8. Attachments

8.A Project Management Form and Programmatic Agreement

(See following pages)

APPENDIX A
MASSACHUSETTS HISTORICAL COMMISSION
220 MORRISSEY BOULEVARD
BOSTON, MASS. 02125
617-727-8470, FAX: 617-727-5128

PROJECT NOTIFICATION FORM

Project Name: Herring River Tidal Restoration Project

Location / Address: Refer to USGS Locus Map

City / Town: Wellfleet/Truro

Project Proponent: National Park Service and Towns of Wellfleet and Truro

Name: William Burke, Seashore Historian, Cape Cod National Seashore

Address: 99 Marconi Site Road City/Town/Zip/Telephone: Wellfleet, MA 02667

Agency license or funding for the project (list all licenses, permits, approvals, grants or other entitlements being sought from state and federal agencies).

Agency Name	Type of License or funding (specify)
Massachusetts Environmental Policy Act (MEPA)	Environmental Impact Report
National Environmental Policy Act (NEPA)	Environmental Impact Study
Cape Cod Commission	Developments of Regional Impact
Wetlands Protection Act	Notice of Intent/Order of Conditions
Massachusetts Endangered Species Act Review (MESA)	MESA Review
Chapter 91 Waterways	Chapter 91 License(s)
401 Water Quality Certification	Certificate
ACOE Section 404 Application	Permit
CZM Coastal Consistency	Consistency Review

Project Description (narrative): The original 1,100 acre Herring River estuary has been severely impacted by long-standing tidal restrictions (See USGS Locus Map). The project seeks to restore the estuary and natural functions to the maximum extent practicable. Measures proposed to change current tidal controls will be developed, during during which public input will be solicited as part of both the Massachusetts Environmental Policy Act (MEPA) and National Environmental Policy Act (NEPA) environmental review processes.

Does the project include demolition? If so, specify nature of demolition and describe the building(s) which are proposed for demolition:
The development of the preferred alternative is dependent upon more detailed hydrodynamic modeling, further planning, and additional public input. Existing tidal restrictions such as the Chequesset Neck Road dike structure and crossings along High Toss, Bound Brook Island, Pole Dike, and Old Country Roads may be reconstructed. Low lying properties and roadways potentially affected by restoration activities have been identified.

Does the project include rehabilitation of any existing buildings? If so, specify nature of rehabilitation and describe the building(s) which are proposed for rehabilitation. Does the project include new construction? If so, describe (attach plans and elevations if necessary). To be determined in the future.

APPENDIX A (continued)

To the best of your knowledge, are any historic or archaeological properties known to exist within the project's area of potential impact? If so, specify. Historic archaeological resources are likely contained within the project area. It is anticipated that restoration activities will require further coordination with the Massachusetts Historic Commission (MHC).

What is the total acreage of the project area? Roughly 1100 Acres. See Attached Vegetation Figure.

Woodland ______________	acres	Productive Resources:	
Wetland________________	acres	Agriculture _________________	acres
Floodplain______________	acres	Forestry ___________________	acres
Open space______________	acres	Mining/Extraction ___________	acres
Developed ______________	acres	Total Project Acreage_________	acres

What is the acreage of the proposed new construction? _________________ acres

What is the present land use of the project area? Primarily open space.

Please attach a copy of the section of the USGS quadrangle map which clearly marks the project location.

This Project Notification Form has been submitted to the MHC in compliance with 950 CMR 71.00.

Name: William Burke, Seashore Historian

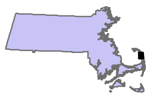
Address: 99 Marconi Site Road

City/Town/Zip: Wellfleet, MA 02667

Telephone: (508) 255 3421 x 16

REGULATORY AUTHORITY

950 CMR 71.00: M.G.L. c. 9, §§ 26-27C as amended by St. 1988, c. 254.



USGS Topographic Quadrangle
Wellfleet, MA

N

0 1,250 2,500 5,000 Feet

Site Locus

Herring River Tidal Restoration Project
Conceptual Restoration Plan
Wellfleet and Truro, MA

SCALE	DATE	PROJECT NO.
1:30000	May 2007	04479-003-300

ENSR | AECOM

Figure Number

1

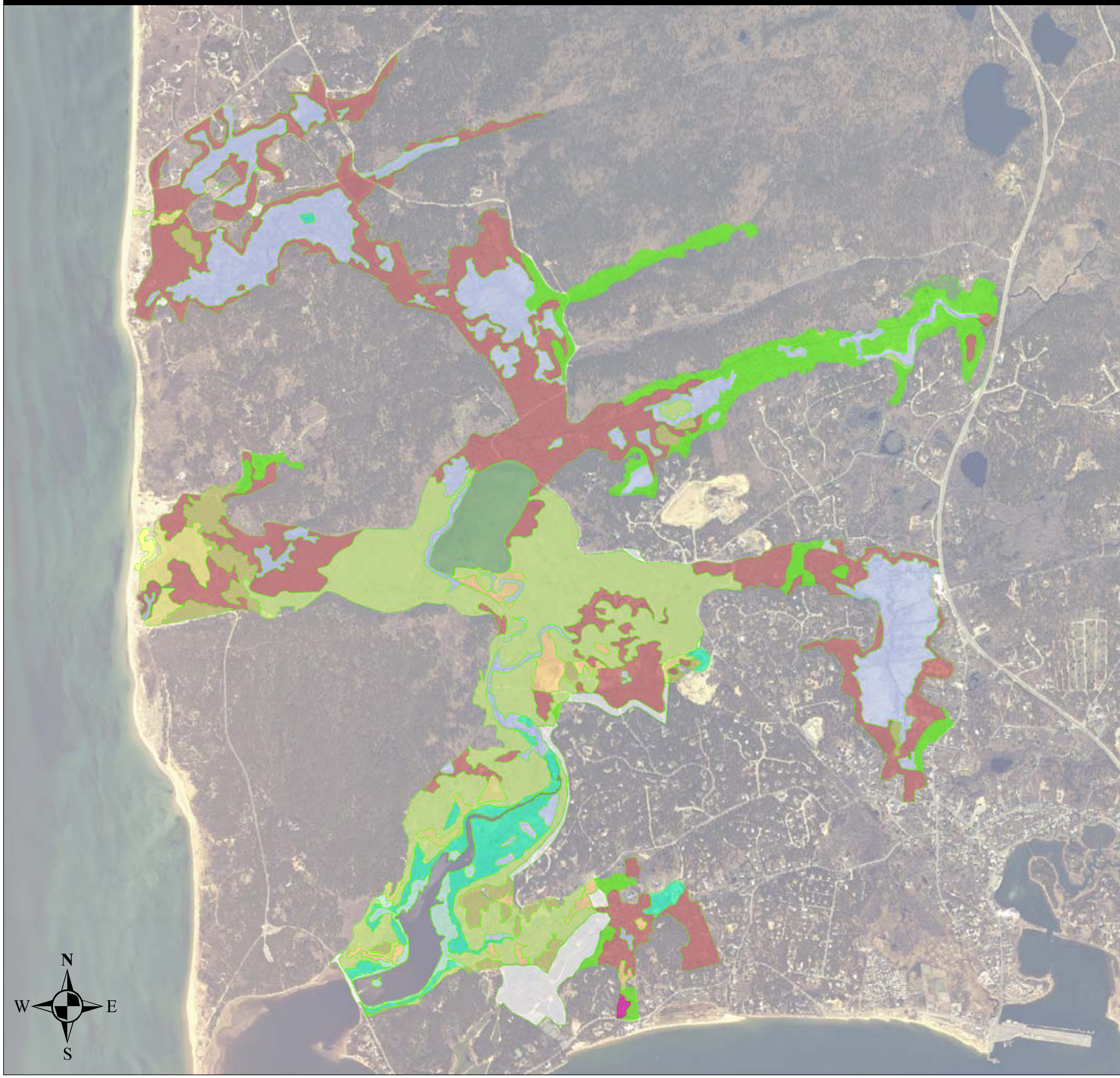
J:\Water\ProjectFiles\P40\4479_CZM\4479003\GIS_May2007\Projects\Fig_Site Locus.mxd

Herring River Vegetation

Updated from 2000 aerial photos with 2007 field observations .

Figure 11

Cape Cod National Seashore
National Park Service
U.S. Department of the Interior



Legend

- FRESHWATER MARSH
- BRACKISH MARSH
- SALT MARSH
- DUNE GRASSLAND
- HEATHLAND GRASSLAND
- OLD FIELD HERBACEOUS
- WET SHRUB
- DRY SHRUBLAND
- PINE WOODLAND
- DRY DECIDUOUS WOODLAND
- DRY DECIDUOUS FOREST
- WET DECIDUOUS FOREST
- DEVELOPED

TYPE	TYPICAL SPECIES
FRESHWATER MARSH	Typha angustifolia, Scirpus cyperinus, Calamagrostis canadensis, Juncus spp., Sparganium americanum.
BRACKISH MARSH	Phragmites australis, Scirpus pungens.
SALT MARSH	Spartina alterniflora, Spartina patens,
DUNE GRASSLAND	Ammophila breviligulata, Deschampsia flexuosa.
HEATHLAND	Arctostaphylos uva-ursi, Morella pensylvanica, Vaccinium angustifolium, Hudsonia ericoides, Hudsonia tomentosa, Corema conradii.
OLD FIELD HERBACEOUS	Schizachyrium scoparium, Deschampsia flexuosa, Holcus lanatus, Festuca rubra.
WET SHRUBLAND	Vaccinium corymbosum, Clethra alnifolia, Rhododendrum viscosum, Decodon verticillatus, Cephalanthus occidentalis, Alnus spp., Chamaedaphne calyculata.
DRY SHRUBLAND	Morella pensylvanica, Quercus velutina, Amelanchier spp.
PINE WOODLAND	Pinus rigida, Gaylusaccia baccatta, Deschampsia flexuosa, Vaccinium angustifolium.
DRY DECID. WOODLAND	Prunus serotina, Amelanchier spp., Viburnum spp.
DRY DECIDUOUS FOREST	Quercus velutina, Quercus alba, Fagus grandifolia, Robinia pseudoacacia.
WET DECIDUOUS FOREST	Acer rubrum, Rhododendron viscosum, Clethra alnifolia.

HOW THIS MAP WAS MADE:

Seemingly “natural” vegetation communities often contain unexpected assemblages of species because of habitat alterations caused by human intervention. For example, Herring River's diked and drained floodplains have dry woodland communities where wet shrubs and marshes would be expected to occur. This general vegetation map of Herring River shows these human-influenced plant communities which are very different from the floodplain types that would result from restoration of tidal influences.

To make this map, color infra red aerial photos were interpreted and assigned vegetation types from a broad classification system of New England plant communities (Sneddon, Leslie, Vegetation of Cape Cod National Seashore Natureserve, 2004). New vegetation classes were then added based on extensive field observations to reflect actual vegetation within the tidal-deprived floodplain. In particular, the apparent wet woodland types dominated by red maple interpreted from aerial photography are actually dry woodlands dominated by black cherry and shadbush.

0 155 310 620 930 1,240 Meters

File: HRveg2000_nvc07 Date:082007

Programmatic Agreement
Among
The Massachusetts State Historic Preservation Officer,
The Mashpee Wampanoag Tribe,
The Wampanoag Tribe of Gay Head-Aquinnah,
And
Cape Cod National Seashore
Regarding
The Identification and Resolution of Effects Upon Archeological Resources
Resulting From the Herring River Tidal Restoration Project

WHEREAS, the National Park Service (NPS) in 2008 entered into a Programmatic Agreement with the Advisory Council on Historic Preservation (ACHP) and the National Conference of State Historic Preservation Officers; and

WHEREAS, Cape Cod National Seashore (CACO), a unit of the National Park Service as a part of the U. S. Department of the Interior, is a party to that Programmatic Agreement, and has stewardship responsibilities for the natural and cultural resources within the lands comprising the CACO; and

WHEREAS, CACO, under terms of a Memorandum of Understanding, joined the towns of Truro and Wellfleet, the U.S. Fish and Wildlife Service, the Natural Resources Conservation Service, the National Atmospheric and Oceanic Administration, and the Massachusetts Division of Ecological Restoration to form the Herring River Restoration Committee (HRRC); and

WHEREAS, CACO, as a partner in the HRRC, is planning to restore tidal exchange to the Herring River estuary (the Herring River Tidal Restoration Project, hereafter referred to as the Undertaking), located in the towns of Wellfleet and Truro, Massachusetts, and containing lands in federal, municipal, and private ownership (36 CFR 800.16(y)); and

WHEREAS, the Memorandum of Understanding that established the HRRC identified NPS as lead federal agency for purposes of National Environmental Policy Act (NEPA) and National Historic Preservation Act (NHPA) compliance, and the towns as co-applicants under the Massachusetts Environmental Policy Act (MEPA) and Cape Cod Commission Development of Regional Impact (DRI) Review Process; and

WHEREAS, CACO and the HRRC desire to simultaneously comply with NEPA and Section 106 of the National Historic Preservation Act (specifically 36 CFR 800) through preparation of an EIS; and

WHEREAS, the office of the Massachusetts State Historic Preservation Officer (SHPO) is reviewing the Undertaking in compliance with applicable federal and state regulations; and

WHEREAS the Advisory Council on Historic Preservation (ACHP) and the Tribal Historic Preservation Officers (THPOs) of the federally recognized Wampanoag Tribe of Gay Head

(Aquinnah) and the federally recognized Mashpee Wampanoag Tribe have been invited to consult on the Undertaking; and

WHEREAS, the Area of Potential Affect (APE) for the Undertaking is the portion of the project area subject to restored tidal exchange in the Herring River estuary as simulated by a hydrodynamic model developed by the Woods Hole Group, Inc. (WHG 2012), and designated upland areas where construction-related impacts may occur, as designated on the attached Appendix A; and

WHEREAS, the potential remains for the presence of unidentified archeological resources that may be eligible for the National Register of Historic Places within the APE for the Undertaking, and this programmatic agreement will guide the identification, evaluation, and protection processes for these resources to comply with the requirements of the combined NEPA/NHPA process and Massachusetts state regulations; and

NOW, THEREFORE, the SHPOs, THPOs and CACO agree that the project shall be implemented in accordance with the following stipulations in order to take into account the effects of the undertaking on the archeological resources of Herring River Basin.

Stipulations

CACO shall ensure that the following measures are carried out:

1. Scaled existing and proposed conditions Project plans for the preferred alternative shall be provided to all signatories for their review and comment as they are developed;

2. An intensive (locational) archaeological survey shall be conducted by an archaeological consultant meeting qualifications standards within the Secretary of the Interior's Standards and Guidelines for Archeology and Historic Preservation. The survey will be performed within all archeologically sensitive portions of the Undertaking's impact area as defined within "Phase IA Archeological Background Research and Sensitivity Assessment, Herring River Tidal Restoration Project, Cape Cod National Seashore, Towns of Wellfleet and Truro, Barnstable County, Massachusetts. (PAL, Inc. 2011). This survey shall meet all requirements for such an investigation stipulated within 950 CMR 70;

   This investigation will be conducted under an Archaeological Resources Protection Act (ARPA; 16 U.S.C. 470aa-mm and its regulations (43 CFR 7) permit and a State Archaeologist's permit for intensive (locational) archaeological testing (950 CMR 70.11);

   Prior to issuance of permits, detailed plans for the intensive (locational) archaeological survey shall be developed in consultation between CACO, the SHPO, THPOs, and as appropriate, other consulting parties. The survey will be implemented in archeologically sensitive areas of proposed ground disturbance prior to any construction activities;

   Archaeological collections recovered from NPS lands within the survey area will be cataloged using NPS systems to Northeast Region standards and shall be curated at CACO; materials recovered from non-federal public or private lands will be cataloged and curated according to 950 CMR 70 guidelines. The NPS and its consultant will make every effort to ultimately keep all federal and non-federal collections together at CACO. It is anticipated that given the limited amount of non-federal lands identified as being archeologically sensitive and subject to project disturbance that the NPS and its consultant will be able to work on a case-by-case basis with state, town and private landowners to achieve this goal.

The completion of intensive survey testing on private property will be contingent on permission of the landowner.

If archaeological resources are identified, CACO shall apply the National Register Criteria of Eligibility (36 CFR 60), and consult with the SHPO and THPOs to develop and implement a plan, that may include archaeological site examination and/or archaeological data recovery, to avoid, minimize, or mitigate any adverse effects to significant and National Register eligible archaeological resources (36 CFR 800.4 -5).

3. CACO shall provide the SHPO and the THPOs with review copies of the technical report(s) of all field and laboratory investigations (including monitoring) in accordance with the State Archaeologist's permit regulations (950 CMR 70) and according to a schedule to be specified in the State Archaeologist's permit application and technical proposal. The final technical report will be prepared by the archeology contractor. To expedite the review process, management summaries and end-of-field letters may be used to communicate the findings for individual phases of the project. No ground disturbing activities will occur in areas subject to archaeological investigations until the results of archeological investigations for that area have been reviewed by the NPS, SHPO and THPOs. Two copies of the final technical report(s), MHC archaeological site inventory forms, and a CD-ROM with the report abstract and bibliographic information will be submitted to the MHC for all technical reports produced as a result of the Project.

4. CACO shall ensure the performance of all archeological activities associated with that portion of the design/build contractor's construction work that relates to the stipulations in this PA and to resource preservation. Personnel from the Northeast Region Archeology Program (NRAP) will provide technical oversight to assist the permitee in compliance with all aspects of the ARPA and State Archeologists permits that will guide this investigation.

5. CACO shall insure compliance with NPS Management Policies and adherence to the policies of the Secretary of the Interior's Standards and Guidelines for Archeology and Historic Preservation and to the NPS's Cultural Resources Management Guidelines, Release 5, 1998. CACO will coordinate all submissions to the SHPO and THPOs for review and concurrence.

6. TRIBAL CONSULTATION

The Tribal Historic Preservation Officers (THPOs) of the Wampanoag Tribe of Gay Head-Aquinnah and the Mashpee Wampanoag Tribe will be consulted on all ground disturbing activities resulting from the restoration of the Herring River estuary and will be given the opportunity to comment on the development of and subsequent results of all archeological investigations and any prehistoric and historic materials uncovered during archeological excavations.

The Mashpee Wampanoag tribe maintains a NAGPRA database that documents known burials that may be present within and around the current APE. This database shall be consulted during the development of the plans for the intensive (locational) survey. Any known burials shall be avoided during the survey. Unknown burials that may be discovered either during the survey or during construction shall be treated in compliance with the terms of Stipulation 8 below.

Ground disturbing activities will be considered to include archeological testing, and THPOs will be notified a minimum of two weeks in advance of the initiation of testing and construction.

7. SHPO REVIEW SPECIFICATIONS:
All submittals to the SHPO shall be in paper format and shall be delivered to the SHPO's office by US mail, by a delivery service, or by hand. Plans and specifications submitted to the SHPO shall measure no larger than 11" x 17" paper format (unless another format is specified in consultation). The SHPO shall review and comment on all adequately documented project submittals within thirty (30) calendar days of receipt.

8. POST-REVIEW DISCOVERIES:

8a. CACO shall notify SHPO, THPOs and other signatories if previously unidentified archaeological resources or if human remains are discovered during archeological and construction activities, and shall cease all work at that location, and protect the location from further impacts. CACO, SHPO, THPOs and signatories shall consult pursuant to 36 CFR 800.13. CACO shall apply the National Register Criteria of Eligibility (36 CFR 60), and consult with the SHPO and federally recognized Indian tribes that may attach religious or cultural significance to the affected property to develop and implement a plan to identify and evaluate, and to avoid, or mitigate any adverse effect to, the historic or archaeological property, or to the human remains found on non-federal property consistent with the Native American Graves Protection and Repatriation Act (NAGPRA, 25 U.S.C. 3001 et seq and implementing regulations at 43 CFR 10), and the Massachusetts Unmarked Burial Law (Massachusetts General Laws, Chapter 38, § 6; Chapter 9, §§ 26A and 27C; and, Chapter 7, § 38A; all as amended) and in a manner consistent with the ACHP "Policy Statement Regarding Treatment of Burial Sites, Human Remains and Funerary Objects" (February 23, 2007; http://www.achp.gov/docs/hrpolicy0207.pdf).

8b. Any non-Native American human remains found on non-federal property shall be treated in accordance with the Massachusetts Historical Commission "Policy and Guidelines for Non-Native Human Remains Which Are Over 100 Years Old or Older," and in a manner consistent with the ACHP "Policy Statement Regarding Treatment of burial Sites, Human Remains and Funerary Objects" (February 23, 2007; http://www.achp.gov/docs/hrpolicy0207.pdf).

9. Should disagreements arise between NPS and SHPO during the course of the undertaking or implementation of this Programmatic Agreement, comments will be requested from the ACHP.

10. Amendments. Any party to this PA may propose to CACO that this PA be amended, whereupon CACO shall consult with the other parties to this PA to consider such an amendment.

11. Termination.

11A. If CACO determines that it cannot ensure implementation of the terms of this PA, or if the SHPO determines that the PA is not being properly implemented, CACO or SHPO may propose that this PA be terminated.

11B. The party proposing to terminate the PA shall so notify all parties to this PA, explaining the reasons for termination and affording them at least thirty (30) days to consult and seek alternatives to termination.

11C. If the terms of this PA have not been implemented by January 1, 2017, this PA shall be considered null and void, and CACO, if it chooses to continue with its participation in the restoration, shall re-initiate its review in accordance with 36 CFR 800.

Massachusetts State Historic Preservation Office:

Brona Simon October 30, 2014

Brona Simon, SHPO, Massachusetts State Historic Preservation Officer Date

Advisory Council on Historic Preservation:

Reid Nelson, Director, Office of Federal Agency Programs Date

Mashpee Wampanoag Tribal Historic Preservation Department:

Ramona Peters, THPO Date

Wampanoag Tribe of Gay Head-Aquinnah Cultural Resource Protection Department:

Bettina Washington, Tribal Historic Preservation Officer Date

Cape Cod National Seashore:

11/6/14

George Price, Superintendent Date

8.B Herring River Adaptive Management Plan

(See following pages)

8.B. Herring River Adaptive Management Plan

The Project proposes to use a process called “adaptive management” to aid in its performance of the Project. Following adaptive management guidelines, decisions about restoration of tidal flow will be formally analyzed and evaluated while water quality, vegetation, tide levels, salinity, sediment movement and other environmental and socioeconomic factors are monitored and compared with pre-restoration conditions and expected changes. The rate of tidal restoration can be slowed, reversed, or increased based on the system response as indicated by monitoring data. The Project’s approach to adaptive management is described below.

A. What is Adaptive Management?

Adaptive management is an inclusive and formal iterative process of making predictions regarding outcomes of management, monitoring the system after management actions are implemented, comparing the predicted outcomes to the observed outcomes, and using the result to formally update our understanding of the system response to our actions. Information obtained from post-implementation monitoring improves our ability to predict future outcomes and make better decisions regarding the selection of appropriate future management actions.

