Inlet modification: an example of an holistic approach to the management of lagoons

S. Olsen, V. Lee
Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island 02881, USA.

ABSTRACT
The development of a management strategy for the inlets of two lagoons in southern New England is offered as an example of an holistic approach to the management of lagoons that are used for multiple purposes. The ecology of Charlestown and Green Hill Ponds was radically altered by the construction in 1952, of a permanent inlet reinforced by massive stone jetties that replaced a natural seasonal inlet. The permanent breachway was built to enhance recreational activities and thus increase the value of adjoining land as house lots and to improve the then large oyster population by providing a constant source of clean salt water with abundant forage. Thirty years later it is clear that the permanent breachway has brought the demise of the oysters and other formerly abundant species such as white perch and alewives. The permanent breachway is also causing large volumes of sand to flow into the lagoon that threatens to cut the lagoon in two within the next 20 to 30 years. The results of an interdisciplinary research effort indicate that the best solution to these problems appears to be the installation of a navigable tidal gate combined with a sediment catchment basin. Gates would permit maximum flexibility for manipulating the salinity and water level and, in combination with catchment basins, to forestall further accumulations of sand in the lagoons. The complex relationship among public interests, local and state agencies of government and university researchers demands a careful effort to build consensus for any course of action. Other management problems, including heavy fishing pressure and continuing residential development around the lagoons must be addressed if any effort to restore and improve the management of these productive and beautiful estuaries is to succeed.


RÉSUMÉ
Modification d'une passe : un exemple d'une approche générale de l'aménagement des lagunes

Le développement d'une stratégie d'aménagement des débouchés de deux lagunes dans le sud de la Nouvelle Angleterre est donné comme exemple d'une approche holistique de l'aménagement de lagunes utilisées à des fins multiples. L'écologie de Charlestown et de Green Hill Ponds fut radicalement transformée par la construction, en 1952, d'un débouché permanent renforcé par de massives jetées de pierres qui remplacèrent la passe naturelle saisonnière. Le canal permanent fut construit pour accroître les activités récréatives, et donc augmenter la valeur des terrains à urbaniser adjacents, et pour améliorer la production d'huitres alors florissante, en fournissant une source constante d'eau salée propre et riche en phytoplancton.

Trente ans plus tard, il est clair que le canal permanent a causé la disparition des huitres et d'autres espèces, abondantes auparavant, telles que des perches blanches et des aloses. Le canal permanent provoque également l'écoulement de grands volumes de sable dans la lagune, qui menacent de couper celle-ci en deux dans les 20 ou 30 années à venir. Les résultats d'une recherche interdisciplinaire indiquent que la meilleure solution à ces problèmes semble être l'installation d'une écluse navigable combinée avec un bassin de captage sédimentaire. Les
INTRODUCTION

The Global future: time to act report to President Carter (Council of Environmental Quality, 1981) concluded an analysis of the environmental outlook twenty years from now with the somber projection of a world "more crowded, more polluted, less stable ecologically, and more vulnerable to disruption than the world we live in now". The report recommended that initiatives to manage resources must be ecologically holistic and politically coordinated. Coastal lagoons are excellent microcosms of the complex problems inherent in natural resources management. They are potentially productive ecosystems (see Nixon, 1982 a) that can support a diversity of human uses, but are all too easily degraded by a large neighboring human population and the conflicting demands placed upon them. In this paper we use the development of a management strategy for the inlets (locally known as breachways) of two New England lagoons to illustrate the complexity of both the natural environment and the politics that must be understood if a sound management strategy is to be formulated and implemented.

Table 1
Principal components of the URI salt pond project.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Principal investigator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrodynamic modeling</td>
<td>Dr. Malcolm Spaulding</td>
</tr>
<tr>
<td>Sediment transport</td>
<td>Dr. Jon Boothroyd</td>
</tr>
<tr>
<td>Nutrient sources and cycling</td>
<td>Dr. Scott Nixon</td>
</tr>
<tr>
<td>Aquatic vegetation</td>
<td>Dr. Marilyn Hilton, Boyce Thorne-Miller</td>
</tr>
<tr>
<td>Fish and fisheries</td>
<td>Dr. Richard Crawford, Stephen Olsen</td>
</tr>
<tr>
<td>Waterfowl ecology</td>
<td>Dr. Stanley Cobb</td>
</tr>
<tr>
<td>Resource management</td>
<td>Stephen Olsen, Virginia Lee</td>
</tr>
</tbody>
</table>

town Pond to the ocean and a narrow channel joins Charlestown Pond to Green Hill Pond. A fertile outwash plain leads north of the lagoons to a line of wooded hills that mark a recessional moraine left in the retreat of the continental ice sheet some 10,000 years ago. Until thirty years ago the area was rural and renowned for its natural beauty and the oysters that grew abundantly in both lagoons. Today the oysters are all but gone and the lands around the lagoons are being rapidly developed as housing lots for a resident population of retirees and commuters to nearby industrial centers. The Rhode Island south shore, although it is today still rural in character, lies within the northeast megalopolis and some 8 million people live within a one hour drive. Human pressures on this coast, and the lagoons in particular, are massive and they are increasing. A lagoon's breachway determines its character. Breachways are the primary control over the salinity, flushing, water levels, sedimentation rates, the species and abundance of algae, fin and shellfish and they determine the ease with which boats may get from the lagoons to the ocean. The Charlestown breachway was dredged and stabilized in 1952 which changed the inlet from a seasonally open channel to a permanent connection between the lagoons and the ocean. This action radically altered both lagoons and is the cause of numerous problems including the loss of the formerly

