Tidmarsh Farms, Massachusetts

Climate Change Adaptation Plan

Manomet Center for Conservation Sciences

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Contents

Tables

Figures

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Site Description and History

Tidmarsh Farms is a 577 acre property in Manomet, a village in the town of Plymouth Massachusetts (Map 1). Comprised of a number of land parcels, Tidmarsh Farms occupies 10% of the Beaver Dam Brook watershed, a small coastal watershed that has been highly impacted by a combination of residential, commercial and agricultural uses.

The Tidmarsh Farms property includes two cranberry bogs complexes, one located west of Beaver Dam Road, and another, much larger complex located in the center of the watershed. The headwaters of Beaver Dam Brook arise in, and the resulting stream runs through this second complex, into a red maple swamp before exiting the property at Route 3A. In 2010, the owners took this bog complex, along with the headwaters and red maple swamp, out of agricultural production and placed 192 acres under a conservation and restoration easement with the USDA NRCS Wetlands Reserve program.

This action created an opportunity to realize a comprehensive ecological restoration of the stream corridor with its associated flood plain. The goal of the restoration is to transition this portion of the property from a retired farm to self-sustaining, high-quality, functional riverine and wetland habitat. Competitively selected as a priority project by the Massachusetts Division of Ecological Restoration (DER) in 2011, the restoration brings together a broad coalition of partners at the federal, state and local level. Today funding for the design and permitting of the restoration has been raised, and the design is 60% complete. The restoration design focuses on alleviating anthropogenic stress to the natural site hydrology, including headwaters to ocean connectivity, stream channel re-naturalization, floodplain reconnection, promotion of species and habitat diversity. The process-based approach selected for the restoration provides an opportunity to incorporate principles of climate change adaptation as part of the project design and implementation.

In parallel with the restoration effort, the project aims to develop a Living Observatory (LO) that allows the public to experience the environment across three venues: outdoor parkland, a visitor center, and a website. This initiative brings a unique focus on long term monitoring, sensor development and evaluation, education, and outreach to the project and will draw expertise from academia, agencies, non-profit organizations and the public, including Massachusetts Institute of Technology (MIT), University of Massachusetts, Mass Audubon, Public Laboratory and Rising Tide Charter School in Plymouth. This effort is well positioned to capture and inform larger regional studies about climate change.

The decision to transition almost half of the Tidmarsh Farms property from agriculture to a conservation wetland raises challenges and opportunities for the owners. In looking forward, it is important to establish a social, scientific, and economic framework that drives available resources and use patterns of this area.

Beaver Dam Brook is a groundwater dominated system that receives approximately 90% of its water budget from groundwater input and 10% from surface water input. Groundwater inputs occur both at the headwaters and along the length of the stream. The groundwater contribution area for Beaver Dam Brook extends up gradient into Myles Standish State Forest, well beyond the boundaries of the watershed.[1] The entire watershed and the groundwater recharge area overlie the Plymouth Carver aquifer system. Plymouth Carver is a sole source aquifer that supplies the majority of the drinking water for the Town of Plymouth and surrounding communities.[2]

Tidmarsh Farms and the surrounding watershed are composed of glacial deposits that overlie Paleozoic crystalline bedrock. While the uplands are predominantly comprised of course sand, the wetland corridor hosts deep deposits of organic peat. The soil survey and a limited number of soil borings carried out by Horsley Witten indicate that the bog area is likely suitable for support of a perennial stream and associated wetlands.[3] Subsequent field investigations, including test pits and ground penetrating radar, have confirmed the presence of deep peat deposits on the site.

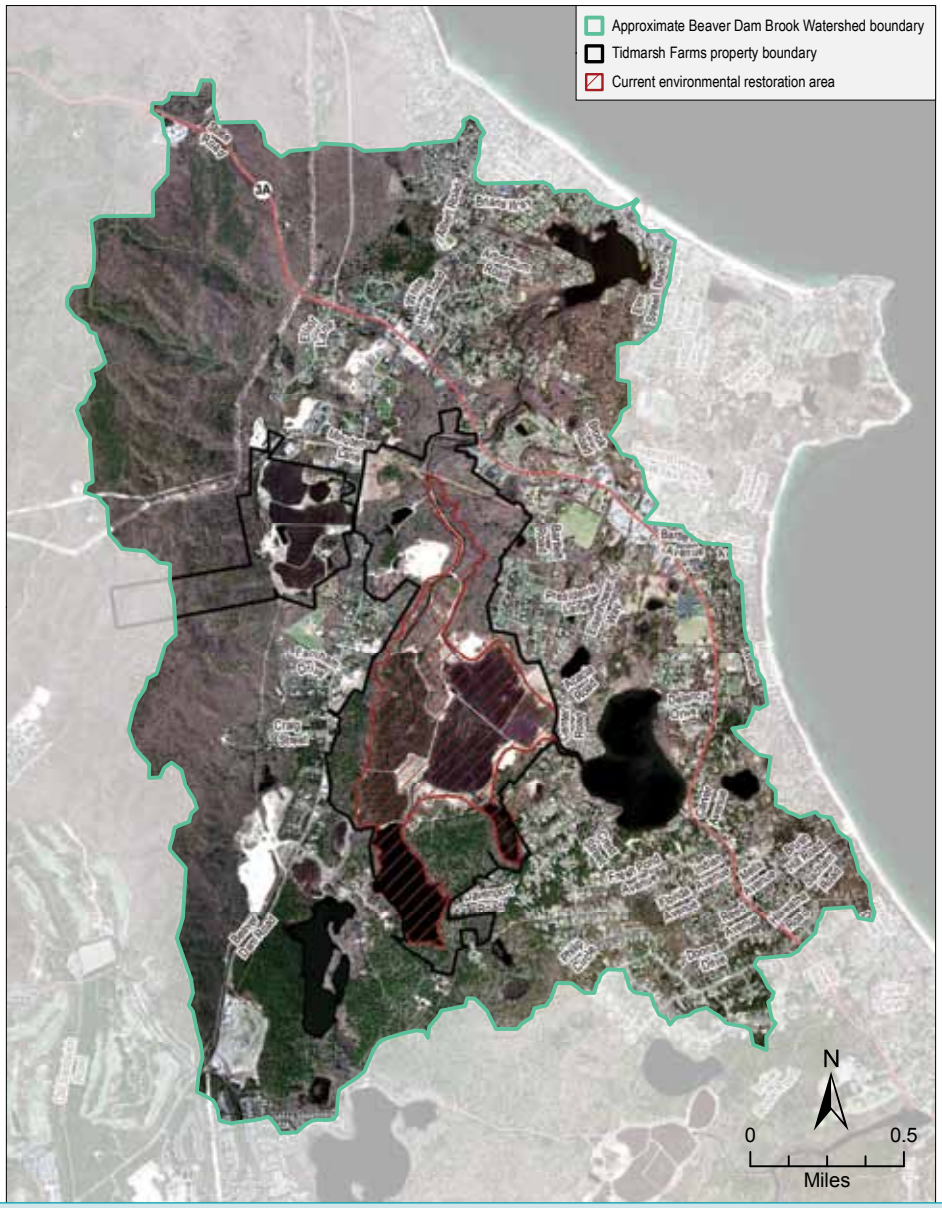
Historic maps indicate this stream valley area was once a forested swamp; modifications to the stream corridor can be traced to the 1830s, but may have begun earlier. In 1923, a dam to hold the headwaters of the Beaver Dam Brook was completed. The resulting 35 acre reservoir provided required flood waters for the 143 acres of cranberry bogs to the north; the reservoir was drained in 2010 as it no longer served its agricultural function and was considered a liability to the owners. The draining of this impoundment provides a significant step in the naturalization of this low-gradient stream system.

