FULL REPORT
OF THE
HERRING RIVER
TECHNICAL COMMITTEE

January 3, 2006

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Synopsis of Findings of the Herring River Technical Committee, 3 January 2006

Pursuant to the August 2005 Memorandum of Understanding (MOU), the Herring River Technical Committee has completed a review of existing scientific and technical reports and participated in numerous technical presentations regarding the Herring River, as directed. Review materials included technical issues relevant to both existing and restored conditions. This Synopsis, prepared for the Wellfleet Community and the Stakeholder Committee, is intended to fulfill the Technical Committee's charge, under Section Two (2), Part A. of the MOU.

Under currently diked conditions:

1. Tide heights, tidal range (difference between high and low tides) and salinity in the diked river are severely restricted; the dike reduces tidal range by nearly 80%, and seawater extends only three-quarters of a mile upstream and encompasses only 6.4 acres of salt marsh (less than 1% of the original salt marsh area);
2. As a result, native salt-marsh plants have been replaced by invasive species including non-native *Phragmites* (common reed);
3. Salt marsh animals, including economically important shellfish, have been eliminated throughout most of the estuary;
4. Diking and drainage degrade water quality, release acidity and metals, cause summertime oxygen depletions and fish kills, and thereby further reduce finfish and shellfish populations;
5. River herring, an historic focus of the Town, are diminished not only by poor water quality but also by high flow velocity and the physical obstruction of the dike itself;
6. With the lack of tidal flushing, poor low-tide drainage and poor water quality for predatory fish, nuisance mosquito production is often very high;
7. Low tidal flushing also allows coliform bacteria to accumulate, closing productive oyster beds, and threatening to close extensive aquaculture grants, seaward of the dike;
8. With diking and drainage the wetland has subsided up to 2.5 feet and continues to subside, reducing storm-surge protection for adjacent private and public properties.

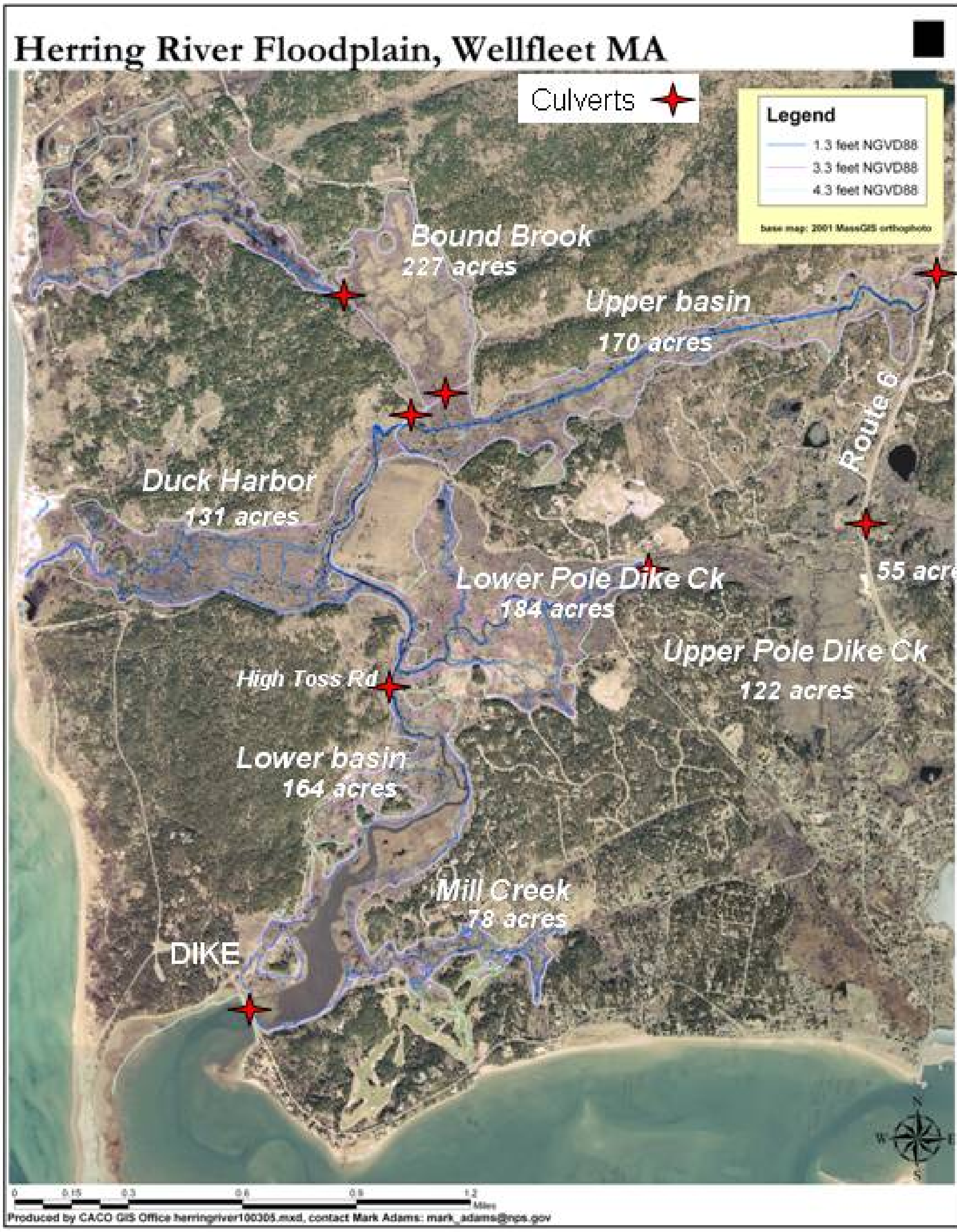
With tidal restoration:

1. High tidal range, salinities and estuarine habitats can be restored, potentially to Route 6 and encompassing up to 1100 acres, approximately 100% of Herring River's original tidal wetlands;
2. Restored salinity will eliminate invasive plants, including *Phragmites*, within the flood plain;
3. Estuarine animals, including finfish and shellfish, will reestablish throughout the ecosystem extending both recreational and commercial fisheries;
4. Increased salinity and water levels will reestablish natural salt-marsh chemistry and eliminate acidity and metals contamination;
5. Increased tidal flushing will dilute other potential contaminants that may discharge into the river;

6. Increased tidal flushing will also increase water-column aeration, reduce summertime oxygen stress and promote survival of all aquatic animals including the migratory river herring, which declined precipitously with diking;
7. Increased tidal flushing, improved water quality and improved physical access for predatory fish will facilitate natural mosquito control;
8. Increased tidal flushing will reduce coliform pollution of shellfish beds seaward of the dike;
9. Sediment from the river will not flow onto downstream shellfish beds; highest flow velocities are during flood (not ebb) tides; therefore, net sediment flow will be upstream and onto the wetland surface, helping the wetland accrete and keep up with sea-level rise;
10. The stability of The Gut barrier beach is dependent on Bayside shoreline processes and will not be affected by increased tidal exchange between harbor and river;
11. Groundwater quality in adjacent supply wells will not be affected;
12. Two septic systems occur within the project area; mitigation options exist and should be investigated further;
13. Various management options exist and should be considered for any impacts to public roads throughout the restoration process. Culverts, clapper valves and road elevations may have to be addressed.

Basic conceptual approach

Research (hydrodynamic modeling) has shown that a new, gated structure with a wide opening at the mouth of the river, along with enlarged openings under High Toss, Bound Brook Island and Old County Roads, can accommodate controlled, incremental and carefully monitored tidal restoration. This would allow for flexible management of the restoration to protect public and private interests.



Map of the Herring River estuary showing sub-watersheds, their respective acreage, and the location of road culverts.

Recommendation

Pursuant to the August 2005 MOU, the Herring River Technical Committee has completed a careful, in depth review of existing technical materials regarding the Herring River. This material had been reviewed through both literature and presentations, including issues relevant to both existing and restored conditions. The Technical Committee had received input regarding community, stakeholder, and resource agency concerns from the Stakeholder Committee and has held a joint meeting with that Committee. This recommendation to the Wellfleet Board of Selectmen is intended to satisfy the Technical Committee's charge, under Section Two (2), Part C of the MOU.

The Herring River Technical Committee hereby recommends that tidal restoration of the Herring River Salt Marsh is feasible and will provide numerous and substantial public benefits. As outlined in the Technical Committee's Synopsis, significant improvements in water quality would provide subsequent public health, recreational, environmental, and economic benefits. Our recommendation includes a new structure capable of full tidal restoration. The new structure should incorporate controlled gates to provide incremental increases in tidal exchange. This would allow for well thought out management, supervision, monitoring, and evaluation.

Responses Technical Questions

Pursuant to the August 2005 MOU, the Herring River Technical Committee has considered Community and Stakeholder interests, as presented to the Committee by the Stakeholders Committee, in writing and at a joint meeting.

The Technical Committee prepared a document entitled " Frequently Asked Questions About Tidal Restoration in Wellfleet's Herring River Estuary". The number reference from this document is included below as applicable as our direct response to the 29 Stakeholder Technical Questions based upon the technical findings of the Technical Committee. Note questions 1 and 17 have been reassigned as management questions #31 and #32.

These answers to Stakeholder questions are intended to satisfy the Technical Committee's charge, under section Two (2), Part B of the MOU.