Figure 1
Rhode Island’s coastal lagoons. Charlestown and Green Hill are the focus of this paper.
productive oyster fishery and the acceleration of sedimentsation in the flood tidal delta inside the breachway which makes navigation hazardous and is reducing water circulation in several areas of the lagoons. Since the lagoons are no longer utilized solely as a source of seafood but also for a variety of sometimes conflicting uses, the task of developing sufficient consensus among both the management agencies and the public to permit an alteration to the breachway, and therefore the lagoons, is a difficult challenge. In this paper we will describe the process of problem definition, applied research, goal setting and framing a management strategy that we hope will be accepted by the public and implemented.

Several agencies of local, state and federal government have authority over the lagoons and must issue permits before any change can be made to the breachways (Table 3). The authorities of these agencies overlap and an initiative to change the status-quo will succeed only if all agencies agree.

Table 2
Characteristics of the Charlestown-Green Hill lagoons and their watersheds.

<table>
<thead>
<tr>
<th>A. The lagoons</th>
<th>Charlestown</th>
<th>Green Hill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>5.308</td>
<td>1.27</td>
</tr>
<tr>
<td>Average depth</td>
<td>1.2 m</td>
<td>0.8 m</td>
</tr>
<tr>
<td>Perimeter</td>
<td>35.1 km</td>
<td>13.1 km</td>
</tr>
<tr>
<td>Salinity</td>
<td>28 ppt</td>
<td>24 ppt</td>
</tr>
<tr>
<td>Tidal range</td>
<td>13.7 cm</td>
<td>3.7 cm</td>
</tr>
<tr>
<td>Breachway dimensions</td>
<td>34 m wide × 2 m deep</td>
<td>7 m wide × 1 m deep</td>
</tr>
<tr>
<td>1979 Fisheries yields</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finfish (kg live weight)</td>
<td>24.948</td>
<td>—</td>
</tr>
<tr>
<td>Shellfish (kg live weight)</td>
<td>70.308</td>
<td>—</td>
</tr>
<tr>
<td>Aquaculture (kg live weight)</td>
<td>2268</td>
<td>—</td>
</tr>
<tr>
<td>Boat slips at marinas</td>
<td>140</td>
<td>226</td>
</tr>
<tr>
<td>Private boat docks</td>
<td>52</td>
<td>90</td>
</tr>
<tr>
<td>Waterfront house lots</td>
<td>359</td>
<td>350</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>B. Watershed</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>29.69 × 10⁶</td>
<td>16.51 × 10⁶</td>
</tr>
<tr>
<td>Land use:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>15 %</td>
<td>27 %</td>
</tr>
<tr>
<td>Commercial</td>
<td>1 %</td>
<td>1 %</td>
</tr>
<tr>
<td>Agriculture</td>
<td>3.2 %</td>
<td>5 %</td>
</tr>
<tr>
<td>Woodland/open space</td>
<td>66.1 %</td>
<td>65 %</td>
</tr>
<tr>
<td>Conservation</td>
<td>15 %</td>
<td>2 %</td>
</tr>
<tr>
<td>Houses, 1980</td>
<td>1215</td>
<td>1223</td>
</tr>
<tr>
<td>Projected houses at full development</td>
<td>4816</td>
<td>3850</td>
</tr>
</tbody>
</table>

Table 3
Government agencies with authority over the breachway.

A. Direct authority

Coastal Resources Management Council
Responsibilities: has the dual role of developing coastal resource management policy and plans and issues permits for any alteration to tidal waters or the shoreline. It has funded major portions of the URI salt pond project and is developing a Special Area Management Plan for the six lagoons. The Council should present the breachway plan to the public, coordinate the reviews and permitting of other agencies. Permits: any alteration to a breachway requires a CRMC permit.

Department of Environmental Management
Responsibilities: include the construction and maintenance of the Charlestown breachway and probably the operation of a tidal gate if one were installed. Responsible for monitoring fishery resources, enforcement of fish and wildlife laws and Council permits. Permits: a water quality certification must be obtained for any proposed alteration to a breachway that may affect a water quality classification.

US Army Corps of Engineers
Responsibilities: include the construction and maintenance of all federally recognized navigational waterways and the review of major projects involving alterations to the shoreline and wetlands.