MAP 1

Map 1. Location Map

Location of the Tidmarsh Farms site and surrounding sub-watersheds in eastern Massachusetts.

To the east, the property includes a small connector channel to Fresh Pond, a 63 acre pond surrounded by dense development. The northern-most extent of Beaver Dam Brook on the property flows through a Red Maple swamp before the property ends at the State Route 3A. Many of the shops, restaurants and businesses in the Village of Manomet are located along this Route 3A corridor. After exiting the property, the brook continues northwards for another mile before entering Bartlett Pond, a 33 acre pond whose outflow is at White Horse Beach, a densely built oceanfront community that surrounds Bartlett Pond. The western portion of the watershed is part of the open space buffering the Pilgrim Nuclear Power Station (Map 2).



Map 2. Aerial Photograph of the Beaver Dam Brook Watershed

Aerial photography (2008) in and around the Tidmarsh Farms site. Aerial photography acquired from MassGIS. Road data from MassGIS. Watershed boundary combined from National Elevation Dataset (USGS) and MassGIS drainage sub-basins data.

MAP 2

Management Goals

The environmental restoration project at Tidmarsh Farms will create significant changes in the ecosystem services provided by the site. Food (i.e., cranberry) production has historically been among the most important services provided by Tidmarsh Farms. The environmental restoration project has taken the majority of the cranberry bogs out of production and will generate a significant positive impact on the ecological health of the watershed by strengthening the ecosystem services associated with a naturally functioning stream system, riparian forest and associated wetlands.

The landowners at Tidmarsh Farms, in conjunction with the restoration project team, have identified several goals for the site:

- Environmental Restoration:
  - Holistic, process-based river and wetland restoration that focuses on re-naturalizing site hydrology to drive a restoration trajectory;
  - Improved stream habitat and connectivity for resident and diadromous fish, as well as increased channel and floodplain interactions;
  - Improved wetland habitat including increased diversity, productivity, and re-establishment of globally rare natural communities such as Atlantic white cedar swamp; and,
  - A more dynamic and self-regulating ecosystem that allows for succession over time with limited or no future human maintenance.
- Living Observatory: The Living Observatory is an initiative that will couple on-site environmental monitoring with virtual access to the data that are collected.
  - Monitoring: The Living Observatory will include monitoring of the site through both traditional and nontraditional means. Measurement of parameters such as air temperature, water temperature and precipitation will be augmented with audio and video recordings. The monitoring data will be served over the internet making it available to a broad audience.
  - Environmental Education: The Living Observatory will support both on-site and virtual education through the establishment of a visitor center and associated website.
- Alternative Energy Development: The landowners have already installed solar power for farm and home use and are exploring the opportunities of other alternative energy installations for the property.
- Residential Development: The landowners have done preliminary analysis of residential development but no definite plans have been made.

Ecosystem Vulnerabilities

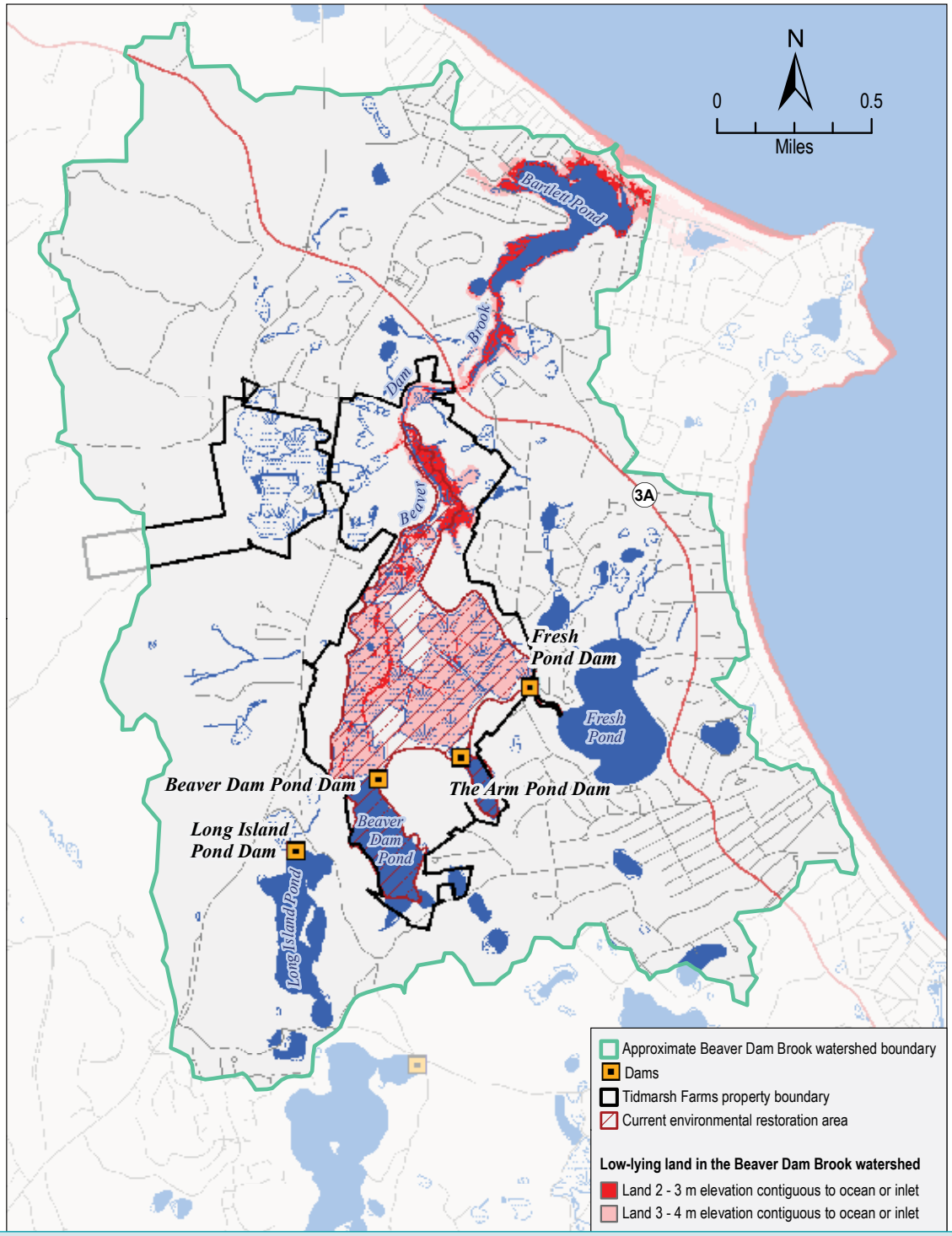
The Beaver Dam Brook watershed is vulnerable to many aspects of climate change due to the wide variety of land uses present, the varied topography, and the exposure of the coastal zone to sea level rise. The environmental restoration effort at Tidmarsh Farms will play a pivotal role in increasing the resiliency of the watershed. Adaptation decisions for the portion of the watershed outside Tidmarsh Farms will also play a significant role in determining the response of the system to climate change. The following discussion and analysis is focused primarily on the ecosystem services that will result from the restoration effort on Tidmarsh Farms. Analysis and recommendations for the remainder of the Beaver Dam Brook watershed are included for several key issues such as sea level rise and wastewater treatment.