The questions including Technical Committee responses are as follows:

Technical Questions

1. What is the proposed plan for the level of restoration? **To be addressed by the restoration plan – see management question #31**
2. What is the proposed plan for the dike structure? **See Reference Document # 1 questions #14 and # 33**
3. What is the minimum elevation that would maximize salt marsh restoration for the entire system? **See Reference Document # 1 questions #12**
4. What is intended for the pole dike area? **See Reference Document # 1 questions #15 and # 39**
5. What would impacts be for the pole dike area? **See Reference Document # 1 questions #15 and # 39**
6. What is intended for the Old County Road area? **See Reference Document # 1 questions #15 and # 39**
7. What would the impacts be for the Old County Road area? **See Reference Document # 1 questions #15 and # 39**
8. Have solutions been identified for culverts in these areas? **See Reference Document # 1 questions #15 and # 39**
9. What measures will be taken to remove ground cover, brush and trees? **See Reference Document # 1 questions #30**
10. Will there be any man made relocation of vegetation or habitat? **See Reference Document # 1 questions #29**
11. Are there any endangered species threatened by restoration? **See Reference Document # 1 questions #29**
12. What will be done to facilitate emigration of free (fresh) water fish and other aquatic life away from the restored area? **See Reference Document # 1 questions #31 and # 39**

13. Will further studies be made to determine potential restoration impact on the integrity of the gut? **See Reference Document # 1 questions #24**
14. Will further studies be performed to determine how restoration will influence the movement of river sediment into the harbor? **See Reference Document # 1 questions #23**
15. Will changes of sediment in the harbor be monitored after restoration? **See Reference Document # 1 questions #23**
16. Will phragmites and sediment be removed before the dike is opened? **See Reference Document # 1 questions #30**
17. How large an area would this take place over? **To be addressed by the restoration plan – see Management question 32**
18. Will restoration introduce breeding areas for salt-water mosquitoes? **See Reference Document # 1 questions #30**
19. What issues would impact ground water at the transfer station landfill? **See Reference Document # 1 questions #8**
20. How will restoration affect the integrity of private water wells? **See Reference Document # 1 questions #16**
21. How will restoration affect the integrity of private septic systems? **See Reference Document # 1 questions #17**
22. How will restoration affect ground water levels? **See Reference Document # 1 questions #6 and # 9**
23. How will restoration affect water penetration in private homes? **See Reference Document # 1 questions #15**
24. How will the Country Club be affected by tidal influx? **See Reference Document # 1 questions #19**
25. How will the Country Club ground water be affected by tidal influx? **See Reference Document # 1 questions #19**
26. Will access to Duck Harbor be affected? **See Reference Document # 1 questions #21**
27. Will access to Bound Brook Island be affected? **See Reference Document # 1 questions #21**
28. Will Access to other town owned properties be affected? **See Reference Document # 1 questions #15**
29. Will previous pesticide use have an impact on restoration? **See Reference Document # 1 questions #26**

Reference Document

1. "Frequently Asked Questions About Tidal Restoration in Wellfleet's Herring River Estuary" **refer to section 4 of this Full Report of the Herring River Technical Committee**

Frequently Asked Questions
About Diking and Tidal Restoration
in Wellfleet's Herring River Estuary
December 2005

Preface

An original "Twenty Frequently Asked Questions…" were compiled for the Town of Wellfleet and Cape Cod National Seashore in 2000 by Brittina Argow, a visiting geologist from the Association of Women Geoscientists. Ms. Argow solicited questions and concerns from the public, and provided answers based upon review of scientific literature and consultation with technical experts. In 2005, the Herring River Technical Committee followed the same procedure to expand the scope of questions and to update answers based on additional research. Relevant supporting literature is listed by number (see attached bibliography) after each answer.

Current conditions

1. *What's wrong with the status quo? Why can't the marsh just stay the way it is?*

The reality is that the marsh *won't* just stay the way it is. Because the watershed's hydrology has been changed profoundly by the emplacement of the dike and by subsequent ditching, the natural systems of the Herring River estuary and marsh are in an ongoing struggle to establish a new state of equilibrium. Over the last century such a balance has not been achieved, and so the ecosystem continues to evolve. Sediment cores retrieved from the Herring River system indicate that it had been a stable salt marsh for approximately 2000 years. The presence of salt water in the system, inhibiting freshwater plant colonization, and the balance between deposited sediment and rising sea level maintained this salt marsh ecosystem. The emplacement of the dike and ditches has artificially induced vegetation succession, creating a strange upland ecology located at elevations below mean high tide! Within our lifetimes, large regions behind the dike have progressed rapidly from a marsh to open meadow to an upland forest ecosystem. The Herring River currently suffers from episodically severe water quality problems related to this change. In addition, with the lack of regular tidal flooding for nearly 100 years, the marsh surface above the dike has severely subsided, and continues to sink. The longer that diking continues, the less marsh peat remains to protect adjacent upland structures from storm surges. There is no inexpensive and practical way to freeze the evolution of the Herring River at this current ecologically and geologically unstable point in its succession. Even if nothing were done at the dike or elsewhere in the Herring River, this area will continue to change. Management action will be necessary to stabilize the system. The most practical and economical management alternative to re-stabilize the Herring River estuary would be the restoration of a tidal salt marsh. **References: 1, 11, 12, 14, 15, 17, 20, 21, 24, 25, 26.**

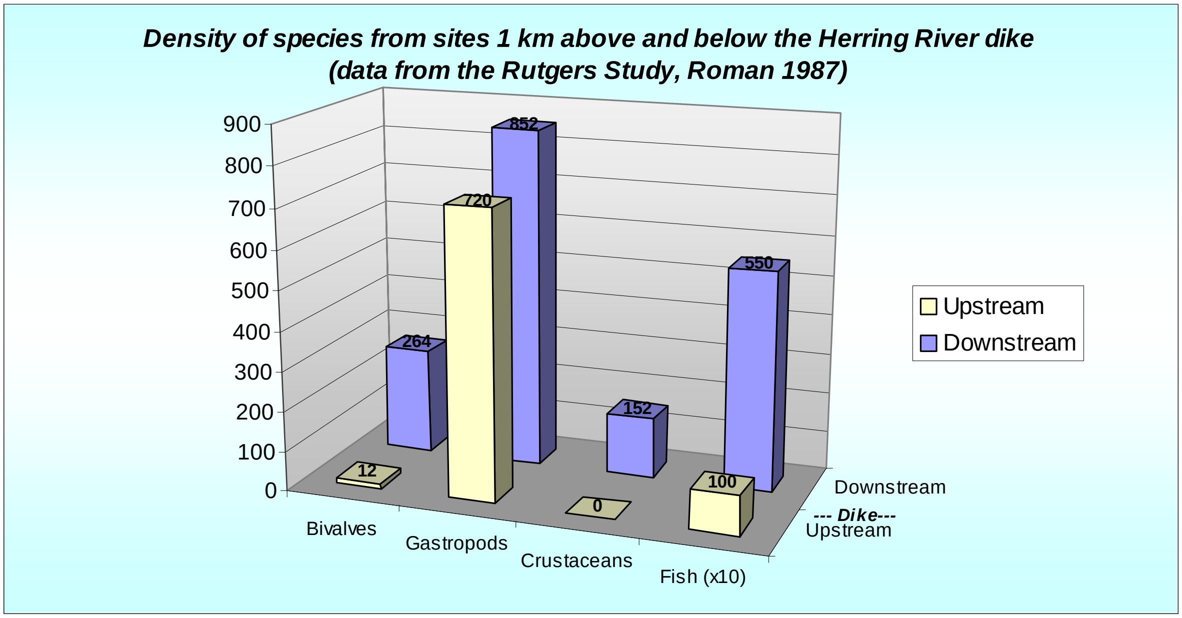
2. *Describe the comparative value of salt vs. fresh water marshes.*

   Both salt and fresh water marshes support productive ecosystems and add to the biodiversity of Cape Cod. Salt water marshes also act as nurseries for a wide variety of salt and brackish-water species, providing shelter and feeding grounds. Geologically, they protect inland areas by absorbing the energy of storm waves as they approach the shore, reducing inland erosion and trapping sediment. Hydrologically, all coastal marshes are groundwater discharge areas that ultimately return rainwater to the sea.

   Importantly, however, much of the diked Herring River flood plain does not support healthy freshwater wetlands. The original low salt marsh between the dike and High Toss Road has been invaded by exotic Phragmites, of much less habitat value to birds and fish. The original high marsh above High Toss, north to bound Brook Island Road and west through Duck Harbor has been so effectively drained that upland shrubs and trees have replaced wetland species. In addition, the drainage has caused sulfur-rich salt marsh peat to oxidize, creating several hundred acres of acid sulfate soils which leach toxic acidity and aluminum into receiving waters, killing fish.