Department of Transportation
Responsibilities: the construction and maintenance of state roads and other state owned transportation facilities include the bridge over the Green Hill breachway. Permitting: any alteration to the Green Hill breachway that involves modification to the bridge will require the Department's approval.

B. Indirect authority

Town Governments
Charlestown and Green Hill Ponds lie within the towns of Charlestown and South Kingstown. Both will comment on any plan to alter the breachways; it is unlikely that action would be taken without the official support of both town governments.

US Department of Fish and Wildlife
Owns the land on the west side of the Charlestown breachway and will be officially invited to comment on any US Army Corps of Engineers involvement in a modification to the breachways.
to the same plan of action and if there is public support for the plan. A determined, adequately funded court fight by any party opposed to a course of action would cause long delays and possibly kill an effort to modify a breachway, irrespective of the merits of the plan. Building a broad base of consensus for a plan of action is therefore as important as conducting a well designed research effort that will delineate how the breachway functions.

FROM RESEARCH TO IMPLEMENTATION; A DIFFICULT TRANSITION

Too often the findings of the scientific community at a university do not get translated into action, and are not given the credibility that they deserve by government agencies with authority over the area or topic in question. Part of the problem is that many scientists feel that efforts to cope with public reaction to new information and the process of moving from an idea to its implementation is a manipulative, less than honest, often distasteful process that they would prefer to leave to that alien and untrustworthy group known as “the politicians”. Producing a scientifically accurate analysis of the dynamics of the Charlestown and Green Hill breachways is only one step towards sound action. A technical report summarizing the research findings and perhaps an analysis of the likely consequences of various alterations to the breachways would almost certainly cause considerable confusion among the public and government agency personnel over what the research findings “really mean”, and disagreement as various people tried to link the science to the problems they perceive in the breachways. Very rarely does scientific research on environmental problems produce a clear statement of certainty that may be directly and simply translated into action. Furthermore the tangle of permits, agency authorities and the absence of a leader who will oversee the necessary negotiations, adjustments and compromises further jeopardizes the chances for sound action.

It is the responsibility of the URI Coastal Resources Center to place the research findings developed through the URI salt pond project in a useful, understandable context and to help build consensus among agencies and the public about what the facts mean, what are acceptable management goals, and finally, after much discussion and careful listening, to frame an achievable management strategy. The Center has played this role on numerous projects over the past decade and we have developed a number of guidelines for this process.

1) Uncertainties must be dealt with openly and directly. Very rarely will a research program end by satisfactorily answering all the major questions; a good case can invariably be made for more research. Resource management is thus the art of assessing the uncertainties and acting with creativity and responsibility. Unfortunately, the public expects that the scientists will “prove” whether something is going to happen and is shocked when a scientist stands up in a public hearing and says, “I cannot prove it will work, but I think it will”. The uncertainties must not be buried and the emphasis to both the public and agencies must be on formulating a reasonable course of action that addresses perceived problems directly. Down playing the uncertainties leads to mistakes that are not forgotten by the public and destroys the credibility of the scientist and the manager.

2) Consensus must be built among researchers and management agencies as the plan of action evolves. The usual procedure for university projects funded by resource management agencies is that the researcher completes the work, and submits a final report after the project has ended and all the money for the research project has been spent. Almost invariably the process of developing a detailed plan of action is left to previously uninvolved people in a government agency who will raise new questions that are best answered by the researcher. Unfortunately, it is then too late; there is no more funding and the researcher is busy on a new project. At the Center the research findings are reviewed as they are produced and used to formulate alternative management schemes that serve to focus discussion and often to influence the direction taken by the researcher as his work continues. For example, a simple numerical model was used to predict the impacts of various changes to the size of the Charlestown breachway. The predictions were discussed with other members of the research team and were the subject of a seminar with state management officials. These discussions lead us to a new set of questions, and a refined list of alternatives that required new field measurements and a fine grid model. Similarly, the steadfast conviction of local residents that the flow of sand into the pond through the breachway is continuous helped persuade Dr. Boothroyd to conduct the dyed sand experiment discussed in the next section. Government agencies are far more likely to adopt and pursue the recommended course of action if they perceive the plan as their own and not something prepared by a group of outsiders. They must therefore have a substantive role in the formulation of the ideas and the way in which information is presented. This is achieved through the discussion of preliminary results and the circulation of a number of drafts of the analyses and recommendations before the final report is written and made public. This is time consuming. It is important that this process of consensus building is permissive to take place privately and without press pressure stories that trumpet any disagreements between university researchers and officials.

3) No course of action is likely to take place unless it is supported by some elements of the public. We have maintained close communications with the public during the project through press releases, a newsletter and public lectures. Many members of the public have also been directly involved in data gathering. Once enough consensus on a plan of action that we feel will be acceptable to the public has been built with the agencies, the plan must be presented as a draft to the public at one or more informal workshops. It must again be made very clear that flexibility still exists and that public reaction and criticism is truly desired and, when appropriate, will be incorporated in the management plan. The public workshop should be called and chaired by the responsible agency with questions fielded by both the research team and officials. This too helps build a partnership between the agencies and research team.