Projected Climate Change Impacts

Many aspects of climate change will impact Beaver Dam Brook including increasing average temperature, increasing extreme high temperatures, changing precipitation patterns and rising sea levels. Sea level rise will create major impacts due the combination of minimal elevation gain along the length of the stream channel and the orientation of the watershed above the unconfined Plymouth Carver aquifer. Four major factors will intersect to impact the future hydrology of the watershed:

- Sea Level Rise: Rising sea level will drive significant changes in the hydrology of the Brook. The combination of increasing sea level and associated rise in water table height has the potential to increase both the frequency and severity of fresh water and storm surge flooding in the lowest areas in the watershed. In addition to the changing flood threat the Brook will likely become a tidal saltwater system when sea level rise exceeds two meters (Map 3).
- Increase in winter precipitation and heavy precipitation events: Average winter precipitation in New England is projected to increase by approximately 20% by the end of the century under higher greenhouse gas emission scenarios. This, in conjunction with the projected increase in the prevalence of heavy precipitation events, will increase the frequency and severity of freshwater flooding.
- Increasing demand on the public water supply system: Increasing withdrawal from the Plymouth Carver aquifer due to population growth over time will likely reduce aquifer levels during peak demand in summer.
- Increasing temperatures, the associated lengthening of the growing season and projected increase in summer drought: These projected changes will coincide with peak groundwater use during the summer season. The combination of these factors will likely create dry summer conditions in the areas of the watershed that are not impacted by sea level rise.

The combined impacts will likely result in a watershed that is increasingly wet in the winter months due to a rising water table, increasing precipitation, and more storm surge flooding. The mix of increasing temperatures, increasing drought and demand for groundwater will likely lead to comparatively dry summer conditions in the upland portion of the watershed.



MAP 3

Map 3: Sea Level Rise Vulnerability Map

Map showing approximate areas of low elevations in and around the Tidmarsh Farms site. 1 meter resolution LiDAR data acquired from MassGIS and hydrologically processed using USGS NHD. Hydrography data combined from MassGIS DEP Wetlands and USGS NHD. Road data from MassGIS MassDOT roads. Watershed boundary combined from National Elevation Dataset (USGS) and MassGIS drainage sub-basins data.

Adaptation Recommendations by Ecosystem Service Category

Ecosystem services are simply those services such as food and water supply that intact, healthy ecosystems supply to man. Climate change, in conjunction with other anthropogenic stressors, will impact ecosystem service delivery. Table 1 outlines key ecosystem service vulnerabilities in the watershed and Table 2 outlines recommended adaptation actions.

Table 1. Vulnerabilities of Ecosystems and Ecosystem Services in the Beaver Dam Brook Watershed to Climate Change

ECOSYSTEMS AND ECOSYSTEM SERVICES	VULNERABLE TO CLIMATE CHANGE?	RATIONALE
PROVISIONING SERVICES		
Food: Cranberry Production	Yes	Increasing risk of heat stress, freeze damage and drought
Fresh Water: Drinking Water Supply	Perhaps	Possible reduction in aquifer replenishment in summer months, possible salt water intrusion into aquifer
REGULATING SERVICES		
Local Climate and Air Quality Regulation	Perhaps	Local air quality could be degraded by a mix of regional factors including increasing impervious surface and increasing automobile traffic, exacerbated by rising temperatures
Carbon Sequestration and Storage	Perhaps	Salt water intrusion and increasing tidal influence on the Brook may lessen carbon storage capabilities of peat soils
Moderation of Extreme Events: Flood Control	Perhaps	More severe, frequent, and prolonged precipitation events could overwhelm ability of watershed to mitigate flood events. Sea level rise will increase storm surge flooding in the lower portion of the Brook.
Wastewater Treatment	Yes	Rising water tables will impact septic systems in low lying areas
ECOSYSTEMS AND SUPPORTING SERVICES		
Ecosystems and Habitat Provision: Cold Water Fish Habitat	Yes	Changes in ambient temperatures and drought regimes could eliminate or degrade this habitat
Maintenance of Genetic Diversity	Perhaps	Invasive species could diminish biodiversity
CULTURAL SERVICES		
Recreation, Mental and Physical Health: Fishing	Perhaps	Loss of cold water-dependent quarry species could reduce recreational angling value of site
Tourism	Yes	Summer cottage rental market at White Horse Beach will be impacted by sea level rise

