Estimates of Ecosystem Service Values from Ecological Restoration Projects in Massachusetts

Commonwealth of Massachusetts
Department of Fish & Game

MASSACHUSETTS DEPARTMENT OF FISH AND GAME
Division of Ecological Restoration

January 2014

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Analysis provided by ICF International under contract to the Massachusetts Department of Fish and Game, Division of Ecological Restoration

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Acknowledgements

The Division of Ecological Restoration would like to thank the economists at ICF International and their sub-consultants at Land and Coastal Services, LLC for their work on this project. In addition, our restoration partners at the Town of Salisbury, Town of Wellfleet, Towns of Chatham and Harwich, and the Cape Cod National Seashore assisted in the production of this report.

Note: a Summary of Findings from this report is available on the
Division of Ecological Restoration web site at:
http://www.mass.gov/eea/docs/dfg/der/pdf/eco-services-summary-ma-der.pdf

Preface

The Massachusetts Department of Fish and Game, Division of Ecological Restoration (DER) collaborates with federal, state, and local partners to implement aquatic habitat restoration projects across the Commonwealth. These projects are planned and designed based on rigorous science and engineering to restore river and wetland habitats and their ecosystem services. The term “ecosystem services” refers to the goods and services that healthy ecosystems provide to humans, such as clean and plentiful water, flood storage, biodiversity, fisheries production, and recreational opportunities. Collectively, these services form a ‘green infrastructure’ foundation that supports economic prosperity, public health and safety, and a high quality of life for Massachusetts residents.

It has long been recognized that healthy ecosystems hold important societal value and that restoration of degraded habitats generates significant benefits for people and the environment. Prior to this study however, the benefits of ecological restoration had not been translated into monetary effects on the Massachusetts economy. To address this information gap, DER initiated a two-phase study in 2011 to begin to estimate the economic value and return on investment of restoration projects in Massachusetts. The goal of the study was to improve our understanding of economic effects and to underpin the qualitative benefits of restoration with quantified dollar value estimates.

In 2011, DER contracted with economists from Industrial Economics, Inc. to complete phase 1 of the valuation study. Design and construction expenditures from four representative DER projects (one dam removal, one culvert replacement, and two multi-practice wetland restoration projects) were analyzed using the IMPLAN model of the Massachusetts economy. The results revealed extensive ripple effects from these investments in indirect and induced economic activity. The analysis showed that the average economic output of DER projects generates a 75% return on investment and creates or maintains 12.5 full-time-equivalent jobs for every $1 million spent. These results equal or exceed those for other capital projects such as road and bridge construction, and replacement of water infrastructure.

Phase 2 of the study estimated the economic value of selected ecosystem services improved by DER projects. Under contract with DER in 2012-2013, economists from ICF International analyzed four types of ecosystem service enhancements: flood protection, water quality, carbon sequestration, and landscape appeal. The findings show a significant increase in value for the selected ecosystem services which represent just one of many service benefits resulting from each restoration project. This document presents the phase 2 findings developed by ICF International.

The combined findings of DER’s two-phase study demonstrate that ecological restoration projects stimulate regional economic activity through design and construction expenditures, and generate substantial economic value by improving ecosystem services.

Section 1: Flood Protection – Economic Impacts of the Town Creek Flood Mitigation and Salt Marsh Restoration Project

Overview

Removal of aquatic barriers like dams and undersized culverts often results in substantial reduction of flood inundation upstream of these barriers. Similarly, improvement of existing tidal control structures can have important flood protection benefits for upstream properties and infrastructure while restoring ecological health.

In 2005, 2006, and 2007, the Town of Salisbury, MA experienced floods that resulted in municipal and business infrastructure and inventory damage, temporary closure of the main transportation artery through town (Route 1), and temporary closure of several local businesses. The floods were caused by the failure during storm events of an old railroad dike and tide gate across the mouth of Town Creek that also blocked salt water from reaching upstream wetlands. The purpose of this economic analysis is to estimate the value of flood damage avoided by implementation of the Town Creek Flood Mitigation and Salt Marsh Restoration Project. The project includes the installation of two new culverts and tide gates in the dike at the mouth of the creek in Salisbury. The project will improve flood protection for upstream properties and infrastructure, and help restore more natural tidal conditions and ecological health to 56 acres of degraded salt marsh.

To quantify the benefit of avoided future flood-related losses, ICF used the estimated damage values associated with 5, 10, and 25-year flood events. The analysis included costs associated with flooding that led to:

- Town infrastructure damages
- Business infrastructure damages and loss of merchandise
- Loss of business activity due to closure

ICF interviewed Town Planning Department staff and relied on input data provided by DER and the Town of Salisbury, including the Benefits-Cost Analysis of Flood Mitigation Projects prepared by the Town and submitted to FEMA. The data were input into the IMPLAN model exactly as reported by the local businesses and by the Town of Salisbury.

Modeling Methodology

ICF used the economic impact modeling software IMPLAN (version 3.0); a tool widely used by state agencies in Massachusetts and throughout the U.S. IMPLAN is created and maintained by the Minnesota IMPLAN Group (MIG). The IMPLAN model is a static input-output framework used to analyze the effects of an economic stimulus on a pre-specified economic region; in this case, the Commonwealth of Massachusetts. ICF used the most recently available data (2011) for the analysis and reported results in 2013 dollars. The IMPLAN model is based on the input-output data from the U.S. National Income and

Product Accounts (NIPA) from the Bureau of Economic Analysis. The model includes 440 sectors based on the North American Industry Classification System (NAICS). The model uses state-specific multipliers to trace and calculate the flow of dollars from the industries that originate the impact to supplier industries. These multipliers are thus coefficients that collectively model the response of all actors in the economy to a stimulus (i.e., change in demand). Three types of multipliers are used in IMPLAN:

- Direct – represents the impacts (e.g., employment or output changes) due to the investments that result in final demand changes, such as investments needed for the construction of a new flood protection project.
- Indirect – represents the impacts due to the industry inter-linkages caused by the iteration of industries purchasing from industries, brought about by the changes in final demands.
- Induced – represents the impacts on all local industries due to consumers' consumption expenditures arising from the new household incomes that are generated by the direct and indirect effects of the final demand changes.

The total impact is the sum of the multiple rounds of secondary indirect and induced impacts that remain in the region (as opposed to "leaking out" to other areas). IMPLAN then uses this total impact to calculate subsequent impacts such as total jobs created and tax impacts. All dollar figures are reported in 2013 dollars and employment impacts in annual jobs.

Post-Model Analysis

Using the IMPLAN model, we estimated the one-time indirect and induced impacts of the flood-related damages for each flooding scenario on the Massachusetts economy. To calculate the expected costs over a 30-year period, however, we needed to account for the expected value of the flood in a given year, or the statistical return frequencies of the storm events (5-, 10-, 25-year flood events). To do this, we assumed that in any given year, a 5-year flood has a 1-in-5 chance of occurring; a 10-year flood has a 1-in-10 chance or occurring; and a 25-year flood has a 1-in-25 chance of occurring. The Town's engineering consultant determined that the three floods events in 2005, 2006, and 2007 corresponded with the statistical flood recurrence frequencies of 5-, 10-, and 25-year floods. Therefore, the costs associated with the three flood scenarios, as determined by the town, are the costs that resulted from each of the three floods from 2005 through 2007.

To calculate the "expected value" of costs in a given year, we multiplied the costs associated with each flood scenario by the "likelihood" of that flood scenario occurring, or more simply, divided the costs by the flood increment (e.g., the costs associated with a 5-year flood were divided by 5). We then assigned the expected values to each year over a 30-year timeframe, which allowed us to assess expected costs incurred (or avoided by flood mitigation) not only over a one year period, but more importantly, over the 30-year period of the study. Finally, we calculated the present value of the avoided flood damages by applying a 7 percent discount rate to the costs in years 1 through 30. The present value cost of the three flood scenarios represent the total present-day cost to the region's economy of the 5-, 10-, and 25-year floods occurring as statistically predicted over the next 30 years, absent the flood mitigation and salt marsh restoration project.

Results

As shown in Table 1, the total avoided economic losses associated with the three flood scenarios are significant. The Town Creek Project avoids $2.5 million in lost economic output over the next 30 years (assuming a 7% discount rate). The majority of the losses would have been incurred as direct and indirect results of the damages to the area's businesses, shown as the "Costs to Businesses," below. The Town Creek Project also avoids municipal damages ("Town & Road Damages," below). Furthermore, avoiding business closures in the days and weeks following each flood avoids further economic losses, shown as the costs related to "Loss of Business" below.

Table 1 – Thirty-Year Avoided Costs of All Flood Scenarios (Present Value at 7% Discount Rate)

Impact Type	Economic Output
Costs to Businesses	$1,348,000
Town & Road Damages	$796,000
Loss of Business	$350,000
Total Effect	**$2,494,000**

This analysis demonstrates that—on its own—the $2.5 million of avoided future flood damage costs makes the $1.3 million project cost a wise investment of public funds. For further clarity, Tables 2, 3, and 4 show the avoided losses broken out by year. However, avoided flood damages are not the only benefit. This project's dual-purpose objectives of flood mitigation *and* ecological restoration means there are many other valuable benefits to the community and economy. For example, the planning, design, and construction of the project will generate increases to employment and economic output. A previous study by the DER found that similar restoration projects result in an average of 12.5 full-time-equivalent jobs and a 75% return on investment per million dollars spent. In addition, projects like the one at Town Creek that restore ecological health to important natural habitats have numerous other economic and social benefits, such as improved water quality, increased resilience of coastal wetlands to sea level rise, and enhanced habitat for commercial and recreation fisheries.