4) Public attention should focus on an individual who has the authority to take action and respond to criticism. Successful consensus building is grounded on a thorough understanding of the regulatory authorities of the various agencies and the power and the positions that interest groups are likely to take during the process of public review. The “lead” agency must have the authority to implement a course of action and coordinate the reviews and permitting functions of other agencies.

5) Debate and discussion over a course of action must be linked to clear goal statements. We have observed on many occasions that the person leading a public discussion on a management strategy will flounder when enough for a clear statement of why a course of action is being proposed. This can be disastrous. Clear, short goal statements must be the reference point for all discussions of alternative courses of action and why something should be done. The process of developing consensus and selecting a course of action usually entails refinement and rephrasing of the goal statements.

THE BREACHWAY AS AN EXAMPLE OF A MANAGEMENT PROBLEM AND PROCESS

The Charlestown breachway is a good example of a management problem that, if it is to be successfully addressed, requires a great deal of effort and a protracted dialogue between the research team, government agencies, and the public to formulate an acceptable course of action and see it implemented.
The history of breachway management

There is a long history of efforts to "improve" the Charlestown breachway. Before the jetties were built in 1952 the lagoons were only seasonally connected to the ocean. The usual sequence was that wave energies on the barrier that drive longshore sand transport would seal off the breachway in the autumn. By spring freshwater flowing into the lagoons would lower the salinity and raise the water level a meter or more above sea level (US Army Corps of Engineers, 1910). The low salinity would kill off such predators as oyster drills and starfish. Traditionally, local residents would dig a ditch across the barrier spit in the spring and the rush of water out of the pond would quickly enlarge the cut into a breachway big enough for small boats to navigate. Large numbers of a variety of estuarine fish would migrate into the ponds to spawn and feed while winter flounder (Pseudopleuronectes americanus) that had spawned the previous autumn left the lagoons for their summering ground offshore. During the summer the breach might need periodic reopening. Since the abundant oysters (Crassostrea virginica) grew best and took a desirable flavor in salty water, it was important to keep the breachway open during the summer.

In this century the beauty of the ponds began to attract visitors. Increasing numbers of summer visitors and colonies of summer cottages were built along the shore. In the late 1940s a building boom began that continues today (Fig. 2).

Nearly all the houses are now occupied as permanent homes rather than summer cottages. This development made easy access for boats from the ponds to the ocean important, and the pressure increased for a permanent breachway.

Attempts to stabilize the breachway with rock walls date at least as far back as 1881 but they did not succeed as permanent structures. In 1952 state and local authorities successfully petitioned the legislature for the funds to stabilize the breachway with two stone jetties. This created a permanent connection to the sea 34 m wide and 2 m deep. In 1962 a channel was dredged across the tidal flats connecting Green Hill Pond directly to the breachway (Fig. 3). It was argued at the time that this action would not only assure year-round access to the ocean but that higher salinities in the lagoon would benefit the oyster population by assuring a constant and abundant source of food.

Toward sound management of the Charlestown breachway

Twenty-five years later it has become widely acknowledged that stabilizing the Charlestown breachway was a disastrous mistake. Public concern about the ruination of the south shore lagoons led the Coastal Resources Management Council to request the Center to investigate the problem and recommend a course of action. Before research on the lagoons began in 1978, Dr. Nixon and Virginia Lee undertook for the Center a review of the history of the area, the available data and opinions on how the lagoons function as ecosystems and the results of past management efforts (Lee, 1980). Local community groups, fishermen, farmers, local industry owners, historians, and governmental authorities were all interviewed. Old timers, lifelong observers and users of the ponds, were sought out for their perceptions of how the lagoon ecosystems had changed and why. Advertisements were placed in the local newspapers requesting old photographs, fishing logs, journals and diaries from which we could document what the lagoons were like in the past and how they have responded to such major perturbations as stabilized breachways. Among the myriad complaints about deteriorating conditions in the lagoons, there were three major problems that could be linked to the stabilized breachway:

1. The stabilized Charlestown breachway radically changed the ecology of both lagoons and ruined the formerly productive estuarine fisheries;
2. Sand transported through the stabilized breachway is causing Charlestown Pond to shoal rapidly; the east end of the pond is becoming a sand flat and boats from Green Hill find it increasingly difficult to negotiate the channel to the ocean. The sand has accumulated a meter deep over both lagoons;
3. The accumulating sand is impeding flushing, causing stagnant circulation in Green Hill Pond and in coves in Charlestown Pond.