Table 2. Adaptation of Ecosystems and Ecosystem Services in the Beaver Dam Brook Watershed to Climate Change

ECOSYSTEMS AND ECOSYSTEM SERVICES	ADAPTATION AND MANAGEMENT MEASURES	RATIONALE
PROVISIONING SERVICES		
Food: Cranberry Production	Modify management practices and cultivars used	Limit vulnerability to changing temperature and precipitation
Fresh Water: Municipal Drinking Water Supply	Avoid excessive drawdown of aquifer	Minimize likelihood of salt water intrusion into aquifer
REGULATING SERVICES		
Local Climate and Air Quality Regulation	Reestablishment of riparian forest	Minimize local heat island effects and improve air quality
Carbon Sequestration and Storage	Reestablishment of wetlands hydrology and forest on site	Maximize carbon storage of peat soils and sequester carbon in new forest
Moderation of Extreme Events: Flood Control	Environmental restoration effort	Replacement of bogs with wetlands and riparian forest will limit severity of and damage associated with flooding.
Wastewater Treatment	Replacement of vulnerable septic systems	Rising water tables will impact septic systems in low lying areas
ECOSYSTEMS AND SUPPORTING SERVICES		
Ecosystems and Habitat Provision: Cold Water Fish Habitat	Establishment of riparian forest adjacent to new stream channel	Provide shade and minimize solar heating of water
Maintenance of Genetic Diversity	Monitor and manage invasive species	Limit establishment of invasive monocultures
CULTURAL SERVICES		
Recreation, Mental and Physical Health: Fishing	Establishment of riparian forest adjacent to new stream channel	Extend viability of cold water fish habitat
Tourism	Multiple measures including upgrading sewage treatment system, elevating structures, establishment of rolling easements	Maintain viability of White Horse Beach neighborhood and public beach access
Aesthetic Appreciation and Inspiration for Culture, Art and Design	Establishment of Living Observatory	Enhanced public access, education and appreciation of a changing landscape

Provisioning Services

FOOD: CRANBERRY PRODUCTION:

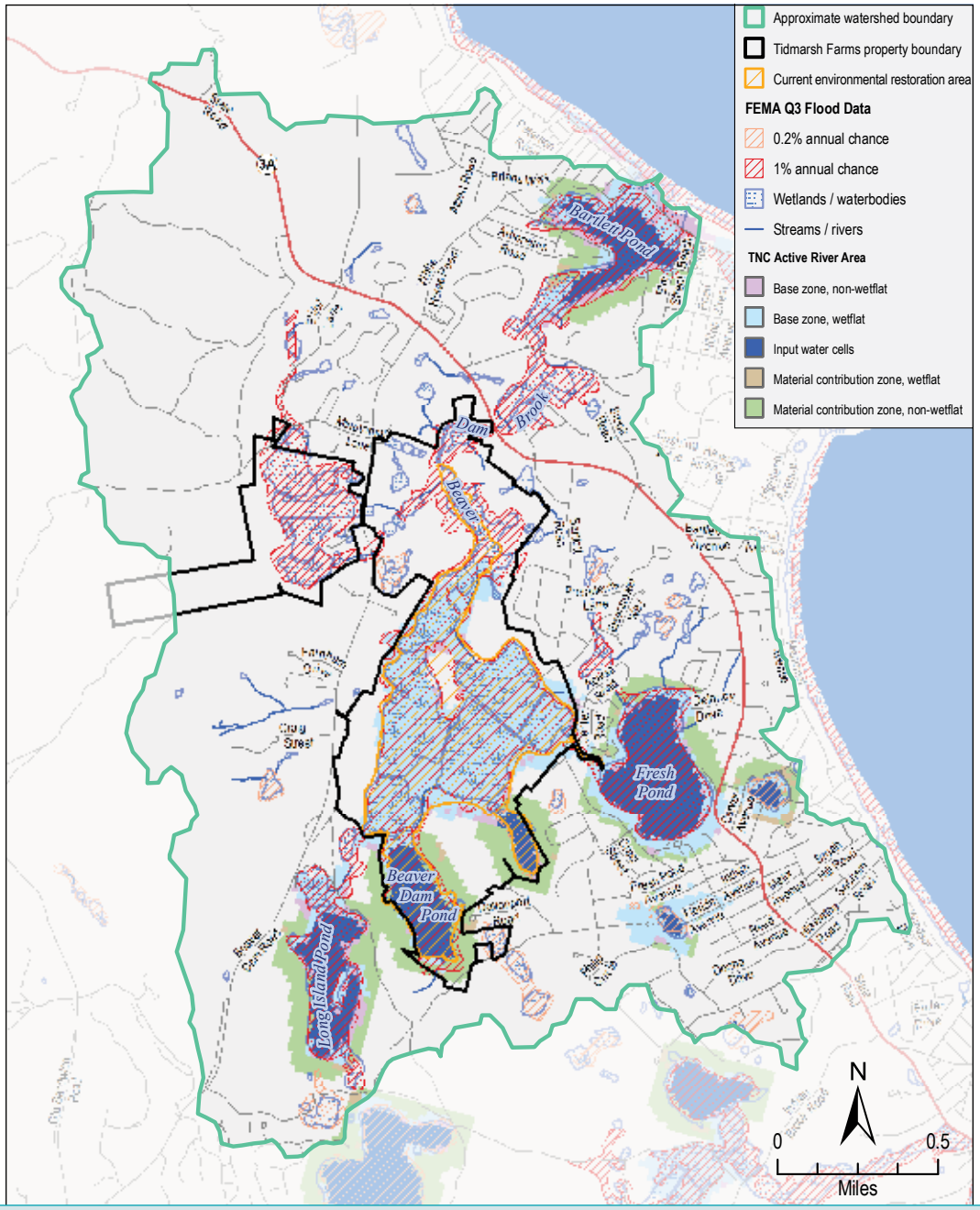
- Climate Change Vulnerabilities: While the large cranberry complex to the East of Beaver Dam Road will be transformed by the environmental restoration effort, the bog complex to the west of Beaver Dam Road will remain in production. Cranberry production is viable in climates that are significantly warmer than Massachusetts, so a warming climate will not cause the termination of cranberry production at Tidmarsh Farms. However, growers in Massachusetts will be challenged by a combination of warmer temperatures, increased risk of frost damage, changing precipitation patterns, growing pest and disease pressure, and increasingly problematic extreme weather events.[4]