Table 2 – Avoided Loss in Labor Income, Value Added, and Output Associated with the 5-Year Flood Event

	Undiscounted			Discounted, 7%			Discounted, 3%		
Year	Labor Income	Value Added	Output	Labor Income	Value Added	Output	Labor Income	Value Added	Output
1	$7,600	$11,100	$15,600	$7,100	$10,300	$14,600	$7,400	$10,700	$15,200
2	$7,600	$11,100	$15,600	$6,700	$9,700	$13,600	$7,200	$10,400	$14,700
3	$7,600	$11,100	$15,600	$6,200	$9,000	$12,800	$7,000	$10,100	$14,300
4	$7,600	$11,100	$15,600	$5,800	$8,400	$11,900	$6,800	$9,800	$13,900
5	$7,600	$11,100	$15,600	$5,400	$7,900	$11,100	$6,600	$9,500	$13,500
6	$7,600	$11,100	$15,600	$5,100	$7,400	$10,400	$6,400	$9,300	$13,100
7	$7,600	$11,100	$15,600	$4,800	$6,900	$9,700	$6,200	$9,000	$12,700
8	$7,600	$11,100	$15,600	$4,400	$6,400	$9,100	$6,000	$8,700	$12,300
9	$7,600	$11,100	$15,600	$4,200	$6,000	$8,500	$5,900	$8,500	$12,000
10	$7,600	$11,100	$15,600	$3,900	$5,600	$7,900	$5,700	$8,200	$11,600
11	$7,600	$11,100	$15,600	$3,600	$5,300	$7,400	$5,500	$8,000	$11,300
12	$7,600	$11,100	$15,600	$3,400	$4,900	$6,900	$5,400	$7,800	$11,000
13	$7,600	$11,100	$15,600	$3,200	$4,600	$6,500	$5,200	$7,500	$10,600
14	$7,600	$11,100	$15,600	$3,000	$4,300	$6,100	$5,000	$7,300	$10,300
15	$7,600	$11,100	$15,600	$2,800	$4,000	$5,700	$4,900	$7,100	$10,000
16	$7,600	$11,100	$15,600	$2,600	$3,700	$5,300	$4,800	$6,900	$9,700
17	$7,600	$11,100	$15,600	$2,400	$3,500	$4,900	$4,600	$6,700	$9,500
18	$7,600	$11,100	$15,600	$2,300	$3,300	$4,600	$4,500	$6,500	$9,200
19	$7,600	$11,100	$15,600	$2,100	$3,100	$4,300	$4,400	$6,300	$8,900
20	$7,600	$11,100	$15,600	$2,000	$2,900	$4,000	$4,200	$6,100	$8,700
21	$7,600	$11,100	$15,600	$1,800	$2,700	$3,800	$4,100	$5,900	$8,400
22	$7,600	$11,100	$15,600	$1,700	$2,500	$3,500	$4,000	$5,800	$8,200
23	$7,600	$11,100	$15,600	$1,600	$2,300	$3,300	$3,900	$5,600	$7,900
24	$7,600	$11,100	$15,600	$1,500	$2,200	$3,100	$3,800	$5,400	$7,700
25	$7,600	$11,100	$15,600	$1,400	$2,000	$2,900	$3,600	$5,300	$7,500
26	$7,600	$11,100	$15,600	$1,300	$1,900	$2,700	$3,500	$5,100	$7,200
27	$7,600	$11,100	$15,600	$1,200	$1,800	$2,500	$3,400	$5,000	$7,000
28	$7,600	$11,100	$15,600	$1,100	$1,700	$2,300	$3,300	$4,800	$6,800
29	$7,600	$11,100	$15,600	$1,100	$1,600	$2,200	$3,200	$4,700	$6,600
30	$7,600	$11,100	$15,600	$1,000	$1,500	$2,100	$3,100	$4,600	$6,400
TOTAL	**$229,000**	**$331,800**	**$468,700**	**$94,700**	**$137,300**	**$193,900**	**$149,600**	**$216,800**	**$306,200**

Table 3 – Avoided Loss in Labor Income, Value Added, and Output Associated with the 10-Year Flood Event

	Undiscounted			Discounted, 7%			Discounted, 3%		
Year	Labor Income	Value Added	Output	Labor Income	Value Added	Output	Labor Income	Value Added	Output
1	$20,000	$28,100	$37,800	$18,600	$26,300	$35,300	$19,400	$27,300	$36,700
2	$20,000	$28,100	$37,800	$17,400	$24,500	$33,000	$18,800	$26,500	$35,600
3	$20,000	$28,100	$37,800	$16,300	$22,900	$30,800	$18,300	$25,700	$34,600
4	$20,000	$28,100	$37,800	$15,200	$21,400	$28,800	$17,700	$25,000	$33,600
5	$20,000	$28,100	$37,800	$14,200	$20,000	$26,900	$17,200	$24,200	$32,600
6	$20,000	$28,100	$37,800	$13,300	$18,700	$25,200	$16,700	$23,500	$31,600
7	$20,000	$28,100	$37,800	$12,400	$17,500	$23,500	$16,200	$22,900	$30,700
8	$20,000	$28,100	$37,800	$11,600	$16,400	$22,000	$15,700	$22,200	$29,800
9	$20,000	$28,100	$37,800	$10,900	$15,300	$20,500	$15,300	$21,500	$29,000
10	$20,000	$28,100	$37,800	$10,100	$14,300	$19,200	$14,800	$20,900	$28,100
11	$20,000	$28,100	$37,800	$9,500	$13,400	$17,900	$14,400	$20,300	$27,300
12	$20,000	$28,100	$37,800	$8,900	$12,500	$16,800	$14,000	$19,700	$26,500
13	$20,000	$28,100	$37,800	$8,300	$11,700	$15,700	$13,600	$19,100	$25,700
14	$20,000	$28,100	$37,800	$7,700	$10,900	$14,700	$13,200	$18,600	$25,000
15	$20,000	$28,100	$37,800	$7,200	$10,200	$13,700	$12,800	$18,000	$24,200
16	$20,000	$28,100	$37,800	$6,800	$9,500	$12,800	$12,400	$17,500	$23,500
17	$20,000	$28,100	$37,800	$6,300	$8,900	$12,000	$12,100	$17,000	$22,900
18	$20,000	$28,100	$37,800	$5,900	$8,300	$11,200	$11,700	$16,500	$22,200
19	$20,000	$28,100	$37,800	$5,500	$7,800	$10,400	$11,400	$16,000	$21,500
20	$20,000	$28,100	$37,800	$5,200	$7,300	$9,800	$11,000	$15,600	$20,900
21	$20,000	$28,100	$37,800	$4,800	$6,800	$9,100	$10,700	$15,100	$20,300
22	$20,000	$28,100	$37,800	$4,500	$6,300	$8,500	$10,400	$14,700	$19,700
23	$20,000	$28,100	$37,800	$4,200	$5,900	$8,000	$10,100	$14,200	$19,100
24	$20,000	$28,100	$37,800	$3,900	$5,500	$7,400	$9,800	$13,800	$18,600
25	$20,000	$28,100	$37,800	$3,700	$5,200	$7,000	$9,500	$13,400	$18,000
26	$20,000	$28,100	$37,800	$3,400	$4,800	$6,500	$9,300	$13,000	$17,500
27	$20,000	$28,100	$37,800	$3,200	$4,500	$6,100	$9,000	$12,700	$17,000
28	$20,000	$28,100	$37,800	$3,000	$4,200	$5,700	$8,700	$12,300	$16,500
29	$20,000	$28,100	$37,800	$2,800	$4,000	$5,300	$8,500	$11,900	$16,000
30	$20,000	$28,100	$37,800	$2,600	$3,700	$5,000	$8,200	$11,600	$15,600
TOTAL	**$598,500**	**$843,200**	**$1,133,400**	**$247,600**	**$348,800**	**$468,800**	**$391,000**	**$550,900**	**$740,500**

Table 4 – Avoided Loss in Labor Income, Value Added, and Output Associated with the 25-Year Flood Event

	Undiscounted			Discounted, 7%			Discounted, 3%		
Year	**Labor Income**	**Value Added**	**Output**	**Labor Income**	**Value Added**	**Output**	**Labor Income**	**Value Added**	**Output**
1	$73,800	$105,700	$147,500	$68,900	$98,800	$137,900	$71,600	$102,700	$143,300
2	$73,800	$105,700	$147,500	$64,400	$92,400	$128,900	$69,500	$99,700	$139,100
3	$73,800	$105,700	$147,500	$60,200	$86,300	$120,400	$67,500	$96,800	$135,000
4	$73,800	$105,700	$147,500	$56,300	$80,700	$112,600	$65,500	$94,000	$131,100
5	$73,800	$105,700	$147,500	$52,600	$75,400	$105,200	$63,600	$91,200	$127,300
6	$73,800	$105,700	$147,500	$49,100	$70,500	$98,300	$61,800	$88,600	$123,600
7	$73,800	$105,700	$147,500	$45,900	$65,900	$91,900	$60,000	$86,000	$120,000
8	$73,800	$105,700	$147,500	$42,900	$61,500	$85,900	$58,200	$83,500	$116,500
9	$73,800	$105,700	$147,500	$40,100	$57,500	$80,300	$56,500	$81,000	$113,100
10	$73,800	$105,700	$147,500	$37,500	$53,800	$75,000	$54,900	$78,700	$109,800
11	$73,800	$105,700	$147,500	$35,000	$50,200	$70,100	$53,300	$76,400	$106,600
12	$73,800	$105,700	$147,500	$32,700	$47,000	$65,500	$51,700	$74,200	$103,500
13	$73,800	$105,700	$147,500	$30,600	$43,900	$61,200	$50,200	$72,000	$100,500
14	$73,800	$105,700	$147,500	$28,600	$41,000	$57,200	$48,800	$69,900	$97,500
15	$73,800	$105,700	$147,500	$26,700	$38,300	$53,500	$47,300	$67,900	$94,700
16	$73,800	$105,700	$147,500	$25,000	$35,800	$50,000	$46,000	$65,900	$91,900
17	$73,800	$105,700	$147,500	$23,300	$33,500	$46,700	$44,600	$64,000	$89,300
18	$73,800	$105,700	$147,500	$21,800	$31,300	$43,700	$43,300	$62,100	$86,700
19	$73,800	$105,700	$147,500	$20,400	$29,200	$40,800	$42,100	$60,300	$84,100
20	$73,800	$105,700	$147,500	$19,100	$27,300	$38,100	$40,800	$58,500	$81,700
21	$73,800	$105,700	$147,500	$17,800	$25,500	$35,600	$39,600	$56,800	$79,300
22	$73,800	$105,700	$147,500	$16,600	$23,900	$33,300	$38,500	$55,200	$77,000
23	$73,800	$105,700	$147,500	$15,600	$22,300	$31,100	$37,400	$53,600	$74,800
24	$73,800	$105,700	$147,500	$14,500	$20,800	$29,100	$36,300	$52,000	$72,600
25	$73,800	$105,700	$147,500	$13,600	$19,500	$27,200	$35,200	$50,500	$70,500
26	$73,800	$105,700	$147,500	$12,700	$18,200	$25,400	$34,200	$49,000	$68,400
27	$73,800	$105,700	$147,500	$11,900	$17,000	$23,700	$33,200	$47,600	$66,400
28	$73,800	$105,700	$147,500	$11,100	$15,900	$22,200	$32,200	$46,200	$64,500
29	$73,800	$105,700	$147,500	$10,400	$14,900	$20,700	$31,300	$44,900	$62,600
30	$73,800	$105,700	$147,500	$9,700	$13,900	$19,400	$30,400	$43,600	$60,800
TOTAL	**$2,212,700**	**$3,172,400**	**$4,426,500**	**$915,200**	**$1,312,200**	**$1,830,900**	**$1,445,600**	**$2,072,700**	**$2,892,000**

Section 2: Water Quality – Economic Impacts of Improving Water Quality Through Implementation of the Muddy Creek Estuary Restoration Project

Overview

When coastal embayments are restricted from tidal flushing, they become sinks for nutrients entering from their watersheds. As a result, water quality in these embayments can decline significantly, often resulting in adverse impacts to ecological and human health. Some communities have sought to address this issue by building sewers in neighborhoods where septic systems are suspected of contributing nutrient-rich effluent. As an alternative in appropriate locations, restoring tidal flushing to restricted embayments can be a cost-effective way to help reduce nutrient concentrations.

