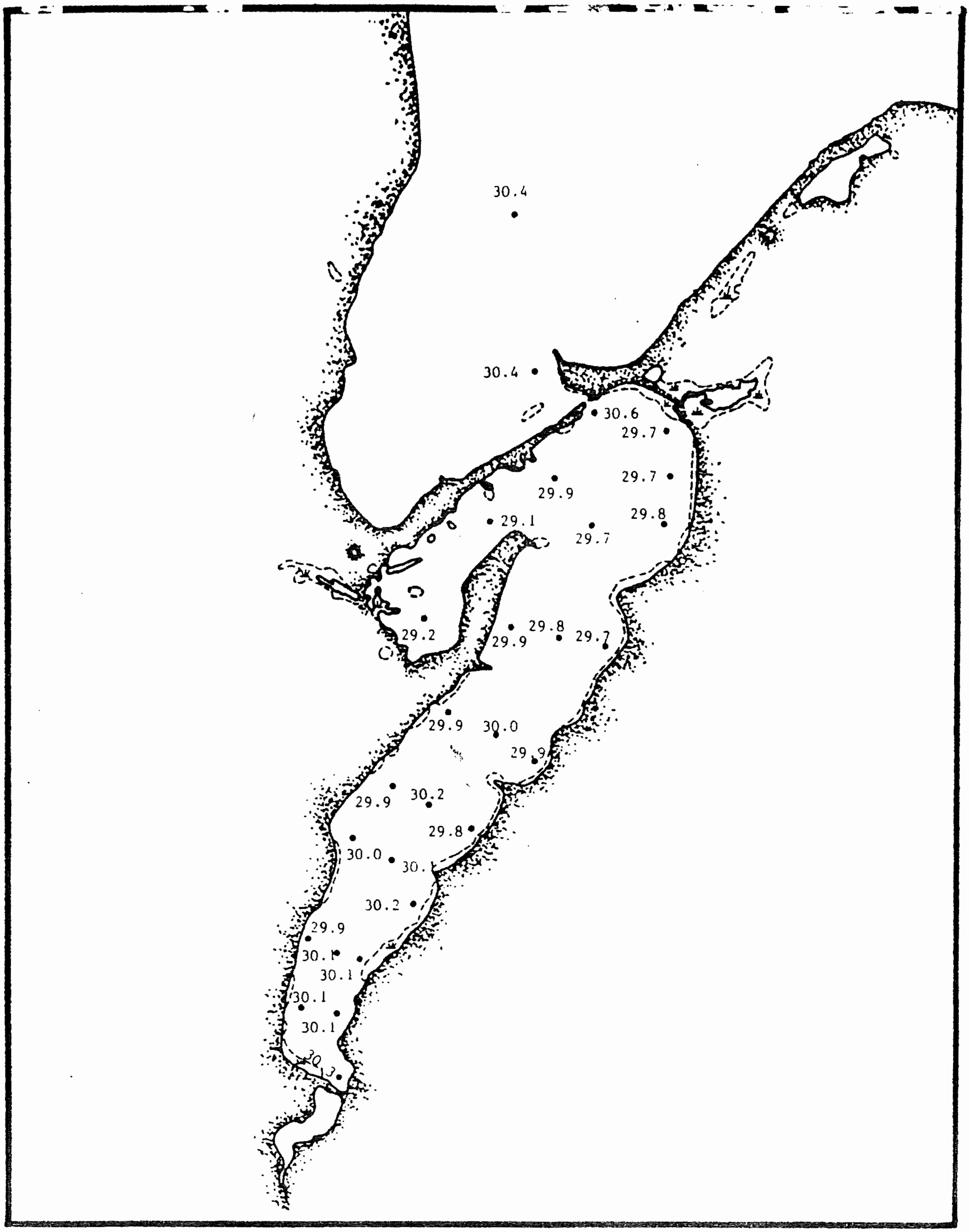


Figure 17. The quasi-synoptic distribution of salinity (ppt) in surface waters of Lagoon Pond, July 31, 1984, 0830 EDT, tidal stage 20 cm.

Table 11. Nutrient concentrations (uM/l) and other variables in surface waters from Lagoon Pond (Martha's Vineyard) along an axial transect of the East Arm. July 31, 1984.

Distance Up Estuary (Km)	PO_4	NO_3	NO_2	NH_3	Total N	Sal. (o/oo)	Secchi Depth (m)	Comments
-	0.12	0.01	0.01	1.22	38.2	0		Herring Brook
3.8	1.33	0.00	0.03	0.51	40.2	30	1.98	Sta 28
3.1	0.98	0.00	0.03	0.42	31.7	30	2.74	Sta 24
2.7	-	-	-	-	-	-	2.94	Sta 21
2.3	0.72	0.00	0.02	0.23	22.1	30	3.07	Sta 18
1.8	-	-	-	-	-	-	3.35	Sta 15
1.2	-	-	-	-	-	-	3.23	Sta 12
0.6	0.41	0.00	0.02	0.26	18.5	30	3.78	Sta 9
-0.7	-	-	-	-	-	-	3.96	Sta 1 (Harbor)