- **Recommended Adaptation Actions:** Climate change will create a number of management challenges for cranberry producers in Massachusetts. The following are the primary challenges and the associated adaptive response.
  - **Chilling Requirements:** Cranberry chilling requirements will likely be met in Massachusetts during the next 50 years even under higher emission scenarios. Beyond 50 years out the A1FI emission scenario may result in insufficient chilling hours. Investigation of cranberry verities that have been developed to thrive in warmer climates is recommended.
  - **Frost damage:** Currently in Massachusetts the chilling requirements are typically met by February. However, if a late winter/early spring warm period occurs, plants can come out of dormancy ahead of schedule, and frost damage can occur. In this situation, growers try to prevent crop damage by irrigating the bogs to form a layer of protective ice on the plants. This approach will still be viable under climate change, but costs associated with starting this process earlier in the spring season will place an additional burden on growers. Automated irrigation systems have been used successfully to both lower labor costs and save water while providing effective frost protection.
  - **Scald:** Cranberry Scald is a heat stress injury that occurs when plants can't transpire quickly enough to keep the fruit cool. Scald can damage the fruit on its own and can make it more vulnerable to rot (fungus) damage. Preliminary studies by the UMASS Cranberry Research Station indicate that the hot, dry summer conditions that are projected to occur more frequently under climate change are a factor in scald damage. The primary adaptive response is to insure that soil moisture is sufficient prior to the onset of heat stress conditions. An additional finding is that scald damage is more prevalent in bogs with relatively young plants due to sparse vegetation that provides less shading than more mature plants.
  - **Flooding:** An increasing percentage of precipitation is projected to come in heavy downpours under climate change. The area has already seen a 67% increase in very heavy precipitation events in the last 50 years. In addition total annual precipitation is projected to increase. In combination these factors will create changing water management requirements to avoid damage to crops.
  - **Rot:** Increasing stress associated with both scald and flooding will likely make cranberries more vulnerable to fungal damage of cranberries. Increased herbicide use may be required to compensate.
  - **Changing insect pressure:** Warming temperatures will increase the northern extent of some insects that are not currently a major threat in Massachusetts. For example the Gypsy Moth is currently a problem for cranberry producers in New Jersey. New England winters have historically been cold enough to kill overwintering eggs.[8] As average winter temperatures increase, Gypsy Moths may become more of a problem for Massachusetts producers. Increasing total precipitation could suppress those insects such as cranberry fruitworm that are typically controlled through flooding of bogs.[9] Monitoring for changing insect pressure and incorporation of management techniques from those areas that currently have those pests is recommended.
  - **Productivity:** Higher average summer temperatures are associated with a decrease in cranberry productivity in Massachusetts. Optimal productivity occurs when temperatures remain between 60 to 86 degrees F in July and August. As previously mentioned Massachusetts growers will eventually need to investigate verities of cranberries developed for warmer climates such as New Jersey.

FRESH WATER: DRINKING WATER SUPPLY

- **Climate Change Vulnerabilities:** Climate change has the potential to impact both the quantity and quality of drinking water in southeastern Massachusetts. The contrasting effects of wetter winters and drier, hotter summers could lead to greater seasonal fluctuation of groundwater availability. In addition, the projected increase in the percentage of precipitation received in heavy downpours could lead to a decrease in groundwater recharge and an associated increase in surface water runoff. Sea level rise, in conjunction with other factors, may eventually cause saltwater intrusion into the Plymouth Carver aquifer.[5] The vulnerability of the aquifer to salt water intrusion will be influenced by several variables including the rate of sea level rise and future groundwater levels as determined by a combination of precipitation rates, evapotranspiration rates and groundwater consumption rates. The Wannos Pond well, part of the Plymouth water supply system, is located adjacent to the Tidmarsh Farms property. Saltwater could intrude locally if the Wannos Pond well removes enough groundwater to cause the freshwater/saltwater interface to move inland. Regional impacts could also occur if significant drawdown occurs across the entire Plymouth Carver aquifer.[6] Additional modeling work is needed to determine the likelihood of impacts of saltwater intrusion on the drinking water supply.

- **Recommended Adaptation Actions:** Several steps are needed to better characterize the likely impacts of climate change on the Plymouth Carver Aquifer. In 2009 the USGS studied the aquifer and modeled the impacts of future groundwater consumption scenarios.[7] Updating that study to include sea level rise, projected changing precipitation patterns and the projected warming climate would provide needed insight into future water availability under climate change. The primary adaptation action to minimize salt water intrusion, should this prove necessary, is to avoid excessive drawdown of the Plymouth Carver aquifer. Related efforts to protect groundwater quantity and quality include low impact development techniques to minimize impervious surface and maximize storm water infiltration. In addition, managing future groundwater demand through water efficiency measures is recommended. In those areas of the watershed where rising water tables will diminish the treatment capacity of septic tanks it will be necessary to explore alternatives such as the installation of a public sewer system. Water quality in the Beaver Dam Brook watershed should improve in response to both the cessation of the pesticide use associated with cranberry production and the reestablishment of wetlands and riparian forest associated with the environmental restoration effort at Tidmarsh Farms. Due to fact that the site has been in cranberry production for approximately 90 years pesticides have accumulated in the soils of the bogs. This issue has been studied by the appropriate Massachusetts state agencies and no remediation will be required in conjunction with the environmental restoration project.



Map 4: Riparian Resources and Flood Zones

Map showing areas vulnerable to flooding and important for riverine processes in and around the Tidmarsh Farm site. FEMA Q3 Flood data acquired from MassGIS, not showing areas of undesignated flood hazard. The Nature Conservancy (TNC) Active River Area (ARA) data (Olivero, 2009) shows areas within which important physical and ecological processes of the river or stream occur. Road data from MassGIS. Watershed boundary combined from National Elevation Dataset (USGS) and MassGIS drainage sub-basins data.