Adaptive management is an extension of the general principles of structured decision-making (SDM), an approach that was developed in the mid-20th century for applications in engineering, operations research, and economics. Adaptive management is a specific application of SDM characterized by those conditions mentioned above, with a focus on reducing the specific uncertainties that hinder our ability to make the best management decisions (Williams and Johnson 1995). Having been applied to natural resource management since the 1970s (Walters and Hilborn 1978), SDM is a logical framework for making decisions by distinguishing those components of a decision that are subjective and values-oriented from those that are objective and science-based. A SDM framework guides a transparent decision-making process by explicitly linking the anticipated outcomes of management alternatives to well-defined objectives and factoring how varied stakeholder viewpoints value these outcomes.

Adaptive management requires careful planning, which can be described as a two-step process: a setup phase and an implementation or iterative phase. In the setup phase, essential components of the decision or problem being faced are identified and developed. The components of the setup phase include:

1. A clear definition of the problem being addressed;
2. Specific objectives to be achieved;
3. Potential policies or management actions (also referred to as alternatives or decisions) that can be selected;
4. Predicted outcomes or consequences of each action with respect to the stated objectives;
5. A method for assessing trade-offs among competing objectives and identifying the policy, decision, or action that is most likely to achieve the objectives; and
6. A monitoring program designed to track outcomes of selected management activities to assess progress towards achieving objectives and to compare with predictions.

The iterative phase involves implementing management actions and the directed monitoring program so that progress can be measured and the predicted outcomes of the action taken can be compared with the actual observed outcomes. As the iterative phase progresses, knowledge of the resource and the effectiveness of the selected management activities is increased, thereby reducing uncertainty and enhancing the ability to predict the outcomes of subsequent management actions. Reassessment of management alternatives with improved predictions of outcomes can lead to identification of a different strategy as the best management approach to achieving the objectives. Additionally, information and understanding gained during the iterative phase can be used to reassess elements of the initial setup phase, potentially leading to modified or refined objectives, new management actions, or changes to the monitoring approach.

B. Rationale for Adaptive Management for the Herring River

Adaptive management differs from 'trial and error' and other reactive decision-making processes. Trial and error approaches simply reject an action that failed to elicit a desired outcome. Adaptive management is a process for decision making under evolving conditions that promotes flexibility by adjusting decisions as outcomes from management actions and other events become better understood. By collecting data to track the system's response to management we can compare our predicted the actual outcomes and improve our understanding of system behavior.

The Herring River Restoration Project is highly conducive to an adaptive management approach. The project involves a broad range of potential system responses to management that make it difficult to determine the best restoration policy and the need to repeat decisions over time. Therefore, an adaptive management framework is the most efficient method for evaluating restoration decisions related to managing tidal exchange within the Herring River estuary.

Collaboration and support of the US Geological Survey (USGS) was initiated by the HRRC in 2014 to begin development of a formal adaptive management decision structure that will help guide management decisions and measure progress toward specific ecological and sociological objectives during restoration of the Herring River. USGS decision scientists are working collaboratively with the project team, Friends of Herring River, other scientists, stakeholders and other interest groups to develop the Herring River Adaptive Management Plan (HRAMP). The HRAMP establishes the framework for decision making on how to operate adjustable tide gates at the new CNR bridge to maximize the ecological benefits of restoring tides to the Herring River estuary while minimizing adverse impacts. The varied effects of opening the tide gates using different management policies encompassing time spans ranging from 5 to 25 years are being analyzed to identify the most advantageous policy for tide gate management. Decision support software has been developed for use by the project team to compare policy options and evaluate trade-offs and uncertainties represented by a comprehensive set of project objectives. Development and testing of the decision framework has been completed. Predictions for the full suite of ecological and socio-economic objectives are being developed and trade-off and risk sensitivity analyses are being conducted to complete a fully operational decision-analysis framework.

The technical team is the primary group that will analyze monitoring data, complete project assessments, and formulate management options for the consideration by the formal decision making group, the Herring River Executive Council (HREC). Tide gate management is expected to continue to the point when gates are open to their fullest extent to achieve the maximum allowable tidal range. In addition to the primary restoration action of increasing tide range, secondary actions will also be implemented before, during, and after the period of tide gate management.

The development of the HRAMP follows a structure common to a decision analysis process:

- Define a comprehensive problem statement,

- Identify management objectives and policy options,
- Predict consequences of the policies,
- Evaluate predicted outcomes considering trade-offs and risk in order to recommend implementation of a preferred policy,
- Design and implement targeted monitoring program to first evaluate baseline conditions and then assess outcomes of management actions.

Each of these is discussed in the following sections.

C. Define a Comprehensive Problem Statement

An effective adaptive management plan requires a clear definition of the problem, or problems, to be addressed in order to identify why the decision needs to be made, and the individuals who can make the decision. Individuals or groups that have an interest in the resources affected and a willingness to work with others on the problem (i.e., stakeholders) should be identified. The problem statement should briefly state the potential range of actions that can be taken, the spatial and temporal scale of the problem, the frequency and timing of the decision(s), the complexity of the problem, uncertainties that make decision making difficult, and any legal, financial, regulatory, or political constraints.

The HREC is the decision-making body that will determine how to manage tide gates while seeking to maximize benefits and minimize adverse impacts over some finite length of time for restoring the Herring River estuary. It is comprised of 2 CCNS representatives (the superintendent and his/her appointee), two Town of Wellfleet ("Town") Selectboard representatives, and the Town manager.

The primary management actions involve decisions regarding the volume of tidal flow permitted through of a series of newly constructed tide gates at the three different locations; these actions involve decisions regarding the number, location, magnitude of opening, and flow direction at the individual tide gate openings at any given time. Timing and frequency of gate operations can be periodic or episodic, coincident with extreme predicted high tides and coastal storm events. At each decision point, one or more gates can be raised or lowered or not changed.

The Project will also implement secondary management actions to accelerate or maximize the recovery of estuarine habitat, enhance the benefits of tidal restoration, and avoid or reduce potential adverse ecological and socioeconomic impacts of restored tidal flow. Secondary actions include management of floodplain vegetation, modification of marsh surface elevations through management of sediment supply and distribution, and restoration of connectivity and natural sinuosity of tidal creeks to enhance the circulation of salt water through the system. Decisions regarding secondary actions will involve where and when to implement management measures, what techniques to use, and how to best coordinate the actions with the tide gate management. Specific details for most of these measures cannot be known until some degree of tidal flow is restored and monitoring information is gathered about how the Herring River system is responding.

Tide gate management is expected to continue until the point when gates are open to the extent permitted under Phase 1 and the maximum allowable tidal range has been reached. Secondary actions may be implemented before, during, and after the period of tide gate management. Within the project area, decisions involving management of the tide gates will be spatially and temporally separated by the sub-basins. Tide gate management will begin soon after construction of the tidal control structures is complete. The temporal and spatial resolution of monitoring data outputs used to make condition-based decisions will drive the frequency and timing of tide gate operations.

Secondary actions may range from simple independent decisions, to complex decisions that are conditionally linked to other management actions. The timing of some secondary actions may have a temporal relationship with the tide gate operations, thus requiring coordination with the tide gate management process. For example, removal of vegetation may be recommended to occur prior to restoration of extensive tidal exchange to facilitate work in more conducive, drier conditions.

Tide gate management decisions and secondary action decisions will be based on:

1. Predicted outcomes for multiple project objectives that result from tide gate changes; and
2. The expected range of outcomes in system response to the actions taken.

In general, the range of expected outcomes for tidal conditions (e.g., water surface elevations, tide range) are quite narrow for specific tide gate configurations. However, the ranges of outcomes driven by salinity and sediment transport are broader for individual tide gate openings.

Decisions about tidal gate adjustments will be legally mandated and subject to regulatory oversight under the US Clean Water Act, the Coastal Zone Management Act, the MA Wetlands Protection Act and Waterways regulations, the Towns of Wellfleet and Truro wetland by-laws, and the MA Endangered Species Act. Tide gate management decisions will be constrained by actions deemed necessary to protect public and private structures within the project area; e.g., at the end of the permitted Phase 1 of the project, the maximum mean daily high tide elevations would be limited to 3.6 feet in the Lower Herring River and 2.5 feet NAVD88 within the Mill Creek sub-basin while no tidal flow would be allowed into Upper Pole Dike Creek.

D. Identify Policy Objectives and Management Outcomes

1. Objectives

Defining project objectives starts with considering what you care about: what is to be achieved and what to avoid. The focus is on achieving ecological and socio-economic objectives using quantifiable metrics to evaluate progress towards achievement of well-defined restoration goals. Clearly defined objectives are the foundation of any decision process. In adaptive management, predicting the consequences of available actions in terms of measurable objectives provides a clear path for identifying the best performing strategy. Thus, the analysis starts with defining the objectives.

To facilitate the analysis, complex sets of objectives are organized hierarchically. Fundamental objectives articulate the over-arching reasons decision-makers are interested in a particular decision. The fundamental objectives can be generically categorized as benefits (restored ecosystem functions and services) and costs or constraints (potential adverse effects and project costs). Each fundamental objective is made up of, or is influenced by, several sub-objectives and each sub-objective is matched to a performance measure.

Performance measures are developed at the most logical level in the hierarchy, with the aspiration to measure performance of the fundamental objectives directly.

Performance measures must serve two purposes: 1) to predict how well a management strategy is expected to meet each of the objectives (i.e., models are used to make predictions), and 2) to provide metrics useful for monitoring; i.e., to determine how the system is responding to implementation of a management action and to evaluate progress towards achieving stated objectives. Comparison of the projected and observed performance measure is the basis for learning in adaptive management. The monitoring needs for adaptive management will be matched to on-going and planned monitoring programs to identify gaps and avoid duplication.

Beginning in 2014, the USGS decision-analysis technical team began to collaborate with project technical advisors, Friends of Herring River, Woods Hole Group, and community stakeholders to identify, define, and specify the objectives hierarchy for the HRAMP. This process was conducted over numerous phone conferences, in-person workshops, and public meetings. A process to develop a prototype adaptive management framework was substantially completed by the end of 2017. Objectives and their measurable attributes will continue to be refined and modified as the AM planning process continues and the project moves into the implementation phase. In addition to identifying fundamental objectives and their associated sub-objectives, the team developed detailed definitions and specifications for each objective including performance measures, monitoring methods, units of measurements, spatial and temporal scales of measurement, and desired direction of change (i.e. minimize or maximize).

For the Project, the fundamental objectives are derived, in part, from NPS management policies as articulated in the current General Management Plan for the CCNS, which states that the objective for managing coastal wetlands is to “Restore the natural hydrography and ecology of estuaries in consultation with affected municipalities” (NPS 1998). This broad policy has been applied to the Herring River project more explicitly through the Adaptive Management Plan, with development of a set of overarching fundamental objectives to restore the ecosystem by:

- Restoring natural hydrography, including tide range and topography / bathymetry;
- Restoring ecological function and integrity, including salinity, water quality, and aquatic habitat quality;
- Minimizing adverse impacts to ecological, cultural, and socioeconomic resources;
- Maximizing ecosystem services (i.e., benefits people receive from the estuary);
- Minimizing the costs of restoration; and
- Maximizing understanding of the project effects to federal- and state-listed rare, threatened, and endangered species.

The hierarchy of fundamental objectives, sub-objectives, performance measures, predictive methods, and monitoring design is summarized in Table 8B-1.

Table 8B-1. Objectives and Performance Measures for Herring River Adaptive Management Plan

Fundamental Objective #1: Restore Hydrography			
Sub-Objectives:	*Performance Measures:*	*Predictions*	*Monitoring*
Restore Tidal Range			
Restore Low Tide	Maximum/Minimum Water Surface Elevations Averaged for Sub-Basins and at Key Locations	EFDC[1] Hydrodynamic Model	Electronic Water Level Data Loggers for Sub-Basins and at Key Locations
Restore High Tide			
Restore Hydroperiod			
Frequency of flooding	Wetting/Drying of Marsh Surface Averaged at Key Locations	EFDC Hydrodynamic Model	Electronic Water Level Data Loggers for Sub-Basins and at Key Locations
Duration of flooding	Duration of Inundation of Marsh Surface at Key Locations		
Maximize Marsh Surface Drainage	Extent of Ponded Water at Low Tide	EFDC Hydrodynamic Model	Electronic Water Level Data Loggers in Areas of Predicted Ponding
Maximize Marsh Surface Elevation			
Marsh surface sediment deposition	Accumulation of Sediment at Key Marsh Surface Locations	Baseline Data; Published Values; Expert Judgment/Elicitation	Deposition/Elevation at Surface Elevation Tables and Markers
Below ground organic matter & pore space volume	Soil Organic Matter and Bulk Density	Baseline Data; Published Values; Expert Judgment/Elicitation	Soil Sampling Associated with Marsh Surface Elevation Monitoring Sites

Fundamental Objective #2: Restore Ecological Function/Integrity			
Sub-Objectives:	*Performance Measures:*	*Predictions*	*Monitoring*
Maximize area restored			
Appropriate salinity gradient	Water Column Salinity Values Averaged for Sub-Basins and at Key Locations	EFDC Hydrodynamic Model	Conductivity Data Loggers for Sub-Basins and at Key Locations

[1] Environmental Fluid Dynamics Code (Hamrick, J. M., and T. S. Wu. 1997)

Fundamental Objective #2: Restore Ecological Function/Integrity			
Sub-Objectives:	*Performance Measures:*	*Predictions*	*Monitoring*
Coverage of New England halophytes	Coverage of Native Estuarine Vegetation Types	SLAMM[2] Informed by EFDC Model Output	Transect/Plot Cover Estimates; Habitat Mapping
Maximize habitat quality for native estuarine animals			
Water Quality	Dissolved Oxygen, pH, Residence Time (Flushing), Ammonium	USGS Nutrient Flux Model[3]; Expert Judgment/Elicitation Informed by EFDC Model	Synoptic Surface Water Quality Monitoring at Key Locations
Benthic Community	Species Composition of Benthic Invertebrate Community	Published Values; Expert Judgment/Elicitation	Benthic Sampling at Key Locations
Maximize connectivity for diadromous fish	Flow Velocity at Culverts/Crossings	EFDC Hydrodynamic Model	Fish Passage Success; Velocity at Culverts

Fundamental Objective #3: Minimize Adverse Impacts			
Sub-Objectives:	*Performance Measures:*	*Predictions*	*Monitoring*
Minimize risk to public safety			
Minimize risk to public at water control structures	Probability of Water-related Incidents	Tidegate Configuration	Observations of Activity During Peak-use Periods
Minimize risk to public elsewhere	Probability of Boating, Transportation, Recreation Incidents in Project Area	Expert Judgment/Elicitation	Observations of Activity During Peak-use Periods
Minimize adverse impacts to shellfish beds in harbor			
Minimize excess nitrogen export	Ammonium Concentration Near Aquaculture Areas	Baseline Data; Published Values; Expert Judgment/Elicitation	Surface Water Quality Monitoring Near Aquaculture Areas

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[2] Sea Level Affecting Marshes Model (Clough, J. et al. 2012)

[3] USGS Nutrient Model (Colman, J. in proc.)

Fundamental Objective #3: Minimize Adverse Impacts			
Sub-Objectives:	*Performance Measures:*	*Predictions*	*Monitoring*
Minimize fecal coliform levels	Fecal Coliform Counts Near Aquaculture Areas	Baseline Data; Published Values; Expert Judgment/Elicitation	Surface Water Quality Monitoring Near Aquaculture Areas
Minimize loss of privacy for abutting property owners	Probability of Complaints	Water Surface Elevations and Vegetation Change from Models	Documentation of Incidents
Maximize aesthetics			
Maximize viewscapes from public vantage points	Horizontal Viewing Distance from Key Locations	Vegetation Change from SLAMM	Time Series Photo Stations
Minimize negative appearance of dead woody veg	Probability of Complaints	Vegetation Change from SLAMM	Time Series Photo Stations
Minimize hydrogen sulfide smell	Probability of Complaints	Expert Judgment/Elicitation	Documentation of Complaints
Minimize community conflict	Probability of Issues Lacking Community Consensus	Expert Judgment/Elicitation	Documentation of Conflicts and Resolutions

Fundamental Objective #4: Maximize Ecosystem Services			
Sub-Objectives:	*Performance Measures:*	*Predictions*	*Monitoring*
Maximize Natural Mosquito Control	Species Composition and Abundance	EFDC Output for Ponding and Salinity; Expert Elicitation	Larvae Counts in Breeding Areas
Maximize greenhouse gas sequestration	Rate of Horizontal and Vertical GHG Fluxes	WBNERR GHG Model[4] Informed by EFDC Hydro Model Output; Expert Elicitation	Atmospheric Carbon Exchange; Soil Carbon Accumulation
Maximize shellfishing opportunities (above & below dike)	Acres of Open Shellfishing Areas	EFDC Hydrodynamic Model	Fecal Coliform Counts
Maximize recreational opportunities			

[4]BWM Wetland GHG Model (Abdul-Aziz, O. and Ishtiaq, K. 2015)

Fundamental Objective #4: Maximize Ecosystem Services			
Sub-Objectives:	*Performance Measures:*	*Predictions*	*Monitoring*
Minimize loss of existing recreational opportunities	Number of Access Points, Parking Areas	Expert Judgment/Elicitation	Documentation of Lost/Gain of Access Points
Maximize newly created recreational opportunities	Rate of Increased Recreation Use of Project Area	Expert Judgment/Elicitation	Car Counts; User Surveys; Observations of Activity During Peak-use Periods

Fundamental Objective #5: Minimize Cost			
Sub-Objectives:	*Performance Measures:*	*Predictions*	*Monitoring*
Minimize time to reach fullest extent of restored tide range	Time to reach maximum tide range	Expert Judgment/Elicitation	Project Timeline/Financial Records
Minimize cost for secondary actions	Cost for secondary actions	Expert Judgment/Elicitation	Project Timeline/Financial Records
Minimize cost for tide gate operations	Cost for tide gate operations	Expert Judgment/Elicitation	Project Timeline/Financial Records
Minimize cost for monitoring	Cost for monitoring	Expert Judgment/Elicitation	Project Timeline/Financial Records

2. Policy Options

Tide Gate Management Policies

The need to control tidal exchange at the Chequessett Neck Road inlet to the Herring River system resulted in the design of a unique bridge and tide gate structure that consists of a number of tidal control elements that reside beneath the road of the proposed bridge. The complex nature of the proposed structure is the key for allowing the adaptive approach to incrementally restore tidal influence to Herring River. The structure design allows varied flow dynamics due to the large number of available tide gate configurations.

To investigate a range of plausible gate management strategies, the USGS and the HRRC developed a series of seven potential restoration trajectory scenarios, referred to as "platform policies", which encompass a representative range of restoration timelines, frequency and size of gate adjustments, and management priorities. Figure 8B-1 outlines the annual projected mean high water (MHW) elevation in the Lower Herring River sub-basin for each policy at each year of implementation

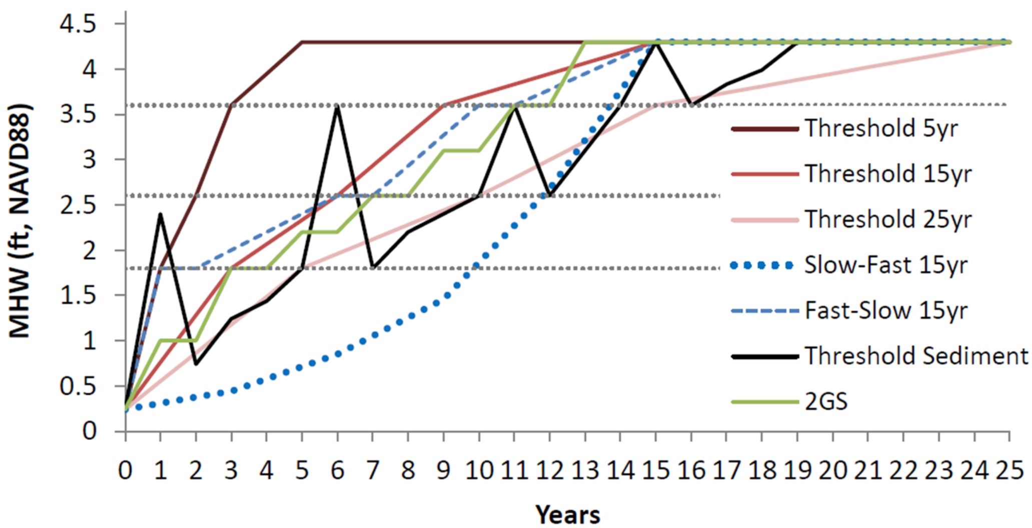

Figure 8B-1. Comparison of Predicted Mean High Water (MHW) Levels for the Full Herring River Restoration Project in the Lower Herring River Sub-basin Among Different Platform Policies. Maximum MHW elevations would not exceed 3.6 feet (NAVD88; top dotted line) for Phase 1 of the Project

Platform policies titled "Threshold 5 year", "Threshold 15 year" and "Threshold 25 year" consist of a time series of incremental tide gate openings that uniformly increase the MHW level in the Lower Herring River sub-basin from the existing elevation to a fully open (i.e. all tide gates set at a 10-foot height opening across the structure's 165-foot width) MHW condition of 4.3 feet in the defined number of years (i.e. 5, 15, or 25 years) in a relatively linear manner (Figure 8B-1). The "Slow-Fast 15 year" and "Fast-Slow 15 year" policies take contrasting approaches; the "Slow-Fast 15 year" policy changes the tidal range slowly at first, requiring 10 years to reach the 1.8 feet MHW elevation, and then increases the MHW quickly in the last few years to reach a fully open MHW condition of 4.3 feet (3.6 feet for Phase 1) by the 15th year, while “Fast-Slow 15 year” alters the tidal range quickly to reach the 1.8 feet MHW threshold in the first year, and the proceeds slowly to the final MHW elevation of 4.3 feet (3.6 feet for Phase 1) over the next 14 years. The “2GS” and “Threshold Sediment” policies have specific ecological objectives. The “2GS” platform policy is designed so that each gate opening configuration would remain in place for two growing seasons, with the assumption that vegetation would have time to establish during the new interim conditions. The “Sediment” platform policy is designed to have periodic but temporary large tide gate openings (concurrent with annual or storm tide events) that would promote large amounts of marine-derived sediments to be transported into the Herring River estuarine system to enhance deposition on the subsided former salt marsh surface, followed by periods when the gates would be reconfigured to reduce the tidal range in Herring River. As outlined in Figure 8B-1, these larger tide ranges (i.e. larger gate openings) would occur years 1, 6 and 11 for analytical purposes only; the actual implementation of this policy is dependent on the occurrence of unpredictable tidal events. To achieve a particular MHW elevation, a particular combination of tide gate openings is necessary. Table 8B-2 outlines the number and height of open tide gates that would be necessary to achieve the interim water surface elevations for each of the platform policies.