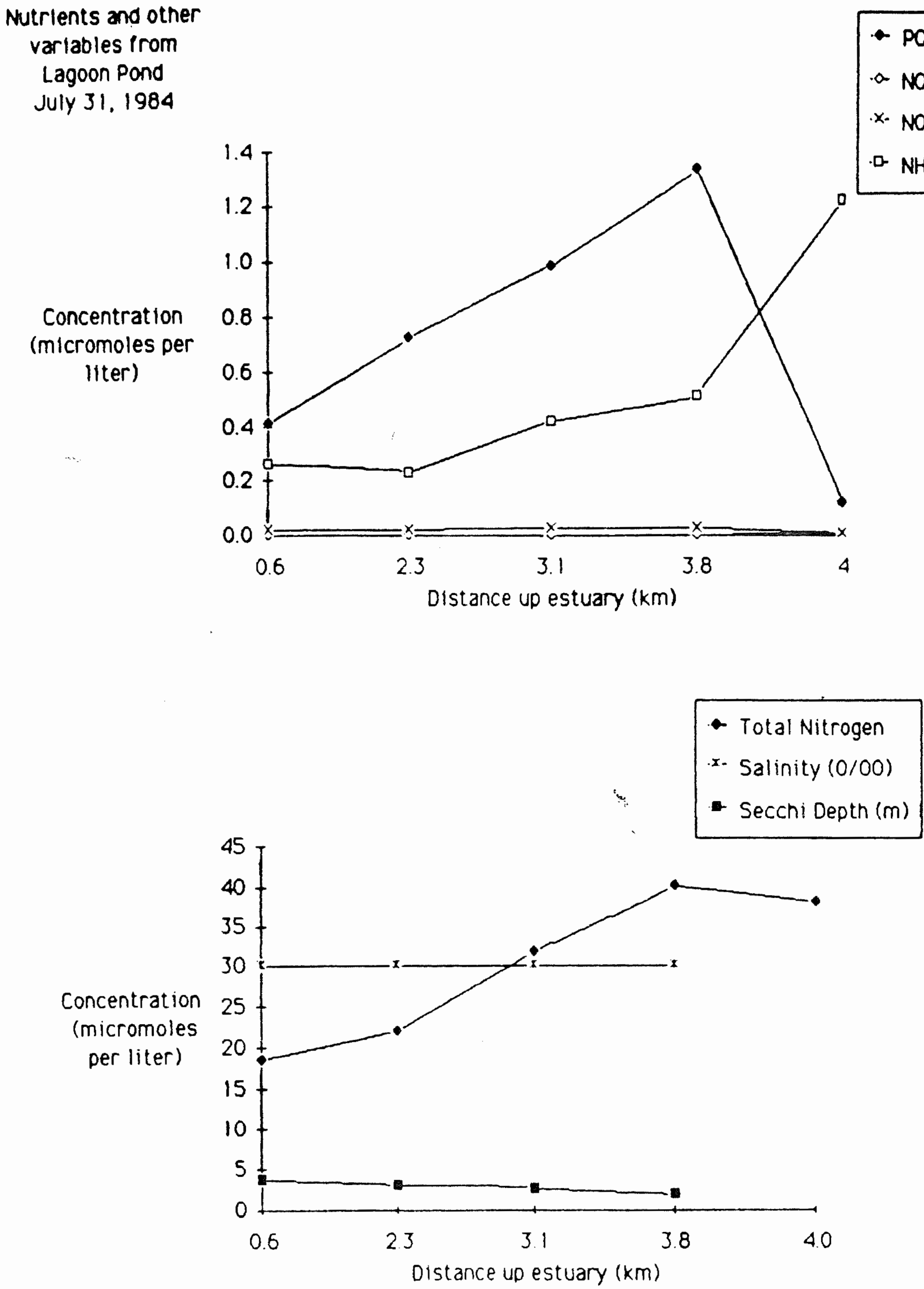
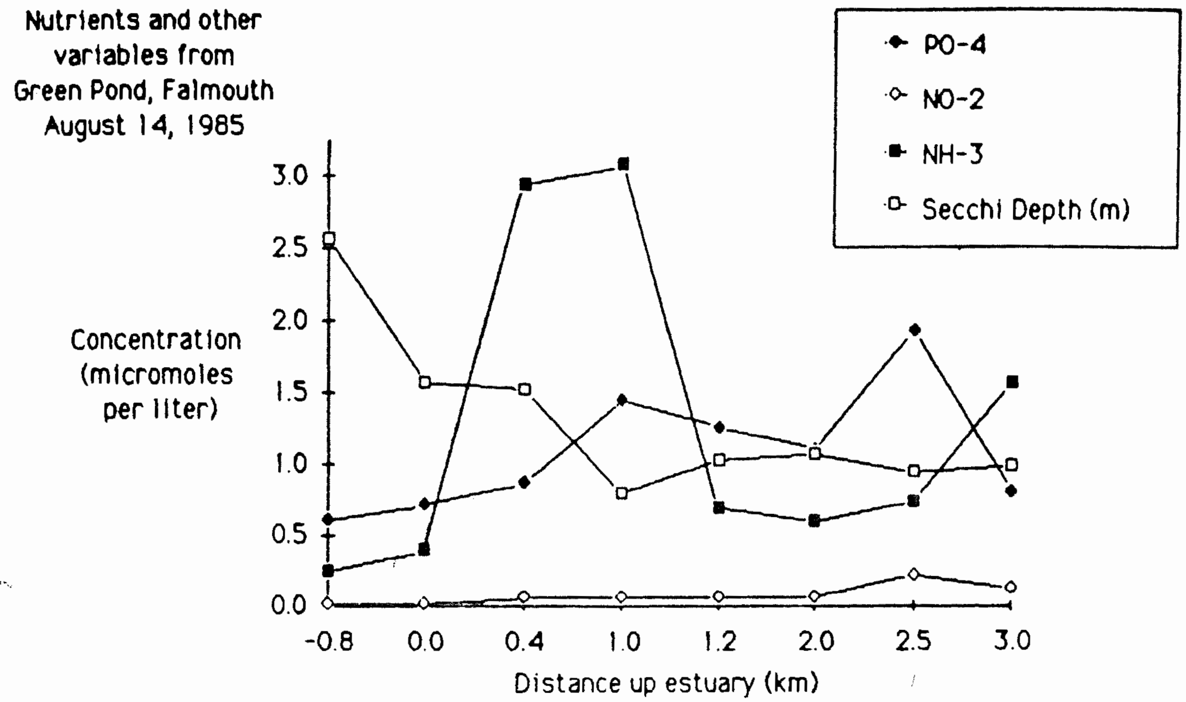


Figure 18. Axial transect of salinity, nutrients and transparency in surface water of Lagoon Pond, July 31, 1984. Data are from Herring Brook and stations 28, 24, 21, 18, 15, 12, and 9.



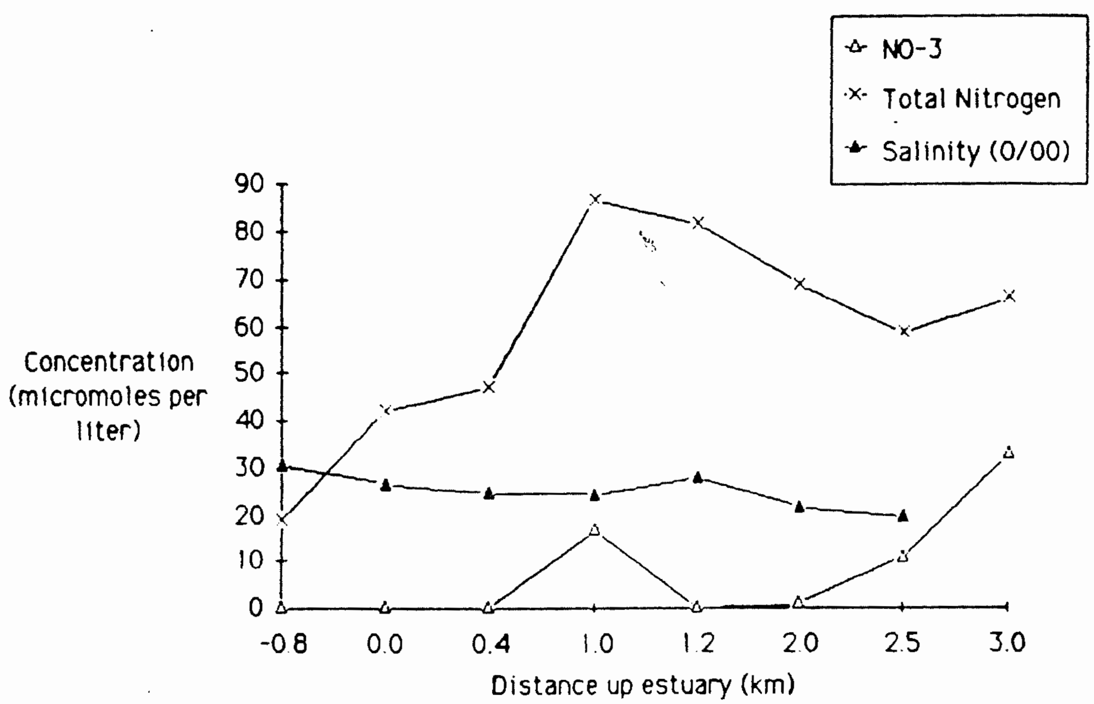


Figure 19. Axial transect of salinity, nutrients and transparency in surface water of Green Pond, August 14, 1984.

the station in Vineyard Haven Harbor, where the Secchi depth was nearly 4 m (=13 feet). Water from Herring Creek had a surprisingly high ammonia and total nitrogen content, but was low in phosphate and in nitrate and nitrite. It would be interesting to know the source of the high total nitrogen. Along this transect phosphate, ammonia and total nitrogen dropped sharply toward the Harbor, while neither nitrate, nitrite nor salinity showed strong gradients (see Figure 18).