The Design of research efforts

The first step in the research project was to translate these concerns into questions that merit scientific research. The research would have to establish whether the problems as perceived by the public are real, or cases of misperception or prejudice. Secondly, we distinguished those problems that are a direct result of a stabilized breachway from other processes. Finally, we selected reasonable solutions to the problems and explored what the likely consequences to the lagoon ecosystem will be for each alternative. Three principal investigators designed a portion of their research effort around the effects of the Charlestown breachway on the ecology of the lagoon. Their research was supplemented by information gathered by the Coastal Resources Center on projections of human activity in the lagoons and their watersheds.

The effect of the breachway on the fisheries

It is clear that the stabilized breachway has caused once abundant fisheries to decline, because the breachway increased salinity, sedimentation and tidal flushing with consequent changes in bottom habitat, food supply, predation, etc., etc.
tion, ice scour, and larval entrainment (Lee, 1980). Fish and shellfish populations are also subjected to an immensely greater fishing pressure than before. Recreational fishing in particular has increased dramatically with the post-war development boom that coincided with the building of the permanent breachway.

In order to address the impact of the breachway on the fisheries, research was designed to quantify:
- the abundance and distribution of dominant shellfish in the lagoons;
- the relationship between the physiography (currents, vegetation, salinity and sediments) of areas of the lagoons and four important shellfish (soft shell clams, hard clams, oysters, and bay scallops);
- the abundance and spawning behavior of the principal finfish, the blackback flounder;
- the size of commercial and recreational harvests of flounder and shellfish;
- the growth rates of oysters in Charlestown and Green Hill Ponds.

Fishing effort and annual yields were estimated by intercepting and interviewing recreational fishermen and tabulating their catch. The daily activity of recreational fishermen was recorded for two years by volunteer “pond watchers” that lived in strategic locations around the two lagoons. The two commercial fishermen that operate small otter trawls agreed to record the weights, sex, and length of the tagged flounder they caught and their total annual harvests. A preliminary estimate of the annual yield of fin and shellfish from Charlestown is summarized in Table 4. Using standard conversion factors of the National Marine Fisheries Service to convert live weight to meat weight for shellfish, the total annual yields from Charlestown Pond ranges from 45 to 150 kg per acre per year. The lower yield is the average for years when bay scallops (Argopecten iradians) are not present.

Unfortunately, there are no quantitative data available on amounts of fish or shellfish harvested prior to the stabilized breachway to compare to present yields. However, there are reports that indicate a dramatic shift occurred in the dominant species. The lagoons now support a predominately hard clam (Mercenaria mercenaria) and flounder (Pseudopleuronectes americanus) fishery with sporadically productive years for bay scallops and a very limited oyster (Crassostrea virginica) population. Before the stabilized breachway Charlestown, supported very productive fisheries for white perch (Morone americana), alewives (Alosa pseudoharengus) and oysters. Flounder, hard clams, blue crabs (Callinectes sapidus), softshell clams (Mya arenaria), and tautog (Tautoga onitis) were also abundant although catches were not recorded since there was no market for these species. Old fishing logs do provide some clues to the magnitude of previous harvests and tell us that a single fisherman regularly seined 9,072 kg of alewives each spring during the 1920s and 1930s from Charlestown and Green Hill. A single cove in Charlestown Pond regularly produced several thousand kilograms of perch before the breachway was opened each spring. There are now virtually no perch or alewives in the lagoons. Both species require brackish water for spawning and nursery habitat. In 1948 prior to construction of the breachway, salinity in Charlestown pond averaged 23 ppt in the west basin and 5.5 ppt in Green Hill Pond in the summer (Wood, unpublished data). Salinity today is 27.6 ppt in the Charlestown west basin and 23.3 ppt in Green Hill and there are no seasonal pulses of low salinity. The effect of the stabilized breachway on the estuarine fisheries in Charlestown Pond may be comparable to the effect in Pt. Judith Pond, a lagoon of similar size and salinity a few kilometers to the east (Fig. 1). The present yields from Charlestown and Pt. Judith Pond are similar and good fisheries data exist for Pt. Judith Pond before a stabilized breachway was built in 1910. A comparison of the early yields to the estimated present day catch indicates that the yield of both fin and shellfish was far greater before the permanent breachway, and was comprised of a greater diversity of species (Table 5). Changes in lagoon ecology brought by stabilization of a wide, deep breachway were probably important contributors to the decline of total fishery yields and shift of dominant species.