Table 8B-2. Lower Herring River Mean High Water (MHW) Estimated Modeled Elevations (NAVD88, feet) Predicted for Various Tide Gate Configurations at Chequessett Neck Road

Tide Gate Configuration		MHW Elevation (ft, NAVD88)
Number of Gates	Gate Height (ft)	
1	1	-0.96
1	2	-0.27
1	8	0.37
2	1	-0.27
2	2	0.59
4	1	0.6
7	1	1.43
2	6	1.81
5	2	1.95
6	2	2.19
3	10	2.51
4	6	2.76
4	8	2.94
5	6	3.03
6	6	3.23
7	10	3.63

These tide gate management strategies are referred to as “platform” policies because they provide the baseline conditions for analysis of project impacts to which secondary management activities can be added to improve performance with respect to specific project objectives. Secondary management actions are those other than changes to tide gate configuration and include direct management of vegetation and sediment, connectivity of tidal channels and pools, and mitigation of potentially adverse project impacts. Secondary actions would be implemented in addition to tide gate management to improve overall policy performance. The purpose of the decision analysis process are to (1) identify the best performing tide-gate management approach, (2) incorporate secondary actions to improve performance, and (3) select the overall management strategy (tide-gate policy plus secondary actions) that provides the best outcomes across the objectives. The location, timing, and other details of secondary actions cannot be anticipated in most cases until an initial policy is implemented and some degree of tidal exchange is restored. The ability to direct secondary actions in reaction to system responses to the implemented tide gate policy is one way of learning from and adapting management as restoration progresses.

Vegetation Management

Vegetation management is a class of project activities, along with incremental tidal restoration and facilitating the recovery of natural tidal marsh channel networks and elevation that are being pursued as part of the adaptive management plan. This section provides a general description of activities, methods, and effects. This information will be supplemented and refined during project implementation and presented by the project team when appropriate in detailed, site-specific Vegetation Treatment Plans (VTPs) for review and comment by the Regulatory Oversight Group and Herring River Stakeholder Group (HRSG), and approval by the HREC.

As Phase 1 is implemented, salt water will cause decline and mortality to much of the herbaceous and woody freshwater-dependent and upland vegetation that has colonized the floodplain. If left standing, dying and dead trees and larger shrubs could hamper the recolonization of native salt marsh plant communities. In some areas currently dominated by herbaceous, freshwater-dependent emergent plant species, the non-native, invasive common reed (*Phragmites australis*) could expand which would have a number of deleterious ecological and socioeconomic effects, including displacement of native vegetation and a reduction in habitat quality for fish and wildlife. The specific goal for managing vegetation as part of the Herring River Restoration Project is to support the long-term, sustainable recolonization of native estuarine vegetation as tidal range, salinity and sediment transport processes are restored.

Vegetated areas that will be affected at each stage of tidal restoration were identified by comparing NPS vegetation cover type data with spatial data output from the hydrodynamic model. Active removal and management of vegetation will be limited to the emergent marsh areas with existing occurrences of common reed, as well as shrublands, and woodlands. Within the area of the Herring River floodplain affected by regular tidal inundation up to the Phase 1 project limit, approximately 43 acres is currently dominated by common reed, most of which occurs within the Lower Herring River sub-basin. Shrublands comprise about 179 acres and are scattered throughout all of the Herring River sub-basins with the exception of Bound Brook. The largest contiguous stands of shrubland currently occur in portions of Duck Harbor, Lower Pole Dike Creek, and the Upper Herring River sub-basins. Woodlands currently make up approximately 126 acres of the Phase 1 project area, with most stands occurring in the Lower Herring River, Mid-Herring River and Lower Pole Dike Creek sub-basins. In total, up to approximately 348 acres within the Herring River floodplain could require some form of vegetation management as part of Phase 1 of the Project.

Vegetation management will be conducted incrementally and be closely coordinated with CNR Road tide gate management and the resulting increases in water surface elevations, tidal range, and salinity. Generally, vegetation management operations would be conducted before tidal flows are reintroduced to a given area before the ground surface is affected by salt or brackish water. Inundation with saltwater that promptly follows vegetation removal is expected to be highly effective for preventing or limiting regrowth of undesirable species and is expected to foster re-colonization of native estuarine plant communities.

In general, woody species management will be conducted under the oversight and guidance of the CCNS Fire Management Program, contingent on availability of future funding to augment personnel and equipment above present levels. The CCNS Fire Program is implemented according to the Fire Management Plan (FMP), which was reviewed and approved by the National Park Service through the National Environmental Policy Act. The Environmental Assessment (EA) and Finding of No Significant Impact (FONSI) for this program (NPS 2007) authorize mechanical and prescribed fire treatment of up to 500 acres per year within the CCNS boundary. The FMP identifies and maps 21 treatment area categories where activities are authorized for specific purposes, including all tidally restricted wetlands under NPS jurisdiction for the purpose of resource management and maintaining a safe urban-wildlife interface. The entirety of the federally-managed portion of the Herring River project area is within the authorized area for FMP activities. In collaboration with the NPS Integrated Pest Management Program, management of common reed, is also authorized by the FMP.

Prior to the reintroduction of tidal influence to the Herring River, vegetated areas expected to be affected at a given stage will be delineated into manageably-sized treatment units. Site-specific Vegetation Treatment Plans (VTP's) will be developed for each treatment unit. VTP's will include, but not be limited to a description of the methods for the removal of above ground tree and shrub material, secondary treatment of downed wood and slash, and the potential use of prescribed fire. Prior to implementation, individual VTP's will be submitted to the Regulatory Oversight Group for comment and approval. Ecological evaluations will be incorporated into the VTP before any treatment activity occurs. An ecological evaluation is an overall assessment of a proposed treatment area which will review possible impacts to vegetation, water resources, and wildlife, and appropriate mitigation measures. Mitigation measures may include, among other elements, specific timing of treatments to minimize impacts and leaving residual coarse, woody debris for animal cover.

If use of prescribed fire is recommended as part of a VTP, prescribed burn plans will be developed to address a full range of factors concerning conditions under which an area will or will not be burned. All burn plans will be based on the guidelines of the CCNS Fire Management Program and will delineate parameters that address how a burn would be implemented including safety factors, a site description, burn objectives, fuel types, weather factors, size of crew, skill set of crew members, and types of required equipment. Additionally, the burn plan would describe conditions that would not allow a burn to take place, including but not limited to smoke exposure to sensitive areas such as residences and roads and firefighter and public safety.

About 31 acres of the Phase 1 restoration area is in private ownership. As tidal range and salinity are progressively restored, the Project will consult with the affected landowners to develop site-specific VTPs for each property that meets both the Project's overall ecological objectives and the owner's preferences. All planning, permitting and on-the-ground work will be funded by the restoration project. With landowner concurrence, the project will submit individual Notices of Intent with the Wellfleet Conservation Commission and any other required permits. No active vegetation management will be pursued on private lands without landowner approval.

The project will employ measures to avoid adverse ecological and socioeconomic impacts that could potentially be caused by vegetation management. These include:

- Maximizing the amount of work done in winter and during the periods of low visitation by the public
- Maximizing work performed in dry conditions
- Maximizing work done by hand
- Specify use of low ground pressure/amphibious equipment
- Use of erosion controls, including hay bales, silt fences, fiber matting, and other ground surface protections
- Avoiding stump removals and ground disturbance
- Maximizing worker safety

Phragmites Control

Common reed is currently not a dominant plant species within the Herring River floodplain. The roughly 1,100-acre Herring River floodplain currently contains only about 45 acres of common reed. Restoration of tidal exchange will increase water column salinity in the Lower Herring River sub-basin to 20 ppt and higher. This rapid increase in salinity and the higher water levels are expected to quickly stress common reed and lead to die-off and eventual re-colonization of native salt marsh species. Consequently, in the Lower Herring River sub-basin, the restoration of tidal flow will be the primary means of common reed control. However, cutting and removal of material prior to tidal flooding will also be considered.

Because there currently is no salinity in sub-basins upstream of the Lower Herring River, future changes in the coverage, distribution and density of common reed are difficult to predict. As a result, predictions of plant community and habitat changes in the upper portions of the Herring River driven by future incremental increases in salinity are less certain. Following adaptive management protocols, this uncertainty will be reduced as the project is implemented and new monitoring data is collected to refine the salinity component of the hydrodynamic model. Based on documented changes in common reed distribution after tidal restoration commences, it is possible that additional management actions, beyond tidal inundation by high salinity seawater, may be necessary to limit its expansion. During each stage of restoration, as extant freshwater and upland dependent species succumb from low to moderate levels of salinity (approximately 5 to 20 ppt) new areas may become susceptible to common reed colonization.

The initial efforts of a common reed control program in the Herring River will be robust monitoring and early detection involving both:

1. Subbasin specific monitoring of the hydrologic conditions which will be driving vegetation change and,

2. Direct ground and aerial observation and quantification of changes to common reed occurrence and distribution using established transects and plots.

As tides are restored and observations of actual salinity changes are made, the ability to predict subsequent salinity changes will be improved. These improved predictions will direct vegetation monitoring to the areas where the anticipated salinity range would make it more likely for common reed to colonize. If new patches or expanding common reed stands are detected, a decision will be made about whether or not to initiate management. The project team will review all data and other available information and make a management recommendation to the HREC. Since the majority of cases where common reed control will be needed occur within the boundary of CCNS, the NPS will consult with its Integrated Pest Management Program and Exotic Plant Management Team to determine the available Best Management Practices for the given situation.

Generally, some degree of long-term control of common reed can be achieved using a combination of methods to be repeated as necessary. Combined control methods typically involve some form of physical removal followed by techniques that inhibit or limit regrowth. Examples include mowing followed by covering areas with black plastic sheeting or mats and digging out roots followed by regrading and planting of more desirable vegetation that can occupy the site and make it harder for common reed to get established. For the Herring River, one novel method that may be appropriate in some cases would be to mow or cut the stand and then use the Chequessett Neck dike tide gates to maintain high water levels to “drown” the cut stems. Similar techniques have demonstrated some success in other low salinity areas (Smith 2005), but its use in the Herring River will need to be balanced and assessed in concert with other ecological and socioeconomic objectives that may be adversely affected by holding high water levels for extended periods. These and other mechanical and hydrologic-based control methods will be undertaken on a case-by-case basis. Factors to be considered when choosing appropriate methods will be the size and density of the common reed stand, the location and physical character of the site (i.e. accessibility, proximity to the river, degree of soil saturation, etc.), surrounding vegetation and habitat types, and the extent of associated impacts from carrying out the control program, such as erosion and soil compaction from machinery. Common reed control areas will be delineated and specific control methods will be described in Vegetation Treatment Plans, as described previously.

Marsh Management

Restoration of natural stream channel connectivity and marsh surface elevation is a major component of the Herring River Restoration Project. Marsh management is a class of project activities, along with incremental tidal restoration and vegetation management that will be pursued as part of the coordinated adaptive management program.

These activities cannot be described in detail at a site-specific level prior to commencing the restoration and adaptive management program. Many of the locations where this work could potentially be necessary are remote and currently either covered in dense, shrubby vegetation or under water. The work is also dependent on specific vegetation, microtopography, and tidal flow characteristics. Attempting to evaluate potential treatment sites and design future marsh surface restoration actions based on existing conditions is not appropriate since these conditions will change after tidal exchange is restored. Conditions will also vary greatly among locations and for different stages of the restoration process. Therefore, this broad summary is based on the best information available and current projections of how restored tidal flow will generally affect the project area as well as the types of interventions that are expected to be necessary for restoring natural stream networks and marsh elevation.

Decisions about implementing any of the proposed management methods described herein will be made by the HREC, based on recommendations from the project team and will be based on the overarching ecological and socioeconomic objectives articulated in the Adaptive Management Plan. In a similar manner to what is proposed for the vegetation management program, specific plans for restoration of stream channel networks and marsh elevation will be presented in Marsh Treatment Plans (MTPs) for specific management areas that will be identified and delineated after tidal flow is restored.

Justifications for Marsh Management

Although reintroduction of tidal exchange and salinity is the primary component and main driver for restoration of the Herring River floodplain, several other actions would likely be necessary to reverse other previous direct and indirect alterations of the system's topography, bathymetry, and drainage capacity. After tidal restoration is initiated, these factors could inhibit circulation of saltwater, prevent recolonization of tidal marsh vegetation, create freshwater impoundments, and expand mosquito breeding habitat if not properly managed. The primary issues to be addressed through marsh management are:

- **Loss/subsidence of marsh surface elevation**: Areas of the Herring River are currently up to three feet lower than saltmarsh surfaces around Cape Cod Bay relative to current sea level. This is the result of three factors: 1) on-going sea level rise in Wellfleet Harbor, 2) lack of sediment supply to maintain marsh elevation, and 3) drainage and erosion of saltmarsh peat. At the current elevations with tidal flow restored, these areas would not support saltmarsh vegetation communities and would not drain properly.
- **Sediment entrained in marsh channels, channel blockages:** Lack of tidal flushing for more than 100 years has allowed the accumulation of sediment and organic matter in tidal channels and ditches throughout the floodplain. Normally this material would be distributed and deposited on the marsh plain by tidal flow or remain part of the suspended sediment load of the tidal prism flowing between the river and Wellfleet Harbor. With tidal exchange restored, this trapped sediment could cause obstructions to flow in some locations, especially during early stages when flow velocity may not be fast enough to mobilize material.
- **Historic grid ditching, channelization, water-logged soils:** Like most tidal wetlands in New England, the Herring River floodplain has been dramatically altered by grid ditches created and maintained by regional mosquito control programs since the 1930s. Many stretches of the Herring River have also been channelized to drain the marshes. Ditching and channelization have re-routed the flow of water throughout the floodplain, resulting in drained soils in some locations and continuously saturated, water-logged soils in others. Extensive marsh ditching has also contributed to greater marsh surface subsidence in some locations (see Figure 8B-2).
- **Spoil piles**: As a customary practice, when channels and mosquito ditches were created or maintained the dredged sediment (a/k/a "spoil") was disposed in linear mounds adjacent to the channel being worked on. These spoil piles are frequent along the river and channels and in some places are identifiable by topographic mapping (see Figure 8B-3). With tidal exchange restored, spoil piles could block the circulation of saltwater and impede drainage.

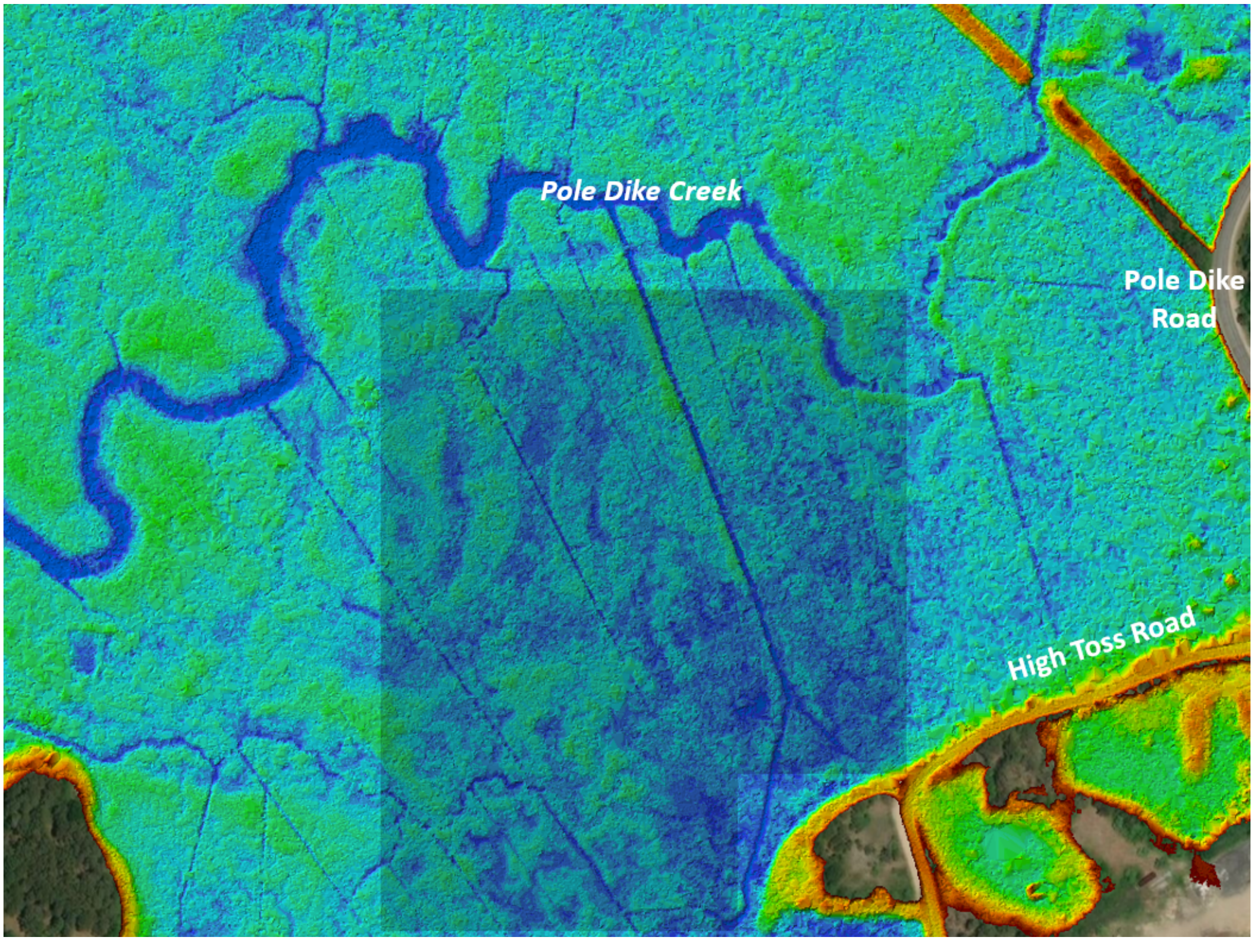

Figure 8B-2. Area North of High Toss Road Where Extensive Grid Ditching Has Led to Severe Subsidence of Marsh Surface (Shaded Area)

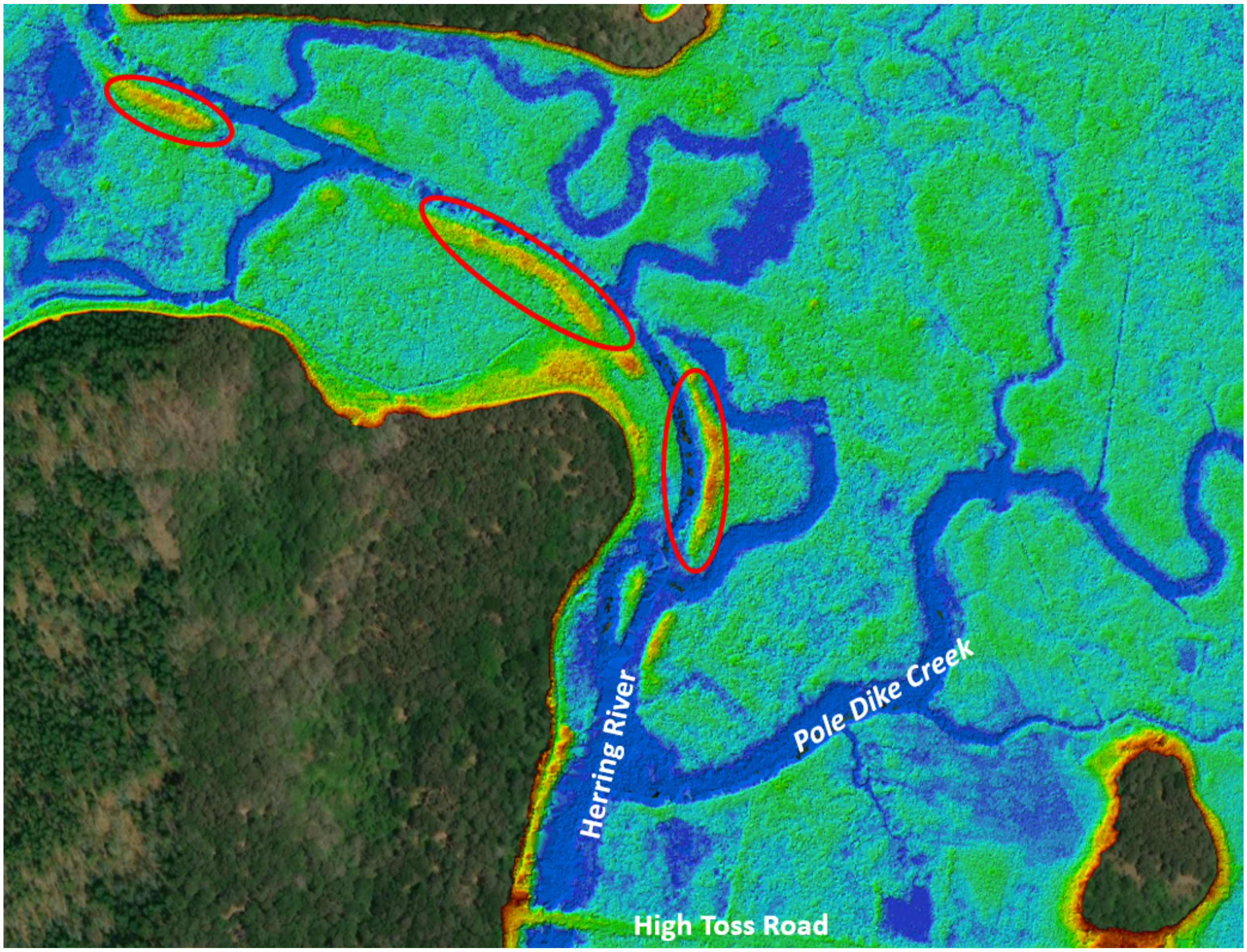

Figure 8B-3. Dredge Spoil Berms (Red Circles) Along Channelized Segments of the Herring River Recognizable with High Resolution LIDAR Imagery; Some of These Will Be Breached or Removed to Improve Tidal Circulation

Marsh assessment and management will be addressed by a three-step process. The initial step is based on the effects of tidal restoration and the degree to which increased tidal flow passively influences sediment transport dynamics. Second, tide gate management policies (discussed above) will be temporarily altered to facilitate increased sediment deposition and vegetation growth. Extensive monitoring systems will be in place to evaluate how marsh sediment and surface processes are affected by changes to tidal flow. Based on knowledge gained with this information, the third step of marsh restoration methods will be designed and implemented. These will involve direct mechanical manipulations on the marshes and in tidal channels. The three steps are described in detail in the following sections.

Step One: Passive Marsh Management

The first tier action is simply to restore tidal flow. In a normal estuary, tidal flow supports the basic ecosystem functions needed to establish and maintain marsh channel networks and surface elevation. Restored tidal exchange in the Herring River will increase flow velocities and will move trapped sediment and erode channels that have narrowed since tides were restricted, resulting in deeper and wider channels and greater flow volume. A portion of the sediment mobilized by this process will be deposited on marsh surfaces adjacent to the channels and contribute to rebuilding marsh elevation. Although natural deposition rates at saltmarshes in New England are typically low, on average approximately 2-3 millimeters per year, it is reasonable to expect that areas of moderately and severely subsided marsh surfaces would receive greater volumes of accumulated sediment since they are artificially lower than other marsh surfaces and would experience longer periods of inundation and slower flow velocities. Several studies have also documented higher accretion rates at marshes immediately following tidal restoration (i.e., Anifield 1999). Finally, as saltmarsh vegetation is reestablished, accumulation of below-ground organic matter is expected to accelerate. These subsurface metabolic processes are the dominant factor contributing to marsh surface elevation, making up to five times the volume of sediment compared to inorganic surface deposition (Turner et. al., 2000). The vertical and horizontal increase of vegetated saltmarsh would roughen the marsh surface, slowing down tidal flow and further contributing to sediment deposition, which in turn would facilitate below-ground accumulation.