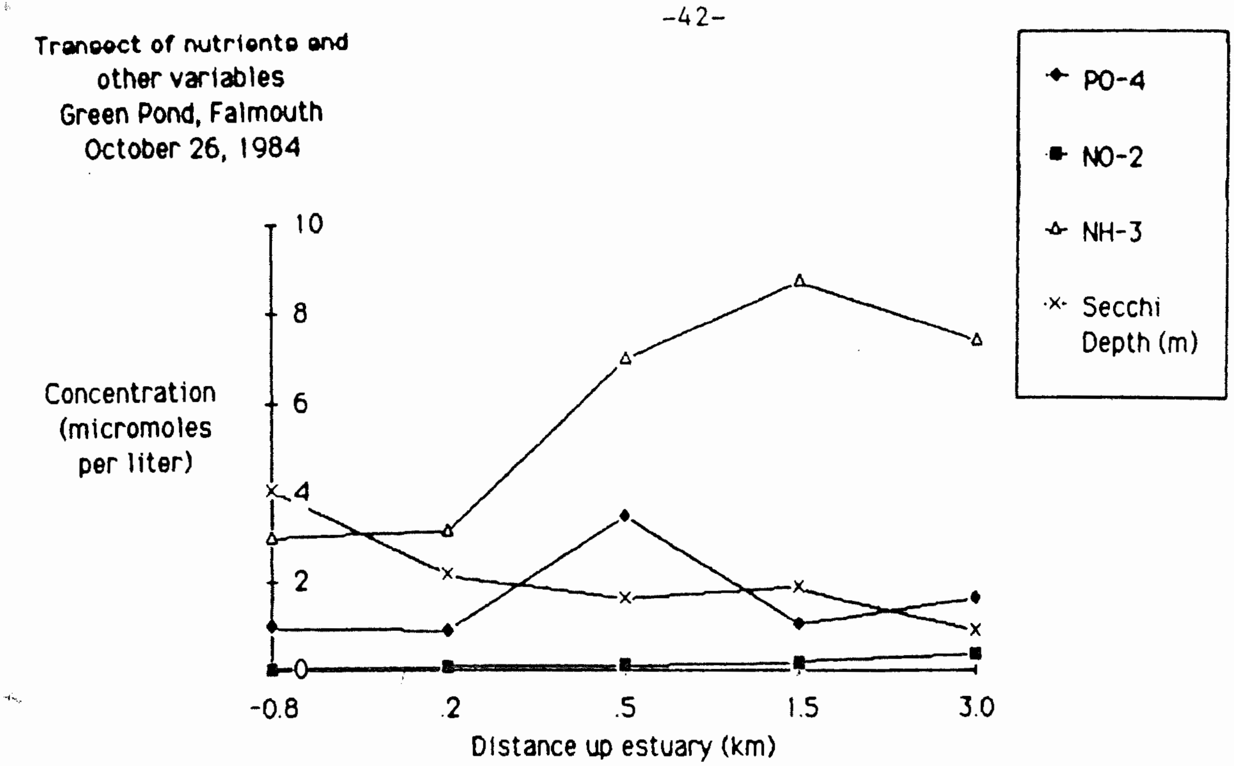
In comparison, the summer transect for Green Pond gave more complex results (Figure 19). Water transparency was considerably less within the estuary (generally 1m [=3 feet] or less) and the Vineyard Sound station had a Secchi depth of only 2.5 m (=8.2 feet) which was less than for any station in the Lagoon except station 28 at the head of the Pond. Ammonia concentrations reached a maximum near the central reaches of Green Pond, where they were more than twice the highest value in the Lagoon and total nitrogen in upper Green Pond was more than double the highest value in the Lagoon. In the autumn station in Green Pond, the trends were more regular, but nutrient concentrations were considerably higher (Figure 20).

The surface distribution of nutrients and other variables was surveyed during January of 1985 to help characterize the winter values of these features in Lagoon Pond. In addition, samples were collected for coliform bacteria, which were processed by D.E.Q.E., Lakeville in cooperation with Ms. Maria L'Annunziata. At the time of the survey Lagoon Pond was frozen at

Table 12. Surface distribution of dissolved nutrients (uM/l), coliform bacteria and other variables in Lagoon Pond (Martha's Vineyard). January 14, 1985 (see Figure 12 for station locations. Lagoon Pond was ice-covered south of station 25 at the time of sampling).

Station	Salinity (°/oo)	Temp. (°C.)	PO_4	TP	NO_3	NO_2	NH_3	TN	Coliform[a] Total	Fecal
Mud Creek	24.9	0	0.61	0.62	35.1	0.16	2.17	62.5	460	43.0
8	31.1	0	0.38	0.57	1.9	0.07	0.52	42.6	9.1	3.0
25	24.9	0	0.45	0.45	15.9	0.08	0.81	40.9	9.1	3.6
24	31.3	0	0.30	0.30	0.5	0.04	0.09	14.2	3.6	3.0
21	31.5	0	0.36	0.46	0.3	0.06	0.25	16.9	3.0	3.0
22	31.2	0	0.39	0.39	0.5	0.05	0.18	23.0	3.0	3.0
18	31.5	0	0.41	0.41	0.2	0.06	0.39	20.4	-	-
19	31.5	0	0.46	0.50	0.5	0.07	0.25	19.9	240	3.0
17	30.5	0	0.36	0.38	0.3	0.05	0.22	21.1	3.6	3.0
15	31.7	0	0.41	0.41	0.2	0.06	0.17	17.0	-	-
12	31.6	0	0.41	0.49	0.3	0.06	0.25	18.1	-	-
13	31.5	0	0.42	0.42	0.3	0.07	0.36	18.6	-	-
11	31.0	0	0.38	0.38	0.5	0.07	0.43	15.2	3.0	3.0
6	32.1	0	0.53	0.53	0.4	0.08	0.39	17.0	3.0	3.0

a/ Coliform data from M. L'Annunziata, D.E.Q.E., Lakeville



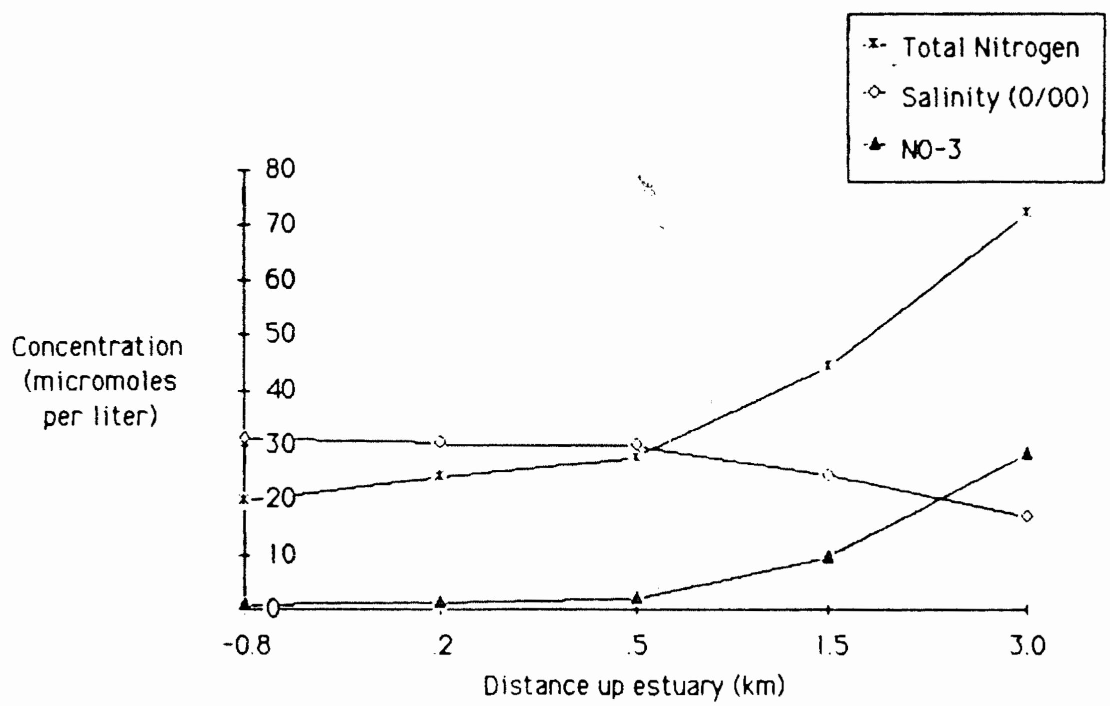


Figure 20. Axial transect of salinity, nutrients and transparency in surface water of Green Pond, October 26, 1984.

places around the edges and cover was complete south of station 25. The results (Table 12) indicate most variables did not depart markedly from summer values for Lagoon Pond, with some notable exceptions. The sample from Mud Creek (collected at the causeway where Lagoon Pond Road crosses the Creek) was considerably higher in all nitrogen and phosphorus species and showed elevated total and fecal coliform bacteria. The strong influence of freshwater was conspicuous in the lowered salinity, and we presume the nutrient materials were delivered to this site in this manner. It should be pointed out that large numbers of waterfowl were evident in the vicinity as well, and this could be a source of both nutrients and coliforms. As Mud Creek has been associated with high (and highly variable) coliform bacteria counts before, this site deserves special attention with regard both to fecal contamination and nutrient loading. This is particularly true as this creek drains a heavily populated section of Vineyard Haven. The sample collected nearby at station 8 in the West Arm of Lagoon Pond also showed slightly elevated concentrations of total phosphorus, nitrate and total coliform bacteria, but to a considerably smaller degree, suggesting the effect at Mud Creek is a localized one.