Table 4

<table>
<thead>
<tr>
<th>Species</th>
<th>Mode</th>
<th>Weight (kg live weight)</th>
<th>Ex-vessel value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter flounder</td>
<td>Commercial</td>
<td>3.538</td>
<td>$ 150</td>
</tr>
<tr>
<td>American eel</td>
<td>Commercial</td>
<td>9,072</td>
<td>$ 6,600</td>
</tr>
<tr>
<td>White perch</td>
<td>Commercial</td>
<td>11,340</td>
<td>$21,250</td>
</tr>
<tr>
<td>Quahogs</td>
<td>Commercial</td>
<td>2,268</td>
<td>$ 6,000</td>
</tr>
<tr>
<td>Oysters</td>
<td>Recreational/commercial</td>
<td>5,443</td>
<td>$ 10,080</td>
</tr>
<tr>
<td>Scallop</td>
<td>Recreational/commercial</td>
<td>1,360</td>
<td>$ 2,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2,268</td>
<td>$ 6,000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>96,638</td>
<td>$149,230(commercial)</td>
</tr>
</tbody>
</table>

The public believes that Charlestown and Green Hill Ponds are shoaling rapidly because great volumes of sand are flowing in through the breachway. The older residents claim

The effect of the breachway on sedimentation

The public believes that Charlestown and Green Hill Ponds are shoaling rapidly because great volumes of sand are flowing in through the breachway. The older residents claim
that before stabilization, much of the pond was 2 meters deep and it is only half that or less today. In order to address these problems the geological research tasks were formulated to quantify the following:

- the processes of sediment transport and erosion within the lagoons;
- the routes and rates of sediment transport into the lagoons;
- the distribution of depositional sites and relative rates of sedimentation throughout the lagoon.

There are several major processes of sediment transport into lagoons: wind, runoff and river transport, accumulations of organic matter from aquatic plant growth, overwash, and transport through inlets. It is known from previous work that rivers and wind blown transport are not major sources of sediment to Rhode Island’s lagoons (Dillon, 1970). A series of cores taken through sediment deposits confirmed that the accumulation of organic matter produced in the lagoons has also been relatively unimportant (Boothroyd et al., 1981).

Sediment washed over the barrier in storm surge channels is clearly a major source. During the past 165 years, 24 documented hurricanes have struck the Rhode Island shore and washed over the barrier spits. Several temporary inlets formed during the major hurricanes of 1938 and 1954, storms which brought surges 4.4 m and 3.0 m above mean high water respectively (Olsen, Grant, 1973). The results of lead (210 Pb) analyses indicate that the sedimentation rate on the washover lobes along the back of the barrier is an order of magnitude less than the accumulation rate on the flood tidal delta (see Fig. 4). The breachway is therefore a major source of sediment to the east end of Charlestown Pond where the tidal delta is accreting at an average rate of 6.9 cm per year.

The effect of breachway stabilization on sedimentation was estimated by comparing changes in the size of the delta using aerial photographs. The depth of the deposits was obtained from core data to give a volume estimate of accretion for each decade since 1939 when the first aerial photos were taken (Fig. 5). These analyses indicate that the tidal delta is growing by an average of 4886 cubic meters per year and the rate has doubled since the permanent breachway was constructed (Boothroyd et al., 1981).

What then are the processes that drive sediment in through the breachway? The local residents were convinced that sand has been flowing in continuously since the breachway was stabilized. However, the weight of geological theory and evidence from other lagoon systems suggest that the sediment transport into the lagoon is storm dependent. The geologists assumed at first that only hurricanes or violent winter storms supply enough energy to erode the barrier beach and transport the sand through the breachway. However, in order to address the weight of public opinion, the geological team conducted an experiment in which fluorescent dyed sand was placed on the ocean beaches on either side of the breachway and in the channel itself and sampled for 3 months during calm summer weather. The experiment demonstrated, much to our surprise, that once sand gets into the breachway it is rapidly and continuously transported onto the tidal flats (Fig. 5). The energy to erode the sand off the beach face and into the nearshore transport systems is probably storm dependent. But in addition to occasional storms of hurricane magnitude, normal winter storms are a regular occurrence and can cause severe erosion. An estimated 22.75 m³/m per year is eroded during a blizzard in 1978. Washover fans behind the dunes account for 27% of the eroded material. Approximately half of it moved along shore or came in through the breachway and the remainder was probably lost offshore. There was a three year lag between the storm and the time when the last of the sand eroded in the 1978 storm was deposited on the delta (Boothroyd et al., 1981).

The public perception that the stabilized breachway is accelerating sedimentation in the pond is correct for the areas where the flood tidal delta is accreting. However, the stabilized breachway is not responsible for shoals elsewhere in Charlestown and Green Hill Ponds. Data collected from a series of hydrography stations show that maximum current velocities on spring flood tides drop from 155 cm/sec. in the breachway to 20 cm/sec. on the margins of the delta and to less than 6 cm/sec. at the Green Hill channel (Fig. 6).
20 cm/sec. is the minimum velocity required to roll medium sized sand grains, currents are too weak to transport sand from the breachway into Green Hill Pond. The shoals and sand flats in these areas are either glacial deposits or the result of storm overflow (Boothroyd et al., 1981).

The remaining puzzle was the reported dramatic shoaling of both Charlestown and Green Hill Ponds after the stabilized breachway was built. A detailed bathymetric map prepared by the US Army Corps of Engineers in 1910 confirmed that there was indeed a major decrease in depth but this cannot be attributed to sediment accumulations. We have concluded that the stabilized breachway permitted the lagoon to permanently equilibrate with sea level. Prior to the permanent opening to the sea, freshwater from surface and groundwater flow accumulated in the ponds. Thus, the loss of about 1 m of water depth throughout the lagoons was due to a drop in hydrostatic head and not to widespread and rapid sediment deposition.