   The Herring River, before diking, was more than just a salt marsh—it was a complex system grading from salt marshes to brackish and freshwater marshes. The lower reaches of the system were estuarine—the largest estuary on the lower Cape; based on surviving 1903 photographs, it looked much like Blackfish Creek just west of Route 6 today. Unaltered estuaries are among the most productive environments on the planet. Unfortunately, Herring River's productivity, along with that of about half of the state's original salt marshes, has been severely compromised by diking and ditching. Restoring the size of the estuary, currently restricted to the river mouth seaward of the dike, will increase the productivity of the many species that rely on this environment for spawning and nursery grounds. In the last few decades, recognition of the economic and environmental importance of estuaries and their associated salt marsh communities has spawned global restoration efforts to remediate these heavily impacted ecosystems. Wellfleet is not alone in its position as a community investigating the health of its wetland environments. For example, the Massachusetts Coastal Zone Management's Wetland Restoration Program is working with communities, other government agencies and non-profit conservation groups to remove tidal restrictions and restore salt marsh estuaries all along the state's coast. Similar programs are under way throughout the U.S. coastal zone. **References: 4, 5, 11, 17, 19, 20, 24.**

3. *Why are there fewer fish upstream of the Herring River dike? Also: What is the cause of summertime oxygen depletion and how can the problem be fixed? And what is the cause/significance of the decaying organic matter within the system?*



Although the Herring River in Wellfleet is a complex system, there are several clear causes for a reduction in fish abundance and diversity in the waters above the dike. The dike's small opening restricts water flow in and out of the upper reaches of the estuary and marsh, decreasing mean tidal range. This reduces the submerged and intertidal habitat available to fish for shelter, forage, and spawning areas. Over the past century, this has made it harder for fish to reproduce successfully and survive in their original numbers. Some species may have disappeared from the marsh entirely. Farther up the system, in the freshwater portion of the marsh, serious water quality issues pose more problems for fish species. The low pH (high acidity) of the water can kill fish directly. Acidic water also leaches aluminum out of clays in the marsh sediments, and aluminum is toxic to fish in very low doses in the water column (0.2-0.5 ppm).

In addition, the lack of regular tidal flushing with well-aerated Cape Cod Bay water leads to dissolved oxygen depletions. Despite the long period of diking and drainage, abundant organic matter remains in the system to consume dissolved oxygen particularly when water temperatures are high in the summertime. Dissolved oxygen even in the river main stem is often so low that there is none left for the fish to breathe, causing massive fish kills. In the past, oxygen depletions have coincided with the annual emigration of juvenile herring from the headwater kettle ponds, causing the mortality of tens of thousands.

A healthy salt marsh has a relatively small region of low oxygen that occurs at the interface between fresh and salt water. This occurs because at this location there is minimal tidal flushing, but organic debris is still abundant. Microbes feeding on large quantities of organic material normally consume dissolved oxygen in the water column. In the Herring River, this region of low dissolved oxygen has been expanded because of the reduced tidal range. It now extends over most of the area between

Route 6 and the dike. Comparatively few species can thrive or even survive in this acidic, toxic, low-oxygen environment.

The high organic content of marsh deposits is natural, and an unaltered marsh can handle the high volume of nutrients and biological consumption of oxygen. This is because an unrestricted marsh is “flushed” twice daily with oxygen-rich seawater. The simplest and most effective way to remedy these problems is to restore the tidal prism behind the dike. This would increase flushing and aeration (oxygenation) of water and would eliminate the acidity problem by resaturating drained marsh peats with sea water. Laboratory experiments show that these and other water quality problems begin to correct themselves within two months of inundation with seawater. **References: 11, 12, 13, 15, 17, 18, 19, 20, 24.**

4. *What is the relationship between water impoundment, sea level rise, and marsh surface subsidence?*

A natural unaltered salt marsh, such as nearby Nauset Marsh or Blackfish Creek, can compensate for gradual rise in sea level through the accumulation of organic material layered with inorganic sediment (mostly silt and clay) washed into the marsh system by flood tides. The Herring River dike blocks the influx of inorganic sediments, handicapping the marsh’s ability to keep up with rising sea level. In addition, as the water table dropped further in response to ditching and channelization, the organic deposits (peats) began to dewater and shrink. The individual pore spaces between grains of sediment and organic debris had been supported by water, but as the peats dried out these pores collapsed under their own weight, and the marsh surface subsided still more. Futher, with drainage and aeration, organic material began to decompose more quickly due to the increased oxygen present in air compared to water, also contributing to subsidence. Nearly all sections of the marsh lost the highly productive *Spartina* communities. Presently, the restricted marsh surface elevation upstream from the dike is 70 cm (over two feet) lower than the natural marsh surface just downstream. A casual observer can note the differing elevations from the hill above the dike, as well as the large difference in tidal range. Mean sea level has risen 20 cm in the past century, which means that the current diked marsh surface is nearly one meter below modern high tide! If the dike were simply removed, there would certainly be significant flooding in the subsided areas of the flood plain. Therefore, a gradual opening of the dike would likely be an appropriately cautious management alternative in this environment. Increasing the tidal prism would increase the amount of inorganic sediment washed into the marsh on flood tides and would slow down peat decomposition, which over time would help the marsh to build up to an elevation consistent with modern sea level.

An excellent example of what can be expected in terms of sedimentation at Herring River after tidal restoration is provided by the Hatches Harbor Salt Marsh Restoration project ongoing in Provincetown since 1999. Monitoring there has shown rapid recovery of the marsh surface with tidal restoration - nearly a centimeter (about ½ inch) of sediment accumulation per year, which bodes well for the subsided Herring River marshes. **References: 5, 11, 14, 16, 17, 19, 22, 24**.

5. *What is the cause of the observed change from sand to mud in the diked Herring River channel?*

   As mentioned, an incoming flood tide carries mostly fine inorganic particles, silt and clay, up onto the salt marsh surface. When the dike was built, these strong flood tides were blocked. Silt and clay carried by flood tides settled in the river channels, instead of being carried onto the wetland surface as it was before tides were restricted. Increasing the tidal prism behind the dike would restore flood-tide velocities so that silt- and clay-sized particles would again be carried onto the marsh surface, instead of settling as muck in the river channel. This would have the added benefit of improving inorganic sediment supply to upstream marshes, helping them to recover their elevation and to keep up with rising sea level. **References: 5, 14, 17, 22.**

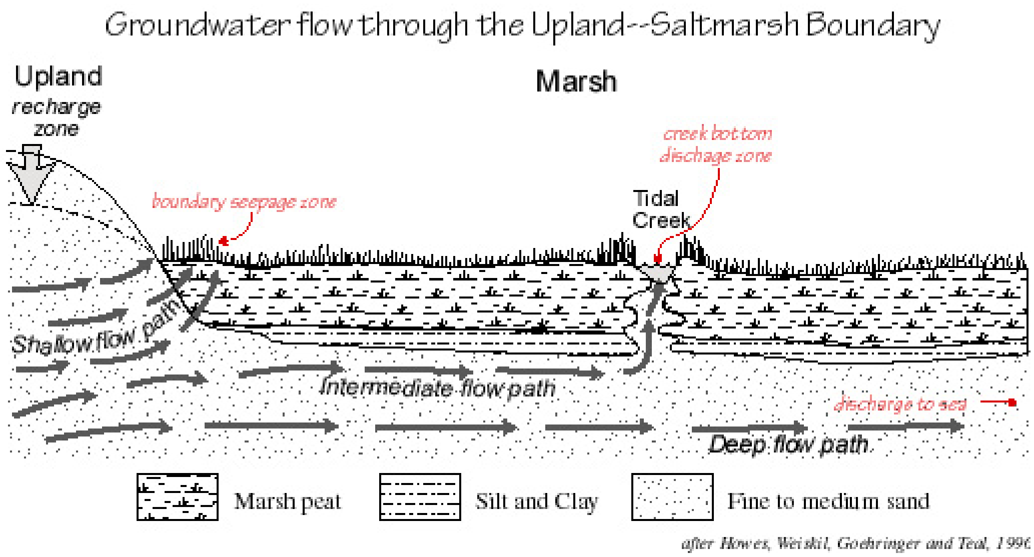
6. *What is the cause of acidification and what are its impacts?*

   The high acidity of water in parts of the Herring River system is an indirect result of the building of the dike in 1909. The dike effectively blocked most salt water flow into the system, allowing discharging groundwater to replace salt water with fresh, and salinity steadily decreased. Diking caused the water table to drop from the elevation of mean high tide elevation to that of mean sea level, the elevation at which groundwater discharges locally. Subsequent ditching and channelization of the river and marsh have further lowered the water table.

   The marsh surface upstream from the dike has subsided, but the water table has dropped even more. Large areas of salt marsh peat which have become completely drained are now well above the restricted high tide elevation. This dried-out peat is the source of the acid that finds its way into the water column in the Herring River. Salt marsh peat contains high levels of the mineral pyrite, which is composed of sulfur and iron. In normal marshes, the peat is consistently flooded daily by high tides, and an anaerobic (low oxygen) environment is maintained. When this peat is dried out, however, the pyrite is exposed to air, which has significantly more oxygen in it than does water. The iron in the pyrite essentially rusts out, liberating the sulfur, which enters the water column as sulfuric acid. This acidity kills or severely limits the range of estuarine animals like fish and shellfish. High acidity also leaches toxic minerals, especially aluminum and ferrous iron, from native clays, further damaging the aquatic fauna. Nuisance mosquitoes are one of the few animal groups who can tolerate the poor water quality, and benefit from the lack of fish predators. **References: 10, 11, 14, 15, 17, 20, 24.**

7. *Do the Herring River marshes accumulate fresh water and contribute it to the drinking water supply*?