MAP 4

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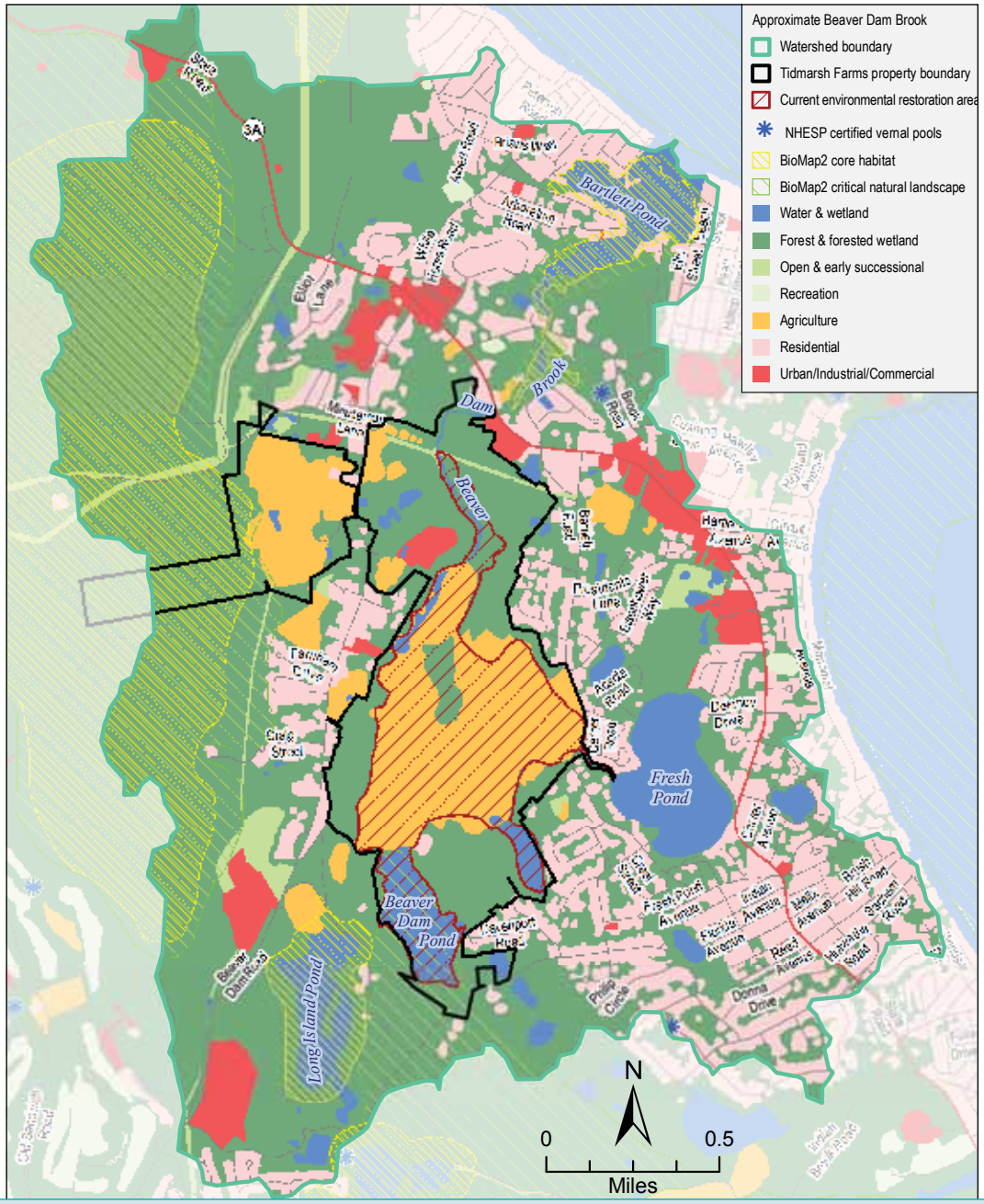

MAP 5

Map 5. Land Use Map

Map showing land use (2005) and important habitat in and around the Tidmarsh Farms site. BioMap 2 data produced by the Massachusetts Natural Heritage and Endangered Species Program (NHESP) and The Nature Conservancy (TNC). Core Habitat is critical to the long-term persistance of rare, threatened, and endangered species, diverse natural communities, and intact ecosystems. Critical Natural Landcape complements core habitat to ensure its long-term integrity. Land use (2005) and road data from MassGIS. Watershed boundary combined from National Elevation Dataset (USGS) and MassGIS drainage sub-basins data.

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Regulating Services

LOCAL CLIMATE AND AIR QUALITY REGULATION

- Climate Change Vulnerabilities: Climate change has the potential to degrade local climate and air quality of the watershed and the surrounding region. An increased incidence of extreme heat, drought, and stagnant weather patterns are projected to degrade air quality in New England.[8] Higher summer temperatures will exacerbate ground-level ozone production in areas with an ample supply of volatile organic compounds (VOC). VOCs are emitted from a variety of manmade and natural sources. Anthropogenic sources include automobiles and fossil fuels used for heating and energy production. Primary natural sources in the Northeastern U.S. include oak, spruce, maple, hickory, pine, fir and cottonwood trees.[9] The most significant climate change related impacts to air quality and local climate will occur in urban areas with preexisting air quality problems, high local production of VOCs and a high percentage of impervious surface. The impacts in suburban areas such as the Beaver Dam Brook watershed will be dependent on the prevalence of natural sources of VOCs in conjunction with anthropogenic sources.
- Recommended Adaptation Actions: Limiting local heat island effects and local production of man-made VOCs are among the most effective approaches to minimizing the adverse impacts of climate change on local air quality and climate. For the Beaver Dam Brook watershed and the surrounding Town of Plymouth, support of transit oriented development patterns and provision of multimodal transportation opportunities such as pedestrian amenities and bike paths will aid in minimizing local anthropogenic production of VOCs. The environmental restoration project at Tidmarsh Farms should provide local climate regulation benefits with the reestablished riparian forest and wetlands cooling both air and water on the site. If residential development takes place on Tidmarsh Farms the utilization of low impact development techniques to minimize new impervious surface is recommended to limit heat island effects.

CARBON SEQUESTRATION AND STORAGE

- Climate Change Vulnerabilities: Climate change will likely have countervailing impacts on greenhouse gas sequestration and storage at the Tidmarsh Farms site. Warming temperatures will enhance forest growth rates and associated carbon sequestration. It also has the potential to increase methane production from wetlands located on the site. The eventual conversion of the riparian wetlands on the site from non-tidal to tidal is difficult to assess in terms of changes in carbon sequestration and storage. If the transition is gradual the sequestration and storage capacity of the site will likely remain near constant as the transition from non-tidal to tidal occurs.[10] A more rapid transition driven by storm surge flooding could result in a period of diminished sequestration and storage capacity.[11]
- Recommended Adaptation Actions: The planned environmental restoration project should increase the carbon sequestration and storage capacity of the site. The reestablishment of wetlands and riparian forest will both contribute to peat soil genesis and to a significant increase in carbon sequestration in above ground biomass. The return to wetlands hydrology on the site will play an important role in preventing further loss of sequestered carbon from the peat soils on the site.