The objective of this economic analysis is to estimate the cost savings that will be realized by substituting the performance of the planned Muddy Creek Estuary Restoration Project for a portion of a sewer project to meet the Total Maximum Daily Load (TMDL) for nitrogen within the Muddy Creek sub-watershed. A TMDL, per the Clean Water Act, is developed for individual contaminants that exceed water quality standards in specific bodies of water. The TMDL establishes the maximum load of the contaminant that the water body can assimilate and meet water quality standards. A TMDL was developed for nitrogen in the Pleasant Bay watershed, and a portion of that total allowable load was allocated to the Muddy Creek estuary that drains to Pleasant Bay. The allocation was calculated using the Massachusetts Estuary Program (MEP) water quality model. The findings presented in this memo are based on available reports from previous modeling studies (SMAST 2006 and SMAST 2010).

The Muddy Creek sub-watershed lies within the towns of Chatham and Harwich. Due to the existing undersized culvert where Route 28 crosses the creek (see Figure 1 below), the 55-acre upstream estuary is tidally restricted and is trending towards a fresh water community, including invasive species such as *Phragmites* and *Typha*. Restricted tidal flushing is also leading to water quality degradation, and the culvert impairs upstream fish passage during certain flow conditions. The Restoration Project will replace the existing culvert with a 94-foot span bridge to restore natural tidal influence to the estuary.

While there may be many alternatives for meeting water quality goals in Pleasant Bay, this exercise is a cost-effectiveness analysis comparing the following two water quality improvement projects in the Muddy Creek estuary sub-watershed of the Pleasant Bay system.

- <u>Regional Sewering Project</u> that involves a wastewater treatment plant and discharge of effluent into another drainage area outside the Muddy Creek sub-watershed
- <u>Ecosystem Restoration Project</u> that replaces the existing culvert at the mouth of the creek with a 94-foot span bridge to increase tidal flow and flushing in Muddy Creek

Figure 1- Aerial View of the Muddy Creek Estuary Showing the Route 28 Tidal Road Crossing at the Inlet

Methodology

To begin, we calculated the total cost to reach the prescribed TMDL loading threshold for Muddy Creek (“threshold”). The Sewer Project would remove the total amount of nitrogen needed to meet the threshold. The Restoration Project alone would not remove sufficient nitrogen to meet the threshold, and partial sewering of the watershed would be required along with the Restoration Project to meet the TMDL requirement. To evaluate the cost to meet the TMDL threshold with and without the Restoration Project, costs for the following two scenarios were calculated and compared:

- Sewer Only Scenario: A sewer and wastewater treatment project that meets the TMDL nitrogen loading threshold
- Restoration Plus Sewering Scenario: Replace the existing undersized culvert with a span bridge and sewer only the portion of the watershed necessary such that the combined effects of the new bridge and partial sewering reduce nitrogen loading to the TMDL threshold

Results are presented in present value terms, using discount rates of 7 percent and 3 percent.[1] Results indicate that the restoration project offsets approximately $3.9 million of sewering costs and is therefore more cost-effective than the sewer-only alternative.

The following sections outline the steps of our analysis:

- Establishment of project costs
- Identification of the effective reduction in nitrogen load relative to the TMDL threshold
- Estimation of cost for per unit (kg/day) reduction in nitrogen loading for each project
- Cost effectiveness analysis

Water quality data used in this evaluation were taken from the results of Massachusetts Estuaries Program (MEP) model runs reported in SMAST (2010) and (SMAST 2006). Table 2 of the 2010 SMAST Technical Memo lists the septic load and the threshold septic load, accounting for a 24-foot wide culvert opening at the Rt. 28 crossing of Muddy Creek. Table VIII-3 of the 2006 SMAST report lists the septic load and the threshold septic load with the existing culvert. The SMAST 2010 report also evaluates the effects of installing the larger opening by comparison to the SMAST 2006 report data (SMAST 2010; Page 2, last paragraph).

Project Costs

As presented in Table 5, the Restoration Project has an up-front estimated capital cost of $3.3 million, with annual operations and maintenance (O&M) costs that vary by year. For the Restoration Project, O&M costs include $255,000 in years 10, 20, and 30 for bridge steel cleaning and painting; $90,000 in year 15 for bridge asphalt cleaning and resealing; and $232,000 in year 30 for deck resurfacing.[2] The annualized payment for O&M over the 30-year period under the Restoration Project is $36,233. The Sewer Project has an up-front capital cost of $17.7 million and $119,000 of annual O&M costs, including $99,000 for the sewer lines[3] and $20,000 for the sewer treatment plant[4]. Table 10, at the end of this section, details the costs in each year between 2013 and 2042 for the two projects.

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[1] Economic analyses of costs to the public sector commonly use discount rates of 7 percent and 3 percent. DER requested results based on a 7 percent discount rate, consistent with the discount rate used by the Federal Emergency Management Agency in its analyses. The analysis below discusses present value (PV) costs based on a 7 percent discount rate. The 3 percent figure is presented for comparative purposes only.

[2] Bridge maintenance costs were estimated by the MA DER using unit cost data available from MassDOT and applying professional judgment for the proposed Muddy Creek bridge. These costs include cleaning and painting of steel members (every 10 years), bridge deck cleaning and re-sealing (once), and resurfacing of the bridge deck (once). This is intended to be a conservative estimate of maintenance costs based on some assumptions and does not reflect any other maintenance needs.

[3] Source: Table 9-2 of the Town of Chatham, Massachusetts Draft CWMP/DEIR. Includes O&M costs associated with sewersheds 7, 8, 9, 10, 11, and 71.

[4] Source: Email correspondence between Jeff Greg (GHD) and Bob Duncanson (Town of Chatham), November 21, 2013.

Table 5 – Capital and Operation and Maintenance Costs

	Restoration	Sewer
Initial Cost	$ 3,310,000	$ 17,700,000
Annual O&M - Lines	N/A	$ 99,000
Annual O&M - Sewer	N/A	$ 20,000
Total Annual O&M	$36,233*	$ 119,000

* Annual restoration O&M cost is calculated as the average annual cost when spreading the periodic O&M nominal costs evenly over the 30-year period. See Table 10 below.

Effective Reduction in Nitrogen Load Relative to the TMDL Threshold

Threshold nitrogen loading required to meet the TMDL, as reported by SMAST (2006 and 2010), is higher with the increased flow with the culvert removed. For this analysis, the "effective" reduction associated with the restoration and sewer projects is the nitrogen load that is no longer required to be removed to meet the TMDL threshold– which would be the sum of the nitrogen removed plus the change in the TMDL threshold. We are referring to this as the effective nitrogen load reduction.

As shown in Table 6, the restoration option reduces the actual nitrogen load by 0.18 kg/day, and raises the TMDL threshold by 5.10 kg, so that the effective reduction relative to the TMDL threshold is 5.28 kg/day. Under the Sewer Project, there is no increase in the TMDL threshold, so the effective reduction in nitrogen loading is the actual amount removed (13.5 kg/day).

Table 6- Effective Reduction in Nitrogen

	Restoration	**Sewering**
Current N Load (kg)	13.50	13.50
Actual Reduction in N (kg)	0.18	13.50
N Threshold (kg)	6.89	1.79
Change in N Threshold (kg)[1]	5.10	0.00
Effective Reduction in N (kg)[2]	**5.28**	**13.50**

[1] Change in threshold is expressed as the difference above the baseline. Baseline assumes N threshold of 1.789 kg.

[2] Effective Reduction in N is calculated as the sum of the change in baseline and the actual reduction in N.

Calculating Unit Costs for Each Project

Once the effective nitrogen load reduction was calculated, ICF calculated unit costs for each Project – the cost to reduce loading by 1 kg of nitrogen per day over 30 years. Table 7 presents this calculation: we divided the total present value cost (the present value costs are broken down in Table 10, below) by the effective reduction in nitrogen for each scenario. As shown, the restoration project is significantly less costly than the sewering project both in terms of total and unit cost. Calculating the costs as "per kg reduced" allows for direct comparability—for each kg of nitrogen reduced (per day). The Restoration Project reduces one kg of nitrogen loading per day at a cost of roughly $686,000 discounted at 7 percent and $742,000 discounted at 3 percent. The cost to reduce nitrogen loading by a kg/day under the Sewer

Project is roughly $1.4 million discounted at 7 percent, and $1.5 million discounted at 3 percent. With costs presented in these terms, we were able to calculate the costs of sewering only a portion of the sewershed, which provides the basis for the analysis in the following section.

Table 7- Unit Cost per 1 kg Load Reduction (30 Year Duration)

	Discounted at 7%		Discounted at 3%	
	Restoration	**Sewering**	**Restoration**	**Sewering**
Total PV Cost	$3,622,570	$19,280,043	$3,917,016	$20,102,426
Effective N Reduced (kg)	5.28	13.496	5.28	13.496
Unit Cost (per kg N reduced)	**$686,483**	**$1,428,575**	**$742,281**	**$1,489,510**

* Totals may not sum due to independent rounding.