Results at two other stations are worth mentioning. A high total coliform (but not fecal coliform) count was observed at station 19, for which we have no explanation to offer. This sample was collected near the ice margin (as all shoreside samples were) and the possible influence of waterfowl exists here. There was no evidence of freshwater discharge at this site and none of the other variables measured were notably high. At station 25, also at the ice margin, however, salinity was significantly depressed and both nitrate and ammonia were higher than for most samples, again pointing to freshwater as a source of nitrogen-containing nutrients. The comparatively high phosphorus content of the sample collected at station 6, near the entrance to Lagoon Pond, is believed to support the contention that offshore water is a principal source of phosphorus for estuaries in this area, both in winter and summer.

FUTURE COURSE OF ACTION

In this report issues and problems of Lagoon Pond have been identified and discussed. The towns need to decide whether this treatment accurately reflects public opinion or not. The lack of data support for the perception that shellfish stocks are declining suggests closer records of catch are needed. Town Shellfish Constables need improved support in their acquisition of field data. New information on nutrients and other variables for Lagoon Pond provided by this study will serve as a valuable benchmark for the future and should help put into sharper perspective many of the issues surrounding its water quality. Several of the information shortcomings identified in the course of this work are already in the process of being remedied by the Clean Lakes Program study, currently under way for Lagoon Pond, for which we helped set goals and work tasks.

The principal issue we have identified in this study is the potential impact of land use on the composition of groundwater, and ultimately its impact at discharge zones, such as in Lagoon Pond. This concern applies not only to nutrients, the focus of our discussion here, but also to many water soluble materials applied purposely or inadvertantly, to the land surface. Again, this matter was not rigorously addressed in the 1977 Water Quality Plan for Martha's Vineyard (although staff of the Martha's Vineyard Commission are aware of this problem). As indicated above, the slow movement of groundwater eans that impacts of land use remote from the immediate shore area can take years to be expressed, at which time little can be done to remedy them.

Lagoon Pond appears to be less eutrophic than Green Pond in Falmouth, based on nutrients, primary productivity, and water clarity. However a much larger portion of the recharge area remains undeveloped for Lagoon Pond and so the potential impact of future land use may be greater. Added land use planning incentive should come from the fact that measures to protect Lagoon Pond also stand to protect the Oak Bluffs town well at the Upper Lagoon, and at least one of the Tisbury town wells that falls within this recharge area.

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PLANNING BOARD

TOWN OF TISBURY
P.O. BOX 1239
TOWN HALL ANNEX
VINEYARD HAVEN, MASSACHUSETTS 02568
(617) 693-2447

TAKEMMY

16 May 1983

Tisbury Board of Selectmen
Town Hall
Vineyard Haven, MA 02568

RE: <u>LAGOON POND BOTTOM STUDY PROPOSAL - YOUR COMMUNICATION OF THE 11th INSTANT</u>

Lagoon Pond - East Arm
======================

Overall conditions are considered good. The East Arm was not the subject of a focused investigation under the Vineyard Haven Inner Harbor studies biological subcontracts.

Tidal Flow: General patterns are consistent with bottom and shoreline contours. Flood tide current entry has nearly twice the velocity of the ebb current - in fact a small tidal bore is frequently seen. Some exceptions to the general flow are found in the Hine's Point, Sand Point and Turtle Hole areas.

Exchange Rate: The exchange rate is excellent; two (2) tide cycles exchange a volume of water equivalent to the entire East Arm content. There was a significant increase in the exchange rate following the most recent dredging of the Lagoon Pond Bridge Channel.

Water Quality: In general, the East Arm water quality is good. However, there have been periods of low quality; in all likelihood due to point source causes such as septage effluent escapement. No significant escapements have been verified as originating from the Tisbury shores, although several have been recorded on the Oak Bluffs side. Nevertheless, steep ravines (in the 'Oklahoma' area) which terminate at the shore are considered high pollution risks. Salinity, due to the many springs in the area, is often low along the shores; however, the high volume exchange rate largely offsets this dilution.

Problems:

1. Codium Fragile - Tomentosoides (a/k/a 'Jap Weed' and 'Spagheti Weed') is becoming well established. By attaching to scallops it restricts their normal movement and feeding; also, during storms the weed may cause the scallop to be washed ashore.

2. The high volume exchange rate probably causes a significant loss of scallop spat during those periods when the spat is dispersed in the water column.

3. Our greatest concern is pollution preventation; a concern tied to uses, density, geography and proximities.

Lagoon Pond - West Arm

The West Arm of Lagoon Pond was included in subcontract investigations relating to Vineyard Haven Inner Harbor studies. For legeslative and administrative purposes, the West Arm is charted and recorded as part of Vineyard Haven Inner Harbor. A Major portion of the West Arm shoreline is in commerical use.

The West Arm is the antithesis of the East Arm; it has several third order problems , major constraints, and few practical solutions identified. Speaking ecologically and in the vernacular, the West Arm is close to being a basket case. For example:

> Intermittent high level point source pollution has been recorded and tracked.
>
> Natural background level nutrients are unusually high.
>
> The water volume exchange rate is very low, requiring more than five (5) tidal cycyles to complete. The exchange rate decreased after the most recent Lagoon Pond Bridge Channel dredging.
>
> In this area, shellfish are usually stunted and sometimes off-color. Scallops do not do nearly as well in the West Arm as in the East Arm - poor water circulation a major cause. The area has several times been closed due high bacterial counts.
>
> Shallow (two foot average depth) water, poor circulation, a low tidal exchange rate and point source and non-point source pollution combine to characterize the area.
>
> Current pattern studies were limited because of the shallow water and low flow rates. However, it is interesting to note that visual signs of circulation are totally absent; no regularly occurring 'eddies', 'rings' or 'gyres' were noted.

These are but some of the highlights of the invesigation. Two marine biologists were engaged in this phase. We also arranged for Dr. Carr to give a public presentation. This well received and informative presentation is still being used by the Board of Health, Conservation Commission and Planning Board as a guide to addressing problems in this area.

Recommendations

Any Tisbury funds put into a biological or oceanographic study in Lagoon Pond should be directed entirely to the West Arm.

The study contract/agreement should be precise as to objectives and those objectives should be potential near term practical and low cost solutions. A generalized study would most likely be redundant.

It is suggested that the Planning Board review the proposed contract/agreement language prior to a commitment.

W H Renear Walter H. Renear, Chairman

APPENDIX 2

John T. Hughes
Vineyard Haven, MA
16 July 1981

What are these chemicals we hear so much about in the sea??? Phosphates, nitrates, chlorides???? Scary, aren't they? How about venus mercenaria, homarus americanus, mytilus edulis, pecten irradians, and especially crepidula fornicata???? These are the quahuag, lobster, mussel, scallop and the quarter deck....Sodium chloride??? table salt: you know that. We also eat phosphates and nitrates every day. We can even buy vitamin capsules that have concentrations of phosphates and nitrates.

Here I have some sea water from the Lagoon. It contains gold, silver, mercury, potassium, sodium: every common element there is. Nothing to be scared about.... as long as the amounts are the same as the good lord made it. This water also contains several hundred quahaugs, a lobster, probably some scallops, mussels, periwinkles, etc. Yes, they are all very small but they're in here..... and billions more in the Pond.