   No. Low-lying marshes in coastal regions are discharge areas for aquifers, meaning that water flows out of, not into, the groundwater aquifer at this aquifer/marsh boundary. Groundwater always flows from the aquifer towards surface water. Water that falls on a marsh in the form of rain washes over the marsh surface and into the tidal channel network, where it is carried to the sea. The salt marsh peat that underlies the Herring River valley has a very low permeability, and therefore allows little exchange between the marsh surface and the underlying aquifer. **References: 8, 9**.



8. *What are the possible sources of nitrogen loading in the Herring River system?*

There are currently no known or suspected point sources (this is generally understood to refer to human waste) for nitrogen loading in the Herring River system. A leachate plume from the recently (summer 2005) capped Wellfleet landfill at Coles Neck appears to flow toward Herring River, but so far monitoring has not detected increased nitrogen at its likely discharge location along the river main stem. There is limited agriculture in the watershed and few fertilized lawns, so non-point sources of nitrogen pollution are minimal.

Nitrogen is naturally abundant in a salt marsh where it cycles between plants, sediment, water column and atmosphere. Most is stored within plant biomass both above and below ground, but some nitrogen is constantly being released by organic decomposition. If too much of this were to reach the water column, it could cause algae blooms, oxygen depletions and fish kills; however, in a natural salt marsh a large fraction is removed by the process of bacterial denitrification. The process only occurs in an environment of both low oxygen, e.g. waterlogged marsh peat, and high pH (low acidity). In contrast, current water management in Herring River results in aerated, low-pH soils.

If nitrogen is in fact high in Herring River, diking and drainage, and their disturbance to natural nitrogen cycling, may be a contributing factor. **References: 11, 14.**

9. *Do the mosquito ditches function as storm-water control mechanisms?*

The mosquito control ditches were not designed as storm-water control mechanisms; rather they were intended to drain the marshlands, lowering the local water table for

the purpose of reducing mosquito breeding sites. The ditches expedite the return of rainwater to the sea. However, the ditches have also effectively eliminated the marsh in areas where they have lowered the water table to the point where upland plants can encroach. Marshes act as buffer zones between the ocean and upland areas during storms. By changing the function of parts of the marsh, mosquito control ditches have reduced the ability of this low-lying area to absorb the energy of incoming storm waves, making upland areas potentially more susceptible to storm damage. Ditching and stream channelization are both intended to drain adjacent wetlands, a action that at Herring River causes peat oxidation, acid sulfate soil formation and fish kills.
References: 5, 9, 10, 14, 17.

10. *What is allowed by the existing Herring Run maintenance Order of Conditions? What was the logic behind the court's decision that established the gate's opening height?*

The dike was built in 1908/1909 and restricted the flow of seawater into the Herring River system while allowing the outflow of fresh water to Wellfleet Harbor. By the 1960s, the original culverts had deteriorated and was allowing seawater to re-enter the diked estuary. Consequently an estuarine community of shellfish, crustaceans, fishes and other species re-established itself upstream from the dike. Federal and State law protects established fisheries; therefore when the dike was re-built in the mid-1970s the Conservation Commission mandated enough tidal flow be preserved to protect the existing marine communities.

Rationale for tidal restoration

11. *What is the overall rationale for a salt marsh restoration effort here at Herring River?*

Many people agree that the Herring River is in trouble. Some are worried about the Herring Run; others miss the migratory birds that used to shelter in these marshlands. Shellfishermen are concerned about the quality of water washing out over their shellfish grants. Landowners are concerned about changes in the current system and what the future might bring. Mosquito control experts all agree that the status quo is a pest control nightmare. Most people involved feel that some decisive action should be taken. In response to all of these interests, a great deal of information has been collected and analyzed to help us understand the Herring River and make the best management decisions possible.

In light of these concerns, several fundamental issues have become clear. Perhaps most critical is the compromised water quality in the existing Herring River. Species decline and periodic die-offs have emphasized this problem, but they are only symptoms of the underlying condition. In fact, marsh surface subsidence, upland forest encroachment onto native open marshlands, and decreasing biodiversity are all problems which are intimately linked to the condition of the water column. Having first identified the problems and then discovered how these conditions evolved in the Herring River, we are now faced with the challenge of remediation. Many communities have struggled with these decisions, and several alternatives have been experimented with in the past.

Liming has been tried in ponds and even over small-scale watersheds in an effort to reduce the acidity of water. The advantage of this approach is that it quickly buffers pH in water. The disadvantages are that it initially kills much of the biota in the system, is non-permanent, and is terribly expensive. The acidified portion of the Herring River system encompasses roughly 300 acres. Liming on this scale is logistically, economically, and ecologically unsuitable. Under the present management regime, acid generation will continue indefinitely.

Wellfleet citizens have annually removed woody debris from the channels in the Herring River to ease river herring passage between Wellfleet Harbor and the headwater spawning ponds. It is important to realize that this action has only been necessary because of the nearly 100-year long program of diking that blocked the seawater which prevented the growth of salt-sensitive woody plants (shrubs and trees). Thus, until tides and salinity are restored, the woody vegetation will continue to invade and channel maintenance will become increasingly difficult and laborious.

Worldwide, most communities and agencies facing these issues have chosen to restore the tidal flow of salt water in an effort to remediate the negative conditions that develop in diked estuaries and marshes. Perhaps the main reason this approach is popular is because it is comparatively low-cost. Even in locations where the existing restricting structure has to be re-built (example: Hatches Harbor), the long-term costs of tidal restoration are ultimately lower than the alternatives. This method is considered advantageous because it treats the underlying problems in the marsh system, rather than just the symptoms. It will also create an environment which can be stable for hundreds, if not thousands of years, reducing the need to constantly monitor the system in the future after equilibrium has been reached.

In early salt marsh restoration efforts, mistakes were made. The rapid reintroduction of salt water to a system which has been primarily fresh causes a rapid and extensive death of salt-sensitive plants, for example following the breach of the railroad grade in the lower Pamet River about 1991. People are right to be concerned about this approach—it is difficult to successfully monitor and predict such a radical change. However, even these early attempts were ultimately successful. Within a decade the salt marsh community began to grow and prosper, eventually re-establishing a healthy ecosystem. Today, the pressures of human activities in and around the wetland areas make such rapid inundation impractical and irresponsible. Laboratory studies and successful salt marsh restoration efforts on Cape Cod and the world over have all demonstrated that gradually increasing the tidal range in a previously restricted marshland will effectively remediate most of the outstanding problems in the region, while allowing careful monitoring and more accurate prediction to guide the project. A carefully monitored, gradual re-introduction of salt water to the Herring River system is a responsible and feasible management option available to the town of Wellfleet. **References: 17, 19. Also see supplemental references.**

Effects of Tidal Restoration

12. *First, what is the goal from a long-term ecological restoration perspective in terms of tide heights, tidal range and salinity distribution?*

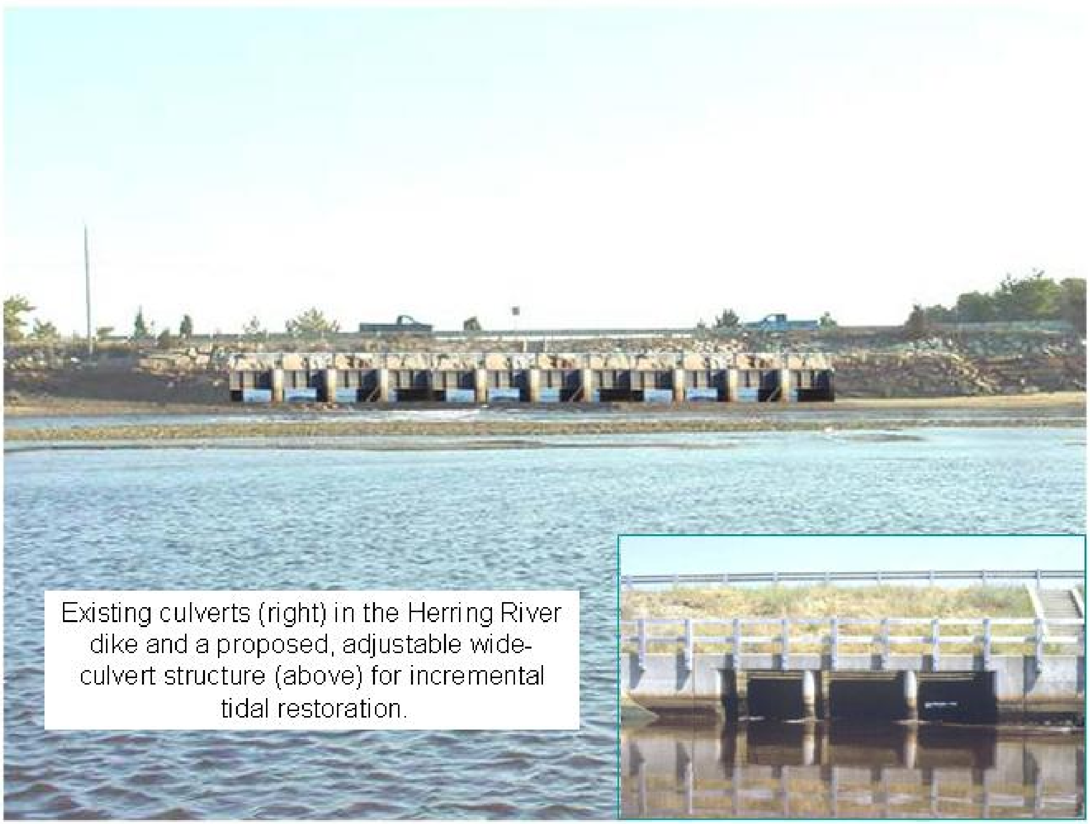
Ideally from this perspective the system would be managed so that it could sustain itself with minimal active human intervention and maximal ecological and social benefits. Given current sea-level rise, and a scientific consensus that the rate of sea-level rise will increase, one would choose to remove all restrictions on tidal and sediment exchange between the river and marine environment. However, the persistence of low-lying structures may make this goal unattainable for many decades. Short of full restoration, a relatively modest goal, but with potentially great benefits, would be to achieve average river tide heights that approximate current conditions in the salt marsh just seaward of the dike. This would bring biweekly spring high tides to about six feet above mean sea level (6-ft-MSL), which roughly defines the upper limit of salt marsh vegetation in Wellfleet Harbor. **References: 5, 22, 23.**