Results

Table 8 presents the total cost incurred by each project to reach the prescribed threshold. For this analysis, the scenarios include (1) the restoration project plus sewering a portion of the watershed in order to reach the prescribed threshold and (2) sewering a portion of the watershed only to the point where the threshold is reached.

Whereas the restoration project alone does not reach the N load threshold, the sewering project goes beyond the threshold (Table 8). The "restoration plus sewering" scenario therefore requires that 47.6 percent of the watershed be sewered in addition to the restoration project. Alternatively, the sewering only scenario reduces the N load beyond the prescribed threshold, and therefore the scenario requires that 13.3 percent less than 100 percent of the watershed be sewered, or 86.7 percent of the watershed.

The total sewering costs offset (i.e., saved) by the restoration project are estimated at $3.9 million (Table 8). This is derived by comparing the total costs of the two options: (1) the restoration project ($3.6 million) plus sewering 47.6 percent of the watershed ($9.2 million) at a total cost of $12.8 million, versus (2) sewering 86.7 percent of the watershed at a total cost of $16.7 million.

Table 8- Total Present Value Cost to Reach Threshold (30 Year Duration)

	Discounted at 7%		Discounted at 3%	
	Restoration + Sewering	**Sewering**	**Restoration + Sewering**	**Sewering**
Req. add. N removed (kg)	6.43	-1.79	6.43	-1.79
Req. add. N removed (% of sewershed)	47.6%	-13.3%	47.6%	-13.3%
Cost for additional N reduction (7%)	$9,185,735	-$2,555,720	$9,577,549	-$2,664,733
Total PV Cost	**$12,808,305**	**$16,724,323**	**$13,494,565**	**$17,437,693**
Cost Savings, Restoration Project	**$3,916,018**		**$3,943,127**	

* Totals may not sum due to independent rounding.

The analysis in Table 9 calculates the cost savings differently, but yields the same results. The restoration project effectively reduces the N load by 5.28 kg, which represents 45.1 percent of the reduction required in reaching the effective threshold.[5] Whereas the cost of the restoration project to remove 45.1 percent of the required nitrogen to reach the threshold is roughly $3.6 million, the equivalent amount of sewering costs roughly $7.5 million. Again, this calculation similarly concludes that the total costs offset by the restoration project are roughly $3.9 million.

Table 9- Cost Comparison of Restoration vs. Sewering (30 Year Duration)

	Discounted at 7%		**Discounted at 3%**	
	Restoration	**Sewering**	**Restoration**	**Sewering**
Effective N Reduced (kg)	5.28		5.28	
Percent of Threshold Reduction	45.1%		45.1%	
Total PV Cost	$3,622,570	$7,538,588	$3,917,016	$7,860,144
Cost Savings, Restoration Project	**$3,916,018**		**$3,943,127**	

This analysis demonstrates a $3.9 million cost savings resulting from restoration of tidal flow in the Muddy Creek estuary compared to sewer construction with equivalent nitrogen reduction benefits. This Restoration Project was chosen to demonstrate one example of ecosystem service economic value (for water quality improvement) because that value can be easily and accurately estimated based on the costs of two alternative infrastructure options which meet the same TMDL water quality requirements. However, this water quality benefit accounts for only one of many Restoration Project benefits; other benefits may generate the same or greater value, including improved fisheries habitat; recreational opportunities for fishing, birding, and boating that also support the region's tourism industry; and improved aesthetics and estuary health that lead to increased property values and quality of life for the local community.

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[5] The 45.1% figure was calculated to show how close (in percentage terms) the Restoration Project gets to reaching the TMDL. It is calculated as the effective N reduced by the Restoration Project (5.28 kg), divided by the delta of the effective N reduced by the Sewering Project (13.496 kg) and the required N threshold (1.789 kg).

Table 10- Thirty-Year Costs by Year in Nominal and Present Value (7% and 3%) Terms

Year		Nominal Costs		Discounted at 7%		Discounted at 3%	
		Restoration	Sewer	Restoration	Sewer	Restoration	Sewer
1	2013	$3,310,000	$17,819,000	$3,310,000	$17,819,000	$3,310,000	$17,819,000
2	2014	$0	$119,000	$0	$111,215	$0	$115,534
3	2015	$0	$119,000	$0	$103,939	$0	$112,169
4	2016	$0	$119,000	$0	$97,139	$0	$108,902
5	2017	$0	$119,000	$0	$90,785	$0	$105,730
6	2018	$0	$119,000	$0	$84,845	$0	$102,650
7	2019	$0	$119,000	$0	$79,295	$0	$99,661
8	2020	$0	$119,000	$0	$74,107	$0	$96,758
9	2021	$0	$119,000	$0	$69,259	$0	$93,940
10	2022	$255,000	$119,000	$138,703	$64,728	$195,436	$91,204
11	2023	$0	$119,000	$0	$60,494	$0	$88,547
12	2024	$0	$119,000	$0	$56,536	$0	$85,968
13	2025	$0	$119,000	$0	$52,837	$0	$83,464
14	2026	$0	$119,000	$0	$49,381	$0	$81,033
15	2027	$90,000	$119,000	$34,904	$46,150	$59,501	$78,673
16	2028	$0	$119,000	$0	$43,131	$0	$76,382
17	2029	$0	$119,000	$0	$40,309	$0	$74,157
18	2030	$0	$119,000	$0	$37,672	$0	$71,997
19	2031	$0	$119,000	$0	$35,208	$0	$69,900
20	2032	$255,000	$119,000	$70,510	$32,904	$145,423	$67,864
21	2033	$0	$119,000	$0	$30,752	$0	$65,887
22	2034	$0	$119,000	$0	$28,740	$0	$63,968
23	2035	$0	$119,000	$0	$26,860	$0	$62,105
24	2036	$0	$119,000	$0	$25,103	$0	$60,296
25	2037	$0	$119,000	$0	$23,460	$0	$58,540
26	2038	$0	$119,000	$0	$21,926	$0	$56,835
27	2039	$0	$119,000	$0	$20,491	$0	$55,180
28	2040	$0	$119,000	$0	$19,151	$0	$53,572
29	2041	$0	$119,000	$0	$17,898	$0	$52,012
30	2042	$487,000	$119,000	$68,454	$16,727	$206,657	$50,497
TOTAL		**$4,397,000**	**$21,270,000**	**$3,622,570**	**$19,280,043**	**$3,917,016**	**$20,102,426**

Section 3: Carbon Sequestration – Estimates of Carbon Sequestration from Wetland Restoration Projects and Reductions in the Social Cost of Carbon

Overview

This analysis calculates the economic value of improved carbon sequestration associated with two wetland restoration projects (Damde Meadows in Hingham and Broad Meadows in Quincy). Several methodological options were available to monetize the carbon benefits of the projects. In a system for pricing and trading carbon "credits", the value of carbon is based on regulatory penalties for emissions, as well as incentives for reducing or offsetting emissions. The second method for valuing carbon, selected for use in this study, is a model to determine the *Social Cost of Carbon (SCC)*, which is based on the projected social damages of climate change due to greenhouse gas (GHG) emissions. This model estimates a dollar value for the societal impact of CO_2 emissions, as well as the reduction or offset of such emissions. Monetized damages accounted for in the model include projected financial losses such as from property damage caused by coastal storms and sea level rise, and increases in human health problems due to heat waves or increasing risk of infectious disease.

Located on The Trustees of Reservations' Worlds End Reservation, the Damde Meadows Tidal Restoration Project restored 19 acres of salt marsh. Prior to colonization, Damde Meadows was a typical New England salt marsh. However, two stone dikes were constructed in the early 1600s to facilitate livestock grazing and isolated the marsh from the tides. The project was completed in 2011, restoring tidal flow to Damde Meadows by creating 20-foot-wide open channels through the dikes.

Through the mid-1900s, over 100 acres of the Broad Meadows Marsh in Quincy was filled in with sand and silt dredged from the Town River. This salt marsh restoration project involved the excavation and relocation of approximately 400,000 cubic yards of that dredge material to restore over 60 acres of tidal wetlands, creeks, and other wetland and grassland habitats. Completed in 2012, this project will greatly enhance the quantity and quality of fish and wildlife habitat in Town River Bay.

Table 11 below presents the carbon storage rates for each project site and the estimated reduction in SCC under both pre-existing (degraded) and restored conditions. The *difference* between the pre- and post-restoration SCC values is the SCC benefit of the projects. At the Damde Meadows site, the projected SCC benefit from 2013-2050 ranges from $19,034 to $138,742 depending on the monetary discount rate used. The range in benefit at Broad Meadows for 2013-2050 is $30,372 to $221,381.

Table 11- Comparison of Pre- and Post-Restoration Carbon Storage Rates and Values of SCC Reductions, 2013-2050

	Degraded				Post-Restoration			
Project Site	Carbon Storage Rate (MT CO_2e/ yr)	Reduction in SCC at Varying Discount Rates			Carbon Storage Rate (MT CO_2e/ yr)	Reduction in SCC at Varying Discount Rates		
		5%	3%	2.5%		5%	3%	2.5%
Damde Meadows	**11.8**	**$3k**	**$13k**	**$22k**	**87.9**	**$22k**	**$100k**	**$160k**
Broad Meadows	**24.8**	**$6k**	**$28k**	**$45k**	**146.1**	**$37k**	**$166k**	**$267k**

Methods to Determine Carbon Sequestration Rates and Benefits

This section discusses the methods used to estimate the carbon sequestration rates and monetary value of additional carbon sequestration resulting from two representative wetland restoration projects: the Broad Meadows Restoration in Quincy, and the Damde Meadows Restoration in Hingham. The goal of both projects was to restore healthy tidal wetland habitats via removal of historically-placed dredged material and/or restoration of full tidal influence. Pre-restoration wetland habitats at both sites were severely degraded (Damde Meadows due to restriction of tidal flow) and completely lost (Broad Meadows due to historic fill).

Figure 2- The New Open Span Crossing at Damde Meadows. The pre-Restoration Condition is shown in the inset.

To determine the carbon *benefit* of completing these restoration projects, we gathered information on the acreage of land and habitat types both before and after restoration (Table 12). We then determined the carbon sequestration potential for 2013 to 2050 under a degraded scenario and under the restoration scenario. The difference between the scenario values provides the actual carbon sequestration benefit. The years 2013 to 2050 were selected as the Social Cost of Carbon (SCC) estimates because they are only modeled through the year 2050 (IAWGSCC 2013); the SCC approach is discussed in more detail below.