The effect of the breachway on hydrodynamics

It is widely believed that the shoaling caused by the breachway is reducing circulation in the ponds and causing stagnant conditions that contribute to the decline in water quality. Those concerned about aquaculture and fisheries contend that the price for any enhancement of flushing will be a further increase of salinity and loss of the remaining oyster populations that today produces the seed for a growing aquaculture cottage industry.

Research was designed to quantify the effect of dredging or changes to the breachway on salinity, flushing, and tidal circulation in the lagoons. Specifically, the physical oceanographers have:

- developed a two-dimensional vertically averaged numerical model of sufficient accuracy to represent present tidal circulation in lagoons with complex inlet geometry;
- used the model to predict changes in salinity and circulation resulting from dredged channels in the lagoons and alterations to the Charlestown and Green Hill breachways.

A simple basin model was developed by incorporating a salt balance equation in the hydraulic inlet model of Scelig et al. (1977). The model was field verified with measurements of tide ranges, current velocities, water depth, sea level, wind velocity, and electronic measurements of volume of flow through the breachway. Annual salinity data for five stations in the ponds were obtained from a previous survey (Marine Research Inc., 1974-1976). The results of this work have shown that the Charlestown tidal hydrodynamics are predominantly controlled by the inlet and that the frictional effects of the delta are crucial when predicting effects of changing the dimensions of the breachway or channel dredging. A finite element numerical model was also developed with particular care given to designing and field verifying the grid pattern for the tidal delta (see Fig. 7; Isaaj, Spaulding, 1981).

Circulation is driven not only by tides but also by the force of winds on the lagoon and sea surface and by atmospheric pressure conditions that set up a difference in hydrostatic head between the lagoon and the ocean. Tidal forcing causes currents of less than 5-10 cm/sec. in the lagoon. The tidal range in the lagoons is one tenth as great as that in the ocean and is commonly overshadowed by the effects of the wind. Atmospheric conditions, wind direction and duration, and freshwater inflow all influence the circulation in the lagoons. When winter winds blow from the north and a low pressure storm cell moves over the area, much more water moves out of the pond than on a normal ebb tide. This phenomenon, long noted by the locals and first declared as improbable by the researchers, exposes acres of shellfish beds to freezing winter temperatures causing major kills. Before the breachway was stabilized, this "blow out" did not occur since the breachway was closed and water levels were high during the winter.

Developing a management strategy

Once it was established from the scientific research that the breachway is, in fact, accelerating the sedimentation rate in the east basin of Charlestown Pond, and that it did dramatically change the ecology of the lagoon by increasing the salinity, then management options could be developed. In order to find alternatives that would address the public's concerns and alleviate the problems caused by the stabilized breachway, the Center relied primarily on the hydrodyna-
mic model to test whether simple modifications of the breachway could achieve the following management goals:
- increase the range of salinity in the lagoons to enhance the formerly abundant brackish water fisheries;
- decrease the sedimentation rate on the delta;
- increase the flushing of Green Hill Pond to alleviate water quality problems;
- allow safe and easy passage of small boats between the lagoons and the ocean.

Four reasonable options were identified and an assessment made of how each would affect conditions in the lagoons. The options are as follows:
1) Do nothing; let the present sedimentation and circulation processes continue.
2) Dredge a sediment catchment basin on the lagoon side of the Charlestown jetties and a small boat channel (10 M x 1 M) across the tidal flats and around to the Green Hill inlet.
3) Narrow the width of the Charlestown breachway.
4) Install tide gates in both breachways, that could be open during the summer and closed in the winter and during storms.

The do-nothing option has little to recommend it. Calculation of sedimentation rates in the flood tide delta suggest that intertidal sand flats could extend across the lagoon to the north shore of Charlestown Pond within 35 years (Boothroyd et al., 1981). This would split the lagoon in two and cut off Green Hill Pond and the east basin of Charlestown from the ocean. Not only would this result in a major reduction in the size of the lagoon itself but it would bring the flushing and boat access problems to a crisis.

Boating interests have long argued for the dredging of channels through areas of heavy sedimentation, such as the channel dredged from the Charlestown breachway due east to the Green Hill breachway in 1962. However, the channel diverted circulation away from the east basin and accelerated sedimentation there. We have used the hydrographic model to test the effect of dredging a small winding channel that follows the flood tidal channels across the delta and around the eastern flats into Green Hill Pond. The model predicted, however, that even a channel 10 M wide and no more than 1 M deep would increase the salinity and tidal exchange in Green Hill Pond. This would jeopardize the remaining oyster population, increase sedimentation, and force the state to commit itself to periodic long term dredging to maintain the channel.