13. *How can the effects of increased tidal exchange on tide heights and salinity be predicted?*

Hydrologists from the United States Geological Survey, Rutgers University and the University of Rhode Island have constructed computer models to predict the influx of seawater into the Herring River valley and resulting tide heights for a range of tidal-restoration scenarios. In a computer model, mathematical equations are used to describe the flow of water from one side of the dike to the other. The “tidal forcing” (i.e. height of the water in the harbor seaward of the dike relative to diked river level throughout the tidal cycle) and size, shape and elevation of the opening in the dike control the volume of water that passes through the structure and into the river. Resulting tide heights are determined by the shape and, thus, volume capacity (bathymetry) of the flood plain. A global positioning system and standard surveying techniques were used both 1) to generate an accurate bathymetric model of the flood plain, for hydrodynamic modeling of tide heights, and 2) to identify critical elevations of potentially flooded structures including buildings and roads up to the 10-foot mean-sea-level contour, i.e. the 100-year flood plain. Results of similar modeling for tidal restoration at Hatches Harbor (Provincetown) have been highly predictive of actual measured tide heights since restoration began in 1999. **References: 19, 20, 22, 23.**

14. *What structural changes are contemplated to alter tidal flow at the river mouth and what are their likely effects on tide heights and tidal range?*

Hydrodynamic modeling has shown that opening the existing three culverts in the Chequesset Neck dike will cause a substantial increase in tide heights; however, modeling also shows that low-tide drainage is impeded; therefore, opening the existing structure actually decreases tidal range and flushing. A high tidal range drives salt-marsh productivity, and good flushing depresses nuisance mosquito production and dilutes contaminants like fecal coliform. In contrast with the poor performance of the existing culverts, modeling results for a low, but much wider culvert opening, as used at Hatches Harbor, were far superior in terms of tidal range and tidal flushing. The hydrodynamic work indicates that the Herring River opening should be at least 30 meters (~100 feet) wide to remove most restriction on tidal exchange. Such a wide culvert (more realistically: culverts) could be gated to allow adjustments and incremental restoration as has been done at Hatches Harbor. The illustration below shows existing culverts and a composite of Hatches Harbor style culverts of 100-foot width in the Herring River dike. **References: 19, 22, 23.**



Existing culverts (right) in the Herring River dike and a proposed, adjustable wide-culvert structure (above) for incremental tidal restoration.

15. *Would tidal restoration cause inundation of, or limit access to, town roads and other structures?*

Flooding to 6-ft-MSL would, at time of high tide, flood portions of High Toss, Bound Brook Island, Pole Dike and Old County Roads where they actually cross the flood plain; hese roads' surfaces are in places below 4.5 ft-MSL. A complete survey of potentially flood-prone structures, including homes, wells and septic systems, is under way. Obviously, alternatives for dealing with this flooding need to be developed prior to increasing tide heights. An in-depth study of potential impacts to the only year-round-occupied home seaward of High Toss Road, and within the flood plain, was recently completed (Reference 27).

It should be noted that, for both ecological and social reasons, the current conceptual plan is to restore tidal exchange, and increase high-tide heights, slowly and incrementally over years. In this way, conditions can be monitored and any problems corrected in a controlled fashion as habitat restoration proceeds.

Although, except for the low-lying roads mentioned above, public road access should not change, public access to the estuary itself should greatly increase. Shrubs, brambles and trees that presently cover the once-open marshlands and tidal creeks would die and be removed with tidal restoration, resulting in open salt marshes and creeks navigable by canoe, kayak and skiff as in unrestricted marshes like Blackfish Creek and the lower Pamet River. **References: 9, 19, 20, 22, 23, 27.**

16. *What is the potential of tidal restoration causing* ***saltwater intrusion into adjacent domestic wells****?*

In 1990, the US Geological Survey used geophysical soundings and well installation and sampling to determine that, with 20 meters of fresh water between domestic well screens and the salt/fresh ground water interface, there was no chance that tidal restoration in Herring River could affect those private wells installed in the adjacent upland. The wells of the two dwellings situated within the flood plain, however, could be affected by either surface seawater flow or a landward repositioning of the salt/fresh ground water boundary, which may be expected with tidal restoration.

This hydrologic work was expanded in 2003 to include the potential for salt water intrusion into supply wells around the Mill Creek tributary of Herring River, also including Chequesset Neck. The USGS Water Resources Division installed three additional observation wells through the fresh-salt groundwater interface, logged their water quality, and modeled the effects of tidal restoration. The investigators applied the tide heights and salinities predicted by the 2001 hydrodynamic model of the surface water system to a model of the local groundwater aquifer; they then ran the model for a virtual 300 years to assess the long-term effects on the interface. Results corroborated the above-mentioned 1990 study, indicating that re-opening the Herring River to tidal exchange should not affect well-water quality. Importantly, this analysis, and its conclusion of no impact, also included wells adjacent to Mill Creek , in the event that the golf course is able to relocate fairways and Mill Creek is kept open for salt marsh restoration. Besides establishing water quality in now six, deep observation wells around the flood plain, this study also summarizes domestic water quality from health records as a base line for future monitoring. **References: 6, 7, 8, 22.**

17. Would existing septic systems be affected by restored tidal flow?

Only septic systems already located inappropriately close to the water table would be affected, i.e. below 6 ft-MSL. An ongoing (December 2005) survey by Slade Associates has identified only two. Issues faced by individual landowners are unique and specific and must be solved on a case-by-case basis. **References: 22, 23.**

18. *How many undeveloped but buildable lots are located within the area that would be subject to inundation?*

There are no legally buildable lots located in the area that would be subject to inundation, because State and local laws prohibit building in the flood plain. Many lots that might otherwise be acceptable for houses are ineligible because their septic systems would have to be placed above ground due to the high water table in these lowlands. In the past, regulations were less strict and so some houses have been built in locations that today would not receive building permits. It is necessary that solutions be found regarding the few affected properties before any restoration effort can proceed.

19. *What are the potential impacts of an increased opening on the Chequesset Yacht and Country Club (CYCC) golf course and their irrigation water supply?*

The CYCC Executive Board has taken a proactive approach to this controversy and are actively seeking a solution that will allow them to move the affected holes to a more appropriate location on higher ground. In 2005, Wellfleet's Annual Town Meeting voted to contribute $1.2 million of Land Bank funds to acquire the low-lying fairways for Open Space, provided matching funds become available to complete the purchase. An additional $500,000 has been promised so far (November 2005) from the federal government, with another $100,000 from various public and private sources for golf course relocation planning. The drinking water at the CYCC will not be affected, although it may be necessary to seek an alternative water source for irrigation. **References: 8, 9.**

20. *Given the rationale for construction of the dike, what are the expected effects on the mosquito population? How does filling and maintenance of ditches play into this?*

Experts at the Cape Cod Mosquito Control Project agree that the Herring River is currently an exceptionally productive mosquito habitat, particularly between High Toss Road and Route 6. The dominant mosquito species caught in the Wellfleet area, *Ochlerotatus cantator*, breeds in fresh to brackish water, and its larvae can tolerate the acidified waters that keep its predators at bay. Restored tidal exchange should therefore decrease the population of this mosquito, as decreased acidity and increased salinity, oxygen, and predation would all have a negative impact on the reproduction of *Ochlerotatus cantator*. Eventually, salt marsh mosquitoes may recolonize the lower marsh, but the Cape Cod Mosquito Control Project reports greater success in controlling this species, so the net impact on the mosquito population of an increased opening in the dike should be to decrease it.