Changes in areas of habitat type for two restoration projects

Table 12- Habitat Types at Restoration Sites

	Site Habitats (Acres)					
	Damde Meadows, Quincy[1]			***Broad Meadows, Hingham***[2]		
	Before Restoration	After Restoration	*Change*	Before Restoration	After Restoration	*Change*
Saltmarsh— High / Salt Panne	0	3.2	*+3.2*	0	20.7	*+20.7*
Saltmarsh—Low	0	8.8	*+8.8*	0	5	*+5*
Intertidal Mud Flat/ Tidal Channel	0	8.1	*+8.1*	0	5	*+5*
Phragmites-Dominated Freshwater Wetland	3.2	0	*-3.2*	30.9	0	*-30.9*
Filled Upland	0	0	*0*	30.9	0	*-30.9*
Coastal Grassland				0	31	*+31*
Subtidal Habitat	16.9	0	*-16.9*	0	0	*0*

1. Source of Damde Meadows information: Franz Ingelfinger, MA Division of Ecological Restoration, Personal Email Communication via Nick Wildman December 11, 2012.
2. Source of Broad Meadows information: Wendy Gendron, Army Corps of Engineers, Personal Telephone Communication, December 19, 2012.

Amount of carbon sequestered annually (*sequestration rate*) for each habitat type

Two approaches for determining a representative annual rate of carbon sequestered for each habitat type were evaluated.

Our first approach considered using vertical accretion rates and a representative percent-carbon for the accreted material to calculate sequestration rates. Accretion rate estimates for other similar sites in the region were gathered from published literature (Table 13). Changes in elevation measured by Surface Elevation Tables which account for surface (sediment deposition and erosion) and subsurface (compaction, decomposition, root growth, pore water flux) processes are also included in Table 13. The accretion rates varied, but indicated lower accretion rates for high marsh (1.7 to 3 mm/yr) than for low marsh (5.8 to 8 mm/yr). The second required factor, carbon content of the accreted material, varies considerably across sites, and between sites with same habitat types. A survey of organic carbon content of marsh sediments by Craft (2007) indicated the carbon content of brackish marsh sediments ranges from 9% to 34% while the carbon content of salt marsh sediments ranges from 3% to 22%. The wide variability of carbon content is dependent on site specific factors including the vegetation type and density. Crooks et al. (2009) concluded that plant harvesting and soil samples are required to obtain accurate carbon estimates at any particular site.

Figure 3- The Broad Meadows Site Viewed from the Air pre-Restoration. Photo: US Army Corps of Engineers

The second approach to estimating carbon storage rates involves using rates from published literature based on actual field measurements of the carbon content of sediments. Rates found in the literature are presented in Table 14 in terms of both carbon and carbon dioxide equivalent (CO_2e)[6]. There is uncertainty in either approach to identifying carbon storage rates for different habitats. Given the complexity and variability of the carbon content of marsh sediments and best available information, we determined that measured carbon storage values reported in the literature from similar coastal habitats would provide the most accurate estimates of carbon sequestration rates.

Carbon storage capacity rates vary widely for a given marsh type, and more precise estimates would need to be based on site specific sample data for any given area. In this analysis, we used separate averages for low and high marsh. All carbon storage estimates used were measured from established wetlands and are presumed to be long-term averages. Carbon storage rates for the low marsh estimates (Choi et al., 2001, Choi and Wang, 2004, and Sorell, 2010) are widely divergent. According to literature, the accretion rates and, therefore, carbon storage rates of low marsh are greater than that of high marsh (Callaway et al., 2012, Argow, 2006, and Fitzgerald et al., 2006), so using the Sorell (2010) estimate alone, although geographically-closer (Schoodic Peninsula, Maine) would not be justified for this study. Although Choi et al. (2011) and Choi and Wang (2004) are based on a marsh area in Florida, we do not have enough information about the Massachusetts restoration sites to indicate that the carbon storage value is as great as what is reported by Choi et al. (2001). To be conservative, we utilized an average of all three studies; the average value is close to the value reported by Choi and Wang (2004).

Sequestration rates for other habitat types were also developed using existing literature as a basis for the analysis. Coultas (1996) reports that the soil carbon accumulation in wetland soils is 10 times that of upland habitats. In order for the carbon benefit calculation to err on the conservative side, we assumed that the storage in uplands is one-tenth that of the low marsh average: 52 g C m^{-2} yr^{-1} (191 g CO_2e m^{-2} yr^{-}

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[6] Converting carbon to its carbon dioxide-equivalent requires multiplying the known amount of carbon by the molecular weight of CO2 (44) and dividing by the molecular weight of carbon (12).

^{1}). Crooks et al. (2009) reports that the sequestration potential for soil in saline mudflats is no more than 50 g C m^{-2} yr^{-1} (184 g CO_2e C m^{-2} yr^{-1}), so this estimate is utilized for the land area that is designated as a mudflat or tidal creek. To estimate the carbon storage of coastal grasslands, a literature review supplied a range of 0.11 to 3.04 MT C ha^{-1} yr^{-1} with an average of 0.54 MT C ha^{-1} yr^{-1} which is 0.25 MT C ac^{-1} yr (0.9 MT CO_2e ac^{-1} yr) (Conant et al. 2001). No data were found for carbon storage in coastal wet meadows so the grasslands estimate will also be used for meadows.

Much of the existing pre-restoration habitat was Phragmites-dominated freshwater wetland. Although *Phragmites australis* plants store much more carbon in their biomass than many other wetland plants, freshwater wetlands also release methane (CH_4) into the atmosphere (Brix et al 2001).

Figure 4- Aerial View of the Broad Meadows Site Post-Restoration Showing Restored Landscape That Will Support Upland Grassland and Tidal Wetland Habitats Over Time. Photo: US Army Corps of Engineers

In contrast, methane emissions from tidal marshes are negligible (Crooks et al 2009). Because the potential warming effect of methane is about 21 times higher on a mass basis than CO_2 over a 100-year timescale, methane loss would to a great extent counteract the carbon sequestration benefit in a phragmites wetland (Brix et al 2001). Without conducting field tests, it would be difficult to determine how much carbon is being accumulated and how much is being released into the atmosphere as methane. Therefore, in this study, we assume no carbon sequestration benefit in terms of GHG reduction and social cost of carbon for freshwater Phragmites wetlands.

Table 13- Elevation Change and Accretion Rates in Wetlands

Location	Elevation Rate	Accretion Rate[7]	Data Period	Source/Principle Researcher
Great Bay	na	4.3 mm/yr	na	Dave Burdick, unpublished
Nauset Marsh, Cape Cod MA	4.28mm/yr	5.39 mm/yr	1998-2011	MJ James-Pirri, University of Rhode Island Graduate School of Oceanography
Herring River Unrestricted side, Wellfleet Harbor, MA	-1.26mm/yr	-1.03 mm/yr	2000-2011	MJ James-Pirri, University of Rhode Island Graduate School of Oceanography
Hatches Harbor, Provincetown, MA	1.88mm/yr	1.11 mm/yr	1998-2011	MJ James-Pirri, University of Rhode Island Graduate School of Oceanography
Thompson Island, Boston Harbor, MA - Low marsh	6.4 mm/yr	7.7 mm/yr	3 year record - 2010-2012	Jim Lynch, National Park Service
Peddocks Island, Boston Harbor, MA - High marsh	0.6 mm/yr	1.7 mm/yr	3 year record - 2010-2012	Jim Lynch, National Park Service
Survey of Published Literature High Marsh	na	2.5 +/- 1.4 mm/yr	3 year record – 2002-2004	Argow 2006
Survey of Published Literature Low Marsh	na	5.8 +/- 2.8 mm/yr	3 year record – 2002-2004	Argow 2006
High Marsh	na	2-3 mm/yr	Synthesis-multiple	Fitzgerald et al., 2006
Low Marsh	na	6-8 mm/yr	Synthesis-multiple	Fitzgerald et al., 2006
Nauset Marsh, Cape Cod (various sites)	Less than accretion, but unspecified	2.6-4.2 mm/yr	3 year record—1991-1994	Roman et al. 1997
High Marsh	na	1-2.5 mm/yr	na	Franz Ingelfinger pers. com.
Low Marsh	na	4-6 mm/yr	na	Franz Ingelfinger pers. com.

Note: This table provides a summary of information from select sources, and does not represent a full search of reported or ongoing studies.

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[7] Summary statistics of carbon content data were not readily available for most of these sites. Roman et al (1977) reports average of 30% carbon content in their study sample set.

Table 14- Literature-Derived Values for Carbon Storage Capacity of Salt Marshes

Marsh Type	**Carbon Storage** **(g C m^{-2} yr^{-1})**	**Carbon Storage** **(MT CO_2e ac^{-1} yr^{-1})**	**Data Source and Study Location Notes**
Low Marsh	949	14.1	Choi et al. (2011); Florida study site
	517.5	8.7	Choi and Wang (2004); Florida Site
	87.4	1.3	Sorell (2010); Schoodic Peninsula, ME
Low Marsh Average	*518.0*	*8.0*	
High Marsh	243	3.6	Choi et al. (2011); Florida study site
	75-400	1.1-5.9	FWS (1982); several New England high marshes
High Marsh Average	*239.3*	*3.6*	
Salt Marshes, Undifferentiated	151	2.2	Duarte et al. (2005), Average
	50-250	0.7-3.7	Crooks et al. (2009), Average
	220	3.3	Chmura et al. (2003); Average
	155	2.3	Chmura et al. (2003); Nauset Bay, MA
	160-230	2.4-3.4	Roman et al. (1997); Nauset Marsh, MA
	170	2.5	Craft (2007); Mean for salt marshes in NE USA Atlantic coast
	144	2.1	Middelburg et al. (1997); Great Marshes, MA
Salt Marshes, Undifferentiated, Average	*170*	*2.5*	

Carbon Sequestration for Project Sites

Carbon sequestration rates for each habitat type in the restoration project areas were estimated based on the results of the steps described in the preceding sections. The carbon sequestration rate (in CO_2-equivalent) per acre was multiplied by the number of acres of each habitat for pre- and post-restoration conditions, and the difference in carbon sequestration per year was calculated. Results, which represent the total carbon sequestration attributable to the restoration projects, are presented in Tables 15 and 16 below. The total additional carbon storage at both sites is equivalent to offsetting the emissions from combusting over 22,000 gallons of gasoline per year.