Step Two: Alternate Tide Gate Management Policies

Seven discrete policies of management for new tide gates at the new Chequessett Neck Road bridge have been developed and are being currently analyzed to identify the gate configurations that result in the greatest overall ecological and socioeconomic benefit. Five of the policies (5 year, 15 year, 25 year, 15 year-slow/fast, 15 year-fast/slow) would generally increase tide range in a step-wise fashion over varying lengths of time. The two other policies ("Sediment" and "2GS") are intended to specifically target sediment dynamics and growth of marsh vegetation. Under the Sediment policy, tide gate openings would normally be made according to the 15-year linear policy. However, during certain coastal storm events and/or predicted astronomical high tides, the gates would be strategically managed to take advantage of high, sediment-laden flows into the river. Gates would remain open throughout the high tide cycle to allow inflowing water and then be closed as tides beginning to recede. Combination slide-flap gates incorporated into the design of the CNR structure would allow water to drain, but the flow would be slower than the incoming tide. This fast-flowing flood tide and slow-flowing ebb tide cycle would produce an asymmetrical tidal hydrology that could deliver and retain a substantial volume of inorganic marine sediment to the Herring River floodplain.

Under the two-growing season tide gate policy ("2GS"), the CNR tide gates would be opened following a generally linear pattern. When the tide range reaches a specified level (still to be determined), tidal hydrology would be maintained at those conditions for a minimum of two growing seasons. This would provide a relatively stable tidal regime during which salt marsh plants could colonize and become established in some areas. The new vegetation would increase surface roughness and promote both surficial deposition of suspended sediment as well as enhanced marsh accretion from below-ground production of organic matter. After a period of maintaining stable marsh hydrology, tide range would be increased again and the process would be repeated within a higher elevation zone. This policy would in effect restore vegetation that would ultimately be sacrificed, but is expected to contribute to marsh surface accretion that would enhance conditions for the establishment of vegetation during later phases of the restoration. Monitoring data collected during the stable tide regime periods would be used to evaluate the effectiveness of the strategy and to refine implementation details for subsequent periods.

Step Three: Active Marsh Management

Based on monitoring results documenting changes to marsh surface elevation and tidal circulation, active marsh management measures may be necessary to address all of the project's objectives. Monitoring variables to be assessed include flood frequency, flood duration, salinity of ponded water, suspended sediment concentration, marsh surface elevation, soil bulk density, and estuarine vegetation species diversity and distribution. If any of these suggest that passive marsh restoration is not occurring at an acceptable trajectory or pace in response to tidal restoration or strategic manipulations to tidal hydrology, implementation of some or all of the active marsh management actions described below will be considered. Because of the spatial and temporal uncertainty in their future application, the descriptions of the actions are necessarily general at this time. If or when any of these are proposed for a specific location, individually or in combination with other management actions, details will be specified in site-specific Marsh Treatment Plans, to be prepared by the HRRC and submitted to the ROG and HRSG for review and comment. Any subsequent permit modifications or amendments would then be submitted for approval by the HREC. In general, active marsh management actions include techniques to maximize tidal circulation and accelerate increases to marsh surface elevation.

Maximize Tidal Circulation and Connectivity: More than 100 years of tidal restriction has led to infilling of the Herring River's tidal channel network. Virtually all of the natural stream channels have also been compromised by channelization (i.e. straightening) and mosquito ditching. Many, if not most, of the anthropogenic ditches have also accumulated sediment and organic matter. If these channels are not flushed out naturally by increased tidal exchange, active measures to dredge material may be necessary. This could be accomplished with small, tracked, low ground pressure machinery designed especially for this type of work. The overall goals of this effort will be, to the extent practicable, to restore the natural channel network that existed prior to extensive ditching and channelization. This would first require identifying which stream reaches are "natural" and which are anthropogenic. Natural streams would be dredged to the depth of the apparent natural bottom, with the dredge spoil used to fill adjacent mosquito ditches. In some instances, anthropogenic channels would be maintained and improved where no other natural connection is apparent. A preliminary assessment of anthropogenic and natural channels and volume of potentially available sediment for beneficial reuse is provided in Table 8B-3 (note; this assessment is for planning purposes only and assumes an average depth of one foot of entrained sediment throughout all apparent anthropogenic channels).

Table 8B-3. Preliminary Assessment: Existing and Proposed Channel Length and Area, by Sub-Basin, Phase 1 Proposed Conditions

Sub-Basin	Existing		Proposed, Phase 1	
	Length (miles)	Area (acres)	Length (miles)	Area (acres)
Lower Herring River	4.2	33.8	2.6	32.0
Middle Herring River	3.6	7.7	2.2	6.9
Lower Pole Dike Creek	5.9	8.0	2.4	3.3
Duck Harbor	4.6	3.7	1.6	2.0

Sub-Basin	Existing		Proposed, Phase 1	
	Length (miles)	Area (acres)	Length (miles)	Area (acres)
Upper Herring River	3.7	6.1	2.4	5.4
Lower Bound Brook	3.6	3.3	1.4	2.1
Upper Bound Brook	1.4	2.1	1.1	1.9
Mill Creek	1.2	1.6	1.2	1.6
Total	28.2	66.3	14.9	55.2

In some locations, spoil material that was side cast during the channelization of the Herring River and construction of the mosquito ditches may also be found to prevent tidal circulation and connectivity for estuarine animals. As tidal restoration progresses, these channel blockages if not breached passively by the reintroduction of tides will be removed using small, tracked, low ground pressure machinery. Active improvements to tidal circulation could also include opening up flow to, and in some cases creating, small pannes and pools on the marsh plain to provide habitat for small estuarine fish species, such as mummichogs (*Fundulus heteroclitus*) that are predators of salt marsh mosquito larvae. Small radial and connector ditches may also be designed to ensure that these pools and pannes are hydraulically connected to the tidal drainage network and that physical access for the fish is maintained.

Accelerate Increases to Marsh Surface Elevation: Tidal restoration is expected to reintroduce large volumes of inorganic marine sediment that will deposit on the Herring River floodplain to enhance the restoration of estuarine vegetation, which in turn will stimulate below ground accumulation of organic matter in the root zone. Both of these processes will eventually contribute to the accretion of the marsh surface. However, the rate at which these processes might occur is dependent on a number of ecological processes that are difficult to predict. Existing rates of sediment deposition and marsh accretion from functional saltmarshes around New England have been estimated to be in the range of 2-6 millimeters per year (Bricker-Urso 1989) and higher in marsh under going tidal restoration (Gonneea, pers. comm. and in press). With the degree of marsh subsidence that has occurred in the Herring River over the last century, natural accretion rates that could occur during the passive processes of sediment transport may be insufficient for the Herring River floodplain to reach elevations to support saltmarsh vegetation. Therefore, it is expected that supplemental supplies of sediment may be necessary to achieve significant gains in saltmarsh and other estuarine vegetation within the current implementation timeline of the project (i.e. up to 25 years). The “Threshold Sediment” policy has been developed to promote accretion of the marsh surface and may be implemented during the restoration process or alternatively, the restoration timeline could be extended beyond 25 years. Rigorous monitoring of salt marsh accretion using Sediment Elevation Tables (SET’s) and feldspar horizon markers being used to document temporal changes in elevation of the restored salt marsh. Other than sediment that may be available from stream channel dredging, the redistribution of historic spoil materials, and the natural erosion (widening and deepening) of tidal channels during the restoration process, no specific sources of external sediment to actively restore marsh surface elevations have yet been identified. The Project may consider linkage to the planned Wellfleet

Harbor dredging project, however no feasibility studies or formal discussions with the Town or U.S. Army Corps of Engineers are currently underway.

E. Predict Consequences of the Policies

Decision making is future oriented – decisions are made after considering “what will happen if an action or an alternate action is taken?” Thus, predicting consequences is an essential part of any decision, with the type or complexity of the prediction dependent on the significance of the outcomes. Performance, or the response of a measurable attribute for each Project objective, is predicted under each tide gate platform policy. Comparing predicted performance across all objectives provides the basis for selecting a policy. Recall that each objective has a performance metric (measurable attribute), including a unit of measure, desired direction of response, and spatial and temporal scales. For each objective, a method of prediction is needed as well as a method for monitoring to determine what actually happens after implementing the policy in order to assess, learn, and adapt.

Prediction of system responses can be quantitative or qualitative. As such, it is imperative to be explicit about underlying predictive models and their assumptions. The degree of uncertainty in these predictions is one significant (but not the only) impediment to making good decisions. Being explicit in predicting outcomes encourages explicit recognition of evolving conditions.

In the development of methods of prediction and monitoring for the Herring River, a tiered approach was used. Tier 1 predictions are best professional judgments developed by the project team. Tier 2 predictions are those provided through formal elicitation methods by subject matter experts and, where appropriate, community stakeholders. Tier 3 predictions are generated by quantitative models. For the Herring River, Tier 1 predictions have already been compiled, but are only being used to assess and develop future decision analyses. Tier 2 and 3 predictions will be used for the actual adaptive management plan and functional decision analysis. Tier 3 predictions can only be applied when a cost-effective quantitative model exists for a given objective. As shown in Table 8B-1, Tier 3 predictions exist or are planned for about two-thirds of the Herring River objectives. Where no quantitative model is available, Tier 2 predictions will be elicited from technical subject matter experts and community stakeholders through formal elicitation processes. This process is underway and will continue into 2020.

The foundational numerical model for the Herring River project is a two-dimensional hydrodynamic model developed by the Woods Hole Group (WHG 2012) using the Environmental Fluid Dynamics Code (EFDC) software package (Hamrick 1996). The EFDC model spatially represents the entirety of the historic Herring River floodplain and has been calibrated and validated to a set of tidal observations collected over full lunar cycles in 2007 and 2010. The model has been used to identify the optimal size of the tide gates at the new Chequessett Neck Road bridge, the Mill Creek dike, and the road culverts to be replaced as part of the restoration project. It has also been used to simulate the extent of tidal exchange under a range of full and partial restoration scenarios. Outputs from the EFDC model include tidal metrics under normal and storm-driven tidal forcing, including water surface elevations, tide range, water column salinity, flow direction and velocity, and hydroperiod (e.g. residence time, flood frequency, flood duration). Data outputs are available for virtually any Herring River location within the model domain and for any time step within the lunar tide cycle.

The EFDC model has also been run to simulate 17 different tide gate configurations at the Chequessett Neck Road bridge in order to understand the hydrodynamic effects of incremental tide gate management (Table 8B-2). Output for these simulations also provide predictions of low and high tide water surface elevations, and other hydrodynamic metrics, averaged by sub-basin and for individual and grouped model nodes. In addition to tabular data output, spatial data have also been compiled to graphically depict the extent of tidal exchange under each of the 17 tide gate configurations. These data were also used to develop the previously-described seven tide gate management platform policies.

In addition to the EFDC hydrodynamic model, other computer-based models have been applied to the Herring River project. The Sea Level Affecting Marshes Model (SLAMM) is open-source software that was originally developed with EPA funding in the 1980s (Warren Pinnacle Consulting 2016). It incorporates a number of input parameters, including Light Detection and Ranging (LiDAR) survey elevations, existing wetland classifications, sea-level rise rates, tide range, and accretion and erosion rates for various wetland habitat types to simulate the dominant processes involved with wetland conversions due to sea-level rise.

Although typically utilized to project wetland changes due to sea-level rise, SLAMM was applied in a unique approach to advance the understanding of how the changing tidal regimes associated with various tide gate scenarios could potentially impact ecological resources and wetland types throughout the Herring River system (WHG 2018). Used in combination, land elevation and tide range are the main drivers of the modeled vegetation predictions. Rather than using SLAMM to predict water level increases that are projected to occur because of sea level rise, this application of SLAMM used different tidal ranges resulting from various tide gate configurations at the Chequessett Neck Road Dike to project how the vegetation would likely respond to changes in tidal conditions. Spatially variable water levels throughout the Herring River system from the EFDC model results were generated for the suite of likely gate openings being considered during adaptive management of the project.

Elicitation planning is currently underway to develop predictions for objectives where use of a quantitative model is not possible or otherwise suitable. Elicitation is a formal process where technical subject matter experts or stakeholders are asked to provide their own informed judgements about how a specific management action, integrated within a platform policy, may influence a specific objective. There are varied methods for conducting formal elicitations, but the basis of the process is to develop data that allow for quantification of uncertainty and also expresses the range of predictions among multiple experts or responders. For the Herring River, two separate elicitation processes are currently being undertaken; one for scientific experts to provide predictions for a number of measurable attributes for several ecological objectives and another for local stakeholders in order to develop information about socioeconomic outcomes that are not addressed by existing ecological models. Table 8B-1 provides a summary of predictive data to be generated through these elicitation processes.

F. Evaluate Predicted Outcomes Considering Tradeoffs and Risks

Tradeoff analysis is the process of evaluating which of several potential courses of action (i.e., Herring River platform policies) offers the best possible outcome. The process of this evaluation can also offer insight into where information deficiencies exist – or what actions must be taken to improve resource outcomes. Tradeoff analysis is typically performed before any action is taken, and it therefore depends on predictions of how a given action will affect one or more objectives.

Accurate predictions are therefore a foundation of quantitative decision analysis, and among the goals of a tradeoff analysis is to base decisions on the best available information.

USGS decision scientists have developed the Herring River Decision Support Tool (Smith et al., in press), an application for the HRAMP to facilitate trade-off analyses by performing the comparative scoring automatically and presenting the results in a flexible and informative manner. Although this is only one element of a comprehensive tradeoff analysis it may be one of the more cognitively difficult components because of the need to track outcomes for numerous policies, objectives, and weighting schemes.

Utility functions transform performance metrics into a standardized scale while representing preference for levels of performance and tolerance for levels of risk. Utility curves can take a variety of shapes depending on risk attitude ranging from risk averse to risk acceptance. Default utility curves were created for each objective based on a range of risk attitudes and can be adjusted within the application prior to conducting a trade-off analysis.

Objectives can all be quantified in some way, usually by measuring some physical attribute. For example, mean high water (MHW) elevations and dissolved oxygen (DO) exceedances are both measurable attributes; MHW is measured in feet relative to mean sea level, and DO exceedances are presented as the number of samples with a DO concentration of less than 5 milligrams per liter. It is impossible to compare how well a management strategy (i.e. Herring River tide gate management policy) satisfies both the desired outcomes for MHW and DO because in their measured units there is no natural scale on which the water level and the dissolved oxygen concentration can be directly compared. To accomplish this comparison, an artificial scale, which is referred to as a utility scale is developed.

The utility scale always scores the most undesirable measurement as 0 and the most desirable measurement as a 1, regardless of the original units of measurement. In order to apply this scale, there is a need to define in advance what constitutes a desirable resource outcome. For some objectives we may desire the highest measurements, while for others we would want the lowest measurements. The desirable direction is toward attaining the resource outcome and there is often a point at which an objective has been adequately achieved.

In addition to the advance recording of the direction of the resource response, risk attitude must also be quantified. Risk attitude is harder to assess than direction because it exists on a subjective gradient that must be characterized by carefully considering how various outcomes affect a level of satisfaction. Thinking of risk attitude in terms of satisfaction is a good way to conceptualize terms like “risk accepting” and “risk averse”, which describe how quickly we transition from a utility of 0 to a utility of 1. To identify our risk attitude we need to examine whether our satisfaction grows at a constant rate with increasingly satisfying measurements (which would be a “linear” risk attitude) or whether small initial changes are more satisfying than large changes later on (which could be a “risk accepting”), or even the opposite case in which we are not happy with small initial changes and are only happy with large changes later on (“risk averse”). For example, if 1 DO exceedance makes us twice as happy as 2 exceedances, and 2 makes us twice as happy as 4, we could characterize our attitude as “linear”. If 2 exceedances make us 4 times as happy as 4 exceedances we might be “risk averse.”

Risk attitude is a difficult concept to comprehend, and describing it simply as satisfaction leaves us prone to misinterpretation as we attempt to visualize converting measured values to utility.

G. Recommend Implementation of a Preferred Policy

The governance and administrative structure for implementing the Herring River adaptive management plan is described in a memorandum of understanding (MOU-IV) between CCNS and the Town of Wellfleet.

The executed MOU IV explicitly acknowledges the responsibility of the town and Cape Cod National Seashore by establishing the Herring River Executive Council (HREC) as the formal, decision-making authority for the project. The HREC is comprised of two select board members and town administrator from Wellfleet, and the Cape Cod National Seashore superintendent, and one additional CCNS representative. MOU-IV identifies the Herring River project team as an informal, intergovernmental technical working group formed for the purpose of providing technical input for Project-related decisions as necessary or appropriate. In September 2017, the HREC established a formal Herring River Stakeholder Group (HRSG), a 19-member body representing a broad range of local and regional interests. The purpose of the HRSG is to communicate with stakeholders within the community to ensure that their respective interests and views are well represented and considered by the HREC and to provide advisory input to the HREC on key implementation issues.

The HREC is the entity primarily responsible for executing the adaptive management plan, with technical input from the project team. Simply stated, the team will provide management recommendations to the HREC which will be responsible for authorizing actions at each major decision point. The team will be responsible for coordinating with the NPS and town to carry out authorized actions in accordance with the guidelines outlined in the adaptive management plan and regulatory permit requirements. The team will also have the role of analyzing, compiling, and summarizing monitoring data, modeling output, field observations, and other information, and providing advisory input to the HREC. The HREC and project team may work with third-party organizations to implement agreed upon management actions, field monitoring, data analysis, and public outreach activities.

The Regulatory Oversight Group will assist in the preparation and review of the final AMP and will review implementation progress on an ongoing basis. The Regulatory Oversight Group is called for under the Secretary's MEPA Certificate to include, at a minimum, representative(s) from the following agencies:

- Federal: NPS, USFWS, NOAA, NRCS, EPA, USACE;
- State: MEPA, DER, DMF, NHESP, MassDEP, CZM, State Historic Preservation Officer (SHPO);
- Regional: CCC;
- Local: Town of Wellfleet, Town of Truro: and
- Tribal: Mashpee Wampanoag Tribe

The decision-making process is grounded on the collection and evaluation of monitoring data intended to measure performance of the specific objectives formulated for the adaptive management plan. The HREC may designate the parties responsible for (1) coordinating with the NPS and Town to carry out authorized actions and (2) analyzing, compiling, and summarizing monitoring data, modeling output, field observations, and other information. During this process, members of the HRTT will provide ongoing advisory technical input to the HREC. Third-party organizations may be engaged to implement approved management actions, field monitoring, data analysis, and public outreach activities. Data collection will be guided primarily by scientists at CCNS and available to, the project team as the basis for technical advisory input to the HREC. As management actions are implemented and the response of the system is monitored, the project team will assess the performance of models and other predictive tools by comparing those outputs to actual, observed outcomes. These results will be summarized in written reports and form the basis for recommended management actions to be implemented during the subsequent time period. The project team will submit written reports to the HREC that will describe previous management actions, data analysis, and recommendations for future management actions. The HREC will either approve the project team recommendations or request additional data collection and/or analysis for further review and possible reconsideration of recommended management actions.

H. Decision Making During Implementation

The project team will use the USGS trade-off analysis software to evaluate the expected performance and trade-offs of various management strategies. The trade-off analysis will help identify which platform policies are most advantageous for achieving the objectives based on weighted preferences and attitudes toward risk taking. The software produces numeric scoring of available management strategies, but it will be up to the HREC and project team to evaluate the results, along with input from the HRSG and other sources to make informed and transparent decisions about the most appropriate actions at any given point in the project implementation timeline. This recognizes the potential that some decisions may carry higher risk than others and that it could be necessary to tolerate some less advantageous effects in the short-term in order to achieve broader, long-term project objectives.

In addition to evaluating trade-offs, while reviewing monitoring data and formulating management options available for advancing the objectives of the Herring River project, the project teamwill consider:

- The current state of the system including:
  - Cumulative changes that occurred since commencement of the restoration process
  - Specific changes that occurred since implementation of the most recent management actions
  - Effects of natural and anthropogenic events that are unrelated to tidal restoration
  - Comparison of observed changes with model predictions
  - Status and effectiveness of mitigation measures employed to prevent adverse impacts
  - Compliance with regulatory requirements and permit conditions
  - Stakeholder comments, concerns, and interactions
- Predicted outcomes of recommended management actions:
  - Specific details of management actions (e.g., changes in tide gate configurations; methods of proposed secondary management actions)
  - Temporal context of management actions (e.g., implications of seasonal effects; anticipated tidal forcing, weather conditions, storms, etc.)

- Spatial context of management actions (e.g., area predicted to be affected by increased tidal exchange; locations of proposed secondary management actions, juxtaposition with other management)
- Expected changes/impacts to be measured through field monitoring (e.g., changes in water surface elevations, salinity, water quality, sediment movement, and vegetation/habitat)
- Confirmation that required mitigation measures are in place to prevent adverse impacts
- Anticipated stakeholder reaction and plans for public outreach/education

- The operational and administrative structure for supporting recommended management actions:
  - Review of monitoring effort (e.g., set up of sensors, data loggers, and monitoring studies, and operational needs for assessing predictions derived from hydrodynamic models)
  - Assessment of available resources (e.g., staff, equipment, funding, contracts, availability for implementation of management actions, including reversing actions, if needed, to address unforeseen effects)
  - Assessment of personnel and funding needs during implementation, monitoring of performance, data analysis, and reporting of results
  - Assessment of personnel and funding needs for public outreach and communications
  - Permit compliance and regulatory approval during implementation of management actions

The entity designated by the HREC will provide written reports the HREC as the basis for recommended management actions to be implemented. Reports will be prepared and delivered at the end of the calendar year and will include a cumulative documentation of all data and project results to date with detailed emphasis on changes that occurred during the latest reporting period. Reports will be posted online and provided to the HRSG and Regulatory Oversight Group. Best Available Data will be included, but all data may not be fully analyzed, assessed for quality assurance and quality control, or peer-reviewed.

Management Recommendations to the HREC will include:

- A brief summary of all results since Project inception
  - Ecological monitoring data: water levels, salinity, water quality, Vvegetation hcange, etc.
  - Socioeconomic data: public safety, visual impacts (aesthetics), public access (privacy), recreation, odors, and resolution of conflict among stakeholders, etc.
  - Review of all prior management action
  - Performance assessment of models and other predictive tools
- A detailed analysis for the reporting period (prior calendar year)
  - Statement of previously proposed management actions ("We planned to do…")
  - Description of executed management actions ("We did...")
  - Statement of expected outcomes, i.e. model hypothesis ("We expected to see....")