May I give a quick description of the love life of shellfish? How they do it underwater??? It's important: especially to the shellfish. It will tie together phosphates, nitrates and sea life.

Let's talk about oysters. The first year of life the oyster switches sexes from male to female and back and forth until it decides what it wants to be the rest of its life. When it's 3 years old it is old enough to reproduce and perhaps 3" in length. When The temperature is right, the female will release her eggs into the sea thru her syphon and it will trigger the male to do the same with his sperm. The eggs and sperm meet in the sea and a baby is formed! The baby oyster feeds on the algae and plankton in the waters around it.....if there is some. Rather simple. But let's take a closer

When we raise them in the laboratory we want a better survival than nature (where there is sometimes a complete bust...as scallop fishermen know). OK. We take the mature and ripe adult oysters and put them into special sea water. What's so special about it? Well, if we just used water from the Lagoon there would be live thing in it that would be bigger than the baby oyster and might even eat the oyster. So we take the Lagoon water and filter it with special strainers and get everything out that is larger than 1 micron or the size of our red blood corpuscle. Now we have nothing larger than the baby oyster but some of the live things STILL in the water can eat the oyster. So we either heat the water to kill all life or we treat it with ultraviolet light which does the same thing. Ah, now we have pure strained sea water with nothing alive in it. Beautiful to put our eggs from the female oyster and the sperm from the male. We get both of these by triggering the oyster to spawn with temperature manipulations. Now we have the baby microscopic oysters in the sterile water. What are they going to eat??? There's nothing in the water. They will starve. Here we have thousands of baby oysters that can only be seen with a microscope. Naturally their mouths are smaller than they are. We'll have to feed them something smaller than small. Fortunately microbiologists have been able to sort out some plankton and diatoms from the sea water and grow these in the laboratory. Some are called isochrysis, some monochrysis and some skeletonema. Great, now we can feed these small plants and animals to the already small microscopic oysters. BUT WAIT, the isochrysis, monochrysis and skeletonema have to eat too. What in the devil do we feed them? They're even smaller than the mouth of an oyster that we need a microscope to see. Anyone want to tackle that problem?? You're off the hook, it has already been solved. We've learned that isochrysis and the others are like our garden plants and vegetables. To live, grow and multiply, they need fertilizers, trace elements, vitamins and especially sun light. So, we add the fertilizers and phosphates, and nitrates andtrace elements to get our oyster food to grow and multiply. The same thing happens in the Lagoon! BUT, if we get too much fertilizer we knock everything out of kilter! Some things grow to fast, some to slow, some not at all--and in the long run, things die. This is very similar to overlapping or skipping with our lawn cart when spreading fertilizer. Some places it's just right, some places heavy green growth and some places it's burnt.

When we fertilize too much in the sea, things die. Death and decay and decomposing uses up a lot of oxygen. In the warm summer there isn't a heck of a lot of oxygen to go around. If surplus phosphates andunitrates are added to the water in wrong concentrations, we're going to upset the apple cart and, believe me, we can't fool mother nature. Surplus phosphates, nitrates, detergents, chlorides, etc. will in the long run cause our edible fish and shellfish to do loop-de-loops!!

So, what's the bottom line? Stop tempting fate by letting more of man's super-rich fertilizer reach the sea in uncomfortable concentrations. In time.....and in a short time....mother nature will get you for it!!!!

APPENDIX 3

MARTHA'S VINEYARD SHELLFISH GROUP, INC.
Box 1552
Oak Bluffs, Massachusetts 02557
617 693-0391

December 16, 1982

Judy Miller, Chairman
Tisbury Conservation Commission
Tisbury Town Hall Annex
Vineyard Haven, MA 02568

Dear Judy,

Thanks for the reminder of the December 20th Board of Health meeting. Unfortunately, I have plans to be off-Island and will be unable to attend. Could you please relay my continued concern over nutrient input to the ponds; the role nitrogen compounds play in accelerating eutrophication and the probable path of septic-related nutrients into the ponds via the groundwater?

Granted, our data base and present scientific theory regarding the effects of nitrogenous compounds in the marine environment make it impossible to draw unequivocal conclusions of cause and effect. It is not unreasonable to suspect a connection between septic leachate and nutrient pollution of the ponds. Our sandy soils do little to bind or breakdown the nitrogen wastes leaching from septic systems. These nitrogen-based compounds enter the groundwater and travel into the ponds within the watershed. Upon entering the ponds these compounds serve as fertilizers to the plant life. In balanced quantities these chemicals are necessary to the productivity of the pond. An overabundance of these nutrients results in an overproduction of plant life and the associated imbalances of light and oxygen characteristic of eutrophication.

Analyses of Lagoon water samples by Bruce Poole of Sea Plantations over the last couple of years revealed ammonia and TKN levels indicative of a eutrophication problem in the Lagoon. Changes in the character of the Lagoon including increased algal growth and turbidity over the past 10 to 20 years as related by long time residents also indicate an accelerated eutrophication. Water samples from springs flowing into the Lagoon have slightly elevated ammonia levels and suggest the movement of nitrogen into the pond with the groundwater. In a protected estuary like the Lagoon, it is likely that much of the nitrogen would be bound in plant and animal tissues and not be flushed from the pond's ecosystem. Over time even a small concentration in the groundwater could accumulate to significant levels within the pond.

Tisbury Conservation Commission
page 2

Failure to read these warning signs and take measures to control the nitrogen loading of the Lagoon and other embayments is a gamble that could very well affect the health of our ponds and their shellfish resources in the near future. Thank you.

Sincerely,

Richard Karney
Shellfish Biologist

RCK/kjc

APPENDIX 4

Codium Fragile and Its Effect on the Nantucket Bay Scallop Industry

Kenneth M. Kelley and Mary Kirby[1]

[1]Biology Department
Southeastern Massachusetts University
North Dartmouth, Mass.

ABSTRACT

Sampling of adult bay scallops in Nantucket and Madaket Harbors was done to assess the amount and effect of Codium fragile settlement on scallops. Sampling revealed Codium settlement was as high as 16% in parts of Nantucket Harbor, while only 5% of scallops in Madaket Harbor had the seaweed on their shells. Scallops sampled around Eel Point on the north side of the island were found to have no Codium on their shells. Lower settlement rates seem due to smaller scallop size rather than distribution of the algae. The paper also discusses adverse economic effects of this seaweed on the scallop industry; including scallops with Codium attached coming ashore on hot summer days, and it interfering with openers and scallop dredging.

INTRODUCTION

There are several theories as to how Codium fragile first came to the northeastern American coast, the most likely being that it was carried on the hull of a ship sailing from an area where it was found. Known locally as Japanese moss, it was first reported on Nantucket by Andrews (personal communication 1981) in 1966. By 1968 he had observed large amounts washing up on beaches in the harbor. On warm sunny days this seaweed produces gases which impart buoyancy to the plant which tends to lift the plant and any attached shellfish to the surface, where its fate is at the mercy of currents and winds. Robert (1978) cites serious problems caused by Codium to bay scallop populations, such as altering circulation and sedimentation patterns, and attachment restricting mobility and causing strandings on windward beaches. Zuraw and Lee (1971) attribute Codium infestation to the decline of scallop stocks in the Niantic River in Connecticut and they felt that it threatens the very existence of the bay scallop fishery in that estuary.

Earlier studies on Nantucket by McKie (1975) reported that *Codium* settled selectively on older, 3 year old scallops and was only found on 3% of the total scallop population. Because of continued complaints from fishermen concerning the seaweed and its deleterious effects on the bay scallop fishery, this study was undertaken to document the extent and nature of the problem.

METHODS AND MATERIALS

Sampling was done concurrently with density and size sampling of adult scallops during the summer of 1980. Percentage of those with *Codium* attached are only for adult scallops; most seed, because of their size, had none attached. Scuba and snorkles were employed to collect scallops. Size measurements were recorded for each area, and the number and size of those with the seaweed were noted. A total of several hundred scallops were sampled, with at least 25 taken from each area.