Table 15- Annual Carbon Sequestration by Habitat Type for Damde Meadows, Hingham

Habitat Type	**Carbon Sequestration Rate (MT CO_2e/ ac/ yr)**	**Pre Restoration Area (Acres)**	**Pre-Restoration Sequestration (MT CO_2e/ yr)**	**Post Restoration Area (Acres)**	**Post-Restoration Sequestration (MT CO_2e/ yr)**	**Increased Carbon Sequestration due to Restoration Project (MT CO_2e/ yr)**
Saltmarsh—High/ Salt Panne	3.6	0	*0*	3.2	*11.5*	***11.5***
Saltmarsh—Low	8.0	0	*0*	8.8	*70.7*	***70.7***
Tidal Mudflat/ Tidal Creeks	0.7	0	*0*	8.1	*5.7*	***5.7***
Phragmites-Dominated Freshwater Wetland*	NA	3.2	*NA*	0	*0*	***0***
Subtidal Habitat	0.7	16.9	*11.8*	0	*0*	***-11.8***
Total Carbon Benefit of Restoration Project		***76.02** MT CO_2e/ yr*				
*Note: Phragmites are known to fix a large amount of carbon in their tissues, but the production of methane from freshwater Phragmites marshes is also known to be high, which could counteract any GHG benefit. For the purposes of our calculations, we are setting carbon sequestration to zero as an input to the SCC model.						

Table 16- Annual Carbon Sequestration by Habitat Type for Broad Meadows, Quincy

Habitat Type	**Carbon Sequestration Rate (MT CO_2e/ ac/ yr)**	**Pre Restoration (Acres)**	**Pre-Restoration Sequestration (MT CO_2e/ yr)**	**Post Restoration (Acres)**	**Post-Restoration Sequestration (MT CO_2e/ yr)**	**Increased Carbon Sequestration due to Restoration Project (MT CO_2e/ yr)**
Saltmarsh—High/ Salt Panne	3.6	*0*	0	20.7	*74.5*	***74.5***
Saltmarsh—Low	8.0	*0*	0	5	*40.2*	***40.2***
Tidal Mudflat/ Tidal Channel	0.7	*0*	0	5	*3.5*	***3.5***
Phragmites-Dominated Freshwater Wetland*	NA	*30.9*	NA	0	*0*	***0***
Filled Upland	0.8	*30.9*	24.8	0	*0*	***-24.8***
Coastal Grassland / Wet Meadow	0.9	*0*	0	31	*27.9*	***27.9***
Subtidal Habitat	0.7	*0*	0	0	*0*	***0***
Total Carbon Benefit of Restoration Project		***121.3 MT CO_2e/ yr***				

*Note: Phragmites are known to fix a large amount of carbon in their tissues, but the production of methane from freshwater Phragmites marshes is also known to be high, which could counteract any GHG benefit. For the purposes of our calculations, we are setting carbon sequestration to zero as an input to the SCC model.

Methods to Determine Reduction in the Social Cost of Carbon (SCC)

There are several methods available to value carbon sequestration or reductions in carbon emissions. In a system for pricing and trading carbon “credits”, the value of carbon is based on regulatory penalties for emissions, as well as incentives for reducing or offsetting emissions. The second method for valuing carbon is a model to determine the so-called Social Cost of Carbon (SCC), which is based on the projected monetized social damages of climate change due to GHG emissions. This model was developed by the Interagency Working Group on the Social Cost of Carbon (IAWGSCC). The IAWGSCC’s *Regulatory Impact Analysis Under Executive Order 12866* estimates a dollar value for the societal impact of CO_2 emissions, as well as for the reduction or offset of such emissions. Although the methodology is currently being re-evaluated and is not exhaustive in its inclusion of societal impacts of CO_2 emissions, it is the best existing resource and is broadly accepted as such. Examples of monetized damages that could be linked to climate change and that are accounted for in the model include projected financial losses due to property damage from coastal storms and sea level rise, increases in human health problems due to heat waves or increasing risk in infectious disease, and reductions in agricultural productivity. Also built into the SCC model are assumptions about changing values for each ton of carbon in the future as projected climate change impacts are occurring.

For this study, estimating reductions in the SCC was selected as a more appropriate method for evaluating the benefits of the restoration projects. It is unknown whether a cap and trade system will be enacted in the United States and, if such a system is enacted, the details and “rules” of the system could vary widely. The model for SCC is based on current knowledge of potential climate impacts and doesn’t require the implementation of a regulatory system for its application.

To calculate the SCC for both project sites, we are using the estimates for *changes* in annual carbon storage (as CO_2e) calculated in the previous step. The IAWGSCC model provides a range of discount scenarios (5%, 3%, 2.5%, and 3% at the 95th percentile estimate for climate change impacts) (IAWGSCC 2013). The discount rate indicates an assumption about people’s level of concern regarding a particular issue over time. For example, a 5% discount rate indicates that in the present day, society would be willing to spend $95 to offset $100 of projected damages due to climate change). Alternately, a discount rate of 0% would indicate that society today believes that the threat of future damages from climate change are just as important as damages that could occur today. This is not a likely scenario, so a variety of discount rates are applied. The model is developed to provide results for all of these discount scenarios, as the most likely scenario has not been identified by the IAWGSCC or any others.

The dollar values per ton of CO_2 estimated using the IAWGSCC model are presented in Table 17 (in 2012 dollars[8]). We only present the values in five year increments, but the model utilizes annual values.

Table 17- Annual Values of each Metric Ton of Carbon Dioxide emitted or mitigated under varying discount scenarios

Year	SCC Value for Each Discount Rate (per MT CO_2e) *			
	5% Average	3% Average	2.5% Average	3% 95th percentile[1]
2013	$12	$38	$59	$109
2015	$12	$40	$61	$118
2020	$13	$46	$69	$138
2025	$15	$51	$74	$154
2030	$17	$56	$81	$172
2035	$20	$60	$86	$189
2040	$23	$66	$93	$206
2045	$26	$71	$99	$222
2050	$28	$77	$105	$237

1. Based on a highly damaging, low probability climate change scenario

Results

The projected reduction in the SCC under each discount rate scenario is presented below in Table 18. For each project, the SCC reduction estimates vary considerably under different discount rate scenarios.

Table 18- SCC Reduction Values Directly Attributable to Restoration, 2012 - 2050

Project Site	5% Discount Rate Average SCC	3% Discount Rate Average SCC	2.5% Discount Rate Average SCC
Damde Meadows	*$19,034*	*$86,414*	*$138,742*
Broad Meadows	*$30,372*	*$137,885*	*$221,381*

As noted in the methodology discussion, the IAWGSCC model also provides an estimate of the potential value of damages under a scenario for which highly damaging (and highly unlikely) climate change occurs—the "*95th percentile*" scenario. The other discount scenarios are based on the 50th percentile estimate of climate change—in other words, the *average* future climate scenario, which is deemed to

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[8] The conversion of the IAWGSCC's values per ton in 2007 dollars to our use of 2011 dollars was obtained from the Bureau of Economic Analysis, National Income, and Product Accounts (NIPA) Table 1.1.9, Implicit Price Deflators for Gross Domestic Product (using the annual, rather than quarterly, GDP for the United States).

be statistically likeliest (IAWGSCC, 2013). Under the 95th percentile (extreme) scenario, using a 3% discount rate, the projected reductions in SCC as a result of the Damde Meadows and Broad Meadows restoration projects, respectively, are $264,165 and $421,509.

While Table 18 provides the pre- and post-restoration *difference* (or benefit) in SCC values as a result of the restoration projects, Table 19 presents the carbon storage rates for each project site and the estimated reduction in SCC under both existing (degraded) and restored conditions. The difference between the pre- and post-restoration SCC values is the SCC benefit of the projects.

Table 19- Comparison of Pre- and Post-Restoration Carbon Storage Rates and Values of SCC Reductions, 2013 - 2050

	Degraded				**Post-Restoration**			
Project Site	**Carbon Storage Rate (MT CO_2e/ yr)**	**Reduction in SCC at Varying Discount Rates**			**Carbon Storage Rate (MT CO_2e/ yr)**	**Reduction in SCC at Varying Discount Rates**		
		5%	**3%**	**2.5%**		**5%**	**3%**	**2.5%**
Damde Meadows	**11.8**	**$3k**	**$13k**	**$22k**	**87.9**	**$22k**	**$100k**	**$160k**
Broad Meadows	**24.8**	**$6k**	**$28k**	**$45k**	**146.1**	**$37k**	**$166k**	**$267k**

Assumptions, Uncertainties and Other Considerations

Changes in Carbon Storage Capacity over Time

The carbon storage capacity for individual wetlands is variable, primarily dependent on accretion rates, vegetation type (broadly, grasses vs. trees), and soil carbon content at particular sites. The pattern of changing carbon storage over time for restored wetlands is complex and uncertain.

In restored wetlands, functionality changes over time as vegetation takes hold and as habitat types gradually evolve over time. One study that provides a general estimate for carbon sequestration in restored grassy wetlands (undifferentiated habitats) indicates that the storage rate in the first five years after restoration was higher (5.72 MT/ac/yr CO_2e) than in subsequent years (1.25 MT/ac/yr) (Hansen 2009). In contrast, the same study (Hansen 2009) cites another source that indicates that storage rates increase over the first ten years (Euliss et al. 2006 as cited in Hansen 2009). In our analysis, we acknowledge that the level of uncertainty for future changes (sea level rise, subsidence, ambient temperatures, shifts from high to low marsh) presents many obstacles for predicting how storage will actually change over time. Since the pattern and magnitude of the changes are currently not fully understood, we do not factor them into our calculations.

Several studies have indicated that restored wetlands may not function as well as native wetlands (Galatowitsch and van der Valk 1996 and Moreno-Mateos et al. 2012). However, given the complexity of a developing restored wetland system, additional research over a long term restoration is needed to fully understand how the evolution of a restored tidal wetland would affect the carbon sequestration rate over time.

Loss of Carbon Storage due to Methane Generation

Natural processes occurring in wetlands provide opportunities for carbon storage, although the GHG mitigation benefits can be offset by the emission of methane due to natural processes. Some studies have found that freshwater wetlands are net emitters of GHGs (rather than acting as net sinks), although methane emissions are negligible in tidal marshes (Crooks et al. 2009; EPA 2012; Brix et al 2001). In this analysis, we are assuming negligible methane emissions for tidal marsh, and the effects of methane emissions are considered to offset the carbon storage benefit in our calculations for freshwater phragmites wetlands.