- Data presentation of actual observations ("We did see…")
- Analysis of expected vs. actual outcome

- New management recommendations
  - Proposal for new tide gate settings, secondary actions
  - Modeled predictions and expected outcomes of proposed management
  - Potential vulnerabilities warranting special attention
  - Changes or modifications to monitoring plan
  - Assessment of financial and personnel resources for continuing management and monitoring plan

I. Design and Implement Targeted Monitoring Program, Evaluate Baseline Conditions, and Assess Outcomes of Management Actions

The collection, analysis, and application of credible monitoring data to compare with predictions from modeling are the primary means in adaptive management to assess progress towards meeting project objectives. Equally important is the ability to predict the variation of expected outcomes across a range of alternative management actions that are under consideration. As previously described, in adaptive management output data from models and other predictive methods are used to conduct trade-off analyses so that predictions of how management actions influence objectives can be compared. After management actions are implemented, monitoring data are used to determine real outcomes, evaluate how models performed, and refine model predictions about the outcomes of future actions.

Since the 1970's, the CCNS has collected most of the research and monitoring data in the Herring River. Much of this work has been done as part of the NPS Northeast Coastal and Barrier Network Inventory & Monitoring Program and CCNS' Cape Cod Ecosystem Monitoring Program which has included both long-term monitoring and focused research projects. USGS, along with a number of university- and NGO-based study groups, have also contributed significantly to the broad database of pre-restoration monitoring data. CCNS will continue to provide leadership and direction for the science and monitoring program as the Herring River enters the construction phase and as the project is implemented. To conduct all of the monitoring required during the long-term implementation of the adaptive management plan, additional resources including staff time, equipment, technical consultation, and funding will be necessary from the NPS, other federal and state agencies, and other sources.

Table 8B-1 provides an overview of available monitoring methods and predictive tools for each objective within the adaptive management plan. These methods are discussed in detail in this section. Both pre- and post-restoration monitoring activities are addressed.

Objectives – Hydrography and Water Quality. Existing and future tidal conditions and water quality are and will continue to be monitored using electronic sensors and data loggers in a number of monitoring applications for the Herring River project. Electronic sensors are highly accurate (when maintained and calibrated), cost-effective, and capable of unattended continuous logging and data storage for several months. Their use is extremely common in any type of water-related environmental study. There are several types of instruments, but the most commonly used for the Herring River are devices for measuring water surface elevation and water column salinity levels. Other instruments for continuous data collection in the Herring River are used to collect water quality variables (i.e., temperature, dissolved oxygen, pH, nutrients, and turbidity), other hydrologic data (i.e., flow velocity), and non-water data (i.e., air temperature, atmospheric pressure, and weather variables).

Data provided by automated instruments are the basis for the EFDC hydrodynamic model and many other hydrologic-related predictions incorporated into the trade-off analysis tool (see Table 8B-1). As the restoration project is implemented new data collected through the network of automated sensors will be used to compare the original set of predictions with observed conditions. Observed outcomes will be incorporated into the models and to develop revised predictions to improve subsequent decision-making. Objectives and their measured attributes most reliant on data collection from automated sensors are:

- Tide range
- Hydroperiod
- Marsh surface drainage
- Salinity
- pH
- Dissolved oxygen
- Prevention of flooding of private structures and public roads

In addition to these specific objectives continuous data may also be used for analysis of other water quality and habitat suitability assessments.

Starting in 2017 the Seashore began collaborating with FHR to expand the network of tide monitoring locations as the project advanced toward the construction phase. Several long-term tide, salinity, and water quality monitoring stations were installed. These stations include radio telemetry systems to provide real-time data to the public via Internet. As Phase 1 of the project is implemented, coverage of tide monitoring will expand throughout the floodplain. If or when tidal influence expands beyond the extent of the Phase 1 project area, the tidal monitoring network can be extended into other sub-basins of the Herring River.

Objective – Water Quality: In addition to data collected by automated loggers for dissolved oxygen and pH, water quality data will be supplemented with synoptic grab samples taken from the river and Wellfleet Harbor at several points throughout the floodplain. CCNS has collected seasonal water quality samples since 2005 with the number of locations and frequency of sampling varying because of changes in funding levels and personnel availability. Pending future funding, synoptic sampling will continue up to the construction start and throughout the implementation period of the project. In addition, USGS has installed, and has been operating and maintaining surface water-quality and streamflow monitoring sites in the Herring River since November 2015. The goals of this data collection program are to establish a pre-restoration baseline water-quality dataset, and to evaluate differences in concentrations of nutrients and other water-quality indicators between the Herring River and the receiving waters of Wellfleet Harbor. CCNS and USGS staffs are collaborating to integrate long-term CCNS data and the

USGS nutrient flux data and to develop a strategy for the long-term monitoring of water quality of the river and Wellfleet Harbor as the Project is implemented.

Water quality sampling will also include levels of fecal coliform bacteria to monitor the expected reduction of bacteria exported from the Herring River to Wellfleet Harbor. This will build on a prior study (Portnoy & Giblin 2006) which demonstrated that dilution with seawater resulting from increased tidal exchange would reduce the occurrence of bacteria originating from the river. Additional baseline data for fecal coliform bacteria will be collected before construction begins and will be repeated seasonally as tidal flow is restored. This will be conducted to evaluate the objective to avoid impacts to Wellfleet Harbor aquaculture areas.

Objective – Habitat Quality: Shellfish habitat suitability will be assessed based on changes in tide range, salinity, and substrate condition (i.e. mud, sand, gravel, etc.) in order to quantify expected increases to potential shellfish growing habitat, independent of whether the area can be opened to harvest based on fecal coliform counts.

Objective – Habitat Quality: A comprehensive survey of benthic macroinvertebrates was completed by CCNS as part of a comprehensive assessment of aquatic habitat of the Herring River between 2013 and 2015 (Fox, et. al. 2017). Samples were taken from 92 stations from above High Toss Road and extended seaward to Wellfleet Harbor. This monitoring effort will be repeated periodically as tidal exchange is restored to assess the objective of maximizing habitat quality for native estuarine animals.

Objective – Marsh Surface Elevation Change: Data relating to sediment dynamics and marsh elevation have been collected by CCNS since at least the early 2000s. The most prominent of these datasets are from an array of surface elevation tables (SETs) installed at three locations in the Herring River floodplain. These are part of the larger network established and administered by the NPS to document long-term changes to marsh elevation and accretion rates at coastal parks throughout the Northeast Region. SETs are used in conjunction with feldspar marker horizons to provide information about the vertical position of marsh surfaces in relation to local sea level. These stations will be maintained throughout CCNS, including the Herring River project area, for the duration of the restoration project. The Herring River SET array has been augmented by an additional station, installed in the tidally unrestricted Blackfish Creek salt marsh system to serve as a reference site for the Herring River. Additional SETs and other methods for documenting accretion and marsh surface elevation changes resulting from the Herring River project are also being considered. Alternate methods include direct ground survey measurements along established transects throughout the floodplain. These data will address the objective of marsh surface elevation change. They are also linked to other sediment-related data focused on Wellfleet Harbor, discussed below.

Objectives – Habitat Quality and Marsh Surface and Benthic Elevation Changes: In addition to the sediment deposition and accretion monitoring methods for the marsh surface areas of the Herring River floodplain, information on sediment grain-size; suspended sediment load; and harbor bottom elevations has been collected – and is planned to assess whether any future changes to sediment transport in Wellfleet Harbor are the result of increased tidal exchange in the Herring River. In 2005, 2010 and 2017 sediment samples were collected from the surface of the tidal flats near the Wellfleet Harbor aquaculture areas in order to evaluate grain-size distribution and organic content. As the restoration project proceeds, this sampling will be repeated and the results compared to the baseline data to help understand whether the restored flow in the Herring River may affect sediment composition in the harbor. Additional sediment related monitoring that will help inform river and harbor sediment dynamics during restoration and to avoid impacts to Wellfleet Harbor aquaculture areas includes benthic habitat mapping to be conducted by the Center for Coastal Studies and USGS suspended sediment sampling at the CNR dike.

Objective – Emergent Vegetation: Long-term vegetation transects and multispectral and low altitude imagery classification are being used to monitor changes to vegetation in the Herring River floodplain resulting from restored tidal exchange. Long-term vegetation transects were established by CCNS in 2004 and vegetation data have been collected at approximate five-year intervals. This will provide at least four data sets of species coverage and distribution before the project is implemented. During the restoration, sampling along the same transects will be conducted at shorter intervals as tidal range is increased. Vegetation transect-plot data will monitor species level changes that occur over the long-term and will be used to assess the objective to restore native halophytic vegetation.

Broad scale changes to wetland habitats will also be monitored using seasonal multispectral imagery and low altitude aerial photography. This will build on the classification and quantification of baseline wetland habitat conditions conducted by CCNS using remote sensing data from 2013 and completed in 2018. This analysis resulted in a stream-lined process for image classification and ground-truthing that will be repeated to update conditions prior to project implementation and as tidal exchange is restored. As a complement to the detailed species-based inventory of the transect-plot sampling, multispectral analysis will provide a more general assessment of changes in habitat types and structure for the entire project area. Aerial based mapping will also provide the ability to monitor a number of hydrologic metrics (e.g. areas of ponded water, changes to tidal channel morphology) and possibly marsh elevation and sediment dynamics.

Objective – Connectivity for Diadromous Fish: Surveys of river herring (*Alosa* spp.) have been conducted by volunteers managed by Friends of Herring River since 2009 using methods developed by the MA Division of Marine Fisheries and the Association to Preserve Cape Cod. These semi-quantitative counts provide information about the relative abundance of migrating herring from year to year and comparisons with similar herring runs on Cape Cod. In addition, researchers from USGS and UMASS-Amherst have conducted a detailed study of herring movements along the Herring River (Castro-Santos and Alcott, in press) using electronic tagging methods. FHR volunteer counts are expected to continue as long as volunteers are available and the program can be managed. Additional intensive surveys could be performed after tidal flow is restored, pending availability of funding and personnel. In concert with other, indirect hydraulic metrics, such as configuration of tide gates and resulting flow velocities, these data will be used to assess the objective to maximize anadromous fish passage.

Objectives – Recreation and Public Safety: Observations of visitor activity will be used to assess the socio-economic objectives of maximizing recreational opportunities while minimizing risk of injuries or accidents. Potential new recreational opportunities include, but are not limited to, increased access for and quality of kayaking/canoeing, fishing, shellfishing, and hiking. Potential risks include, but are not limited to, increased boating activity near the new CNR bridge, changes in tidal flows that affects recreation, and the inherent increased risk resulting from expected increased activity levels. Refinement of recreational and other socio-economic objectives and their associated monitoring techniques for baseline and future conditions are still under development by the project team and USGS decision scientists.

Objective – Public Satisfaction: Refinement of objectives and monitoring techniques related to general public satisfaction of project effects, including changes to viewscapes, potential changes in odors, and perceived loss of privacy for residents are under development. It is likely that monitoring will occur through a combination of public surveys and by tracking and documenting incidents and complaints presented to project managers.

Objective – Public Viewscapes: Time series photo documentation used in combination with public surveys are planned to evaluate a number of aesthetically based objectives, including viewsheds from both private residences and public access points. Fixed stations will be established and photographs will be made at regular intervals to track vegetation changes and other factors that contribute to viewshed quality.

Objective – Climate Change: Detailed measurements of carbon storage and fluxes between water, soil, and the atmosphere have been made by the Bringing Wetlands to Market project team since 2016. In addition to establishing the baseline understanding of carbon dynamics in the Herring River, these data will also be applied to a carbon flux model (Abdul-Aziz and Ishtiaq 2015). This model uses relatively simple inputs of salinity, water depth, water temperature, and light to generate predictions of Net Ecosystem Productivity (NEP) under future tidal conditions. Pending available funding and personnel, carbon flux measurements will be repeated until the NEP model can be verified.

Objective – Natural Mosquito Control: Mosquitoes have been monitored in the Herring River by CCNS and Barnstable County Mosquito Control Project primarily using larval counts. Counts of adult mosquitoes and larvae are standard methods for species distribution and population estimates. Other metrics relating to mosquito breeding (i.e., ponded water, salinity levels) will also be used to assess the extent of breeding habitat for fresh, brackish, and saltwater species. Mosquito counts will also continue for the duration of the project.

Objective – Cost: Actual costs, including financial expenditures, human resources, and other costs will be modeled and monitored in the same manner as ecological and socioeconomic objectives. Cost estimates will serve as the model, or prediction, and actual expenditures will provide the monitoring data. As the project is implemented, actual costs will be tracked and compared to cost estimates in a systematic manner to improve future cost estimates and increase efficiency.

Objective – Threatened and Endangered Species: In order to understand how populations of state-listed rare, threatened, and endangered species respond to tidal restoration, implementing monitoring plans for these species and their habitats is a fundamental Project objective. The capacity of the Project to implement these plans and provide timely information to the MA Natural Heritage and Endangered Species Program (NHESP) will be tracked and used to assess the probability that monitoring and reporting can be completed to predict the effects of future management actions. This information will be presented in a detailed Habitat Management Plan, which is under development and will be subject to approval by NHESP.

8.C Groundwater Studies

Technical Memorandum on Wellfleet Landfill Leachate

The Johnson Company. May 21, 2019.

Evaluation of the Potential for Private, Domestic Wells to be Affected by Restoration of Tidal Flow in the Herring River Basin, Cape Cod, Massachusetts

Martin, Larry. December 2018

(See following pages)

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ENVIRONMENTAL SCIENCE AND ENGINEERING SOLUTIONS

TECHNICAL MEMORANDUM

TO: Brian Carlstrom, National Park Service

FROM: The Johnson Company

DATE: May 21, 2019

RE: Wellfleet Municipal Landfill Memorandum

This memorandum provides an overview of the current status of groundwater contamination within the immediate vicinity of the Wellfleet Municipal Landfill in Wellfleet, Massachusetts, and how the landfill may be affected by Herring River restoration activities. The 2018 Biennial Post-Closure Monitoring Report for the Wellfleet Municipal Landfill and the PowerPoint slides put together by John Portnoy were reviewed for this assessment. It is not clear when the slideshow was put together, but based on current data there does not appear to be a contaminated groundwater plume associated with the landfill. The vast majority of organic and inorganic data was either non-detect or significantly below the drinking water criteria. The only constituents that exceed any type of standard are pH, iron, manganese, and 1,4-dioxane. In general, it appears that the upgradient wells have similar levels of contamination to wells that are downgradient of the landfill.

Figure 1 (attached) shows the analytical results and groundwater flow for the Wellfleet Municipal Landfill. The tables shown on the figure show the results only for an analyte that was detected above a standard in one of the samples in the most recent sampling round. Wells CSAW-3D, CSAW-2D/2S and CSAW-4S appear to be the upgradient wells. Please note that the groundwater elevations are the average of the 1998/1999 sampling events, which are the sampling events with the most recent groundwater elevation data available. The analytical results are from the September 2017 sampling event. Note that the Herring River is located to the north and west of the landfill.

It appears that pH and chloride standard exceedances are unrelated to the landfill: the highest chloride concentration was detected in upgradient well CSAW-4S, and the lowest pH concentration (the concentration furthest outside of the Standard range) was also detected in this well. Regarding iron and manganese, these results were for total metals rather than dissolved, and the high values are likely associated with suspended sediment. In addition, it is not clear that the landfill is the source of these higher values, as upgradient well CSAW-2D had the highest concentration of total Iron, and a higher concentration of total manganese than two out of three downgradient wells.

Regarding 1,4-dioxane, the only well it was measured in above detection limits during the September 2017 sampling was downgradient well CSAW-1D at 0.904 ug/L. This well also had detections of 1,4-dioxane in April 2013, April 2014, and September/December 2016. Upgradient well CSAW-3D had one detection of 1,4-dioxane in October 2014. Downgradient well MW-1 had two detections of 1,4-dioxane, one in April 2015 and one in September 2016. The table inserted on the following page from the 2018 Biennial Report summarizes these results.

Sampling Date	Apr 2013	Oct 2014	Apr 2015	Sept/Dec 2016	Sept/Dec 2017
CSAW-1D	0.3	ND	0.6	0.866/1.05	0.904/0.514
CSAW-3D	ND	0.3	ND	ND	ND
MW-1	ND	ND	0.3	4.76/ND	ND

Note: All results in µg/L

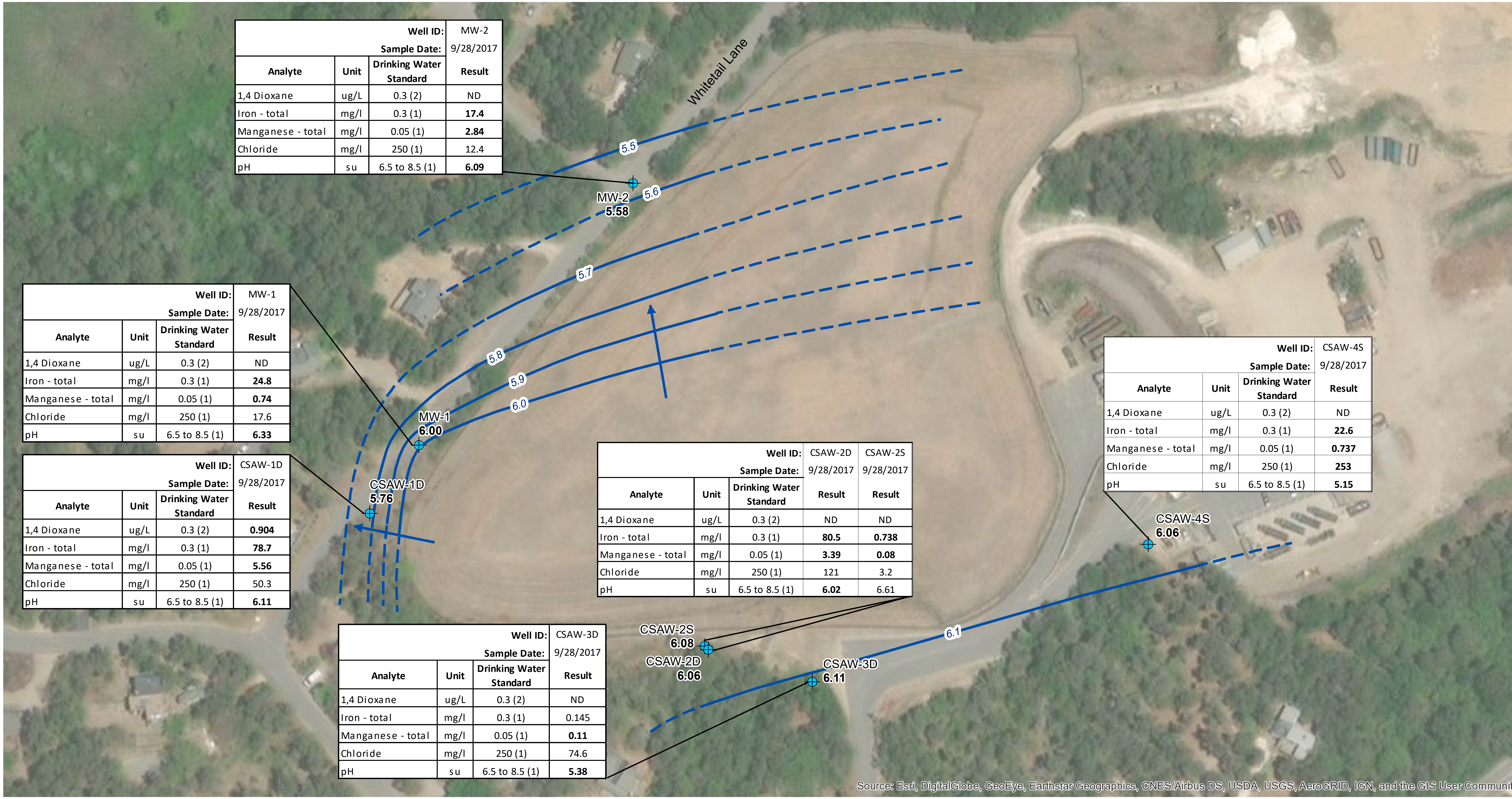
The biennial report concluded that based on the low concentrations detected, and the lack of private wells in the vicinity, there are no potential human receptors or human health risk of ingestion associated with the 1,4-dioxane in groundwater. Unlike manganese and iron which are naturally occurring, 1,4-dioxane is a synthetic industrial chemical most commonly used as a stabilizer for chlorinated solvents. As 1,4-dioxane has been detected historically in upgradient well CSAW-3D, it is not clear if the concentration encountered in downgradient well CSAW-1D is reflective of landfill leachate. Furthermore, stable isotope monitoring indicates that landfill leachate is not reaching the Herring River, as detailed in the Portnoy slideshow.

In conclusion, it appears that the 2005 landfill closure was successful and that landfill leachate has been reduced and/or stopped. Furthermore, it appears that there is no longer a contaminated groundwater plume associated with the landfill. There was most likely a contaminated groundwater plume in the past and the landfilling of waste, more likely than not, did have an impact on the environment and the groundwater during landfill operation. However, current conditions indicate very minor, if any, groundwater contamination. The restoration of the Herring River into a salt water marsh, rather than a fresh water marsh, will have some effect on the tidal cycle in the vicinity of the landfill; I believe any affect will be minor and should not significantly impact the groundwater flow from the landfill to the river.

The observations of limited groundwater contamination from this closed landfill may seem unexpected to some; however, I am currently evaluating the groundwater at several historical landfills and they surprisingly also have limited groundwater contamination. It may be that the landfills have been flushed over the years with rain or, in this case, the closure activities have been successful.

Therefore, for the reasons summarized above, I concur with three of Mr. Portnoy's observations:

- There is no detectable contamination plume in groundwater;
- Tidal restoration will bring surface water no closer to the landfill than it is today, >500 ft;
- Groundwater levels and flow direction at the landfill will not change as a result of the tidal restoration.