The filling and maintenance of the ditches is controversial. Ditching lowers the water table and begins the chain of events resulting in acidified water, which has negative ecological effects and, ironically, protects the mosquito larvae. Some scientists have argued that regular tidal flushing of a salt marsh washes mosquito larvae out to sea, helping to control populations as much as ditching might. Regardless of what management action is taken with the ditches, mosquito experts agree that tidal restoration, and its anticipated improvement of river water quality and flushing, would be a good thing relative to the current situation. **References: 10, 13, 15, 23.**

21. *What impacts would tidal restoration have on the historically open inlets at Duck Harbor and Bound Brook?*

An increased opening at the Herring River dike will have no impact on the barrier beaches at Duck Harbor and Bound Brook. The stability of these beaches is controlled by the sediment budget of Cape Cod Bay. Even if the barriers were to overwash during a storm, their back-barrier embayments have filled with sediment and have too little capacity to maintain a new inlet. Therefore, there is no reason to anticipate an opening at either of these locations under current sedimentation and erosion patterns. **Reference: 5.**

22. *What are the potential impacts to the shellfish industry? Will the fecal coliform contamination at the river mouth, which has caused shellfish-water closures since the 1980s, worsen with tidal restoration?*

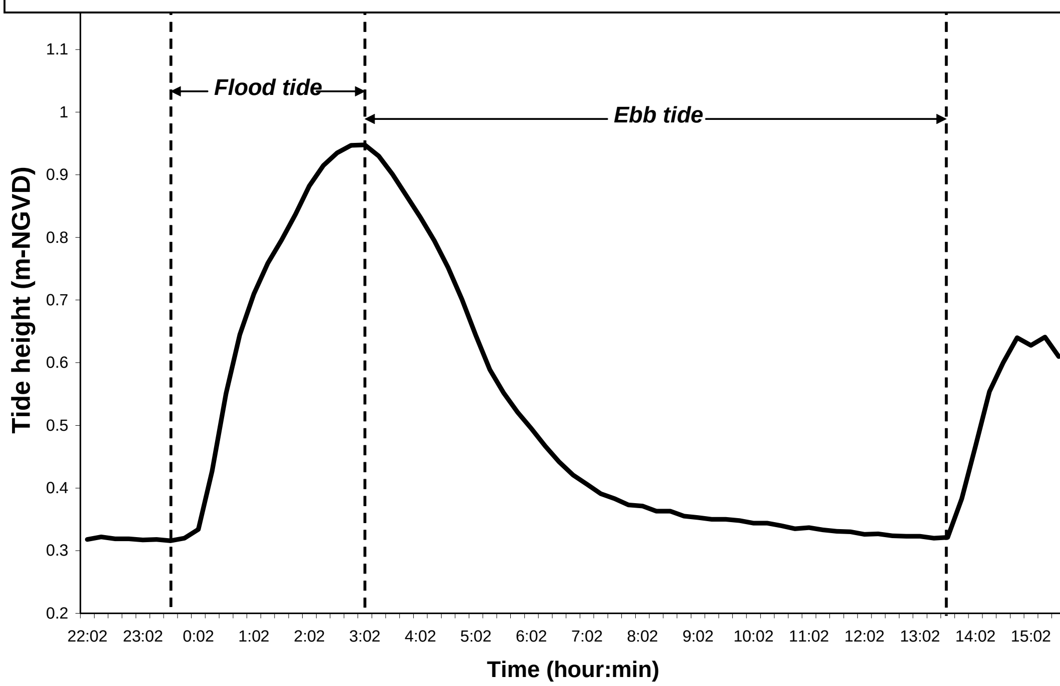
The source of fecal coliform bacteria, the standard indicator for shellfish-growing waters, in Herring River has always been a bit of a mystery: there is little development in the river flood plain and no major change in land use at least since the Seashore was established in 1961. It seems most likely that wildlife are the ultimate source of bacteria, and these microbes can survive and perhaps grow in the river sediment for some time. Recent (2005) research has shown that fecal coliform bacteria concentrations in Herring River are strongly associated with freshwater discharge, and greatly diminish once the fresh river water mixes with high-salinity Wellfleet Bay water en route to the sea. The extensive and productive shellfish-aquaculture beds of Egg Island are currently protected from high fecal coliform by the daily infusion of relatively clean Cape Cod Bay water, while the rich oyster beds in the river channel between Egg Island and the dike always have high bacteria counts during low tides, when river discharge predominates, and have been closed to shellfishing for about 20 years. With tidal restoration, the volume of clean seawater entering and leaving Herring River during each tidal cycle will increase <u>by over 13 times</u>. By simple dilution, this should reduce fecal coliform to concentrations that would allow the reopening of shellfish beds below the dike that have been closed for decades, and increase the high-salinity buffer between Egg Island aquaculture and river water. In addition, it is well known that coliform survival time is reduced in surface waters of high clarity, salinity, pH, and dissolved oxygen – the very water-quality factors that will increase most dramatically with restored tidal flow. Thus, the most effective and efficient way to reduce coliform levels in the Herring River system is to restore flushing by seawater.

According to George Heufelder of the Barnstable County Department of Health and Environment, Robert Duncanson of the Chatham Water Quality Laboratory and others with experience in managing bacterial contamination in coastal systems, increasing tidal exchange in Herring River should reduce coliform counts at and seaward of the dike. Operative factors include increased water clarity and UV penetration, improved aeration and survival of microbial predators, lower temperature and increased salinity; however, the overwhelming factor is increased dilution by the much increased tidal volume. Duncanson did caution that to the extent that high marsh pools develop and are not flushed daily by the tides, we could see episodic “coliform” release into surface waters after spring tides or storm events. Although this release is a potential in all of our salt marsh estuaries, we should plan to monitor it. **Reference: See Presentation 6.**

23. *Will increased tidal velocities carry fine sediments from above the dike to shellfish beds downstream?*

Regarding sediment transport, studies have shown that flood-tides will flow faster than ebb tides so that most sediment will be transported upstream with restored tidal flow. This is the mechanism in unaltered estuaries (see graph below for tide-restored Hatches Harbor): relatively strong flood-tide currents carry fine particles onto the marsh surface, and ebb currents are too weak to remove them. The accumulation of fine sediment (black muck) in the river channel today is a symptom of the interruption in this natural process of sediment transport; flood tides are blocked by the dike, so fine sediments fall short of the wetland, and settle in the channel. It’s noteworthy in this respect to recall that shellfishermen complained about fine sediment accumulation both just above and below the dike structure <u>after the dike was rebuilt</u> in the mid-1970s, and not during its prior failure when shellfish actually proliferated for the first time since 1908 in the river above the dike. **Reference: 5, 22.**

Tide-restored Hatches Harbor, like other outer Cape salt-marsh estuaries, is flood-tide dominated, with a relatively brief and rapid flood tide and long and slow ebb. This kind of tidal asymmetry forces most sediment to move upstream, contributing to wetland sediment accretion.



24. *Will increased tidal flow increase the chances of a breach of The Gut barrier beach, and consequent change in the salinity and temperature of harbor water?*

The stability of The Gut barrier beach depends on the balance between sand transport and sea-level rise on the Cape Cod Bay shore, not on the hydrodynamics of Herring River. Old charts and aerial photos dating back to 1848, well before the river was even diked, make this very clear, with the river channel always in the same place, relative to The Gut, with or without the river diked. The Gut has always affected Herring River, and deflected it to the east and south, rather than the reverse. Of course, an overwash of the barrier beach is always possible during storms, but formation of a permanent breach is very unlikely. Permanent breaches happen where there are large differences in water level on either side of the barrier beach at times during the tidal cycle; this never happens at The Gut because water readily exchanges, and water levels equilibrate, between Cape Cod and Wellfleet Bays through the huge opening south of Jeremy Point – the path of least resistance.

According to Dr. Graham Giese, who has studied the coastal geology of the outer Cape for the past 40 years, the stability of The Gut is primarily dependent on littoral sediment transport along the Cape Cod Bay shore and aeolian (wind-borne) transport within the barrier dune system. The broad salt marshes behind The Gut barrier beach, which incidentally impose a formidable resistance to erosion in the case of storm overwash from the Bay, have been very stable for decades, as observable on aerial photographs. In addition, the occurrence of a broad mudflat of fine-grained sediments on the river side of this peat bank attest to low flow velocities under present conditions with no scouring. Increased flow from Herring River during the ebb will be accompanied by increased water velocities through the channel along this creek bank; however, flows are unlikely to be sufficient to resuspend sediment.

As a base line for future monitoring, AmeriCorps volunteers collected elevation profiles along four east-west transects across the Gut and also mapped the peat bank adjacent to Herring River in the winter of 2001-2002. As far as we know, this is the first such data set available and establishes a quantitative means of addressing changes to The Gut barrier beach and salt marsh system. **Reference: 5.**

25. *What are possible sources for funding if we agree that tidal exchange should be restored?*

There are many federal, state and even local sources for funding. Money can be used for research, monitoring, assessment, planning, permitting and actual implementation of all phases of a marsh restoration project. Massachusetts Coastal Zone Management's Wetland Restoration Program, Coastal America Foundation, Natural Resource Conservation Service, The Nature Conservancy, Conservation Law Foundation, Massachusetts Executive Office of Environmental Affairs, the US Army Corps of Engineers, Environmental Protection Agency, US Fish & Wildlife Service, National Oceanic and Atmospheric Administration, National Park Service and the

United States Geological Survey have all helped support projects of this nature, and several of these have already contributed funds and/or in-kind service to this project. A particularly useful contact for the Town of Wellfleet might be the Corporate Wetlands Restoration Partnership of the Massachusetts State Wetlands Restoration and Banking Program. This state agency specializes in finding matching grants for marsh restoration projects, and can generate three dollars for every dollar that comes from private or corporate funds. A small seed grant from Wellfleet or a private or corporate donor could therefore be used to secure significant federal and state funds.