Observations were made during hot, sunny, summer days on windward beaches, and numbers of beached scallops with attached *Codium* were recorded. Personal observations were also made while opening scallops and working on commercial scallop boats to assess the impact of this seaweed on these aspects of the scallop fishery.

RESULTS

Codium settlement was highest in the upper harbor with lesser amounts in the faster current areas at the mouth of the harbor near the West Jetties. The highest amount of settlement was on scallops found off East Pocomo Point where it was on 16.6% of those scallops sampled. Other areas checked in Nantucket Harbor were Quaise Point with 16% settlement, and the West Jetty with 12%. The amount of *Codium* settlement in Madaket Harbor was lower, with the seaweed on 8% of scallops in Warrens Landing, and on 4% of those sampled off the entrance to Hither Creek. Scallops sampled in the area off Eel Point on the north side of the island had no *Codium* on them.

In Nantucket Harbor scallops with *Codium* attached ranged in size from 47 to 78 mm. Of those scallops with *Codium*, 2.5% were three year olds (possessing two growth rings) while the rest were adults with one growth ring or annullus. The average size of scallops with *Codium* on the by area is as follows: (range in parentheses) Quaise Point 61mm(55-6

E. Pocomo Point 64.1 mm (61-72 mm), West Jetty 68.3 mm (63-74 mm), Warrens Landing 64.7 mm (53-78 mm), and outside Hither Creek 64.7 mm (53-78 mm). At Eel Point, where no scallops were found with attached Codium, the average size of scallops was 51.3 mm with a range of 44-62 mm.

Observations during August revealed several hundred adult scallops ashore on West Pocomo Point on three different hot, sunny days. The most ashore on any one day was eighty along 2000 yds. of beach. It is possible that there were more instances of strandings which were not seen or reported.

Personal observations while commercial scalloping in areas with dense Codium resulted in great difficulty in pulling up dredges even with a donkey motor. Hand-hauling was physically impossible in these areas, and those in the fleet who fish in this manner were forced to move elsewhere. Personal experiences while opening scallops during the season resulted in a considerable slowdown when opening scallops with Codium attached.

DISCUSSION

These studies have revealed a greater level of Codium infestation than the 3% noted by McKie in 1975. Furthermore settlement on scallops is no longer confined to three year olds but in most cases was found on two year old adults. While the degree of infestation of scallops is lower in Madaket Harbor (6% overall vs. 15% overall in town), this seems due to the smaller average size of scallops in Madaket. The scallops at Eel Point were the smallest (avg. size 50 mm) of any area sampled and this is a probable reason for the lack of this seaweed on their shells.

It is difficult to say whether the higher degree of Codium on scallops as compared to 1975 reflects a greater degree of infestation in Nantucket Harbor. According to Andrews (personal communication 1981) the seaweed seems to have reached an equilibrium in some areas of the harbor, and is declining in others. However in some areas of the harbor Codium still seems to be spreading according to scallopers. Other studies on Nantucket (Marshall 1974) showed that eelgrass can outcompete Codium, and since eelgrass is slowly recolonizing upper areas of Nantucket Harbor it is possible that this may effect Codium distribution in the future.

It is obvious that Codium does seem to restrict water circulation in parts of the harbor where there are dense patches of it. Current is a contributing factor to good scallop growth and it is very possible that Codium adversely affects scallop meat yields in this way.

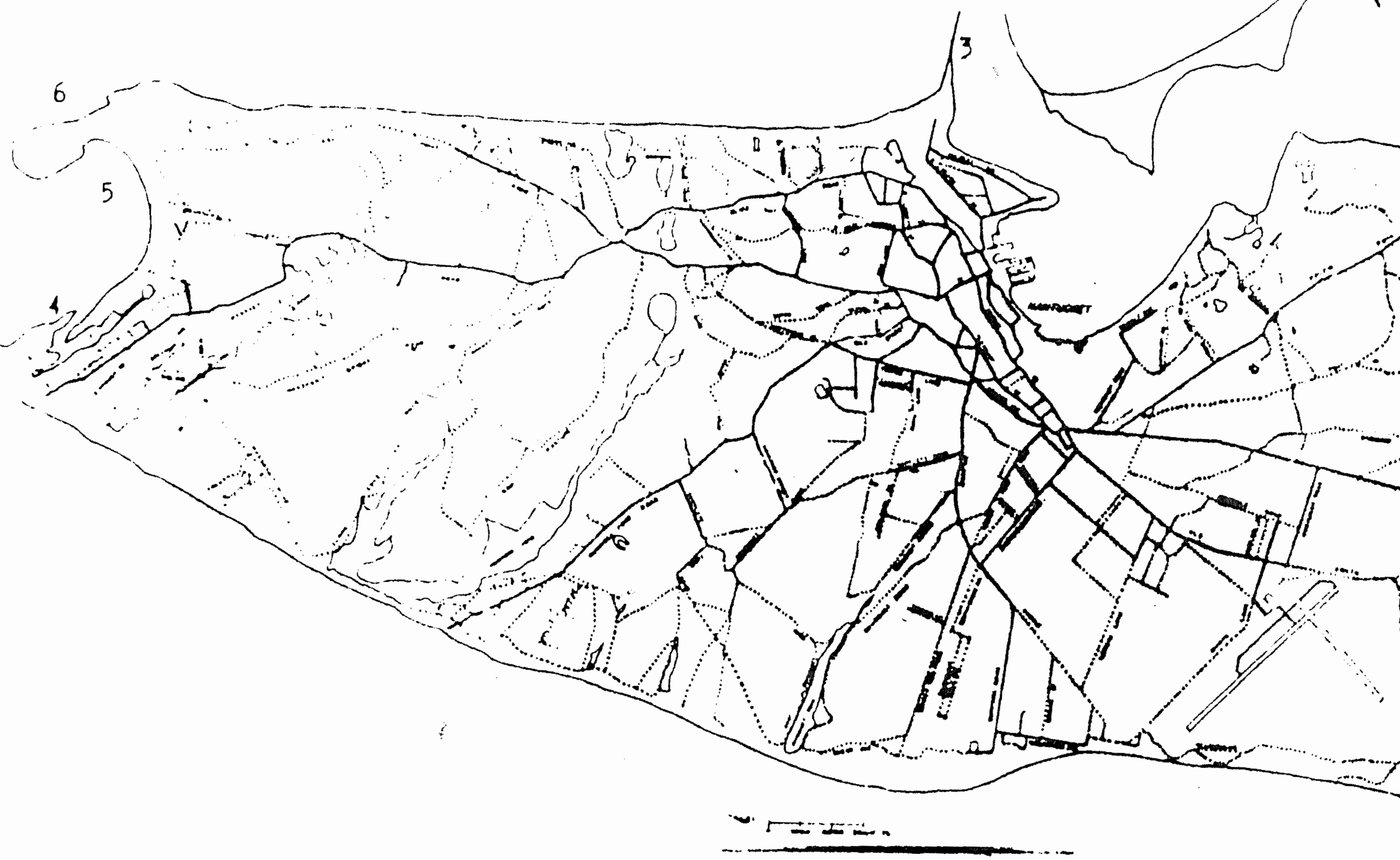
Past efforts at controlling Codium on Nantucket included paying scallopers $1 for each bushel brought to shore, afterwhich it was disposed of at the dump. According to Holdgate (personal communication 1981) this drastically reduced amounts of this seaweed in areas like Folgers Channel. On the other hand, O'Brien (1974) suggests that Codium will easily reestablish itself in dredged areas and feels that dredging to remove it from the harbor is impratical. While it is debatable whether or not disposing of the seaweed on shore is really helping the matter much, it certainly is not hurting the situation. In light of the continued amount of Codium in the harbor and the nuisance it causes, it may be worth trying again on a voluntary basis. Next season dumpsters could be provided for scallopers at the Town Pier, Boat Basin, Children's Beach and Madaket to leave Codium they have collected while fishing, afterwhich it could be picked up by the DPW. If the seaweed could be used as a fertilizer or as a source of fuel in a methane digester it would serve two purposes, to clear the harbor of the seaweed and relieve demands for petrochemical fuels and fertilizers on the island.