		Well ID:	MW-2
		Sample Date:	9/28/2017
Analyte	Unit	Drinking Water Standard	Result
1,4 Dioxane	ug/L	0.3 (2)	ND
Iron - total	mg/l	0.3 (1)	**17.4**
Manganese - total	mg/l	0.05 (1)	**2.84**
Chloride	mg/l	250 (1)	12.4
pH	su	6.5 to 8.5 (1)	**6.09**

		Well ID:	MW-1
		Sample Date:	9/28/2017
Analyte	Unit	Drinking Water Standard	Result
1,4 Dioxane	ug/L	0.3 (2)	ND
Iron - total	mg/l	0.3 (1)	**24.8**
Manganese - total	mg/l	0.05 (1)	**0.74**
Chloride	mg/l	250 (1)	17.6
pH	su	6.5 to 8.5 (1)	**6.33**

		Well ID:	CSAW-1D
		Sample Date:	9/28/2017
Analyte	Unit	Drinking Water Standard	Result
1,4 Dioxane	ug/L	0.3 (2)	**0.904**
Iron - total	mg/l	0.3 (1)	**78.7**
Manganese - total	mg/l	0.05 (1)	**5.56**
Chloride	mg/l	250 (1)	50.3
pH	su	6.5 to 8.5 (1)	**6.11**

		Well ID:	CSAW-2D	CSAW-2S
		Sample Date:	9/28/2017	9/28/2017
Analyte	Unit	Drinking Water Standard	Result	Result
1,4 Dioxane	ug/L	0.3 (2)	ND	ND
Iron - total	mg/l	0.3 (1)	**80.5**	**0.738**
Manganese - total	mg/l	0.05 (1)	**3.39**	**0.08**
Chloride	mg/l	250 (1)	121	3.2
pH	su	6.5 to 8.5 (1)	**6.02**	6.61

		Well ID:	CSAW-4S
		Sample Date:	9/28/2017
Analyte	Unit	Drinking Water Standard	Result
1,4 Dioxane	ug/L	0.3 (2)	ND
Iron - total	mg/l	0.3 (1)	**22.6**
Manganese - total	mg/l	0.05 (1)	**0.737**
Chloride	mg/l	250 (1)	**253**
pH	su	6.5 to 8.5 (1)	**5.15**

		Well ID:	CSAW-3D
		Sample Date:	9/28/2017
Analyte	Unit	Drinking Water Standard	Result
1,4 Dioxane	ug/L	0.3 (2)	ND
Iron - total	mg/l	0.3 (1)	0.145
Manganese - total	mg/l	0.05 (1)	**0.11**
Chloride	mg/l	250 (1)	74.6
pH	su	6.5 to 8.5 (1)	**5.38**

Legend

- Monitoring Well with **Groundwater Elevation**[1] (ft)
- Groundwater Equipotential[1] (dashed where inferred)
- Groundwater Flow Direction

Notes:
(1) Denotes EPA Drinking Water Secondary MCL/guideline.
(2) Denotes Massachusetts Drinking Water MCL
Results are shown for all analytes which had an exceedance of one of the standards listed in tables above in a sample during the most recent sampling round.
Bold result in table indicates above standard.
[1]Groundwater elevation data only available for the 1998/1999 sampling round. The average GW elevation from the four sampling events for each well was used for the flow map.

0 25 50 100 150 200
Feet

N

Figure 1: Groundwater Flow Map and Analytical Results
Wellfleet Municipal Landfill
Wellfleet, Massachusetts

The Johnson Company

Drawn by: DEB	Date: 05/01/2019
Reviewed by: SJH	Date: 05/02/2019
Scale: 1 " = 100 '	Project: 58345.10

C:\Users\dbroderick\OneDrive - VHB\Desktop\Wellfleet\MXDs\Figure 1 Groundwater Flow Map and Analytical Results.mxd

Evaluation of the Potential for Private, Domestic Wells to be Affected by Restoration of Tidal Flow in the Herring River Basin, Cape Cod, Massachusetts

Larry Martin, Hydrogeologist
Ft. Collins, CO
December 2018

Summary

This report reviews the findings and conclusions of multiple prior investigations into the effects of tidal influence on groundwater and adjacent private domestic water-supply wells at several locations on Cape Cod, Massachusetts. The findings of these investigations were used to evaluate the potential effects of tidal restoration on drinking water wells from the planned Herring River Estuary Restoration Project in Wellfleet, MA.

Importantly, the understanding of interactions between various tidal restoration settings and adjacent groundwater conditions has evolved significantly over the nearly three decades spanned by these investigations. Multiple studies evaluated the effects of tidal restoration on water quality for wells adjacent to a permanently flooded ocean shoreline. This approach was subsequently determined to be inapplicable for evaluating the effects of tidal restoration on groundwater in an intertidal estuary, where the dynamics between tidal flow and groundwater differ substantially from those that occur in an ocean shoreline setting.

More recent investigations for Herring River correctly evaluated the effect of tidal restoration on groundwater beneath and adjacent to an intermittently flooded intertidal estuary. These studies found that tidal restoration is expected to increase the mean water level in the river and streams, resulting in a slight increase of the water table elevation and consequent increase in thickness of the freshwater zone in the aquifer. These investigative findings support the conclusion that only wells exposed to salt water inundation at the ground surface around the casing are likely to experience water quality impacts resulting from tidal restoration at Herring River.

Based on this understanding of impact risk, a total of seven wells were identified with the potential for salt water inundation at the ground surface resulting from full tidal restoration of the Herring River Estuary. Two of those wells will be plugged and abandoned. Mitigation actions have been identified for the other five wells, two of which would not be affected by Phase 1 of the Project. Installation of new wells on these properties in upland locations, and with screened intervals located at proper elevations in the aquifer's freshwater zone, will maintain quality drinking water for the affected properties.

1.0 Purpose and Scope

The purpose of this report is to (1) review the basic science of the freshwater/saltwater relationship in aquifers on Cape Cod, addressing the potential effect of restored tidal flow in the Herring River on groundwater quality, and (2) summarize the key findings of previous hydrological assessments of the effects of tidal restoration in private, domestic wells that are in low-lying areas within the Herring River basin and within a short distance of saltwater at high tide. This report incorporates the work of many investigators over the past several decades. Previous investigations include work by the U.S. Geological Survey, National Park Service, Cape Cod Commission, and others, as noted in the text and attached list of references.

2.0 General Science of the Saltwater-Freshwater Relationship in Coastal Aquifers:

The relationship between freshwater and saltwater in coastal aquifers has been studied by many investigators (e.g. see Fetter (2001), pp. 331-338). Freshwater, being less dense than saltwater, floats on top of saltwater in the shape of a lens within the groundwater system. Infiltration of precipitation provides the source of freshwater. A good example of this type of separation of two liquids with different densities is a bottle of vinegar and oil salad dressing.

The relation between the height of the water table and the thickness of the freshwater lens was discovered independently by W. Badon-Ghyben and A. Herzberg; and is generally referred to as the Ghyben-Herzberg relationship. This relationship expressed as an equation is;

$$h_s = \frac{\rho_f}{\rho_s - \rho_f}(h_f)$$

where; h_s is the depth of freshwater below sea level

ρ_f is the density of freshwater, 1.000 g/cm^3

ρ_s is the density of saltwater, 1.025 g/cm^3

h_f is the elevation of the water table above sea level

Substituting the values for density of freshwater and saltwater into the equation;

$$h_s = \frac{1.000}{1.025 - 1.000}(h_f)$$

Yields;

$$h_s = 40h_f$$

Thus, the freshwater lens should extend to a depth below sea level equal to 40 times the height of the water table above mean sea level. Figure 1 shows an example of a freshwater lens in a cross-section through the Truro area (Barlow, 2003). Freshwater in this area extends to a depth of more than 150 feet below sea level.

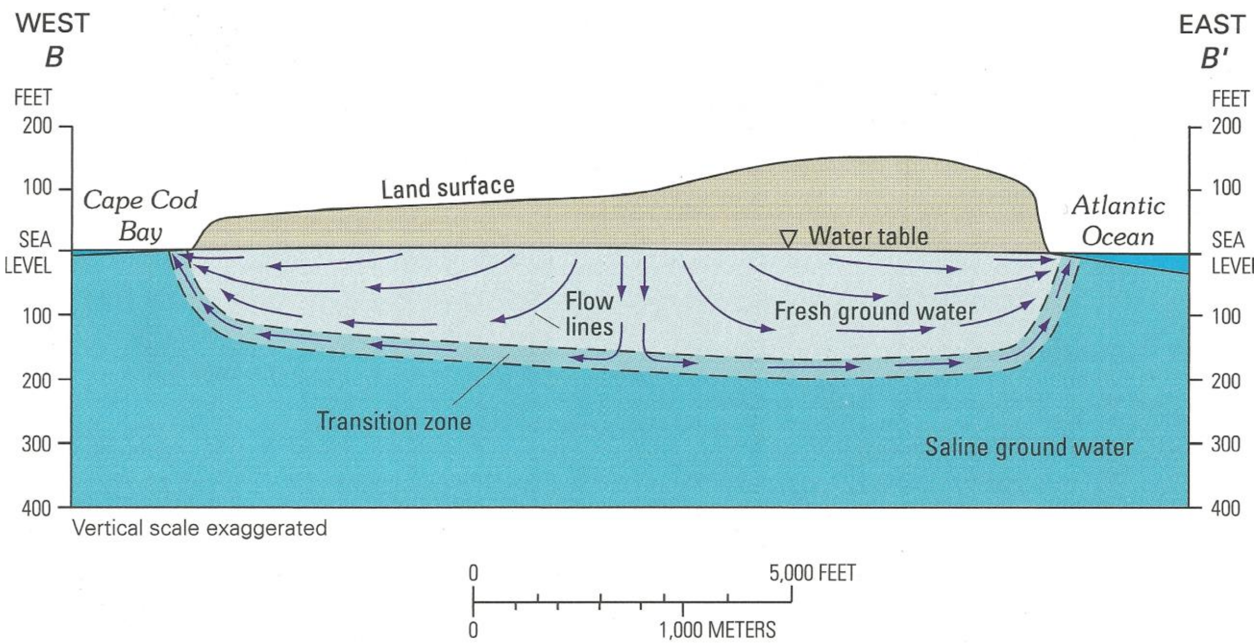


Figure 1. Cross-section through the Truro area showing an example of a freshwater lens floating on saltwater. Vertical exaggeration 10X. From Barlow (2003).

On most areas of Cape Cod, there is sufficient thickness of the freshwater aquifer to supply water for domestic wells. Only wells that are located very near permanent saltwater bodies, such as Cape Cod Bay or the Atlantic Ocean, are at risk of saltwater intrusion. Martin (2004) concluded that domestic wells located more than about 200 feet from ocean shorelines and having their screened interval a significant distance above the bottom of the freshwater zone in the aquifer generally produce good quality water. At a distance of 200 feet from a high salinity ocean shoreline, the thickness of the freshwater zone in the Cape Cod aquifer is expected to be 25-30 feet. The relationship between freshwater and saltwater in the near-shore environment is shown in Figure 2. However, in estuaries where there is a salinity gradient with saltwater at the mouth of the estuary and freshwater farther upstream, the freshwater aquifer can be much thicker (see Fitterman and Dennehy, 1991 below).

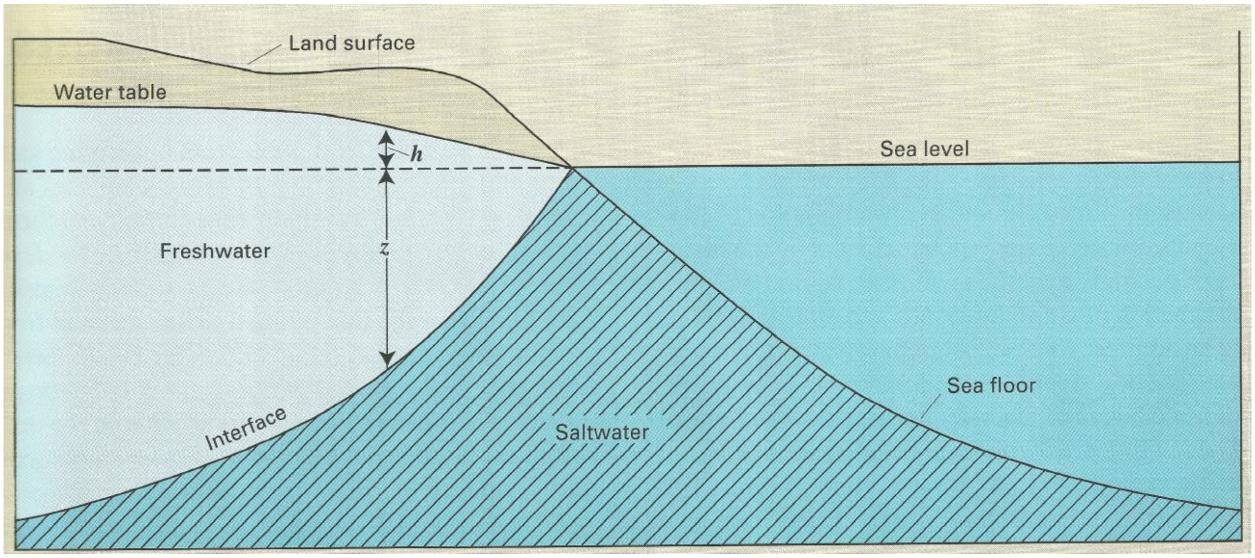


Figure 2. Cross-section showing the relationship between freshwater and saltwater adjacent to a permanent saltwater body. The thickness of the freshwater zone in the aquifer (z) is equal to 40 times the elevation of the water table above sea level (h).
(Barlow, 2003, Figure B-1)

2.1 Saltwater-Freshwater Relationship in Estuaries and Salt Marshes

Niedoroda and April (1975) investigated the relationship of salt and fresh groundwater underlying salt marshes at three locations on the outer part of Cape Cod. They found that the zone of high salinity water from tidal inundation infiltrated only a few feet into the marsh peats and underlying sandy sediments. Salinity at depths of more than 5 feet below the marsh surface showed brackish to almost fresh groundwater. They surmised that the flow of freshwater from adjacent upland areas counteracted the infiltration of saltwater during high tide. Saltwater that had infiltrated the marsh sediments was partially flushed and diluted by the much larger flow of fresh groundwater beneath the marsh peat. Infiltration of saltwater through the marsh sediments occurs only at high tide, whereas the flow of fresh groundwater from the upland areas is continuous.

Barlow (2003) summarized the work of Portnoy and others (1998) and other investigators regarding the relationship of saltwater and freshwater in areas adjacent to estuaries. Groundwater discharge to the estuary is affected by the tidal cycle of the estuary. At high tide, saltwater infiltrates into the near-surface sediments. The saltwater cannot infiltrate very far into the sediments because high tide lasts only a few hours and fresh groundwater is flowing in the opposite (seaward) direction (Figure 3, top). As the tide recedes, fresh groundwater flows from the aquifer, discharging at the estuary shoreline. This flow of fresh groundwater begins to flush saltwater from the near-surface sediments (Figure 3, middle). At low tide, mostly freshwater is being discharged from the aquifer into the estuary. A small amount of saltwater may remain in the near-surface sediments (Figure 3, bottom). This cycle of infiltration of a small amount of saltwater at high tide and flushing by freshwater discharge is repeated with each tide cycle.

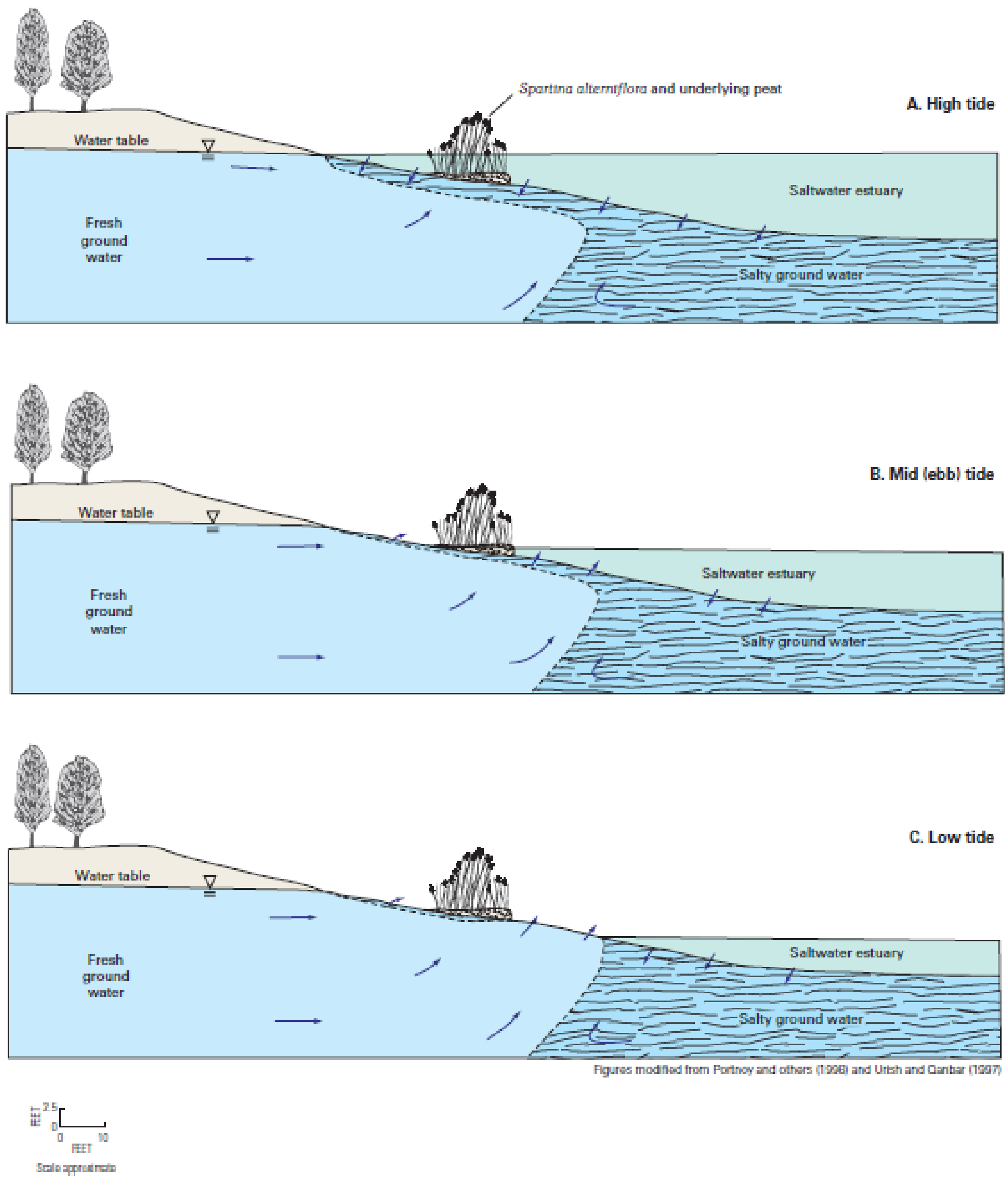


Figure 62. *Ground-water discharge and saltwater infiltration at the aquifer-estuary boundary during a tidal cycle: (A) high tide; (B) mid (ebb) tide; and (C) low tide.*

Figure 3. Reproduction of Figure 62 from Barlow (2003) showing the effects of tides on underground freshwater and saltwater flow at an estuary shoreline.

Barlow (2003) also summarized the work of previous investigators regarding groundwater flow near, and discharge of fresh groundwater to, salt marshes. A typical example of groundwater flow at a salt marsh is provided from investigations at Namskaket Marsh near Orleans (MA), on Cape Cod. A conceptual model of groundwater flow and discharge to the marsh is shown in Figure 4.

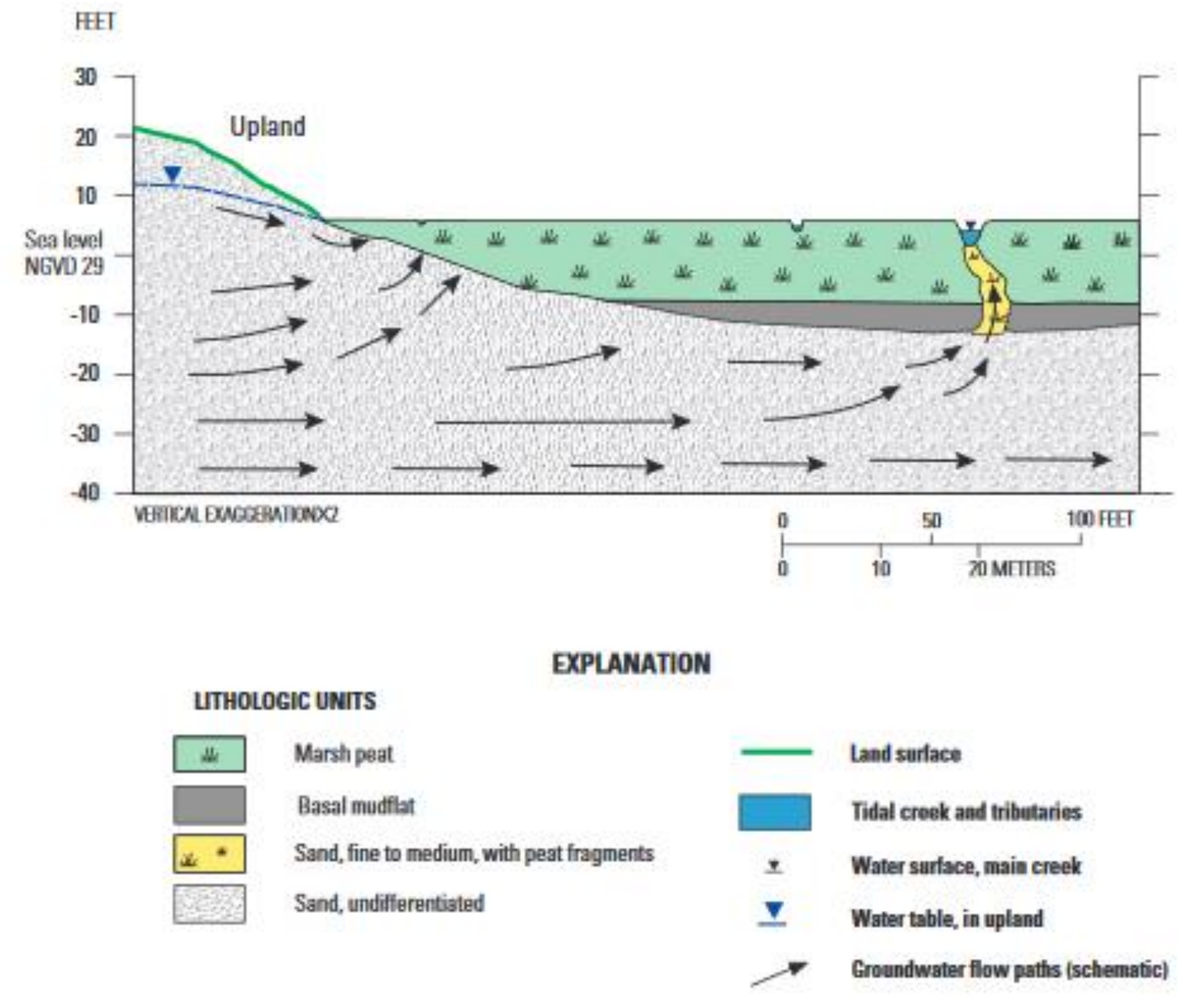


Figure 3. Inner Namskaket Marsh cross section *B–B'*, showing major sediment types inferred from sediment sampling and subsurface probing with a steel rod. Arrows show inferred directions of groundwater flow, and observed zones of groundwater discharge near the marsh-upland boundary and at the main creek bottom. See figure 1 for location of cross section.

Figure 4. Groundwater flow pattern (freshwater) in a typical salt marsh environment. (From Weiskel and others, 2016)

Most of the groundwater discharge occurs at the estuary boundary between the upland areas and the edge of the peat beds, and as upward flow through the permeable sediments underlying the creek. Groundwater discharge in the interior vegetated areas of the marsh is limited because the thick overlying marsh peat beds have a low permeability. The low permeability of the peat beds also impedes downward percolation of saltwater at high tide. Additionally, the hydraulic gradient in the peat beds is upward as the fresh groundwater underlying the peat beds is under pressure due to the confining nature of the low-permeability peat beds. This is in contrast with a sandy ocean shoreline beach with no marsh border and where full-strength seawater percolates into the shoreline aquifer up to the elevation of high tide.