26. *Are there contaminants stored in the sediments upstream of the dike, and, might increased flow lead to their activation?*

Because of the long history of diking and peat drainage, marsh sediments above High Toss Road are extremely acidic with porewater rich in dissolved aluminum and ferrous iron, explaining the depauperate aquatic fauna and past fish kills. Note however that these contaminants have not been introduced to the marsh (from the watershed or elsewhere) but have been generated within the marsh peat by diking, peat drainage and aeration. The production of these “acid sulfate soils”, of which there are hundreds of acres north of High Toss Road, is a widely observed and studied problem associated with salt marsh drainage worldwide.

NPS and cooperating scientists at the Marine Biological Laboratory Ecosystems Center and Boston University conducted field and greenhouse experiments in the early 1990s to assess the effects of restored tidal flow and salinity on sediment and water quality and salt-marsh plant growth above the Herring River Dike. This work showed that restored high water levels and salinity reversed the chemical processes responsible for the release of acidity and toxic metals; pH rebounded within a few months. Salt marsh grasses thrived once pH had recovered. Importantly, the sulfide produced by sulfate reduction, a process that will occur with re-flooding of the marsh, strongly precipitates aluminum, ferrous iron and whatever other metals may be present (and whatever their origin), eliminating their potential toxicity to aquatic fauna. Thus, the return of regular seawater flooding both eliminates an existing problem and helps to protect the estuary and receiving shellfish waters from any future contamination by metals.

Regarding other contaminants recent (1999) sampling just above and below the Herring River Dike by Dr. James Quinn of URI revealed little to no contamination by synthetic organic compounds; this is expected because of the lack of commercial and industrial development. Even if isolated pockets of synthetic organic contaminants already occur within the flood plain (e,g. landfill leachate), it’s important to realize that the dike presently restricts the inflow of relatively clean seawater, and not the discharge of freshwater and any potentially entrained contaminants. Increased seawater flow would at the least dilute any contamination from an upstream source. **References: 11, 13, 14, 24.**

27. *How would restoring tidal exchange in Herring River alter the salinity patterns of Wellfleet Harbor?*

Freshwater discharge from Herring River is about 0.1 m^3/sec (=3.5 cubic feet per second); Wellfleet Harbor's tidal flow is at least 100 times greater; expectedly, low-tide salinity rarely goes below 25 parts per thousand(ppt) at Egg Island. With tidal restoration, low-tide salinities at Egg Island channel would increase slightly, increasing protection from upstream coliform sources (see above); importantly, salinities within the tidal river proper will increase dramatically throughout the tidal cycle, extending habitat for marine bivalves at least to Old County Road.
References: 15, 22, 23 and Presentation 6.

28. *What changes would occur in both nutrient inputs and phytoplankton (food for shellfish) in the harbor should tidal exchange be restored?*

As mentioned (#27), the influence of Herring River discharge on harbor water quality is very small given the huge difference between their volumes. Thus there would be little change in nutrient flux, and dependent phytoplankton, <u>on the seaward side</u> with tidal restoration. In greenhouse microcosm experiments NPS did observe that re-salination of acid sulfate soils, typical of the drained wetlands above High Toss Road, mobilized ammonium-nitrogen; however, this should be a short-term phenomenon. The ammonium is presently adsorbed to clay particles. To the extent that seawater reaches these sediments, ammonium will desorb and will be available as a nitrogen source to primary producers, both phytoplankton and wetland vascular plants. However, with a incremental and slow restoration of tidal exchange, any increases in ammonium will be gradual, i.e. not a large pulse. Also, with the high flushing rate in Wellfleet Harbor proper, this nitrogen is not expected to cause excess algae blooms.
Reference: 11.

29. What will happen to the salt-sensitive plants and animals that presently inhabit those portions of the flood plain that will be affected by tidal restoration?

Woody vegetation, e.g. shrubs and tress, will die once saltwater encounters their root systems during the growing season. Many herbaceous plant species of the brackish and tidal-freshwater marsh (e.g. marsh mallow) have some salt tolerance and will shift farther upstream over time – a process that will occur over years to decades.

Use of the flood plain by larger mammals (e.g. coyotes, raccoons, deer) will change little. Small mammals like voles and mice will continue to be very abundant in marsh grasses.

As shrubs decrease and open marsh and tidal flats increase, waterfowl and shorebird use will increase. Songbirds will likely decline in the interior marsh but persist along shrubby upland borders.

It is important to realize that the restoration of tide heights and salinity can be managed to occur slowly over a time span that is much longer than the life span of most small mammals. Thus individual animals will be less affected than their species' ultimate distribution within the floodplain.

Special consideration must given to rare plants and animals. There are no federally listed threatened or endangered species within the Herring River flood plain; however, the Massachusetts Natural Heritage Program lists four rare animal species of concern: water-willow stem borer (a moth), four-toed salamander, northern harrier, and diamondback terrapin. The stem borer feeds on water willow, a shrub that has invaded the Herring River salt marshes since saltwater was excluded nearly 100 years ago. A recent survey has found this insect in many water willow stands that would be damaged or eliminated by tidal restoration. Four-toed salamanders have been found in the most inland portions of the flood plain, e.g. sphagnum swamps in Paradise Hollow and Prince Valley; these swamps would be the last to be affected by tidal restoration, if at all. Northern harrier nest sites may be affected by increased tide heights; a survey is under way. Terrapins would be benefited by restored tidal restoration because habitat for these salt-marsh turtles would increase greatly. For all of these species, project proponents will consult with the Conservation Commission and the Natural Heritage Program prior to any alterations in tidal exchange. **References: 15 and Presentation 8.**

30. How will dying and dead woody vegetation be managed during the restoration process and the transition back to herbaceous salt marsh cover?

Several alternatives can be considered and will be subject to management review. Dead woody vegetation is unsightly, shades the ground surface and thereby retards recolonization by salt-marsh grasses, and will likely topple and leave depressions for mosquito breeding. Woody debris that falls into the main stream can impede migratory fish passage. It could be cut, with stems less than six inches stacked and burned; larger logs may be made available to the public for firewood. Alternatively, there is low-ground-pressure equipment that is capable of chipping the above-ground portions of trees and shrubs in place. Chips could be burned or removed: however, because this woody material would decompose slowly and represent little oxygen demand, it could be left to rot on the wetland surface.

The dense stand of exotic and invasive *Phragmites* between the dike and High Toss Road are a special case that will take some careful planning to avoid its spread. Given its current position at low elevations and very near the river mouth, the current stand should be severely stressed by tidal restoration and increased salinity; however, active control will probably be necessary at its northern extent to prevent spread upstream of High Toss Road. **Reference: Presentation 8.**

Additional questions related to migratory fish

from Phil Brady, Division of Marine Fisheries

31. *Will access for all anadromous and catadromous fish species into and out of Herring River be improved with the new designed dike openings?*

Yes. With a new dike with a wide (at least 100-foot) culvert, which modeling showed was the minimum width to remove all restriction (assuming no vertical restriction), peak current velocity would be only 2 meters per second and negotiable for most strong swimmers. Flows through the existing dike reach 6 meters per second, a velocity that prevents all fish from entering or exiting the system. Further consultation with anadromous fish experts is required for an optimum culvert design and opening schedule. **References: 22, 23.**

32. *With tidal restoration, how much longer during the tidal cycle will fish have access through the dike structure, in both upstream and downstream directions?*

After restoration it is expected that the period of time during which fish can enter or exit the Herring River will increase. Depending on the species, the window of time for passage will differ. Each species uses particular cues to begin a feeding or spawning migration. Under the current configuration of the dike's culverts, many species are blocked or inhibited from entering or exiting the Herring River during most of the tidal cycle. Additionally, as the fish wait to pass the dike, they expose themselves to predation and sub-optimal environmental conditions that may impact vital future activities, like feeding or breeding. With restoration, the cross-sectional area of the dike opening available for passage will increase greatly, with a corresponding decrease in tidal velocities. This will substantially enlarge, over existing conditions, the time window for fish passage. **References: 22, 23.**