Options for Improving Estimates for Future Studies

Better understanding of the carbon sequestration rates for various types of habitat would improve this analysis. At the outset of our research, we intended to utilize estimates of accretion rates to estimate carbon sequestration rates for both sites. As the project moved forward, it became clear that it would not be possible to use accretion rates for our calculations due to the highly variable carbon data reported in the literature. This presents a future research opportunity for improving the accuracy of the estimates. Field work to conduct vegetation coverage surveys and/or soil core samples in multiple locations would allow future researchers to improve the accuracy even further if the cost-benefit analysis indicates such work would be beneficial. Completing these field studies at sites where surface elevation and vertical accretion rate studies are ongoing would provide the data to show bulk density and percent organic matter to calculate carbon quantities per area per year and to estimate future benefits.

Another option to improve value estimates for carbon sequestered at restoration project sites would be to calculate the SCC for other marshes that are the subject of ongoing research projects that may generate useable site data. This would involve identifying appropriate sites and data sets, working with the researchers to produce statistical data that would be useable in our models, calculating the SCC for each of the marshes, and then reviewing and evaluating relevant site data to define typical scenarios that could be applied to restoration projects. In this approach, sites would be characterized by location, salinity regime, tidal range, and habitat type, and then a SCC rate per acre for each marsh-type would be calculated.

Section 4: Landscape Appeal – Analysis of Property Value Changes Resulting from the Herring River Restoration Project

Overview

Restoration of coastal wetlands by removing historic fill and/or restoring tidal flushing can produce dramatic improvements to water quality, viewscape, recreation opportunities, and wildlife habitat that, commonly, are aesthetically and functionally preferable to users of a site and to those who live close by. Accordingly, the value of nearby properties may increase after a tidal restoration project is complete. The objective of this analysis is to estimate the potential change in value for properties abutting the planned Herring River Restoration Project on Cape Cod.

In this study, we used the benefit transfer method to adapt previous hedonic pricing studies on the impact of wetlands on adjacent property values. The hedonic pricing method involves statistical analyses of large amounts of real estate transactions to isolate the impact of different housing attributes on home values; they are time and resource intensive studies. The development of this functional relationship often requires analyses not only of real estate transactions in the study area, but also for an area similar to the study area but that does not contain the environmental amenity being studied. The properties not including the environmental amenity are used to isolate and estimate the impact of property values of the environmental amenity. In this study, we used the benefit transfer method to leverage the results of previous hedonic pricing studies conducted on the impact of coastal wetlands on property values, and adapted these previous results to match the context of the Herring River Estuary.

The steps of the analysis are listed below:

- Identify source studies to be used in the benefit transfer exercise
- Using the hedonic function from the source study, define a function that estimates the change in property value relative to a change in type of and distance to wetlands
- Using GIS data, estimate the distance of each affected property to the wetland types before and after restoration, identifying the inputs needed to calibrate the hedonic function for the context of the Herring River Restoration Project
- Aggregate the per-parcel change in value across all affected properties to estimate the expected total change in property values from the restoration project
- Identify the key assumptions of the analysis and limitations of the results

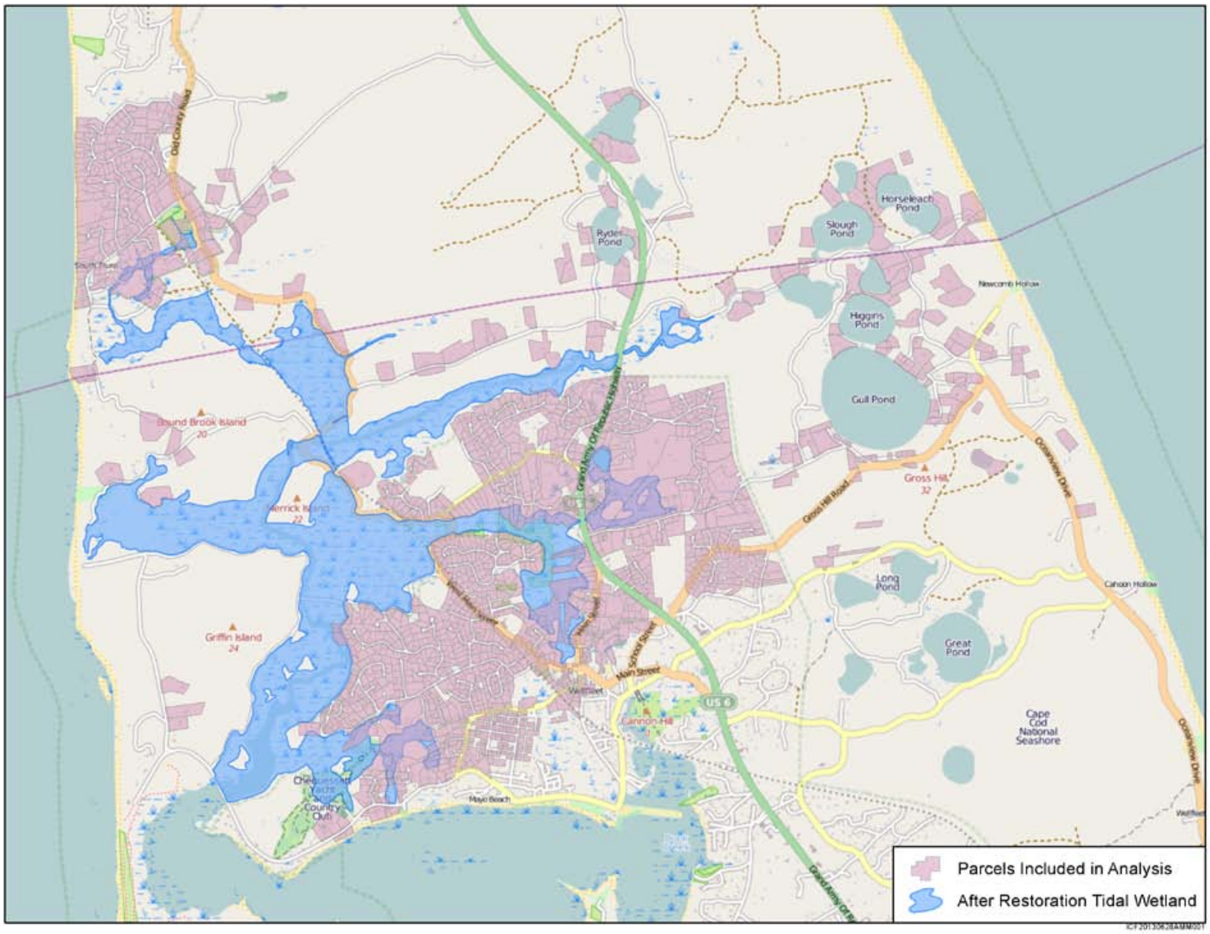
Methodology

We first identified several hedonic pricing studies that estimated the effects on property value based on proximity to different types of wetlands. We evaluated each of these studies to determine their suitability as a source study for the Herring River analysis. We evaluated each study on several criteria:

- similar real estate market (in terms of characteristics of properties and socioeconomic characteristics of residents);

- wetlands similar to those found in the Herring River project region;
- robustness of the analysis and statistical models; and
- externally reviewed, preferably in a peer-reviewed journal.

Figure 5- GIS Image Showing Parcels Included in the Analysis Relative to the Modeled Post-Restoration Tidal Wetlands



Based on our evaluation of multiple hedonic pricing studies, we identified a source study that estimates the impact of proximity to coastal and inland wetlands on property values in North Carolina (Bin and Polasky 2003). After evaluating this study based on the criteria listed above, we selected it as the most suitable source data for a benefit transfer exercise. First, the real estate market in the North Carolina study has several characteristics in common with the market surrounding the Herring River Restoration Project. For example, both locations offer vacation amenities, inland bay areas, and ocean amenities. Second, it is advantageous that both studies involve a coastal location. More specifically, because the North Carolina study explicitly accounts for the distance to the ocean in the estimated hedonic pricing function, it controls for the proximity of properties to the ocean and attempts to isolate the impact on property values of being located close to a wetland.

Next, the North Carolina study examines two types of wetlands, tidal wetlands and non-tidal wetlands. This is important due to the fact that the Herring River Restoration Project will restore non-tidal wetlands to tidal wetlands within the project area. Because the hedonic pricing function in the North Carolina study estimates the impacts on property values of both types of wetlands, we can define a baseline value (based on proximity to non-tidal and tidal wetlands in the pre-restoration project area) and measure the change in property values based on the anticipated conversion of the restoration area's non-tidal wetlands to tidal wetlands.

To estimate the change in value for each parcel, we estimated the distance to tidal and non-tidal wetlands before and after the Herring River Restoration Project, based on hydrologic modeling data of tidal influence previously produced to support restoration project design (see Figure 5 above). Later sections outline the assumptions in the GIS model to estimate the distances for each parcel.

Using the hedonic pricing function estimated in the North Carolina Study, we next defined the change in price of each property as the difference between the hedonic pricing function before the restoration project and after the restoration project. Because we only change the distance to the tidal and non-tidal wetlands in the variables defined in the hedonic pricing function, all other variables in the hedonic function drop out of the equation. It is thus not necessary to incorporate other characteristics of properties in the vicinity of the Herring River Restoration Project in order to use the hedonic pricing function from the North Carolina Study in this new context. The variables from the source study that generate a positive change in property value for the Herring River context are a net reduction in distance to tidal wetlands and a net increase in distance to non-tidal wetlands.

Results

Based on the difference equation developed from the hedonic function, we identified a positive property value increase for 1,436 properties that would result from the planned Herring River Restoration Project. All of these properties are projected to be closer to tidal wetlands after the restoration project is implemented. Some will also be further away from non-tidal wetlands. Of these 1,436 properties, 67 were condominiums. The real estate market for condominiums and houses might differ in important ways (i.e., housing attributes might be valued differently for condominiums than they are for houses). Because condominiums were not included in the North Carolina source study, we do not have any basis for estimating changes in condominium property values. We thus present the total impacts on property values with and without the increases from condominiums.