The actual economic impacts of Codium on the Nantucket scallop industry are hard to quantify. Amounts of scallops with the seaweed attached coming ashore during the summer appear to be minimal, at the most fifty bushels, probably lower. The time lost to openers of Codium laden scallops, and to scallopers pulling up heavy dredges full of seaweed seems to be a greater impact. In both cases it does not cause a loss of earnings, but rather an inconvenience which consumes time, which in turn results in a loss in pay rate for openers and scallopers.

It is also possible that Codium competes with phytoplankton for nutrients, thus causing a food loss to scallops and other shellfish. Although Codium has been shown to provide a setting substrate for scallops in areas devoid of eelgrass such as Wyer's Point, its disadvantages seem to far to outweigh its advantages as it relates to the bay scallop fishery on Nantucket.

AREAS STUDIED FOR CODIUM ON SCALLOPS (% in parentheses)

1-E. Pocomo Point (16%)
2-Quaise Point (16%)
3-West Jetty (12%)
4-Hither Creek (4%)
5-Warrens Landing (8%)
6-Eel Point (0%)



Oak Bluffs Shellfish Department
Box 874
Oak Bluffs, Ma. 02557-0874

Tel. 693-2763

APPENDIX 5

Shellfish Constable
Edwin Bugbee

Nov. 21, 1984

Mr. Arthur Gaines

Dear Sir,

As you can see from the copies of my daily log, on Aug. 6, 7,8, 1984 there was considerable concern about the algae mats in Lagoon Pond and on the beaches. There were many complaints from residents about the odor and the weed making it impossible to swim or even walk the beach.

On Aug. 7 and 8, 1984 I surveyed the Lagoon and found enteramorpha growing on ell grass from the bottom to the surface in the following areas; from the town line at the draw bridge to Lagoon Road from the beach out to a depth of approx. 6 feet and from Maderias Cove to the former Girl Scout camp. There were spots in other areas. Near the Lobster Hatchery it was nearly impossible to run a small outboard. There was a large area from the draw bridge to and beyond the launching ramp in Vineyard Haven.

The complaints continued throughout the month of August until cool weather when the algae mats began to disappear.

Respectfully yours,
Edwin A. Bugbee
Edwin A. Bugbee, Shellfish Constable

THE MARTHA'S VINEYARD COMMISSION

1974 - 1984

BOX 1447
OAK BLUFFS
MASSACHUSETTS
02557
617-693-3453

APPENDIX 6

December 17, 1984

Arthur Gaines Jr.
Sea Grant Office
Woods Hole Oceanographic
Institute
Woods Hole, MA 02543

Dear Dr. Gaines:

Pursuant to our conversations, enclosed is the information regarding Lagoon Pond.

Based on groundwater contours which are delinated on a plan produced by the U.S.G.S. (Delaney 1980, HA-618) I have estimated the area from which groundwater discharges to Lagoon Pond. This area is 194,720,000 FT^2 (approximately) and is shown by Attachment 1.

Using a recharge rate of 22 inches/year (Delaney) it is estimated that 7,408,226 gallons of groundwater reaches the Lagoon per day. (See Attachment 2). The Oak Bluffs municipal well at the head of Lagoon Pond pumps 500,000 gallons per day in the winter and 800,000 gallons per day in the summer.

The number of houses within the groundwater discharge areas shown by Attachment 1 were counted from 1978 aerial photographs. Ten Percent or 100 plus houses have been added to the number counted from the aerial photograph. The groundwater discharge area was divided into 10 sections and the areas in square feet was planimetered (see Attachment 3). The number of houses and any large wastewater generators within the area are listed by Table 1.

The following list shows how the yearly volumes were estimated for the large wastewater generators.

- M.V. Hospital's Secondary Treatment Plant has an effluent of 15,500 gallons/day. (average)

- O.B. Septage is disposed of at the landfill which is essentially on the groundwater divide. For that reason, only half the volume of wastewater is assumed to be within the Lagoon Pond groundwater discharge area. From the Oak Bluffs Facility Plan Oak Bluffs

TABLE 1

Area	FT^2 (x 1,000)	# of houses	other large generations
1	3,840	79	Hospital
2	7,840	170	
3	14,400	234	(½) Oak Bluff Septage
4	17,120	57	
5	24,800	33	High School
6	27,840	41	Campgrounds (Webb)
7	31,680	46	
8	29,440	123	Campgrounds (Famil
9	31,200	142	Elderly Housing & Tisbury Septa
10	6,560	143	
	194,720,000	1,068	

- M.V. Regional High School uses between 700-800,000 gallons of water per year (O.B. Water Dept. records) most of which leaves the building as wastewater. (i.e., 700,000 gallons/year)

- Both campgrounds have approximately 150 tent sites. Using the State Environmental Code (Titel 5), waste generation rates of 75 gallons/day/site we estimate the wastewater volume to be 1,125,000 gallon for the 100 days of summer.

- Tisbury's Facility Plan estimated that the facultative lagoon system treats 3,500,000 gallons per year.

- Elderly Housing has around 60 residents. Again, using Title 5 waste generation rates we calculate the yearly volume to be 1,200,000 gallons/year.

The state maintains that for single family residences the wastewater generation rate is 55 gallons/day. Assuming that on the average each house has 3.5 people we can estimate the total wastewater generation for each of the 10 areas shown on Attachment 3.

Table 2 lists the waterflows for the large generators within the prescribed areas.

AREA	TABLE 2	WASTEWATER GENERATED
1	M.V. Hospital	5,657,500 gallons/year
3	(½) Oak Bluffs Septage	2,250,000 gallons/year
5	M.V. Regional High School	700,000 gallons/year
6	Campground (Webbs)	1,125,000 gallons/year
7	Campground (Family)	1,125,000 gallons/year
9	Elderly Housing	1,200,000 gallons/year
9	Tisbury Septage	3,500,000 gallons/year

The EPA found that the effluent leaving a residential septic tank has a total nitrogen concentration on the order of 40 mg/l. This figure will be used to estimate the amount of nitrogen entering each area from septic tanks.

This does not include the hospital's secondary treatment facility and the Tisbury's facultative septage lagoon's. The effluent nitrogen concentrations for these facilities is taken to be 20 mg/l and 10 mg/l respectively.

Using these figures we can estimate the total nitrogen entering the groundwater for each area from wastewater. If we dilute the nitrogen entering the groundwater with the rainwater recharge for that area we derive a relative value for the concentration of nitrogen that may be expected from each area.

It should be noted that complete mixing with the rainwater recharge is assumed and that no dilution with the groundwater was calculated. Another factor that has not been addressed are transport times from the nutrient sources to Lagoon Pond.

Therefore, the last column in Table 3 represents the total nitrogen that may enter the Lagoon from one area relative to the other areas. In other words, a high value would show that that area probably contributes more nitrogen than the other areas with lesser values. An example of how the relative values for each area was calculated is shown by Attachment 4.

TABLE 3

AREA	WASTEWATER VOLUME (gallons/year)	TOTAL NITROGEN (lbs./year)	RELATIVE VALUE
1	11,208,238	2,805	6.09
2	11,944,625	4,000	4.90
3	18,691,425	6,257	4.37
4	4,004,962	1,340	1.65
5	3,018,662	1,010	1.34
6	4,005,762	1,341	1.40
7	3,232,075	1,082	1.29
8	9,767,287	3,270	1.92
9	14,681,775	4,036.	3.83
10	10,047,538	3,364	4.91

Given all the assumptions and estimates and the very nature of the hydraulic system, the values that have been calculated should be viewed on a relative basis only.

To accurately define the amount of nitrogen entering the Lagoon from these sources we would require extensive ground and surface water monitoring and then utilize a model developed for this system, or some other methods.

I trust this meets with your approval.