33. *Will the new dike openings have top or bottom control mechanisms?*

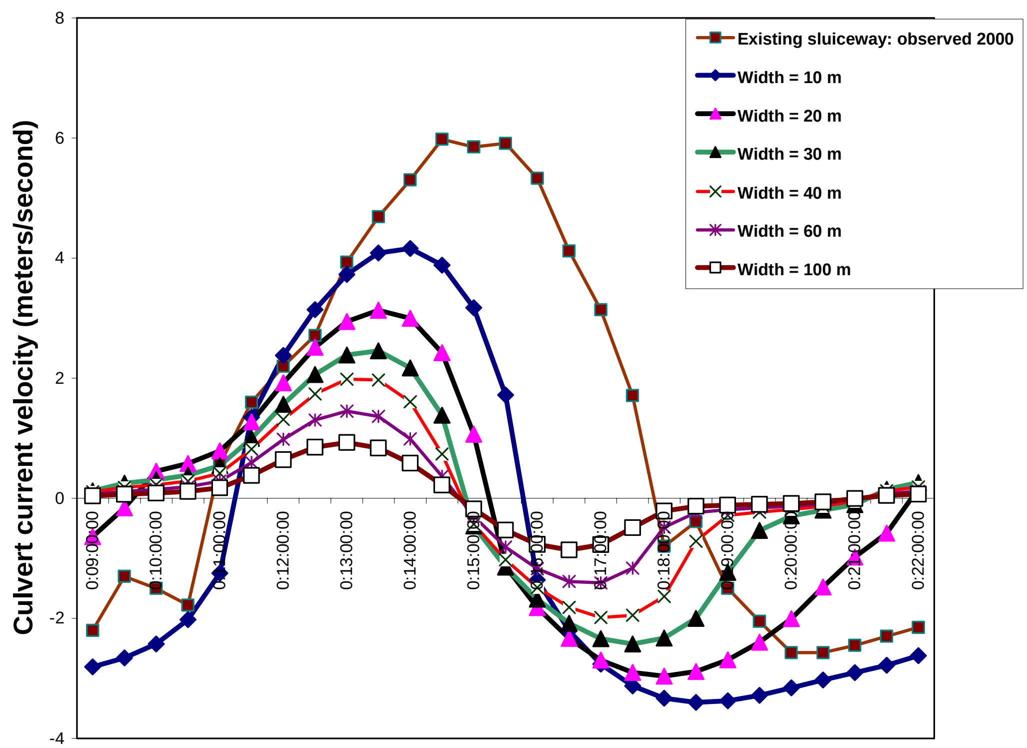
Decisions about actual design have not been finalized, but the Technical Committee has considered a structure similar to that installed at Hatches Harbor, where sluice gates are opened from the bottom up. The Hatches culverts are easily adjusted by a couple of people with manual house jacks. As mentioned above, additional consultation with anadromous fish experts is required to ensure improved fish passage.

34. *What will be the minimum water depth through the dike openings at low and high tides? As long as velocity criteria can be maintained, deeper and narrower is better than wider and shallower.*

The currently proposed openings will be shallow and wide: at dead low tide, water depth in the culverts would probably be about 0.9 ft; at high tide water depth would be about 3.7 ft, assuming a 30-m (100-ft) wide culvert. The objective here at the dike is to minimize restriction, and thereby simulate the geomtery and flow characteristics of the natural channel as much as possible. The increase in passage area through the structure, and decrease in tidal velocities will hopefully mitigate the impact of any sub-optimal passage conditions on all species, especially on species of interest, e.g., American eel and river herring. **References: 22, 23.**

35. *What will be the minimum and maximum water velocities through the new dike openings during period of potential fish passage?*

Although velocities acceptable for fish passage vary with fish species, age or size, the length of time that the tidal velocities are low (e.g. <0.5 meters per second) increases as the opening size increases. With the current culvert configuration the amount of time that the velocities are slow enough to allow passage for most weak swimmers (e.g., juvenile river herring) are very brief. Velocities under current conditions, and for a 100-foot wide culvert open to different heights, are depicted in the graph below for a normal 13-hour tidal cycle. **References: 22, 23.**



Comparison of water flow through the existing Herring River dike culverts versus a modeled wide culvert shows that flow velocity decreases with increasing culvert width. For the proposed 100-ft (30-m) wide culvert, peak velocity would be 1/3 of existing conditions.

36. *Will fish passage conditions be improved at the High Toss Road culvert?*

Yes. Modeling indicates that an opening 10 meters (about 33 feet) wide would remove all restriction on water movement here, assuming no restriction on tides at the mouth of the river, i.e. at the location of the existing dike. Essentially, the High Toss passage will allow the same tidal flow as the original tidal creek did through this part of the system, simulating original conditions. **Reference: 23.**

37. *If the High Toss Road culvert is not removed or replaced, what will be the minimum and maximum water velocities through that structure during the flood and ebb stages of flow?*

A significantly enlarged opening at High Toss is required for salt marsh restoration upstream; therefore, increasing tidal flow into the lower river without restoring original flow at High Toss is not a good option. **References: 22, 23.**

38. *At maximum restoration how much farther upstream will the salt wedge penetrate?*

Again, this depends on the which management alternative is selected. Modeling indicates that the 30-m wide culvert open only 0.4 meters (1.3 feet) high would bring the salt wedge to Old County Road; if this culvert were opened fully (e.g. 2 meters (6.6 feet) high), seawater could reach the wetlands just below Route 6 at high tide. **References: 22, 23.**

39. *Will any new hydraulic control points be established along the river's course from the upstream tidal intrusion?*

The town needs to decide on how to manage the 177 acres of the flood plain upstream of Pole Dike; if it's decided to exclude this from the restoration area, a clapper valve will be needed on the existing culvert. Elsewhere, an enlarged culvert would be needed at Bound Brook Island Road to minimize that restriction.

40. *Will any additional channelization or stream modifications of the river, upstream of High Toss road, occur during the restoration process?*

During the early 20th century, the river above High Toss Road was channelized and straightened, and the wetlands ditched for mosquito-control drainage. All involved, including the Cape Cod Mosquito Control Project, Division of Marine Fisheries, the National Park Service and the Town, need to consider and decide on the plan for restoring native hydrography. For example, should we restore cut-off meanders? Flexibility for adaptive management, acknowledging that we cannot foresee all possible outcomes, must be accommodated in the plan. For example at Hatches Harbor, during the restoration process it was found that original creeks had filled since 1930 diking and were not functioning to transport water, plant propagules and fish (mosquito predators) into the interior marsh. Mosquito Control and the Seashore responded to this problem by restoring (re-digging) Race Run and a tributary creek.

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Presentations

Summaries of above research presented to the Technical Committee, Oct-Dec 2005:

Presenters: John Portnoy, Evan Gwilliam and Steve Smith, Cape Cod National Seashore

Note that presentations are available on the Town of Wellfleet website: www.wellfleetma.org

1. Herring River tide heights and salinities under current and tide-restored conditions
2. Sediment transport and the stability of The Gut barrier beach with Herring River tidal restoration
3. Effects of tidal restoration on the freshwater aquifer and private water supplies adjacent to Herring River
4. Impacts of diking, drainage, and tidal restoration on Herring River water chemistry and aquatic habitat
5. Impacts of diking, drainage, and tidal restoration on Herring River nuisance mosquito production and control
6. An assessment of Herring River (Wellfleet, MA) microbiological (fecal coliform) water quality under existing tide-restricted and proposed tide-restored conditions (this 2005 research is in review and not yet published)
7. Herring River restoration: Fish and decapod crustacean monitoring 1984-2005 and response to restoration
8. Wellfleet's Herring River: History and future of the vegetation landscape

Responses Management Questions

Pursuant to the August 2005 MOU, the Herring River Technical Committee has considered Community and Stakeholder interests, as presented to the Committee by the Stakeholders Committee.

Technical Questions #1 and #17 (reassigned as Management Questions #31 and #32) and Management Questions #1 through #30 relate to the development of a restoration plan as required under the Technical Committee's charge, under Section Two (2), Part D of the MOU. These will be addressed pending acceptance of the Technical Committee's recommendation to the Wellfleet Board of Selectmen.

Management questions, included here, will be answered pursuant to the MOU, Section Two (2), Part D.

The Management Questions are as follows:

Management Questions

1. Have expenses and financing for culverts at Pole Dike & Old County Roads been identified, if not when will these be addressed?
2. Will the agreement to initiate restoration between the Town and the CCNS be subject to Town Meeting approval or referendum?
3. Have all federal permits been identified?
4. Have all state permits been identified?
5. Have all local permits been identified?
6. What is the procedure to include all permitting?
7. What oversight is proposed during the initial phases of restoration?
8. What oversight is proposed during the remaining phases of restoration?
9. Which agency will authorize any physical changes in elevation at the dike opening to adjust mean high water levels?
10. Which agency will implement these changes?
11. Who will authorize an operation and management agreement?
12. Who will implement a management agreement?
13. When will it be appropriate to recommend initializing an internal scoping process?
14. When will an environmental impact study be performed?
15. When will a fund be established to mitigate any damage caused by restoration to private property owners, businesses and shellfishermen?
16. When and how will federal, state, town or individual liability decisions be addressed?
17. Where will the funds come from?
18. Who will administer claims and issues?
19. When will a financial plan covering costs, funding, and assignment of liability be drafted?
20. Will the town and CCNS employ an administrator to manage certain aspects of this process?

21. Who would facilitate the emigration of fresh water aquatic life away from the restored area and when would it occur?
22. What will be done to monitor the integrity of the Gut after restoration?
23. If the Gut were to be eroded by the restoration, what impact would that have on continuing restoration?
24. Who will be responsible for monitoring changes in sediment in the harbor?
25. Will CCNS be allowed continued access after restoration?
26. Does an environmental impact study need to be done?
27. What will be done to compensate private individuals for damages resulting from restoration?
28. Can undesirable effects of restoration at the Country Club be resolved?
29. How will the costs of restoration affect the tax rate?
30. Would scrutiny by an independent agency (reviewing restoration plan) enhance credibility?
31. What is the proposed plan for the level of restoration?
32. How large an area would this take place over?

Suggested Additional Publications

1. Boumans, R.M.J., D. Burdick, M. Dionne. 2002. Modeling habitat change in salt marshes after tidal restoration. Restoration Ecology 10(3):543-555.
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