2.2 Conceptual model of existing conditions in the Herring River basin

Currently there is no significant amount of tidal inflow to the diked Herring River basin. It is essentially at a continuous state of low tide. Fresh groundwater from adjacent upland areas flows toward and discharges into the stream channels. The stream channels essentially act as drainage ditches, causing the water table in adjacent areas to be lowered. After tidal flow is restored, there will be significant portions of each day when fresh groundwater will not be able to discharge into the stream channels because they are flooded with tidal water. During the period when fresh groundwater flow toward the stream channels is reduced, the water table will rise because there is still groundwater flowing toward the stream channels from adjacent upland areas. In effect, the high tide acts as a dam to freshwater outflow. The net result is a slight rise of the mean water table elevation.

According to the Ghyben-Herzberg relationship, described previously, the thickness of the freshwater zone in the aquifer is directly related to the height of the water table above sea level. The ratio is 1:40; for every foot that the water table is above sea level, the depth to the freshwater-saltwater interface will be 40 feet deep. For example, if restoring tidal flow to the Herring River basin increased the mean water table elevation by 3 inches (¼ foot), then the thickness of the freshwater aquifer would increase by 10 feet. The result could improve existing water quality in wells that currently have their screened interval deep in the freshwater aquifer, near the current transition zone from freshwater to saltwater, because the freshwater-saltwater transition zone will be forced downward.

2.3 Summary of Section 2

A lens of freshwater floats above the saltwater in the Cape Cod aquifer. The freshwater zone in the aquifer extends below sea level a distance equal to 40 times the elevation of the water table above sea level. In general, wells located more than 200 feet from the ocean shoreline will encounter a freshwater zone that is thick enough to provide good quality groundwater for domestic use. The thickness of the freshwater zone in the aquifer is expected to be 25-30 feet at a distance of 200 feet from a high salinity ocean shoreline.

Tidal estuaries will have salty water in the near-surface sediments from infiltration of seawater during high tide. However, groundwater underlying the low-permeability peat and marsh sediments will be fresh. The low permeability of peat coupled with upward pressure of fresh groundwater limits the infiltration of saltwater.

Current tidal restriction in Herring River causes a perpetual "low tide" condition that allows groundwater to discharge into stream beds unrestricted by higher tides, thereby lowering the water table. By reintroducing a more natural tidal cycle, the Herring River restoration will cause the water table to rise, and consequently the thickness of the freshwater aquifer will increase.

The basic groundwater science described above suggests that restoration of tidal flow to the Herring River would increase the elevation of the surrounding water table, lower the freshwater/saltwater interface, and thus increase the thickness of the freshwater zone in the aquifer. Hydrogeologic investigations in the Herring River and Mill Creek helped to validate this prediction. Two key points in reaching these conclusions are; 1) there will be a salinity gradient between the mouth of the river and upstream reaches, and 2) tidal restoration will result in an increase in the mean water level in the streams.

3.0 Hydrogeologic Investigations in the Herring River Basin, Mill Creek, and similar hydrogeologic settings

The effect of tidal restoration in the Herring River basin on the freshwater/saltwater relationship in the underlying aquifer has been addressed by several studies using different methods. Some of these studies are summarized in this section.

3.1 Geophysical monitoring wells; Fitterman and others (1989), Fitterman and Dennehy (1991)

Fitterman and others (1989) conducted geophysical surveys on the highlands to the east of the Herring River. They determined that the freshwater aquifer was at least 10 meters (33 feet) thick at the very edge of the flood plain and increased with distance away from the river. They used an analytical equation to evaluate how increased tidal fluctuation in the river would affect the water table adjacent to the stream. They concluded that completely opening the existing tide gates would have no effect on wells in the uplands east of the river because the mean river level would not change, and the area affected by water table fluctuations would be limited to "a few tens of meters" from the river. The distance is of little importance as they were only considering the distance within which tidal flow in the river would affect water table elevations at nearby wells. They did not evaluate the potential effect of tidal restoration on the freshwater/saltwater interface or the thickness of the freshwater zone in the aquifer.

In a subsequent study, Fitterman and Dennehy (1991) installed monitoring wells that verified the results of the geophysical investigation conducted in 1989. They found that the thickness of the freshwater aquifer at four monitoring wells (Figure 5, wells labeled WNW 115-118)) ranged from 18-22 meters (56-72 feet). At two monitoring wells immediately landward of the flood plain of the Herring River (WNW-115 & WNW-117), the thickness of the freshwater aquifer was determined to be approximately 65 and 56 feet respectively.

Fitterman and Dennehy (1991) assumed that completely opening the existing tide gates would cause both static-water and high-tide levels in the Herring River to increase by less than 0.5 meter. They then concluded that such a small increase, compared to the large thickness of the freshwater aquifer, makes it unlikely that the thickness of the freshwater aquifer or the position of the fresh/salty groundwater interface would change at wells in the highlands east of the Herring River. They did acknowledge that wells in the former tidal flood plain areas along High Toss Road could potentially draw salty water due to infiltration of saltwater from the surface or repositioning of the fresh/salty groundwater interface (Fitterman and Dennehy, 1991). Subsequent investigations by Howes and others (1996), Weiskel and others (2016), and Martin (2007) show that infiltration of saltwater penetrates only a few meters below the ground surface in an estuary flood plain and occurs only within the immediate vicinity of areas flooded by saltwater at high tide. Thus, unless a well is flooded at high tide and experiences saltwater infiltration around the casing, it is unlikely to be affected as the screened interval is typically 15-20 feet below ground surface.

Figure 5. Location of USGS geophysical monitoring wells in the Herring River and Mill Creek basins

Two additional geophysical monitoring wells were constructed in September 2003 to facilitate monitoring the depth of the freshwater/saltwater interface in other areas near the flood plain that might be affected by restoration of tidal flow in Herring River and Mill Creek (Wells WNW-133 and WNW-134). Well WNW-141 was constructed in 2004. The locations of wells installed by Fitterman and Dennehy, and subsequent wells installed in 2003 and 2004 are shown on Figure 5.

Figure 6 shows an example of the geophysical log from one of those wells located in upland adjacent to the estuary flood plain. The log clearly shows the low conductivity of the freshwater zone to a depth of about 65 feet, then a transition zone from 65-75 feet, then high conductivity below 75 feet, indicative of salt water.

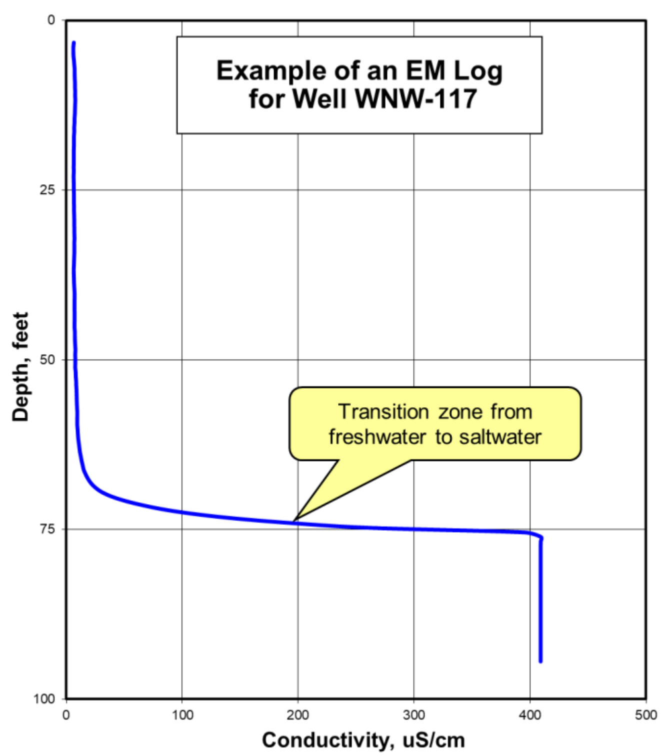


Figure 6. Example of electromagnetic induction log at Well WNW-117

3.2 Namskaket Marsh; Howes and others (1996)

Howes and others (1996) showed that the area in which saltwater infiltrates into the sediments underlying a tidal salt marsh is limited to the area that is regularly inundated and to a depth of 2-3 meters (Figure 7). Deeper sediments adjacent to the tidal flooding are consistently saturated with freshwater, as shown in Figures 3, 4, and 7.

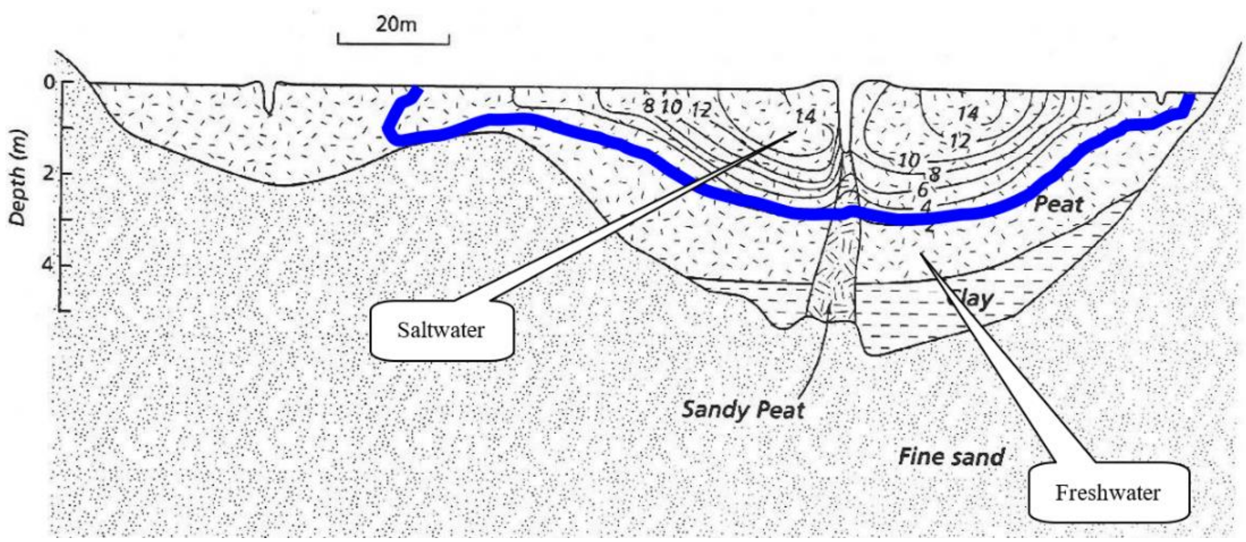


Figure 7. Salinity of groundwater in sediments underlying Namskaket Marsh. Contour lines are labeled in ppt salinity. (From Howes and others, 1996)

3.3 Wellfleet Harbor; (Portnoy and Martin, 2007)

Portnoy and Martin (2007) investigated tidal fluctuations in groundwater at various distances from a salt-marsh fringed ocean shoreline (Figure 8). They showed that the tidal fluctuation of groundwater levels was greatly dampened, even at short distances from the shoreline in Wellfleet Harbor where the tidal range is 9 feet. Additionally, they showed that there was fresh groundwater (245 µS/cm) at Well # 3, located just 59 feet from the edge of the salt marsh, despite biweekly seawater inundation of the salt marsh during spring tides.

National Park Service staff recently started monitoring groundwater levels and salinity in these wells. Data from these wells are expected to verify the presence of fresh groundwater underlying areas that are regularly inundated by tidal flow.

Figure 8. Well locations downstream of the Herring River dike. Portnoy and Martin (2007)

3.4 USGS computer modeling of potential effects of tide restoration in the Herring River

Masterson (2004) conducted a regional investigation of the lower Cape Cod aquifer system. The investigation was designed to improve the understanding of the hydrogeology of the aquifer system and to assess the effects of changing groundwater pumping, recharge conditions, and sea level rise on the groundwater flow system. Near the end of the investigation, after the first draft of the report had been written, Masterson was asked to include an assessment of the effects of tidal restoration in the Herring River basin. The computer model that had been constructed to evaluate the original objectives of the investigation did not include the site-specific data that would be needed to perform the local-scale analyses to assess the effects of tidal restoration.

Output from the hydrodynamic model of tidal flow developed by Spaulding and Grilli (2001) was used to develop four scenarios to assess the effect of restoring tidal flow in the Herring River basin on the altitude of the freshwater/saltwater interface. The four computer model scenarios evaluated combinations of increasing the mean water elevation and changing the salinity distribution in the Herring Basin.

Computer modeling produced mixed results in predicting future conditions of the elevation of the fresh/salt groundwater interface and the thickness of the freshwater zone in the aquifer. The predictions produced by these modeling scenarios are not applicable to the planned restoration of tidal flow in the Herring River system because the model parameter inputs that were used do not reflect the hydrologic conditions of an intertidal estuarine system. The computer model was designed to assess groundwater flow on a regional scale, not to evaluate conditions on a local scale. The model does not mimic the salinity gradient and ebb and flow of saltwater that occur in an intertidal estuary

3.5 Summary of Section 3

Hydrologic investigations in the Herring River basin show that the freshwater zone in the aquifer adjacent to the river flood plain is 33-72 feet thick. Investigations at other locations with similar hydrogeologic conditions show that the area in which saltwater infiltrates into the sediments underlying a tidal marsh is limited to the area that is regularly inundated, and in those locations, infiltration only occurs to a depth of 2-3 meters. The aquifer underlying tidally flooded areas will continue to have a zone of freshwater after tidal flow is restored. Tidal restoration is expected to increase the mean water level in the river and streams, thus slightly raising the surrounding water table, increasing the thickness of the freshwater lens, and lowering the elevation of the salt/freshwater interface. Restoration of tidal flow in the Herring River is not expected to affect adjacent water-supply wells unless a well were regularly inundated by tidal flow at the ground surface.

Masterson (2004) attempted to model the potential effect of tidal restoration in the Herring River system on the depth to the fresh/saltwater interface and thickness of the freshwater lens; however, the model did not mimic the ebb and flow of saltwater in the river system. Therefore, the model outputs are not valid predictions of expected future conditions after tidal restoration in Herring River. Results from multiple investigations strongly support the conclusion that water quality in all wells above the reach of predicted surface-water flooding will not be affected by tidal restoration.

4.0 Investigations of potential effects of restored tidal flow on domestic water-supply wells:

The basic groundwater science described in Section 2 and the hydrogeologic assessments described in Section 3 show that restoration of tidal flow in the Herring River basin is not expected to have an impact on domestic water-supply wells unless the well heads were inundated with salt water at the ground surface.

Larry Martin, author of this report and retired National Park Service Hydrogeologist, conducted several investigations to further assess the potential for restored tidal flow to affect private domestic wells in the Mill Creek and Herring River (Martin, 2004; Martin, 2007).

4.1 Martin (2004)

Martin (2004) evaluated the potential for saltwater intrusion by comparing hydrogeologic conditions in the Herring River basin with other, similar areas (Namskaket Marsh, Lieutenant Island, Wellfleet Harbor along Chequessett Neck Road) that are adjacent to saltwater bodies and tidal estuaries. Evaluation included computer modeling of the local groundwater flow system using the predicted tidal conditions that would result from various alternatives of opening or removing the existing tidal control structures (as described in Spaulding and Grilli, 2001). This investigation relied on findings from previous computer modeling of the groundwater flow system (Masterson 2004) that indicated that the thickness of the freshwater aquifer could become thinner for certain simulated conditions.

As a worst-case condition, Martin (2004) evaluated the potential extent of saltwater intrusion as if the restored tidal areas were permanently flooded with seawater, creating a new ocean shoreline at the margin of tidally flooded areas. Analytical modeling of the depth of the freshwater/saltwater interface at various distances from the tidally flooded areas showed that any change in the thickness of the freshwater aquifer would be restricted to an area underlying and immediately adjacent to the newly restored tidal estuaries (within about 200 feet), because the thickness of the freshwater aquifer increases quickly inland from ocean shorelines.

After examining available data for wells at properties adjacent to the ocean shoreline (for example along Chequessett Neck Road west of Wellfleet town center and the Indian Neck area), it was determined that wells constructed less than about 200 feet from the ocean and/or screened near the bottom (less than 10 feet above the freshwater/saltwater interface) of the freshwater aquifer could be susceptible to saltwater intrusion. Wells located more than about 200 feet from ocean shorelines and having their screened interval a significant distance (more than 15 feet) above the bottom of the freshwater zone in the aquifer generally produce good quality water.

Further investigation of existing wells in the Wellfleet area that are located adjacent to salt-water bodies (Wellfleet Harbor and Cape Cod Bay) showed that wells with poor quality water are typically; 1) located less than 100-150 feet from a high salinity oceanic water body, where the freshwater aquifer is thin , and/or 2) have well screens deep enough below the water table to draw water from the transition zone between fresh and salty groundwater. Wells providing good quality groundwater are typically located more than 150 feet from a salt-water body and have the well screen located only a few feet below the water table, which is far above the transition zone.

The 200-foot distance from ocean shorelines was considered a conservative scenario for evaluation of potential impacts on wells in the Herring River and Mill Creek areas because, as has been discussed in previous sections of this report, numerous investigations have shown that there is generally fresh groundwater underlying tidal estuaries. Salt water floods estuaries for only a few hours during each tidal cycle, unlike an ocean shoreline setting where saltwater is continuously present, such as at the edge of Wellfleet Harbor or Cape Cod Bay. In the Herring River estuary, the upward flow of fresh groundwater underlying the salt marshes impedes the infiltration of saltwater. The extent of saltwater in sediments underlying tidal marshes and estuaries is limited to the area flooded with saltwater at high tide, as shown in Figure 7.

In Figures 4 and 19 of the report, Martin (2004) showed conceptual illustrations of the upward relocation of the freshwater/saltwater interface to a higher elevation following tidal restoration. Subsequent field studies have shown that those conceptual illustrations are incorrect. For example, investigations of saltwater infiltration at Namskaket Marsh (Weiskel and others, 2016) clearly show that saltwater infiltrates only a few meters and that freshwater occurs in deeper sediments below the tidal estuary.

4.2 Martin (2007)

After the 2004 report, it was decided that further investigations would be conducted to identify any private domestic wells that could potentially be affected by full tidal restoration. The work began in 2006 by examining well records for homes along Chequesset Neck Road, south of the Herring River dike which border Wellfleet Harbor and the Indian Neck area on the east side of the harbor. Both areas represent the worst-case condition for changes of the fresh/salt water interface, assuming a permanent saltwater body adjacent to the upland. Because the freshwater lens is thinner at the shoreline of a permanent saltwater body, the well's setback from the shoreline generally needs to be greater than it does for wells within the Herring River estuary.

Basic water chemistry from 24 wells at Indian Neck showed variation in their salt content, but all were below EPA's maximum limit for drinking water. Many of the wells were less than 250 feet from the shoreline and still yielded good quality drinking water. The wells along Chequesset Neck Road also varied in water quality. Some of the wells within 100-150 feet from the harbor had poor water quality because their screens were set too deep, probably approaching the fresh/saltwater interface. Those that were further from the shoreline had acceptable water quality.

Using the results of the first part of the 2007 report, additional analyses within the Herring River basin were then conducted to identify private properties within 250 feet of areas that would potentially be flooded by salt water during high tides, following restoration of tidal flow. Previous work had shown that the freshwater zone in the aquifer would have sufficient thickness to provide good quality water to wells located more than 200 feet from a saltwater shoreline. However, in order to ensure a conservative and comprehensive analysis, Martin used a distance of 250 feet in the 2006-07 investigation. Those parcels were then individually examined to determine the location of the well on the parcel, the depth of the well, depth of the screened interval, water table elevation, and the salt content of well water. That information allowed an assessment of the potential for saltwater intrusion at those wells on an individual basis.

In the summer 2007, the location of domestic wells adjacent to the Herring River flood plain basin was determined by examination of Assessors' Atlas maps, information on file at the Truro and Wellfleet Health Departments, and field inspections of individual properties. Wells that were located more than 20-30 feet away from, and at an elevation more than a few feet higher than, potentially flooded areas were deemed to be beyond the area of potential impact from tidal flooding. These criteria were based on the numerous investigations cited previously in this report and from observations of other areas on the outer Cape Cod where there are domestic wells close to tidal wetlands.

The office and field investigations in 2007 showed that most of the private domestic wells identified as potentially "at risk" in the report by Martin (2004) were outside the area of potential tidal flooding and, thus, would not be impacted by restoration of tidal flow. A small number of properties were identified as having wells that could potentially be impacted by full restoration of tidal flow. Wells on seven parcels were identified as at risk of surface inundation by salt water from restoration of full tidal flow. They include three wells on the eastern side of the Lower Herring River sub-basin and four wells in the Mill Creek sub-basin, one on the northern side and three on the southern side. Two of the properties (70 Way 672 and 90 Way 672) on the eastern side of the Lower Herring River have been, or are anticipated to be, acquired by the National Park Service, with buildings removed and wells plugged.

The five remaining wells would be susceptible to saltwater inundation at the ground surface of the casing at various points during the restoration of tidal flow. Since the restoration will proceed in phases, not all these wells would need to be protected at the same time in the restoration. Phase 1 restores a smaller portion of the flood plain with a lower maximum water surface elevation than the full restoration. It covers only a portion of the Mill Creek sub-basin and excludes the Upper Pole Dike Creek sub-basin. The maximum water levels for Phase 1 would only reach three of the five wells in the absence of protective actions. Those include one well in the Lower Herring River sub-basin and two in Mill Creek sub-basin. The other two wells would not be vulnerable to tidal inundation until later phases of the restoration. Options to protect all five of the wells in advance of when water levels would reach them are discussed below.

4.3 Water-supply well at 505 Old Chequessett Neck Road in Mill Creek:

The water-supply well for this property is located about 60 feet east of the house at a surveyed elevation of 4.0 feet NAVD88 (Figure 9). A tributary of Mill Creek called Snake Creek, is south and east of the house. Current plans for tidal restoration are to limit mean high spring tides in the Mill Creek sub-basin to 2.4 feet NAVD88 and the maximum water surface elevation during extreme storm events to 3.7 feet NAVD88 to prevent flooding of unprotected structures. Both tidal elevations are below the ground elevation at the well casing.

In October 2014, I compiled all the available information and wrote a summary report to assess the potential for the well at this property to be affected by tidal restoration (Martin, 2014). The report was not published or distributed.

The report (Martin, 2014) provides clear evidence that the well was drilled too deep. The perforated interval of the well is at a depth of 52-55 feet below ground surface, near the transition zone between the freshwater aquifer and the underlying saltwater. Water pumped from the well has higher concentrations of sodium (115 mg/l) and higher conductivity (683 umhos/cm) than water pumped from the freshwater aquifer at adjacent properties. Based on tide-height model predictions, mean water level in the restored estuary will increase, causing the mean groundwater table elevation in adjacent locations to increase slightly. Based on the

Ghyben-Herzberg relationship (see Section 1 of this report), this will result in a thicker freshwater lens and lower elevation of the fresh-salt groundwater interface in areas abutting the estuary, possibly improving water quality at the well.