MODERATION OF EXTREME EVENTS: FLOOD CONTROL

- Climate Change Vulnerabilities: Tidmarsh Farms and the surrounding Beaver Dam Brook watershed are vulnerable to both enhanced fresh water flooding associated with changing precipitation patterns and increasingly severe storm surge flooding associated with sea level rise (Map 4). The low-lying areas of the White Horse Beach neighborhood surrounding Bartlett Pond will be most severely impacted by a combination of a rising water table and higher sea level.
- Recommended Adaptation Actions for Tidmarsh Farms: The reestablishment of a sinuous stream channel, wetlands and riparian forest associated with the environmental restoration effort will contribute to managing an enhanced freshwater flood threat associated with the combined impacts of projected increase in heavy precipitation events and total precipitation, and a rising water table. Removal of the dam at Beaver Dam Pond will eliminate the possibility of flooding associated with failure of the aging structure. The reestablishment of wetlands vegetation should result in an increase in the capacity of the site to buffer heavy precipitation events. If new residential development takes place on-site including low impact development features such as clustering of the houses, minimizing impervious surface, maximizing stormwater infiltration and avoiding development in flood prone areas will all contribute to moderation of the impacts of extreme precipitation events.
- Recommended Adaptation Actions for White Horse Beach: The portions of the White Horse Beach neighborhood at lower elevation will be extensively impacted by sea level rise. The management decisions taken by the Town of Plymouth and the State of Massachusetts will have a significant bearing on the long-term character of the lower portion of the watershed. Over the next 30 years efforts to elevate and flood proof existing structures are recommended. Beach nourishment and living shoreline methods could also be implemented to both extend the recreational use of the beach and provide flood protection. As sea level continues to rise the frequency and severity of storm surge flooding will increase. Eventually it will be necessary to consider abandonment of low elevation structures and establishment of a riparian buffer sufficient to accommodate the transition of the lower portion of the Brook to a tidal system. The establishment of rolling easements could be used to facilitate this transition.

WASTEWATER TREATMENT

- Climate Change Vulnerabilities: The combination of rising sea levels and associated rising water tables will place new limitations on use of septic tanks to treat wastewater. The White Horse Beach neighborhood in particular will be impacted. On Tidmarsh Farms the rising water table will decrease the viability of new septic tanks in low lying areas.
- Recommended Adaptation Actions for Tidmarsh Farms: Any new wastewater treatment system or individual septic tanks should take the rising water table into account. One of the possibilities explored in the Horsely Witten study of Tidmarsh Farms is the establishment of a sewage treatment facility with sufficient capacity to serve both new on-site development and to provide capacity to take less than optimal septic systems from the surrounding area off-line. The need for shared water treatment facilities will become greater as the water table rises.
- Recommended Adaptation Actions for White Horse Beach: An alternative to the existing septic systems in the low lying areas of White Horse Beach is needed. Establishment of a city sewer system to service this area should be investigated.

Ecosystems and Supporting Services

ECOSYSTEM AND HABITAT PROVISION: GENERAL

- **Climate Change Vulnerabilities:** Climate change will likely cause a substantial transition in the type and structure of the ecosystems currently present both at Tidmarsh Farms and in the surrounding region. Sea level rise in particular has the potential to change the Brook from a freshwater to saltwater system, causing a major shift in both in-stream conditions and the surrounding riparian buffer. In addition, the warming climate and changing precipitation patterns will cause realignment in the spatial and temporal structure of natural systems in the region.
- **Recommended Adaptation Actions:** The proposed environmental restoration project at Tidmarsh Farms will have significant value in addressing the stressors associated with climate change. Given the uncertainties associated with timing and extent of climate change specific management measures are difficult to identify. General guidance on best management practices for managing natural systems for climate change include:
  - Maximize the health of ecosystems by minimizing non-climate change stressors such as invasive species, insect infestations, and water and air pollution,
  - Shift from managing for the existing mix of species on the site to managing for ecosystem function and biodiversity, and
  - Maintain and restore a network of open space (Map 5) to allow for species migration and range shifts.[12]

The restoration project will address all these best management practices in a general sense and can be fine tuned for maximum adaptation benefit. The replacement of the cranberry bogs with wetlands and riparian forest will improve water quality over time and enhance resiliency to invasive species and insect infestations. The reconnection of the headwaters of Beaver Dam Brook with the downstream section through the removal of the dam at Beaver Dam Pond will mark an important shift to managing for ecosystem function and biodiversity. Finally the restoration effort will contribute to the enhancement of a green infrastructure network that connects the downstream section of the Brook and Bartlett Pond with the Critical Natural Landscape block directly to the south of the Tidmarsh Farms property.[13]

The northern portion of the property contains a forested red maple swamp and a section of the original stream corridor. A survey of the area by Horsley Witten found a dense tree canopy dominated by red maple with occasional tupelo and eastern white pine. A mix of shrubs including sweet pepperbush, highbush blueberry and arrowwood occupy the understory. Birch and willow overhang the stream banks in many locations.[14] The intact stream corridor and the red maple swamp provide insight into the type of system that will likely result from the restoration effort. The adjacent Eel River restoration included the planting of white cedar in an effort to reestablish a white cedar swamp in the watershed. Both the red maple and white cedar are found substantially south of Massachusetts and should be robust in the face of rising temperatures. Sea level rise may limit the long-term viability of these ecosystem types on the Tidmarsh Farms site if extensive salt water intrusion into the groundwater system occurs.

ECOSYSTEM AND HABITAT PROVISION: COLD WATER FISH HABITAT

- **Climate Change Vulnerabilities:** Beaver Dam Brook provides valuable cold water fish habitat due to the fact that it is a groundwater dominated system. Local fishermen identify the Brook as a good location for catching smallmouth bass, brook trout and smelt.[15] The state of Massachusetts stocks the Brook with a combination of brook trout, brown trout and rainbow trout. Rising air temperatures associated with climate change will threaten the viability of cold water fish habitat, particularly in stream segments that have little shade and are therefore subject to solar heating.
- **Recommended Adaptation Actions:** Design features that limit thermal pollution of Beaver Dam Brook should be considered in the design of the environmental restoration project. Maximizing shading of the stream through establishment of riparian forest and minimizing features that allow surface water to heat in the sun are recommended. However, the vulnerability of the system to sea level rise will limit the long-term viability of the Brook as freshwater fish habitat.