Narrowing the width of the breachway has also been suggested. The simple basin model suggested that this might effectively reduce the flow of water and, therefore, the amount of sand carried into the lagoon and also lower salinities. The fine grid model, however, showed that a reduction in the width of the breachway sufficient to significantly lower salinities in the ponds would not allow boat access. For instance, a 50 percent reduction in the width of the breachway would not significantly lower salinities in the lagoons yet current velocities in the breachway would increase to 5 knots, which is too much for most small craft to negotiate safely (Table 6).

We have concluded that the best most flexible management option is to install tide gates in the Charlestown breachway and in the Green Hill channel. These can be opened in the summer for boating and closed in the winter and during storms. A sediment catchment basin inside the Charlestown breachway would capture much of the reduced sand flow and could be easily dredged out by a dragline operating from the parking lot. The geologists estimate that this would, under normal circumstances, be necessary only every five to seven years. With the tide gate in the Charlestown breachway the Green Hill inlet can be expanded to twice its present width, doubling the exchange between Green Hill and Charlestown. This would alleviate summer stagnation in Green Hill without permanently increasing the salinity. If the Charlestown breachway gate was kept closed during the winter, water would no longer be blown out of the pond causing massive winter kills and salinities would fall low enough to discourage oyster spawning and kill predators. The gates can be opened to allow access to migratory fish. It appears, therefore, that tidal gates would enable us to meet all four management goals.

Discussions and refinements to these options have now been proceeding with the responsible government agencies for nearly eight months. Local leaders have promised their support in preliminary discussions. Public workshops on a draft proposal will soon be conducted jointly by the Center, the Coastal Council, and the Department of Environmental Management and, at present, the prospects appear good for seeing the plan implemented. The Coastal Council will sponsor the project and the Department of Environmental Management will oversee construction and operate the gates.

**Table 6**

<table>
<thead>
<tr>
<th>Option</th>
<th>Central basin</th>
<th>Charlestown Pond</th>
<th>Foster's cove</th>
<th>Fort Neck cove</th>
<th>Green Hill Pond</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present conditions</td>
<td>29.8</td>
<td>27.6</td>
<td>24.6</td>
<td>28.3</td>
<td>23.3</td>
</tr>
<tr>
<td>Reduce breachway 50 %</td>
<td>29.2</td>
<td>26.3</td>
<td>22.6</td>
<td>27.2</td>
<td>22.2</td>
</tr>
<tr>
<td>63 %</td>
<td>28.7</td>
<td>25.2</td>
<td>21.2</td>
<td>26.1</td>
<td>21.4</td>
</tr>
<tr>
<td>75 %</td>
<td>27.9</td>
<td>23.3</td>
<td>18.1</td>
<td>24.5</td>
<td>17.4</td>
</tr>
<tr>
<td>88 %</td>
<td>25.8</td>
<td>18.4</td>
<td>6.5</td>
<td>20.1</td>
<td>10.4</td>
</tr>
<tr>
<td>Dredged channel</td>
<td>29.9</td>
<td>27.8</td>
<td>24.9</td>
<td>28.4</td>
<td>23.4</td>
</tr>
</tbody>
</table>

*Isaji and Spaulding, 1981.*
bring major improvement in annual yields and the prospect of reviving a formally important cottage industry unless fishing effort is controlled. Even if the salinity and flushing in the lagoons were sufficiently lowered by a tidal gate to enhance oyster habitat, the enormous and increasing fishing pressure would keep the oyster population at a low level. Similarly, if the towns of Charleston and South Kingstown do not make radical alterations to their building density regulations in the watersheds of the lagoons, we predict that saturation development, with more than four times as many houses as are present today is likely to be attained within the next two decades. Not only will this result in a major decline in the beauty of the area and the irrevocable disappearance of its present rural character, but we can predict that nitrate inputs to groundwater and bacterial contamination carried in surface runoff will greatly increase the areas of the lagoons where the symptoms of eutrophication are prevalent. Bacterial contamination may rise to levels that will force the state to close much or all of the lagoons to shellfishing. In 1979 and 1980 Green Hill Pond showed fecal coliform levels during summer months that surpassed the legal limit for shellfishing, and nitrate-nitrogen levels in densely developed areas are in some cases already high enough to be considered a health hazard (Nixon, 1982b). Therefore, unless two other separate and politically highly charged issues, namely fishing efforts and development in the lagoon's watershed are simultaneously and successfully addressed, the benefits of redesigning the breachways will be overshadowed by other problems and very little real progress will have been made toward managing two valuable and potentially highly productive lagoons. The URI salt pond project has addressed these issues in detail and the Center is now working with local governments and state agencies to develop strategies that could solve these problems. It is not yet too late to do so. The public's acute awareness that the lagoons and the lands around them are being rapidly degraded makes us optimistic that the necessary political support will be mustered and that the results of the research and our suggestions for holistic management will be implemented.

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