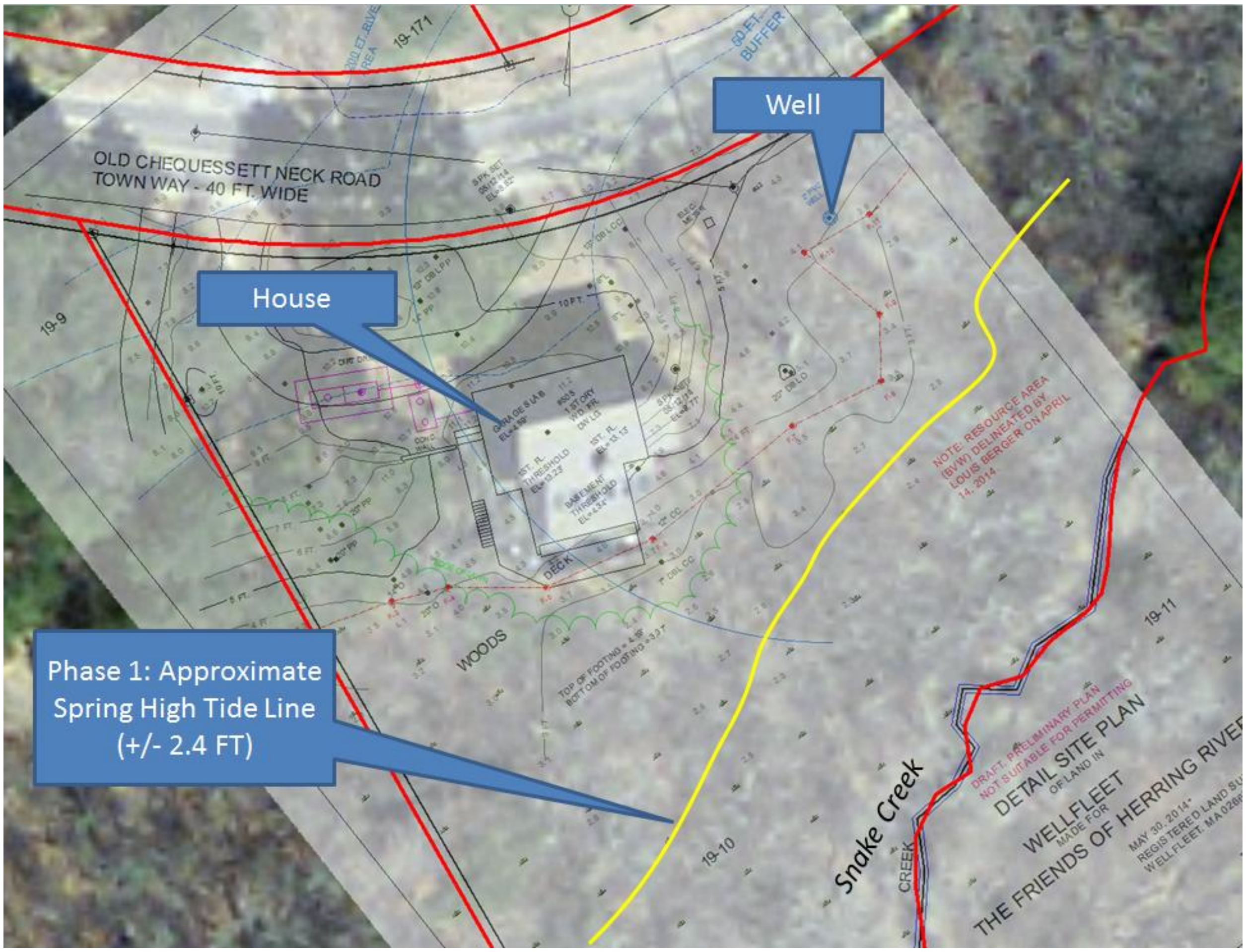


Figure 9. Site plan of the property at 505 Chequessett Neck Road.

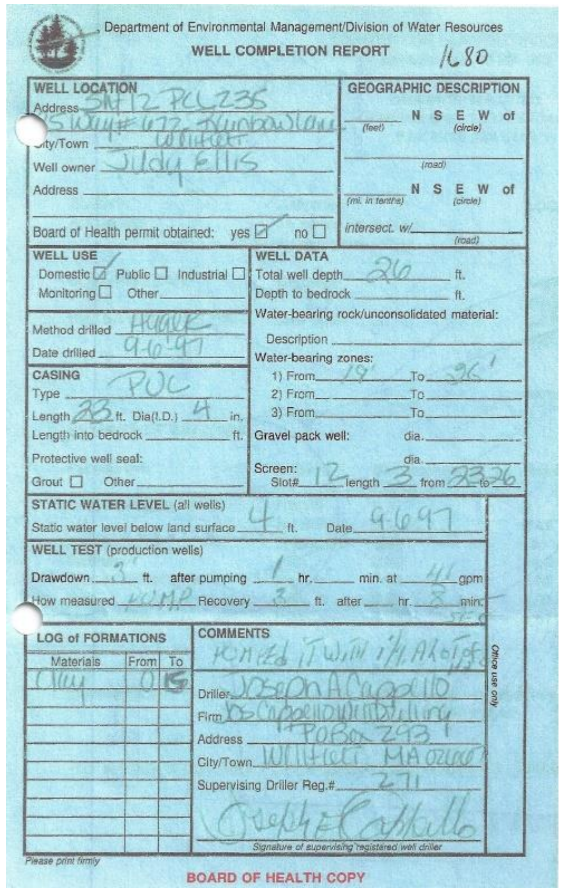
Earlier in this report, several examples were provided to show that tidal marshes are underlain by freshwater, and that saltwater generally does not infiltrate from the surface because it is opposed by the seaward flow of freshwater toward tidal streams. The well at 505 Chequessett Neck Road will not be threatened from surface infiltration of saltwater during Phase 1 of restoration because maximum normal and storm tide water levels will remain below the land surface at this well.

4.4 Water-supply well at 27 Way 672 in the Lower Herring River sub-basin

The property at 27 Way 672 is south of High Toss Road, on the east side of the Herring River valley (Figure 10). The existing water-supply well is located in the lowland area on the west side of Way 672. Land surface elevation at the well is 3.2 feet NAVD88.

Figure 10. Site plan of the 27 Way 672 property.

The well completion report for the well is shown in Figure 11. The well is 26 feet deep. The geologic log shows a clay layer from the land surface to a depth of 15 feet. Presumably, sand underlies the clay, as the completion report identifies the water bearing zone from 19-26 feet. The well was completed with PVC casing to a depth of 23 feet and with a well screen from 23-26 feet. Infiltration of rainfall on the adjacent upland areas recharges the freshwater aquifer. Fresh groundwater flows from recharge areas in the uplands toward discharge areas in the stream valley as shown in Figure 4. Figure 12 shows the addition of the well to the schematic cross-section from Figure 4 of this report.



Department of Environmental Management/Division of Water Resources

WELL COMPLETION REPORT 1680

WELL LOCATION
Address SM12 PCL235
S Way#672 Rainbow Lane
City/Town Wellfleet
Well owner Judy Ellis
Address
Board of Health permit obtained: yes ☑ no ☐

GEOGRAPHIC DESCRIPTION
(feet) N S E W (circle) of
(road)
(mi. in tenths) N S E W (circle) of
intersect. w/ (road)

WELL USE
Domestic ☑ Public ☐ Industrial ☐
Monitoring ☐ Other

Method drilled Auger
Date drilled 9-6-97

CASING
Type PVC
Length 23 ft. Dia(I.D.) 4 in.
Length into bedrock ft.
Protective well seal:
Grout ☐ Other

WELL DATA
Total well depth 26 ft.
Depth to bedrock ft.
Water-bearing rock/unconsolidated material:
Description
Water-bearing zones:
1) From 19' To 26'
2) From To
3) From To
Gravel pack well: dia.
dia.
Screen: Slot# 12 length 3 from 23 to 26

STATIC WATER LEVEL (all wells)
Static water level below land surface 4 ft. Date 9-6-97

WELL TEST (production wells)
Drawdown 3" ft. after pumping 1 hr. min. at 41 gpm
How measured PUMP Recovery 3 ft. after hr. 8 min.

LOG of FORMATIONS

Materials	From	To
Clay	0	15

COMMENTS

Driller Joseph A Cappello
Firm Jos Cappello Well Drilling
Address PO Box 293
City/Town Wellfleet MA 02667
Supervising Driller Reg.# 271

Signature of supervising registered well driller

Office use only

Please print firmly

BOARD OF HEALTH COPY

Figure 11. Well completion report for the Way 672 well.

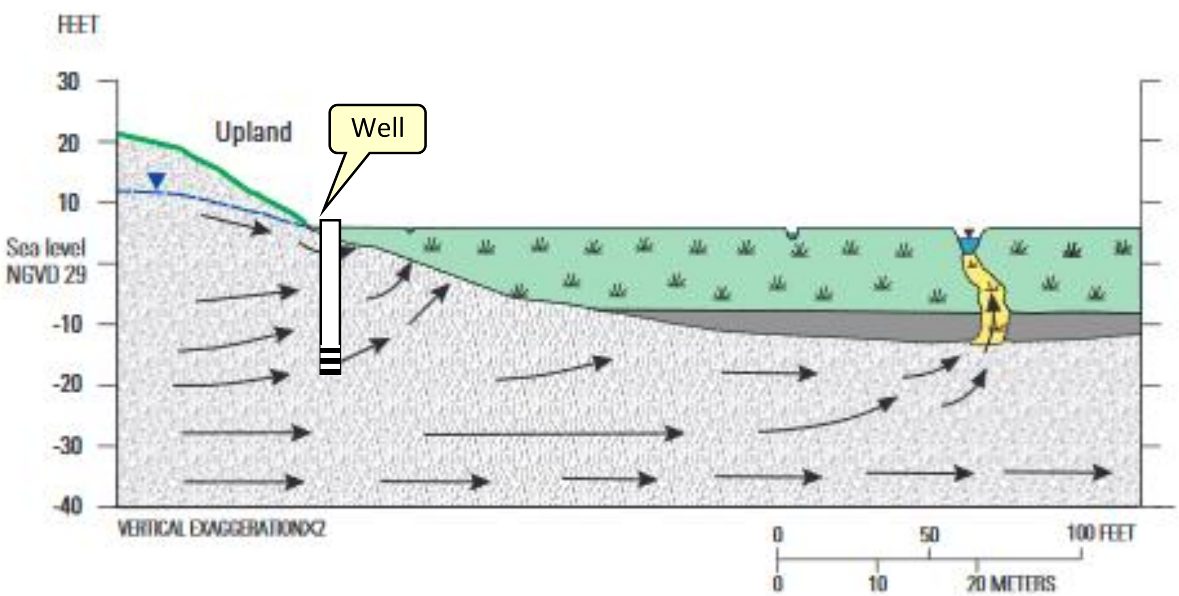


Figure 12. Schematic cross-section showing the relationship of the existing well serving Way 672 to hydrogeologic features.

Records of water quality from two tests of the well are available. In 1997, the sodium concentration was 35 mg/l and the specific conductance was 284 umhos/cm. In 2015, the sodium concentration was 40 mg/l and the specific conductance was 320 umhos/cm. Specific conductance of water from the well can easily be monitored as a surrogate for salinity. If saltwater was getting into the well, the conductance would increase.

The water quality of the well can be compared with that from a neighboring well serving 255 High Toss Road. That well was constructed and tested in 1988. The well is screened from 31-34 feet below ground surface, but since the ground surface is higher than at the well serving 27 Way 672, the well is screened higher in the freshwater aquifer. The well serving 255 High Toss Road had a sodium concentration of 15 mg/l and specific conductance of 129 umhos/cm, typical of high-quality Cape Cod groundwater.

The well serving 27 Way 672 is located at a ground surface elevation that, absent mitigation measures, would be inundated during Phase 1 of the restoration. In discussions of mitigation options with the landowner, the Project proponents proposed to relocate the well to an upland area on the property that is outside the area of tidal inundation and that would provide good quality potable water for the residence (Figure 13). The water quality data from a comparably located well serving a neighboring property show that relocating the well to the upland location and screening the new well higher in the freshwater aquifer would likely result in water quality equal to or better than the existing well. However, as of the publication date of this report, the property owner has not agreed to the well relocation.

Phase 1 plans include construction of a physical barrier on adjacent NPS property to prevent tidal flow from inundating the properties at #25 and #27 Way 672. This barrier will also prevent salt water inundation of the well at #27 Way 672 and therefore prevent adverse effects on well water quality from tidal restoration. The physical barrier will be built with adequate freeboard above the elevation of the storm of record.

4.5 Water-supply wells at 60, 70, and 80 Mill Creek Lane in the Mill Creek sub-basin:

The land surface elevations at two wells that are on the southern side of the Mill Creek sub-basin are below the maximum water surface elevation under full restoration (3.7’ NAVD88) and near the elevation of the spring high tide (2.4’ NAVD88) for Phase I restoration. Land surface elevation at the wells providing water to the residences at 70 Mill Creek Lane and 80 Mill Creek Lane is 2.6’ NAVD88 for both wells. Wells at 70 and 80 Mill Creek Lane will be replaced with new wells, consistent with the property owners’ permission, at locations above the maximum water surface elevation of even full restoration.

The well serving the residence at 60 Mill Creek Lane is at an elevation of 5.6’ NAVD88, nearly two feet higher than the projected water surface elevation at full restoration. It is unlikely that this well would be affected by the tidal restoration project, but it will be monitored for potential water quality changes. If necessary, project proponents would work with the landowner to either protect this well in place or relocate the well at a higher elevation.

4.6 Summary of Section 4:

The vulnerability criteria of wells in a worst-case situation, i.e. adjacent to a permanent saltwater body, were applied to the estuary landscape throughout the Herring River basin, resulting in a conservative vulnerability screening analysis. Properties within 250 feet of areas that would be inundated by tidal flow were evaluated to assess the potential vulnerability of water-supply wells to salt water inundation. Most wells evaluated are located in upland areas or with sufficient setback from areas that will be inundated and therefore will not be affected by restoration of tidal flow in the Herring River and Mill Creek basins.

Seven wells were identified as having potential impacts during full tidal restoration. Two of those wells are located on properties now, or soon to be, owned by NPS and will be capped and abandoned. Of the five remaining wells identified, three would be susceptible to tidal inundation under Phase 1 of the restoration. One well in Lower Herring River will be protected by a physical barrier that will prevent tidal flow from inundating the well casing. The two wells at risk during Phase 1 in Mill Creek will be replaced with new wells located at higher elevations on those properties.

The two other wells that could be susceptible to water quality impacts in future restoration phases, are located in the Mill Creek basin and are not at risk of inundation during Phase 1.

Summary of findings for the seven wells discussed in Section 4:

- 70 and 90 Way 672: these properties have been, or will be, acquired by the National Park Service prior to tidal restoration, and the wells will be plugged and abandoned.
- 27 Way 672: an offer to relocate this well was declined by the property owner; this well will be protected from salt water inundation by construction of a physical barrier on National Park Service property.
- 505 Old Chequessett Neck Road: the maximum water surface elevation under Phase 1 restoration will be lower than the elevation of the ground surface at the well head and so protection from tidal inundation is not necessary until later phases of the Project.
- 70 and 80 Mill Creek Lane: since these wells would be overtopped by tidal water during Phase 1 restoration, they will be relocated to a location above maximum water levels under both Phase 1 and also for full restoration, consistent with permissions granted by property owners.
- 60 Mill Creek Lane: the well is at a higher elevation than the projected water surface elevation at full tidal restoration and is unlikely to be affected.

5.0 Conclusions

Assessment of the potential for tidal restoration to affect private, domestic wells in the Herring River basin has proceeded in a sequential and methodical manner over the past several decades. Numerous analytical and modeling evaluations, and field investigations have been conducted to enhance the scientific understanding of the interaction between tidal flow and groundwater hydrology in the Herring River and other similar Cape Cod estuaries. These studies evolved over time to provide a solid basis for assessing the risk of impacts to water quality in drinking water wells during the restoration of tidal flow into the Herring River estuary.

1. Field investigations and analytical modeling using the Ghyben-Herzberg relationship determined that the freshwater zone in the Cape Cod aquifer should generally be 25-30 feet thick at a distance of 200 feet from a permanently flooded ocean shoreline. However, salinity gradients within estuaries can result in adjacent freshwater aquifers being much thicker than those adjacent to permanently flooded, sandy ocean shorelines. This has been confirmed by test wells driven at the edge of the Herring River estuary.
2. Hydrogeologic conditions of intertidal estuaries differ substantially from those of permanently flooded ocean shorelines. Intertidal estuaries maintain a freshwater aquifer beneath the surface sediments. The intermittent ebb and flood cycles of tidal inundation in an estuary, combined with low permeability of peat and upward pressure of fresh groundwater, limit the infiltration of saltwater to shallow surface sediments.
3. Initial efforts to assess potential effects of tidal restoration in the Herring River basin on nearby domestic water-supply wells assumed (incorrectly) that saltwater fully penetrates sediments underlying tidal estuaries. In addition, some investigations used data inputs and produced findings that are not applicable to the Herring River intertidal estuarine setting because they assumed and/or applied hydrogeologic conditions found along oceanic shorelines with consistently high surface-water salinity.
4. Current tidal restriction in the Herring River basin creates a perpetual "low tide" condition that allows groundwater to continuously discharge to stream channels, unrestricted by high tides. These conditions create an artificially low water table compared to an unrestricted tidal estuary that is flooded by high tides twice daily. By reintroducing a substantially larger, more natural tidal range, the restoration project will increase the mean water level in the system. An increase in mean water level in Herring River will cause the water table within and directly adjacent to the flood plain to rise slightly. Thus, per the Ghyben-Herzberg relationship, the thickness of the aquifer's freshwater zone, as well as the depth to the fresh/salt groundwater interface, will both increase in locations adjacent to areas of increased tide range.
5. Most private, domestic wells near Herring River are located in upland areas, outside the limits of proposed tidal flooding. These wells will not be affected by restoration of tidal flow.

6. Domestic water-supply wells at seven properties were identified as potentially at risk from full restoration of tidal flow. These wells are located in the flood plains of estuarine streams and could be inundated at the ground surface by salt water. Mitigation measures have been identified to protect water quality for five wells that would be susceptible to inundation during Phase 1 of the restoration. The two other wells that could be inundated during future phases of restoration beyond Phase 1 would require mitigation measures (relocation or protection) before additional tidal restoration is implemented.

<u>References</u>

Barlow, Paul M., 2003, *Ground Water in Freshwater-Saltwater Environments of the Atlantic Coast*, U.S. Geological Survey Circular 126, 113 pp https://pubs.er.usgs.gov/publication/cir1262

Fetter, C.W., 2001, *Applied Hydrogeology*, 4th ed., Prentice Hall publisher, 598 pp.

Fitterman, David V., Glenn A. Brooks, and Stephen L. Snyder, 1989, *Geophysical Investigation of Depth to Saltwater Near the Herring River, Cape Cod National Seashore, Wellfleet, Massachusetts,* USGS Open-File Report 89-677, 69 pp. https://pubs.er.usgs.gov/publication/ofr89677

Fitterman, David V., and Kevin Dennehy, 1991, *Verification of Geophysically Determined Depths to Saltwater Near the Herring River, Cape Cod National Seashore, Wellfleet, Massachusetts*, USGS Open-File Report 91-321, 47 pp. https://pubs.er.usgs.gov/publication/ofr91321

Howes, B.L., P.K. Weiskel, D.D. Geohringer and J.M. Teal. 1996. Interception of freshwater and nitrogen transport from uplands to coastal waters: the role of saltmarshes. Pages 287-310 in K.F. Nordstrom and C.T. Roman, editors, *Estuarine shores: evolution, environments, and human alterations*. John Wiley & Sons, New York.

LeBlanc, Denis R., J.H. Guswa, M.H. Frimpter, and C.J. Londquist, 1986, *Ground-water Resources of Cape Cod, Massachusetts*, U.S. Geological Survey Hydrologic Atlas 692, 4 sheets https://pubs.er.usgs.gov/publication/ha692

Martin, Larry, 2004, *Salt Marsh Restoration at Herring River: An Assessment of Potential Saltwater Intrusion in Areas Adjacent to Herring River and Mill Creek, Cape Cod National Seashore*, National Park Service Technical Report NPS/NRWRD/NRTR-2004/319, 25 pp. https://irma.nps.gov/DataStore/Reference/Profile/563504

Martin, Larry, 2007a, *Assessment of Potential Saltwater Encroachment in the Herring River Basin, Cape Cod National Seashore* NPS/NRPC/WRD/NRTR—2007/370, National Park Service, Ft. Collins, CO. https://irma.nps.gov/DataStore/Reference/Profile/2174236

Martin, Larry, 2007b, Memo to John Portnoy, National Park Service, *Identification of private domestic wells adjacent to the Herring River flood plain that could be affected by restoration of tidal flow*, 8 pp.

Martin, Larry, 2014, *Comments regarding the potential for saltwater intrusion at the Nieski water-supply well*, unpublished, 9 pp.

Masterson, J.P., 2004, *Simulated Interaction Between Freshwater and Saltwater and Effects of Ground-water Pumping and Sea-Level Change, Lower Cape Cod Aquifer System, Massachusetts*, U.S. Geological Survey Scientific Investigations Report 2004-5014, 78 pp. https://pubs.er.usgs.gov/publication/sir20045014

Niedoroda A and April R., 1975, *Report on Groundwater Flow Beneath Coastal Salt Marshes*, University of Massachusetts - National Park Service Cooperative Research Unit, Amherst, MA, 49 pp. https://irma.nps.gov/DataStore/Reference/Profile/104409

Portnoy, John, and Larry Martin, 2007, *Tidal Fluctuations in Groundwater Level Normal to a Salt-marsh-fringed Shoreline, Herring River Estuary, Wellfleet (Massachusetts)* unpublished, 9 pages https://irma.nps.gov/DataStore/Reference/Profile/2198112

Portnoy, J.W, B.L. Nowicki, C.T. Roman, and D.W. Urish, 1998, *The Discharge of Nitrate-Contaminated Groundwater from Developed Shoreline to Marsh-Fringed Estuary*, Water Resources Research, Vol. 34, No. 11, pp. 3095-3104

Spaulding, M., and A. Grilli. 2001. Hydrodynamic and salinity modeling for estuarine restoration at Herring River, Wellfleet, Massachusetts. Report to National Park Service. 94 pp.

Weiskel, P.K., Barbaro, J.R., and DeSimone, L.A., 2016, *Environmental Conditions in the Namskaket Marsh Area, Orleans, Massachusetts -A Summary of Studies by the U.S. Geological Survey, 1989–2011*, U.S. Geological Survey Scientific Investigations Report 2016–5122, 29 pp., https://pubs.usgs.gov/sir/2016/5122/sir20165122.pdf

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Mr. Martin has 40 years of experience as a professional hydrogeologist, including 25 years with the National Park Service. During that time, he authored or coauthored 13 peer reviewed reports along with numerous memos and trip reports specific to the hydrology and hydrogeology of Cape Cod National Seashore.

During his 25-year career with the National Park Service, He conducted investigations at more than 90 different park units, resulting in more than 200 reports.