Increases in property values ranged from \$24 to \$92,572 with a mean increase of \$7,527. Properties with a small increase in value were properties that were already located close to tidal wetlands before the restoration project. Properties with the highest value were properties adjacent to the restoration project and that were relatively far from tidal wetlands before the restoration project. Aggregating across the 1,436 properties, we estimated a total increase in property values of \$10.9 million (\$10.4 million without condominium properties) that would result from the Herring River Restoration Project. Figure 6 presents the distribution of the parcels relative to the increase in property value and distance from the restoration project. Figure 7 presents the frequency table of the parcels by the estimated additional property value.

Figure 6- Change in Property Value Based on the Distance from the Restoration Project

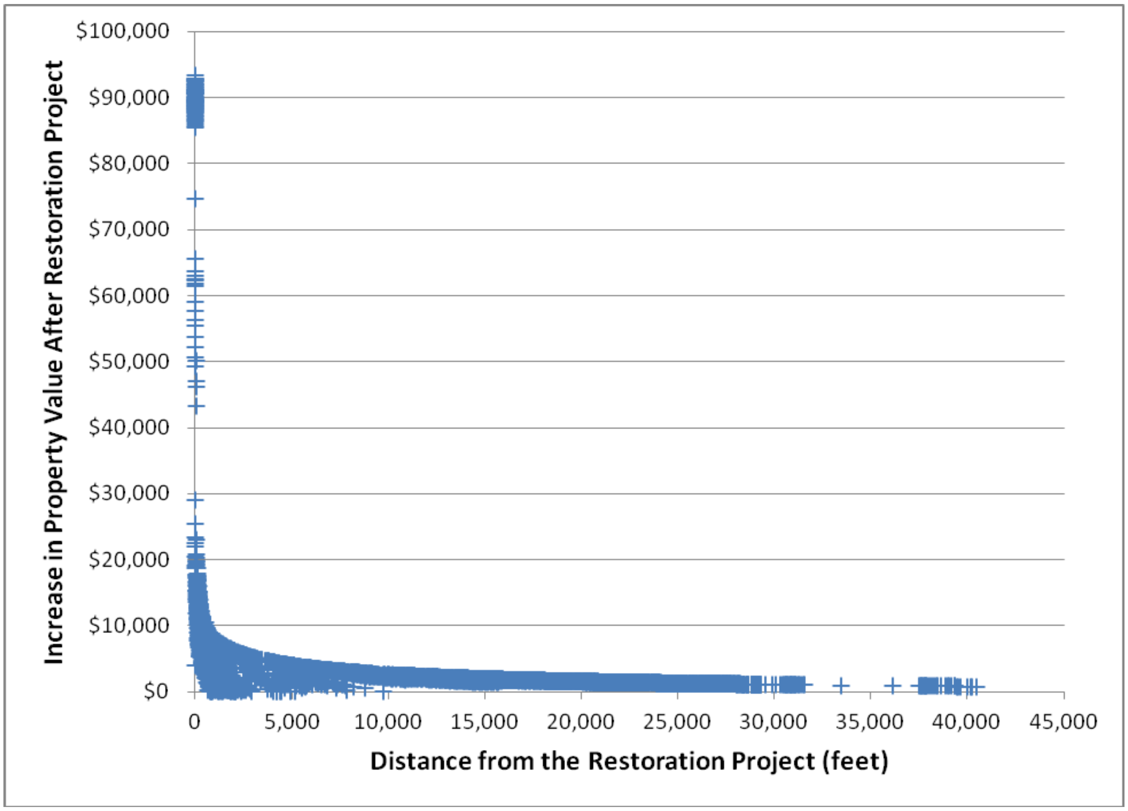
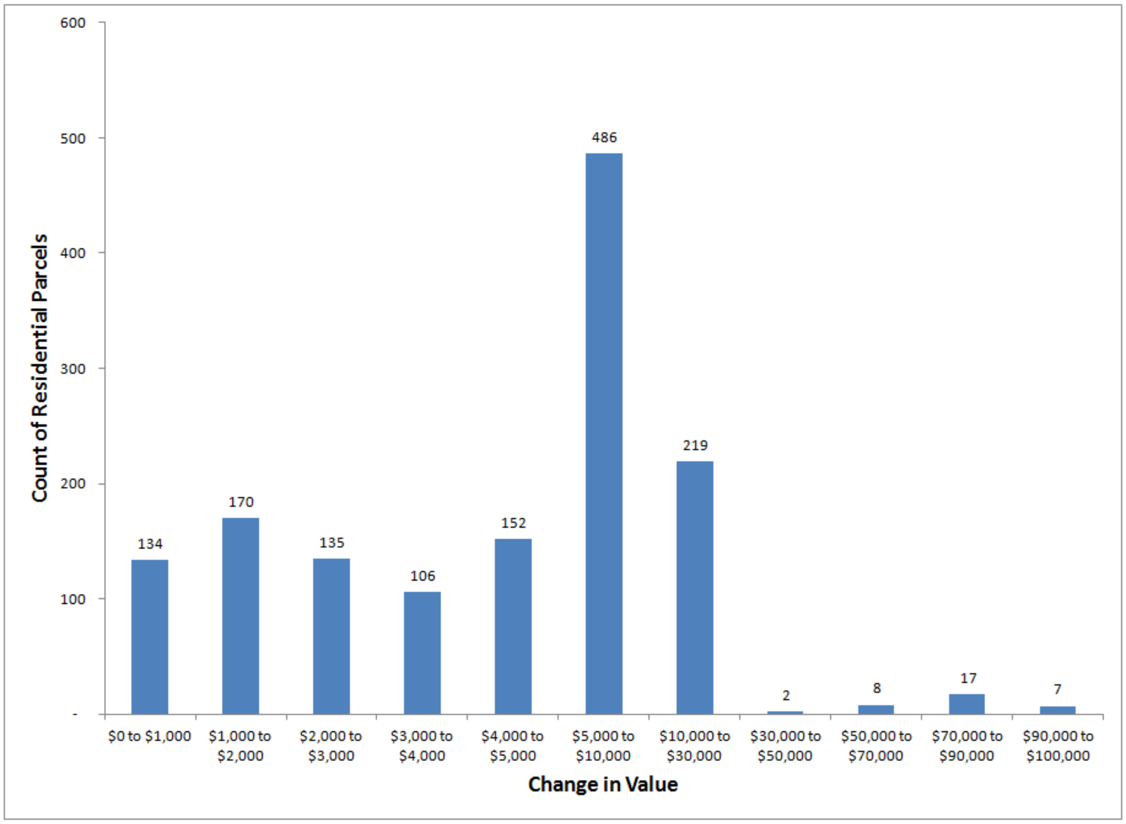


Figure 7- Distribution of the Change in Property Value



Methodological Assumptions and Limitations

Due to the time and resource constraints of this project, we used the benefit transfer method to adapt previous results rather than collecting new primary data specific to the Herring River project area. Our estimate of the change in property values resulting from the Herring River Restoration Project was thus reliant on the hedonic pricing function developed in the North Carolina study (our chosen source study). While benefit transfer is an effective and efficient means for leveraging the results of previous studies, it is a "second best" approach to collecting primary data, and the results of benefit transfer studies are subject to certain limitations.

First, although real estate markets in the Cape Cod region and coastal North Carolina are similar, they are not identical. The average property value in the Cape Cod region is higher than the average value of properties in the North Carolina study. Although the hedonic pricing function is designed to estimate property values based on specific characteristics of the property (lot size, number of rooms, distance to wetlands, etc.), applying this function to another area in a benefit transfer will only be valid if these housing attributes are valued by the populations in each location in a similar fashion. For example, the number of rooms in a house, or other similar housing attributes, might be more valuable in the Cape Cod region than in the North Carolina region. We are unable to account for these differences without doing a primary hedonic pricing study in the Cape Cod region. Our results thus implicitly assume that housing attributes are valued in a similar fashion in the Cape Cod region as they are in coastal North Carolina.

Another limitation of using hedonic pricing functions in a benefit transfer exercise is that we are constrained to considering the housing attributes included in the source study. For example if property values in the Cape Cod region are based on housing attributes that were not considered in the North Carolina study, there is no way to account for the impact of these omitted attributes. In regards to this study, this issue is most relevant in relation to the value of the wetlands in each location. If the wetlands on Cape Cod offer different or better amenities than those in North Carolina, the benefit transfer approach will underestimate the change in property value resulting from the Herring River Restoration Project. For example, if the project alters the viewshed in a way that is unique to the region and in a way that provides unique positive amenities to properties, the North Carolina study will not be able to capture the increases in property values due to these unique changes in amenities.

GIS Assumptions

This model was based on measurements of distance from residential property to the nearest tidal and non-tidal wetland before and after the restoration project. We defined distance to wetland measuring from the centroid (geometric center) calculated for each residential parcel. A GIS was used to calculate distances. Pre-restoration wetlands were based on the Massachusetts Department of Environmental Protection wetlands data layer downloaded from the MA Office of Geographic Information (MassGIS) web site. Post-restoration tidal wetland boundaries were measured using a GIS shape file delineating the boundary of tidal wetlands after the restoration project is fully implemented. This post-restoration tidal wetland boundary is defined by the hydrologic modeled post-restoration mean high water spring (MHWS) tidal benchmark within the restoration project area.

Also included in this analysis was a GIS layer showing all residential parcels from municipal parcel data sets for the towns of Wellfleet and Truro that were downloaded from the MassGIS web site. To select the parcels for analysis, we eliminated all parcels that were closer to a tidal wetland pre-restoration than to the post-restoration tidal wetland project boundary. These parcels would receive no direct property value benefit from the restoration project because they are closer to tidal wetlands under pre-restoration conditions than their distance to the post-restoration tidal wetland project boundary.

Measurement of distance to pre- and post-restoration non-tidal wetlands required modification of the GIS data to account for margins of error between the MA DEP wetlands data layer and the post-restoration project tidal wetland data layer. We next developed an error assumption to account for data layer boundary errors where the post-restoration tidal wetland boundaries should, but do not, exactly coincide with the pre-restoration non-tidal wetland boundary. We defined a buffer around the post-restoration tidal wetland boundary of 100 feet. Any non-tidal wetland within this 100-foot buffer was considered to be a post-restoration tidal wetland. Any non-tidal wetland that extended beyond the 100-foot buffer was considered to be post-restoration non-tidal wetland. This correction addressed the small inconsistencies between the two GIS shape files.

Finally, we measured the distance to the post-restoration tidal wetlands for each parcel. These four distances (pre-restoration non-tidal and tidal wetlands, and post-restoration non-tidal and tidal wetlands) serve as the inputs to the hedonic pricing function.

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