MAINTENANCE OF GENETIC DIVERSITY:

- **Climate Change Vulnerabilities:** Climate change will expand the range and enhance the competitiveness of several invasive species. Glossy buckthorn, Japanese barberry, and phragmites are already present in New England and invasive plants such as kudzu, Japanese stiltgrass and mile-a-minute vine are moving north.
- **Recommended Adaptation Actions:** The owners of Tidmarsh Farms are currently inventorying the site for invasive species. Continued monitoring and management efforts are recommended.

Cultural Services

RECREATION, MENTAL AND PHYSICAL HEALTH:

- **Climate Change Vulnerabilities:** Sea level rise could eventually cause the loss of recreational use of White Horse Beach.
- **Recommended Adaptation Actions:** The adaptation actions described under the flood control and wastewater treatment sections are applicable here.

TOURISM:

- **Climate Change Vulnerabilities:** The White Horse Beach neighborhood supports a significant summer tourist population through weekly cottage rentals. Sea level rise threatens both the beach and the dwellings at lower elevation.
- **Recommended Adaptation Actions:** The adaptation actions described under the flood control and wastewater treatment sections are applicable here.

Economic Valuation of Ecosystem Services

Assessment of the economic value of ecosystem services is challenging due to the fact that many services are not directly traded in the marketplace. Approaches such as contingent valuation, avoided cost and replacement cost evaluation are used to provide estimates of market value. A recent evaluation for the State of Maine utilized several non-market approaches to estimate ecosystem service values based on land cover categories. The library of value estimates assembled for that study is applicable in Massachusetts due to the similarity in climatic, ecological and economic conditions. The land cover categories include information on the proximity of the beneficiaries to the services provided. A given land cover category in close proximity to an urban or suburban area is valued higher than a similar land cover in a rural setting. The Beaver Dam Brook watershed is split between urbanized and non-urbanized areas based on the definitions used in the 2010 U.S. Census. The three land cover categories that most closely fit the portion of the watershed that is within the urbanized area are:

- Forest: suburban: Estimated Value of $3,193 per acre per year
- Open water: urban/suburban river: Estimated value of $28,715 per acre per year
- Wetland: urban/suburban (fresh or salt): Estimated value of $33,122 per acre per year

The three categories that most closely fit the portion of the watershed that is outside the urbanized area are:

- Forest: adjacent to stream: Estimated value of $1,414 per acre per year
- Open water: river: Estimated value of $1,182 per acre per year
- Wetland: non-urban, non-costal: Estimated value of $1,846 per acre per year

The applicability of the valuation numbers will to some extent depend on how much development that takes place adjacent to the restoration site and the extent to which public access is allowed.

Other Issues

- Education: The restoration effort will include the establishment of the Living Observatory, an environmental monitoring program coupled with a visitor's center. This combination will provide an opportunity to track climate change impacts on the site and the response of the restored ecosystems to those changes.
- Climate Change Mitigation: Three specific opportunities exist to include mitigation of climate change in the restoration and development process at Tidmarsh Farms. As previously mentioned the reestablishment of riparian forest on the site will provide carbon sequestration benefits. The landowners have expressed an interest in alternative energy development. Linking solar or wind energy development to new residential development could provide an opportunity for a carbon neutral (net-zero) project. Finally the Living Observatory provides an opportunity to include mitigation in the educational message.

End Notes

1 *Preliminary Feasibility Assessment, Wetlands Restoration, Tidmarsh Farm, Plymouth, MA* (Horsley Witten Group, Inc., August 2010).

2 John P Masterson et al., *Hydrogeology and simulation of groundwater flow in the Plymouth-Carver-Kingston-/Duxbury aquifer system, southeastern Massachusetts*, 2009, http://purl.access.gpo.gov/GPO/LPS122562.

3 *Preliminary Feasibility Assessment, Wetlands Restoration, Tidmarsh Farm, Plymouth, MA*.

4 *21st Century Challenges to Cranberry Production in Massachusetts*, Horticulture in a Changing Climate., 2010, http://vimeo.com/17001202.

5 John P Masterson et al., *Hydrogeology and ground-water resources of the coastal aquifers of southeastern Massachusetts*, 2009, http://purl.fdlp.gov/GPO/gpo3388.

6 Ibid.

7 Masterson et al., *Hydrogeology and simulation of groundwater flow in the Plymouth-Carver-Kingston-Duxbury aquifer system, southeastern Massachusetts*.

8 U.S. Global Change Research Program, *Global climate change impacts in the United States: a state of knowledge report* (Cambridge [England]; New York: Cambridge University Press, 2009).

9 SM Bernard et al., "The potential impacts of climate variability and change on air pollution-related health effects in the United States.," *Environmental health perspectives* 109 (2001): 199–209.

10 Ken W Krauss and Julie L Whitbeck, "Soil Greenhouse Gas Fluxes during Wetland Forest Retreat along the Lower Savannah River, Georgia (USA)," *Wetlands* 32, no. 1 (2012): 73–81.

11 RD DeLaune and JR White, "Will coastal wetlands continue to sequester carbon in response to an increase in global sea level?: a case study of the rapidly subsiding Mississippi river deltaic plain," *Climatic Change* 110, no. 1–2 (2012): 1–2.

12 Cynthia Rosenzweig and New York State Energy Research and Development Authority, "Responding to climate change in New York State: The ClimAID integrated assessment for effective climate change adaptation in New York State: final report," 2011, http://onlinelibrary.wiley.com/doi/10.1111/nyas.2011.1244.issue-1/issuetoc.

13 James DeNormandie, Andrew Finton, and Henry Woolsey, *Biomap 2: Conserving the Biodiversity of Massachusetts in a Changing World* (Massachusetts Department of Fish and Game, 2010).

14 *Preliminary Feasibility Assessment, Wetlands Restoration, Tidmarsh Farm, Plymouth, MA*.

15 "Beaver Dam Brook Fishing Near Plymouth, Massachusetts," *Hook and Bullet.com*, June 27, 2012, http://www.hookandbullet.com/fishing-beaver-dam-brook-plymouth-ma/.

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