Sincerely,

Russell H Smith

Russell H. Smith, E.I.T.
Water Quality Program Manager

RHS/phd

Relative Value (RV)

Mix recharge and wastewater assume rainwater (22 inches) at 1 mg/l of total nitrogen

$$RV = \frac{C_R Q_R + C_W Q_W}{Q_T}$$

RV = relative value or diluted concentration (mg/l)
C_R = total nitrogen in rainwater (1 mg/l)
Q_R = Volume of recharge (gallons/year)
C_W = total nitrogen in wastewater (40 mg/l)
Q_W = Volume of wastewater (gallons/year)
$Q_T = Q_R + Q_W$

Q_R = (22 inches/12 x 3,840,000 ft^2) x 7.48 gal/FT^3

= 52,659,200 gallons/year

$$RV = \frac{(1)(52{,}659{,}200) + 30(11{,}208{,}237)}{52{,}659{,}200 + 11{,}208{,}237} = 6.09 \text{ mg/l}$$

charge be withdrawal ... saltwater encroachment is minimized because most of the water is returned to the ground as domestic waste water by septic systems, cesspools, and municipal sewage-treatment facilities.

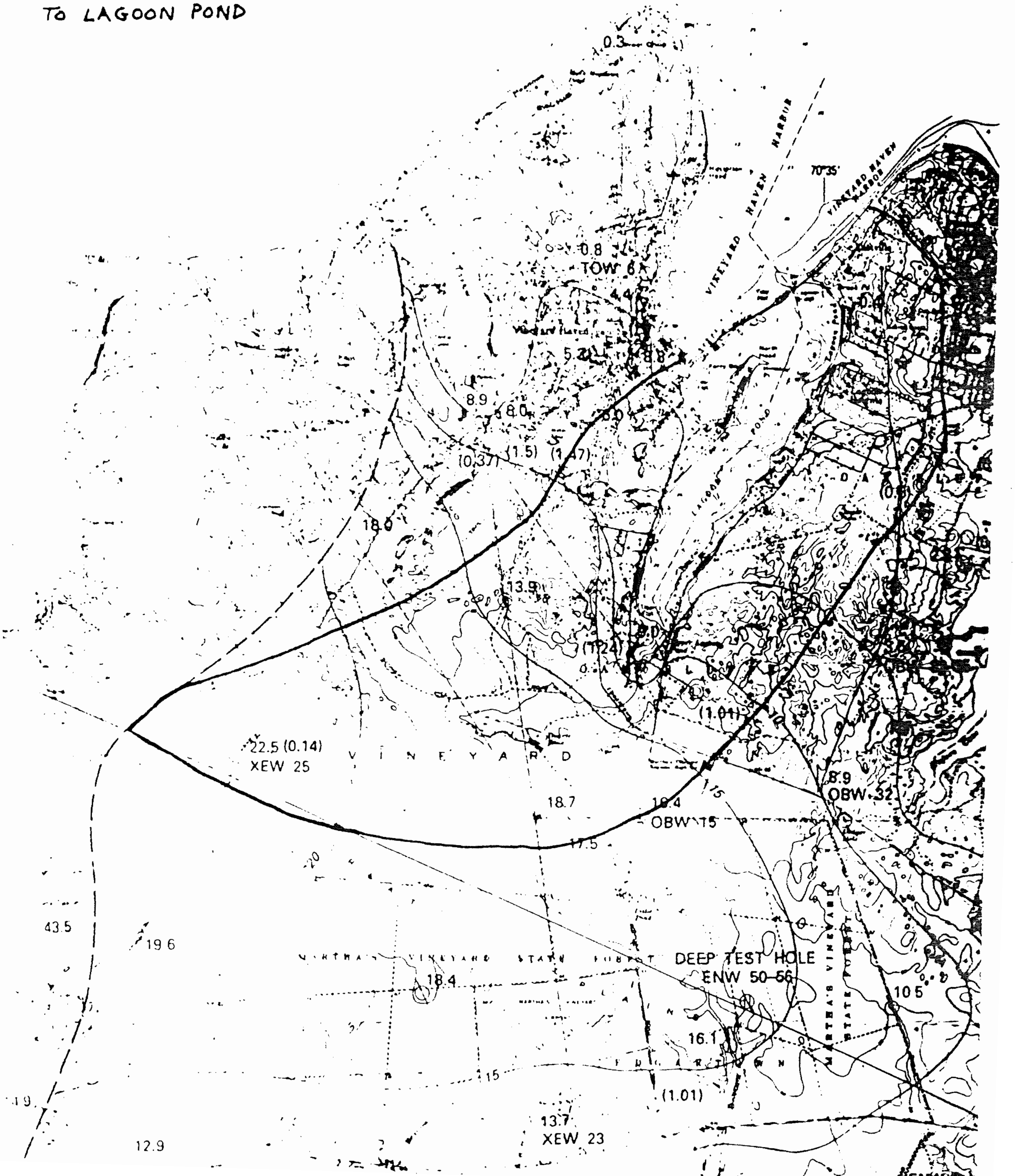
ATTACHMENT 1

IN PRI
A-A's

FROM "GROUNDWATER HYDROLOGY OF MARTHA'S VINEYARD" U.S.G.S. HA(618) DELANEY

SCALE
1" = 4000'

AREA OF GROUNDWATER DISCHARGE
TO LAGOON POND



AREA OF GROUNDWATER DISCHARGE TO LAGOON POND

TOTAL AREA — 216,000,000 FT^2

(MINUS) AREA OF LAGOON — 21,280,000 FT^2

194,720,000 FT^2

USING DELANEY'S HYDROLOGIC BUDGET

AVERAGE ANNUAL PERCIPITATION — 46 INCHES

(MINUS) ANNUAL EVAPOTRANSPIRATION — 23.7

ANNUAL RECHARGE — 22.3 INCHES

ANNUAL FRESH WATER RECHARGE TO LAGOON POND

$$194{,}720{,}000 \times \frac{22.3}{12} = 361{,}850{,}000 \ FT^3/YEAR$$

$$\div 365 = 990{,}410 \ FT^3/DAY$$

$$\times 7.48 = 7{,}408{,}266 \ GALLONS/DAY$$

ANNUAL PERCIPITATION FALLING ON THE LAGOON POND

$$21{,}280{,}000 \times \frac{46}{12} = 81{,}573{,}333 \ FT^3/YEAR$$

$$\div 365 = 223{,}488 \ FT^3/DAY$$

$$\times 7.48 = 1{,}671{,}694 \ GALLONS/DAY$$

TOTAL FRESH WATER INPUT TO LAGOON POND

$$7{,}408{,}266 + 1{,}671{,}694 = 9{,}079{,}960 \ GALLONS/DAY$$

ATTACHMENT 4

Sample Calculation for Table 3

Area # 2

Wastewater Volume

numbers of houses = 79 (TABLE I)

79 × 3.5 people × 55 gallons/day/person × 365

= 5,550,737 gallons/year

hospital wastewater + 5,657,500 gallons/year

Total 11,208,237 gallon/year

Total Nitrogen in Wastewater

residental houses

5,550,737 gallons/year × 40 mg/l × 3.8 l/gal × (1 lb./454,000 mg)

= 1,858 lbs of nitrogen/year

M.V. Hospital treatment plant

5,657,500 gallons/year × 20 mg/l × 3.8 l/gal × (1 lb./454,000 mg)

= 947 lbs. of nitrogen/year

Total = 2805 lbs of nitrogen/year

Change units

(2805 × 454,000)/(11,208,237 × 3.8) = 30 mg/l charge by withdrawal from wells. The effect of ground-water withdrawal on saltwater encroachment is minimized because most of the water is returned to the ground as domestic waste water by septic systems, cesspools, and municipal sewage treatment facilities.

FIGURE 1
IN PRI
A–A' sh

ATTACHMENT 3

FROM "GROUNDWATER HYDROLOGY OF MARTHA'S VINEYARD" U.S.G.S. HA(618) DELANEY

SCALE
1" = 4000'

AREA OF GROUNDWATER DISCHARGE
TO LAGOON POND